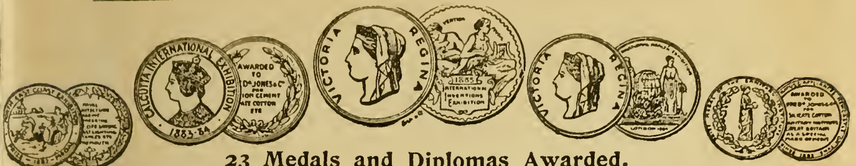
REFRIGERATING
AND
ICE-MAKING MACHINERY

A. J. WALLIS-TAYLER



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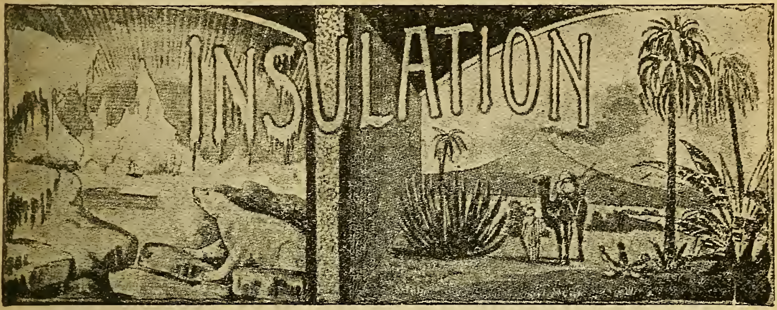

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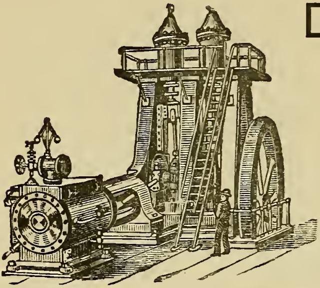

REFRIGERATING AND ICE-MAKING MACHINERY

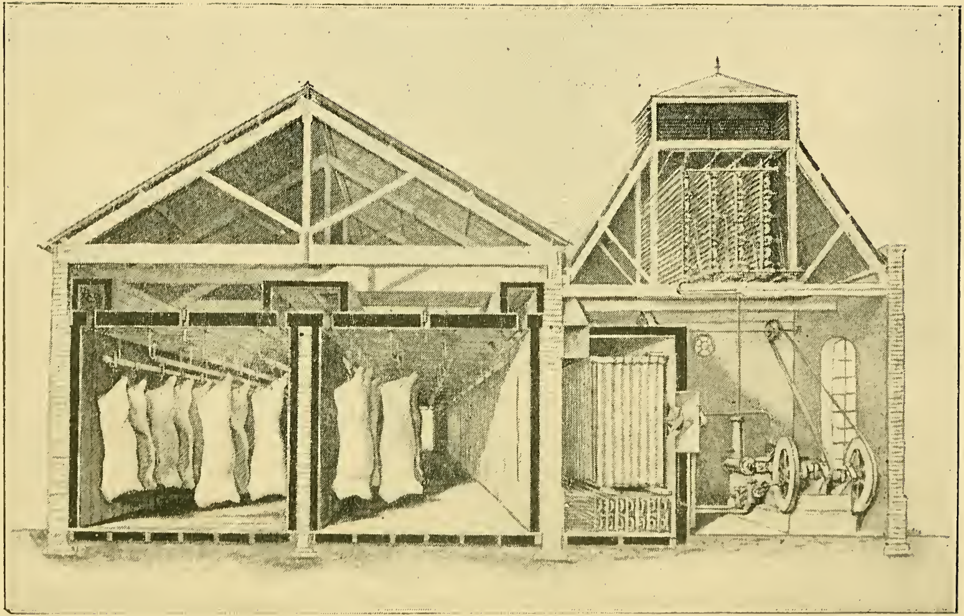

FIG. 31*d* (P. 75).—SMALL AMMONIA MACHINE, WITH PATENT BRINE-COOLING BATTERY.

[*Frontispiece.*

REFRIGERATING

AND

ICE-MAKING MACHINERY

A DESCRIPTIVE TREATISE FOR THE USE OF PERSONS EMPLOYING REFRIGERATING AND ICE-MAKING INSTALLATIONS, AND OTHERS

BY

A. J. WALLIS-TAYLER, C.E.

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ETC. ETC.

SECOND EDITION, WITH ADDITIONS

Illustrated with about One Hundred Diagrams

Capio Lumen

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PREFACE.

THE subject of the present volume is one which ought to be of interest to a very large number of readers, inasmuch as machinery and apparatus for the production of cold by artificial means, in addition to its more legitimate uses for ice-making and the preservation of provisions of a perishable nature, is now employed, and plays an important part, in many industries and manufactures. Notwithstanding this, however, with the exception of the scattered information comprised in the few interesting and valuable papers which have been contributed from time to time to the engineering and other institutions and societies, and of the able descriptive articles which have appeared in the leading technical journals at more or less wide intervals, but little has been written treating generally of machinery of this class.

The author is, therefore, led to hope that a treatise dealing with the machinery and apparatus used in the principal systems of refrigerating and ice-making will prove not unuseful both to those employing, or intending to employ, and to those in charge of such machinery and apparatus, and to others who, whilst desiring to obtain information upon the subject, have neither the opportunity or the facility for obtaining it from the sources above referred to.

In the execution of the present work every endeavour has been made to place the matter before the readers in a concise form, and to include therein as much and as recent information upon the subject as practicable, thus rendering the scope of the book as wide as possible, without unduly swelling its bulk or overstepping the limits of a publication capable of being produced at a moderate cost. Simplicity and clearness of classification and description have been also aimed at throughout.

To render the work as valuable as possible for purposes of reference, the construction and arrangement of rooms and of cold stores and chambers for freezing and preserving provisions, and other manufacturing and industrial applications, and also the cost of working complete installations, have been gone into as fully as the space at command would allow; and to these have been added a chapter containing a short collection of useful tables and memoranda pertinent to the subject.

It is hoped that the end in view has been fairly attained, and that the book will be found of some service to those for whose use it is primarily intended.

A. J. WALLIS-TAYLER.

124, CHANCERY LANE.
London, W.C., 1895.

PREFACE

TO THE SECOND EDITION.

But little more than a year having elapsed since the first edition of this work was placed before the public, no very material advance has since been made in the design of the class of machinery under consideration, and consequently no considerable alterations or additions to the book are called for. Some twenty pages of descriptive matter and as many illustrations, however, relating to subjects of interest not dealt with, or not fully dealt with, in the previous edition, have been added, and a small part of the original matter has been re-written, and the illustrations replaced by views showing even more modern types of machines.

That the object with which the book was written, as set forth in the Preface to the first edition, has been fairly attained, so that the volume has met an actual demand for such a work, is evidenced by the comparatively rapid sale and favourable reception of the first edition; and the author trusts that the second edition may meet with a not less gratifying amount of success.

A. J. WALLIS-TAYLER.

323, HIGH HOLBORN,
London, W.C., 1897.

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FOLDING PLATES.

REFRIGERATING AND ICE-MAKING MACHINERY.

CHAPTER I.

INTRODUCTION.

ALTHOUGH refrigerating and the production of ice by artificial means is said to have been known to, and practised by, the Ancients, it is only in comparatively recent times that improved systems and apparatus have enabled operations to be carried out profitably on a commercial scale, and have rendered possible the numerous manufacturing and industrial applications now made.

In addition to their employment for the manufacture of ice, more durable, and—by reason of the known purity of the water congealed—more palatable and sanitary than the natural product; to their extensive use for the freezing or chilling of freshly killed meat in abattoirs; and to their application to the cooling of stores or chambers for the preservation of meat, fowl, fish, fruit, vegetables, and other provisions of a perishable nature: refrigerating machines are now commonly employed in a number of different manufacturing processes, a brief description of the most important of which will be found in the chapter devoted to industrial applications.

The trade in fresh provisions is one that during the last few years has made enormous strides, and at the present time vast quantities of frozen carcasses, and of fish, fruit, vegetables, and milk are being imported into this country.

Space does not, unfortunately, admit of entering into any lengthy account of the history of this trade, which is one of great interest, or of indulging in statistics relative to the constantly increasing amounts of these imports; which figures can, however, readily be got from a variety of sources by anyone interested therein, and which, moreover, hardly come within the province of a book purporting to be devoted to a description of the various machines and appliances adapted for refrigeration and ice-making. The following, however, are a few of the leading facts:—

The first cargo of frozen meat was brought to this country in the beginning of the year 1881, in the *Strathleven*, which is said to have been fitted with a Bell-Coleman cold-air machine, and this was quickly followed by another consignment in the *Protos*, refrigerated by means of a cold-air machine of the Lightfoot pattern. On October 5th of the same year the steamship *Orient* arrived at London with a cargo of frozen meat, she being also fitted with refrigerating apparatus on the cold-air principle, in this instance one of Haslam's patent dry-air refrigerators being employed, which worked without interruption during the entire voyage of six weeks duration. On the 26th September in the succeeding year the clipper ship *Mataura*, also fitted with a Haslam patent cold-air machine, arrived with a cargo of frozen meat from New Zealand.

Such were the commencements of the trade in refrigerated meat, and it has so rapidly advanced that, in mutton alone, from a few hundred carcasses in 1881 it has risen to upwards of three millions in 1894, one million carcasses coming from Australia, and nearly one million four hundred thousand from the Argentine Republic. The total amount received in this country from the starting of the frozen meat trade up to the present date from all sources is twenty-six million carcasses of sheep and lambs, thirteen millions of which came from New Zealand, nine millions from the River Plata, three millions from Australia, one hundred and fifty thousand from the Falkland Islands, and the remaining eight hundred and fifty thousand from various other localities.

In 1886 the steamship *Nonpareil* (Scrutton, Sons & Co.), which had been fitted for the purpose with a Haslam dry-air refrigerator, brought to this country the first cargo of West Indian fruit; and early in 1888 a cargo of apples was shipped from Melbourne in the *Oceana*, in chambers also cooled by a Haslam machine, both cargoes arriving in good condition. Since then many of the ships belonging to the Peninsular and Oriental Steamship Company, and others, have been fitted up for this trade.

Within the last two years a considerable import trade in milk has also arisen ; one firm alone, during the past winter, having regularly sold 500 gallons of foreign milk daily, and thousands of gallons of foreign cream were likewise imported into this country within the same period, to be used for butter-making. The bulk of this milk is shipped to London from Gothenburg by steamer, having been frozen chiefly by refrigerating machines on the ammonia compression principle, and costing, it is stated, 25 per cent. less than English milk.

All these provisions can now be brought to this country in excellent condition, the chief dangers of deterioration being from hurried and consequently careless stowing, from bumps and bruises caused by rough and unskilled handling, and from exposure to higher temperatures during transit from the vessel to the cold stores on land, and subsequent distribution by road or rail to the retailers.

To enable the following description of the several classes of refrigerating machinery to be clearly understood, it is absolutely necessary to be conversant with the usually accepted definitions of heat and the terms relating thereto, that have to be more or less frequently referred to in dealing with the subject. These definitions and terms will, no doubt, be perfectly familiar to most readers of this book, but everyone is liable at times to lapses of memory and doubt, and on such occasions it is found convenient to have the wherewithal to refresh it, and those, on the other hand, who are unacquainted with the subject will be saved the trouble of referring to other works in order to obtain the said definitions, and the meaning of the said terms.

The principal terms that have to be used in treating of refrigerating, and which will be met with in the following pages, are :—Thermal unit of heat (British), mechanical equivalent of heat, specific heat, and latent heat.

The standard unit of heat used (thermal unit) in England is the heat necessary to raise the temperature of 1 lb. of water from 32° Fahr. by 1°, or that given up by 1 lb. of water in cooling 1° Fahr., viz., from 33° down to 32°.

As to what heat really is. According to the accepted definition, heat is motion, which theory was finally arrived at by Sir Humphrey Davy in 1812, as the result of his observations of the experiments which he made in 1799, and of those of Benjamin Thompson (Count Rumford) in 1798. In spite of this, however, it is extremely doubtful whether this is correct, or whether it is not as fallacious and misleading as numerous other scientific definitions, the accuracy of which is usually taken for granted.

The absolute truth upon the subject is that nothing, or next to nothing, is actually known for certain as to what heat really is. In a most interesting paper by Dr. Ernst Mach, Professor of Physics in the University of Prague, which appeared in the "Monist" of October, 1894, this deep and original thinker, after showing the absurdity of many universally accepted theories, remarks with reference to thermodynamics that, as it has been shown that heat is not a substance, the usually accepted theory is that it is a mode of motion, but Dr. Mach most conclusively proves that this is not true. In an able article upon the fallacy of scientific definitions published in the "Engineer" of October 12th, 1894, the writer, after referring to the fact that the exact nature of heat is as yet absolutely unknown, truly observes that heat really behaves sometimes like a substance and sometimes not.

Joule's mechanical equivalent of heat equals 772 ft.-lbs. That is to say that heat demands for its production, and produces by its disappearance 772 ft.-lbs. for each unit of heat. The experiments by which Joule determined the above equivalent were conducted by means of a falling weight, which actuated an agitator or paddle-wheel placed in water, the friction caused by a weight of 1 lb. falling though a distance of 772 ft., or of a weight of 772 lbs. falling through a distance of 1 ft., being found sufficient to heat 1 lb. of water 1° Fahr.

Specific heat is defined as being that amount of heat necessary to raise the temperature of a body of a given weight 1°. The unit of measure is that quantity of heat that is necessary in order to raise the same weight of water to an equal temperature. If equal weights of different bodies are raised the same number of degrees of temperature, each one takes up a different amount of heat, moreover, the specific heat of the same substance differs in accordance with its state, *i.e.*, whether it be solid, liquid, or gaseous, and under varying conditions of temperature and pressure, increasing invariably with an increase of temperature or pressure. The specific heat of water is exceeded by but few bodies, and the variation thereof at different temperatures is so small as to be unworthy of notice. The specific heat of water is therefore taken as the standard of comparison, and at 32° Fahr. it is represented by unity.

Latent heat, the existence of which was first discovered by Dr. Black in 1762, has been thus clearly and concisely defined by Balfour Stewart, in his "Treatise on Heat":—"Latent heat is the heat which is absorbed by bodies in passing from one state to another, but it does not manifest itself by producing an increase of temperature, and is on this account called latent heat. . . . A pound of water at 212°, mixed with a pound of water at 32°, gives 2 lbs. of water at 122°, the mean of the two components; if, however, a pound of ice at 32° be mixed with a pound of water at 212°, we have 2 lbs. of water at 51° only. . . . The difference being equal to that required to raise 2 lbs. of water through a range of 71° . . . . representing the heat required to liquefy 1 lb. of ice."

In addition to the above, calculations made with respect to heat will entail the use of the terms, absolute pressure and temperature. The first of these is pounds per square inch above a vacuum. Hence, as the zero on a steam pressure gauge represents atmospheric pressure it will be necessary to add 14·7 lbs. to any particular gauge pressure to convert it into absolute power. Temperature is a term which implies that degree of sensible heat which a body possesses when compared with another body. The zero upon the thermometrical scale is an arbitrary zero or starting point, adopted because the real zero was unknown; recent experiments place it at 461° Fahr. Thus the absolute temperature of a body is that of absolute zero added to the ordinary thermometrical temperature thereof. For instance, if the latter be 32° Fahr. then the absolute temperature would be 493° Fahr., or 461 were it zero Fahr. on the thermometer.

According to Boyle's or Marriotte's law the temperature remaining the same, the volume of any given quantity of gas will be in the inverse ratio to the pressure which it sustains.

Finally it must be borne in mind that all substances contain, more or less, heat; and that as heat cannot be created, nor yet can it be destroyed, a body can only be reduced in temperature by the transference of more or less of its heat to another body.

The abstraction of heat, therefore, from one body and its transfer to another, called the refrigerating or cooling agent, is naturally the main function of refrigerating and ice-making apparatus, and in order to insure continuity of action, the said refrigerating agent—the temperature of which must necessarily be lower than that of the substance upon which it is desired to act—must be either periodically renewed, or suitable means must be provided for the removal therefrom of the heat extracted or abstracted from the latter. That is to say, a continuously working machine comprises a heat-abstracting apparatus, and suitable means for automatically renewing at the requisite intervals the cooling agent or medium, or for the removal from the latter of the heat extracted from the body it is desired to cool, so as to enable it to be used over and over again in a continuous cycle.

The various inventions for refrigerating and ice-making that are now in use, can be conveniently classified for the present purpose under the following five principal heads, viz.:—

First, those wherein the more or less rapid dissolution or liquefaction of a solid is utilised to abstract heat. This is, strictly speaking, more a chemical process.

Second, those wherein the abstraction of heat is effected by the evaporation of a portion of the liquid to be cooled, the process being assisted by an air-pump. This is known as the vacuum system.

Third, those wherein the abstraction of heat is effected by the evaporation of a separate refrigerating agent of a more or less volatile nature, which agent is subsequently restored to its original physical condition by mechanical compression and cooling. This is called the compression system.

Fourth, those wherein the abstraction of heat is effected by the evaporation of a separate refrigerating agent of more or less volatile nature under the direct action of heat, which agent again enters into solution with a liquid. This is termed the absorption system.

Fifth, those wherein air or other gas is first compressed, then cooled, and afterwards permitted to expand whilst doing work, or practically by first applying heat, so as to ultimately produce cold. These are usually designated as cold-air machines.

CHAPTER II.

THE UTILISATION OF THE MORE OR LESS RAPID DISSOLUTION OF A SOLID TO ABSTRACT HEAT, OR THE LIQUEFACTION PROCESS.

LIQUEFACTION is one of the most ancient methods employed for artificial cooling. The reduction of temperature of water and other liquids by the melting of saltpetre is said to have been known in India at a very remote period, and it is on record that one Blasius Villafranca, a physician of Rome, utilised it for this purpose as early as 1550. The Romans are said to have cooled wine by immersing the bottle containing the latter in a second vessel filled with cold water into which saltpetre was gradually thrown, whilst at the same time the said bottle was rotated rapidly. Freezing water by the use of a mixture of snow or powdered ice and saltpetre was mentioned by Latinus Tancredus of Naples in 1607, and wine by means of snow and common salt by Santorio in 1626. This was also in all probability the method employed by the Esthonian tribe for producing artificial cold, and freezing the dead, and liquids, as mentioned by Orosius about A.D. 400.

To this class belong the numerous ordinary and well-known machines and apparatus employed for icing creams, lemonades, &c., which usually consist of a tub constructed of wood into which a vessel containing the substance to be cooled or frozen is placed, and is surrounded by a frigorific agent, such as a mixture of pounded ice or snow and chloride of sodium; or a combination of certain chemicals may be substituted for the former.

This method is also used on a more extensive scale for ice-making and cooling, but although ice can be produced on a commercial scale with improved apparatus, it is still more expensive than strictly mechanical methods. The best among the many forms of apparatus for making ice on this principle are probably those of Toselli and Siemens.

In Toselli's machine the frigorific agent consists of a mixture of ammonium nitrate and water, which produces a reduction of temperature of about 40° Fahr. The apparatus requisite is one of extreme simplicity, consisting merely of a vessel in which the solution of the salt is effected, and a can wherein are placed a number of moulds of different sizes, circular in cross section, and formed with a slight taper. These moulds, previously filled with water, are inserted in the freezing mixture, and a thin film of ice is formed round their edges in a few minutes; these slightly tapered tubes of ice are then withdrawn from the moulds, and placed one inside the other, thus forming a small stick of ice. The relative dimensions of the moulds are of course such as to form the ice tubes suitably proportioned to admit of the above operation.

In Siemens' apparatus calcium chloride is employed as the frigorific agent. The dissolution of this salt in water produces a reduction of temperature of only about 30° Fahr., and to admit of this reduction being sufficient to produce ice with water at an initial temperature of 65° Fahr., a heat interchanger is provided, wherein the spent liquor, which is at a temperature of about 30° Fahr., is employed to cool the water before it is mixed with the salt. It will thus be seen that there will be a gain in reduction of temperature equivalent to the amount of this cooling action. The salt can be recovered by evaporation, and employed over and over again. This apparatus is stated to have worked well, producing ice on a large scale in a satisfactory manner, but owing to its being on the whole found to be inferior, and more costly than purely mechanical methods of producing ice, it has never come into general use.

In an American machine, wherein ammonium nitrate is likewise employed as the frigorific agent, cylindrical receptacles fitting one within the other, so as to leave annular spaces or clearances, are provided. The water to be frozen is placed in the centre, the frigorific agent in the said annular spaces or clearances, so that the first or outermost acts to cool the second, the second the third, and the third the fourth, and so on, the cold being intensified at the centre in accordance with the number of the said annular spaces containing the frigorific agent. The series of cylindrical vessels or receptacles are arranged in a wooden outer casing so mounted as to be capable of being slowly revolved, and thereby promoting the more rapid dissolution of the salt. This apparatus is analogous to that employed many years ago on a small scale for laboratory experiments by Walker, and by means of which he succeeded in sinking the spirit to —91° Fahr.

When any of the above methods are employed for refrigerating purposes, brine, previously cooled in the apparatus, is circulated in the usual manner through a system of cooling pipes.

The general law governing the production of cold by frigorific mixtures is, that during the liquefaction of a solid, a certain amount of heat not indicated by or sensible to the thermometer is absorbed, which heat is abstracted from any surrounding bodies. The absorption of heat, consequently the production of cold, in the said environing bodies is the more marked in proportion as the solid is more suddenly or rapidly liquefied.

The following observations on frigorific mixtures are extracted from a paper* on "Refrigerating and Ice-making Machinery and Appliances," by Mr. T. B. Lightfoot, C.E., M.I.C.E., who is a well-known authority upon the subject: "When a substance changes its physical state, and passes from the solid to the liquid form, the force of cohesion is overcome by the energy in the form of heat. The effect may be produced without change in sensible temperature, if the heat be absorbed at the same rate as it is supplied from without. Thus, as is well known, the temperature of melting ice remains constant at 32° Fahr., and any increase or decrease in the heat supplied merely hastens or retards the rate of melting without affecting the temperature. Mixtures of certain salts with water or acids, and of some salts with ice, which form liquids whose freezing points are below the original temperatures of the mixtures, do not however behave in this way; for under ordinary circumstances the tendency to pass into the liquid form is so strong, that the heat is absorbed at a greater rate than it can be supplied from without. The store of heat of the melting substances themselves is therefore drawn upon, and the temperature consequently falls until a balance is set up between the rate of melting and the rate at which heat is supplied from outside. This is what takes place with ordinary freezing mixtures. The amount of the depression in temperature appears to depend to some extent on the state or hydration of the salt, and the percentage of it in the mixture. Almost the only salts used are those of certain alkalies, few others possessing the requisite solubility at low temperatures."

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* "Proceedings, Institution of Mechanical Engineers," 1886, p. 201.

Table of Principal Freezing Mixtures.

COMPOSITION OF FREEZING MIXTURES.	Reduction of temperature in degrees Fahr.		Amount of fall in degrees Fahr.
	From	To	
Snow or pounded ice, 2 parts; muriate of soda 1 part		− 5	
Snow 5; muriate of sodium 2; muriate of ammonia, 1		−12	
Snow 24; muriate of sodium 10; muriate of ammonia 5; nitrate of potash 5		−18	
Snow 12; muriate of sodium 5; nitrate of ammonia 5		−25	
Snow 4; muriate of lime 5	+32	−40	72
Snow 1; chloride of sodium or common salt 1	+32	0	32
Snow 2; muriate of lime crystallized 3	+32	−50	82
Snow 3; dilute sulphuric acid 2	+32	−23	55
Snow 3; hydrochloric acid 5	+32	−27	59
Snow 7; dilute nitric acid 4	+32	−30	62
Snow 8; chloride of calcium 5	+32	−40	72
Snow 2; chloride of calcium crystallized 3	+32	−50	82
Snow 3; potassium 4	+32	−51	83
Snow 2; chloride of sodium 1		− 5	
Snow 5; chloride of sodium 2; chloride of ammonia 1		−12	
Snow 14; chloride of sodium 10; chloride of ammonia 5; nitrate of potassium 5		−18	
Snow 12; chloride of sodium 5; nitrate of ammonia 5		−25	
Snow 2; dilute sulphuric acid 1; dilute nitric acid 1	−10	−56	46
Snow 12; common salt 5; nitrate of ammonia 5	−18	−25	7
Snow 1; muriate of lime 3	−40	−73	33
Snow 8; dilute sulphuric acid 10	−68	−91	23
Chloride of ammonia 5; nitrate of potassium 5; water 16	+50	+ 4	46
Nitrate of ammonia 1; water 1	+50	+ 4	46
Chloride of ammonia 5; nitrate of potassium 5; sulphate of sodium 8; water 16	+50	+ 4	46
Sulphate of sodium 5; dilute sulphuric acid 4	+50	+ 3	47
Sulphate of sodium 8; hydrochloric acid 9	+50	− 0	50
Nitrate of sodium 3; dilute nitric acid 2	+50	− 3	53
Nitrate of ammonia 1; carbonate of sodium 1; water 1	+50	− 7	57
Sulphate of sodium 6; chloride of ammonia 4; nitrate of potassium 2; dilute nitric acid 4	+50	−10	60
Phosphate of sodium 9; dilute nitric acid 4	+50	−12	62
Sulphate of sodium 6; nitrate of ammonia 5; dilute nitric acid 4	+50	−14	64

Table of Principal Freezing Mixtures—*Continued.*

COMPOSITION OF FREEZING MIXTURES. (Materials previously cooled.)	Reduction of temperature in degrees Fahr.		Amount of fall in degrees Fahr.
	From	To	
Phosphate of sodium 5; nitrate of ammonia 3; dilute nitric acid 4	0	−34	34
Phosphate of sodium 3; nitrate of ammonia 2; dilute mixed acid 4	−34	−50	16
Snow 3; muriate of lime 4	+20	−48	68
Snow 1; muriate of lime crystallized 2	0	−66	66
Snow 2; muriate of lime 3	−15	−68	53
Snow 8; dilute sulphuric acid 3; dilute nitric acid 3	−10	−56	46
Snow 3; dilute nitric acid 2	0	−46	46
Snow 1; dilute sulphuric acid 1	−20	−60	40
Snow 2; muriate of lime crystallized 3	−40	−73	33
Snow 8; dilute sulphuric acid 10	−68	−91	23

CHAPTER III.

THE ABSTRACTION OF HEAT BY THE EVAPORATION OF A PORTION OF THE LIQUID TO BE COOLED, THE PROCESS BEING ASSISTED BY AN AIR-PUMP, OR THE VACUUM PROCESS.

THIS class includes all such machines as operate to extract heat by the evaporation or vaporization of a portion of the water or other liquid to be cooled or frozen.

The cooling of liquids on this principle depends upon the conversion of the sensible heat into latent heat during evaporation, and, in its most primitive form, its use is almost coexistent with that of the world, having been commonly employed for refrigerating purposes in all ages. It is obvious, however, that as a portion of the liquid to be cooled is permitted to go to waste, it can be only profitably applied direct to liquids of little or no value, such as water.

A common example of this method in its crudest form is found in the ancient plan, so universally adopted in hot climates, of cooling water by the evaporation of a portion of the contents of a porous jar or vessel from the outer surface thereof, by hanging the said vessel in a position where it will be subjected to either a natural or an artificial draught.

It is stated that the practice of procuring ice by exposing water to the night air in shallow porous vessels has been practised in India during the cool season from the remotest ages. The said vessels are placed on a bed of straw, cornstalks, or megass (crushed cane stalks) in shallow excavations made preferably in an exposed situation on an extensive plain, being filled with water to be congealed or frozen, and in the morning, provided the night be clear, are found covered with thin crusts of ice.

This process is also said to have been practised, both in

France and in this country, in the latter part of the last century, with perfect success, so far at least as the production of ice was concerned, but it failed commercially by reason of the large expenses entailed.

The first machine on the vacuum principle for the production of artificial ice by the conversion of sensible into latent heat by evaporation, of which there is any record, was that invented by Dr. Cullen, in 1755, who in that year made the discovery that the evaporation of water could be facilitated by the removal of the atmospheric pressure by means of an air pump, to such a degree as to enable him to freeze water even in summer.

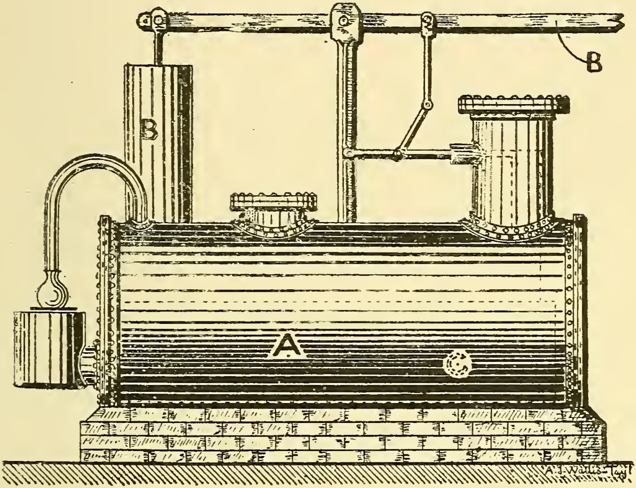

Fig 1.

This apparatus was the parent of all those subsequently designed for cooling and congealing liquids by their own evaporation in vacuo, that is to say, wherein the vapour is drawn off from the partial vacuum wherein it is formed, and is condensed in another partial vacuum with or without the help of absorbents, and is expelled by pressure.

In 1777, Nairne found that, by the introduction of sulphuric acid into a receiver for the exhaust, the aqueous vapour could be absorbed from the rarified air and the latter dried; and by taking advantage of this discovery he was enabled, in 1810, to construct an apparatus wherein he got rid of the vapour that rose from the water, and thus prevented it from forming a permanent atmosphere, and hindering the continuity of the operation.

Further attempts were made by Leslie (1810), Vallance (1824), Kingsford (1825), and others, but without any much greater success attending their efforts, Edmond Carre's sulphuric acid freezing machine being the first to be commercially successful.

This apparatus, acting to refrigerate by evaporation and rarification, and which was adapted to produce the *carafes frappés* commonly used in Parisian cafés and restaurants, consisted, as shown in Fig. 1, of a cylindrical vessel, A, intended to contain the charge of concentrated sulphuric acid; an air-pump, B, so arranged that it could be connected to the mouth of the carafe, and of an agitator, C, which is so coupled to the air-pump lever that it will be operated during the working of the said pump in such a manner as to keep the sulphuric acid in the cylindrical vessel A continually in motion.

The machine of course only operates intermittingly, but the large body of sulphuric acid used in the vessel A prevents a rapid loss of absorptive power taking place through dilution, and the agitation obviates the formation of a more diluted stratum on the surface, which would be highly detrimental to the proper working of the apparatus.

The chief drawback to this machine, besides its intermissive action, is the difficulty experienced in maintaining the pump in good working order, and the various joints all perfectly gas tight.

Franz Windhausen patented in 1878 a compound vacuum-pump designed to produce ice directly from water without using sulphuric acid; and likewise a modified arrangement wherein sulphuric acid could be employed. In this latter apparatus the sulphuric acid is cooled by water whilst absorbing the vapour, and is subsequently concentrated, when it becomes over-diluted, thus obviating the necessity for the insertion of a fresh supply of acid.

An improved form of this machine constructed in 1881, nominally capable of producing from 12 to 15 tons of ice per 24 hours, and which was first put up at the Aylesbury Dairy, Bayswater, London, and afterwards removed to Brompton, was fully described in a paper* written by Dr. Hopkinson.

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* "Journal of the Society of Arts," 1882, Vol. xxxi., p. 20.

The ice-forming vessels or moulds, which are six in number, are constructed of cast-iron, circular in transverse section, and slightly tapered. These cans, moulds, or cases moreover are steam-jacketed, so as to admit of the ice being melted or thawed off and readily disengaged therefrom, and are provided at their lower ends with hinged doors, which, when closed, form fluid-tight joints.

The sulphuric acid is contained in a long cylindrical vessel wherein rotating agitators maintain the said acid in continual motion during the operation of the apparatus, and the said cylindrical vessel is water-jacketed so as to carry off the greater portion of the heat that becomes liberated during the absorption of the vapour.

The sulphuric acid cylinder or vessel communicates with the upper parts of the ice-forming vessels or moulds, and with the vacuum-pump, which latter has two cylinders, viz., a large double-acting one and a small single-acting one.

The water is admitted to the moulds through nozzles at a regulated rate, the fine streams offering an extended surface for evaporation, and becoming instantly congealed into ice globules or particles, which, falling into the bottoms of the said moulds, are frozen, together with the water that collects there.

In the operation of the apparatus the air, and any vapour that may pass over from the sulphuric acid cylinder or vessel, are drawn into the large pump-cylinder, by which they are slightly compressed and passed on into the condenser, wherein a portion of the said vapour is condensed by cold water, the rest, together with the air, entering the second or smaller pump-cylinder, where they are compressed up to the tension of the atmosphere and discharged. This pump, it is stated, admits of a vacuum of half a millimetre of mercury being constantly maintained; 2½ mm., however, being as low a vacuum as it is found necessary to have during actual work.

By the employment of a compound pump with an intermediate condenser, and performing the compression in two distinct stages, the losses that would otherwise occur from the clearance spaces in the large pump are greatly reduced.

The concentrator for the diluted sulphuric acid consists in a lead-lined vessel or receptacle fitted with a steam-heated coil of lead piping and connected with an ordinary air-pump. The acid is transferred from one vessel to the other by atmospheric pressure, and the diluted or weak acid, which is at a comparatively low temperature, is heated on its way to the concentrator in an interchanger, by the strong concentrated acid returning from the latter.

The ice produced by this machine, like that of all those on the vacuum principle acting direct, is in an opaque and porous condition; and the avoidance of this defect, and the production of clear transparent crystal ice by freezing it in moulds plunged in brine previously cooled by evaporation in a vacuum, would render the process too expensive to be commercially successful.

The total amount of water that is used in working is from 10 to 12 tons per ton of ice, and the fuel 180 lbs. of coal to each ton of ice produced; the latter is employed in raising the requisite supply of steam for driving the pumps, and heating the coil in the sulphuric acid evaporator.

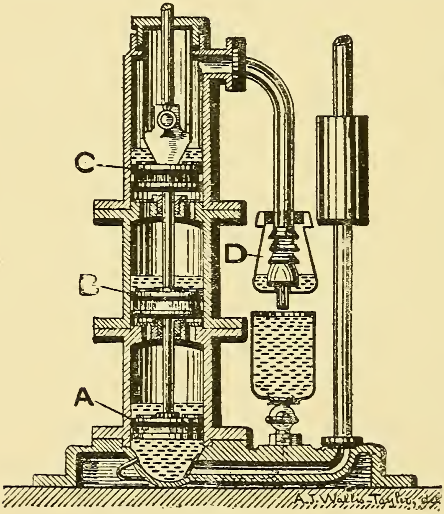

Fig. 2.

Fig. 2 is a vertical central section partly in elevation showing Langé's improved pump for exhausting the air from the absorber of a vacuum machine. As will be seen from the drawing, three pistons, A, B, and C, are employed, placed in line one above the other and working in three separate cylinders. The valves are so arranged that each of the uppermost cylinders draws from the one below, and they are sealed with oil, which latter constantly circulates through the pump. The mixed oil and air on leaving the top or uppermost cylinder is discharged into a separator D, the air being permitted to escape into the atmosphere, and the oil passing into a receptacle from which it can be returned to the pump when required.

The vacuum apparatus for the refrigeration of a liquid by its partial evaporation, for which James Harrison took out a patent in 1878, is designed to produce opaque ice at a very low cost (about one shilling per ton), by reducing the fuel consumption, which, as already mentioned, is the chief item of expense. This is effected by getting rid of the bulk of the friction engendered in the usual vacuum and air pumps, and also by a saving of the fuel expended in concentrating the weak or diluted sulphuric acid in the previously described apparatus. The main feature of Harrison's invention is the process of refrigerating by the evaporation of the liquid to be cooled or congealed, by carrying its vapour under a head of neutral non-evaporable liquid, condensing the compressed vapour at the ordinary temperature, and removing the resulting liquid and air by a pump.

One form of his apparatus consists in a rotating pump or cylinder which seems to provide a ready means of exhausting large volumes of low tension vapour, without the expense of the labour entailed in maintaining ordinary piston packings in an effective condition, and the great loss through friction therefrom. This device consists, as will be seen from the sectional diagramatical view, Fig. 3, of an iron cylinder, rotatably mounted horizontally upon hollow or tubular shafts or axles, and divided internally into different compartments by longitudinal partitions of an L shape in transverse section. This cylinder is connected through one of the hollow shafts or axles with the refrigerating or ice-making vessels or moulds, which may be of any convenient form, and it is partly filled with oil or other liquid, which latter must invariably be either non-evaporable or one which is only vaporizable at a temperature greatly in excess of that at which the refrigerating liquid can be vaporized, and it must, moreover, be perfectly neutral chemically to the vapour with

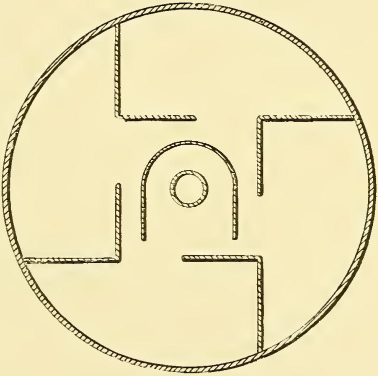
Fig. 3.

which it will be brought into contact when the machine is at work.

The operation of the apparatus is as follows, viz. :—The cylinder rotates upon one of the fixed hollow axles, through which the vapour or gas to be compressed is delivered from the refrigerator or ice-making vessels, and the longitudinal partitions or compartments moving round with their apertures downwards carry with them charges of the vapour, and compress them to a degree varying in accordance with the depth to which they dip below the surface of the liquid. After attaining the lowest position the compressed vapour is liberated, and rises into a fixed hood or inverted channel, situated centrally and communicating with the other hollow shaft or axle, which is placed at the other side of the cylinder, through which it passes to a surface condenser. In this surface condenser the compressed vapour is partially condensed, both by direct cooling action and also by the evaporation of water flowing over the surface, and the condensation water, together with any air present, are then compressed to the atmospheric tension and discharged.

Several modifications are also described, viz. :—First, a series of buckets attached to endless chains dipping into a reservoir of the compressing liquid, and delivering the compressed gas or vapour into a reservoir. Secondly, a gasometer-shaped vessel, rising and falling in an annular space filled with a non-evaporable neutral liquid. The vessel, on being lifted, becoming filled with the air or vapour, and on being depressed delivering it under a head of liquid. Thirdly, a tapering archimedean screw working in a reservoir of non-evaporable neutral liquid by which the vapour is taken in at the larger upper orifices, and is discharged, compressed, and liquefied at the lower or smaller end. Fourthly, pumps with actuated valves and with arrangements for complete expulsion of air or vapour. And finally, fifthly, fans working in the air or vapour, and forcing it from one compartment into another, or exhausting it and forcing it into the atmosphere.

A patent was obtained by Blyth and Southby some years back for a vacuum refrigerating machine of great simplicity of design. The main feature of their apparatus consists in the provision of two pumps, viz., a large main pump and a small auxiliary one, the former being heated by means of a steam jacket or otherwise.

The large, single acting, steam-jacketed vapour pump, is driven by a crank, which is situated beneath, and is enclosed in a suitable cylindrical casing or chamber, having at one side a door or cover admitting of access thereto, and so arranged that when closed it forms a gas-tight joint. The crank is driven by belt gearing, from any suitable source of motive power, and the pulley for the latter is fixed upon the end of a shaft or spindle passing through a stuffing box provided upon the opposite side, or wall, of the crank chamber, to that fitted with the said door or cover.

A heavy balanced fly-wheel is also mounted upon the crank shaft, and is enclosed within the said chamber, which, as above mentioned, is made perfectly fluid tight.

The ice box is fitted with an automatic feeding arrangement for filling the ice-can or case with water, which mechanism is operated by an eccentric upon the crank shaft, and the said box is connected with the pump through a pipe governed by a stop-cock or valve, a similar cock or valve being also fitted in the pipe leading to the cooling vessel, and another suitable valve in the vapour exit to the condenser.

A double-acting air or ejector pump worked off the eccentric is moreover provided for removing the air from the interior of the machine, and a vacuum gauge for ascertaining the degree of vacuum produced.

The operation of the machine is as follows, viz. :—Any air that may be contained within the large pump cylinder is first pumped or drawn off by the small air or ejector pump, thereby producing a vacuum which is filled by vapour from the water to be frozen or cooled. The large single-acting pump, which draws the vapour from the said water through a suction valve situated in the piston, compresses the said vapour and delivers it through the outlet or discharge valve to the condenser, where it is condensed by water in the usual manner, is removed by the small air or ejector pump, together with any air that may have passed into the machine through leakage, and is discharged into the atmosphere. The vapour is prevented from condensing in the cylinder by the steam-jacket, which maintains the temperature of the said cylinder above that at which the said vapour will condense into water. Were this not the case, and were the vapour permitted to condense in the cylinder, the quantity to be discharged would be so small as not to be capable of being forced through the delivery or outlet valve.

When starting the machine, communication between both ends of the vapour pump cylinder can be kept open for any requisite length of time during the first portion of the delivery stroke, so as to permit the air to return to the underside of the piston, and thereby lessen and regulate the expenditure of power required in getting up the vacuum. This is effected by means of a bye-pass and valve, which can be opened at starting, and kept open for about nine-tenths of the piston stroke, being closed gradually as soon as the vacuum becomes more perfect, and altogether as soon as all the air has been got rid of. The average pressure upon the piston is light, not exceeding about one-sixth of a pound.

In all the above arrangements, a portion of the refrigerating agent itself, together with the heat it has absorbed, is rejected, consequently water, as the only one sufficiently inexpensive, is invariably employed. Water has a boiling point of 212° Fahr. at atmospheric pressure, a latent heat of vapour of 966·6 and a tension of vapour of 0·623, and having so high a boiling point it requires a vacuum of ·089 lb. per square inch to boil at a temperature of 32° Fahr., and consequently a vacuum at the very least as high as this must be maintained to produce ice by the vacuum process.

CHAPTER IV.

THE ABSTRACTION OF HEAT BY THE EVAPORATION OF A SEPARATE REFRIGERATING AGENT OF A MORE OR LESS VOLATILE NATURE, WHICH AGENT IS SUBSEQUENTLY RESTORED TO ITS ORIGINAL PHYSICAL CONDITION BY MECHANICAL COMPRESSION AND COOLING, OR THE COMPRESSION PROCESS.

So far the refrigeration has been effected by evaporation, the air gaining access under natural conditions, or by an artificial draught, or the evaporation has been accelerated by reducing the atmospheric pressure, the latter operation being next still further facilitated and rendered practically continuous by providing for the absorption of the vapour given off or evolved by means of an absorbent, such as sulphuric acid.

More volatile liquids, however, are employed as agents, such as, for instance, alcohol, sulphurous and carbonic acids, bisulphide of carbon, gasoline, ether, methylic and sulphuric ether, carbon bisulphide, methyl chloride, ethylene, anhydrous ammonia, &c.

In the year 1755, Dr. Cullen found that, by removing the atmospheric pressure, ether and other liquids which boil at low temperatures would evaporate at temperatures below freezing point, with sufficient rapidity to congeal water brought into contact with the exterior surfaces of the vessels or receptacles wherein they were contained.

In a refrigerating and ice-making apparatus invented by Jacob Perkins about the year 1834, compression was first introduced, the volatile liquid used, according to Sir Frederick Bramwell, being one derived from the destructive distillation of caoutchouc. This invention of Perkins' is the origin from which has sprung all those machines operating upon the compression principle.

Perkins' apparatus is shown in Fig. 4 in side elevation, partly in vertical section, and consists simply, as will be seen from the illustration, in a jacketed pan A, clothed externally with non-conducting material, and a pump B connected to the upper part of the jacket, and to the first or uppermost convolution of a coil or worm fitted in a tank or vessel C wherein cooling water can be freely circulated, and the last or lowermost convolution of which coil or worm is connected to the lower part of the said jacket. The water to be frozen is placed in the jacketed pan, the space or clearance between the latter and the jacket being partially filled with the distillate from caoutchouc, or the ether, or other volatile liquid intended to form the refrigerating agent. The vapour given off or evolved from the volatile liquid contained in this space or clearance is drawn off from the top by the pump B, and is delivered compressed to the water-cooled worm or coil, which is shown by dotted lines in the tank C, wherein it is again liquefied and returned from the bottom of the latter to the lower part of the said space or clearance. The complete cycle of operations is thus continuous, and the only loss of the volatile liquid used as a refrigerating agent that is possible, is that which may take place through leakage.

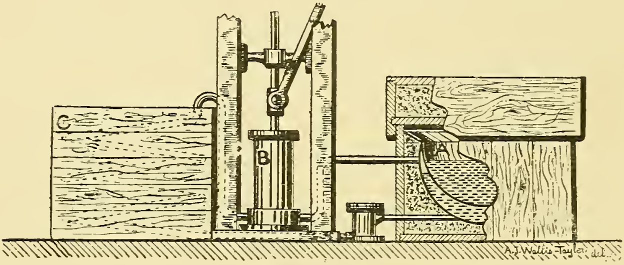

Fig. 4.

The system of absorbing heat and thus producing cold, partly by the expansion and vaporization or gasifying, and subsequent liquefaction, and partly by compression and cooling, is in accordance with the well-known law of physics, viz., that all gases during the process of passing from a liquid to a gaseous state are bound to absorb a certain amount of heat, and whilst returning from a gaseous to a liquid state to give up or throw off the same amount of heat.

Whatever the refrigerating or heat-absorbing agent that may be used, the following cycle of operations is obligatory in all machines working upon this principle, viz. :—

First, compression, that is the refrigerating or heat-absorbing agent in gaseous form, is subjected to a pressure sufficient to reduce it to a liquid form, the said pressure varying with the nature of the agent, and the temperature of the condensing water. During this compression, a degree of heat is developed in accordance with the amount of pressure to which the gas is subjected, or to the volume to which it has to be reduced relatively to that of the gas, in order to produce liquefaction. This heat is carried off by means of condensing or cooling water.

Second, condensation, during which process the heat developed during the above-described compression of the gas is carried away by forcing the latter through water-cooled pipes, the heat being transferred to the said cooling water. At this point the gas is ready to assume the liquid form, in doing which an additional amount of heat is given off to the said water.

Third, expansion, during which the liquefied gas is admitted to series or coils of pipes, and being suddenly relieved of pressure, instantly flashes or expands into a gaseous form; in doing which, according to the above-mentioned law of physics, it is forced to absorb or take up a quantity of heat which it renders latent, and which it draws from the surrounding objects, viz., firstly, of course, the pipes or coil wherein it is confined, and secondly, such substances as may be brought in contact with the latter, and which it is desired to cool, as air, water, brine, &c.

The amount of heat thus abstracted or absorbed is equal to that previously given up to the cooling water in the condenser, the gas being then ready for compression, &c., and the cycle of operations can thus be repeated *ad infinitum.*

These three operations being essential, all machines of this class, however much they may differ in more or less important points of detail, must perforce consist of the following three series of parts, viz. :—

First, a compression side, wherein the gas is compressed in some suitable and convenient manner.

Second, a condensing side, wherein the gas circulates through water-cooled pipes or coils or their equivalent, gives off its heat, and liquefaction takes place.

Third, an expansion side, consisting of pipes or coils, or other space, wherein the gas can re-expand and perform its work of cooling or refrigerating, by abstracting heat in the above-described manner from the surrounding objects.

It will be seen that the heat only that has been acquired by the refrigerating agent is rejected, the latter being used over and over again, the only loss, therefore, is that sustained through accidental leakages.

Such liquids only, however, are capable of being used as refrigerating agents as possess vapours capable of being liquefied under pressure at ordinary temperatures. Hence, owing to the latter operation being an absolute essential, it is generally known as the compression process.

The next attempt at improvement in these machines was made by Professor Twining, who obtained a patent for his invention in this country in 1850, and in the United States in 1853. His apparatus comprises an exhaust or expansion vessel, a pump, and a condenser. The water to be frozen is placed in chambers or cells situated between thin metal pipes, plates, or partitions, through which circulates the vapour evolved from a suitable volatile liquid, such as ether, sulphide of carbon, &c., which vapour is drawn off by an air pump, compressed, condensed in a coil or worm, cooled by water, and is then returned to the reservoir in which it is once more vaporised, in a manner substantially similar to that of Perkins'. In fact, as already intimated, all machines of this class are bound to operate upon the same principle as that of the latter inventor, and can only differ therefrom in details of construction of more or less importance.

It is stated that a machine of Twining's, of a capacity designed to produce 2,000 lbs. of ice in twenty-four hours, was in operation in 1855 in Cleveland, Ohio; and that, although working under somewhat serious disadvantages, it did actually produce 1,600 lbs. of ice per twenty-four hours in a tolerably satisfactory manner, and was in use off and on for about three years.

Another machine, which comprises certain further improvements on Perkins' apparatus, was invented and patented by James Harrison in the year 1856.

The novel feature claimed especially, in Harrison's compression machine, is the evaporation of volatile liquids in vacuo, and the reduction to a liquid form in a separate vessel by pressure. The essential parts of his apparatus consist of three vessels connected by tubes, a vacuum being established throughout the apparatus, and the air being expelled by the vapour of ether, ammonia, or other volatile liquid. The first vessel is charged with the volatile liquid; the second vessel contains a pumping and compressing apparatus, by means of which the vapour is withdrawn from the first vessel and forced into a third; and the third or last vessel is immersed in water or kept moist, so that the heat generated by the compression and liquefaction of the vapour may be carried off. The resulting liquid passes into the first vessel to be again evaporated under diminished pressure, and again withdrawn, compressed, liquefied, and returned, the process being capable of indefinite prolongation, until the apparatus be either injured or becomes worn out.

The general arrangement of an improved Harrison machine constructed by Siebe Gorman & Co., is shown in side elevation in Fig. 5, wherein A is the steam-engine cylinder; B is the pump or compression cylinder, which is kept cool by a suitable water-jacket; C is the refrigerator, which consists of a copper cylinder, fitted with sets of copper tubes arranged horizontally; D is the ether condenser, which is composed of sets of copper tubes also arranged horizontally in a wooden tank or casing, and cooled by a circulation of water.

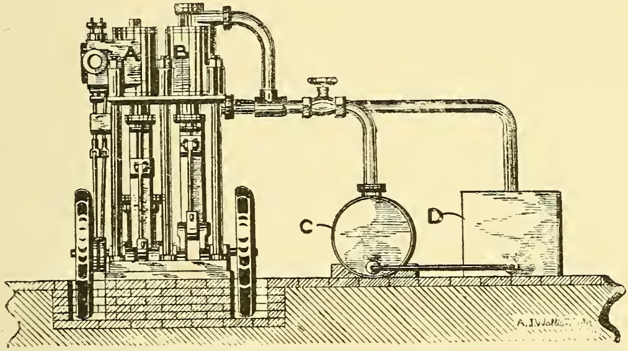

Fig. 5.

Suitable connections are provided between the refrigerator C, pump B, and condenser D.

The refrigerating agent employed in this apparatus is sulphuric ether, which is the result of the action of sulphuric acid upon vinous alcohol, and which has a specific gravity of

0·720, a latent heat of vaporisation of 165, a specific gravity of vapour of 2·24 as compared with air, and the boiling point of which is 96° Fahr. at atmospheric tension.

The liquid sulphuric ether is delivered from the condenser D to the refrigerator C, through a pipe fitted with a stop cock by means of which the amount admitted can be nicely adjusted to the capacity of the pump B. The weight of ether capable of being drawn off by the said pump B is dependent upon the pressure at which evaporation takes place, as it is perfectly obvious that the denser the said vapour, the greater the weight drawn off at each stroke of the pump.

In order to ensure this apparatus working up to its fullest capacity the boiling point of the sulphuric ether must be so regulated as to impart the exact reduction of temperature desired, consequently the pressure at which evaporation is caused to take place depends upon the degree of temperature to which it is required to lower the brine.

The amount of water required to be passed through the ether condenser D, for cooling purposes, naturally varies in different climates, and in accordance with the season of the year; in this country it is stated to be about 150 gallons per hour for each ton of ice produced per twenty-four hours. The liquefaction of the vapour is said to take place with cooling water at the temperature usually obtainable here at a pressure of some 3 lbs. per square inch above that of the atmosphere; in a hot climate, however, a very much higher pressure is required, rising sometimes to as much as 12 lbs. above that of the atmosphere.

The apparatus, when employed for making ice, is provided with an ice-making tank, usually fitted with copper moulds; or, when used for refrigerating purposes, it may be connected with a system of cooling pipes. The brine circulation is maintained by means of a suitable pump, and the brine, which is, as a rule, reduced to a temperature of about 10° Fahr. during its passage through the sets of tubes in the refrigerator C, is returned, after circulation, to the said refrigerator to be recooled. The sets of tubes in the refrigerator are so arranged that the brine to be cooled circulates through them successively, being thus gradually reduced in temperature.

When employed for cooling water or other liquids, the said liquid is usually passed at once through the refrigerator C in place of the brine.

In Charles Tellier's apparatus, which was designed some years later, the refrigerating agent employed is methylic ether, which liquid has a latent heat of vaporisation of 473, and which enters into ebullition at tension of the atmosphere at a temperature of from 20° to 25° below zero Fahr., whereas sulphuric ether, employed in the improved Harrison machine, as before mentioned, boils at 96° Fahr., a difference, of about 121°.

Methylic ether is the result of the action of sulphuric acid upon ligneous alcohol, that is to say, alcohol distilled from wood. To obtain methylic ether, sulphuric acid is mixed with ligneous alcohol in equal proportion, and heated until the ether is evolved, carrying with it a number of bye products, such as sulphurous acid, carbonic acid, and empyreumatic vapours, which must be eliminated by passing the impure vapour through or over liquids, etc., by which they will become absorbed and retained. For instance, by passing the adulterated vapour over potash, the carbonic and sulphurous acids will be retained by the alkali, the aqueous vapour being at the same time carried away mechanically.

In the distillation of methylic ether on a large scale, a great difficulty would be experienced, under ordinary conditions, in getting a liquid, having so low a boiling point as —25° Fahr., to flow through the requisite pipes. To overcome this difficulty, Tellier designed the special apparatus illustrated in sectional elevation in

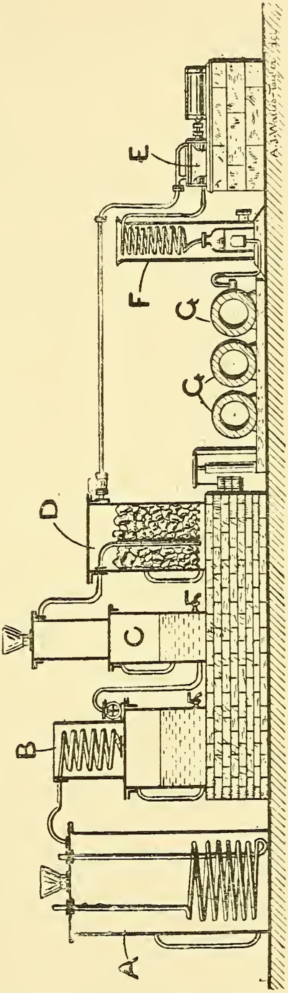

Fig. 6.

Fig. 6, wherein the vapour, after purification, is brought back to a liquid state by pressure, and is thus rendered manageable.

In the drawing A, B, C are large cast or wrought-iron drums or receivers; D is the purifier; E is a special pump which sucks off the purified vapour and delivers it through the worm F in a liquid state into a set of receivers G, which latter are capable of withstanding a very high pressure, and from whence it can be drawn off, and will flow through the rest of the apparatus as easily as water.

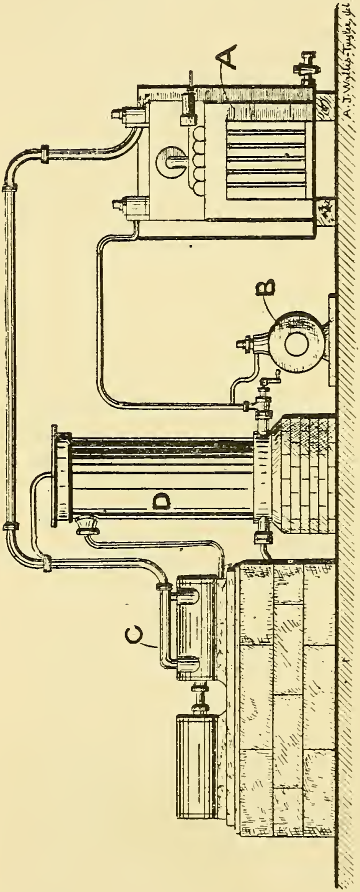

Fig. 7.

Tellier's apparatus for the production of cold is shown in elevation in Fig. 7, wherein A is the refrigerator; B is a receiver or vessel in which the methylic ether is evaporated; C is the pump for drawing off the vapour from the latter; and D is the condenser, which is fitted with a suitable worm or coil. The vaporised methylic ether is either employed to lower the temperature of a solution of brine, by passing it through a series of tubes situated in the refrigerator and plunged in the latter; or it is carried on and permitted to expand in a suitable system of pipes, and so act direct to reduce the temperature of air-tight chambers. When in operation it is found that the pipes leading from the receiver B are so cold that they become coated with hoar frost; whilst, on the contrary, when giving up the absorbed heat during compression and liquefaction, the gas raises the tubes to a very high temperature, sometimes even approaching to a red heat.

The liquefaction of the methylic ether in the worm or coil of the condenser D gives rise to a certain amount of pressure, and to allow for this, and at the same time to permit a supply of the liquid to pass from the said condenser to the receiver B as required, a device called a distributor, the construction of which will be readily understood from the enlarged sectional view, Fig. 8, is employed. **E** is the aperture through which the liquid methylic ether is delivered to a small chamber or recess F. G is the outlet aperture, the upper portion of which is bifurcated as shown at G^1, G^1, and which communicates with the refrigerator. H is a valve having two recesses H^1, H^1, which correspond with the holes or apertures G^1, G^1, and which valve is mounted on a spindle I, which is capable of being rotated through the bevel or mitre gearing K, and shaft L, and works upon a suitable seating in the bottom of the said recess or chamber F. During the revolution of the valve **H** in the chamber F, which latter is always maintained full of liquefied methylic ether, the recesses H become filled with the latter, and every time that the said recesses pass over the corresponding holes or ways G^1, the liquid contained therein falls by gravity into the latter and passes away to the refrigerator through the outlet G.

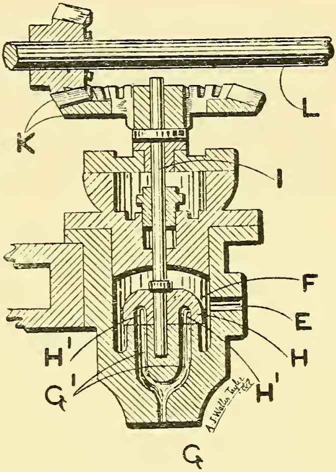

Fig. 8.

About the same time as the preceding, an ether machine was patented by Della Beffa and West, which comprised a multitubular refrigerator in which the ether was volatilised, a double-acting air or vacuum pump exhausting this vessel and pumping the ether vapour into a condenser; and likewise a special form of the latter for condensing the said ether vapour.

The following particulars regarding an ether machine are given[*] by Mr. Lightfoot as being the result of actual experiments made in this country, and serving to show what may be expected under ordinary conditions:—

Production of ice per twenty-four hours	15 tons.
,, ,, per hour	1,400 lbs.
Heat abstracted in ice-making, per hour ..	245,000 units[**]
Indicated horse-power in steam cylinder, excluding that required for circulating the cooling water and for working cranes, etc.	83 I.H.P.
Indicated horse-power in ether pump	46½ I.H.P.
Thermal equivalent of work in ether pump, per hour,	119,261 units[**]
Ratio of work in pump to work in ice-making ..	1 to 2·05
Temperature of water entering condenser	52° Fahr.

Mr. Frederick Colyer, C.E., M.I.C.E., states[†] that he obtained the following results with a first-class apparatus when testing the working of some of the leading ether machines, viz.—"In an ether machine made by Messrs. Siebe Gorman & Co., capable of cooling 3,200 gallons of water from 60° down to 50° or abstracting 320,000 heat units[**] per hour, the average experiments gave 4,250 gallons per hour cooled 10° Fahr. The temperature of the water at the inlet was 54° and that of the water used for condensing purposes was the same. The maximum cooling effected was 449,437 heat units[**] abstracted per hour, being from 35 to 40 per cent. above the nominal power of the machine. The condensing water used per hour was 1,262 gallons, or about 3-10ths of a gallon for every gallon of water cooled. The coal consumed was 3¼ cwts. per hour; it was of indifferent quality, or the consumption would have been smaller. The steam cylinder was 21 in. diameter and 27 in. stroke; the air-pump 24 in. diameter and 27 in. stroke. The speed of the engine was 58 revolutions per minute, with 48 lbs. of steam cut off at one-third of the stroke. The indicated power of the engine was 53 horse-power, and of the air-pump 29·2 horse-power. The boiler was 7 ft. diameter and 24 ft. long, and gave an ample supply of steam."

This, he stated, was the most efficient ether machine that had

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[*] "Proceedings, Institution of Mechanical Engineers," 1886, page 214.

[**] A thermal unit is that amount of heat required to raise the temperature of 1 lb. of water 1° by the Fahr. scale when at 32°.

[†] "Proceedings, Institution of Mechanical Engineers," 1886, page 248.

come under his notice at that date, and contained several improvements not usually found in others of the same class.

According to the same authority the ether system is more expensive than the ammonia system (which latter will be next considered), especially in London where coal is expensive, and water has frequently to be obtained from the water companies. The latter item is undoubtedly in this case one of considerable moment, as water is required in larger quantities for condensing purposes in the ether system, and consequently the high temperature which it sometimes attains in the street mains during the summer months becomes a matter of serious importance, as regards the economical working of the machines.

Other objections to the use of ether as a refrigerating agent are, that, owing to its low vapour tension, a very large volume has to be circulated to perform a given refrigerating effect, thus abnormally increasing the dimensions of the apparatus; rapid deterioration under repeated vaporisation and recondensation; and finally that it is extremely inflammable and explosive.

On the other hand, however, it is possessed of the quality of working with a low pressure in the condenser, which renders its use advantageous in hot climates.

Van der Weyde's (American) apparatus comprises exhaust and force pumps, a cooling coil and two refrigerators, the latter also acting as reservoirs for the condensed liquid. The most usual refrigerating agents employed are naphtha, gasoline, rhigoline, or chimogene.* The water to be frozen is placed in moulds or vessels plunged in other vessels containing glycerine, and which latter are surrounded on the outside by cyrogene. The naphtha, gasoline, rhigoline, or chimogene is evaporated by means of an air pump and forced through the refrigerator, the evaporation of the said cyrogene abstracting sufficient heat to form ice.

In Raoul Pictet's machine sulphur dioxide or sulphurous acid (SO_2) is employed as a refrigerating agent. Sulphur dioxide is prepared by burning sulphur in dry air or oxygen gas, or by removing the elements of water, and an additional atom of oxygen from sulphuric acid by heating it together with copper clippings or mercury. The purification of the resultant gas is effected by washing, and it is collected either by displacement, or over mercury. It is completely colourless, has the over-

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* Knight's "Practical Dictionary of Mechanics."

powering odour of burning sulphur, neither supports combustion or respiration, is 2·247 times heavier than air, is easily condensed, is liquefiable by cooling down to 14° Fahr. under ordinary atmospheric pressure, and congeals into a transparent solid at temperatures below —168° Fahr. This gas deviates considerably from Boyle's law of pressures, and occupies less space for equal increments of pressure than does air under like conditions, this variation becoming more marked as the temperature is reduced. Sulphurous acid is extremely soluble in water, one volume of the latter at a temperature of 50° Fahr. being capable of dissolving 51·38, and at 68°, 36·22 volumes of the former. It has a molecular weight of 65 and a density of 32. The latent heat of vaporisation of this liquid is 182, and it boils at a temperature of 14° Fahr. at the tension of the atmosphere.

In Pictet's apparatus the refrigerator and ice-tanks are combined, the circulation of the brine being effected by means of a fan, and the space occupied is thus considerably reduced, the efficiency being also somewhat augmented.

In 1885 Pictet applied for a British patent for an improved material for use in refrigerating apparatus wherein anhydrous sulphurous acid is employed, consisting of the admixture with the latter of carbonic anhydride. The sealing, however, was successfully opposed and consequently no patent was granted for this invention.

The employment of sulphurous acid is highly objectionable, by reason of its becoming converted, by combining with the constituents of the atmosphere, into sulphuric acid and corroding the machine.

In a patented machine of Windhausen's the refrigerating agent employed is what is indifferently known as carbon-dioxide (CO_2), carbonic anhydride, or carbonic acid, which material is gaseous at ordinary temperatures, and under ordinary pressures, but which liquefies at a pressure of 540 lbs. Carbonic acid gas does not burn, neither supporting combustion nor respiration.

Windhausen's apparatus is fitted with a pair of compressors placed in line with steam cylinders of the compound type, arranged side by side with a surface condenser between them. The gas condensers are situated in the base of the machine, and a separate refrigerator is provided in connection with each of them, constructed of coils of wrought-iron pipes mounted in a steel casing, wherein the brine is circulated. The duplicate portions of the machine are usually so arranged as to admit of either of them being worked separately, or both together, if desired. This is advantageous inasmuch as it renders the apparatus practically equal to two independent or separate machines, and affords the same immunity from a complete breakdown. The later machines comprise several patented improvements by J. & E. Hall, Ltd., which firm are also (we are informed) the proprietors of the original Windhausen patent.

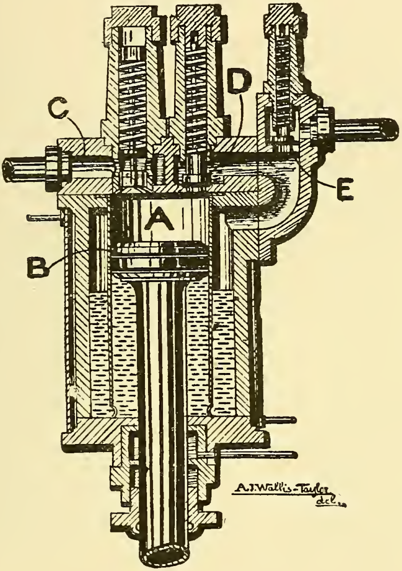

Fig. 9.

Fig. 9 is a vertical central section, some of the parts being left in elevation, showing the Windhausen compressor for treating the gas in two stages. Figs. 10 and 11 are enlarged views, showing more clearly the details of construction of the inlet or suction valve, and of the outlet or discharge valve. As will be seen from the illustration the inner cylinder A is surrounded by an annular space communicating with the former through the valve D; C is the inlet which communicates with the cylinder A through a suitable valve, and through which the gas to be compressed is drawn or sucked into the said cylinder; B is the piston, and E is a valve through which the annular space or clearance round the cylinder A communicates with a pipe leading to the condenser.

In operation the gas is primarily drawn into the cylinder A, through the inlet valve C, where it is compressed, and discharged through the valve D to the above-mentioned annular space, wherein it is finally compressed by the oil shown in the latter and the cylinder A, which communicate at their lower ends through suitable holes or apertures, and which oil forms a liquid piston. After this second and final compression the gas is discharged through the valve E to the condenser.

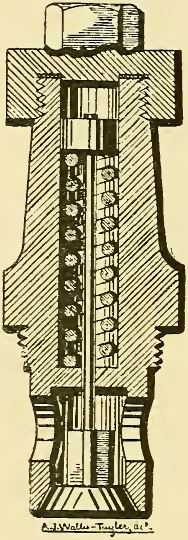

Fig. 10.

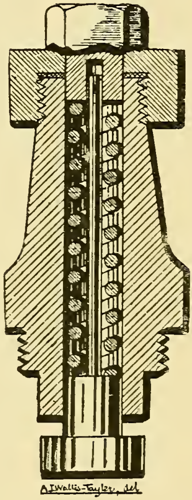

Fig. 11.

Another machine adapted for the use of carbon dioxide as a refrigerating agent is found in that of Lowe. It comprises a gasometer or gas-holder, a pump, a condenser or cooler, a drier charged with chloride of calcium, a water-cooled condensing coil, and a refrigerator or ice-making tank. In operation the gas is admitted to the pump, liquefied under the action thereof, and the heat thus generated is absorbed or taken up in the cooler, after which it is allowed to expand into the refrigerator, where it acts in the usual manner, and is finally returned to the gas-holder.

Refrigerating machines on the carbonic acid or carbonic anhydride system are also made by the Pulsometer Engineering Company, Limited, and others.

Carbonic acid, carbon dioxide, or carbonic anhydride (CO_2) is completely inodorous; and the further advantage is also claimed for it, that, as it has no affinity for copper, it can be used with that metal with impunity. This is an important quality for marine installations, and consequently it has been used to a certain extent for that purpose. On the other hand, however, it is a deadly poison and fatal to animal existence, and has the further drawback that with water at a temperature of 70° Fahr. it requires a very high pressure to liquefy it, viz., one amounting to about 1,000 lbs. per square inch, whilst when the temperature of the said water exceeds 80° Fahr. it is for this reason practically impossible to economically employ it as a refrigerating agent at all.

Carbonic acid or carbon dioxide must not, however, be mistaken for the still more deadly gas known as carbon monoxide or carbonic oxide gas (CO), the inhalation of even a minute quantity of which will produce death. Carbonic acid or carbon dioxide (CO_2), which is the poisonous gas found at the bottom of old wells, &c., and forms the choke-damp of coal mines, is nevertheless sufficiently dangerous, and according to Sir Henry E. Roscoe, F.R.S., the presence of only 0·10 per cent. (1 part per 1,000) of this gas will render air unfit for continued respiration. The same authority gives the vapour tension of carbon dioxide or carbonic acid, at 35·5 atmospheres at a temperature of 0° Cent. (32° Fahr.), and at 73·5 atmospheres at a temperature of 30° Cent. (86° Fahr.).

According to Mr. T. B. Lightfoot, M.I.C.E.,* the horse-power required in carbonic-acid machines, for producing a given quantity of ice with cooling water at 90 degs., is just about double that required for producing the same quantity with cooling water at 50 degs. He is also of opinion that the refrigerating effect falls off so fast as to render a carbonic-acid machine practically useless long before a temperature of 87 degs. is reached.

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* *Engineering*, 6th December, 1895.

CHAPTER V.

THE COMPRESSION PROCESS (*continued*).—AMMONIA MACHINES.

THE refrigerating agent now most largely employed, and by far the most efficient one known at present, is anhydrous ammonia (NH_3), which has a molecular weight of 17 and a density of 8·5. This liquid boils at 40° below zero Fahr. at atmospheric pressure; it has a latent heat of vaporisation of 900, and a vapour tension of 108 lbs. per square inch at a temperature of 60° Fahr. Gaseous ammonia can be liquefied at a pressure of 128 lbs. to the square inch, at a temperature of 70° Fahr., and at a pressure of 150 lbs. at a temperature of 77° Fahr., the pressure required to produce liquefaction rising very rapidly with the temperature. To liquefy by cold it requires to be reduced to a very low temperature, viz., —85·5° Fahr. The latent heat of ammonia is very great, consequently its value as a refrigerating agent is proportionately large.

The only alterations required in an ether machine to render it suitable for use with anhydrous ammonia as a refrigerating agent, are those made necessary by reason of the higher pressure of its vapour, and of the injurious action which it exercises upon copper, which causes the use of brass or gun metal in any of the parts with which either the liquid or the vapour comes in contact to be undesirable.

The chief advantages derived from the use ot anhydrous ammonia as a refrigerating agent are that it possesses greater heat-absorbing power than any of the others named, excepting water; that it liquefies at a comparatively low pressure; and that it is neither so deadly in its effects upon animal life as carbonic anhydride or carbonic acid gas (CO_2), nor as explosive or inflammable as ether, and consequently its use is claimed to be practically free from danger.

Ammonia is, however, far from being perfectly innocuous and safe, and due precautions should be taken to avoid accidents where it is in use. It is a colourless irrespirable gas, having an extremely pungent, peculiar, and easily recognisable odour, and it is also slightly combustible when mixed with a sufficient proportion of air, burning feebly with a flame of a greenish-yellow hue, and when mixed with about twice its volume of air being capable of exploding with considerable violence. From this it will be clear that it is absolutely essential that no part of an ammonia apparatus should have a naked light inserted into it, until it has been open and exposed to the air for a sufficient time to render the presence of such light harmless. The tendency of ammonia gas, owing to its being only half the weight of air, is to rise when set free, so that there is the less likelihood of any person who might chance to be near when an ammonia pipe happens to burst, or a bad leak to take place, becoming overpowered by the gas.

Another objectionable feature of ammonia, which has been already alluded to, is its very strong action on copper and its alloys, by reason of which no such material can be employed for any part of an ammonia machine.

Common ammonia of commerce is a solution of ammonia gas in water, and its usual strength is 26° Beaumé.* Anhydrous ammonia is pure dry ammonia gas compressed to a liquid, and it is manufactured by the distillation of the ordinary 26° ammonia of commerce in a suitable apparatus. This apparatus, which should be of sufficient strength to stand a pressure of 65 lbs. on the square inch, comprises a still, a condenser, three separators, and a drier or dehydrator. The still is heated, by a suitable steam coil, to a temperature of about 212° Fahr., when the ammoniacal gas, together with a certain amount of water, passes off into the first separator, which latter is usually situated on the top of, and forms an upward extension of, the still. In this first separator the greater portion of the watery particles carried over are eliminated by a series of perforated plates, through which perforations the gas has to pass, and are returned to the still through a dip pipe From this first separator the partially dried gas passes through a water-cooled worm in the condenser, and then successively through the two other separators to the drier or the dehydrator, where it is passed through a set of similiarly perforated plates

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* See Table of Comparison of various hydrometer scales, Page 244.

to those in the first separator, but having small sized lumps of freshly burnt lime placed upon them, by which any moisture that may still remain in the gas is removed, and the completely anhydrous product can then be passed into the ammonia pump or compressor.

It is found advisable to work the still at a pressure of about 30 lbs. to the square inch, so as to admit of its being raised to a slightly higher temperature than the boiling point of water at atmospheric pressure, without causing the water to boil, the result of this being that the whole, or practically the whole, of the ammonia will be set free, whilst at the same time the least possible amount of the water will be vaporised and pass over with the said ammonia gas.

To ascertain whether or not all the ammonia has been eliminated, two methods of testing the charge in the still are usually practised. The first is to draw off a small quantity of the charge, and if this fails to turn litmus paper, then the charge is exhausted and all the ammonia has been driven off. The second is to allow a small amount of the gas leaving the still to escape through a small cock or valve specially provided for the purpose, when if this gas be tested with turmeric paper, and if this latter remains unchanged in colour (yellow), the charge is completely spent; if, however, the said paper on the contrary turns of a brown hue, there is still some ammonia left.

After the distillation is finished the water remaining in the still should be run out, and as soon as the temperature of the latter is sufficiently lowered it can be again charged. The water accumulating in the second and third separators, being saturated with ammonia gas, may be returned into the still when recharging the latter. The amount of ammonia water, however, that becomes deposited in the said separators will be very small if the pressure in the still is maintained at about 30 lbs., as above-mentioned.

The lime in the drier or dehydrator must be removed whenever it is found to have become in any degree slacked.

Commercial ammonia of 26° Beaumé contains 38·5 per cent. of anhydrous ammonia by volume, it is therefore easy to calculate from this the quantity that it would be necessary to distil in order to produce any given amount of anhydrous ammonia.

Ammonia gas or vapour is, owing to its searching nature, very troublesome to deal with, even at a low pressure, consequently this difficulty is greatly increased by the comparatively high pressure or tenuity that is obtained in a compression machine, and which rises in the condenser to as much as 180 lbs. per square inch. Leakage of the ammonia gas at the pump glands and other parts of the apparatus forms, therefore, the main objection to the use of ammonia as a refrigerating agent, and the means employed to prevent this leakage one of the chief points of difference between ammonia and ether machines. Another difficulty to overcome is the liability to an imperfect discharge of the gas from the compressor-pump, and the expansion and consequent back pressure of that remaining therein.

The most important part of an ammonia machine working on the compression principle, and indeed of all apparatus wherein a volatile liquid is compressed, is the gas compressor. In ammonia machines both single and double-acting compressors are employed. A single-acting compressor has the advantage when working with a gas of the tenuity of ammonia, owing to its only carrying the lesser pressure of the suction side over the stuffing box, of preventing the said stuffing box from being subjected to the high pressure of the condenser, which is unavoidably done at the termination of each stroke in a double-acting compressor, and on this account the chance of leakage is, of course, greatly reduced. On the other hand, however, it is obvious that a double-acting compressor must be more advantageous from an economical point of view, inasmuch as it deals with twice the amount of gas at each revolution of the crank-shaft, that a single-acting compressor of the same diameter and stroke is capable of operating upon. Moreover, the same amount of friction is engendered in each case, although with a double-acting compressor double the duty is being performed, and the friction of the moving parts—such as the cross-head, piston, piston-rod, and connecting-rod—causes no inconsiderable loss, for to overcome friction, power has to be expended, and waste of power means loss of fuel, *i.e.*, money. The amount of saving effected in a machine having two gas compressors may be taken to be one-eighth of the whole amount of power required for compressing the gas. A further economy is that a double-acting compressor is capable of performing the work of a pair of single-acting ones of the same size, and consequently there is a saving in the first cost of the apparatus and in space occupied.

The construction of a gas compressor for operating with ammonia does not, as already mentioned, vary in any very material point from that of one intended to work with ether, and, however much they may differ from one another in minor points of detail, they all work upon the following broad principles, viz. :—

The gas compressor, which is operated by a steam-engine or other suitable motor, draws the gas or vapour from the evaporating coils or tubes of the refrigerator after it has performed its duty of cooling, compresses it on the return stroke of the piston, and forces it into a system or series of pipes or coils in the condenser, in which coils, under the cooling action of water, it resumes its liquid form. From the condenser it is again passed in the liquid state, through a minute opening of the expansion or regulating cock, into the evaporating coils or tubes of the refrigerator, wherein it again expands into gas or vapour, owing to the diminished pressure there prevailing, by reason of the sucking action of the gas compressor. The pressure in the pipes or coils in the refrigerator is usually maintained at from 15 lbs. to 30 lbs., whilst that in the condenser as above-mentioned, may rise as high as 180 lbs., the former depending of course on the amount of opening given to the expansion cock. The liquid ammonia passing suddenly from the above high pressure of the condenser to the comparatively low pressure in the refrigerator, instantly flashes into gaseous form, and whilst doing so, in conformity with the well-known natural law, is forced to absorb a quantity of heat which it renders latent; this it does from the surrounding objects, which in the present instance are either the pipes or coil in the refrigerator, and the brine circulating round the latter, or when used for cooling on the direct system, the sets of refrigerating pipes into which it is passed and the surrounding air.

In order to avoid any chance of accidents occurring through the machine being started with all the valves closed, a suitable relief or safety valve and bye-pass should invariably be provided.

Expressed generally, then, the cycle of operations in machines on the ammonia compression system is the same as that of those described in the preceding chapter, viz., compression, condensation, and expansion; and the said machines, no matter how they may differ in more or less important points of constructional detail, must all likewise consist of three different parts, viz., a compression side, a condensing side, and an expansion side. The said operations are rendered continuous by suitably connecting all these sides or parts together so that the gas passes through them in the above order.

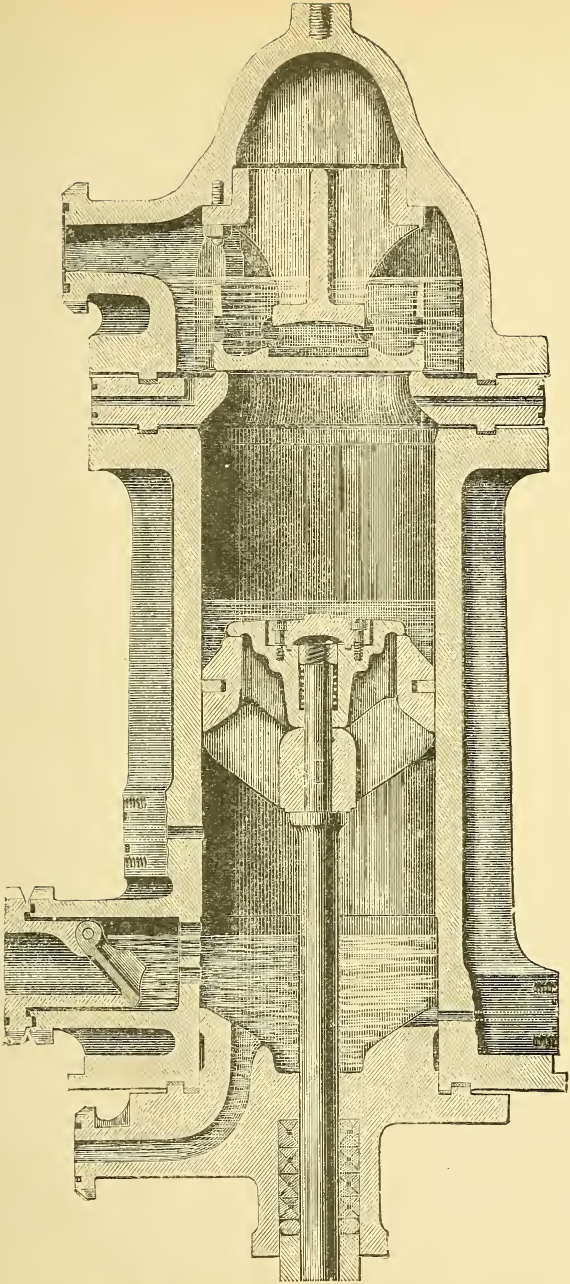

Fig. 12.

Fig. 12 is a vertical central section illustrating the De La Vergne single-acting compressor, constructed by L. Sterne & Co., Limited. The characteristic feature of this machine consists in the patented system for preventing the occurrence of any leakage of gas taking place past the stuffing box, piston, and valves, and extracting the heat from the said gas during compression, by the simple device of injecting into the said compressor, at each stroke, a certain quantity of oil or other suitable lubricating fluid. By means of this sealing, lubricating and cooling oil, not only are the stuffing-box, piston, and valves effectually sealed, and the heat developed during compression taken up, but all clearances are entirely filled up. This latter is a matter of the utmost importance, as it ensures a complete discharge of the gas from the pump cylinder, and were this not effected, and an imperfect discharge thereof only to take place, by reason of a portion of the said gas remaining at the termination of each stroke in the clearance, however small, that must of necessity be ordinarily left between the piston or plunger, and the cylinder-head, the gas thus left over would re-expand on the reverse stroke of the said piston or plunger, and the pressure thus set up against the incoming charge of gas cause a very considerable loss of power and efficiency.

This method of sealing the stuffing-box and piston enables the leakage and consequent introduction of air into the pump, or drawing out or wasting of a volume of the refrigerating gas at each alternate stroke of the piston, to be effectually prevented without necessitating the packing of the said piston and gland so tightly as to bind and set up an excessive amount of friction, the power required to overcome which has been sometimes found to exceed that necessary to perform the entire work of compression. Moreover, when working constantly against a pressure of from 125 to 180 lbs., it is obvious that the slightest wear would cause a considerable leakage of gas to take place past the piston into the adjoining chamber, and like difficulties would also be encountered with the valves, allowing the gas to regain access to the pump cylinder by leaking past the discharge valves, or to be re-admitted to the suction side past the corresponding valves. The losses occasioned in this manner through abnormal friction, and the reduction in efficiency and loss of valuable material through leakages constitute in some machines a very large item, and are the chief cause of failure to give satisfactory results.

It is claimed by the inventor that the oil injected into the compressor cylinder for the above-mentioned sealing purposes, not only effectually overcomes the above difficulties, but also

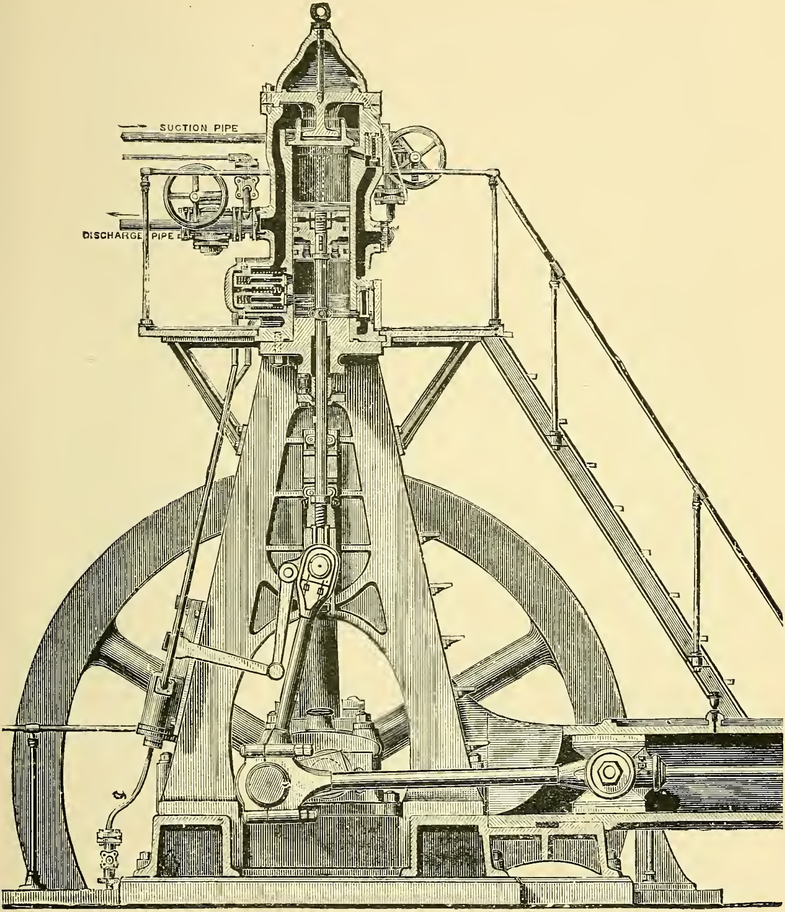

Fig. 13.

acts in a more efficient manner to absorb or take up the heat generated during compression by the mechanical energy exerted by the compressor piston or plunger upon the gas, than does a water-jacket to the cylinder and hollow water-cooled piston and rod, the useful effect of which latter is to a great extent prevented

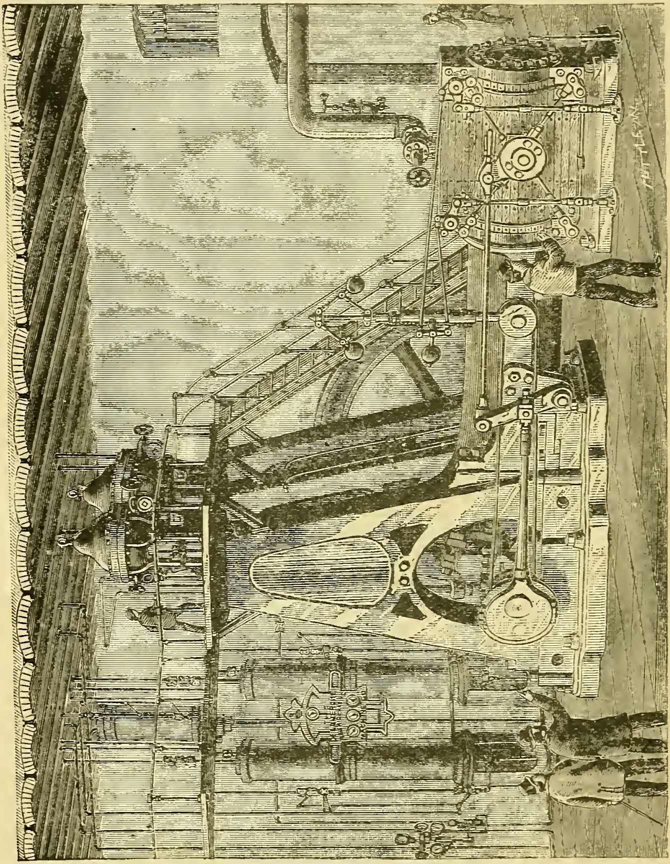

Fig. 14.

by the thickness of metal required in a pump destined to work at a high pressure. In order to ensure the highest efficiency in a compressor, it is essential that the heat generated by the act of compressing be eliminated as far as practicable, as otherwise the said heat, by expanding the gas itself during compression, increases its volume, and consequently necessitates an opening of the discharge valve prior to the time that would be required were the gas cooled during compression. It is obvious that all the energy expended in effecting such premature discharge of the increased volume of gas is so much loss.

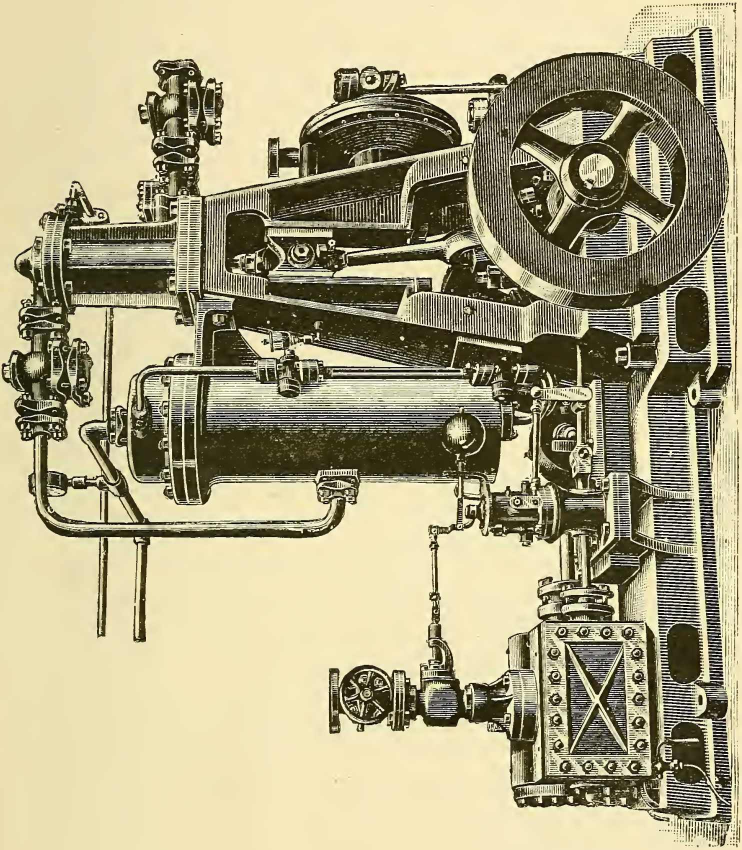

Fig. 15.

The oil used is of a special quality, which is unaffected by the chemical action of the ammonia, it being absolutely essential that it be of a nature that will not saponify, and that is capable of withstanding both extremes of heat and cold.

Fig. 13 is a vertical central section, showing a double-acting compressor on the De La Vergne system, fitted with Louis Block's patent arrangement of valves, the main object of which is to secure the discharge of the oil at the lower end of the cylinder taking place immediately after all the gas is gone and not before, as in the latter case re-expansion will take place, resulting in loss of efficiency of the pump. To effect this, two valves are provided in the lower end of the compressor cylinder, one above the other.

Either or both of these valves may open on the down stroke of the piston, until the latter covers the upper one, when only the lower one is left open to the condenser. During the remainder of the stroke of the piston, after the lower valve is also closed, the other or upper one opens communication with an annular chamber formed in the said piston. In the bottom of this annular chamber are provided, moreover, valves which open as soon as all the other outlets from the underside of the piston are closed, to ensure which they are loaded with springs, so arranged as to require somewhat more pressure to open them than the discharge valves on the side of the cylinder. The gas, and afterwards the oil, then all pass out through the piston, no trace of the former being present at the completion of the down stroke. In this manner the oil system of sealing can be advantageously retained, and the pump will work as well at the lower side as the upper.

Fig. 14 illustrates a complete De La Vergne refrigerating machine of a capacity of 220 tons.

Fig. 15 shows a marine type of the De La Vergne machine. It is a vertical single-acting compressor, actuated by a high pressure horizontal steam-engine, fitted with a special governor, which admits of the steam supply being determined for wide ranges of speeds when required, say for any speed between 30 and 300 revolutions per minute, without interfering with the running, or stopping the machine. The construction of the compressor cylinder is identical with that illustrated in the enlarged sectional view, Fig. 12.

A complete installation of a refrigerating plant on the De La Vergne ammonia compressor system is shown in side elevation in Fig. 16, from which view the circulation of the ammonia and sealing oil can be easily traced, viz :—

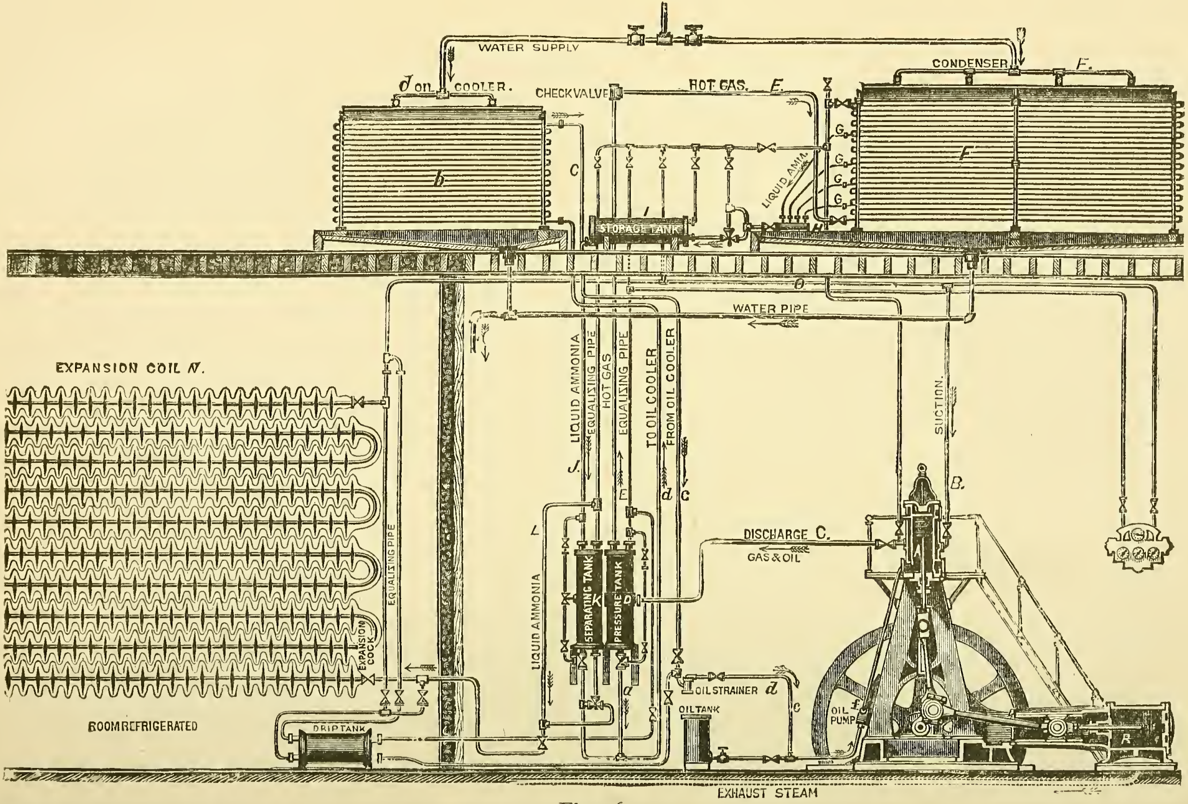
WATER SUPPLY
d OIL COOLER.
b
CHECKVALVE
HOT GAS. E.
CONDENSER
F.
F
G
G
G
G
LIQUID AMM.
H
C
I
STORAGE TANK
θ
WATER PIPE
EXPANSION COIL N.
LIQUID AMMONIA
EQUALIZING PIPE
HOT GAS
EQUALIZING PIPE
TO OIL COOLER
FROM OIL COOLER
J.
E
d
c
SUCTION.
B.
L
DISCHARGE C.
GAS & OIL
EQUALIZING PIPE
EXPANSION COCK
LIQUID AMMONIA
SEPARATING TANK
K
PRESSURE TANK
D
a
OIL STRAINER
d
c
OIL TANK
OIL PUMP
f
R
ROOM REFRIGERATED
DRIP TANK
EXHAUST STEAM

Fig. 16.

Firstly. Following the path taken by the ammonia, in order to produce the frigorific effect. A is the compressor cylinder, which in this instance is of the double-acting type, and similar in construction to that shown drawn to a larger scale in Fig. 13; and R is the steam-engine cylinder, which is likewise arranged horizontally. B is a pipe through which the gas is drawn or sucked from the evaporating coils into the compressing cylinder A. The said gas is then discharged by the action of the compressor A through the pipe C into the pressure tank D, where the sealing oil or liquid, the course of which will be next followed, falls to the bottom; the upper half or portion of the said pressure tank being fitted with suitable cast-iron baffle or check plates serving to more completely retain the said oil and ensures its deposition. From the pressure tank D the gas, which still retains the heat due to compression, passes through the pipe E into the bottom or lower pipe of the condenser F, wherein, by the cooling action of cold water running over the pipes, the heated gas is first cooled and then liquefied. The ammonia, in this liquid condition, is then led by the small liquid pipes G, through the liquid header H, into the storage tank I, from whence it flows through the pipe J into the lower part of the separating tank K, which latter must be constantly maintained at the very least three-quarters full. L is a pipe of small bore, through which the liquid ammonia is forced, by reason of the pressure to which it is now subjected, to the expansion cock or valve, through which it is injected into the evaporating or expansion coil N which is situated in the room or chamber to be refrigerated or cooled.

The ammonia gas resulting from the expansion and evaporation of the liquid ammonia in the evaporating or expansion coil N, having absorbed or taken up the heat from the atmosphere surrounding them, passes away through the pipes O and B, back again into the compressor cylinder, and the cycle of operations of compressing, &c., are again performed as above.

Secondly. Following the course of the oil employed for sealing, lubricating, and cooling purposes, which, as previously mentioned, is heated with the gas during compression, and is passed into the tank D, to the bottom of which it falls. From the bottom of the tank D, the said heated oil is conducted through a pipe *a* to the lowermost pipe of the oil-cooler *b*, which is practically similar in construction, but on a smaller scale, to the ammonia condenser, and is likewise cooled by sprayed or atomised cold water. After being sufficiently reduced in temperature in the oil-cooler *b*, the oil flows through the pipe *c*, strainer *d*, and pipe *e*, into the oil pump *f*, which latter is so constructed that it delivers the cooled oil into the compressor, distributing it to either side of the piston or plunger during its compression stroke, that is to say, in such a manner that no oil is furnished during the suction stroke of the said piston, but only during the time of compressing, thereby cooling the gas during its period of heating. The heated oil, after leaving the compressor, then again returns, together with the hot compressed gas, to the pressure tank D, and follows the same round through the oil-cooler *b*, strainer *d* and oil pump *f*, back to the compression cylinder. It will be obvious that the oil, as well as the ammonia, is used over and over again, no loss or waste of either taking place except that which may occur through leakage.

Any small quantities of oil, however, that may be carried over with the current of the gas from the pressure tank D into the condenser F, pass along with the liquid ammonia into the separating tank K, where, by reason of its greater weight, the said oil falls to, and collects at, the bottom of the said tank. As soon as a sufficient quantity of oil has become thus deposited, it is drawn off and passed through the oil-cooler back into the oil-pump. The oil reservoir or tank is also connected to the oil pump F.

When the apparatus is employed for the manufacture of ice, the evaporating coils N are placed in a tank containing brine, sufficient space or clearance being left between them to admit of the insertion of ice-cans or moulds containing the water to be frozen. In this instance the steam used for driving the motor, after doing its duty in the steam-engine cylinder R, is led through the exhaust pipe S into a steam filter and condenser, where it is purified and condensed. The purified condensation water then passes from the said condenser into a water regulator tank, and from the latter through a water-cooled coil of substantially similar construction to that of the ammonia condenser F and oil-cooler *b*, and finally is delivered into the ice cans or cases, which are usually constructed of galvanised iron, through suitable india-rubber hose, fitted with stop-cocks or valves.

When the water in the ice-cans or cases is frozen, they are lifted out and transported by means of the overhead travelling crane to the dip-tank or a sprinkler, where the blocks of ice are thawed or melted out, after which the empty cans are refilled with water through the hose, and the process of making other blocks of ice is commenced.

The various parts are clearly indicated upon Fig. 16, and the paths taken by the ammonia, the sealing, lubricating, and cooling oil, and the steam are shown by the arrows.

The advantages derived from the use of the sealing, cooling, and lubricating liquid in the compressor cylinder will become very apparent on a comparison of the diagram shown in Fig. 17, which was taken from a gas compressor worked without employing the said liquid, with that shown in Fig. 18, which was taken from a similar compressor, but with the charge of liquid.

The diagram shown in Fig. 17 was taken from a 14 in. × 28 in. single-acting gas compressor, working with a direct pressure of 157 lbs., and a back pressure of 20 lbs., and at a speed of thirty-six revolutions per minute, no sealing, cooling, and lubricating liquid being used. A indicates the adiabatic curve, and B the isothermic curve.

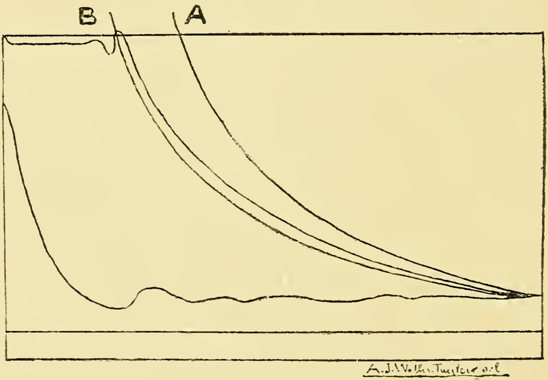

Fig. 17.

The adiabatic curve is, as is well known, that curve which would be produced were the air or gas to be instantaneously compressed, that is to say, without transmission of heat, and the isothermal curve is that which would result if it were possible to compress the same without raising its temperature at all. In actual working the curves obtained fall between the adiabatic curve and the isothermal curve.

It will be seen by an inspection of this diagram that the compression curve, which by right should approach the adiabatic curve A, on the contrary falls into close proximity to the isothermic curve B, and indicates the existence of a leakage past the piston of 15·2 per cent. of the gas being compressed, and as is shown by the curved line, which is produced by the re-expansion of the gas filling the clearance between the piston and compressor head or cover, a further loss from the latter source of 7·4 per cent., that is a total loss of 22·6 per cent., due to not employing the liquid. The horse-power shown on this indicator card is 44.

The diagram shown in Fig. 18 was taken from a similar compressor running at the same speed, and working at 150 lbs. direct pressure, and with a back pressure of 27 lbs. The actual power indicated by this card is 48. The horse-power measured to the adiabatic curve A equals 53·6. The horse-power saved by employing the sealing, lubricating, and cooling liquid is 5·6 for each compressor, or in a machine having two compressors a total saving of 11·2 horse-power. The efficiency of the compressor is 98·6 per cent. of its theoretical value, a result attained by the use of the liquid. The efficiency of the compressor, as indicated by the card shown in Fig. 17, is only 77 per cent. of that indicated by the card shown in Fig. 18, the loss being the result of the non-use of the said liquid.

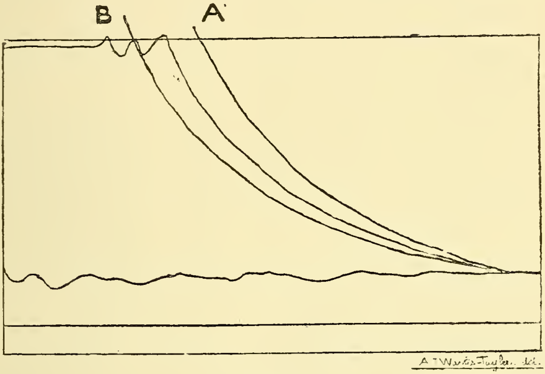

Fig. 18.

Fig. 19 shows a diagram taken from a 12 in. × 24 in. double-acting gas compressor, running at a speed of thirty-four revolutions per minute, and fitted with Louis Block's patent improvements, which latter have been already described on page 47.

The steam cylinder actuating the above-mentioned 14 in. × 28 in. gas compressor, whilst the diagrams shown in Figs. 17 and 18 were being taken, was 18 in. × 42 in., and was working under a steam pressure of 68 lbs. per square inch, the speed being, of course, the same as that of the gas compressors, viz., 36 revolutions per minute.

Indicator diagrams taken from the said steam cylinder showed on the card an initial pressure of 65 lbs., and the mean effective pressure of the diagrams equalled 32·4 lbs. The horse-power developed was 63, and the expansion line approached so close to the theoretical curve, as to show that the cut-off valve worked well, thus effecting a great economy in steam consumption.

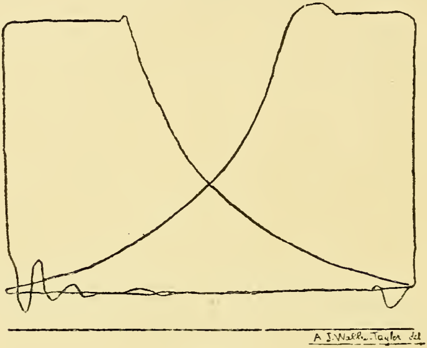

Fig. 19.

Machines on the compression system have been devised by a number of others, certain specific improvements, in most instances patented, being claimed to give to each of them some particular advantage. Amongst those having some special or distinctive features, mention may be made of those of Frick, Linde, Fixary, Neubecker, the Pulsometer Company, Kilbourn, Lightfoot, Pictet, Puplett and Rigg, and Haslam.

The characteristic feature in the Frick machine is the means adopted for permitting the compressor to be safely worked without clearance, and thereby ensuring the complete, or practically complete, discharge of the gas therefrom. Two

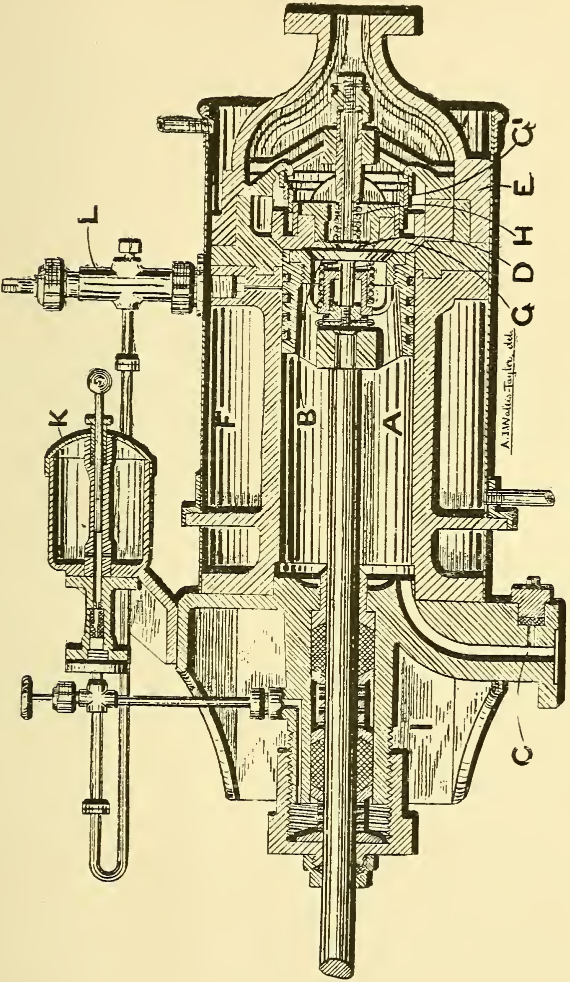

Fig. 20.

forms of compressors, constructed on this principle, are illustrated in Figs. 20 and 21.

Referring to the drawings, A is the compressor pump piston, in which is placed the suction valve B, which is of ample area, and is balanced by a spring; the said piston working metal to metal against the top cylinder head without clearance. C is the inlet for the ammonia gas, and D is the outlet valve through which the compressed gas is discharged from the pump barrel or cylinder through the aperture in the apex of the dome E. F is a jacket surrounding the pump cylinder, and into the clearance or space thus provided, a constant stream of cold water is kept circulating, so as to take up as much of the specific heat of compression, and of the latent heat, through the wall of the cylinder as possible, and thus obviate superheating thereof. G is a relief valve situated in the cylinder head, and normally retained upon its seating by a powerful spring, G^1. The ordinary discharge or outlet valve D, which is situated centrally in the large relief valve G, is also governed by a spring H. I is the piston rod stuffing box. K is an oil reservoir and hand pump for lubricating the piston rod, and through the small plug and valve L the pump cylinder when required, which is usually only when starting a new machine, or one that has been standing for a considerable time; the latter also serves for the attachment of an indicator, to enable indicator diagrams to be taken from the pump.

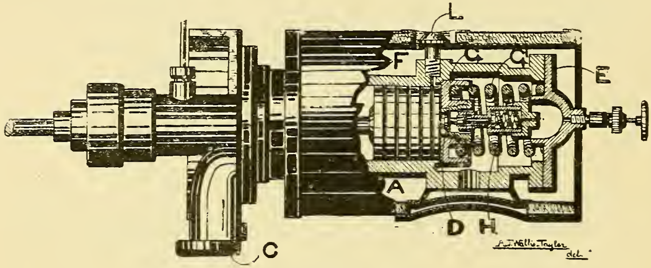

Fig. 21.

It will be seen that the compressors in question are of the single-acting type, the pistons are long, and are each provided with five carefully fitted rings, and the arrangement of the stuffing boxes and glands (shown in section in Fig. 20) is such as to render the escape of gas round the piston rods practically impossible under proper working conditions.

The two compressors shown in Figs. 20 and 21 are constructed upon a substantially similar principle; that shown in Fig. 21, however, has certain improvements in detail, chiefly relating to the patent safety, head, and discharge valve. In both arrangements the discharge valve, relief valve, together with the guides, speeder, and false seat, are entirely self-contained and independent of the pump cylinder, rendering it possible to expeditiously replace the whole mechanism by a new one, or to speedily execute any necessary repairs. In the latter arrangement, however (Fig. 21), the valve mechanism can be more easily got at, it being only necessary for that purpose to remove the light pump head. For convenience of illustration the cylinders are shown in the drawing in horizontal positions, but in actual practice the Frick compressors are usually placed vertically.

The operation is as follows:—The suction valve B being, as before mentioned, of very ample area and balanced by a spring, affords no resistance to the passage of the gas upon the return or backward stroke of the piston, but allows of its flowing freely and rapidly into the pump cylinder, through the gas inlet C, under the action of the back pressure, to the vacant space above the piston. The rapid closing of the suction valve B at the instant of the piston beginning its forward or up-stroke is ensured by a cushion spring, and the gas is gradually compressed until it equals the condensing pressure acting upon the discharge valve in the relief valve located in the cylinder head, which then opens to admit of its escape to the condenser. There being no clearance between the piston A, when at the termination of the up or forward stroke, and the cylinder head, no gas remains in the cylinder to re-expand on the return or backward stroke of the said piston, and destroy the vacuum.

It will be seen that it is rendered possible to do this with perfect safety, as in the event of any foreign body or obstruction getting accidentally between the piston A and the cylinder head, the valve or movable portion G of the latter, which is of the full dimensions of the pump bore, will give way and allow the compressed gas to pass into the dome E, and thence to the condenser, the said movable portion or relief valve G being returned to its seat, under the action of the spring G^1, and the back pressure. Under normal conditions, however, the relief valve G does not work, the discharge, as already mentioned, being effected through the smaller discharge or outlet valve D, which is usually of steel, and is fitted upon a seat in the centre of the movable portion of the head or relief valve G.

Were no provision, such as the above-described relief valve or safety head G, provided, and any obstruction to become accidentally interposed between the piston and the cylinder end, not only would the latter be knocked out, and serious damage to the mechanism ensue, but the full charge of ammonia gas, which in a large machine is worth a considerable sum, would be lost.

The ammonia compression machines designed by Carl Linde, and first patented by him in the year 1870, have been in extensive use for some years, more especially in Germany, and are said to give very favourable results; they are made in several different patterns.

In the land type of Linde machine, double ammonia compressors, arranged in line horizontally and driven from a crank upon a crank shaft placed centrally between the two compressors, and at right angles thereto, are employed. The necessary motion is imparted to the said crank shaft by means of a tandem compound jet-condensing engine.

In the marine type a single compound ammonia compressor is employed, which is also driven by means of a tandem compound engine. The ammonia condenser is situated below the compressor, and is fitted with sets of endless coils or worms. By the use of a compound compressor, that is to say, one wherein the compression of the ammonia gas is effected in two stages, the loss from re-expansion of gas left in the clearances is completely got rid of, as such loss is experienced in the low pressure compressor cylinder only, none taking place in the high pressure compressor cylinder.

The method employed by Linde to prevent leakage of gas past the piston rod stuffing box and gland, is to provide a chamber or recess in the said stuffing box, glycerine or some other suitable lubricant being constantly forced into this chamber or recess at a somewhat higher pressure than that existing in the compressor cylinder, the result of which is that the tendency is rather for the lubricant to leak or escape inwardly, than for the ammonia to leak outwardly. A suitable separator is provided for the elimination of any lubricant that finds its way into the pump or compressor cylinder, and passes out with the ammonia.

Another important feature in the Linde machine, is the method of cooling the vapour in the compression cylinder, by the introduction into the latter of a small portion of liquid ammonia with the said gas or vapour, at the commencement of each stroke, whereby it is reduced to a refrigerating temperature.

According to Mr. Lightfoot, the following are the results that were obtained from tests made, in an exhaustive and impartial manner, by a committee of Bavarian engineers, with an ammonia compression machine constructed on the Linde system, and erected in a brewery in Germany:—[*]

Nominal capacity of machine, ice per 24 hours . .	24 tons
Actual production of ice, per 24 hours . . .	39·2 tons
,, ,, ,, per hour	3,659 lbs.
Heat abstracted in ice-making, per hour . . .	731,800 units.[†]
Indicated horse-power in steam cylinder, excluding that required for circulating the cooling water, and for working cranes, &c.	53 I.H.P.
Indicated horse-power in ammonia pump . . .	38 I.H.P.
Thermal equivalent of work in ammonia pump, per hour	97,460 units [†]
Ratio of work in pump to work in ice-making . .	1 to 7·5
Total feed-water used in boiler, per 24 hours . .	26,754 lbs.
Ratio of coal consumed to ice made, taking an evaporation of 8 lbs. of water per lb. of coal . . .	1 to 26·3

The pumps were driven by a Sulzer engine, developing one indicated horse-power with 21·8 lbs. of steam per hour, including the amount condensed in the steam pipes.

The Fixary compressor is shown in vertical central section, some of the parts being left in elevation, in Fig. 22. It consists of two vertical, single-acting cylinders A, B, having an equalising chamber C, situated between them, at the upper extremity of which is provided a small valve governing an aperture leading to the suction side of the compressor. In the upper extremity of each of the cylinders A, B, are provided two valves, that on the right-hand side opening inwardly and being the suction or inlet valve, and that on the left-hand side opening outwardly and being the outlet or delivery valve. The space below the pistons is filled with oil which lubricates the said pistons, whilst at the same time preventing the gas from escaping past them to any great extent. Any gas that does find its way beneath the pistons passes into the equalising chamber C, where any accumulation of it is drawn off by the compressor, through the small valve in the upper extremity thereof, and one or other of the

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[*] "Proceedings, Institution of Mechanical Engineers," 1886, page 218.

[†] A thermal unit is the amount of heat necessary to raise the temperature of 1 lb. of water 1° by the Fahr. scale when at 32°. Mech. eq. 772 ft. pounds.

suction or inlet valves, and again returns to the system through the outlet or delivery valves. The oil that may be carried through the valve in the equalising chamber, serves the purpose of sealing the valves and filling up the clearance spaces.

The characteristic feature of the Neubecker system is the special device for preventing leakage taking place round the piston rod. To effect this, the stuffing or gland box, through which the piston-rod passes, is so enlarged as to form an annular recess or chamber surrounding the rod, which chamber is partly filled with oil, and maintained at a corresponding pressure to that prevailing in the surrounding atmosphere, by means of a compensating chamber, which latter is connected at its upper extremity to a small auxiliary pump through a pipe, the inlet to which is governed by a valve connected to, and controlled by, a metallic diaphragm, the upper side of which diaphragm is exposed to the pressure of the atmosphere.

The operation of this compensating chamber is as follows :—The gas which may escape into the stuffing-box chamber, passes into the said compensating chamber, and as soon as sufficient has thus accumulated to raise the pressure therein above that of the atmosphere, it acts upon the flexible diaphragm to expand it outwardly, and thereby open the valve communicating with the above-mentioned auxiliary pump, by which the said gas is drawn off or removed and delivered into the refrigerator. The pressure in the separating chamber then again falls below that of the atmosphere, and the diaphragm being forced inwardly by the atmospheric pressure, the outlet valve closes. The lower portion of the compensating chamber forms a well, wherein any oil that leaks past the piston-rod gland of the compressor, as also that coming from the separator, accumulates, and is heated by a steam coil or worm, so as to drive off any gas that has been absorbed by the said oil, after which the latter is drawn off from the bottom of the said compensating chamber to be cooled and filtered for further use.

In Figs. 23, 24, and 25 are illustrated various patterns of compressors constructed by the Pulsometer Engineering Company, Limited, on their improved system. Fig. 23 shows a small complete ice-making plant on the ammonia compression system, intended to turn out 1 ton of clear block ice per twenty-four hours; installations on the same principle are, however, made by the company with a capacity for an output up to 25 tons of ice or more per day of twenty-four hours.

In a type of apparatus particularly suited for export, everything, including the steam-engine, compressor, gas condenser, refrigerator, and ice tank, is mounted on one continuous bed, all the ammonia connections are ready made, and the whole can be readily put in one case and sent abroad, all that is necessary on its arrival being to charge the machine with gas and the ice tank with brine.

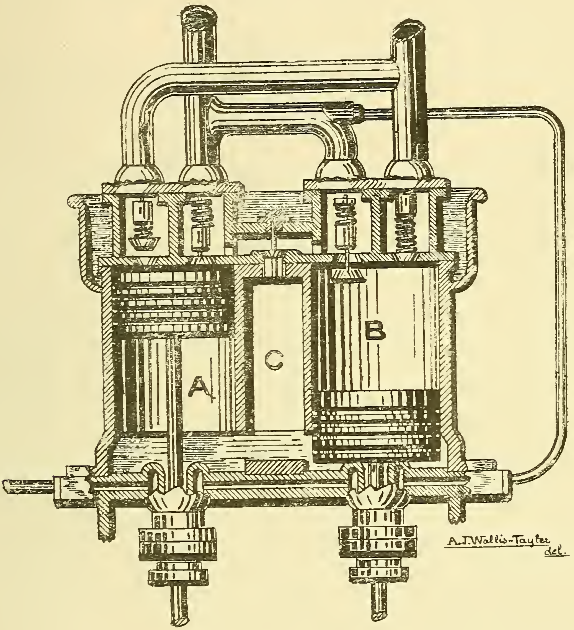

Fig. 22.

In the case of a small machine, such as that shown in Fig. 23, either a vertical high-pressure engine, as shown in the drawing, or an horizontal one, or any other suitable motor, is employed; for larger sizes, however, these makers prefer to use cross compound condensing engines of the horizontal type, and of extra size to provide an ample margin of power in hot weather, and to give the best results as to saving of steam consumption from an early cut-off, and each engine driving a compressor tandem. The engine condenser is generally made of the surface condensing type, and, together with the water circulating pump, placed between the engines and driven from the low-pressure crosshead. This arrangement has been found in practice to be, with long strokes of, say, at least 30 inches,

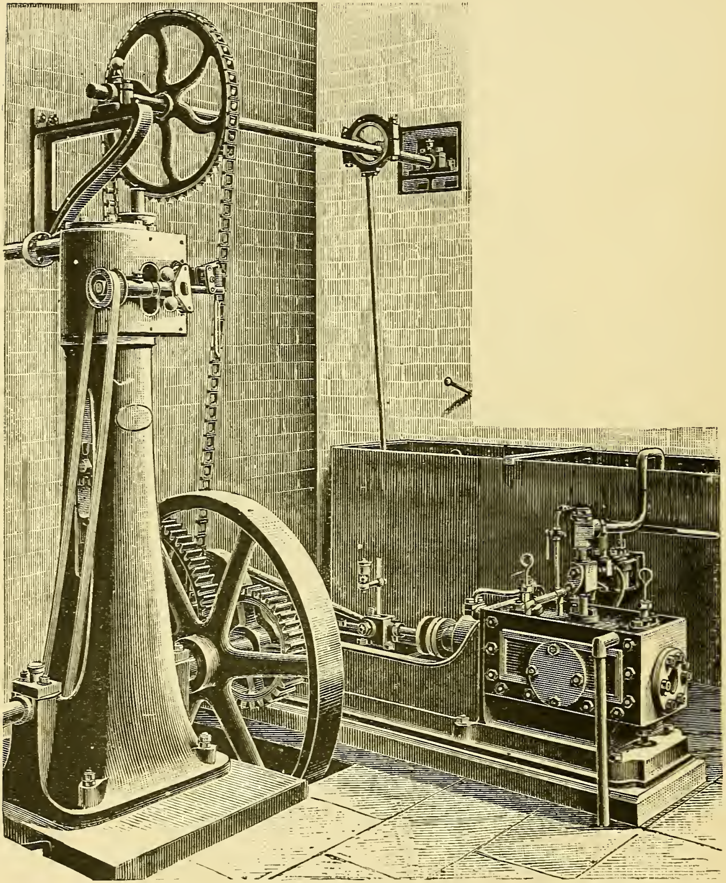

Fig. 23.

most reliable, and it admits, moreover, in the event of an emergency, of running at a high speed. In cases where the very highest economy is desirable, triple or quadruple expansion engines are desirable.

Fig. 25 illustrates one of a pair of pumps employed in a brewery and having a cooling capacity of one hundred barrels per hour.

As will be seen from the drawing (Fig. 25), the ammonia pump is of the double-acting type, and is arranged horizontally. It is intended to be driven from any convenient source of power already extant in the brewery. To obviate leakage and loss of ammonia gas, the stuffing box is fitted with a special oil-lubricating arrangement, by means of which a gas-tight joint is secured without any necessity for screwing up the gland so as to grip too tightly. The valves work without any springs or buffers, and in the larger sizes are so arranged that they can

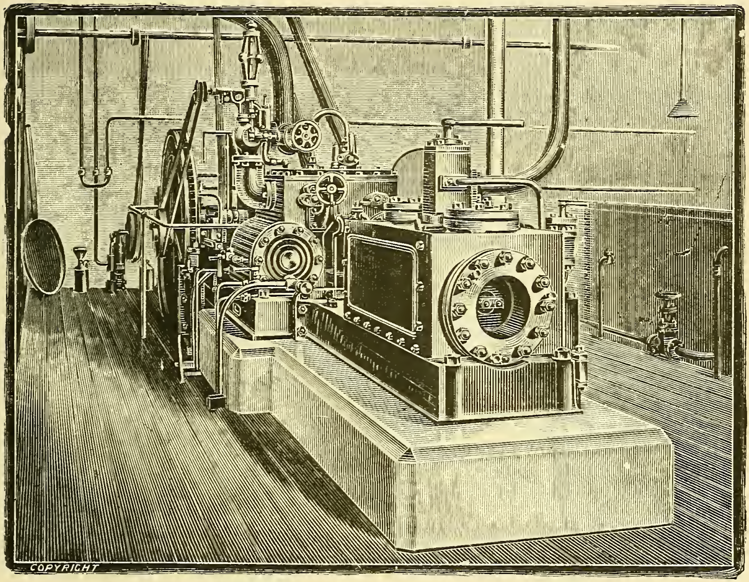

Fig. 24.

be adjusted from the exterior; they are also of ample area, thereby reducing the pressure on the pump, and preventing the latter and the engine from being overworked.

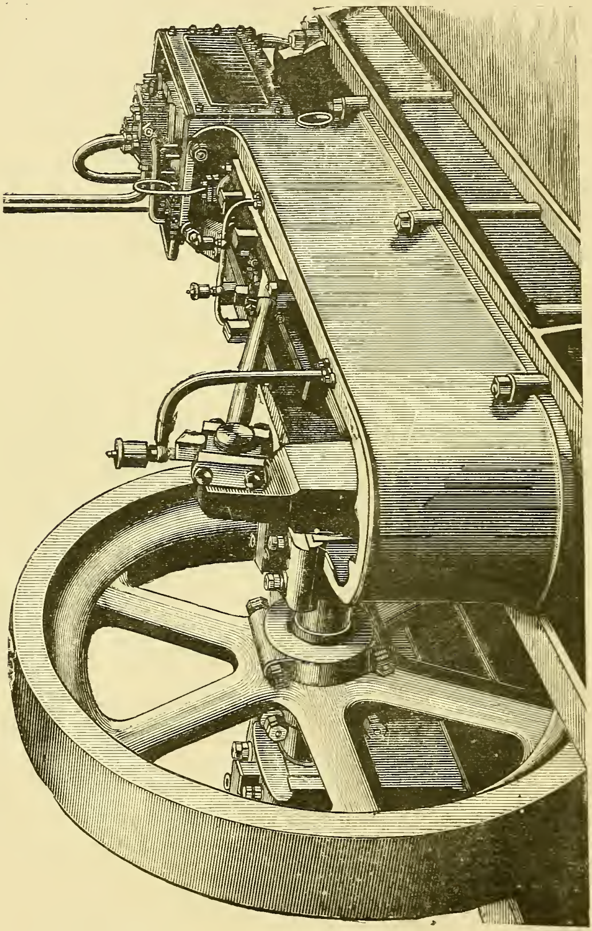

Fig. 25.

The condenser is fitted with sets or series of lap-welded tubes, which are subjected to high tests both by hydraulic and air pressure, and are secured in a patented arrangement of return heads or ends of forged steel. The inlet and outlet valves are also of forged steel.

The refrigerator consists of a welded steel shell, having hammered steel tube plates into which are fitted lap-welded tubes (subjected to a similar test to those of the condenser) in such a manner that they can be readily withdrawn from the shell for inspection or renewal, and the whole is fitted in a tank with suitable brine-pump connections. The inlet and outlet tubes are likewise of forged steel. This arrangement is also patented.

The makers prefer the use of sets or series of tubes in their condensers, and refrigerators, to that of coils or worms, for the following reasons. That coils or worms are usually made in long lengths with a number of welds, consequently should such a tube at any time exhibit signs of weakness it would entail a heavy expense to renew it, both on account of the weight of metal and the difficulty of replacement. In a refrigerator, in addition to the above, the use of a coil gives rise to a tendency to prime, and thus cause damage to the pump, and there is, moreover, considerable trouble in bringing the brine into such intimate contact with the outer surfaces of the tubes as is advisable.

When desired, an arrangement can be fitted to this ammonia compression machine, by means of which the ammonia can be pumped from the refrigerator into the condenser or *vice versâ*, or, if desired, out of the machine altogether.

An advantage of no small importance possessed by this apparatus is that of the utmost simplicity of construction, thus considerably facilitating the management. The workmanship and design, moreover, are calculated to ensure the attainment of the greatest strength and of the maximum durability possible.

Fig. 26 is a perspective view illustrating a small single-acting vertical ammonia compression machine constructed on the Kilbourn system; Fig. 27 is a similar view showing a pair of large double-acting horizontal machines; and Fig. 28 is a perspective view showing another pattern of horizontal machine.

In the installation shown in Fig. 26 the machine is driven by a gas-engine of 4 horse-power nominal, and it is designed for cold storage on the direct expansion system. The floor space occupied is small, being only for the entire plant 12 ft. by 4 ft. 6 in., and the machine is capable of maintaining a storage capacity of from 8,000 to 10,000 cubic ft. at a suitable temperature for frozen mutton, or, with the necessary appliances, of making from 2½ tons to 2 tons of ice per twenty-four hours.

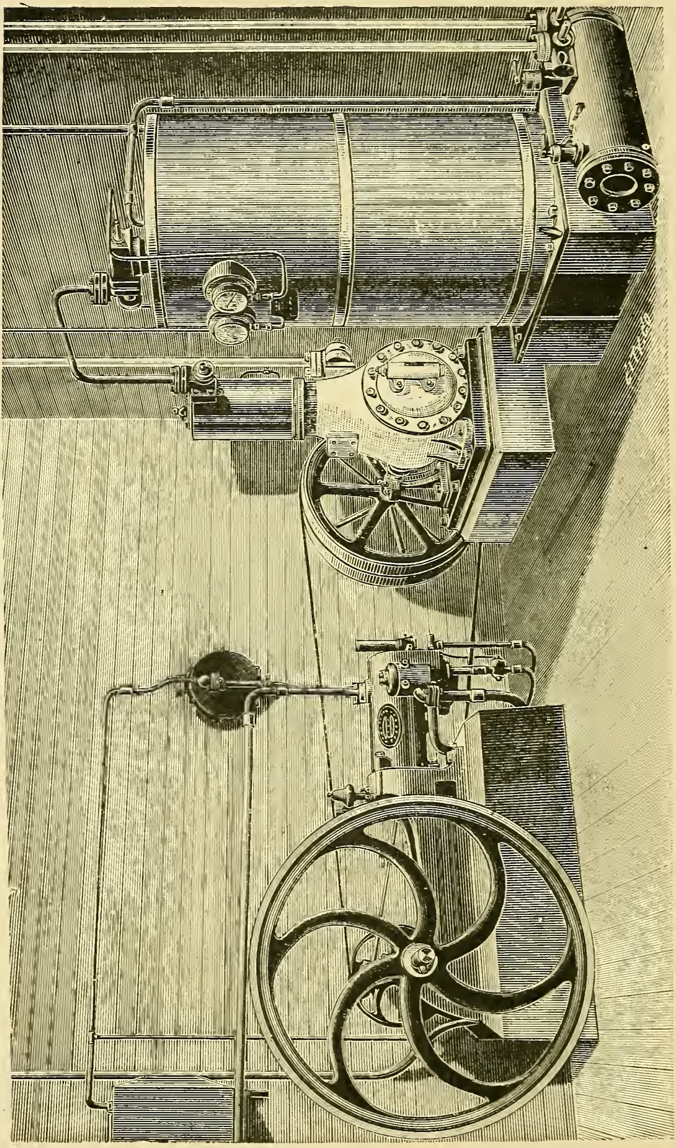

Fig. 26.

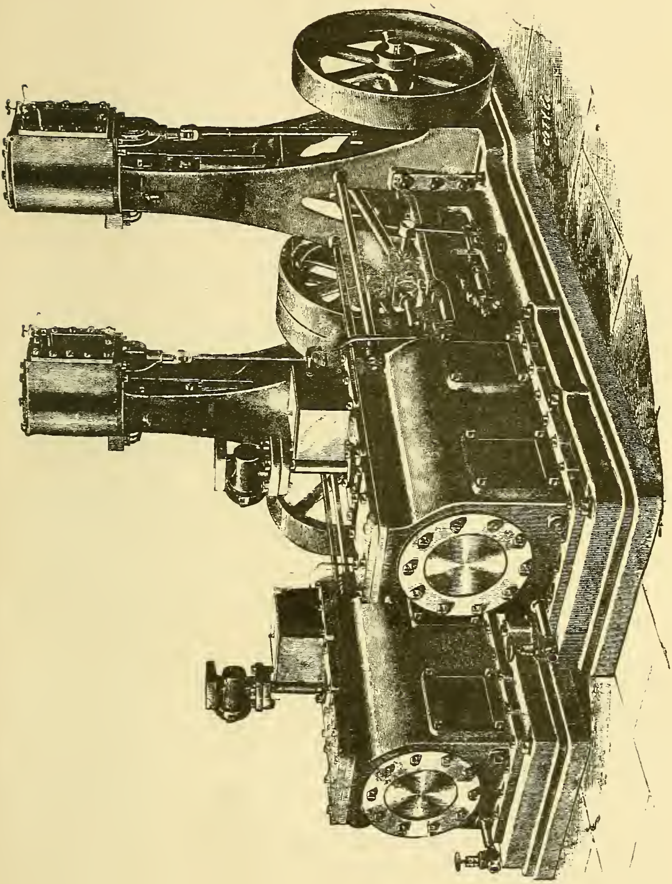

Fig. 27.

The condenser and refrigerator are composed of lap-welded iron coils fitted in steel or wrought-iron shells.

The double-acting horizontal ammonia compression machines, shown in Fig. 27, are each driven by a vertical engine, which is fixed upon the same base or bed-plate in such a manner as to render the complete machine very compact in design, one of sufficient power to keep a storage capacity of 22,000 to 26,000 cubic ft. at a suitable temperature for chilled beef, 40,000 to 44,000 ft. for frozen mutton, or of making about 6 tons of ice per day of twenty-four hours, requiring only a floor space of 10 ft. by 10 ft., including that required for both the refrigerator and condenser.

The compression cylinders are inclosed in water-jackets, and are fitted with Webb's patent arrangement of suction valves. The stuffing-boxes and glands are of the Kilbourn double pattern, that is, each box is formed with a chamber placed centrally therein, and into which oil is injected constantly for sealing purposes by a small force-pump fixed on the side of the bed-plate, and worked, as shown in the drawing, from a lever connected to the compression pump crosshead. The steam-cylinder piston-rods are coupled by means of forked connecting-rods to the same crank-pins as those of the compression pumps. These machines are suitable for either land or marine installations, and are similar to those fitted on board the Cunard steamships *Campania* and *Lucania*, a description and illustration of which will be found on pages 182-185.

An improved form of gas-tight joints and stop-cock or valve, which will be found described and illustrated on page 154, have been also devised, and were patented in 1882 by the same inventor.

The arrangement of the machine illustrated in Fig. 28 is very compact, having been just recently designed with that end more especially in view, and for which purpose the ammonia condenser is placed underneath the compressor.

The main features of novelty claimed in the ammonia compression apparatus, invented by Thomas Bell Lightfoot, for which he obtained a patent in 1885, are as follows:—First, a combined refrigerating and ice tank, in which moulds are arranged between coils or pipes through which a vaporised freezing medium is caused to circulate, the said moulds and pipes being surrounded by brine or uncongealable fluid, not mechanically circulated. Second, a condenser, comprising coils or zigzag pipes, arranged within a zigzag passage or passages formed in a tank or vessel, the arrangement being such that the vapour or gas to be condensed travels in a zigzag course in one direction, whilst the cooling fluid travels in the contrary direction, also in a zigzag course, and in contact with the outer surfaces of the pipes in which the vapour or gas is travelling in an opposite direction. Third, a refrigerator comprising coils or zigzag pipes arranged within a zigzag passage or passages formed in a tank or vessel, the arrangement being such that the refrigerating medium enters the coils or zigzag pipes at the bottom, the vapour being drawn off by the pump at the top, while the water fluid to be cooled enters at the top of the tank, and after travelling along the whole length of each coil or zigzag is drawn off at the bottom. Fourth, a pump for compressing condensable gas or vapour in which compression is effected at one side only of the piston, the other side being exposed merely to the pressure of the vapour as drawn in from the refrigerator, the suction valve being placed concentrically within the piston, and the delivery valve within the cylinder cover.

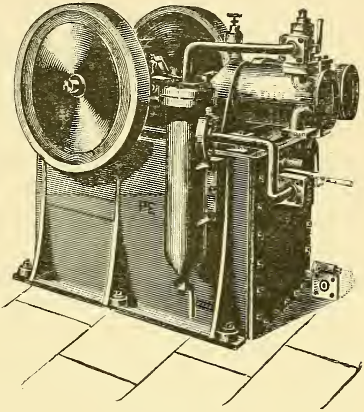
Fig. 28.

The main distinctive feature of the Pictet machine is the means adopted for preventing superheating of the ammonia gas during compression in the cylinder of the pump and the loss that would ensue therefrom, which, were there no means employed for its reduction, might amount to as much as 30 per cent. in a double-action compressor. In some arrangements provision is made for effecting this by injecting a small quantity of liquid into the compressor, which liquid in evaporating maintains the gas or vapour in a condition of saturation, thereby admitting of the compression being effected under such conditions as to approximate more closely to the isothermal function; in others, again, the compressor cylinder is water-jacketed for a like purpose. In the Pictet machine, however, in addition to a water-jacket round the compressor cylinder or barrel, the piston and piston-rod of the compressor are likewise formed hollow, and through this space a constant stream of water is kept circulating for cooling purposes.

The results obtained by this arrangement are much lessened by the great thickness of metal that is required in the parts. The loss in a well-jacketed and water-cooled compressor, according to the experiments* of Professor Denton, amounting to 21·4 per cent., and where less efficiently jacketed the loss will be from 21·3 to about 25 per cent.

In the specification of a patent granted to Raoul Pictet in 1887 he describes an improved vessel or compartment for use in a refrigerating apparatus, wherein the volatile liquid employed is subjected to evaporation so as to produce cold, which refrigerates brine or other non-congealable liquid surrounding the evaporating compartment. The said improved cooler or refrigerator is claimed to be suitable for use with either a compression or an absorption machine, and consists of two tubes arranged horizontally and connected at their extremities by bent tubes, and at their lower sides by pendent U-shaped tubes, which latter are preferably secured by means of solder joints to sockets brazed on the tubes, and are further connected with each other by conducting bands.

In the latter part of 1887 a patent was obtained by Samuel Puplett and Jonathan Lucas Rigg for improvements in refrigerating machines, and several further improvements have since been added by Puplett.

The main features of the 1887 patent, which are equally applicable to any ice-making and cooling apparatus wherein any one of the condensable gases is used as a frigorific agent, are as follows:—

The provision of chambers or reservoirs either situated directly at the bottom of, and communicating with the inlet valve chests, or in any other suitable position, and connected thereto by means of pipes. These chambers or reservoirs serve to receive the oil which finds its way into the cylinder of the compressor pump, principally round the piston-rod, and which would otherwise accumulate beneath the valves. To the undersides of the said chambers or reservoirs are fitted draw-off cocks, by means of which the oil may from time to time be withdrawn whilst the machine is in motion, and with-

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* "Transactions, American Society of Mechanical Engineers," vol. xii.

out any appreciable loss of gas or admission of air taking place.

A separator, for retaining any oil that may pass over with the gas, consisting of a cylindrical vessel having a water-jacket through which a circulation of cooling water is maintained, and provided centrally with two or more sheets or screens of wire gauze or perforated sheet metal, by which the said cylindrical vessel or chamber is divided vertically into two compartments. The gas from the compression pump is discharged into this vessel or chamber against the sheets or screens, and is forced through the interstices or meshes, the surface contact separating the oil, held in mechanical suspension, from the gas. The separator being maintained at a lower temperature than the gas by means of the above-mentioned water-jacket, a rapid condensation of any oil passing over with the gas takes place, and this oil is first deposited on the sheets or screens, from which it falls to the bottom of the separator, from whence it can be drawn off through a discharge-cock fixed therein, without stopping the machine, and without any material loss of gas or admission of air occurring.

To catch any oil that may pass down the return-liquid pipe an interceptor is attached to the latter in any convenient position, but preferably as near as possible to the refrigerator. This interceptor is formed of a cylindrical vessel having a diaphragm extending from the cover to within a short distance of the bottom, and another diaphragm extending from the bottom thereof to within a short distance of the cover, thus forming three compartments. The return-liquid pipe passes through the cover nearly, but not quite, to the bottom of the interceptor on one side of the first diaphragm—that is in the outer compartment—and is continued from near the bottom of the interceptor to beyond the second diaphragm, that is to say, out of the third compartment. Any oil that passes down the return-liquid pipe collects in the first compartment of the interceptor, from whence it can be withdrawn through a cock fixed in the said first compartment without stopping the machine, or causing an appreciable loss of gas or the admission of air to any injurious extent. This interceptor is preferably jacketed, and is surrounded with, and maintained at a suitable temperature by means of cold brine, in order to aid in separating the oil from the liquefied gas.

Complete liquefaction of the gas is ensured by carrying the return-liquid pipe between the condenser and refrigerator through the refrigerating or ice-making tank or box, instead of outside the latter, as is usually done, thus utilising the low temperature of the brine to complete the condensation of the gas.

The stop-cocks or valves for regulating, or completely cutting off or arresting, the flow of the gas or liquids to the various parts of the apparatus have metal seats. To prevent leakage of the gas or liquid, the stuffing-boxes of these valves are provided with screwed glands, which are likewise screwed on to the valve spindles, which latter are screw threaded for their entire length, and are packed with some suitable yielding fibrous or metallic packing, such, for instance, as hemp or lead. This packing is caused to enter into the screw-threads upon the spindles as the glands are forced or screwed down, thus making gas-tight joints round the latter, without causing the valves to set fast.

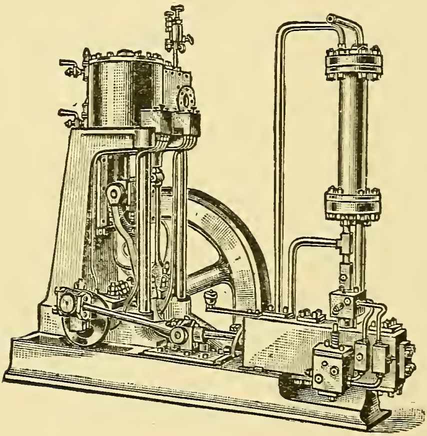


Fig. 29.

The very considerable improvements which have, as already mentioned, been since added by Puplett, are illustrated in Figs. 29, 30, and 31, which show three of his latest pattern machines, viz., a marine type of horizontal compressor with vertical engine, an arrangement especially designed for use in breweries for cooling worts and yeast rooms, and lastly a horizontal machine intended more particularly for marine work.

Machines of the pattern shown in Fig. 29 are made in sizes varying from the smallest with an equivalent of ice made per day of 5 cwt., capable of maintaining a properly insulated room of 1,000 cubic ft. at 20° to 25° Fahr., consuming one nominal horse-power, and occupying a floor space of 5 ft. by 6 ft., up to the largest, which has an equivalent of ice

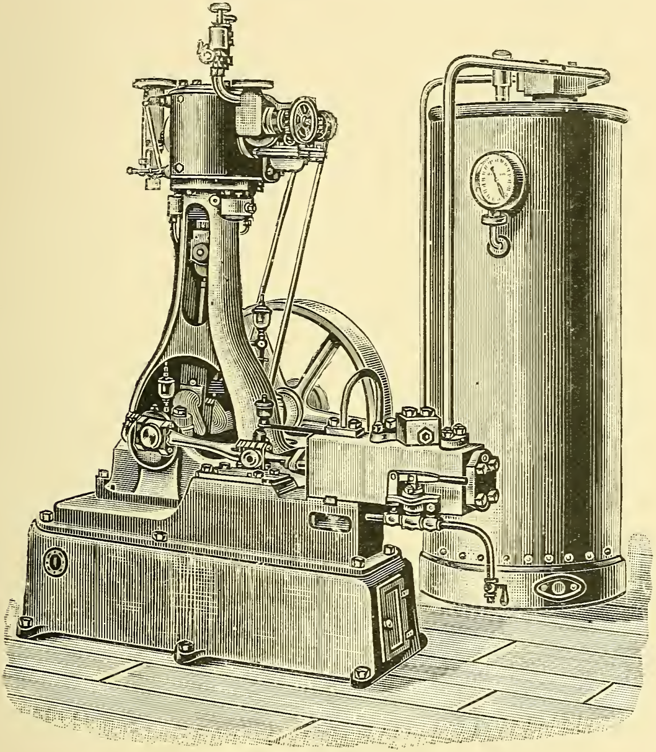


Fig. 30.

made per day of 480 cwt., is capable of maintaining a properly insulated room of 160,000 cubic ft. at the said temperature, requires a driving-power of 40 nominal horse-power, and occupies a floor space of 20 ft. by 20 ft. The cooling capacity of the machine shown in Fig. 30 varies from 20 barrels of worts per day to 200 barrels per day, and the horse-power required from 3 up to 12, in accordance with the size of the machine. The apparatus can be connected to existing hot and cold liquor backs and collecting tanks.

Sir Alfred Seale Haslam took out a patent in 1894 for an improved compressor especially intended for use with refrigerating machines, and particularly applicable to compound compressors wherein the gas is compressed in stages. The objects of the invention are to prevent the gas from escaping or coming in contact with the air, and to avoid dead spaces in the apparatus. The chief novel features are claimed to be as follows :—First, a pump cylinder having a chamber at one or both ends through which the piston-rod passes, and which is kept supplied with lubricating and sealing liquid from a reservoir through which the gas to be compressed also passes. Second, two single and double-acting pumps arranged tandem to each other, and with the compression ends of their cylinders next each other, and having between them a chamber supplied with lubricating and sealing liquid, through which their common piston-rod passes. Fig. 31*a* shows the improved machine in plan and side elevation, and Fig. 31*b* is a vertical central section through one of the ammonia compressors, drawn to an enlarged scale, illustrating the self-sealing oil chamber.

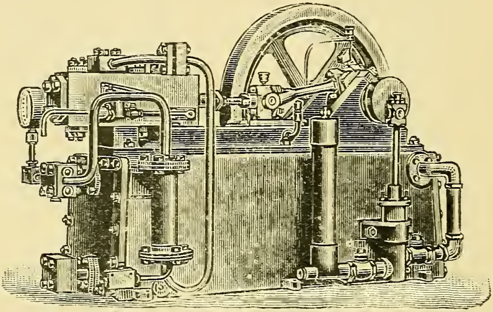


Fig. 31.

The operation of Haslam's improved compressor is as follows :—After adjusting the glands of the receiving and separating vessel, the latter, and the central chamber, is charged with lubricating and sealing fluid to a suitable height. The gas is then drawn through the supply pipe, accompanied by the requisite amount of the lubricating and sealing fluid, which latter is admitted to the low-pressure cylinder by a cock or

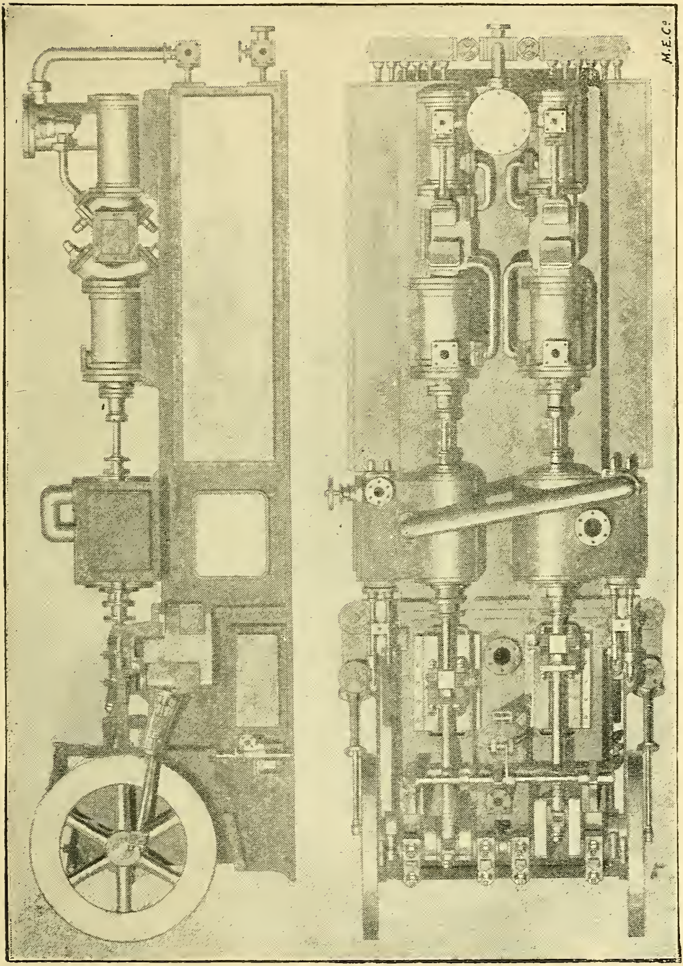


Fig. 31*a*.

valve, through the suction-valve, and compression to the desired extent is then carried out.

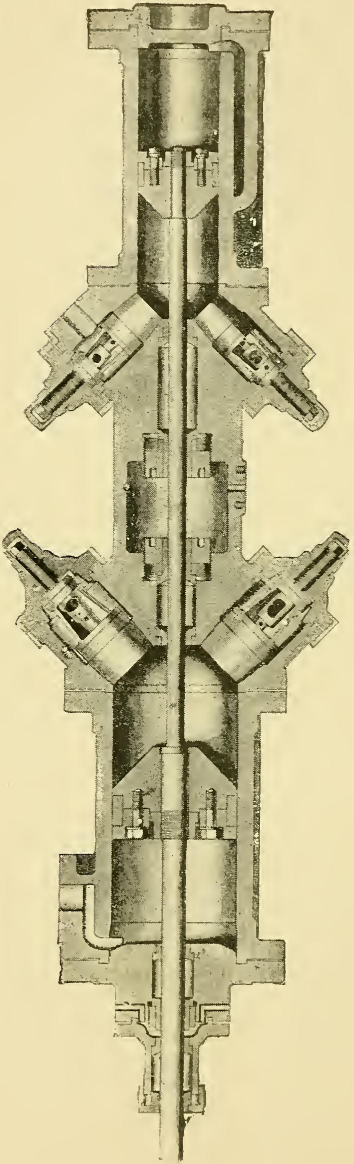


Fig. 31b.

Another patent was taken out in the beginning of this year (1895) by Sir A. S. Haslam for an improved apparatus for cooling air to be circulated through rooms or stores. The main feature of this invention consists in the provision of an air-cooler or chamber, wherein the air or other gas to be cooled is carried between a number of fixed vertical metal plates, down which cold brine or other uncongealable liquid is constantly caused to flow. These plates or diaphragms are, as shown in the plan, Fig. 31*c*, which illustrates an arrangement for use in connection with a meat chamber, preferably of a corrugated form, and their lower extremities are placed either in or above a receiver for the liquid which trickles down their surfaces. To maintain the plates or diaphragms at suitable distances apart, and parallel one with the other, distance-pieces or blocks are placed between them at the top and bottom, which distance-pieces have lugs or recesses on their sides to provide passages for the liquid. The tops of the upper distance-pieces form the bottom of a tank supplied with the cold liquid, and from which it flows down the plates in thin streams; and they have, moreover, vertical projections at each end, which together form the ends of the tank. Above this tank are situated suitable numbers of troughs or pipes, and a shower of brine at a low temperature, drawn or lifted from the receiver below, in which it is cooled by a pump or otherwise, is distributed over the bottom of the upper tank, from whence it trickles down the surfaces of the corrugated or other plates, or diaphragms. Through the spaces or clearances provided between these plates a current of air is driven by means of a fan or blower, the blast being divided by the said corrugated plates into a number of thin sinuous currents, and being reduced to a very low temperature by impinging against their surfaces and the cold fluid trickling down their sides. It has been found in practice to be preferable to place the above-described plates or diaphragms as close together as can possibly be done without injuriously checking the flow of air.

Flat plates, or plates with horizontal corrugations, are not found to be so advantageous, because the air can pass between them in a straight line, instead of being compelled to wind backwards and forwards between the corrugations and impinge again and again against the cold liquid and the surfaces of the plates; in the case of flat plates, moreover, they have to be much thicker in order to insure the requisite stiffness.

Both the compound-ammonia compression apparatus shown in Figs. 31*a* and 31*b*, and the cooling battery illustrated in Fig. 31*c*, are said to have given very favourable results under most exhaustive tests.

A view (Fig. 31*d*) is given in the frontispiece illustrating in sectional elevation a small ammonia machine with the patent brine-cooling battery, for refrigerating air in large quantities, to be blown or forced into the room or chamber, which latter is also shown in vertical section on the left-hand side of the drawing.

The Boyle compressor is of the vertical single-acting type, compressing on the up stroke only, and the extreme lower part of the cylinder forms an oil-chamber to seal the stuffing-box. The gas is admitted freely below the piston for cooling purposes.

The St. Clair compressor is of a compound form, being a combination of two or more single-acting compressors in such a manner that the gas is partly compressed at a lower pressure

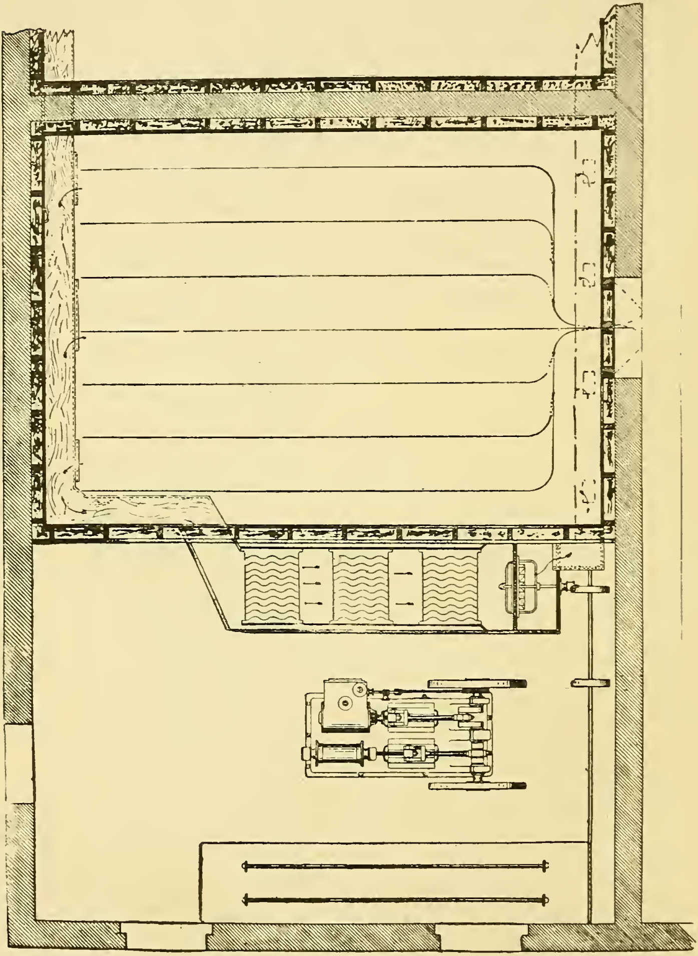


Fig. 31*c*.

in one compressor, and then passed to another, wherein the higher compression is applied.

CHAPTER VI.

MANAGEMENT OF AMMONIA COMPRESSION MACHINES.

EVERY particular type of machine working on this principle has, as a rule, certain distinctive or characteristic features, and will, of course, so far at least as these are concerned, require special care and adjustment, and it would consequently be totally impossible to lay down an arbitrary set of rules for working, that would be suitable to all; nor is this necessary or required, as full particulars relating to the manipulation of each particular machine are invariably supplied by the makers. The following points, however, are more or less applicable to all machines working on the ammonia compression principle, and should therefore be familiar to those in charge of same.

Before charging an empty machine with anhydrous ammonia, all air must first be carefully expelled. This is effected by working the pumps so as to discharge the air through special valves which are usually provided on the pump dome for that purpose.

The entire system should have been previously to this thoroughly tested by working the compressor, and permitting air to enter at the suction through the special valves provided for that purpose, and it should be perfectly tight at 300 lbs. air pressure on the square inch, and should be able to hold that pressure without loss. Whilst testing the system under air pressure it should be also carefully blown through and thoroughly cleansed from all dirt, every trace of moisture being also removed.

It is totally impossible to eject all air from the plant by means of the compressor, therefore it is advisable to insert the requisite charge of ammonia gradually and not all at once, the best practice being to put in from 60 to 70 per cent. of the full charge at first, and cautiously permit the air still remaining to escape through the purging-cocks with as little loss of gas as possible, subsequently inserting an additional quantity of ammonia once or twice a day, until all the air has been got rid of by displacement, and the complete charge has been introduced.

To charge the machine, the dryer or dehydrator of the apparatus for manufacturing or generating anhydrous ammonia, or where no such apparatus is included in the installation, the drum or iron or steel flask of anhydrous ammonia should be connected, through a suitable pipe, to the charging valve; the expansion valve must be then closed, and the valve communicating with the dryer or dehydrator, or that in the flask or bottle opened. The machine should be run at a slow speed when sucking ammonia from the drier, or whilst the flask is being emptied, with the discharge and suction valves full open. In the latter case, when one of the said flasks or bottles has been completely emptied it must be removed, the charging-valve having been first closed, and another placed in position, until the machine is sufficiently charged to work, when the charging-valve should be finally closed, and the main expansion valve opened and regulated. A glass gauge upon the liquid receiver will show when the latter is partially filled, and the pressure gauges, and the gradual cooling of the brine in the refrigerator (in the case of a brine circulation or ice-making apparatus), and the expansion pipe leading to the refrigerator coils becoming covered with frost, indicate when a sufficient amount to start working has been inserted.

It is sometimes advisable to slightly warm the vessels or bottles containing the anhydrous ammonia by means of a gas jet, or in some other convenient manner, whilst transferring their contents to the machine, as otherwise if frost forms on the exterior of the said bottles they will not be completely discharged, and loss of ammonia will ensue.

The flasks, bottles, or other receptacles containing the anhydrous ammonia should be always kept in a tolerably cool and a perfectly safe situation, and they should moreover be moved and handled with the utmost caution and care.

In the event of an accident occurring, and any considerable quantity of the ammonia becoming spilt, it is well to remember that it is so extremely soluble in water that one part of the latter at a temperature of 60° Fahr. will absorb some 800 parts of the ammonia gas, therefore water should be employed to kill or neutralise it, and any person attempting to penetrate an atmosphere saturated with this gas should not fail to place a cloth well saturated with water over his nose and mouth. See table on page 258 for solubility of ammonia in water.

The machine having been started, and the regulating valve opened, it is essential to note carefully the temperature of the delivery pipe on the compressor, and if it shows a tendency to heat then the said regulating valve must be opened wider; whilst, on the contrary, should it become cold, the said valve must be slightly closed, the regulation or adjustment thereof being continued until the normal temperature of the said pipe is the same as that of the cooling water leaving the condenser. When the charge of ammonia in the machine is insufficient, the said delivery pipe will become heated, and that even when the regulating valve is wide open.

There are many additional signs of the healthy working of the apparatus other than the fact that it is satisfactorily performing its proper refrigerating duty, which soon become easily recognisable to those in charge; for example, every stroke of the piston will be clearly marked by a corresponding vibration of the pointers or indexes of the pressure and vacuum gauges. The frost visible on the exterior of the ammonia pipes leading to and from the refrigerator will be about the same. The liquid ammonia can be distinctly heard passing in a continuous and uninterrupted stream through the regulating valve. The temperature of the condenser will be about 15° higher than that of the cooling water running from the overflow. And finally, the temperature of the refrigerator will be about 15° lower than the actual temperature of the brine or water being cooled.

Air will find its way into the system through leaky stuffing-boxes, improper regulation of the expansion valve, &c. Its presence in any considerable volume is shown by a kind of whistling noise, the liquid ammonia passing through the expansion valve in an intermittent manner, a rise of pressure in the condenser, and also loss of efficiency thereof, and other obvious signs. In this case the said air must be got rid of through the purging-cocks in a similar manner to that which remains in the system when first charging the machine.

The presence of any considerable amount of oil or water in the system, which may result from careless distillation, will cause a reduction in efficiency, and will be evidenced by shocks within the compressor cylinder.

The temperature can be regulated either by running the machine at a higher speed or by increasing the back pressure, or by a combination of both. The back pressure can be regulated by means of an expansion valve or valves fitted between the receiver and the refrigerator evaporating coils or pipes in the main liquid pipe. Fig. 32 is a view partly in vertical central section showing a very common form of expansion valve of the taper spindle type, which is adapted for use with a manifold. The construction of this valve will be obvious from the drawing.

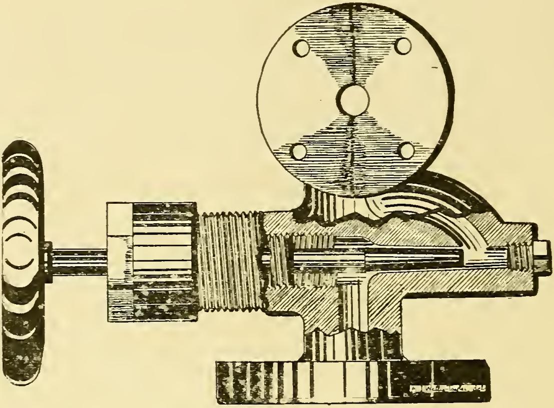


Fig. 32.

Fig. 33 is a plan, Fig. 34 is a vertical central section, and Fig. 35 is a view of the plug partly in vertical section through the port or way, showing the De La Vergne improved expansion cock, for regulating the flow of the liquid ammonia into the expansion coils.

The port or passage through the plug (Figs. 34 and 35) is so formed as to admit of the nicest regulation being effected. With this object the round hole is not carried completely through the plug, but only through about three-quarters the thickness thereof, as shown in Fig. 35, and the remaining thin bridge of metal is perforated in the shape of a very narrow wedge as shown in Fig. 34.

The plug is rotated by means of a worm and worm wheel in the manner which can be clearly seen from the drawing, and whereby very fine or delicate adjustment can be readily imparted thereto. The narrow wedge-shaped passage or aperture

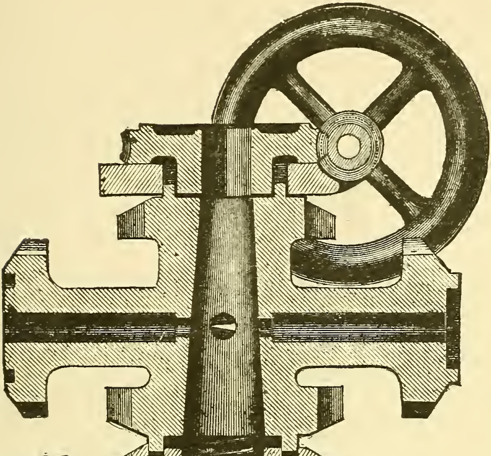


Fig. 34.

Fig. 35.

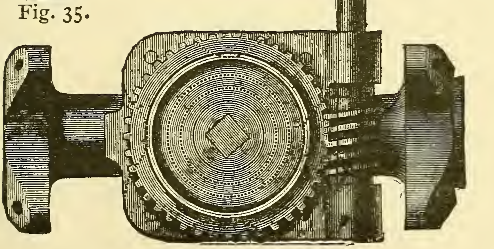


Fig. 33.

allows of the flow of the liquid ammonia being regulated to the minutest possible amount, the point or apex thereof being the first to open.

A brief account of Puplett's regulating or expansion cock or valve has been already given on page 70 when dealing with Puplett and Rigg's 1887 patent, and a description of the Pontifex valve will be found on page 107, being one of the improvements included in his 1887 patent.

It is absolutely necessary that an ample supply of oil for lubricating purposes be forced into the stuffing-box of the compressor at frequent intervals, otherwise it will be found that the heated ammoniacal gas at high pressure will very rapidly cut through even the very best packing. Pure mineral oil of good body is found to be the best lubricant; animal and vegetable oils should not be used, as, on contact with ammonia, they will saponify, and much trouble and loss will ensue therefrom.

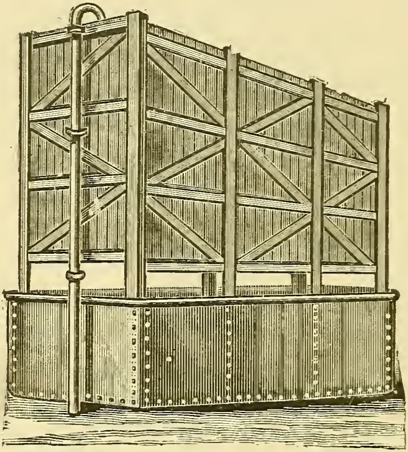


Fig. 36.

Another matter requiring special attention is the proper lift of the suction and discharge valves, and these should invariably be provided with proper means for admitting of the high lift being readily adjusted. The lift should not be too otherwise the said valves will not close with sufficient promptitude, and a loss of efficiency will result, and that more especially in compressors running at a high speed.

When superheating of the ammonia gas in the compressor is guarded against by the circulation of cooling water through a jacket surrounding the latter, it is desirable to ascertain the proper amount of water necessary to secure the best results. This will, of course, vary with the condensing pressure, about 12 gallons of water per hour for each ton of refrigerating effect per day of 24 hours being usually found to be sufficient for low condensing pressures of, say, from 95 to 110 lbs., whilst, on the other hand, with a high condensing pressure of about 150 lbs., the amount will have to be increased to 50 gallons or more per hour.

The larger the amount of cooling water that is employed in the separator jacket the better; and this water need not be wasted, as it may be conducted through a suitable overflow into the condenser, and utilised together with that delivered specially thereto. The overflow pipe conducting this water to the condenser should preferably dip down for a certain distance into the said condenser.

Respecting the quantity and temperature of the cooling water for the condenser, it must be remembered the lower the temperature of the condensed ammonia the less will be the pressure against which the compressor has to work, and consequently the greater will be the saving in fuel and in wear and tear to the moving parts.

The amount of condensing water required will vary in accordance with the temperature at which it is run from the condenser; for instance, if the condensing water be run into the said condenser at a temperature of about 60° Fahr., and leaves at the overflow or waste at a temperature of say 90° Fahr., the quantity of water required will be about 1 gallon per minute for each ice capacity of one ton per twenty-four hours; whilst if the temperature of the overflow or waste were 75° Fahr. the original temperature at the inlet being the same as before, the amount of water required would be about 2·5 gallons per minute for each ice capacity of one ton per twenty-four hours, and a reduction of about 40 lbs. in the condensing pressure would be effected.

In large towns and cities, however, where the water from the water companies' mains has to be used, and paid heavily for, it is often doubtful economy to attempt to reduce the temperature of the condensed ammonia below a certain point, say 60° Fahr., during the winter months, and 70° Fahr. during the summer months. It is obvious that when a high price has to be paid for the water employed for cooling and other purposes, every effort possible should be made to utilize it to the fullest extent, and, with this end in view, it is desirable to use the overflow water from the condenser for boiler-feeding purposes, or to employ some means, such as a cooling tower, for saving that which would be otherwise run to waste and be completely lost.

An efficient and economical arrangement for this latter purpose is Puplett's improved water-saving and cooling apparatus, which is illustrated in Fig. 36. It is claimed by the inventor that the use of this contrivance enables the condensing water to be used over and over again with comparatively little loss, the waste indeed being practically confined to the quantity taken up by evaporation, which loss is, of course, more considerable in hot weather, and the consumption of condensing and circulating water is thus minimised as much as possible. It is stated to have been clearly demonstrated that in regular working for a considerable period, with a temperature in the sun of 93° Fahr., the entire loss experienced did not exceed 3 per cent. of the total quantity of water circulated. The cost of the up-keep of the apparatus, moreover, is trivial, being one farthing per thousand gallons cooled, and the power required under ordinary conditions is one horse-power indicated for the same amount.

To prevent loss of efficiency from heating of the condensed ammonia, it is advisable that the receiver and piping should be covered with a thick layer of some suitable non-conducting material, which precaution is the more necessary, inasmuch as the said piping generally passes through the engine-room, and consequently the temperature of the ammonia is not infrequently raised as much as 25° above that at which it left the condenser, before it enters the coils or pipes of the refrigerator, which causes a loss of about 2·5 per cent. on the ice-making capacity of the machine. The pipes conveying the ammonia gas from the coils or pipes of the refrigerator to the compressor should be likewise well covered with non-conducting material, so as to prevent, as far as possible, any further accession of heat in the said gas during the transit. The desirability of this will be readily seen when it is remembered that the refrigerating capacity of a machine of this type is dependent upon the weight of ammonia circulated, and that the volume of a given weight of the gas increases in proportion to the elevation of its temperature, and consequently the higher this is raised the smaller will be the weight of the gas circulated or dealt with by the compressor, although the volume may be the same.

In the case of a compressor wherein the cylinder is cooled by a water circulation round the exterior walls thereof, and not by the introduction of cooling liquid to the interior thereof, a certain amount of the oil employed for lubricating purposes will gain access to the interior round the piston rod, and this oil would, unless proper means be taken to prevent it, be carried through the discharge valve along with the ammonia gas, and, after first passing into the condenser, would finally gain access to the evaporating or expansion coils or pipes of the refrigerator, and also stop or clog up the expansion valve, and otherwise reduce the efficiency of the machine.

The method employed for recovering any oil carried over with the ammonia gas in a compressor of the De La Vergne type, employing a sealing, cooling, and lubricating liquid in the cylinder, has been already mentioned (page 48) when dealing with that machine, with compressors wherein other means are employed for ensuring a complete or a practically complete discharge of the ammonia at each stroke of the piston, suitable oil separators or collectors for the mechanical separation of the oil from the gas, and in some cases rectifiers are used.

The separator or oil collector frequently supplied consists merely in a cylindrical vessel into which the ammonia gas is conducted at one extremity and leaves at the other, the said inlet and outlet being situated at some inches from the ends or covers, the gas is supposed to be freed from the oil carried over therewith by coming in contact with the sides of the cylinder, and it passes on to the condenser, whilst the said oil falls to the bottom of the vessel.

A better form of separator is that wherein baffles or plates, descending vertically to slightly below the centre of the cylindrical vessel, and extending alternately nearly but not quite to the opposite sides thereof, are employed. In this arrangement the gas is admitted at one side of the cylinder and, after taking a zigzag course between the said baffles or plates, leaves at the other side thereof. A very considerable increase of contact surface is thus ensured in a separator of this type, a modified form of which is employed in the De La Vergne system, and the said separator is rendered considerably more efficient.

The gas being at a temperature of some 200° Fahr. when passing through the separator or interceptor, the oil contained or carried over therewith is in a limpid condition, and is, therefore, difficult to eliminate from the gas. To obviate this objection the separator or oil collector is sometimes water-jacketed, by which means the temperature can be maintained low enough to cause the oil to separate easily from the gas and fall to the bottom of the cylinder or vessel. By this arrangement its efficiency is still further increased.

Puplett and Rigg's patent separator or interceptor has been already described on page 69, and centrifugal oil separators have also been used with some success.

Even the best of the ordinary separators or oil collectors at present in use, however, are more or less defective in action.

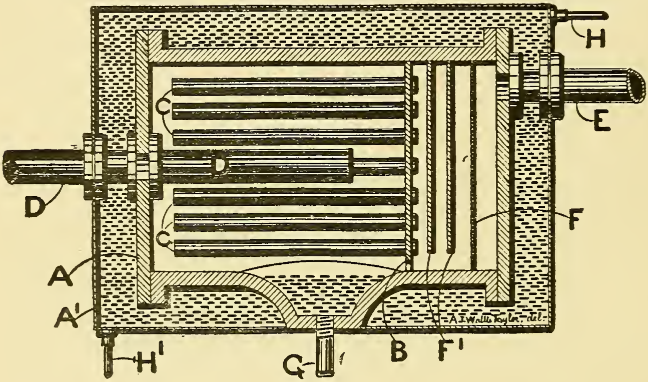


Fig. 37.

Fig. 37 shows a modified arrangement of the catch-alls or interceptors employed on the Yaryan patent evaporators, which would, in all probability, ensure a more perfect elimination of the oil. As will be seen from the illustration it consists in a cylinder A, which is water-jacketed as shown at A^1, and divided into two compartments by a tube-plate or partition B, from which project tubes C, C, which extend round the gas outlet pipe D, and extend nearly but not quite to the end of the cylinder, the said outlet pipe extending into the cylinder for a distance equal to about half the length of the tubes. E is the inlet pipe through which the ammonia gas and the particles of oil carried over therewith are delivered into the first chamber of the separator or oil collector, F is a wire gauze or perforated screen or diaphragm, and

F^1, F^1, are baffle or check-plates which extend alternately to within close proximity to the opposite sides of the cylinder. A clearance is likewise provided at the bottom of each of the said baffle or check-plates F, and of the partition or tube-plate B, to allow the free passage of the oil from the first compartment or chamber to a well formed in the bottom of the separator cylinder A; G is a pipe leading from the said well, through which the oil can be drawn off when required; H, H^1, are respectively the inlet and outlet pipes for the cooling water to the water-jacket.

In operation the gas and oil enter the first chamber or compartment of the separator, and pass to the tubes C, through the wire gauze diaphragm F, and taking a zigzag course from side to side of the separator past the baffle or check-plates F^1. A large proportion of the oily particles strike against the said diaphragm, and the check, division, or baffle-plates F^1, and become separated from the gas, finally falling to the bottom of the compartment and passing to the well A^2. The partially cleared gas then passes through the interior of the open-ended tubes C into the second chamber or compartment, and returns along the space on the outside thereof to the outlet pipe D, the remainder of the oily particles becoming deposited on the interior and exterior surfaces of the tubes C, and on the walls of the compartment, from which they likewise fall, and are collected in the well in the bottom of the latter. The very extended surfaces with which the gas thus comes in contact during its passage through the separator or collector, will ensure the complete deposition of the oil held in suspension by the gas, and the said gas will finally pass out from the separator or oil collector at the outlet pipe D completely, or practically completely, freed therefrom.

The separator or oil collector is sometimes so connected with the compressor that the oil can be used over again; this, however, is objectionable in the case of a double-action compressor, as the connection is liable to become choked with pieces of packing that find their way into the separator. When a rectifier is used, the separator is in some instances connected therewith through a rotary cock, operated from the main shaft by means of a band, which cock is kept constantly working discharging a small quantity of oil at each revolution into the rectifier, so long as any remains in the separator. The failure of oil in the separator is indicated by the connecting pipe between the latter and the separator becoming covered with frost, when the cock must be immediately thrown out of gear and the oil allowed to accumulate in the separator before restarting it. When the separator is connected directly with the rectifier the cock in the connecting pipe should be opened periodically, say about every twelve hours. The oil may be discharged from the rectifier at about similar intervals, and the amount of oil that is found to be entering the compressor cylinder is an index to the state of the packing in the stuffing-box, a large quantity being a certain sign that it requires renewal or seeing to. It is most important that the separator or oil collector be cleaned out at pretty frequent and regular intervals.

It not infrequently happens that deposit accumulates on the exterior surface of the condenser coils from sediment in the water, and on the interior surface thereof from oil and foreign bodies. The smaller ammonia pipes may sometimes become filled with obstructions to the extent of completely blocking them up. These bodies may consist of lumps of solder or other matter accidentally left in the tubes when making the joints, or of pieces of packing from the stuffing-box carried over with the gas. The deposit or furring of the condenser coils or pipes is objectionable inasmuch as it acts as a non-conducting covering, and prevents them from freely transferring the heat to the cooling water, and the choking of other conduits is likewise followed by corresponding loss of efficiency, for example, that of one of those leading to one of the refrigerator coils or sets of pipes will result in the latter not acting at all, or only very slightly. Complete choking up or obstruction of one of these latter conduits is evidenced by that particular pipe, and also the corresponding return pipe, not becoming covered with frost at all, or only so to a very small extent; and a slightly less degree of frost upon any of these pipes indicates partial choking or obstruction, and a consequent very feeble action of the said coil or set of pipes.

The coils or pipes in the condenser should be frequently cleaned on the exterior with a suitable brush, and whenever practicable removed at fixed periods and carefully scaled. This is best and most easily effected by heating the tubes, care being taken however not to carry such heating to an injurious extent. The interior surfaces of the tubes can be cleansed by blowing steam through them at a considerable pressure. To clear small obstructions from a conduit leading to one of the refrigerator coils or sets of pipes, it is usually sufficient to turn the entire stream of ammonia into it. Should, however, the said obstruction prove obstinate, and it be found impossible to shift it in this manner, an early opportunity must be taken to clear it by blowing steam through it. Any considerable choking of the conduits leading to the refrigerator coils is followed by a very marked decrease of efficiency in the latter.

Whenever a joint has to be broken, and any portion of the machine opened for any purpose whatever, it is absolutely essential that the whole of the ammonia contained in that part should be pumped or transferred to another part, or if this cannot be done it should be discharged, preferably into water, which can readily be effected by means of a short strong india-rubber tube. On account of the already-mentioned great solubility of ammonia in water, it will become readily absorbed, if the vessel into which it is discharged be kept sufficiently replenished with cool water. It is of the utmost importance that the rule of carefully removing all ammonia pressure before breaking a joint be strictly adhered to.

In warm weather, or in hot climates, the joints will require constant attention, and periodical inspection, and tightening up of the bolts; and at all times, even in the winter in this climate, they are liable to develop leaks through the working of the machinery.

Ammonia being a good solvent, and having no effect upon iron or steel, the parts will become clean and free from deposit, after working for a short period, and the cylinder and piston will be found highly polished. Ammonia also possesses some slight lubricating qualities, and, therefore, after starting, no other lubricant need be introduced into the compressor cylinder. The cylinder covers, as also the valve box covers, should be occasionally removed and a thorough inspection made of the piston, cylinder, and valves. The latter are exceedingly apt to become cut or marked by fragments of scale, and require grinding in periodically.

A properly packed piston-rod will remain in good order for at least six months, provided the said rod be in first-rate condition and perfectly true ; under contrary conditions, however, trouble will be experienced in a fortnight, or less. The usual precautions to be observed in order to properly pack a steam-engine or other stuffing-box, which are well known, or should be so, to those in charge of ammonia plants, are equally applicable in the case of the compressor, but the hereinbefore-mentioned extensively searching nature of ammonia gas demands the exertion of extra care. These observations apply more especially in the case of a double-acting compressor where the pressure upon the gland may reach 180 lbs. to the square inch. In a single-acting one, where the pressure should not exceed 28 lbs., this extreme care is not of so much moment, though it is, of course, still important to have a tight joint.

The stuffing-boxes should be formed unusually deep, say about a foot, from ½ to ¾ of an inch being left between the piston-rod and the interior of the box. For single-acting compressors metallic packing will be found the best, that of Victor Duterne, the patent for which expired many years ago, being an excellent one for the purpose. Double-acting compressor stuffing-boxes should be packed with a combination of packings, a perforated ring being placed between them, and many of the special and patented packings will be found suitable for the purpose. Plaited cotton packing cut into suitable lengths and inserted in the form of rings will also be found effective; it is desirable, however, to finish off with one or two india-rubber insertion rings. The packing should be driven home tightly, piece by piece, with a packing stick formed of hard wood, and a mallet, and the gland finally screwed on by hand only, so as to allow for the expansion of the said packing. This latter precaution is absolutely necessary in order to ensure the maximum life of the latter. When tightening up the gland care must always be taken to do so equally all round, and not to screw up the nut on one bolt more than on any of the others.

To determine the efficiency of an installation on the ammonia compression system, the following fittings are required, viz. :—An indicator, so that diagrams can be taken from the compressor; stroke counters, to enable the number of strokes made by the steam-engine and brine pumps to be ascertained; and mercury wells to admit of the temperature being obtained at various points throughout the system.

In making a test it is desirable that it should last at the very least for fully twelve hours, and it is better to carry it on for twenty-four hours. The number of readings which it is desirable should be taken from the various instruments will vary in accordance with whether or not the work is steady or otherwise, and the person carrying out the test will have, of course, to use his own judgment on this head. Where artificial ice is made, for example, twice an hour will be sufficient, whilst on the other hand, four or more readings per hour should be taken in cases where the variation in the temperature of the materials to be cooled is wide. Indicator diagrams should be taken from both the steam-engine cylinder and the compressor cylinder every two hours.

A mercury well, for an horizontal pipe, when the latter is of sufficient dimensions, consists usually in a short piece of tubing closed at its lower end, and fitted into the pipe by means of a suitable bushing. It is filled about three parts full of mercury, and the thermometer, which should have an elongated cylindrical bulb, is held in position therein by means of a perforated cork. For vertical pipes, or pipes of very small dimensions, where this arrangement would be impracticable, the well is generally formed by means of a wooden or other block, one side of which is shaped to the outline of the pipe to which it is to be applied, and has a suitable recess formed therein. This block is firmly secured against the pipe by metal straps in such a manner that a portion of the wall of the well will be formed by the pipe, the latter being scraped perfectly clean at that part. The joint between the block and the pipe must be made perfectly tight, which can easily be effected by means of a little white lead paint, there being no pressure, and the whole should be surrounded by a thick layer of non-conducting composition, through which the stem of the thermometer is permitted to project.

The points in the system where it is desirable to locate the mercury wells are:—The suction pipe just at its connection with the compressor; the discharge pipe, as close as possible to its connection with the compressor; the ammonia discharge pipe from the condenser, as near the latter as practicable. Where a brine circulation is employed:—The pipe or manifold supplying the various coils or sets of pipes in the refrigerator; the discharge pipe of the refrigerator; the brine discharge pipe, at the point where it connects to the refrigerator; and the brine return pipe in proximity to where it connects with the refrigerator.

Before closing this chapter, a few words upon the excess condensing pressure invariably found in ammonia compression machines will not be out of place. This excess of the actual working condensing pressure over the theoretical is caused by the ammonia gas being imprisoned in the comparatively confined space afforded by the coils or pipes in the refrigerator, and the excess pressure is more marked in an horizontal compressor running at a high speed of, say, 140 revolutions per minute, than it is in vertical ones having only a low speed of from 35 to 60 revolutions per minute; it varies, moreover, in almost every make of compressor. At a low suction pressure of about 15 lbs. it should not be more than 10 lbs., but with a suction pressure of, say, 27 or 28 lbs. it may rise to 50 lbs., or even more.

The condensing pressure affords a means of ascertaining whether or not the apparatus contains the proper full charge of ammonia, or if the losses sustained by leakage are sufficient to render it necessary to insert an additional supply. For this reason it is advisable for the person in charge to keep a record in a proper book, suitably ruled for the purpose, of the temperature of the condensed ammonia when leaving the condenser, and also of the condensing and suction pressures, at regular intervals of, say, three hours. This will enable him to follow the state of the ammonia charge, for example, if the condensing pressure is found to be gradually falling during a three months' period, as compared with the average condensing pressure of the previous three months, whilst at the same time the condensing temperature and the suction pressure remain constant, it will be evident that the charge of ammonia has become reduced by leakage to a sufficient extent to require replenishing. This reduction in the condensing pressure is caused by the diminution in the charge of ammonia giving larger condenser space, the gas having thus a much more extended worm, coil, or tube space wherein to condense and liquefy, and hence the decrease. As a general rule it may be taken that, whenever the condensing pressure is found to have fallen about 8 lbs., enough ammonia to restore the original condensing pressure should be inserted into the machine.

CHAPTER VII.

THE ABSTRACTION OF HEAT BY THE EVAPORATION OF A SEPARATE REFRIGERATING AGENT OF A VOLATILE NATURE UNDER THE DIRECT ACTION OF HEAT, WHICH AGENT AGAIN ENTERS INTO SOLUTION WITH A LIQUID, OR THE ABSORPTION PROCESS.—THE BINARY ABSORPTION PROCESS.

THE principle involved in the operation of machines for the abstraction of heat by the evaporation of a separate refrigerating agent of a volatile nature by the direct action of heat, and without the use of power, is, as has been previously observed of the liquefaction process, more a chemical or physical action than a mechanical one. It is founded upon the fact of the great capacity possessed by water for absorbing a number of vapours having low boiling points, and of their being readily separable therefrom again, by heating the combined liquid; hence it is commonly known as the absorption process.

The absorption process was invented by Ferdinand Carré (brother to Edmond Carré, whose sulphuric acid freezing apparatus has been previously mentioned), about the year 1850. This system involves the continuous distillation of ammoniacal liquor, and requires the use of three distinct sets of appliances, viz.:—

First, for distilling, condensing, and liquefying the ammonia. Second, for producing cold, by means of a refrigerator, an absorber, a condenser, a concentrator, and a rectifier. Third, pumps for forcing the liquor from the condenser into the generator for redistillation. The three operations are each distinct from the other, but when the apparatus is in actual work they must be continuous, and are dependent upon one another, forming separate stages of a closed cycle.

An advantage of the absorption process is that the bulk of the heat required for performing the work is applied direct without being transformed into mechanical power. The first machines, however, constructed upon this principle were very imperfect in operation, by reason of the impossibility of securing an anhydrous product of distillation, and as the ammonia distilled over contained as much as 25 per cent. of water, a very large expenditure of heat was required for evaporation, and the working of the apparatus, moreover, was rendered intermittent. This was owing to the distillation, which is the most important operation, and has of necessity to be executed in a rapid manner, being, in the first machines, very imperfectly effected, and the liquor resulting therefrom being naturally much diluted with water. Another serious result of the above defect, was the accumulation of weak liquor in the refrigerator, and the consequent necessity for constant additions of ammonia.

By subsequent improvements, however, made by Rees Reece in 1867-70; Mort in 1870, who introduced an improved temperature exchanger or economiser; H. F. Stanley, 1875; F. Carré (the original inventor), in 1876; W. H. Beck, in 1886; Mackay and Christiansen, and E. H. Tompkins, in 1887; and later still in the same year by E. L. Pontifex, the distillate has been rendered nearly anhydrous, and absorption machines have been brought to a very considerable degree of efficiency.

In Fig. 38 is illustrated F. Carré's continuous acting absorption machine. As above mentioned, the agent employed in this apparatus is ammonia. In the drawing A indicates the generator, B is the liquefier, C is the refrigerator, D is the absorber. Aqua ammonia is introduced into the generator A, the level of the liquid being indicated by a gauge glass which is shown on the left-hand side of the said generator, and which is practically similar to that used on steam boilers, and the evaporation is effected by heat from the furnace shown beneath. The gas from the generator A is conducted by a suitable pipe E to the liquefier B, wherein it passes through a congeries or series of coils or zigzags arranged in a bath of cold water, which is kept constantly renewed from the reservoir F. By the time the ammonia has reached a vessel situated at the termination of the coils or zigzags in the liquefier it is in a liquid condition, and under a pressure of about 150 lbs. per square inch, which pressure is constantly maintained in the generator A.

In the liquid state the ammonia flows through the pipe G to the regulator H, by which it is admitted to the distributor I through a pipe K, which latter is wound spirally round the

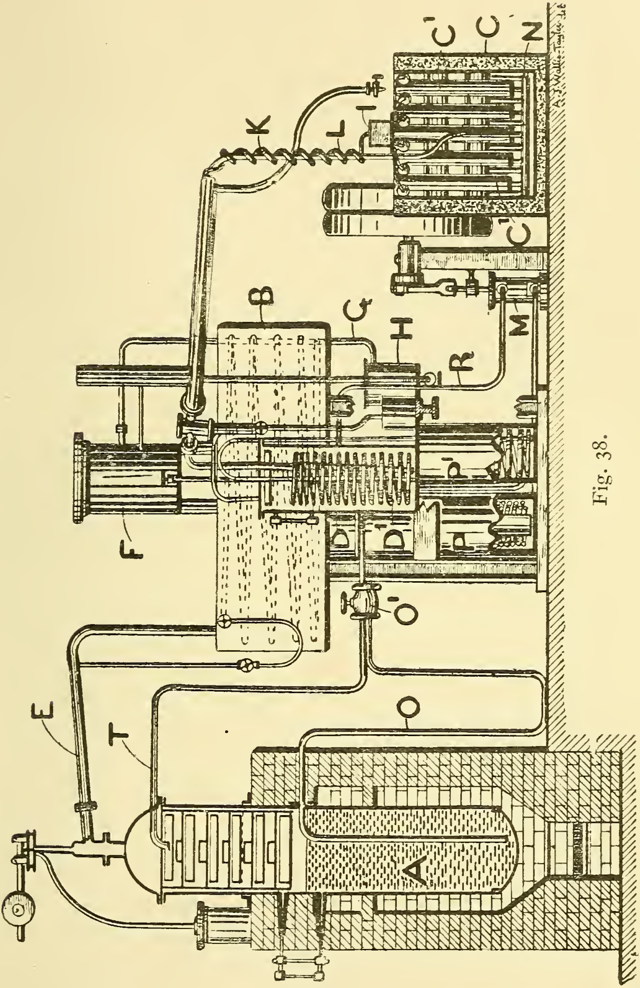


Fig. 38.

pipe or tube L, which is of larger bore, and through which the vaporised or gasified ammonia returns from the refrigerator C, after having performed its heat-absorbing duties therein. By this arrangement the said returning vapour or gas is made to do some further work by absorbing or taking up heat from the liquid ammonia on its way to the refrigerator.

The refrigerator represented in the drawing consists of a set or series of six or other suitable number of spiral or zigzag tubes C[1], C[1], which return upon themselves, forming an equal number of partitions in the tank wherein they are immersed, which latter is constructed of suitable non-conducting material. Each of these zigzags receives an equal supply of the liquid ammonia from the distributor I, and the space in the insulated tank surrounding them is filled with some uncongealable liquid, or one that will congeal only at very low temperatures, such as alcohol, or a solution of chloride of calcium or of common salt, which is usually known as brine.

The ice-cans or cases are immersed in the liquor between the zigzags, and are sustained upon a carriage capable of being moved by the same mechanism that works the pump M, by which the resaturated solution of ammonia and water is returned to the generator.

The ammonia gas or vapour from the zigzags in the refrigerator C is collected in the cylindrical vessel N, from which it passes up through the tube L to the absorber D, where it meets the water that has been brought from the bottom of the generator A, and which partially fills the latter. This water being nearly free from ammonia, it having been exhausted therefrom by evaporation in the generator A, greedily absorbs or takes up the ammonia gas or vapour injected into it from the tube L.

The absorber D is fitted with a worm D[1] which receives cooling water from the supply tank F, and the water from the generator A, which is brought by the pipe O, is first passed through the coolers P, P[1], before delivery into the absorber D, and is thereby cooled so as to fit it to absorb the ammonia gas or vapour in the said absorber D more freely.

The transference of the water from the bottom of the generator A to the absorber D is effected by the pressure in the former, whenever the stop-cock or valve O[1] in the pipe O is opened. The pipe O is carried in a double coil through the cooler P, which consists of two concentric cylinders, and in a single coil through the cooler P[1], discharging through a sieve, strainer, or perforated tray, in a fine shower into the absorber D. The strong ammoniacal solution from the absorber D, which is considerably reduced in temperature, is passed through the spaces round the coils of pipe O in the cooler P, and whilst reducing the temperature of the hot exhausted solution or water from the bottom of the generator A on its way to the absorber D, is itself raised several degrees before being returned to the said generator, to the mutual advantage of both. The coil of pipe O, in the second cooler P^1, is water cooled from the supply tank F.

The saturated solution from the absorber D is drawn off by the force pump M (which is driven by a steam-engine or other motor), through the pipe R, and is delivered thereby to the space round the coil in the cooler P, passing from the said cooler, through the pipe T, to the dome on the upper part of the generator A, where it falls upon, and trickles downward through, a series of perforated strainers or trays, whilst the ascending ammoniacal gas or vapour, on the other hand, takes a sinuous upward course, alternately passing round the edge of one of the trays, and through a central hole or aperture provided in the next, and so on to the gas or vapour pipe E; any aqueous vapour, which might otherwise be carried off with the ammoniacal gas or vapour, being thus condensed and returned to the generator.

The constant pressure maintained in the generator A is, as already mentioned, about 150 lbs. per square inch, and to prevent this pressure from being exceeded a safety valve is provided on the dome of the generator A. Any gas that escapes through this safety valve is led through a suitable pipe to a small water tank, where it is absorbed.

As will be seen from the above description, the operation is shortly as follows:—

The aqua ammonia is first introduced into the generator A, the gas or vapour expelled therefrom by heat into the condenser B; and so that the process may be carried out continuously and not be arrested by the exhaustion of the solution, the exhausted or impoverished liquor is slowly drawn off at the bottom of the generator, an equal volume of fresh strong solution being constantly inserted at the top thereof. The united effects of the cooling and pressure produce liquefaction of the ammoniacal gas or vapour in the condenser, and the liquid ammonia passes to the refrigerator. It will thus be seen, that, as the ammoniacal gas or vapour from the tubes of the refrigerator is re-absorbed, and a rich solution formed to feed the generator, the absorbing water used being that withdrawn exhausted from the latter, the said generator and the condenser will keep up a continuous supply of the liquid, and the refrigerator will continue to freeze successive charges of water in the ice-cans or cases, provided, however, that the requisite heat to vaporise or gasify the ammonia is supplied to the said generator. If, therefore, the entire apparatus be perfectly fluid tight, as it is theoretically supposed to be, no escape could take place by leakage or otherwise, and the same materials would go on indefinitely producing the same uniform effect.

In starting a machine constructed on the absorption principle it must be first blown through to expel all the air. In Carré's apparatus the air escaping from the absorber is conducted by a suitable pipe into what is known as a purger, where it is passed below the surface of water to absorb or retain any ammonia that would otherwise escape therewith.

A large amount of water is required for cooling purposes in the condenser or liquefier, and absorber, and a considerable consumption of fuel is also necessary to heat the generator, when this is performed directly by means of a furnace, as shown in Fig. 38 (page 95); when, however, this is effected by steam-heated pipes, as in Stanley's 1875 patent, or, as will be described later on, by coils of pipe heated by the exhaust steam from an engine, or even by direct or live steam from a boiler, there is a considerable saving on this head. Steam or other motive power is likewise required for driving the force pump.

It is claimed by Mr. Carré that for each pound of coal consumed as fuel, from 8 to 12 lbs. of ice can be produced, in accordance with the size of the apparatus. For working the larger form of machine, capable of making 500 lbs. of ice per hour, two men are required; the force pump is capable of forcing 220 gallons of liquid per hour into the generator, and during the same time 100 lbs. of pure ammonia is liberated from solution, liquefied, evaporated, and re-dissolved or re-absorbed.

Rees Reece's chief improvement is founded on the fact that two vapours having different boiling-points, when united, can be recovered by fractional condensation, and by means of his apparatus a practically anhydrous distillate can be obtained.

The special feature in the invention described in his 1867 patent is the method of obtaining nearly anhydrous liquid ammonia by means of an analyser, a rectifier, and a condenser, the peculiar construction and arrangement of which enables a continuous distillation and rectification of a dilute solution of ammonia to be effected upon the separative principle. The ammoniacal gas is reduced by its own pressure to a liquid condition in the condenser, from which it passes into the refrigerator at a very low temperature, quickly abstracting the heat from any fluid passed through the latter.

A boiler is connected with an analyser consisting of a series of plates arranged in the usual manner within a strong iron vessel. The analyser is connected with a rectifier, which is provided with a series of vertically arranged tubes surrounded by cold water, through which tubes the ammoniacal fluid passes to the condenser; or in an alternative arrangement the rectifier is provided with a series of vessels placed one above the other with a space between them, the said vessels being so connected that a passage is formed from end to end thereof for a continuous stream of cold water. The condenser is either fitted with tubes and is practically similar in construction to the first arrangement of rectifier above mentioned, or it consists simply of a cylindrical or other suitably shaped iron vessel, of sufficient strength to resist the internal pressure of the gas, and immersed in cold water. From this condenser the condensed ammonia passes to a refrigerator, which may be of any convenient form and construction. The liquid cooled in the refrigerator parts with the greater portion of its heat to the condensed ammonia, which is again vaporised, and in this form passes into an absorbing vessel which is kept cool by water, and which serves to maintain the required vacuum in the refrigerator. The ammoniacal solution passes from the absorber into a heating vessel, from which it is returned into the analyser. The latter may, however, on occasions be dispensed with, and the boiler connected directly with the rectifier.

In his 1870 invention further improvements are introduced, and the entire apparatus comprises a generator, an analyser, a rectifier, a liquefactor, a receiver, a refrigerator, an absorber, and a heater, an engine placed between the refrigerator and the absorber being sometimes, moreover, employed.

The first five of these vessels form what may be called the distillery part of the apparatus, and the main object of these improvements is likewise to ensure the more perfect elimination of liquid ammonia in an anhydrous condition, or practically so, from its aqueous solution, and in one continuous uninterrupted operation.

The analyser consists of a vessel fitted with a series of perforated cups or dishes, a dividing plate, an overflow pipe, and a dead plate or baffle to prevent the direct passage of the steam through the cylinder. The absorber comprises a series of pipes arranged together within a tank or cistern.

The ammoniacal gas eliminated from its solution in water by the action of the generator, analyser, and rectifier, passes onwards to the liquefactor or liquefier, wherein by its own pressure it is reduced to a liquid, and is collected in the receiver; the liquid ammonia so obtained being practically anhydrous. This anhydrous ammonia is then passed into the refrigerator, in which is placed a coil of pipe, any liquid passing through which will be cooled by the evaporation of the liquid ammonia surrounding it.

The refrigerator is connected through a stop-cock or valve to another coil contained or enclosed in an iron pipe, which coil extends to the absorber vessel, the latter being connected to the coil of piping contained in the refrigerator. The object of this second vessel and coil is to effect an interchange of temperature with the gas.

During its further onward passage to the absorber the ammoniacal gas comes in contact with the spent or exhaust liquor of the distilling apparatus in which it dissolves, yielding back the original quantity of the ammonia solution, to be used over again repeatedly without any appreciable loss or waste. This solution of ammonia is forced by a pump into the top of the analyser, wherein the ammonia is separated from the water, and passes to the condenser to be liquefied, whilst, on the other hand, the exhausted liquor goes to the generator, and from thence into the temperature exchanger or heater, and on to the absorber.

The tension or elastic force possessed by the gas as it passes from the refrigerator to the absorber, especially when employed for cooling water, admits of its being utilised for driving the pumps of the apparatus, or for other purposes.

The operation of Reece's improved apparatus is briefly as follows:—

The charge of liquid ammonia (the ordinary commercial quality of a density of 26° Beaumé) is vaporised by the application of heat, and the mixed vapour of water and ammonia passed to the vessels called the analyser and the rectifier, wherein the bulk of the water is condensed at a comparatively elevated temperature, and is returned to the generator. The ammoniacal vapour or gas is then passed to the condenser, where it is treated in a substantially similar manner to that in Carré's apparatus, that is to say, it is caused to liquefy under the combined action of the condensation effected by the cooling water circulating round the condenser tubes, and of the pressure maintained in the generator. The liquid ammonia (in this case practically anhydrous) is then used in the refrigerator, and the vapour therefrom, whilst still under considerable tension, is admitted from the refrigerator to a cylinder fitted with a slide valve, and entry and exhaust ports, practically similar to those of a high pressure steam-engine, and is thus utilised to drive the force pump for returning the strong solution to the generator, after which it is passed into the absorber, where it meets, and is taken up by, the weak liquor from the generator, and the strong liquor so formed is forced back into the generator by means of a force pump as before described.

The temperature exchanger or economiser introduced by Mort in 1870, provides for the hot liquor on its way from the generator to the absorber, giving up its heat to the cooler liquid from the absorber on its way to the generator, thereby saving the abstraction of so much heat from the generator, and admitting of the liquid in the absorber being kept at a lower temperature, which is of great importance to the economical working of the apparatus.

The invention which Harry Frank Stanley patented in 1875 comprises several important improvements upon the foregoing, the chief of which are as follows:—

In place of applying fire heat to the generator, as had been hitherto customary, a coil of steam pipes is employed for evaporating the ammoniacal vapour. The advantages derived from this are that the pressure and temperature in the generator can be much more easily regulated, and, moreover, the ammonia separates from the water better at a low heat, and an even temperature is found to be most essential to the efficient working of the apparatus. The steam-heated evaporating pipes consist of a number of straight pipes connected together by bends, giving a very large heating surface, and when the exhaust steam from the engine is employed therein for heating purposes, a very great saving of fuel is effected.

The analyser is placed upon the generator so as to economise space and save the connections otherwise necessary. The said analyser is formed preferably cylindrical, and is fitted with a series of dishes or trays having passages so arranged that the vapour impinges on the undersides thereof, and traverses the vessel without passing through the liquid. Each of the dishes or trays is provided with an overflow pipe which is raised above the level of the bottom thereof, so as to keep some liquid in the said dish or plate, but always below the top of the vapour outlet. As the ammonia vapour is driven off from the solution of ammonia and water, by the heat of the vapour rising from the tray below, it passes through the vapour outlets into the rectifier without going through the liquor on the tray or trays above.

By this means a considerable saving of fuel is effected, as the ammonia when once separated from the water on each tray or plate is at once delivered to the rectifier. Otherwise, were this not so, water has such a strong affinity for ammonia, that the vapour which had been separated from the liquor on one plate would quickly become absorbed again by the liquor it had to pass through on the next plate.

The rectifier is placed on the condenser, the two forming in fact one vessel, and the same condensing water does duty for both, the latter passing in at the bottom of the condenser where the coldest water is wanted, and up the outside of the coil into the rectifier, from which it passes to the absorber. The ammoniacal gas or vapour passes from the analyser into the top of the coil in the rectifier, which coil is fitted at intervals with pockets to carry off the water resulting from the condensation of the vapour coming from the analyser, so that immediately any such condensation occurs the liquor passes at once out of the coil, and the ammoniacal vapour does not come in contact with the water after being separated from it. By providing the said pockets with cocks or valves suitable adjustments of the apparatus can be effected.

The ammonia gas thus passes to the condenser in a practically anhydrous condition, which is absolutely essential to the economical working of the apparatus, and which would not otherwise be the case, as if the said gas comes into contact with the water resulting from its condensation it would re-absorb a portion of it.

The condenser coil is contained in a cast or wrought-iron cylinder, and to simplify the apparatus and to save space, the condenser is placed upon the receiver, the latter being a plain wrought or cast-iron vessel serving, as before, to store the anhydrous ammonia before it goes into the cooler or refrigerator; it is fitted with a glass gauge, or a float gauge to indicate the level of the liquid therein. When the latter is employed, revolving spindles or rods working vertically through stuffing boxes in the usual way are preferably used, as tending to minimise friction and prevent leakage.

The refrigerator or cooler is substantially similar to that employed in the former arrangements, but is fitted with a self-closing gauge in case of breakage.

The absorber is constructed of smaller pipes or tubes, so as to enable a greater number to be used than heretofore, and thus for a given content to secure a very much larger surface exposed to the action of the cold water which surrounds the said tubes ; the latter are preferably constructed of wrought-iron.

Another saving of condensing water is effected by having a few of the top pipes above the upper extremity of the water cistern, and letting the warm water coming from the rectifier drip over the outside of the said pipes. The heat due to the ammoniacal gas being absorbed by the weak liquor, which is given off from the inside, is sufficient to vaporise a portion of the water, and a large quantity of heat becomes latent in the vapour, producing a refrigerating effect.

The pump employed for drawing the strong solution of ammonia produced in the absorber, and forcing it through the coil of pipe in the heater into the analyser, against the pressure, is so constructed that there are the very least possible clearances, and that the whole or practically the whole contents are discharged at each stroke, thus preventing expansion of gas on the return stroke, tending to keep the suction valves closed. The pump cocks, valves and gauges are provided with water containers, so that should any leakage of ammonia through the stuffing box occur, the water will absorb it, the latter being returned into the apparatus when it becomes thoroughly saturated. The stuffing box cock is constructed with a guard, and with an adjustable clamp screw, which holds the key to its seat, preventing leakage from compression of the packing, and admitting of the said stuffing box being repacked whilst the apparatus is at work.

To allow for the gradual weakening of the solution of ammonia, a small vessel or still is provided in connection with the generator, wherein the weak solution from the latter is evaporated off at a low temperature into the apparatus, where the least pressure exists.

In the invention patented by William Henry Beck, in 1886, some still further improvements in various details of construction are described, notably in the arrangement of the analyser and rectifier, and the absorber.

In the first-mentioned vessel a series of sheet iron or steel trays with or without perforations, the edges whereof are drifted or set up so as to form short adjutages, are provided. Each alternate one of these trays has a central opening, and each intermediate tray an annular space left between its circumference and the enclosing case or cylinder. An inner sheet metal casing is, moreover, provided in which the water separating trays are secured, and which, together with such trays, can be easily removed and replaced in position; and the mouth of the vapour outlet pipe is sometimes surrounded by a finely perforated wire gauze chamber or guard.

The absorber is formed with a primary absorbing vessel, wherein the absorption of the ammonia gas is effected to an extent dependent upon the temperature of the ordinary cooling or condensing water, combined with a secondary absorbing vessel wherein a further absorption of the ammonia gas is effected by the cooling action of a current of cold brine, or of water, cooled to a temperature below that of the ordinary cooling or condensing water used in the primary absorber.

The weak liquor cooler, the liquid ammonia receiver, the condenser, and the rectifier are contained in a single open-topped tank provided with divisions or partitions so arranged as to ensure the passage of the cooling or condensing water successively through each of the compartments.

Frederick Noel Mackay and Adolph Gothard Christiansen obtained a patent for improvements in ammonia absorption machines in 1887, the main features of which that are claimed as novel being as follows, viz.:—

The separation of the ammoniacal gas from the liquor in which it is absorbed, by boiling the said liquor in stages within the same boiler.

An analyser consisting of a chamber containing superimposed spirally corrugated plates having perforations or openings.

The combination within one chamber, of an ammoniacal liquor boiler and analyser.

A rectifier consisting of such an arrangement of a coil or coils, that the gas will take an upward direction, and the liquid a downward direction.

A condenser wherein the coils are so connected that the gaseous ammonia passes from coil to coil in an upward direction, whilst the liquid ammonia flows in a downward direction.

A multiple coil condenser so constructed that it has but one single through way.

A rectifier and condenser consisting of chambers containing coils, all the joints whereof are situated on the exterior.

An auxiliary cooler composed of a chamber fitted with a coil and regulator, and suitable connections.

A vaporiser and refrigerator wherein the brine flows through a chamber, whilst the liquid ammonia expands through small perforations or apertures into tubes contained in the said chamber.

An absorber constructed with a concentric corrugated chamber.

Ammonia pumps provided with a chamber through which ammonia liquor from the absorber passes.

An arrangement whereby ammoniacal liquor from the absorber is caused to cool ammoniacal liquor from the boiler.

In Edward Henry Tompkins' patent, which was granted in the latter part of 1887, for improvements in refrigerating apparatus of the kind or class for which previous letters patent were granted to Rees Reece and William Henry Beck, the chief novel points claimed are :—

The placing of the generator within the boiler so as to secure the full efficiency of the heat given off by the steam generated therein.

The combination and connection with the main gas pipe from the generator, of a vessel doing the triple duty of heater, rectifier, and analyser; which vessel consists of an iron tank with an arrangement of tubes, and a sealed joint or joints at the base through which the gas rises.

An improved form of condenser, consisting of an ordinary condenser of the multi-tubular pattern, wherein the tubes are passed through a tube plate and expanded in the usual manner, but having in addition horizontal partition plates of metal at the alternate ends of the tubes, whereby the ammonia is caused to travel backwards and forwards along the alternate layers or sets of tubes, and thereby to receive the full benefit of the cold of the condensing water. By the removal of the end covers, moreover, each layer or set of tubes is rendered readily accessible for cleaning or repairs.

A cooler or refrigerator comprising a system of horizontal tubes placed in a large tank, within which latter a solution of chloride of calcium is caused to circulate so as to secure an equable temperature throughout the entire length of the tank.

An absorber, wherein provision is made for intimately mixing the ammonia gas from the refrigerator or cooler, with ammonia liquor, cooled, firstly, by passing it through a small cooler, and secondly by bringing it in contact with a series of tubes through which water is made to circulate, thereby effecting a considerable gain in the working of the apparatus.

An ammonia pump provided with a stuffing box wherein is inserted a hollow steel or iron ring of suitable dimensions, to which ring is connected a pipe leading to a receiver having a glass gauge to show the height or quantity of liquor ammonia which has escaped past the first series of packing, and is contained therein. From this receiver a pipe fitted with suitable stop-cocks or valves leads to a small hand-force pump or compressor of the ordinary type, so that by opening and closing the said stop-cocks the escaped liquor can be withdrawn into the pump or compressor, or forced back into the generator, as may be desired.

The provision of means whereby the ammonia liquor from the absorber is passed through a coil contained in the compound vessel doing triple duty as heater, rectifier, and analyser, and consequently enters the generator at a high temperature, and the temperature of the ammonia gas on its way to the condenser is likewise reduced. The condensation from this ammonia gas which occurs in the rectifier and analyser, is conveyed back to the generator by gravitation; the above-mentioned compound or triple vessel being situated above the level of the said generator, and the pressure in both vessels being equal.

A small cooler wherein the weak liquor ammonia coming from the generator in its heated condition, is reduced to a state of comparative coolness, by contact with tubes cooled by a circulation of cold water, to which water may be added, if required, waste ice to increase its cooling capacity. The advantage claimed for thus reducing the temperature of the weak ammonia solution, is that its power of absorbing the ammonia gas from the cooler or refrigerator is thereby greatly increased.

The patent granted to Edmund Lionel Pontifex in 1887, subsequently to both those just mentioned, for improvements in cooling and refrigerating machines of the class described in the specification of former letters patent, granted to H. F. Stanley, in 1875, lays claim to the following :—

The method of mounting the condenser coils upon brackets projecting inwards from the side of the cistern, and retaining them in position by means of uprights extending vertically from these brackets; some of which uprights are extended above the tops of the condenser coils for the purpose of supporting the rectifier coil, and also for carrying a vertically arranged cylinder occupying a space in the centre of the rectifier coil, and extending to above the level of the overflow from the cistern. The object of this cylinder is to ensure that the cooling water, that rises up through the cistern, should flow only through the annular space or clearance situated between the exterior surface of the said cylinder and the inner surface of the cistern, and thus cause it to act in a more efficient manner to cool the rectifier coil which is contained in this space or clearance.

An arrangement for ensuring an uniform action taking place in all the concentric coils of the condenser, and causing the liquid coming therefrom to be of the same temperature, consisting in spacing the outer coils vertically further apart than the inner coils, so that the increased diameter of the outer coils is compensated for by the greater number of the inner coils.

To provide for the more perfect regulation of the admission of the anhydrous ammonia liquid to the cooler, which requires very fine or minute adjustment, a stop-cock is provided with a plug through which, in addition to the way or passage which is usually formed therein, there are, at the sides of this way or passage, other narrow passages which, when the said stop-cock is partially turned on, allow of a small and easily regulated quantity of liquid or fluid being permitted to pass; whilst, on the other hand, it likewise admits of a large volume of the said liquid being allowed to pass quickly, whenever the cock is turned full open, as is sometimes necessary for the purpose of clearing the small passages by blowing out any obstructions which may lodge therein and choke them.

The insurance of a more effective absorption of the gas, by so arranging the absorber that the weak ammonia liquor or solution is made to fall in the form of a shower on to the surface of a tray, which latter is provided with small holes or perforations arranged in concentric circles. Through these holes the said weak ammonia liquor percolates or drops down on to the tops of the coils of cooling pipes, trickling slowly from coil to coil until it reaches the bottom of the absorber, from which latter it is sucked by the ammonia pump through a pipe fitted at its inlet end or extremity with a perforated strainer or guard, in order to prevent the said ammonia pump suction pipe from becoming accidentally choked or stopped up by any foreign bodies.

In order to enable the interior of any of the coils of pipe in the absorber being readily cleared of any deposit, suitable means are provided for admitting of a pump cylinder being easily attached to the outlet of each of the said coils. This cylinder is fitted with a piston which, by means of a piston rod extending therefrom, can be jerked or moved suddenly and violently to and fro, whilst the cooling water is flowing through the coil. The shock thus caused liberates any scale that may have become deposited inside the coil, and the said scale is carried off by the flow of the condensing or cooling water.

An improved method of forming gas-tight joints, for use wherever the end of a coil or of a pipe is to be secured to the sides or ends of any of the vessels or chambers, is moreover set forth and claimed. A nut is screwed on to the pipe on either side of the plate, and on one or both sides of the said plate a circular recess is formed around the said pipe. Into this recess, and around the pipe, is inserted a packing ring or insertion of india-rubber or of any other suitable material, which ring is circular in transverse section. The nut screwing on the pipe is likewise shaped circular at one end so as to enable it to enter and fit into the said recess, or in some instances a washer, so formed, or dished or hollowed out, that when forced against the said packing ring it will cause it to press inwardly against the pipe, is interposed between the nut and the plate. In this manner a perfectly gas-tight joint, capable of withstanding considerable pressure, is formed, the india-rubber or other packing ring or insertion being firmly held in position so that it cannot escape from the pressure that is put upon it.

The Pontifex ammonia absorption machine has been further improved by Wood, and the Pontifex-Wood apparatus, as at present constructed, is probably as near to perfection as can be attained in machines of this class.

Fig. 39 is a perspective view, showing in elevation the general arrangement of a machine of the Pontifex and Wood type, which comprises a generator, a separator, a condenser, a refrigerator, an absorber and an economiser, all of which are fitted with the latest improvements.

Referring to Fig. 70, page 190, and Fig. 74, page 200, which views show two applications of the said machine, A is the generator, B is the separator, C is the condenser, D is the refrigerator, E is the absorber, and G is the economiser. The ammonia pumps shown in Fig. 39 are of the original pattern employed; those illustrated in Figs. 70 and 74 are of the latest design, the construction of which will be more clearly understood from the enlarged views, Figs. 40 and 41.

The generator A consists of an horizontal cast-iron cylindrical vessel, containing a coil of steam-pipe adapted to be heated by direct or live steam from the ordinary steam boilers, and into which the charge of commercial ammonia is inserted.

The separator B, which is connected to the top of the generator by suitable flanges, and arranged vertically, and at right angles to the latter, is so constructed that any aqueous vapour that rises with the vaporised or gasified ammonia from the generator, will be arrested or trapped by a suitable arrangement of baffles or checks, and is returned into the said generator; the practically anhydrous ammonia passing through a pipe from the top of the separator to the condenser D.

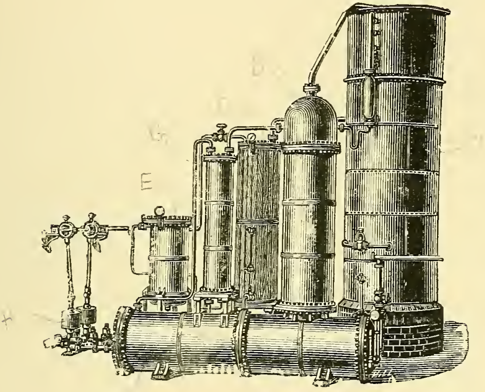


Fig. 39.

In the condenser D, which consists of a number of coils of pipes enclosed in a wrought-iron vertical cylinder which is constantly kept full of cold water in circulation, the anhydrous ammoniacal gas or vapour is condensed and liquefied by the pressure caused by its own accumulation.

The liquid ammonia, which leaves the condenser at a temperature of between 70° and 80° Fahr., next passes into the cooler or refrigerator E, which is a vertical cast-iron vessel fitted with coils of wrought-iron pipes, through which a circulation of water or brine is kept running. In this cooler or refrigerator the said liquid ammonia instantly expands, and again takes the form of gas or vapour. During this expansion its sensible heat becoming latent, as already stated, its temperature is reduced instantly to from 10° to 20° Fahr., or considerably lower if required, and the water, or where employed for ice-making, the brine is reduced or cooled down to any predetermined temperature.

After performing its cooling office in the refrigerator D the ammonia gas or vapour is led through another pipe into the absorber E, wherein it comes into contact with, and is taken up and absorbed by, the water from which it was first eliminated in the generator A, the strong solution thus formed being drawn off by the ammonia pumps F and forced back through the economiser or heater G (wherein its temperature is raised by the water which is passing from the generator into the absorber) into the generator A to be re-evaporated.

The improved ammonia pumps, which are of a patented design, are mounted in A frames, as shown in Fig. 70, and when employed with a brine circulation, a brine pump is also attached to the outside of one of the said A frames, and is driven by means of a disc crank fixed upon the shaft carrying the eccentrics for working the ammonia pumps.

One of the ammonia pump cylinders is shown in side elevation, and vertical central section, in the enlarged views Figs. 40 and 41. As will be clearly seen from the sectional view, Fig. 41, the pump is of the piston type and double-acting.

A great advantage in having two ammonia pumps is that they can be so arranged, that, if necessary, one of them can be shut off for repairs or overhauling, whilst the other is continued in work.

The method of working the Pontifex-Wood improved ammonia absorption machine is as follows:—

All connections being properly made, and the generator filled or charged, with the ordinary ammoniacal liquor of commerce, up to the proper level, as indicated by the gauge attached thereto, a little steam is admitted to the coil of pipes inside the said generator, so as to raise just sufficient pressure of gas or vapour to expel all the air from the apparatus through an escape valve provided for that purpose in the absorber.

As soon as all the said air is thus expelled, the full pressure of steam is turned on to the heating coils in the generator, and the ammonia in the solution, being extremely volatile, is instantly driven off in the form of gas or vapour, and passes up through the separator, where any aqueous vapour is arrested, and returned to the top of the condenser; the aqueous portion of the ammoniacal solution remaining behind in the generator.

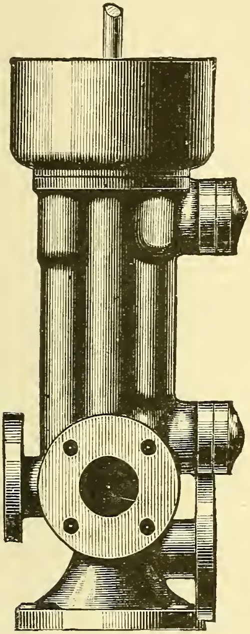


Fig. 40.

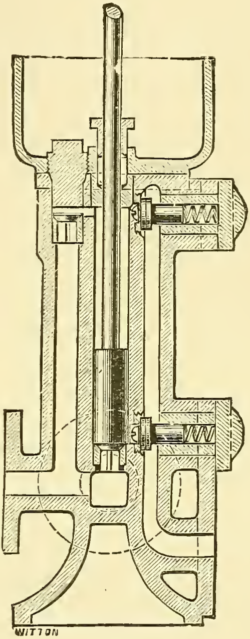


Fig. 41.

The condensing water is admitted at the bottom of the condenser and is taken off at the top, the ammoniacal gas or vapour taking the opposite course and passing downwards through the coil of pipe therein, the upper portion of which coil is provided at intervals with traps or pockets, and is known as the rectifier. During its passage through this coil the gas or vapour is reduced in temperature by the condensing water, and any watery particles that may have escaped the separator, and been carried over with the ammonia, are caught in the above mentioned traps or pockets, and are immediately passed out of the coil and returned to the said separator, through the connection shown in the drawing. After passing the lowermost trap or pocket the ammoniacal gas or vapour is quite dry or anhydrous, and it is the practically perfect reduction thereof to this condition that constitutes the chief advantage of the Pontifex-Wood improved machine.

The dry or anhydrous ammoniacal gas or vapour now continues to descend the coil in the condenser, until, by reason of its accumulation, it reaches a pressure at which it becomes liquefiable, the said liquefaction being greatly forwarded by the reduction of temperature effected in the said condenser by the constant circulation of the cooling water. The apparatus is so constructed and regulated, that, as the gas or vapour becomes liquefied, the product of liquid anhydrous ammonia passes into the refrigerator, wherein it vaporises at the ordinary atmospheric pressure, at a temperature as low as —28° Fahr., and at the moment it thus changes its form it absorbs and renders latent a very large amount of heat, as has been already mentioned.

The water or other liquid to be cooled is passed direct through the coil arranged in the refrigerator; or, where ice-making is carried out, a strong solution of chloride of calcium or brine is passed through it, cooled to the requisite low temperature, and pumped into the ice-making or freezing tanks.

The ammonia, which has now again assumed a gaseous form, passes from the top of the cooler or refrigerator into the absorber, which latter is connected to the bottom of the generator, through a suitable pipe, the pressure in the latter forcing a constant stream of the water left in it at starting into the absorber, where this weak solution greedily absorbs or takes up the gas coming from the refrigerator, and the strong solution thus formed, which is similar to that first placed in the generator, is drawn off by the ammonia pumps.

The strong rich solution is then forced through a coil of pipe in the economiser or heater into the top of the separator, wherein it passes down through a succession of trays, which latter are heated by the hot vapour or gas ascending from the generator and: he ammonia is once more separated from the water in which it is dissolved, the solution gradually becoming weaker, until it finally falls back into the generator almost entirely exhausted of ammonia.

As in Carre's apparatus the complete process forms, it will be seen, a continuous closed cycle, the changes from liquid to gas and *vice versâ* being constantly repeated.

Theoretically the only outlay for working the machine, outside the small amount of oil required for lubricating the moving parts and the labour, is that entailed for the coal or other fuel consumed in raising steam for heating purposes, where exhaust or waste steam is not employed, and for supplying the small steam-engine requisite to drive the ammonia pumps; in cases, however, where water has to be paid for, there is an additional outlay for the water that is used for condensing and other purposes. The boiler power required, where direct or live steam is used, varies from 2 horse-power in the smaller machines, which are capable of performing work equal to the reduction of 225 gallons of water 10°, or of 60,000 cubic ft. of air 20° Fahr. per hour, or of an ice equivalent melted per 24 hours of 1½ tons; up to 15 horse-power in the larger sizes adapted to so treat 8,000 gallons of water, or 1,900,000 cubic ft. of air, or of an ice equivalent in tons melted per 24 hours of 50 tons. In like manner the indicated horse-power that is necessary for driving the ammonia pumps will run from one, in the small machines, up to six in the larger sizes; and the amount of condensing water at 50° Fahr. from 100 to 3,000 gallons per hour.

In practice a certain amount of the ammonia is always unavoidably lost by leakage, even under the most favourable circumstances. The amount of ammonia that thus goes to waste and has to be replaced depends chiefly upon the care taken in packing the ammonia pumps, but under average conditions it usually varies from 240 to 400 lbs. per annum. The price of the ordinary commercial liquor ammonia used in the machine is from 3d. to 4d. per lb. In some exceptional cases, however, machines have run in a satisfactory manner for two or three years without any additions of ammonia having been made.

Other refrigerating machines acting on the above principle, of which mention may be made, are those of Hill, Seeley, and another one of French origin.

A number of British patents have been obtained by Frederick Barker Hill, both singly and in combination with others, for improvements in ice-making and refrigerating machinery. No. 3427 of 1876, Nishigawa and Hill; No. 6808 of 1885, Hill and Gorman; and No. 15914 of 1886, Hill and Gorman, contain certain improvements in absorption machines, the latter patent comprising mainly improved means for heating the ammonia boiler and for the formation of cold stores for refrigerating purposes. Hill, No. 13487 of 1887, describes a refrigerating machine with mercurial pump, wherein mercury is employed for drawing air or other gas or vapour into and discharging it from one or more chambers. It is stated that the mercury acts as a seal to close the aperture of the suction pipe, and that, consequently, the use of a suction valve can be dispensed with. This pump may be adapted for use with an apparatus such as described in the previously mentioned patent.

No. 17071 of 1888, Hill and Sinclair, contains a description of a refrigerator or ice-making machine mounted upon road or travelling wheels, and provided with suitable means whereby motion may be transmitted to its driving-shaft from one of the said wheels during transport.

No. 20811 of 1889, Hill and Sinclair, contains certain improvements in the absorption machine described in No. 15914 of 1886. The ammonia boiler or still is formed in this case of two horizontal tubes connected by suitable pipes which extend longitudinally within the said tubes. The horizontal parts of the said pipes are perforated at their upper sides to ensure uniformity in the action of the apparatus. In combination with the refrigerating apparatus are employed two slabs or tables formed of metal or other suitable material of good thermal conductivity, beneath which circulates brine or other non-congealable liquid for conveying the cold from the refrigerating tubes or chambers to the slabs or tables. These cold slabs or tables are adapted for facilitating and expediting the manufacture of chocolate, confectionery, pastry, and other substances which are formed in moulds, and which can be manipulated upon the said slabs or tables.

Hill, No. 16253 of 1889, describes an improved refrigerating and ice-making machine, adapted to work on the intermittent ammonia-absorption process. The main features of the invention consist in the production of cold by this method, wherein impoverished ammoniacal liquor from the ammonia boiler is caused to pass into one or more supplementary or auxiliary absorbers, in which the ammoniacal gas is subsequently absorbed, and from which the said liquor together with the gas absorbed thereby is then returned to the ammonia boiler.

In ammonia-absorption refrigerating and ice-making machines as constructed before the date of this invention, it was necessary, after the distillation of the ammonia, to reduce the temperature of the liquid in the boiler until the pressure became sufficiently diminished to permit the vaporization of the liquid ammonia in the refrigerator, and until the liquid in the boiler was sufficiently cool to permit the absorption of the ammoniacal gas thereby. This cooling of the said liquid necessarily occupied a considerable space of time. Besides, in many of these refrigerating and ice-making machines the absorption of the ammoniacal gas took place only at the surface of the liquid in the boiler, and was necessarily a slow process, the liquid being of higher temperature at the surface than at any other part thereof, and having its temperature raised at the surface by the condensation of the gas.

The inventor claims to have discovered that, by employing one or more separate or auxiliary absorbers, which can be put in communication with the boiler, the cooler or condenser, and the refrigerator as required, and in which the ammoniacal gas can ascend through a body of liquid, he can very rapidly diminish the pressure in the ammonia boiler by absorbing the gas from the boiler, the rectifier, and the condenser in the absorber or absorbers; and is enabled to effect the absorption of the ammoniacal gas from the refrigerator, either in the supplementary or auxiliary absorber or absorbers or in the boiler, immediately or very soon after the distillation, thus greatly expediting the production of cold by the machine.

Fig. 41*a* is a front view partly in section, and Fig. 41*b* is an end view of Hill's refrigerating apparatus provided with a supplementary or auxiliary absorber.

A indicates the ammonia boiler, B the separator or rectifier, C the cooler or condenser, and D the refrigerator. E is the supplementary or auxiliary absorber, which is connected with the boiler A, the condenser C, and the refrigerator D by pipes F, F^1, F^2, F^3, fitted with stop-cocks or valves G, G^1, G^2, G^3. By the manipulation of these cocks as may be required, the impoverished ammoniacal liquor from the boiler may be introduced into the absorber E after the distillation of the ammonia, and the liquid charged with gas by absorption may be caused to return from the absorber to the boiler. Thus when the liquid anhydrous ammonia has been collected in the refrigerator D, the cocks G^2, G^3 are closed and the cocks G, G^1 partly opened, so as to admit of the weak or impoverished solution from the boiler A, or a sufficient portion of it, being forced into the absorber E; the cock or valve G^1 is then closed, and the cock G^2 is opened to rapidly relieve the pressure in the condenser, rectifier, and boiler, by allowing the gas therefrom to become absorbed by the weak solution in the absorber E. As soon as the solution in the boiler is sufficiently cooled to permit reabsorption of the gas thereby, the boiler is placed in communication with the refrigerator by opening the cocks or valves G^1, G^3. The ammonia solution from the absorber E will be returned by gravity or in any other convenient manner into the ammonia boiler A, through the cocks G, G^1, when required.

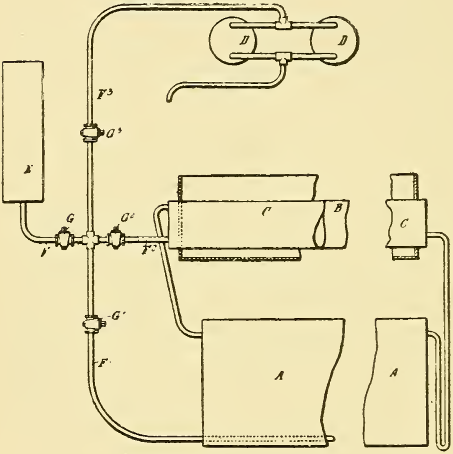


Fig. 41*a*.

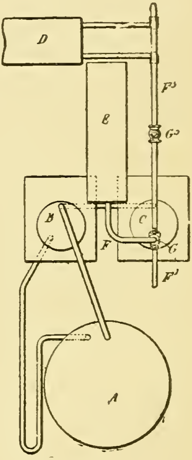


Fig. 41*b*.

Instead of placing the refrigerator D in communication with the boiler A, it may be so connected with the supplementary or auxiliary absorber E, thereby permitting the vaporization of liquid ammonia in the refrigerator, and the absorption of the ammoniacal gas by impoverished ammoniacal liquor previously introduced into the said absorber E from the ammonia boiler. While the vaporization of the ammonia in the refrigerator is thus proceeding, the weak solution in the ammonia boiler may be cooled, after which the refrigerator may be put into communication with the said boiler.

In Fig. 41*c* is illustrated the combination of an ice-making apparatus, comprising a refrigerator D^1, with an apparatus constructed as above-mentioned for cooling a room or chamber, and with one or more supplementary or auxiliary absorbers E, E^1. The auxiliary absorber E^1 is connected with the refrigerator D^1 and with the cooling apparatus by pipes F^4, F^5, provided with stop-cocks or valves G^4, G^5, so that the absorber E, E^1 can be used separately or simultaneously, either with the cooling apparatus or with the ice-making apparatus.

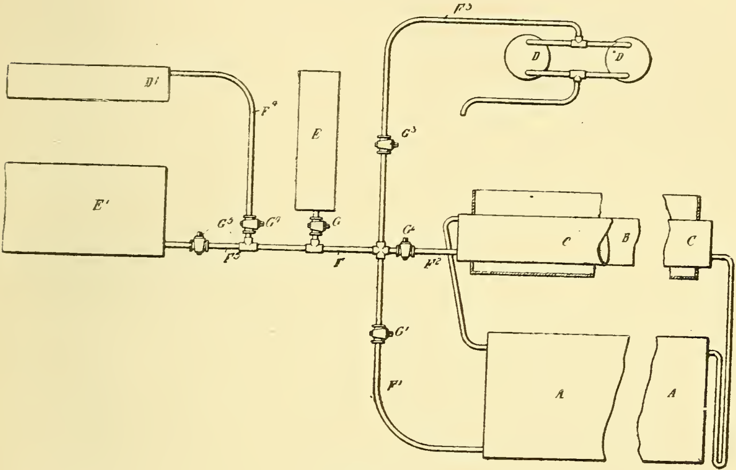


Fig. 41*c*.

Fig. 41*d* illustrates another arrangement wherein a single auxiliary absorber E is used in combination with a cooling apparatus and an ice-making apparatus, or with two or more sets of cooling or ice-making apparatus.

By the above arrangements the cooling of rooms or chambers and the making of ice can be very effectually performed either separately or simultaneously. If desired, suitable provision may be made for effecting the return of the liquor from the absorber or absorbers to the boiler by the pressure from the refrigerator or in any other convenient manner.

In Fig. 41*e* is shown an entire cold storage apparatus having the said inventor's present improvements applied thereto. L is a coil boiler for heating the solution in the ammonia boiler A, with which the said coil boiler is connected through the medium of a separator M. N is the room or chamber to be cooled. In the upper part of this chamber is arranged a tank H containing the non-congealable liquid in which the refrigerator tubes D are immersed. The bottom of this tank is made with corrugations or **V**-shaped portions H^2, and gutters or channels K are arranged beneath the **V**-shaped portions for the purpose of collecting any dripping therefrom

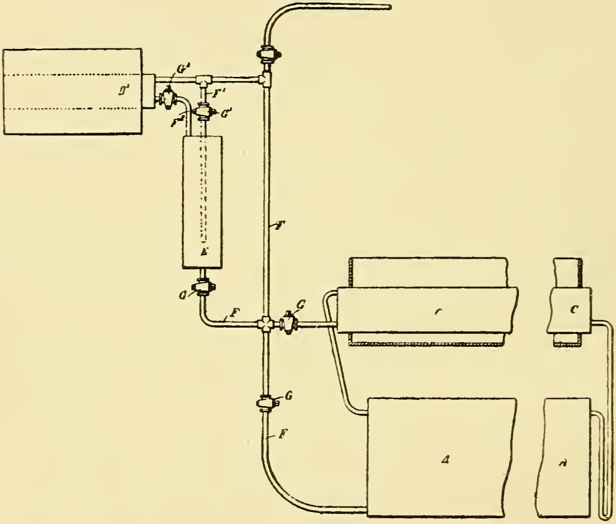


Fig. 41*d*.

In Seeley's absorption machine anhydrous ammonia is also the agent or medium employed. The novel feature in his apparatus is the arrangement of the generators, which can be alternately heated by means of steam coils, and which are charged with dry

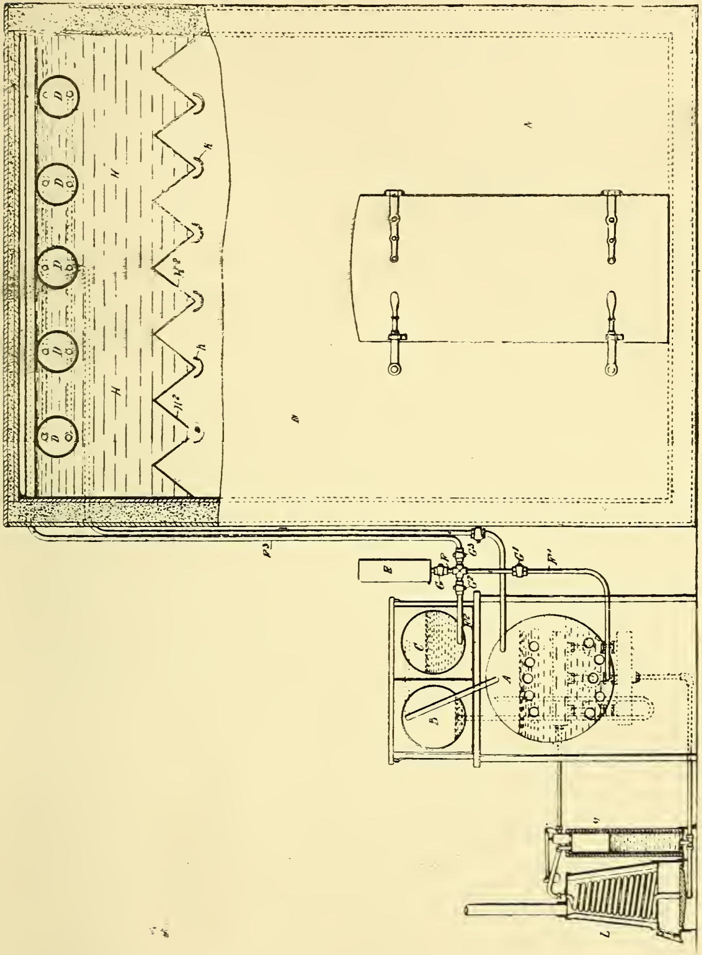


Fig. 41e.

pulverised chloride of calcium. On heat being applied to one of the said generators the liberated gas rises, is passed through a condenser, expanded and evaporated in a refrigerator, and lastly returned to the second generator, wherein it is taken up or absorbed by the dry chloride of calcium. Heat is then applied in its turn to the said second generator, and the operation is reversed, and so on *ad infinitum*, the said generators alternately becoming absorbers.

In the French machine the refrigerating agent used is amylic ether, which is capable of dissolution under the action of sulphuric acid. The ether is first extracted from the acid under the action of heat, is liquefied under a considerable pressure, and is passed into a suitable receiver or container, from which it can be admitted by means of a stop-cock or valve to spiral ducts surrounding a cylinder or vessel containing the water to be frozen, wherein by its expansion into gas it abstracts the heat, as already mentioned with respect to other machines of this class. The vapour is then returned to a vessel containing sulphuric acid, by which it is once more absorbed, to be subsequently again expelled or driven off therefrom by heat, and to pass through the same cycle of operations as before.

Those machines wherein a refrigerating agent is used, which consists of a compound or dual liquid, one of which is capable of liquefaction at a comparative low pressure, taking the other or second one into solution by absorption; or, in which the refrigerating agent is liquefied partly by absorption and partly by mechanical compression, are said to work on what is usually known as the binary or dual absorption system.

Johnson and Whitelaw's machine is designed for use with bisulphide of carbon. This refrigerating agent is first vaporised, and with the air introduced by the force-pump is passed through chambers charged with oil, by which the bulk of the moisture of the gas is taken up or absorbed, provision being made for extracting that of the air by passing it through a pipe leading to the air-pump, which pipe is partially filled with chloride of calcium.

Pictet's refrigerating agent consists in a combination of carbon dioxide and sulphur dioxide, which forms a liquid having a vapour tension much less than that of carbon dioxide, or even of sulphur dioxide, at temperatures above 78° Fahr. An improved cooler or refrigerator patented by Pictet in 1887, which can be employed either with a compression or an absorption machine, has been already briefly described on page 68.

In Nicolli and Mort's machine the refrigerating agent used is ammonia. The apparatus consists essentially in three main parts, viz., an evaporator, a pump, and an absorber, and the operation is as follows :—

The evaporator or generator is first charged with strong ammoniacal liquor, vaporisation being effected by reducing the pressure through the action of the pump, and heat being abstracted thereby from the liquor to be cooled in the usual manner; the evaporator or generator thus performs a dual office inasmuch as it also acts as the refrigerator.

The weak or exhausted liquor passes out at the bottom of the evaporator and is conducted through suitable pipes to the pump, where it meets the ammonia gas or vapour, and, together with the latter, is pumped into coolers, sufficient pressure being applied to liquefy the vapour, and cause a re-dissolution thereof; the strong solution is then returned to the evaporator, passing on its way through an interchanger wherein its temperature is reduced by that of the cold, exhausted, or weak liquor also passing there through to the pump.

De Motay and Rossi use as a refrigerating agent a mixture of common ether and sulphur dioxide or sulphurous acid (SO_2), which compound is known as ethylo-sulphurous dioxide. It was found by experiments that, at ordinary temperatures, liquid ether has the power of taking up or absorbing large volumes of sulphur dioxide, amounting to as much as three hundred times its own bulk, the tension of the vapour given off from the dual liquid being below that of the atmosphere at a temperature of 60° Fahr.

The two liquids are evaporated in the refrigerator by reducing the pressure through the action of the air-pumps. The pressure in the condenser is at no time in excess of that required to cause a liquefaction of the ether. The capacity of the pump need not be so large as that which would be necessary were ether employed by itself, but it is necessarily somewhat more than that demanded for pure sulphur dioxide.

De Motay and Rossi's apparatus is said to have given very good results in the United States, where it has been in use for the past twelve years.

CHAPTER VIII.

THE ABSTRACTION OF HEAT BY FIRST COMPRESSING AIR OR OTHER GAS, COOLING SAME, AND AFTERWARDS PERMITTING IT TO EXPAND, THAT IS FIRST APPLYING HEAT IN ORDER ULTIMATELY TO PRODUCE COLD, OR THE COLD-AIR SYSTEM.

MACHINES constructed on this system operate on a principle which is one of the simplest in physics, viz., that the compression of air or other gas generates heat, and the subsequent expansion thereof cold.

Mechanical work and heat being respectively convertible, it follows that should a gas be caused to perform certain work on a piston during expansion, its store of caloric will be exhausted thereby to a degree equal to the thermal equivalent of the work done, the gas after expansion being at a lower temperature than it was before expansion, that is, provided always no heat is supplied from any other source to restore that so lost.

Machines of this kind or class, although used from time to time for cooling hydrocarbons of a volatile nature, are more generally employed with ordinary atmospheric air only, hence they are commonly known as cold-air machines. Their invention is ascribed to Gorrie, who is said to have designed the first machine of this class in 1849.

In Gorrie's machine the cooling water was injected into the compression cylinder, and brine to be refrigerated or cooled into a jacket surrounding an expansion cylinder. His apparatus consisted essentially of a double-action pump or compressor, a cooler connected with a compressed air vessel or reservoir, and a jacketed auxiliary pump. The operation of the machine was as follows: Water was injected into the compressor cylinder at each stroke, on the side of the piston on which condensation or compression was taking place. The compressed air was then led through a worm or coil in the cooler to the compressed air vessel or reservoir, from whence it was admitted to the auxiliary pump, which latter was driven by the expansion thereof. Through the jacket surrounding this auxiliary pump a circulation of brine or other non-congealable fluid was maintained, which brine was cooled by the expansion of the air in the pump cylinder, and which in turn reduced the temperature of an ice-making tank situated above the latter to the requisite degree.

Imperfect cooling of the air after compression, combined with the damp condition of the said air, caused the failure of this machine to act in a satisfactory manner.

(improved system of Gorrie)

The next advance was made by Dr. Alexander Kirk in 1863. Dr. Kirk's machine had three cylinders, viz. one for compressing the air, and two for the expansion thereof, all three of which had reciprocating motion imparted to their pistons by a single crank. One of the expansion cylinders was connected to each end of the compressor, thus actually forming two distinct systems. The pistons of the expansion cylinders were hollow and were perforated by a number of small holes, and fitted internally with filters consisting of several layers of very fine wire gauze, the reciprocating action of the said pistons alternately causing air to pass through these perforations and filters, and drawing back the said air.

The operation of the machine was as follows:—The air was compressed between the piston of the compressor, during its stroke in one direction, and one of the expansion cylinder pistons, the heat of compression being carried off by a suitable water jacket provided round the said expansion cylinder. On the descent of the expansion piston, the air passed through the perforations, parting with some more of its heat whilst traversing the sheets or layers of wire gauze, and finally expanding in the upper portion of the said cylinder, and performing work upon the descending piston. The cold air was caused to abstract heat from brine which circulated round the top cover of the expansion cylinder, and through a number of hollow corrugations. The operation of the second or other expansion cylinder which was connected to the opposite end of the compression cylinder was, of course, identical.

This machine was worked up to a pressure of 200 lbs. per square inch, and a temperature of —39° Fahr. was obtained.

In 1869 a cold-air machine adapted to compress air in stages was invented by Marchant. In his apparatus the air passed first into one cylinder wherein it was compressed, and was then exhausted into another cylinder of smaller dimensions in which it was still further compressed.

Giffard's first (1873) machine was so arranged that the air was mingled in the compression cylinder with sprayed water, which became vaporised by the heat of compression, and rendered the said heat latent. The discharge valve from the expansion cylinder was situated in the piston, and was so adjusted that it would open automatically upon the pressure in the cylinder falling below a predetermined point, the air then passing through to the other side of the piston, and afterwards to the refrigerator.

In the same year (1873) Postle designed a machine which was practically a modification of Kirk's cold-air machine. As in the latter the compression cylinder was connected at each end to an expansion cylinder, but the pistons of the expansion cylinders, which were each composed of an upper part of smaller diameter and a lower part of larger diameter, were so arranged, that when the compressor piston started upon its stroke in either direction, the valve connected with that end of the compressor was forced upon its inner seat, and the air pressure moved that particular expansion piston to the inner end of its cylinder, the said valve being opened outwardly, however, before the end of its stroke by its projecting spindle striking against the inner cylinder end, and the latter part of the compression taking place in a small space cooled by a water jacket, and wherein the heat of compression was carried off. Upon the reverse stroke of the piston the said valve was raised against its outer seat by the current of air passing through the circumscribed passage around it, and a partial vacuum having been formed above the small portion of the expansion piston, the latter was moved outwardly by the unbalanced pressure in the expansion cylinder, the cooled compressed air passing through the piston to the inner portion of the cylinder.

Similarly, however, to on the inward, the valve was opened before the end of the outward stroke of the piston by the other extremity of its spindle coming in contact with the top of the cylinder, but this time outwardly, and the air in the said inner portion thus expanded, and at the same time performed work on the compressor piston. The air reduced in temperature during expansion cooled brine circulating through a jacket which also formed the inner cylinder head of both expansion cylinders, the latter being placed end to end.

The great improvement in this machine was that the bulk of the compression was performed during the period wherein the compressor was in connection with the water-cooled spaces, and most of the expansion whilst the said compressor was exhausting from the spaces in contact with the brine circulation.

A very decided advance was next made by Windhausen, for whose improved cold-air machine a German patent was granted about this time. The characteristic feature of his apparatus, was the improved method by which the air, that had become heated by compression, was first cooled in a series of condensers or coolers by means of a circulation of cold water, and was then passed into a chamber where expansion or dilation took place behind a piston. That is to say, in point of fact expansion was effected by the simultaneous action of the machine before the said air was utilised for refrigerating purposes.

The original Windhausen cold-air apparatus is shown in plan and side elevation in Figs. 42 and 43, by which the principle of the machine is sufficiently clearly illustrated to render an extended description thereof unnecessary. On the drawing, A indicates the compression cylinder, B the expansion cylinder, C the steam engine or other motor for operating the machine, and D, D^1, D^2, the condensers or coolers through which a constant current of cold water is maintained for cooling purposes. The cylinders A and B are arranged tandem fashion, and are worked simultaneously from the engine crank-shaft E, through the crank E^1, and connecting rod F.

The air enters the compression cylinder A through the inlet A^1, as indicated by the arrows, and after compression the current passes through the pipe A^2 to the first condenser or cooler D, from which it is conducted successively to the coolers D^1, D^2, and from the latter to the expansion cylinder B, as shown by the arrows.

Within the coolers or condensers D, D^1, D^2, are arranged a series of pipes through which the blast passes, and around which a constant circulation of cold water is kept up, the latter entering the cooler D^2 at a suitable inlet, and flowing through the said coolers in the opposite direction to the compressed air. A portion of the heat that has been imparted by compression is thus extracted, and the compressed air, which is at a temperature only a few degrees above that of its natural state, is led into the expansion cylinder B, wherein the expansion is effected under a gradually decreasing pressure, which latter is automatically regulated by valves operated by the simple expansive force of the compressed air itself.

Were the air to be dilated to its normal volume it is clear that an amount of heat equal to that which has been abstracted or

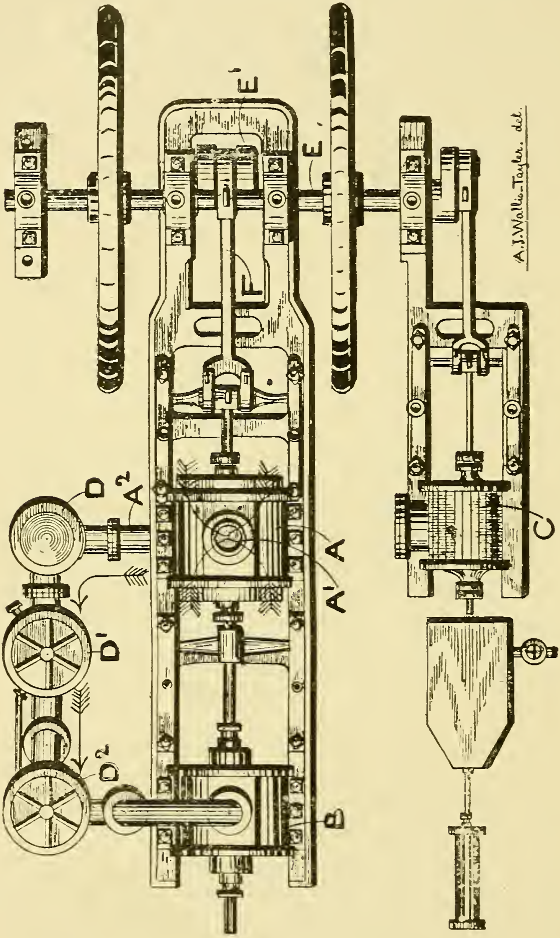
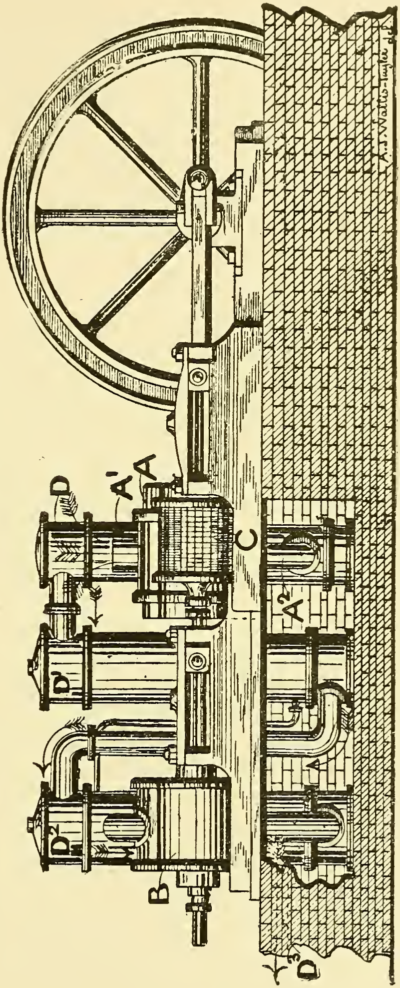


Fig. 42.

taken up by the cold water in the coolers would be required ; as this, however, can be only partially returned by the small volume of air within the expansion cylinder, a low degree of temperature is immediately obtained, which is more and more reduced with each stroke of the compressor, as the original air in the expansion cylinder is replaced by the cooled compressed air.



From the compression cylinder B the air is conducted to the space to be cooled, escaping with a velocity sufficient to admit of the current being conducted for 300 ft. through a channel 2 ft. in diameter, the temperature at the orifice of the latter being from $-30°$ to $-35°$ Fahr., or from 62° to 67° of frost. It has not been found advisable however, in practice, to employ a conduit of this excessive length.

In the apparatus shown the dimensions of the compression cylinder are such that at each stroke of the piston 35 cubic ft. of air, and at every complete revolution of the engine, 70 cubic ft. of air are compressed, being reduced to the extent of from two and a half volumes to one volume, or to a pressure of 35 lbs. per square inch; thus, at a speed of 36 revolutions per minute, over 150,000 ft. of cubic air will be compressed per hour.

From actual experiments it was found that with the air entering the compression cylinder at a temperature of 80° Fahr., it rose after compression to 205°, thus giving a gain of 125°, inasmuch as this acquired heat is subsequently got rid of in the condensers or coolers and expansion cylinder; and an atmosphere is thus obtained which, whilst under a tension of two and a-half atmospheres, is almost at the same temperature as the air previous to treatment, the expansive force, and effect, of a volume two and a-half times larger, being at the same time retained.

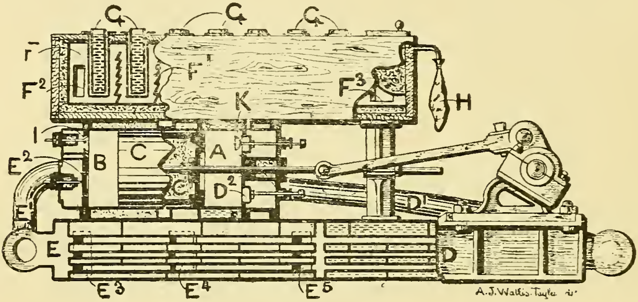


Fig. 44.

Fig. 44 is a vertical central section illustrating a modified arrangement of Windhausen's cold-air machine, wherein a single cylinder is used for compression and expansion, the air being condensed or compressed at one side of the piston, and expanded on the other. Two coolers are provided, situated in the bed of the machine, one of which is cooled by a circulation of cold water, and the other by the expansion of the compressed air. The refrigerator is situated above the compressing and expansion cylinder, and receives the expanding air from the expansion side of the cylinder through a temperature regulator.

In the drawing A is the compression side of the cylinder, and B is the expansion side thereof; C is the piston, which is formed hollow and filled with non-conducting material C^1; D is the cooler, through which a circulation of cold water is kept constantly flowing, and which is connected to the compression side A of the cylinder through the pipe or tube D¹ and valve D², and E is the second cooler, which is connected to the first cooler D and to which a certain amount of the expanding compressed air from the expansion side of the pump is admitted for cooling purposes. The tubes in both the coolers D and E, through which the compressed air passes from the compression side A of the cylinder, communicate through the pipe or tube E¹ and valve E² with the expansion side B thereof.

F is the ice-making tank or refrigerator, and G, G, are the ice-cans or cases. The ice-making tank F consists of a double-cased rectangular wooden box or vessel, the spaces between the outer and inner cases of which are filled or packed with loose cotton, or other suitable non-conductor of heat. The cover, which is formed of a single thickness of wood, is pierced with holes in which are fixed metallic cases or pockets for receiving the ice-cans G. F¹, F¹, are zig-zag partitions arranged between the rows of ice-cans so as to cause the air to come fully into contact with the metallic cases or pockets supporting them. H is an india-rubber bag, which acts to maintain an uniform pressure within the ice-making tank or refrigerator F, by admitting or giving out air in accordance as to whether the pressure happens to be above or below that of the atmosphere. I is a valve which is open during the entire compressing stroke of the piston C, and which communicates through a suitable pipe or tube with the temperature regulator, from which a portion of the expanding air passes to the ice-making tank or refrigerator through a tube communicating therewith through the aperture F², the remainder being delivered through another pipe or tube to the space round the compressed air tubes in the cooler E, through the aperture or orifice E³, with which latter space the ice-making tank or refrigerator is likewise connected through a suitable pipe or tube, and the apertures F³, E⁴. The temperature regulator and pipes or connections are situated at the rear of the apparatus, and are not shown in the drawing. The compression side A of the cylinder is also connected with, and derives its supply of air from, the expanded air space in the cooler E through a suitable pipe opening into the latter at E⁵, and communicating with the former through the valve K.

The operation of the apparatus is as follows, that is to say: The piston C, during its forward or compression stroke, compresses the air contained in the compression side A of the pump cylinder, and under the pressure of the said air the valve

D^2 opens, and the latter passes through the pipe or tube D^1 to the water-cooled tubes of the first cooler D, from which it then passes to the air-cooled tubes of the second cooler E. The cool compressed air next flows into the pipe or tube E^1, and is admitted through the valve E^2 to the expansion side B of the pump cylinder during a portion of the stroke, when the said valve E^2 is closed, and the air expands in the said chamber B during the remainder of the stroke. The cooled and expanded air flows out of the expansion chamber B through the valve I, during the entire return or back stroke of the piston C, to the temperature regulator, from whence a portion of it passes to the ice-making tank or refrigerator F, and the remainder to the space round the compressed air tubes in the second cooler E. On the said return or back-stroke of the piston C, the air in the space round the tubes in the second cooler E is drawn or sucked into the compression chamber A thr ugh the inlet valve K.

The improvements introduced into cold-air machines in 1877 by Bell-Coleman added very considerably to their practical value. This invention comprised suitable means for cooling the air both in, and as it left the compressor, by spray or jets of water, and also for drying it again before it was passed into the expansion cylinder. The latter object was effected by causing it to flow through a set of coils, or pipes, situated in the chamber cooled by the machine; or by providing for exposing these pipes to a current of the used or spent air passing out from the said chamber.

On leaving the compressor the moist air was first passed through a chamber with perforated diaphragms, and was then conducted to the expansion cylinder through coils or pipes which had a very extended surface, and were cooled on the exterior to a lower temperature than that of the cooling water, thus still further reducing the temperature of the air, and inducing a deposition of moisture.

A great objection to this system of cooling by internal injection is the loss occasioned by the saturated condition in which the air, even when employed continuously over and over again, is constantly delivered to the machine.

In 1877 Giffard also greatly improved his (1873) machine, and brought it to the form shown in Fig. 45. In the drawing (which illustrates the apparatus in side elevation, some of the parts being shown in vertical central section) A indicates the compression cylinder and B the expansion cylinder, which are both of the single-acting type, and open at their upper ends; C is the condenser or cooler. The inlet and outlet valves to the expansion cylinder B, as also the inlet valve to the compression cylinder, which, as shown in the drawing, are situated in

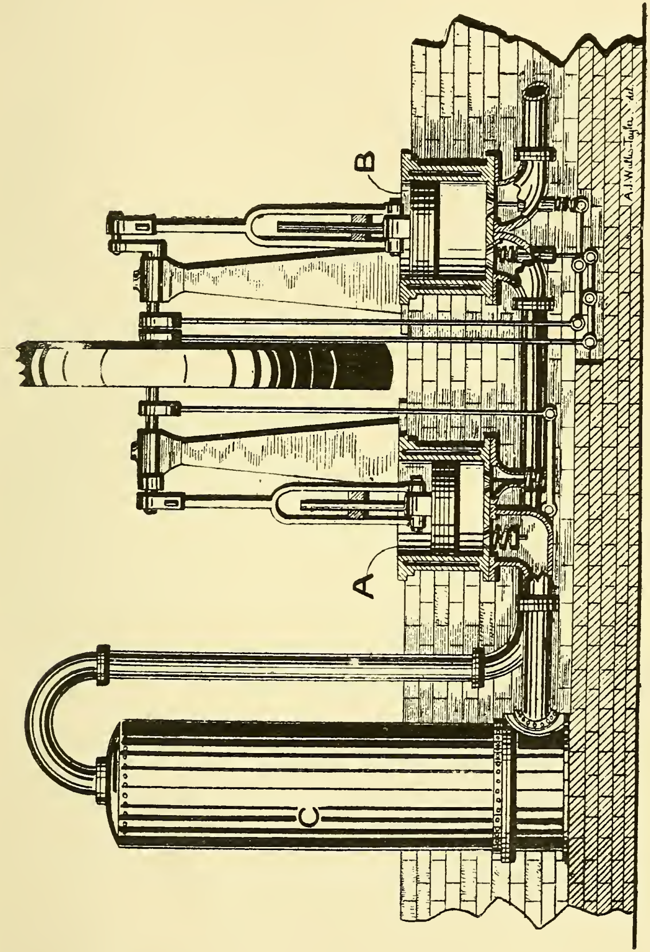


Fig. 45.

the lower ends to the said cylinders, are actuated through cams upon the shaft of the machine. The outlet valve from the compression cylinder A governs the delivery of the compressed air to the lower end of the condenser or cooler C, wherein, after passing through top and bottom chambers or spaces, and a central series or set of vertical water-cooled tubes, it is delivered through a suitable pipe to the inlet valve of the expansion cylinder, from which latter, after doing work upon the expansion piston, during its upward stroke, it is discharged during its return or downward stroke through the outlet valve (shown on the right-hand side) and led away through a suitable pipe to perform its cooling office where desired. The compression cylinder A is jacketed, and the heat generated during compression removed as far as possible by a circulation of cold water.

In operation the air which enters the compression cylinder A through the inlet valve (shown on the right-hand side) is first compressed up to the normal pressure existing in the condenser or cooler C, when the outlet valve lifts and admits of its being passed into the latter, wherein it is cooled and dried by contact with the water-cooled tubes. The valve regulating the admission of compressed air to the expansion cylinder B is so arranged that it will admit to the latter an amount of air equal to that which is being forced into the condenser or cooler C during the downward or compression stroke of the compressor piston, thus tending to maintain an equality of pressure in the said condenser. The pistons are thus constantly moving in opposite directions, that of the expansion cylinder being, however, a quarter stroke in advance of that of the compressor. During the upward stroke of the expansion piston, the inlet valve from the condenser or cooler C (shown on the left-hand side) remains closed, the expanding air performing a portion of the work of driving the machine; whilst on the down stroke the outlet or exhaust valve (shown on the right-hand side) opens, so as to admit of the cooled air passing through the discharge pipe, by which it is led away, as above mentioned, to perform its cooling or refrigerating office where required.

A form of cold-air machine was designed by Hargreaves and Inglis in 1878, wherein they dispensed with the use of separate compression and expansion cylinders, employing instead a single cylinder having two pistons connected by means of a trunk. The inlet and outlet valves, which were of the Corliss pattern, were arranged to be operated through suitable eccentrics on the main shaft of the machine.

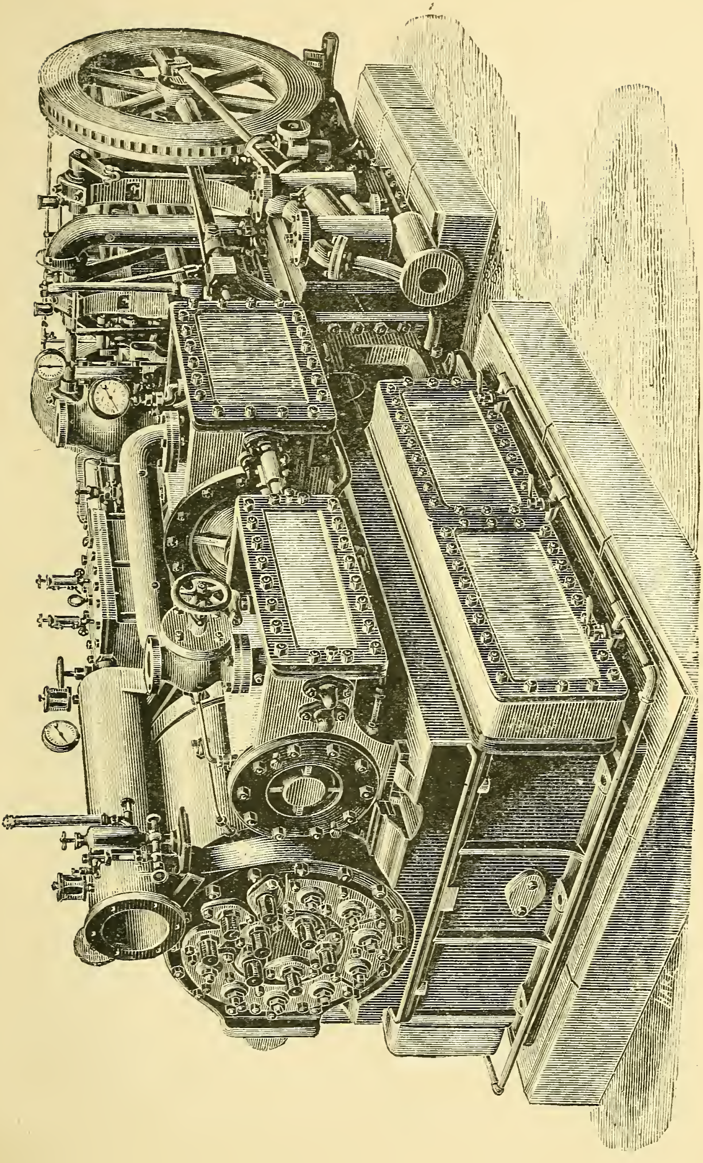


Fig. 46.

In Tuttle and Lugo's machine the air is forced after compression through a set or series of tubes in a cylindrical or tubular chamber or vessel, which is cooled by a constant circulation of cold water, and through a similar set of tubes in a chamber or vessel, wherein the latter are surrounded by a volatile liquid. After leaving this second vessel it is allowed to expand into the refrigerator or ice-making tank, rising through some such volatile liquid as ether or bisulphide of carbon, which is placed in the bottom of the latter, and the said air and the vapour from the volatile liquid fill the interior of the refrigerating chamber surrounding the ice-cans or cases, and freeze or congeal the water therein. A bye-pass is also provided through which the compressed air can be conducted direct to the ice-making tank or refrigerator.

Lugo and McPherson's apparatus comprises a blower, the air from which is forced through a cooler consisting of a chamber filled with some suitable porous material kept saturated with water. The cooled air is then passed into a compressor, the upper part of which is kept full of water, which serves to keep it cool and also to prevent leakage of the said air past the piston. From the compressor the air is led to a cooler, and from this to a compressed air reservoir or vessel, from which latter it is in turn admitted to, and allowed to expand in, the interior of a large ice-making tank or chamber, having non-conducting walls and rails for cars carrying the ice-cans or cases. The piston of the compressor is worked by La Hire's epicycloidal device.

In 1880, Haslam (Sir Alfred Seale Haslam) brought out a cold-air machine of the type usually known as dry air refrigerators, which comprises certain very important improvements on the Bell-Coleman type of machine, which have had the effect of rendering it one of, if not the most successful machines of this class hitherto designed.

Figs. 46, 47, and 48 are perspective views illustrating three different cold-air machines of the Haslam type.

That shown in Fig. 46 is of the horizontal pattern, and is made in sizes adapted to deliver from 20,000 to 30,000 ft. of air per hour. Compound duplicated horizontal machines of heavier build are, however, also constructed, in sizes adapted to deliver from 35,000 to 300,000 ft. of air per hour. The apparatus is driven by a compound condensing engine, and this, together with the air-compressing and expansion cylinders, and the requisite water-pumps, are all mounted upon a cast-

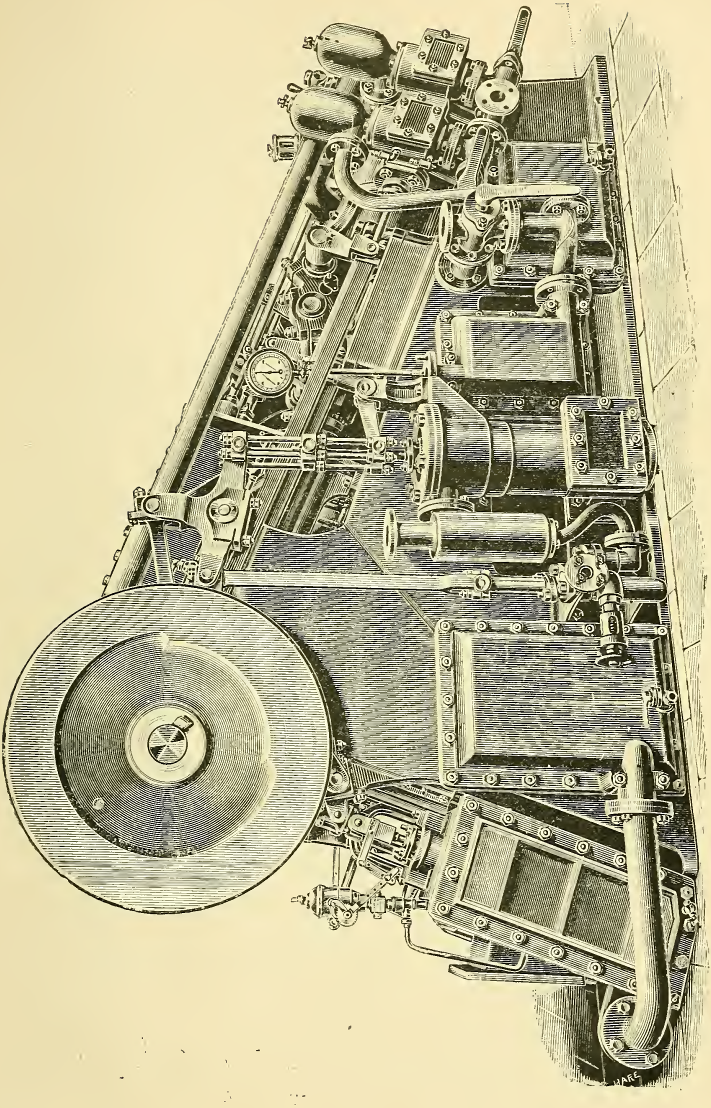


Fig. 47.

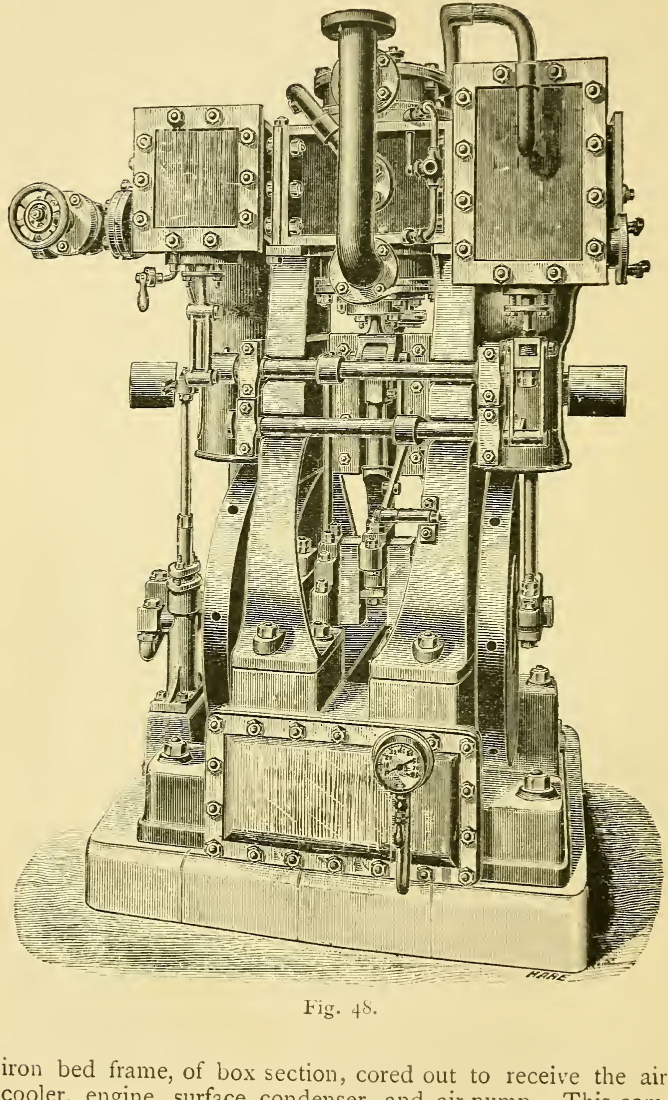


Fig. 48.

iron bed frame, of box section, cored out to receive the air-cooler, engine, surface condenser, and air-pump. This combination of the condenser casing with the refrigerator forms a foundation for the bed-plate of the steam-engine. The feed pumps are bolted on to the side of the bed, and are driven from an overhead rocking shaft, which likewise works the air-pump. Variable cut-off gear is fitted to both the steam cylinder and the air-expansion cylinder, and the pistons of both the compressor and expansion cylinders are directly coupled to tail rods from the steam cylinder pistons. By locating the inlet and outlet valves in the cylinder-covers they are rendered very easy to get at for repairs and other purposes. The height of this machine is such as to admit of its being conveniently placed "between decks" of steamers.

The patent diagonal pattern machine (Fig. 47) is made of smaller sizes, viz., to deliver from 10,000 to 12,000 cubic ft. of air per hour, and where a machine of still smaller capacity is required, one of the vertical pattern, such as that shown in Fig. 48, is preferably used, the latter machines being constructed of sizes to deliver from 2,000 to 6,000 cubic ft. per hour. In the diagonal pattern machine the compound high and low pressure steam cylinders, and the air compressor cylinder, are placed on the top of the bed, the air expansion cylinder is located at the end, and the water, air, and feed pumps are bolted to the side thereof.

The bed is, as will be seen from the illustration, of massive box section, and is suitably cored out to receive the water-cooler tubes, the condenser tubes, and the patent drying pipes, and it likewise supports the main crank shaft bearings. The condenser tubes are fixed in position by means of screwed ferrules, and the air cooler tubes and drying pipes are secured in tube plates by expanding the ends in the usual manner. The several tube plates are provided with covers having ribs arranged for the proper circulation of air and water. As will be seen, the machine is peculiarly compact and self-contained, and the air-pump is arranged vertically, and is worked through a T bob from an eccentric on the crank shaft.

The type of machine illustrated in Fig. 48 occupies but little floor-space, and its height allows of its location "between" decks of small steamers and yachts. The steam cylinder, air-compression cylinder, and expansion cylinder, are mounted vertically upon cast-iron standards, which latter are securely bolted to a cast-iron bed of hollow box section, supporting the crank-shaft bearings and containing the air cooler, and the water-pump is bolted to the base-plate and worked vertically from a crosshead-pin.

The crank-shaft, valve-rods, and connecting-rods, are of mild forged steel, and the slides are of the open type, and easily accessible. A portion of one of the cast-iron standards is made loose so as to admit of the crank being readily removed when desired.

The above machines all have double-acting cylinders. The compressors are either of the water injection type, or of the dry type and water jacketed, discharging into the surface coolers in the beds. When a compressor of the first, or water injection type is employed, the above-mentioned cooler is dispensed with, and a separate water tower is provided. After being cooled in the ordinary way by water, the temperature of the compressed air is still further reduced by passing it through an interchanger, wherein it is subjected to the cooling action of either the spent cold air leaving the enclosed space or chamber where it has been used for cooling purposes, or else of the cold air as it passes out of the expansion cylinder. In the first instance separate boxes containing the drying pipes are provided inside the said cold chamber, in the second case the device is fitted in the forepart of the bed of the machine; the advantage derived from both these arrangements is that a further condensation and deposition of moisture are thereby effected. The exhaust valves of the expansion cylinder are separate from the admission valves, and they are so designed as to afford as few obstacles to the free passage of the air therethrough as practicable.

In the same year (1880) Lightfoot introduced an improved machine, wherein the expansion is performed in two stages. The advantage of this arrangement is that during the first stage of expansion the air can be made to deposit most of its moisture, after which the dry air is further expanded until it attains the required temperature and pressure.

The operation of Lightfoot's machine is as follows:—The compressed air, which is partially cooled, and which when direct atmospheric air is employed is always in a condition of saturation corresponding to its temperature and pressure, is first passed into a small primary expansion cylinder, wherein it is expanded beneath a piston to a pressure that will give a final temperature of about 35° Fahr. By this means almost the whole of the vapour held in suspension in the air is condensed, and in the form of mist is discharged, together with the air, into a separator, upon the surfaces of which the said mist is deposited in the form of water, and, falling to the bottom, is drawn off. From this separator the dried air, which is still at a considerable pressure, is conducted to the second expansion cylinder, in which latter it is expanded down to the pressure of the atmosphere, and passed out cold and practically freed from moisture.

The following table* gives the calculated relative amounts of vapour condensed and deposited in the various stages of cooling, with a machine on the Lightfoot system, capable of delivering 15,000 cubic ft. of cooled air per hour, and dealing with air in a tropical climate, having an initial temperature of 90° Fahr., and fully saturated with vapour:—

	Lbs.	Per hour.	Per cent.
Total amount of vapour entering with the air .		45·36	100·00
Deposited as water in the cooler . . .	33·61		74·10
Deposited as water after first expansion . .	9·26		20·40
Discharged as ice in cooled air	0·93		2·05
		43·80	
Balance, being residual vapour still existing in cooled air		1·56	45

Fig. 49 is a vertical central section through the air compression and expansion cylinders, and the valves of one of Lightfoot's recent patterns of improved cold-air machines, which may be also classed amongst those which have afforded very satisfactory results, even when subjected to very severe tests. A is the compressor, which is of the double-acting type; and B is the expansion cylinder, which is of the single-acting type.

The cylinders A and B, which are arranged tandem style or fashion, and have a common piston-rod, are placed close together, sufficient clearance being left, however, to permit of the inspection or examination of the pistons being conveniently effected. An advantage of this arrangement is that the coldest portion of the expansion cylinder is placed at a distance from the hottest end of the compressor.

The air-valves are circular slides formed of phosphor bronze, and are operated by eccentrics in the ordinary manner. The advantages claimed for this type of valve are, that they admit of the parts being formed very short and direct, are perfectly noiseless in action, and allow of a high piston speed being used without any injurious results. They are said to have been

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* "Proceedings, Institution of Mechanical Engineers," 1881.

found to work very satisfactorily, and to have given no trouble as regards wear, even when in almost constant use for some years.

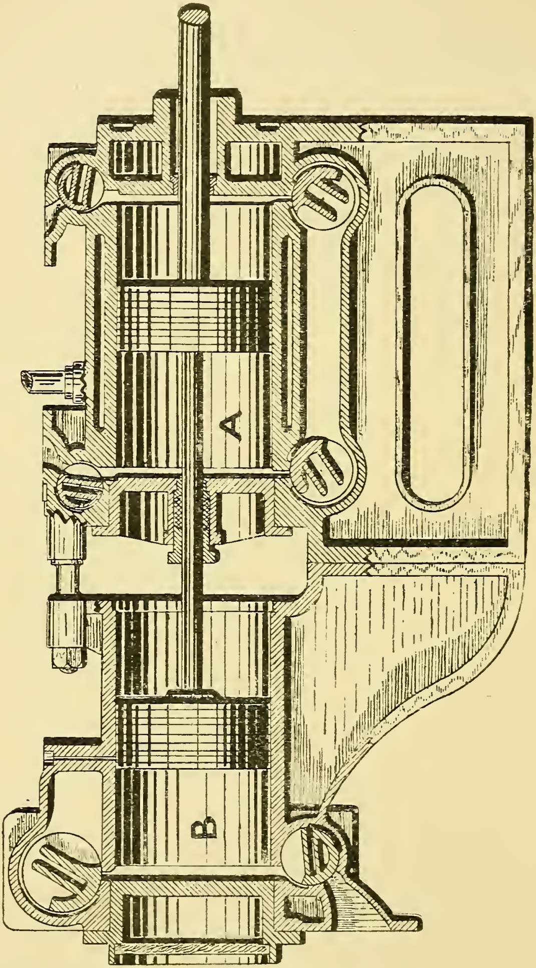

Fig. 49.

The coolers consist of a pair of iron vessels fitted with sets or clusters of solid drawn Muntz-metal tubes $\frac{3}{4}$ of an inch external diameter. Through these tubes and the compressor jacket cold water is constantly circulated for cooling purposes in an opposite direction to that taken by the compressed air, by means of a force-pump driven off the crank shaft. Any water that may become deposited from the air by condensation in the coolers is blown off through suitable drain cocks.

After passing through both the coolers the compressed air is reduced in temperature to within some 5° or 6° of the initial temperature of the cooling water; the amount of which latter that is required being usually from 30 to 40 gallons for every thousand cubic feet of cold air discharged, or some three to four times the weight of the air. From the second cooler the cooled compressed air is conducted to the expansion cylinder B, where it performs work upon the piston, and so returns some 60 per cent. of the power that has been expended in its compression, and is then exhausted at a temperature of from —70° to —90° Fahr., or 102° to 122° of frost.

The steam-engine is either of the high-pressure or of the condensing type; in the latter case the jet or surface condenser is placed below the cylinder, which is overhung from strong brackets on the bed-plate, and the air-pump is operated from a continuation of the piston-rod. It will be seen that this arrangement admits of a condensing engine being employed without occupying any additional space, or it allows of the engine being compounded by the addition of a second cylinder tandem fashion, in which case the condenser is preferably located below the high-pressure cylinder, and the air-pump is driven off a crank-pin in the fly-wheel. When a condensing engine is used, the cooling water, after performing its work in the coolers, is passed to the condenser.

Fig. 50 is a side elevation partly in vertical central section, showing the air cylinders of a single-acting Lightfoot cold-air machine.

Lightfoot machines of the vertical pattern, with the exception that the coolers are cast in one piece with the frame, do not differ in construction to any material degree from those of the horizontal type.

Vertical machines adapted to be driven by belt gearing from any convenient source of power, where same is already available, have been also designed by Lightfoot, Haslam, and others.

Cold-air machines have been likewise designed, and are manufactured by J. & E. Hall, Limited, Hick Hargreaves & Co., Stevenson & Co., Sturgeon, and numerous others: the remaining space at our disposal, however, will only permit of concluding the notice of cold-air machines by a brief description of the types made by those named.

The Hall cold-air machine, when driven by a steam-engine, has three double-acting cylinders located side by side at the end of a suitable bed-plate, one of which is for steam, the second for compression, and the third for expansion of the air. The cylinders have the usual arrangement of moving parts, that for compressing the air being water-jacketed, and the connecting-rods working on cranks on the same shaft. The valves for the compression and expansion cylinders consist of main and expansion slides operated from two weigh-bars. These valves were in some earlier types of machines situated on the under side of the cylinders, where they were very inconvenient to get at, but in those of later patterns, however, they are located on the top side of the cylinders, where they are more readily accessible. The coolers, which are placed below the bed-plate or frame, are arranged for surface cooling and are of the ordinary multitubular type. An interchanger was also sometimes provided, wherein the air that had done duty in the storage or cold chambers was utilised for further reducing the temperature of the compressed air. In recent machines, however, a patented form of centrifugal moisture separator is used for drying the compressed air.

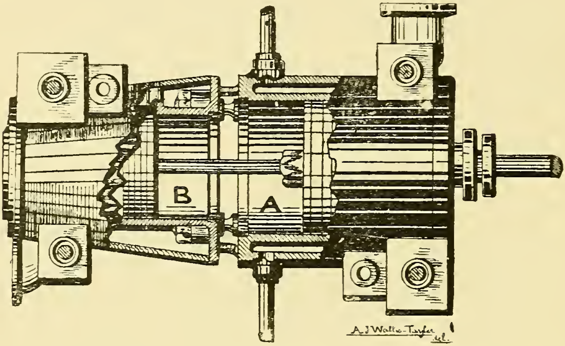

Fig. 50.

Hick Hargreaves' machine is of the double-acting horizontal type, water being injected into the compressor at each stroke for cooling purposes. After compression it is passed through a series of receivers wherein the watery particles carried over are deposited, after which it flows into the expansion cylinder, in which it is expanded down to the pressure of the atmosphere. Corliss cut-off gear is fitted to the inlet valves of the expansion cylinder. A large snow-box is provided in the air-trunk, fitted with baffle or check plates for arresting the snow, which, as the air enters the expansion cylinder fully saturated with moisture for its temperature and pressure, becomes rapidly filled with snow, and requires to be frequently cleared out.

Stevenson's cold-air machine is also of the horizontal pattern. The compression, expansion, and steam cylinders have their pistons coupled to a single crank-shaft. The compression and expansion cylinders are single-acting, and are arranged to face each other, their pistons being coupled by means of T-headed rods, which form vertical guide bars, between which slides a motion block driven by the crank-shaft, and thus imparts the requisite reciprocating motion. The steam-engine is either single-acting and of the trunk type, or it may be of the simple high-pressure, condensing, or compound type.

Sturgeon's horizontal pattern machine is so constructed that the compressed air is delivered into a cooler formed of sets of tubes surrounded by a circulation of cooling water, whereby its temperature is partially reduced, and it is afterwards caused to pass through some absorbent material, such as charcoal, before admission into the expansion cylinder.

The main objections to all cold-air machines are:—The necessity for using a lubricant in the compression cylinder, which results in the air having an unpleasant odour of burnt oil. The cold air is, as a rule, employed direct, in which case the temperature of the chamber refrigerated rises immediately in case any stoppage of the machine has to be made for repairs or other purposes, by reason of there being no reserve store of cold that can be utilised. They are very costly to maintain and manage, entailing a large outlay for coals or other fuel, lubricants, and wages, and also by reason of the large quantities of condensing and circulating water that they require.

The counterbalancing advantages are:—First and chiefly, that no chemicals of any description are required, consequently their employment is not attended by constant dangers from possible explosions and fires, or loss of life through the accidental escape of deadly gases. Very low temperatures can be rapidly obtained by their use. Their construction is comparatively simple, and their application is easy. The entire machine is situated externally to the chamber or store being refrigerated, and every part thereof is consequently accessible at all times.

A matter of the greatest importance where cold-air machines are concerned is to ascertain to what degree any water that may be present, either in the form of steam or mist, or of actual liquid, may affect the heating or cooling of air, and alter the working of a cold-air machine, besides the formation of snow and ice, which unavoidably results therefrom, and which is a most objectionable feature.

On this head Mr. Lightfoot observes,* "The important fact to be noted in this investigation is, that air at constant pressure, having free access to water, will hold a different quantity of water in solution or steam at each different temperature; or conversely the temperature of the '*dew point*' for any body of air varies with each quantity of water held in solution by it. The hotter the air, the more water can be held without depositing. (See table on p. 241.)

"Thus, if air is highly heated by compression, and water is then admitted to it, in the form of spray or injection, it will take up much more water before becoming saturated than it could have held before it was thus heated. Again, if air under compression and saturated with vapour is allowed to expand, a large quantity of such vapour will condense and freeze into snow, thereby giving up a large quantity of heat to the air, which air is, in consequence, cooled less than it would have been had it been dry air to start with. This freezing is also a serious practical evil, from the deposition of ice about the valves and in the air passages, which necessitates frequent stoppages even in small machines. . . .

"Various means have been devised for ridding the air more or less completely of its contained moisture by employing some chemical material, such as chloride of calcium or sulphuric acid, which is a powerful absorbent of water. But, in the Author's opinion, the use of such chemicals as are known to him is inadmissible, except perhaps for small machines, or for those working under special conditions, because of the trouble which would be experienced in changing the material and evaporating off the water it has absorbed, so as to render it again fit for use."

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* "Proceedings, Institution of Mechanical Engineers," 1881.

In a subsequent paper* the following particulars are given by the same authority as the result of his very extensive experience in the working of machines of this class:—"The amount of aqueous vapour present in the atmosphere varies from that required to produce saturation down to about one-fifth of that quantity. At any given temperature a volume of saturated air can contain only one definite amount of vapour in solution; and if from any cause additional moisture be present, it cannot exist as vapour, but appears as water in the form of fog or mist. The temperature of saturation, or dew point, varies according to the quantity of vapour in solution; the smaller the quantity, the lower being the dew point. The capacity of air for holding moisture is also affected by pressure, a diminution in volume under constant temperature reducing this capacity in direct proportion. In the former paper reference was made to various means that had been devised for ridding the air more or less completely of its contained moisture, in order to obviate as much as possible the practical evils resulting from its condensation and freezing; this being at the time considered one of the most important points in the construction of cold-air machinery. Since then, however, experience has demonstrated that these evils were much exaggerated, and that the condensation of the vapour and deposition of the moisture in the ordinary cooling process after compression, which is common to every cold-air machine, are amply sufficient to prevent any serious deposition of ice about the valves and in the air passages: provided, firstly, that these valves and passages are well proportioned; and, secondly, that proper means are adopted for obtaining in the coolers a deposition of the condensed vapour, which would otherwise pass with the air into the expansion cylinder in the form of fog, and become converted into ice. Reference to the table (page 241) shows that, if the compressed air be thoroughly deprived of its mechanically suspended moisture, the amount of vapour entering the expansion cylinder is extremely small. Another matter from which the mystery has now been dispelled is the meaning of the term 'dry' air, so much used by the makers of cold-air machinery; this being a point that was just touched upon towards the close of the discussion upon the previous paper. No doubt it is still to a great extent popularly supposed that, unless the air be subjected in the machine to some special drying process, it will be delivered from the expansion cylinder in

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* "Proceedings, Institute of Mechanical Engineers," pp. 225, 226; 1886.

a moist or damp state, and in consequence be unfitted for use in the preservation of perishable food and for other purposes. But no such state could really exist; for whether the air be specially 'dried' or not, its humidity when delivered from the expansion cylinder is precisely the same, so long as its temperature and pressure remain the same, inasmuch as in practice it is always in a saturated condition for that pressure and temperature. The difference lies in the amount of ice formed, which of course is greater if the amount of moisture entering the expansion cylinder is greater; but this quantity, it has been already stated, may, in the author's opinion, be brought down within perfectly convenient limits by a proper construction of the cooling vessels. In his latest machines, therefore, all special drying apparatus has been dispensed with, the air being simply compressed, passed through a surface cooler, and expanded back to atmospheric pressure."

In a paper * on "Refrigerating Machines," by Arthur Robert Gale, C.E., he makes the following observations on refrigerating machines of this type, pertinent to the point in question:—"One of the chief difficulties in cold-air machines is the presence of moisture held in suspension by the atmosphere; this applies especially to the open cycle machines. Moisture in the air occasions loss of efficiency in two ways. If the air enters the expansion cylinder in a saturated condition, when the air is cooled by expansion whilst performing work, a certain amount of vapour is condensed and thrown down—the point of saturating being dependent on the temperature. The vapour, in changing to the liquid state, gives its latent heat of vaporization to the air; and as the expansion of the air continues, and the temperature is still further diminished, the liquid freezes and accumulates in the form of snow and ice in the valves and passages, giving up its heat of liquefaction to the air. Thus not only does the presence of moisture in the air produce mechanical difficulties, choking the air passages and impeding the action of the valves, but, for the same expenditure of energy, the cold air leaves the machine at a higher temperature than would have been the case if there had not been a superabundance of moisture in the air during expansion.

"As the cold-air machine is the direct reverse of the heat-engine, so also its conditions of greatest efficiency differ from those of the latter. The maximum theoretical efficiency of a refrigerating machine may be expressed by the formula—

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* "Minutes of Proceedings, Inst.C.E.," vol. cxviii., Session 1893-4, pp. 421, 422.

$$\frac{Ha}{E} = \frac{T}{Tc - T}$$

where E is the thermal equivalent of the work of compression,
Ha denotes heat-units abstracted by the system,
Tc denotes absolute temperature at which rejection of heat takes place,
T denotes absolute temperature at which absorption of heat takes place.

From the above it follows that—

$$E = Ha\,\frac{Tc - T}{T}$$

i.e., in any refrigerating machine the greatest efficiency will be obtained with a small range of temperature; the greater the range the smaller the efficiency will be, other conditions being equal; also the efficiency is increased as the lowest limit of the range of temperature is raised. Thus a machine working between the temperatures of 100° Fahr. and 0° would, other conditions being unaltered, be more efficient than when working between 60° Fahr. and −40° Fahr. These remarks are applicable to any system of refrigeration, and are not peculiar to the cold-air machine."

For some time it was very generally supposed that many kinds of provisions of a perishable nature were liable to receive damage from the snow held in suspension in the cold air from these machines, and it was this fear of injurious effects which prompted inventors to design those forms of special drying apparatus intended to remedy this defect, such as the Bell-Coleman interchanger wherein the air is dried by passing it through a series or set of coils situated in the chamber cooled by the machine; of the improved form of the above designed by Haslam, wherein the interchanger is cooled either by the spent cold air on its leaving the chamber wherein it has been utilised, or by the cold air as it passes out of the expansion cylinder; the Lightfoot machine, wherein the expansion is performed in two stages; or of Hall's centrifugal moisture separator. Hence the term "dry-air refrigerator."

This objection to the cold-air machine arose, however, from a fault the evil effects of which, it has now become evident, have been undoubtedly much exaggerated, as in practice no such damaging results to the contents of the stores or chambers are experienced as it was supposed and predicted would ensue, although of course the snow that is formed in the manner above described is an undeniably objectionable product. If a cold-air machine be worked on the principle of exclusion of the aqueous vapour, after a few cycles of operations the air will have become dry, and will thenceforward work like a true gas.

Owing to their compactness and simplicity, to the non-requirement of any chemicals, and to the great facility of application, cold-air machines are found to be very suitable for marine installations, and for this purpose they are extensively employed. They are also, however, in use to a considerable extent for refrigerating cold stores or chambers for the preservation of provisions of a perishable nature.

An objection, however, to machines of the Bell-Coleman type, wherein the air is partially cooled during compression by the injection of cooling water into the compressor, is experienced at sea, by reason of the corroding action of the salt-water, in addition to the loss of efficiency common to all machines of this class. Considerable difficulty is also experienced in tropical climates, where, with the cooling water at about 90° Fahr., the moisture-laden air would be delivered into the cooling pipes at a temperature of 95° Fahr., or more, and the absolute pressure would be about 65 lbs. per sq. in. Now, as there is, as Mr. Lightfoot observes,* "precisely the same amount of dry cold air circulating outside the cooling tubes in a given time, as there is warm compressed air within, it follows that by whatever amount the temperature of the internal air is reduced, by an equal amount must that of the external air be raised. But, in addition, the internal air has vapour mixed with it, which, as the temperature falls, gives off heat, measured not only by the reduction in its sensible temperature, but by the latent heat of vaporisation; and this heat also has to be taken up by the external air. It will be found that, assuming each pound of internal air, with its proportion of vapour, to be reduced to 42° Fahr., the pound of external cold air, which has to take up all the heat due to this reduction, will be raised in temperature by 84° Fahr."

Instead of using the spent air for cooling purposes, the cold air from the expansion cylinder may be applied direct to the cooling apparatus; but in this case difficulty would be experienced from the deposited moisture inside the tubes actually feezing from the intense cold of the external air, a difficulty which, it appears, has often occurred with this apparatus. This, apart from the mere obstruction of the pipes, would involve a further sacrifice of cold, owing to the liberation of the heat of liquefaction.

* "Proceedings, Institute of Mechanical Engineers," 1881.

The following table gives the results of test experiments made with modified Giffard, Haslam, and Bell-Coleman machines, and designed to deliver about 15,000 cubic ft. of cold air per hour, when running at a speed of 60 revolutions per minute:—

	Giffard.*	Haslam.†	Bell-Coleman.‡
Diameter of compression cylinder, in ins.	27	25¼ (2-cy.)	28
,, expansion ,, ,,	22	19½ ,,	21
Stroke of each ,,	18	36	24
Revolutions per minute	62	72	63·2
Air pressure in receiver (absolute), in lbs. per sq. in.	65	64	61
Temperature of air entering compression cylinder (containing vapour up to 88 per cent. of saturation)	52° F.	..	65½ F.
Temperature of air discharged from compression cylinder	267° F.		
Temperature of compressed air admitted to expansion cylinder	70° F.		
Temperature of air after expansion	−82° F.	−85° F.	−52° F.
Work done in compression cylinder, from diagram	43·12 h.p.		
Work given off in expansion cylinder, from diagram	28·05 h.p.		
Difference in work done in compression cylinder, and work given off in expansion cylinder	15·07		
Diameter of steam cylinders, in ins.	12		
,, trunks in cylinders, in ins.	10		
Stroke of trunks ,,	15		
Initial steam pressure in cylinders (absolute) per sq. in.	55 lbs.		
Work given off in steam cylinders, from diagram	24·6 h.p.		
Initial temperature of cooling water	57° F.		
Final ,, ,, ,,	145° F.		
Quantity of cooling water passing per minute in lbs.	9·25		
Work lost in heat taken off by cooling water	19 h.p.		
I. h.p. in compression cylinder	43·1	346·4	124·5
,, in expansion cylinder	28·0	176·2	58·5

The proper management of cold-air machines is far simpler than that of those working on other principles, the exact treatment of each particular machine, however, varying of course somewhat with the make. In all machines, however, the parts most liable to give trouble are the valves, and these, as also the pistons and slide valves, should be periodically tested, and any defect promptly remedied.

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* “Proceedings, Institution of Mechanical Engineers,” 1881.

† “Proceedings, Manchester Society of Engineers,” 1894.

‡ Professor Schroeter, “Untersuchungen an Kaeltemaschieren verschiedener Systeme,” 1881.

CHAPTER IX.

REFRIGERATION.

THE class of machines described in the last chapter, viz., those wherein the abstraction of heat is effected by first compressing air and afterwards permitting it to expand, or cold-air machines, are, as already mentioned, somewhat extensively applied to the preservation of meat and other comestibles of a perishable nature. Those wherein the evaporation of a volatile liquid is employed to produce the cold are likewise in use to a considerable extent for this purpose, and it would be difficult to decide which type of apparatus is the best suited for a land installation, as favourable results are obtained from the use of both. Much can be said, however, in favour of cold-air machines, in cases wherein the cost of fuel is not a matter of vital importance, and, as already mentioned, they possess certain qualities which seem to render them especially advantageous for marine installations. For breweries, chemical works, paraffin oil and other works, it is probable, on the other hand, that those machines operating to produce cold by the evaporation of a volatile liquid, especially ammonia machines, will be found the best.

When a cold-air machine is employed for refrigeration, the cold air is, as a rule, admitted to the cold chamber or chill room through ducts placed near the ceiling, and after it has done its duty is conducted back again to the compressor, wherein, after being mixed with a sufficient amount of fresh air, it is again compressed.

The most advantageous method of conveying the cold air from the machine to the chill room or cold store or chamber, is by means of wooden trunks or conduits discharging into the latter through an inlet situated at or near the ceiling at one extremity thereof, the used or spent air being withdrawn through a similarly situated outlet and conduit at the other extremity.

All abrupt rises or falls or bends in the air trunks should be avoided, and their length should not be excessive, as the loss experienced through the rise in temperature of the air in the latter case would be very considerable. The extreme limit of distance to which it is advisable to convey the cold air through these conduits is 200 ft.

When carcasses are to be congealed, the temperature of the freezing chamber or room should be maintained at about 10° Fahr.; as has been already stated, however, the cold should on no account be applied too rapidly at starting, but gradually, so that the internal heat may be first sufficiently reduced, to avoid injury to that portion of the meat, before the outer surface becomes frozen.

For after preservation of frozen meat it is sufficient to keep the atmosphere of the chamber or store down to a temperature of about 15° or 18° Fahr.; it should not, however, be allowed to rise above 20° Fahr.

According to Colonel B. H. Martindale, C.B., R.E., the general manager of the London and St. Katherine Dock Company, in 1886 they had 56 refrigerating chambers in two vaults, the smallest of which chambers had a cubic content of 2,273 ft., and the largest thereof of 9,280 ft., the total content of the said 56 chambers being something over 183,000 cubic ft. The carcasses of the sheep averaged in weight 56, 60, and 72 lbs. each; and the whole of the chambers completely filled would contain about 59,000 sheep of the first weight, 56,000 of the second, and 44,000 of the third; in practice, however, a space or clearance had to be left for gangways, and for separating different marks, for which a deduction had to be made from the total storage capacity, and taking the shipments as they chanced to arrive, the above space was equal to the storing of the carcasses of about 44,000 sheep.

The cold-air machines employed in connection with the 56 chambers in question comprised four Haslam 60,000 cubic ft. machines, and three Hall 30,000 cubic ft. machines. supplied with steam from three multitubular boilers of the marine type, and four boilers of the locomotive type, the former having been found in practice to be the best. One of the Haslam 60,000 cubic ft. machines, worked on 15 chambers, having a total capacity of 48,000 cubic ft., and capable of storing 11,000 carcasses of sheep averaging in weight 72 lbs. each, but which storage capacity was reduced by gangways, &c., to between 8,000 and 9,000. The engine was kept running twenty hours out of every twenty-four, the said stoppage including the time required for clearing the snow from the valves, snow boxes, and air-trunks. The average speed was 80 revolutions per minute, at an air pressure of 44 lbs. per square inch, giving a temperature of —70° in the snow boxes, and keeping the temperature of the chambers down to from 15° to 18° Fahr., which was found in practice to be about the best temperature to keep the meat at. Better results were obtained in proportion to the fuel consumed, by working at an air pressure of about 44 lbs. per square inch, instead of 50 lbs. and upwards; not giving such a low temperature in the snow boxes, but about —50° Fahr. instead of —60° or —70°, and delivering a larger volume of cold air into the chambers. The proportionate rise in temperature was then much less between the delivery from the expansion cylinder and the distant chambers. Twenty-four chambers, with a capacity of 90,000 cubic ft., were worked by two Haslam 60,000 cubic ft. machines, running at an average of 70 revolutions per minute, with an air pressure of 40 lbs. per square inch, the temperature in the snow box being —55° Fahr.

The temperature of the chamber next the machine could, as a rule, be kept at a sufficiently low temperature with but little opening of the delivery ports in the air-trunks, and almost without admitting air at all, as the mere passage of the said air-trunks through it kept it nearly cool enough. The greatest care was taken in regulating the delivery and return air-ports or apertures, gradually increasing the area of both in proportion to the increased distance from the machine; the greatest distance to which the cold air was conveyed being 180 ft.

The practical result of the observations taken, which extended over some time, was that the rise of temperature in travelling was 1° Fahr. for every 18 or 20 ft. travelled; but this, of course, must not be taken for more than the result arrived at from general working under existing conditions. It was likewise found that from 1 to 1½ cubic ft. of cold air per hour would keep cool—say at 18° Fahr.—1 cubic foot of storage at a distance not exceeding 180 ft., or say, at an average distance of 90 ft. from the machine. The first amount named, viz., 1 cubic foot of cold air per hour to each cubic foot of storage, was the result arrived at during temperate weather, and this, it is estimated, would most probably be amply sufficient were the chambers fully stored with carcasses, and left entirely undisturbed; but as this is not possible in practice, an allowance has to be made for the opening of doors for the purpose of deliveries and so on; and the second amount, or 1½ cubic ft. of air per hour for every cubic foot of storage that it was desired to keep down to, say, 18° Fahr. was found to be about correct for general practice.

The coal consumption, he stated, was, for three machines, giving out nominally 120,000 cubic ft. of air (one 60,000 cubic ft. and two 30,000 cubic ft. machines), 4½ tons of coal in twenty hours; and two 60,000 cubic ft. machines, working under practically similar conditions, had a like consumption. The coal used was ordinary Welsh coal, costing about 16s. 6d. per ton.

When refrigerating machines wherein the cooling is effected by the evaporation of a volatile liquid are employed, the refrigeration can be conveniently effected in three ways, viz. :—

First—by cooling a non-congealable salt brine, and then pumping it through a system of pipes, or of open troughs in the chambers. Secondly—by causing a current of air, generated by means of a fan or otherwise, to impinge against surfaces reduced to a low temperature by the expansion of the refrigerating agent itself, or by an internal circulation of cooled brine, and conducting the said cold air to the refrigerating chambers. And thirdly—by expanding the gas direct through pipes placed in the said chambers.

The main advantage claimed for the first of these plans is that it admits of the machine being stopped, and when an independent brine pump is employed, the brine wherein a large reserve of cold is stored up, can be continued in circulation for a considerable time before any thawing from rise of temperature and consequent dripping will take place from the pipes.

Fig. 51 is a vertical section through the end of a refrigerating chamber as designed by the Pulsometer Engineering Company, Limited, showing an arrangement of cooling pipes on the brine circulation system. The pipes are of galvanised wrought iron, which, being very much lighter and thinner than those formed of cast iron, ensure the maximum amount of head room, and thereby enable a considerable amount of space to be economised.

The agent employed in the brine circulating system consists of a solution of chloride of sodium or common salt,* or of chloride of calcium,* chloride of magnesium, or any other

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* For proportions, &c., of these solutions, see p. 253.

suitable solution capable of standing very low temperatures

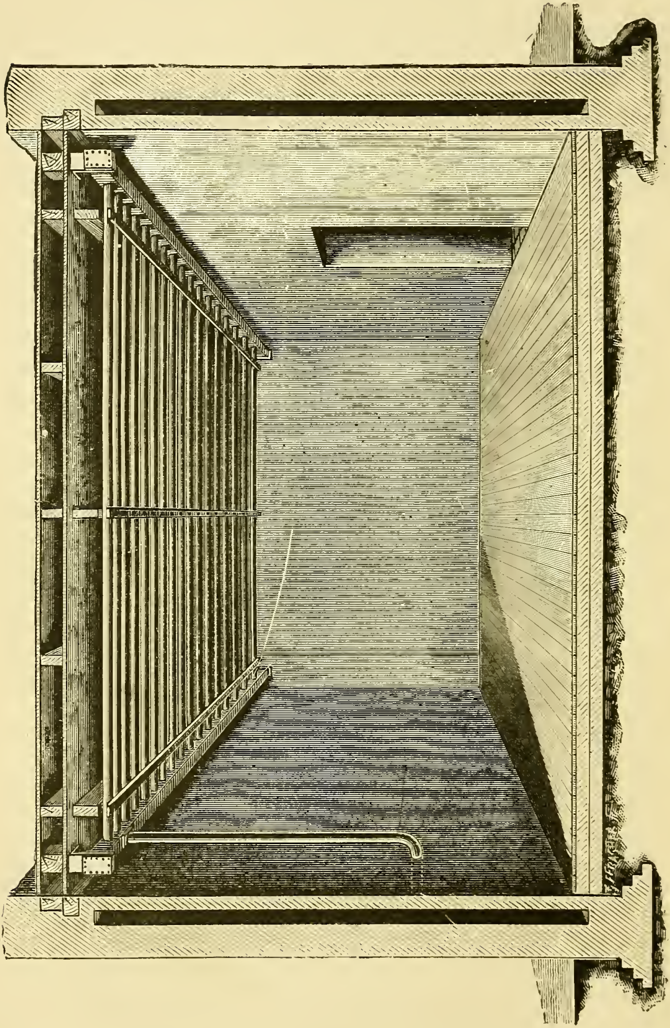


Fig. 51.

without congealing. To extract or absorb the heat from the brine, the simplest and best method is undoubtedly that most commonly employed, which consists in enclosing it in a tank of ample dimensions fitted with vertical coils of pipes, through which the chilled liquefied ether, ammonia, or other volatile refrigerating agent, circulates, vaporizes or gasifies, expands, and subsequently returns therefrom in the form of a gas or vapour to the compressor, in one system; and in the other, in the form of a strong solution to the generator. In some instances expansion valves or cocks, such as one of those illustrated in Figs. 32 to 35 (page 80), are fitted to the inlet ends of the said submerged coils. The brine, being thus deprived of a large portion of its heat, is then drawn away from this refrigerating or cooling tank or vessel by the brine circulating pump, and is forced through the system of cooling pipes in the refrigerating chamber or cold store.

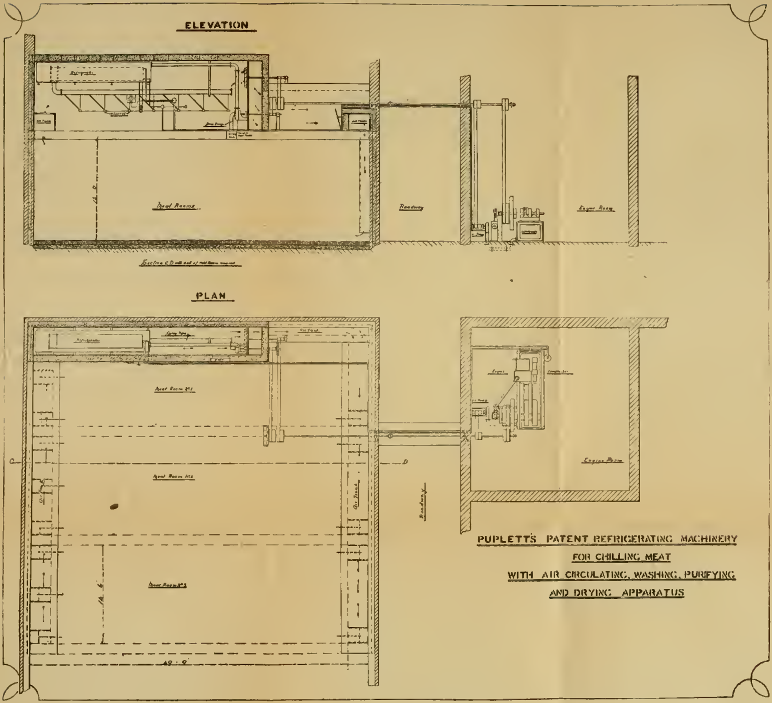
A plan of chilling and freezing by a circulation of cold brine on the wall system has been patented by Hall. In this arrangement the congealing or freezing room or chamber is fitted with parallel hollow or cellular walls constructed of steel or iron plates, and situated at short intervals apart. The carcasses to be chilled or frozen are hung in the spaces or passages left between these walls, which latter can be maintained at a very low temperature by the cold brine circulating therethrough. An advantage possessed by this method is, that, owing to the extensive surfaces afforded by these hollow or cellular walls or plates, an intense cold can be rapidly produced, and the heat very expeditiously abstracted from the carcasses, which are thus quickly frozen or congealed. On this account, as the space taken up by the said hollow walls is so trifling as not to necessitate any increase in the dimensions of the freezing chamber for a given number of carcasses, the proportion usually allotted to the latter may be reduced, and a saving of labour and of depreciation through handling is also effected. The carcasses when frozen are at once removed to cold stores or chambers kept at a proper temperature for preserving the contents, by a circulation of brine through a system of pipes arranged near the ceiling; or air, cooled in the machine-room, may be circulated therethrough for a like purpose.

On the other hand, however, these hollow or cellular walls would seem to be open to the objections that they are far more difficult to maintain tight and free from leakage than a system of pipes, and, moreover, that the shallow space left between the walls is liable to become choked by any foreign matter in the brine, and from deposits from the latter. The first of these objections renders this plan unsuitable for the direct expansion system.

In order to facilitate and hasten the operation of chilling and freezing, and lessen the handling to which it is necessary to subject the carcasses, an arrangement for slowly traversing the latter through the freezing or congealing chamber or room has also been devised by the same inventor, wherein an endless chain provided with hooks at proper intervals for hanging the carcasses, and operated by suitable gearing, is provided.

The open trough system has been already alluded to, and it is one of great simplicity, and is frequently used for the hog cooling rooms in bacon factories. Two, three, or other suitable number of troughs are usually placed in line, vertically, one above the other, over each hook or hanging rail, and the flow of brine can be regulated by any well-known and convenient means. A large surface of cold brine is in this system advantageously exposed for absorbing heat ; on the other hand, however, the open troughs have the disadvantage of taking up a very considerable amount of valuable space.

The cooling pipes are arranged in the chilling, cooling, and curing rooms of bacon factories in a number of other different ways, the system having frequently to be specially adapted to the existing buildings. Sometimes the said pipes are placed in the form of coils in a separate chamber provided in the ceiling of the main room or chamber (as shown in Fig. 64, page 178), and air, admitted through suitable apertures from the room beneath, or by means of ventilators, and cooled by passing over the surface of these coils, is rapidly circulated through the said room. A somewhat similar arrangement of brine or cooling pipes is also often employed in beef and other meat rooms. The advantage of this plan is that it effectually prevents any dripping and moisture in the chill room. In the folding plate facing this page, the refrigerating pipes or coils and circulating fan are fixed in a separate compartment quite distinct from the cold rooms, but connected therewith by trunks or ducts. The cooling is effected by the constant circulation through the chill or meat rooms of a current of air that has first been cooled by passing it over the refrigerator. The air is washed and purified by being passed through a series of sprays of cold brine, and then over the refrigerator, by which it is dried and reduced to any desired temperature. The fan draws the air from the rooms through the suction trunk, and returns it by the de-



PUPLETT'S PATENT REFRIGERATING MACHINERY
FOR CHILLING MEAT
WITH AIR CIRCULATING, WASHING, PURIFYING
AND DRYING APPARATUS

livery trunk after it has passed through the refrigerating chamber and been washed, cooled, and dried; the air thus becomes colder, and is purified each time it passes over the refrigerator.

Another method of arranging the cooling pipes in a chill room is to provide coils on the sides thereof, or where the chamber is of considerable dimensions, in rows placed vertically at suitable intervals lengthways of the latter, the carcasses being suspended by hooks in the usual manner from meat or hanging rails, situated overhead, between the said coils.

When the refrigerating pipes are placed directly in the cold store, suitable drip trays (as shown in Fig. 62) can be provided if required, to catch any water falling from the said pipes, upon the exterior surfaces of which the moisture present in the atmosphere of the room becomes condensed, either in the form of water or of hoar frost.

In the British patent of F. B. Hill, No. 16253 of 1889, is described an arrangement in which, as shown in Fig. 51*a*, the refrigerating apparatus is located on a floor above the cooling chamber. This arrangement, moreover, permits the circulation of the cooling medium by gravity, so that the use of pumps or other machinery for effecting such circulation can be dispensed with. H is the refrigerator tank; H^1 is another tank or vessel which is preferably arranged at a lower level than the refrigerator-tank, and is connected therewith by means of pipes J in such a manner that a constant circulation of the brine or other non-congealable liquid from one tank to the other will be maintained by gravity during the refrigeration of the liquid.

It is stated by the inventor that, by the use of tanks connected in this manner, the reservoir or store of cold is greatly increased. The bottom of the cooling tank H^1 may if desired serve as the top of the chamber to be cooled, as shown in Fig. 41*e*, page 113*f*.

The bottom of the tank H^1 is formed with a series of V-shaped portions or corrugations H^2, and suitable gutters or channels K are arranged beneath the tank, so that any moisture collecting on the underside will flow to the lower edges of the corrugations or V-shaped portions, and will fall into the said gutters or channels, whereby it will be conducted away to any convenient place. The dripping of moisture from the under surface of the tank into the room or chamber to be cooled is thus avoided. This arrangement also increases the area of cooling surface and the strength of the bottom of the tank.

In a later patent, viz., No. 20509 of 1890, the same inventor describes means for removing snow or hoar-frost from the refrigerating surfaces used for cooling air, which consists in the employment of rotating screw-blades or conveyors, or of annular or other suitable scrapers, or brushes arranged to move to and fro, or up and down, in contact with the surfaces to be cleared. These screw conveyors, scrapers, or brushes, are placed within or outside, or both within and outside, the refrigerating tubes or chambers.

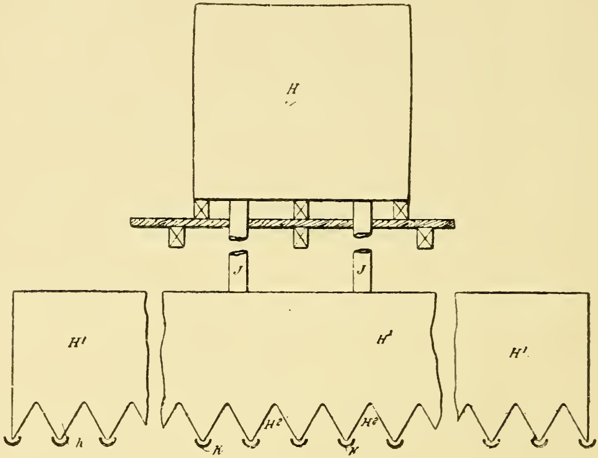


Fig. 51a.

F. N. Mackay, No. 16745 of 1886, provides for the combined utilization of cold air from an air expansion machine and brine cooled by an absorption or compression machine. The rooms or chambers are partly cooled by the cold air, and the brine from the latter machine is circulated through an arrangement of pipes in the cooling chamber, to which brine pipes corrugated metal sheets are attached to increase the refrigerating effect. Or the corrugated metal sheets may be formed into narrow chambers to receive the brine directly.

To increase the effective surface of cooling pipes F. S. Thomas, No. 2568 of 1888, forms them with four concavities, or approximately star-shaped in transverse section, and also employs lugs or ribs.

One advantage of the third system, or that wherein the refrigeration is effected by expanding the gas or vapour direct through the system of refrigerating pipes in the stores or chambers, is that a more economical and rapid cooling is effected than with the brine circulation; another is the simplification ot the apparatus and the reduction in the first cost thereof. To counterbalance which advantages, however, there is the danger to human life, of damage to the contents of the refrigerating chambers, and of fire, should any leakage of the gas or vapour from the cooling pipes take place, and also the impossibility of shutting down the machine even for a few minutes without the said pipes commencing to drip.

So far, however, as ammonia is concerned, the fears of any deterioration in the quality of fresh meat, which is being frozen or preserved, resulting from any accidental leakage of the pipes, would seem to be totally groundless, judging from the results of recent practice, and the opinions of experts.

On this head the following extract from an article published in the *Scientific American*, in 1889, is of interest :—

"Some years ago Dr. B. W. Richardson, in a communication to the Medical Society, called attention to the antiputrescent properties of ammonia, and showed that blood, milk, and other alterable liquids could be preserved for a long time by adding to them certain quantities of solution of ammonia; and solid substances, such as flesh, by keeping them in closed vessels filled with ammonia gas. Some doubts that would appear to have been raised as to the results reported, on the ground that ammonia was itself a product of decomposition, induced Dr. Gottbrecht, of the University of Greifswald, to repeat the experiments with the result of practically confirming all Dr. Richardson's statements. After some preliminary experiments, in which animal matter placed in 5 per cent. of ammonia solution was found free from putrescence after nearly two years, ammonium carbonate was used in place of the free alkali for the sake of convenience. The first experiment made with the washed intestines of freshly killed pigs, showed the power of ammonium carbonate to retard putrefaction to be directly dependent upon the concentration of the solution, a 1 per cent. solution retarding it until the third day, a 10 per cent. solution until about the sixtieth day. When added to gelatine in which putrefaction had already been set up by inoculation, it was found that a 5 per cent. solution so modified the conditions that the putrescence ceased, and a $2\frac{1}{2}$ per cent. solution inhibited the development of bacteria, so that the liquefaction of the gelatine was practically stopped. Other experiments showed that in an atmosphere impregnated with ammonium carbonate meat could be kept for six months, and at the end of that time remain nearly unaltered."

When chambers are refrigerated on the direct expansion system it is nevertheless essential that the system of pipes employed, which can be arranged on any ot the plans for brine circulation that have been already mentioned, should be such as to reduce as far as practicable to a minimum the chance of leakage taking place at the joints, cocks, valves, &c., as independently altogether of any possible damage to the contents of the stores or chambers, it is highly desirable for economical reasons, that as little as possible of the ammonia be lost. The Pontifex joint for ammonia has been already briefly described when dealing with his patent of 1887. Amongst the numerous other special joints mention may be made of those of De La Vergne and Kilbourn.

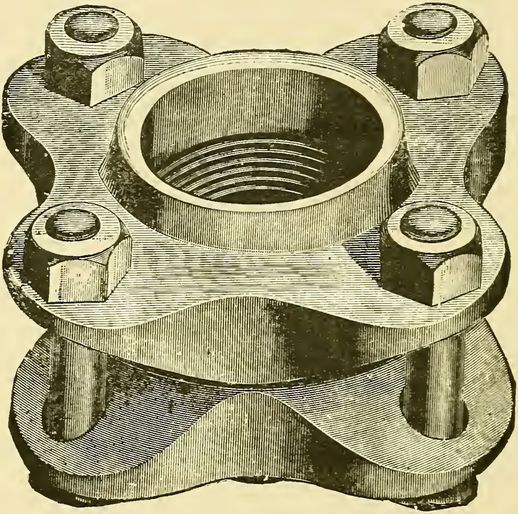


Fig. 52.

Figs. 52 and 53 illustrate, in perspective and vertical central section, the De La Vergne patent pipe joint. To ensure a tight joint to withstand high pressure the flanges are connected to the pipes both by screw threads and solder, the latter being run into the annular recesses or clearances shown above the threaded portions, the surfaces of which are well tinned.

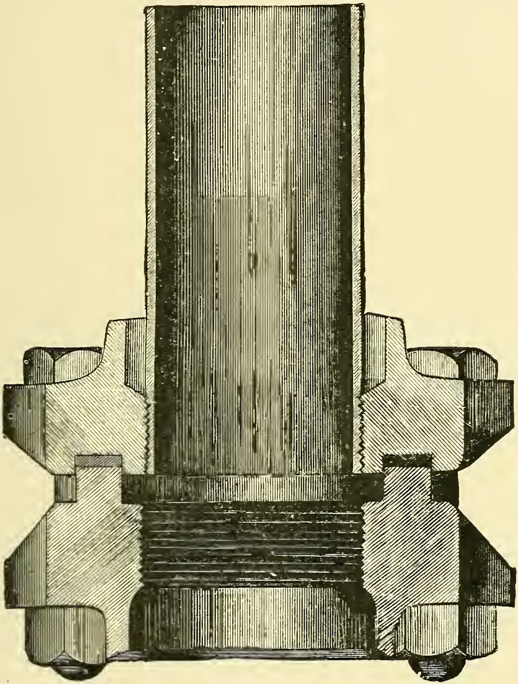


Fig. 53.

The joint between the flanges is formed by an annular projection upon the one fitting into a corresponding groove formed in the other, which, when the nuts are screwed up upon the bolts for connecting the said flanges, is pressed home and bears upon a suitable packing ring inserted into the bottom of the said corresponding groove or recess, and thus forms a perfectly gas-tight joint. Similar screwed and soldered joints are likewise employed wherever it is necessary to use a return bend, elbow, tee, cross, or other connecting piece. The fittings are either made of malleable iron or steel.

The result of covering the thread of the pipe with solder, and running the latter into the above-mentioned annular recess or clearance, and thus forming a compound screwed and soldered joint, is, that what is otherwise the weakest part of a length of piping becomes the strongest. It is stated by the inventors that it has been invariably found that when the usually applied test of 1,000 lbs. hydrostatic pressure to the square inch is overrun, the pipe rips open before the joint gives out.

Fig. 54 is a vertical central section illustrating Kilbourn's patent joint, which is especially intended for use where it is necessary to set tubes or pipes in places where an expander cannot be used, or where sweating or soldering is requisite to make a perfect gas-tight joint adapted to withstand very high pressures. As will be seen from the illustration the extremity of the pipe is flanged and secured in a recess in the plate by means of a nut or collar, after which solder is run round it. Where the plate is of insufficient thickness to allow for a depression being left for the said solder a rib is formed thereon, as shown. In this manner the inventor claims that the pipe or tube can be so secured to a tube plate or its equivalent that it will be perfectly firm and rigid, and that the solder will retain its hold against all ordinary or usual contingencies, whilst at the same time forming a perfectly gas-tight joint. In Fig. 55 is shown Kilbourn's patent coupling for connecting together different lengths of pipes, or forming joints between the latter

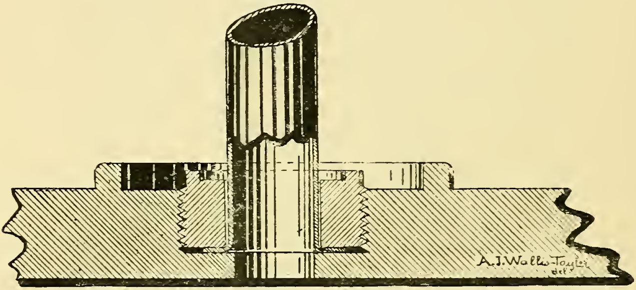


Fig. 54.

and their connections, where fluid-tight joints to withstand very high pressures are demanded. The usual internally screw-threaded socket is chamfered or bevelled at its extremities, and caps having internally chamfered shoulders and bored to fit over the pipes, and over the said socket, are forced against the latter by means of back-nuts, so as to compress the packing rings or jointing materials, placed between the chamfers on the socket and caps, as shown, and thus form a perfectly gas or fluid-tight joint.

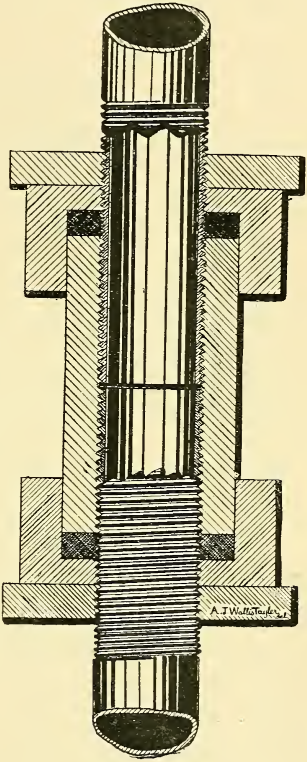


Fig. 55.

The De La Vergne patent improved form of stop-cock for ammonia gas is illustrated in Figs. 56 and 57, which show vertical central sections through the shells or casings of a $2\frac{1}{2}$-in. and a 1-in. cock, the plugs being left in elevation.

As will be seen from the drawings, the square for operating the plug is, contrary to the usual custom, placed at the small end thereof, the latter being pressed to its seat by a spiral spring inserted between its large end and a cap bolted up to the shell or casing, and having an annular projection adapted to engage in a corresponding groove formed in the latter, and wherein is provided a lead or other washer. Similar means for forming a gas-tight joint are provided at the small end of the said plug, and in this manner the escape of any fluid into the chamber that might chance to pass the plug, is prevented. The even and constant pressure of the spiral spring maintains the plug always on its seat, and prevents any grit or other impurities from getting between the surfaces and cutting or abraiding them. The shell of the small-sized cock or valve (Fig. 57) is of slightly modified form.

The Kilbourn patent stop-cock is provided with a cone, gland, nut, or sleeve, and collar, so constructed and combined that by turning the gland nut in the one direction the cone will be forced into and held in its seating, whilst on the other hand by turning it in the other, or opposite direction, the said cone will be started from its seating.

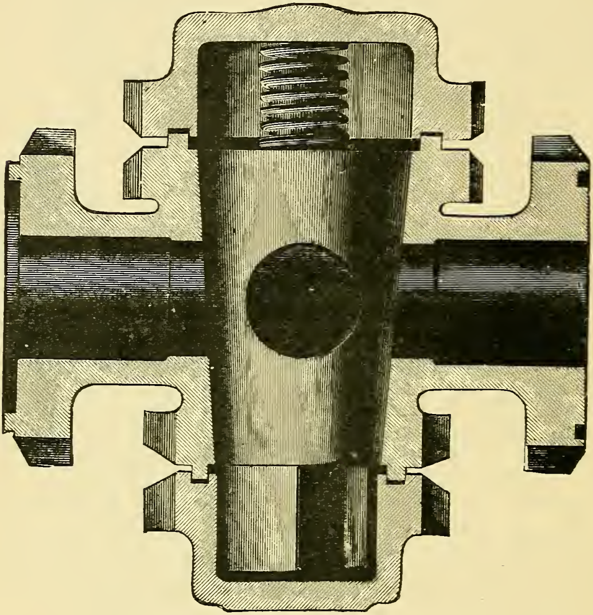


Fig. 56.

Fig. 58 is a perspective view of a disc or gill which is formed in halves, one of which is shown removed in Fig. 59. The two halves or parts of the disc are adapted to be secured together upon the pipe by means of iron clips which press them against the said pipe. These discs are fixed at regular intervals upon the cooling or refrigerating pipes in the cold stores or chambers, after they are all put up, and, according to the inventors, their effect is to increase the cooling surface to such an extent that only one foot of pipe is found requisite where four would be necessary without them.

Ammonia, both in a liquid and gaseous condition, has no chemical effect whatever upon iron, consequently the cooling pipes require no protection except upon the exterior, which should receive a coat of paint every year to prevent them from rusting.

So long, however, as the pipes are coated with snow or ice no corrosion will take place, even externally, as they are thoroughly protected thereby from the oxidizing effect of the atmosphere; when, however, they are subjected to alternate freezing and thawing, as is usually the case during actual work, when the chambers or stores are alternately in and out of use, they must be protected as above mentioned.

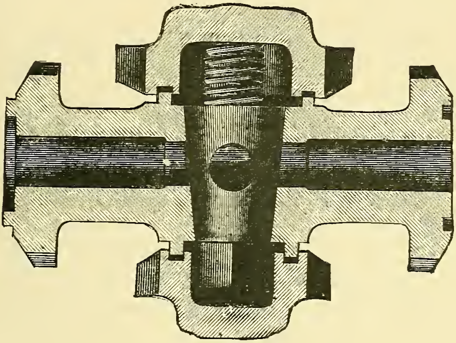


Fig. 57.

There is not the least doubt but that the direct expansion system is, as has been before mentioned, more economical than the brine circulation system. This will be obvious when it is remembered that every transmission of heat must of necessity entail a loss of efficiency. A far higher evaporating pressure can be maintained in direct pipes than in evaporating coils in a brine tank, whilst at the same time they have still within them a far lower temperature than in the latter. The result of this is that, in the compression system, the gas is sucked into the compressor at a greater back pressure when direct expansion is employed, and a far larger amount of efficiency is obtained. The cold, moreover, being produced exactly where it is required, there is practically no waste.

In the brine system, on the other hand, the large refrigerating or cooling tank is exposed to the atmosphere, and even when insulated as perfectly as possible, a considerable amount of heat is unavoidably absorbed, which is, of course, a total loss; considerable fuel consumption is moreover required in the brine circulation system, for the power consumed in pumping the large quantities of brine through the system of pipes in the refrigerating chambers or cold stores, which pipes some-

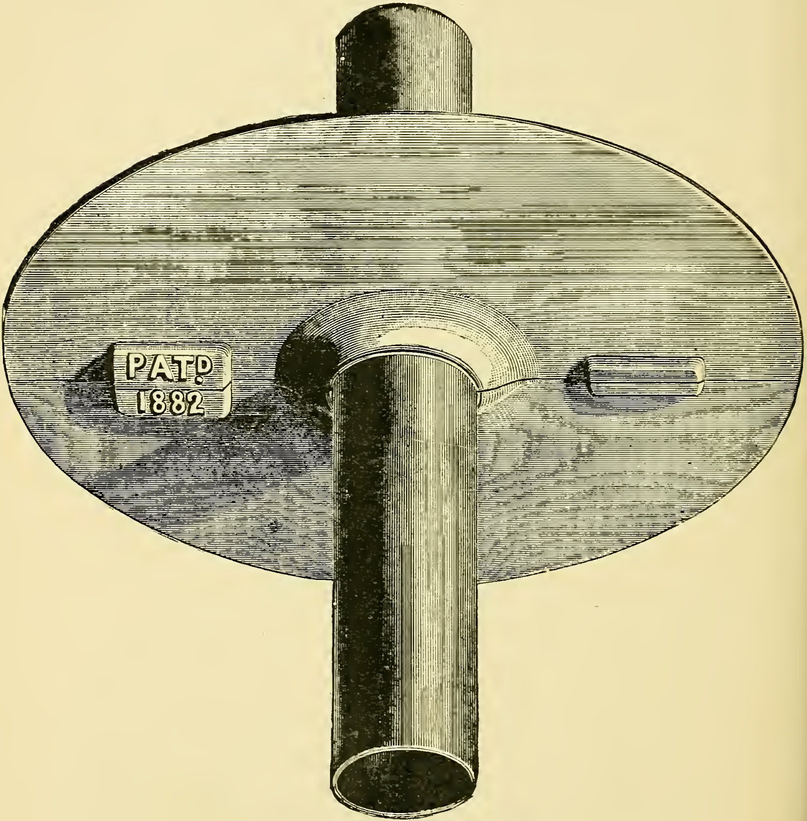


Fig. 58.

times run to many thousands of feet in length, thus giving rise to a large amount of friction; and besides, after being in use for some time, they become internally coated with rust, and with a slimy deposit, which not only produces a considerable increase in the amount of the said friction to be overcome in driving the brine through them, but furthermore forms a sort of non-conducting coating, and lessens, to an appreciable extent, the heat-absorbing qualities of the system. Altogether it is not improbable that the entire loss through the additional consumption of fuel entailed from all the above causes does not, in many instances, fall far below 25 per cent. of the entire amount.

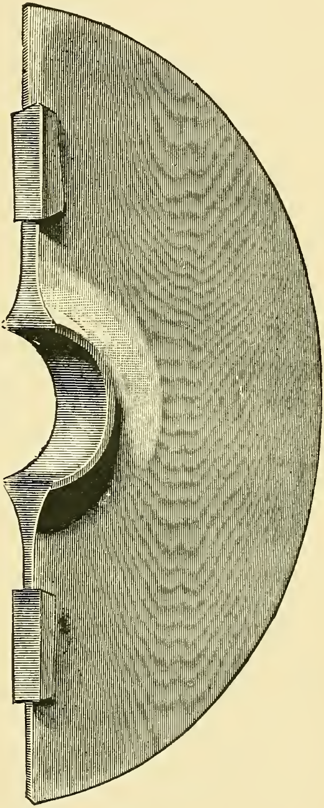


Fig. 59.

At the Southampton Docks four cold stores or chambers, having a joint capacity of 47,000 cubic ft., are refrigerated on the direct expansion system by a 6 in. by 12 in. double-acting De La Vergne machine, having two compressors driven by a 10 horse-power gas-engine. The proper insulation of the stores or chambers has been very carefully attended to, and a few hours' working out of every twenty-four is stated to maintain the temperatures sufficiently low.

Apparatus is also in use which is so arranged that the refrigerating coils or pipes are placed in a separate compartment connected with the refrigerating chambers or cold stores, and air, having been cooled in the first, is passed into the latter, the circulation being kept up by means of a fan or blower. The refrigerated air is sometimes first washed and freed from snow by passing it through a shower of cold brine. This arrangement is possessed of one of the advantages derived from the use of cold-air machines, viz., that every part of the apparatus is situated externally to the refrigerating chamber or cold store, and consequently accessible at all times. Dripping from the refrigerating pipes when the machine is stopped for a short time, and the temperature of the said chamber or store rises slightly, is also avoided.

On the other hand, however, there is a considerable loss by reason of the absorption of heat by the cold air on its way from one chamber to the other; an increased consumption of fuel, owing to the power required to work the fan or blower for keeping up the air circulation; and finally the loss of valuable space taken up by the chamber required for the purpose of cooling the air.

The plan wherein air, refrigerated by contact with brine-cooled surfaces, is passed into the chambers or stores, is evidently still more costly, inasmuch as there are not only the losses entailed from the above-mentioned sources, but, furthermore, that caused by another transmission of heat.

CHAPTER X.

CONSTRUCTION AND ARRANGEMENT OF ROOMS AND COLD STORES AND CHAMBERS FOR FREEZING AND PRESERVING PROVISIONS.

THE knowledge of the conservative action of cold upon organic substances is probably as old as the existence of human beings, and has been constantly utilised to preserve from putrefaction various alimentary substances.

Attempts were primarily frequently made to produce a refrigerated atmosphere by means of ice, but the results obtained were far from satisfactory, the atmosphere of the stores or chambers so cooled being more or less saturated with moisture from the melting ice, and the meat preserved therein assuming a musty and disagreeable flavour. The possibility, however, of successfully keeping meat in artificially cooled stores or chambers dates only from the invention of Charles Tellier's machine and brine circulating system in 1873, by which he was enabled to create a cold dry atmosphere, wherein organic substances could be maintained constantly at that temperature which is found to be preservative. It is therefore an art of comparatively modern origin.

For the preservation ot meat the machines in most general use are those working upon the ammonia compression, or upon the absorption system, and cold-air machines. Ether machines, however, are also used, though to a less extent, and they have the advantage over ammonia machines, of a low working pressure in the condenser, which, as already mentioned, is found to be very advantageous in hot climates.

In freezing carcasses for transportation, the cold is best applied gradually at first, so as to ensure an even freezing throughout, and prevent damage to the inner portions of the meat, by the freezing of the external surfaces thereof before the internal heat is sufficiently lowered. When frozen or congealed a temperature of at least as low as 18° Fahr. should be maintained. For cooling ships' holds, cold stores or chambers, and other similar purposes, temperatures varying from 15° to 55° Fahr. are required, in accordance with the material being dealt with, an even temperature in every part being absolutely necessary. When freezing carcasses they must be hung at such distances apart as to admit of a ready circulation of the cold air round them taking place; for storage for transportation, however, it is recommended to pack them as tightly together as possible, provided no injury through bruising be caused, and that a sufficient clearance or free space be left for the circulation of the cold air between the said carcasses and the inner lining of the storage chamber. The temperature of cold land stores or chambers for storing and preserving unfrozen meat need not be lower than 25° Fahr., but should not rise above 30° Fahr. When the meat is frozen, however, as it must be when it has to be kept for any length of time, it may advantageously be maintained at as low a temperature as 15° Fahr.

The arrangement of the cooling pipes in cold stores for preserving provisions of a perishable nature requiring to be kept at various temperatures between 25° and 45° Fahr., in accordance with the description of the said provisions; or of those in chambers for freezing or congealing meat and keeping it frozen, which require to be maintained at temperatures of between 10° and 18° Fahr., according to the work demanded, only differ from other installations in the particular disposition and number of the said pipes, the chambers intended for the latter purpose being, of course, fitted with the greatest number.

When the direct expansion system is in use the pipes should invariably be of wrought iron, and even where the brine circulating system is employed they should preferably also be of the latter material in the case of freezing-chambers, as the heat from the said chambers passes more readily through the thinner walls of the smaller wrought-iron pipes. Besides which there is, as has been already mentioned elsewhere, a considerable saving of space.

The atmosphere of cold stores in some instances should be kept as dry as practicable; whilst in others a certain amount of moisture is desirable, as, for instance, when used for preserving fish which are injured by the air being too dry. For preserving meat for comparatively short periods the best temperature is from 30° to 40° Fahr., as most descriptions are injured to a greater or less extent if permitted to freeze, by the bursting of the vesicles of which flesh is composed. When, however, it is required to be preserved for a longer period than, say, three weeks it is absolutely essential that the meat should be frozen, otherwise a slight decomposition will take place, and it will become greatly deteriorated.

The efficient insulation of a freezing room or of a cold store, or refrigerating chamber, is a matter of very great importance from an economical point of view. This will be apparent when it is remembered that when once the contents of the said cold store or chamber are reduced to the requisite temperature, the entire work required of the refrigerating machine will be only that which is necessary to neutralise the heat that passes through the walls, floor, and ceiling thereof, from the exterior. Consequently, the more perfect the insulation, the less the machine will be called upon to work, and naturally in a corresponding ratio also will be the saving effected in fuel, wear and tear of the working parts, and in attendance.

The means adopted for insulation consist in lining the room, or, in the case of a marine installation, the hold of the vessel, with some material forming a very bad conductor of heat. The exact method of carrying this out, as also the nature of the non-conducting material employed, must necessarily be considerably varied according to the circumstances of each case. In New Zealand and Australia pumice is much used.

Mr. Lightfoot recommends as a fairly good protection an outer and an inner layer of tongued and grooved boards, 1 in. or 1½ in. thick, with a 9 in. space or clearance between them filled with charcoal, or in some cases preferably with silicate cotton or slag wool.

In France and Germany cork is used with marked success as a non-conductor, and it is evidently a substance exceedingly suitable for the purpose in question, being a material very impervious to heat, and capable of withstanding moisture. Either ordinary cork cut into thin slices, or refuse or waste cork, from other industries, thoroughly ground up or disintegrated into a coarse powder, is employed, the former being the best but the most expensive.

Various other substances such as asbestos, cotton-wool, sheep's-wool, pine-wood, loam, gas works breeze, coal ashes, sawdust, hair felt, lamp black, mica, paper, fine cinders, pitch, &c., are likewise employed for purposes of insulation. A number of different compositions have also been tested and used as heat insulators, amongst which may be mentioned the following:—Composition of fossil meal, composed of 60 per cent. of washed white German kieselguhr, and 40 per cent. of binding material; composition of kieselguhr from German mines, with 10 per cent. of binding matter, such as fibre, and mucilaginous extract of vegetable; cement composed of blue clay mixed with flax; jute, and woollen waste, or cow's hair, in equal proportions; fibrous composition of fine blue clay mixed with flax, hemp, rope, jute, cow-hair, and woollen waste; and a papier-maché composition composed of paper-pulp mixed with clay and carbon, together with hair and fragments of hemp-rope.

In choosing a substance other considerations besides its good insulating powers must be taken into consideration, such, for instance, as its capacity for withstanding moisture. This latter quality is of the utmost importance, inasmuch as at very low temperatures moisture from the air is very readily absorbed by many substances, and fermentation, rotting, and decay will result therefrom. It is for this reason that cork forms so desirable a material for insulating purposes, although surpassed in non-conductibility by some others. For a like reason pitch, or some form of enamel composed of bitumen and other ingredients, are found to be very valuable. Lampblack is claimed to be a very good material for insulating purposes in railway and other portable refrigerating chambers, by reason of its lightness and elasticity, and more particularly on account of its non-liability to pack from jolting, and complete in perviousness to moisture. This material is the one employed by Henry Carr Godell, in his patent (1884) movable refrigerating chamber. When it is desirable to increase the elasticity and reduce the cost, he sometimes uses a mixture of either short fibre or scales of mica.

Whatever the filling material that may be employed for insulating purposes, however, it should always be borne in mind that the more air that is enclosed with it between the walls or skins the better, for it is a well-known fact that the best non-conductor of heat is dry air, the units of heat transmitted per square foot per hour, through a layer of confined air of 1 in. in thickness, being about ·29.

The following materials and dimensions have been recommended for walls of cold chambers:—

14 in. brick wall, 3½ in. air space, 9 in. brick wall, 1 in. layer of cement, 1 in. layer of pitch, 2 in. by 3 in. studding, layer of tar paper, 1 in. tongued and grooved boarding,

2 in. by 4 in. studding, 1 in. tongued and grooved board, layer of tar paper, and, finally, 1 in. tongued and grooved boarding, the total thickness of these layers or skins being 3 ft. 3 ins.

36 in. brick wall, 1 in. layer of pitch, 1 in. sheathing, 4 in. air space, 2 in. by 4 in. studding, 1 in. sheathing, 3 in. layer of mineral or slag wool, 2 in. by 4 in. studding, and, finally, 1 in. sheathing; total thickness, 4 ft. 7 in.

14 in. brick wall, 4 in. pitch and ashes, 4 in. brick wall, 4 in. air space, 14 in. brick wall; total thickness, 3 ft. 4 in.

14 in. brick wall, 6 in. air space, double thickness of 1 in. tongued and grooved boards, with a layer of waterproof paper between them, 2 in. layer of the best quality hair felt, second double thickness of 1 in. tongued and grooved boards, with a similar layer of paper between them; total thickness, 2 ft. 2 in.

14 in. brick wall, 8 in. layer of sawdust, double thickness of 1 in. tongued and grooved boards, with a layer of tarred waterproof paper between them, 2 in. layer of hair felt, second double thickness of 1 in. tongued and grooved boards, with a similar layer of paper between them, total thickness, 2 ft. 4½ in.

See also pages 172, 177, 182, and 183 for further plans for the insulation of cold stores or chambers.

The following table, from experiments by Peclet, gives the amount of heat in units transmitted per square foot per hour, through various substances, in plates or layers of 1 in. in thickness, many of which are suitable for insulating cold-air or refrigerating chambers. The experiments were made by heating one side of the plates or layers by means of hot water, and cooling the other side by cold water, the difference between the temperature of the two faces being 1° Fahr. The materials are arranged in consecutive order, commencing at the worst non-conductors, or best conductors of heat.

Materials.	Units of heat transmitted.	Materials.	Units of heat transmitted.
Gold	625	Stone	14
Platinum	600	Glass	6·6
Silver	595	Terra-cotta	4·8
Copper	520	Brickwork	4·8
Iron	230	Plaster	3·8
Zinc	225	Sand	2·17
Tin	178	Oak, against the grain or fibre	1·7
Lead	113		
Marble	24		

Materials.	Units of heat transmitted.	Materials.	Units of heat transmitted.
Walnut, with the grain or fibre . . .	1·4	Charcoal (wood) in powder	·63
Fir, with the grain or fibre . . .	1·37	Straw, chopped . .	·56
Guttapercha . .	1·37	Coal, powder sifted .	·54
India-rubber . .	1·36	Wood ashes . .	·53
Brickdust, sifted . .	1·33	Mahogany dust . .	·52
Coke, in powder . .	1·29	Canvas, hempen new .	·41
Iron filings . . .	1·26	Calico, new . . .	·40
Cork	1·15	Writing paper, white .	·34
Chalk, in powder .	·86	Cotton and sheep's wool	·32
		Eiderdown . . .	·31
		Blotting paper, grey .	·26

The quantity of heat in units, transmitted through one square foot of plate per hour, may be found thus: subtract the temperature of the cooler side from that of the hotter side of the plate, then multiply the result by the number in the preceding table corresponding to the material used, and divide the product by the thickness of plate. Thus an iron plate 2 in. thick, having a temperature of 60° on one side and 80° on the other, will transmit $80 - 60 = \frac{20 \times 230}{2} = 2{,}300$ units of heat per square foot per hour.[*]

A series of five experiments[†] on radiation at low temperatures were conducted by Raoul Pictet on the rate of heating of a body cooled to $-170°$ Cent. ($-338°$ Fahr.), the surrounding atmosphere being at a temperature of $+11°$ Cent. ($+51·8°$ Fahr.). The refrigerators employed were cooled by a mixture of sulphur dioxide and carbon dioxide (Pictet's special liquid), or by liquid nitrous oxide, their thermal capacity being considered in every case. In the first experiment the surface of the refrigerator was uncovered; in the second it was encased in a sufficient covering of cotton waste to prevent the formation of hoar frost on the metal; whilst in the third, fourth, and fifth series protecting layers of 10, 25, and 50 centimetres in thickness were employed.

The results showed that at extremely cold temperatures be-

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[*] Hutton. "Works Managers' Handbook." Crosby Lockwood & Son.

[†] "Comptes Rendus de l'Académie des Sciences," Paris, vol. cxix., p. 1202: 1894.

tween −170° Cent. (−338° Fahr.) and −100° Cent. (−212° Fahr.) a thick layer of cotton afforded but a slight protection. It was only between the temperatures of −20° Cent. (−68° Fahr.) and + 10° Cent. (+ 50° Fahr.) that the effect of the protecting layers became proportional to their thickness.

In the opinion of Mr. Pictet, bad conductors of heat are capable of absorbing, with considerable efficiency, the radiations from bodies at temperatures between −60° Cent. (−140° Fahr.), and + 11° Cent. (+ 51·8° Fahr.), but are ineffective as regards calorific vibrations at temperatures below −60° Cent. (−140° Fahr.). With other non-conducting substances, such as silk, wool, sawdust, cork, charcoal powder, and peat, the results were identical, and, as a rule, bad conductors appeared to be freely permeable to heat at low temperatures between −100° Cent. (−212° Fahr.), and −170° Cent. (−338° Fahr.).

The table on the next page gives the results of tests* undertaken by Professor Andrew Jamieson, M.Inst.C.E., for the purpose of determining the relative and absolute thermal conductivities of substances used as lagging for steam-boilers, for parts of steam-engines, and for refrigerating machines. The method adopted was to observe the fall of temperature in a known weight of hot water contained in a vessel coated on all sides with a certain thickness of the material under examination, the outer surface of which was maintained at a constant temperature by the continuous flow of cold water through a water-jacket.

The apparatus consisted of three cylindrical tin cases, the innermost of which was fitted with a water-tight lid having central funnel through which the hot water was inserted. The space or clearance of 1 in. left between the first or innermost vessel, and the second vessel, contained the non-conducting material under test; and the space between the second and third vessel formed the water-jacket. Thermometers were placed in the hot-water chamber and water-jacket, and an arrangement for stirring the water in the said hot-water chamber in the innermost vessel was likewise provided. Each specimen of non-conducting material was placed upon a separate inner case, each of the latter being covered to a uniform thickness of 1 in. in the manner in which the said material would be employed in actual practice. The non-conducting composition was applied in layers, carefully dried in succession, so as to ensure the dryness necessary to the accuracy of the tests being obtained.

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* "Minutes of Proceedings, Institution of Civil Engineers," vol. cxxi., Session 1894-95, pp. 291, 292, 293, 294, 295.

The covered tin cases were tested as follows:—10 lbs. of boiling water was poured through a funnel into the hot-water chamber. Cold water was then allowed to flow uniformly from the main water-pipe, and to circulate freely through the cold-water chamber. During no test was the temperature in this chamber observed to rise as much as 1° Cent. The outer surface was, therefore, kept at a constant temperature throughout each test. In order to prevent the temperature of the hot water from falling too quickly at first, and to bring the non-conductor and the whole apparatus to a condition of constant temperature or heat equilibrium, steam at atmospheric pressure generated in a Florence-flask, was first passed into the inner vessel by means of a glass tube led into it through the funnel. The steam-pipe was then removed, and a paraffined cork fitted tightly into its position. The first reading was always taken when the temperature of the hot water had just fallen to 94° Cent. (201·2° Fahr.). The water in inner chamber was stirred by a perforated piston prior to the readings of the thermometers in the two chambers, which were taken simultaneously, being noted. Successive readings of both thermometers were taken in the same way, and recorded every ten minutes.

Results of the Tests.

Name of Material.	Weight of Sample (including Tin).		Total fall of Temperature in 120 minutes.	Thermal Conductivity in Absolute Measure.	Conductivity as Compared with Dry Still Air.
	lbs.	oz.	Deg. Cent.		
Dry air	—		6·0	0·0000558	1·00
Fossil meal composition	7	2	21·5	0·0002689	4·82
Cement with hair felt*	5	15	30·0	0·0003613	6·47
Silicate cotton,† or slag wool	—		29·0	0·0003875	6·95
Kieselguhr‡ composition	7	13	29·0	0·0004336	7·77
Papier maché composition§	7	6	35·5	0·0004424	7·93
Fibrous composition (flax, hemp, cow-hair, and clay)	9	9	34·5	0·0004550	7·98
Papier maché composition‖	8	12	37·5	0·0005019	8·99

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* The outside diameter of this sample was about $\frac{1}{4}$ in. smaller than the inside diameter of the middle tin-case or vessel, and it had consequently a

The results of tests[¶] made by Mr. John G. Dobbie, superintending engineer at Calcutta to the British India Steam Navigation Company, to determine the conductivities of asbestos and Kieselguhr composition were as follows :—

RESULTS OF TESTS.

	Asbestos.	Kieselguhr Composition.
	Water Condensed in Inches.	Water Condensed in Inches.
After 15 minutes . .	4¼	2½
,, 30 ,, . .	3¾	2⅜
,, 45 ,, . .	3⅜	2¼
,, 60 ,, . .	3⅜	2⅛
Totals in one hour . .	14¾	9¼

This experiment shows a saving of 36 per cent. in favour of Kieselguhr composition. The tests were made with two boiler-tubes—3½ in. in outside diameter and 7 ft. long, closed at both ends, and covered with a thickness of 2 in. of asbestos and Kieselguhr composition respectively. The tubes were suspended side by side, and steam was admitted at the top, a gauge-glass being fitted at the bottom of each by which the amount of condensation inside the tubes could be accurately observed. Steam at a pressure of 30 lbs. per square inch was used in the tubes. In the first trial, which lasted one hour, 12·375 in. of water were condensed in the tube covered with

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slight advantage over the other samples in having a thin layer of air between its outer surface and the latter.

[†] The silicate cotton was pressed together tightly, and thus its conductivity appears greater than would have been the case had it been more loosely packed.

[‡] The Kieselguhr employed consisted on the average of Silica 83·8, Magnesia 0·7, Lime 0·8, Alumina 1·0, Peroxide of Iron, 2·1, Organic Matter 4·5, Moisture and Loss, 7·1. It was employed in conjunction with 10 per cent. of binding material, viz., fibre and mucilaginous extract of several vegetable matters.

[§] Papier-maché composition, consisting of paper pulp mixed with clay and carbon, together with hair and fragments of hemp rope.

[‖] A lighter modification of above.

[¶] "Minutes of Proceedings, Institution of Civil Engineers," vol. cxxi., Session 1894-5, pp. 301, 302.

asbestos, and 8·375 in. in that covered with Kieselguhr composition, showing 33 per cent. less water condensed with Kieselguhr composition. In the second trial, of one hour also, the condensation was noted every fifteen minutes, and gave the results shown in the above table.

From these and other tests the author has been led to the conclusion that hard-pressed asbestos paper or cloth is a better conductor of heat than silicate cotton or slag wool, felt, hair, wool, or some of the Kieselguhr compositions. The main reason for the superior non-conductivities of porous materials is on account of the entrapped and occluded air, hence the looser asbestos and other fibrous materials are laid on the better will they prevent radiation of heat.

In an appendix* to his paper on heat-insulators, Professor Jamieson gives some accounts of previous experiments, of which the following is a brief extract:—

"In 1881, Mr. Charles E. Emery, Ph.D., wrote a paper† on 'Experiments with Non-conductors of Heat,' wherein the results of his tests on fourteen different substances are given. The apparatus used consisted of a boiler, 4 ft. in diameter and 12 ft. long, constructed with three 10-in. tubes. Into these tubes were placed smaller tubes to receive steam, and around the inner tubes were placed the non-conducting substances, water being circulated through the larger shell outside of the outer tubes. The results (see table) were shown by the amount of steam condensed in the inner tubes, the water of condensation being conducted to small cylindrical vessels, each provided with a glass gauge."

In 1884, Professor John M. Ordway, of Boston, Mass., described in a paper‡ on "Experiments upon Non-conducting Coverings for Steam-pipes," tests of a great variety of substances by three methods, viz.: (1) by measuring the temperatures on the outside of the coverings; (2) by measuring the weight of steam condensed in a certain time over a certain length of covered pipe; (3) by a calorimeter.

In 1884, Mr. J. J. Coleman gave§ the results of a series of

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* "Minutes of Proceedings, Institution of Civil Engineers," vol. cxxi., Sessions 1894-5, pp. 298-299.

† "Transactions, American Society of Mechanical Engineers," vol. ii., 1881, p. 34.

‡ "Transactions, American Society of Mechanical Engineers," vol. v., 1883-84, p. 73.

§ "Proceedings, Philosophical Society of Glasgow," vol. xv., 1883-84, p. 90.

experiments (see table) on nine substances tested by means of Lavoisier's ice-calorimeter. The object of the experiments was to find the substance which would make the best covering for the "Bell-Coleman Freezing Machines."

In 1884, Mr. D. K. Clark, M.Inst.C.E., reported* to the National Smoke Abatement Institution the results of tests carried out at the works of Messrs. Samuel Hodge & Sons, Millwall, of seven substances as compared with a bare pipe.

In 1891, Mr. W. Hepworth Collins read a paper† on "The Comparative Value of Various Substances used as Non-Conducting Coverings for Steam Boilers and Pipes," giving the results of experiments in which a mass of each material to be experimented upon, 1 in. thick, was carefully prepared and placed on a perfectly flat iron plate or tray, which was then maintained at a constant temperature of 310° Fahr. The heat transmitted through each non-conducting mass was calculated in lbs. of water heated 10° Fahr. per hour (see table).

RESULTS OF DIFFERENT EXPERIMENTS ON THE HEAT CONDUCTIVITIES OF VARIOUS SUBSTANCES.

(*Silicate cotton being taken as* 100.)

Substance.	C. E. Emery. 1881.	J. J. Coleman. 1884.	W. H. Collins. 1891.	Prof. Jamieson. 1894.
Fossil meal composition	..	..	..	70
Cement with hair-felt	83	..	..	93
Silicate cotton or slag wool	100	100	100	100
Hair-felt or fibrous composition	..	117	114	112
Papier-maché	..	..	147	111
Kieselguhr composition	..	136	..	112
Sawdust	122	163	142	..
Charcoal	132	140	..	..
Cotton wool	..	122	..	..
Sheeps' wool	..	136	..	..
Pine wood (across the grain)	150	..	..	..
Loam	..	..	..	..
Gasworks breeze or coal ashes	240	230	299	..
Asbestos	229	..	179	..

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* *The Engineer*, vol. lvii., 1884, p. 65.

† "Report of the British Association for the Advancement of Science," Cardiff, 1891, p. 780.

As a further example of methods that have been actually successfully employed for insulation, it will be interesting to know that the cold storage chambers built at the St. Katherine Dock, London, were constructed as follows :—

On the concrete floor of the vault, as it stood originally, a covering of rough boards 1¼ in. in thickness were laid longitudinally. On this layer of boards were then placed transversely, bearers formed of joists 4½ in. in depth by 3 in. in width, and spaced 21 in. apart. These bearers supported the floor of the storage chamber, which consisted of 2½ in. battens tongued and grooved. The 4½ in. wide space or clearance between this floor and the layer or covering of rough boards upon the lower concrete floor was filled with well-dried wood-charcoal. The walls and roof were formed of uprights, 5½ in. by 3 in., fixed upon the floor joists or bearers, and having an outer and an inner skin attached thereto; the former consisting of 2 in. boards, and the latter of two thicknesses or layers of 1¼ in. boards, with an intermediate layer of specially-prepared brown paper. The 5½ in. clearance or space between the said inner and outer skins of the walls and roof was likewise filled with wood-charcoal, carefully dried.

A chill room or cold storage chamber should open into a porch, lobby, or anteroom, by which means the penetration of heat into the said chamber when it has to be entered to place provisions therein, or to remove them therefrom, is lessened.

The ducts or inlets for the admission of the cold air into the store or chamber when the refrigeration is effected by means of a cold-air machine, or by air reduced in temperature in a separate chamber as before described, are preferably placed as close to the roof or ceiling of the room, whether land or marine, as can conveniently be done, this having been found in practice to be the most advantageous position, and the said cold air having performed its work is drawn off at outlets also situated in this position.

In packing carcasses in a cold store or chamber, they should be placed as close together as possible, taking care, however, to leave a free space or clearance between them and the inner lining of the room, through which the cold air can freely circulate.

When hanging frozen mutton before cooking, care must be taken that it is so placed that the juice will not run out of the cut-end. For example, hind-quarters, haunches, and legs must be invariably hung with the knuckle-end downwards; and loins and saddles by the flaps, so as to give them an horizontal position. The cut-end, moreover, should always be presented to the fire first when cooking, thereby sealing it and preventing the gravy from escaping from the joint. Frozen lamb does not need any preliminary hanging, but can be cooked as soon as thawed.

The proper stowage of a fruit cargo in the cold store or chamber is likewise a matter that must be carefully attended to, in order to ensure its arrival at its destination in good condition. The essential point to be insisted upon is that clear spaces or clearances of at least ½ in. be left between each tier of cases, and between the said cases and the bottom, sides, and ceiling, of the chamber. These clearances can be managed by the insertion of laths of a suitable thickness between the cases. Passages should be also provided for admitting of inspections of the state of the fruit being made during the voyage.

The best temperature to maintain for fruit is one of from 45° to 55° Fahr., and this should be evenly kept up throughout the entire cargo. It must be borne in mind that the slightest degree of frost will destroy a whole cargo of fruit. It will generally be found sufficient to run the refrigerating machine about 12 hours per day in hot latitudes and 6 hours per day in cooler ones.

In a marine installation the pipe or trunk for admitting the cold air is usually fixed along one side of the cold store or chamber in the hold, as near the top or ceiling as possible, the return pipe or trunk being placed at the opposite side of the said chamber. As in a land installation the inlet trunk or pipe is fitted with a number of apertures governed by sliding doors; these are only opened to a very slight extent at the end nearest the machine, and gradually more and more as they approach the end furthest therefrom, thus equalising the temperature in the chamber. The most important point is to ensure the cold air being thoroughly circulated, and penetrating every portion of the chamber, and thermometers should be hung in different positions therein to form a check to the deck pipe ones. The snow box must be cleared out repeatedly, to prevent the passages, and also the slide valve ports, from becoming blocked up, and the trunk or inlet pipe must be cleared once a day or oftener. Previous to storing the carcasses in the cold store or chamber, a thorough inspection thereof should be made, and any damage to the walls made good. When the cold store or chamber is filled, the hatches should be made tight by caulking with oakum, or preferably they should be fitted with India-rubber insertions, which afford a greater certainty of air-tight joints being made.

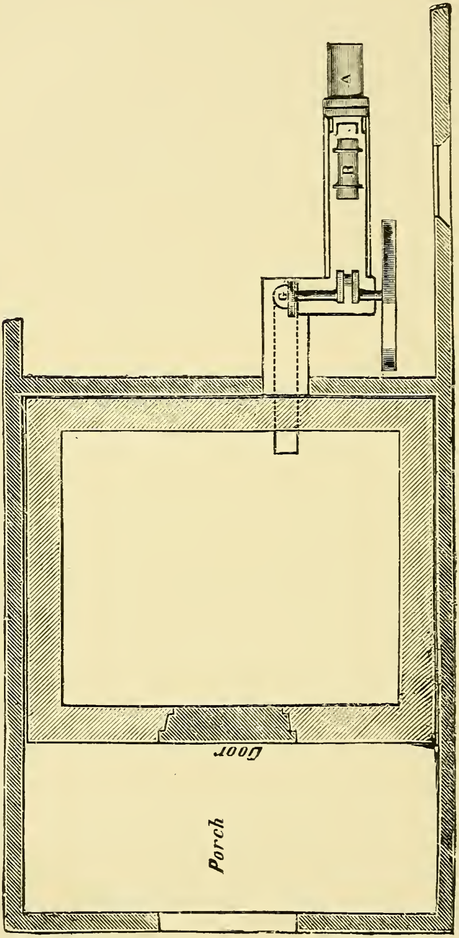

Fig. 60.

As regards the capacity of a machine required for the refrigeration of a cold store or chamber of any given dimensions, it would be obviously impossible, in view of the constantly varying circumstances of each individual case, to lay down any hard-and-fast rules. It will have to be separately estimated for each particular installation, in accordance with the amount of cooling work which is necessary, and which it is desired to perform upon the material enclosed in the cold store or chamber, and by the amount of heat that is calculated to pass into the latter from the outside, through the walls, floor, and roof. It will consequently be thus seen that the capacity of the apparatus will depend upon the lowest internal, and the highest external temperature, the area of the said walls, floor, and ceiling, and also to a great extent upon their construction being carried out in a manner more or less impervious to heat.

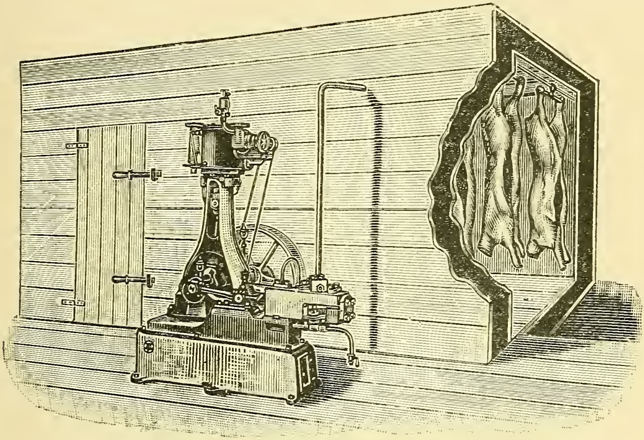

Fig. 61.

As a general rule, however, it will be found that, owing to the circulation of the air, and the radiation through the floor, walls, and roof of the chamber, the cubical contents of the air in the latter will require to be cooled from eight to fifteen times in every hour, in order to ensure the temperature being assimilated to that of the air or gas passing out of the machine.

Small cold stores or chambers are now commonly used by retail butchers for the preservation of both frozen and unfrozen meat, and also by dealers in fish, poultry, and game, butter salesmen, and others.

Fig. 60 is an horizontal section showing a plan of a small cold storage chamber of 1,000 cubic ft. capacity, adapted for such service. The refrigeration is effected by a Haslam cold-air machine, of 6,000 cubic ft. per hour capacity, arranged to be driven direct by means of a gas-engine. A is the gas-engine cylinder, B the air compression cylinder, and C the expansion cylinder. The air compression cylinder B is arranged horizontally in front of, and in line with, the cylinder A of the gas motor, and the expansion cylinder C, is placed vertically, and works a disc secured upon the opposite end of the crank shaft from the fly-wheel.

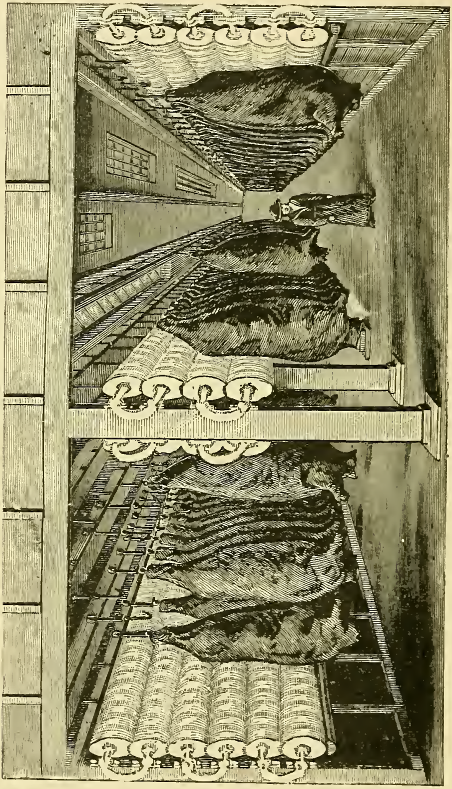

Fig. 62.

The advantages of a gas motor for driving the small cold-air machine required for an installation of this description are obvious, and comprise: non-increase of fire insurance premium, and ability to start the machine at any time, without having to wait to get up the necessary steam pressure in a boiler, as must be done in the case of a steam-driven cold-air machine.

Fig. 61 is a perspective view, the end wall and a portion of the front wall being removed, showing a small cold store or chamber, refrigerated by means of a Puplett patent ammonia compression machine, which chamber is especially designed for bacon-curers, butchers, dairymen, fish and game dealers, &c. Chambers of this description are constructed with an outer and an inner skin, each of which is composed of two layers of 1 in. tongued and grooved boards, put together perfectly air-tight, and having an intervening space or clearance of about 8 in., filled with charcoal, cork, or other good non-conducting material. The dimensions of the chambers, as usually constructed, vary from a storage capacity for frozen meat of 6 to 50 tons or more, and their daily meat-cooling capacity to 32° Fahr. runs from 20 cwt. up to 200 cwt. or more.

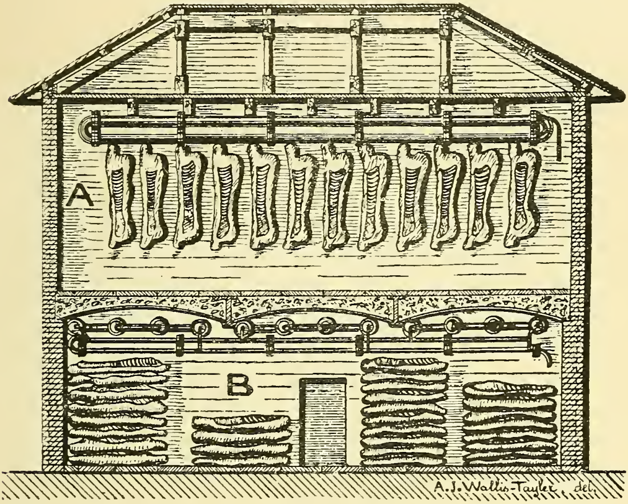

Fig. 63.

Fig. 62 shows a beef chill-room fitted with the De La Vergne

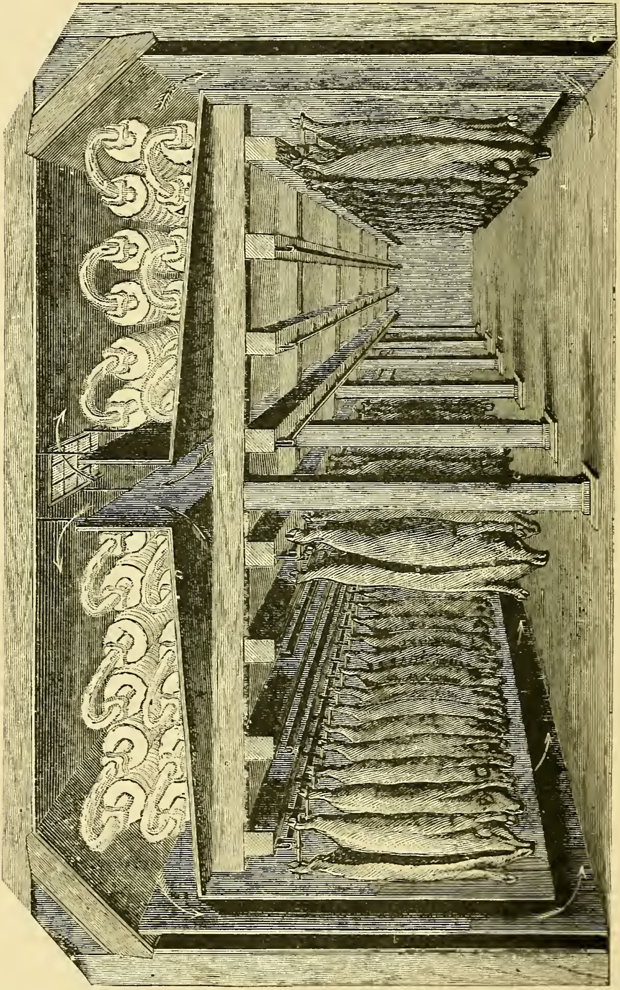

Fig. 64.

patent pipe system, a description of which has been already given on pages 153 and 156; and Fig. 31*d* (frontispiece) illus trates another beef chill-room fitted up with the Haslam patent air-cooling battery.

Refrigerating machines are likewise very advantageously employed in bacon-curing factories or works, for enabling mildly cured bacon to be produced in summer, by artificially reducing the temperature of the chill-rooms and curing cellars.

A usual arrangement is shown in Fig. 63, which comprises rows of cast-iron flanged pipes which are fixed overhead, preferably suspended from the ceiling, over the whole area of the chill-rooms and curing cellars, and through which system of pipes brine cooled in the usual manner is circulated so as to lower the temperature of the said rooms to about 40° Fahr. By means of cocks provided on the different branch mains the speed of the flow of brine through the various circulations, and consequently the temperature of the rooms, can be regulated, and reduced or increased at pleasure. In factories of moderate size the machine may usually be stopped at night and on Sundays, the cold stored up in the brine in the pipes being enough to keep the temperature of the room sufficiently low; in very hot weather, and in very large establishments, however, the machine will have to be run continuously night and day.

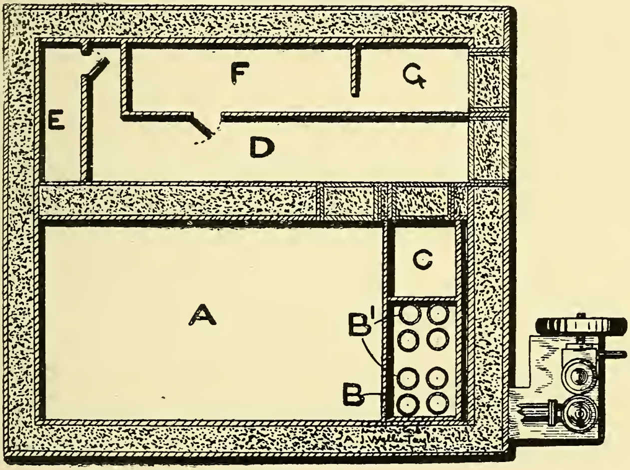

Fig. 65.

Both the chill or cooling-rooms and the curing-cellars are fitted up in practically the same manner; the work in the chill or cooling-rooms where the hot meat is cooled down is much greater in proportion to their size, however, and is moreover intermittent, consequently a proportionately larger number of brine pipes are placed therein, and the brine is turned on or off as the rooms are full or empty; on the other hand the work in the curing-cellars is less and regular, and, therefore, a much smaller number of brine pipes are required, the circulation of brine being kept up all the time the machine is running, and a perfectly steady and even temperature maintained.

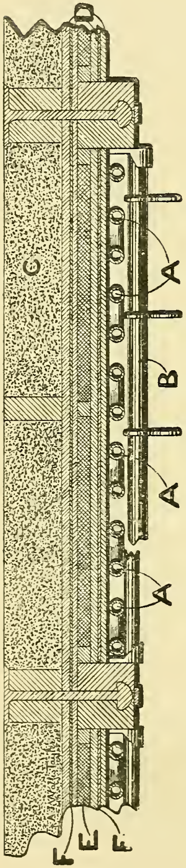

Fig. 66.

Fig. 64 illustrates a hog chill-room, fitted with the De La Vergne patented system of pipes, working with direct expansion of the ammonia gas or vapour (see pages 153, 156).

The reason that artificial refrigeration is now imperatively required in bacon-curing works is on account of the demand that has arisen for mild-cured bacon. Formerly the pigs, after being killed, were cooled simply by exposure to the atmospheric air, being subsequently cured in underground cellars at the temperature of the earth or from 52° to 55° Fahr. In order to prevent the rapid decomposition, and consequent taint of the bacon which would otherwise inevitably occur at these comparatively high temperatures, the latter was charged with an excessive amount of salt as a preventative. This excessive salting was indispensable in summer especially, when, indeed, curing was almost prevented, although bacon at that season is in the greatest demand, and the highest prices are obtainable. The modern requirement, however, for more, and more mildly-cured bacon has rendered absolutely necessary an artificial reduction of the temperature of the chill-rooms and curing-cellars.

The first attempts in this direction were made by constructing the cellars with iron ceilings, on the tops of which were stored vast quantities of ice, a system which is found to be sufficiently effective, but is very expensive, not only by reason of the first cost of the iron ceilings and the necessary supports, but also by reason of the space occupied by the said ceilings and ice chambers, and furthermore on account of the large outlay entailed for the ice itself, and the labour of handling it. There is, besides this, the risk of the supply of ice running short in the hot weather, with, of course, disastrous results.

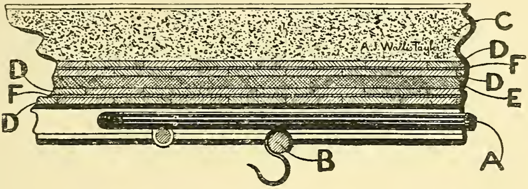

Fig. 67.

An arrangement of a small cold store or chamber, such as is very frequently constructed on board a large passenger steamer, is shown in sectional plan in Fig. 65. The refrigeration is effected by means of a Lightfoot, Haslam, or other cold-air machine of the vertical type.

The arrangement of this cold store or chamber, which is practically similar to that of those used on the passenger steamers of the Peninsular and Oriental Company, will be very readily understood from the drawing, wherein A is the meat room, the temperature of which is kept down to about 20° Fahr., and wherein are situated the ice-making or freezing tank B, the ice cans or cases B¹ B¹, and the ice store C. D is the vegetable room, which is maintained at a temperature of about 40° Fahr., and in which are placed the water-cooler E, wine closet or cooler F, and hanging room G.

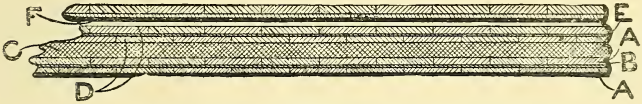

Fig. 68.

The cold air provision stores or chambers on board of the Cunard Company's steamships *Campania* and *Lucania* are fitted up with refrigerating plants, on the De La Vergne ammonia compression system.

The refrigeration is effected on the brine circulation, and not upon the direct expansion system, a solution of calcium chloride being the agent or medium employed, and the said solution is reduced to a very low temperature in the usual manner, by the expansion of the ammonia gas or vapour, in coils or pipes submerged therein, and is circulated by a special pump through the system of cooling or refrigerating pipes, which latter are fixed to the underside of the roof or ceiling of the cold store or chamber. The method employed for the insulation of the store or chamber is shown in Figs. 66 and 67, which are vertical sections through the roof or ceiling thereof. A, A, are the refrigerating pipes; B, B, the meat rails; C is a filling of sawdust; D, D, are layers or skins of tongued and grooved boarding; E is a layer of hair felt; and F, F, are layers of tarred water-proof paper. The brine pipes are divided into two sections or sets, thereby admitting of any necessary repairs being effected in one section, without in any way interfering with the circulation of the cold brine through the other section, and special means are also provided for withdrawing the brine from one set or section without interfering with the working of the other.

The ammonia compressor is of the vertical single-acting type, and is actuated by a high-pressure horizontal steam-engine. The compressor cylinder is 4½ in. in diameter, by 9 in. stroke, and the steam-engine is of 2½ horse-power, and is fitted with a special governing arrangement, by means of which the steam supply is determined, the speed being capable of variation within a wide range (say between 30 to 300 revolutions) without interfering with the running of the machine. The construction of the compressor is substantially similar to that described with reference to Fig. 15, and the oil separator and other parts only differ from the arrangement shown in the general view of a complete installation shown in Fig. 16, in that the ammonia compressor is of the single-acting type, and by reason of the smaller capacity of the present plant, and the absolute necessity on shipboard for economising every cubic inch of room possible. The operation of the apparatus is, however, in every way identical, and the description of the said complete installation will apply equally well in this case.

The apparatus is capable of making 5 cwt. of ice daily, in addition to the performance of the refrigeration required in the cold store or chamber.

The cargo holds of the same steamships are refrigerated with machines of the Kilbourn type. The meat-carrying chambers in each of these vessels consists of three chambers situated forward on the orlop or lower deck, and having a total capacity of 20,000 cubic ft., which renders them able to carry 2,700 quarters of beef. The chambers are very carefully insulated, the walls consisting, as shown in Fig. 68, first of a double thickness of tongued and grooved boards A, A, having a layer of waterproofed paper B between them, next a 2-in. layer of good quality hair felt C and another double thickness of tongued and grooved boards D, D, with a similar layer of paper E between them, and finally an inch air space F between the latter and the inner or iron deck, the whole being well varnished. The brine cooling pipes, which are of heavy 2-in. galvanised tube with malleable cast return bends, are placed on the ceiling between the deck beams, thus economising head room, and the rails for the meat-hooks are of $1\frac{1}{8}$ in. galvanised round iron, firmly clipped to the beams supporting the decks. The meat hooks which are placed upon the latter, for carrying the quarters of beef, are of steel galvanised. Thermometer tubes from the upper deck are provided to each chamber, so that the temperature may be ascertained in any part of the said chamber, when desired.

Fig. 69 is a plan showing the general arrangement of the machine-room. A pair of compressors are employed. A, A, are the steam-engine cylinders; B, B, the compression cylinders; C, C, the ammonia condensers; D, D, the liquid ammonia reservoirs; E, E, the refrigerators; F is a brine circulating pump of the duplex pattern; G a manifold or distributing pipe to the different cooling pipes in the chambers; H is the collecting pipe at the top of the refrigerator. It will be seen that the cold parts of the machine are enclosed in a separate chamber having walls insulated in a similar manner to those of the meat-carrying stores or chambers, thereby preventing as far as practicable loss through absorption of heat.

The compressors are similar in construction to those already described with reference to Fig. 27, and are of an ice-producing capacity of 12 tons a day, the compression cylinders being 6 in. in diameter by 12 in. stroke, and the steam cylinders 8 in. diameter by 12 in. stroke.

The ammonia condensers C are constructed of a cylindrical form, the shells being made of wrought-iron, and the covers of cast-iron, and they are fitted with concentric coils of $1\frac{1}{2}$ in. galvanised iron pipe, connected together at their extremities by means of tee-pieces made of malleable castings. The said ammonia condensers, moreover, are carefully lagged with teak wood. The water for use in the ammonia condensers C is supplied and circulated by means of a duplex steam pump (not shown in the drawing), located in the forward boiler-room of

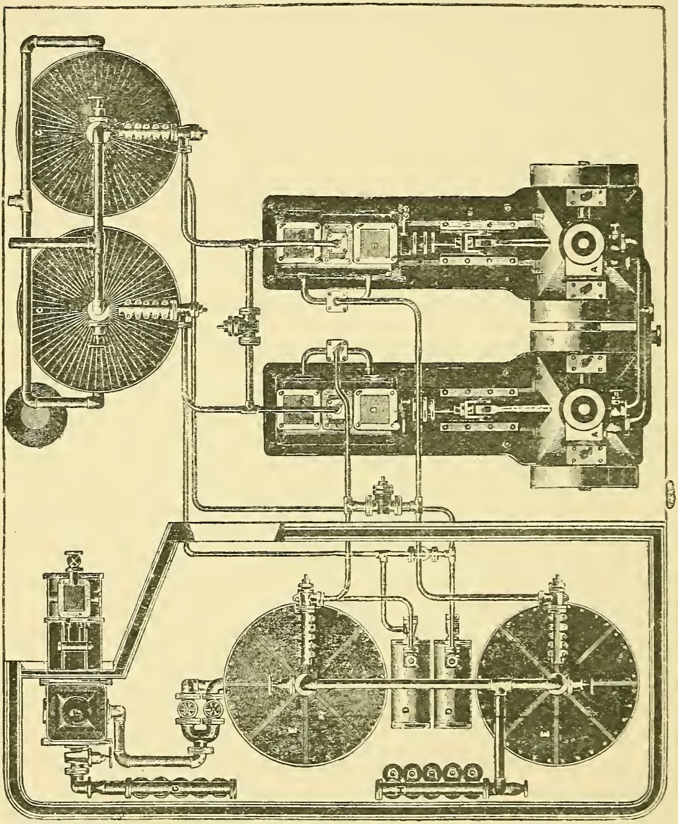

Fig. 69.

the steamship. The ammonia gas after compression in the compressors B, and liquefaction in the condensers C, under the combined pressure of the said pumps or compressors B, and the cooling action of the condensing water circulating on the exterior of the coils or worms in the condensers, is delivered to the reservoirs D for the liquefied ammonia, through small bore pipes. From these reservoirs the said liquid ammonia is admitted through suitable graduated expansion or regulating valves to the lower ends of the expansion coils in the refrigerators E, wherein the liquid ammonia again vaporises or gasifies, abstracting the heat required for this process from the brine surrounding the expansion coils, and being again returned to the compressors, and so on *ad infinitum* in the manner already described. The absolute working pressure in the refrigerators is about 30 lbs. per square inch.

The brine having been reduced to the desired temperature in the refrigerators, passes into the system of brine circulating pipes, and maintains the atmosphere of the cold stores or chambers at a temperature suitable for the proper preservation of the meat. The circulation of the brine is effected by the brine pump F, which draws the cooled brine from the bottom of the refrigerators E, and discharges it through the distributing tee-piece and valves, or manifold G, to the different sections of the cooling pipes in the chambers, and returns it through a similar tee-piece, manifold or distributor H, to the top of the refrigerator to be again cooled. The return brine pipes are each fitted with a regulating valve and a thermometer.

An important type of portable refrigerator is that adapted to meet the requirements of barges, railway trucks, and cars or vans, which it is desirable to maintain at a low temperature for considerable periods, but which, for obvious reasons, it is undesirable, in doing so, to encumber with machinery, to increase in weight to any considerable extent, or to render in any way necessary the employment of special labour to take charge of same.

The frozen meat, as a rule, arrives in good condition on board the vessels, and deterioration in quality usually takes place during its transference to the cold stores on land, and again during the subsequent delivery thereof to the retailer, when the said meat is exposed to temperatures frequently much higher than what is required to preserve it in good condition. The great desideratum for this purpose is a plan which will avoid the necessity of carrying the source of refrigeration upon the conveyance itself, which necessity has hitherto rendered the latter too expensive for practical purposes; this the Pulsometer Engineering Company, Limited, claim to have successfully accomplished in their system of refrigeration for barges, railway trucks or cars, and other portable chambers, and they state that they are willing to guarantee to maintain below the freezing point properly fitted portable chambers of all kinds, for ample time for transit between Penzance and Aberdeen.

Since the beginning of 1888, moreover, the London and Tilbury Lighterage Company, Limited, have had barges fitted with special refrigerating apparatus successfully plying upon the Thames, the meat landed by them being invariably in good condition, and not infrequently at a lower temperature then, than when first discharged from the vessel.

The method of refrigeration primarily employed in vans and railway trucks, was to effect the production of cold with mixtures of ice and salt. The great objection to this arrangement is the large increment of weight, and the nuisance and damage caused by the moisture due to the melting ice.

As early as the year 1867 a refrigerator car was constructed in the United States having a refrigerating chamber surrounded by an air space. A fan or blower was provided, driven off one of the car axles, and air was forced by this blower through a compartment containing ice into the refrigerating chamber. The water resulting from the liquefaction of the ice in the said compartment, which had a capacity of about 2 tons, was drawn off through a suitable trap. In some instances the ice was replaced by a refrigerating mixture passing through a suitable pipe in the ice-box or chamber. The air was drawn in by the fan during the forward motion of the car, and after being passed through the ice-chamber was delivered at the top of the refrigerating chamber. A car of this description is said to have successfully transported meat slaughtered in Illinois to New York, during the hottest part of the summer, no perceptible deterioration in quality having occurred during the ten days' journey.

Another refrigerator car of somewhat similar construction, having the external appearance of an ordinary freight car, has an ice-box at each extremity wherein the ice is placed upon gratings so arranged that a current of cold air circulates continually through a flue situated near the top of the chamber, over the surface of the ice, down to the floor, and then up again amongst the meat. The air circulation is maintained by a fan in a like manner to that above-mentioned. The car was also built double, with inside double doors, filled in with charcoal, and the temperature of the meat was easily kept at about 40° Fahr. even in the hottest weather.

As has been already mentioned Godell uses lampblack, or a mixture of lampblack and mica scales, as non-conducting material for use in refrigerator cars.

In another arrangement, also used in America, the car is cooled by means of some suitable volatile liquid, which is allowed to vaporise slowly through a system of pipes from one reservoir into another, thus reducing the temperature of the chamber. The objection to this arrangement is the danger of leakage of the said volatile liquid taking place into the refrigerating chamber.

CHAPTER XI.

VARIOUS OTHER MANUFACTURING AND INDUSTRIAL APPLICATIONS.

USES are now made of refrigeration in many manufactures and industries, besides that of its more legitimate and important application to the preservation of various provisions of a perishable nature, which latter has been already dealt with, so far as space would allow, in the preceding chapter. All the systems hereinbefore described, with the exception of the first or that wherein the abstraction of heat is effected by the more or less rapid dissolution or liquefaction of a solid, are, to a greater or less degree, advantageously applicable for this purpose.

Although the preservation of organic substances was the first known and the most obvious use, the successful application of artificial refrigeration to a process of manufacture is somewhat older than that to the preservation of provisions, a Harrison ether machine having been erected at Trueman, Hanbury & Co.'s brewery about 1856, which machine was stated, at a meeting of the Institution of Mechanical Engineers, held in 1886,* to be still at work and acting efficiently. A machine of the same type was also said to have been put up by A. C. Kirk in 1861,† who employed it for the extraction of solid paraffin from shale oil.

The application of a refrigerating machine to the cooling of chocolate during the process of manufacture was first made by J. S. Fry in 1882,‡ in which year he employed one of Lightfoot's double expansion horizontal cold-air machines, and was enabled to proceed without interruption throughout the whole year with work that had previously to be suspended during the hot

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* "Proceedings, Institution of Mechanical Engineers," 1886, p. 246

† *Ibid.*, p. 231.

‡ *Ibid.*, p. 236.

weather. Since that time the use of refrigerating machines in chocolate works has become almost universal.

One of the, if not the, most important of the other industrial applications of refrigerating machines is that of cooling water to be used for refrigerating and attemperating purposes in breweries. This is more especially required when the supply of water is derived from a river or other source exposed to the heat of the sun, or from the water mains in large towns, the water from both of these sources usually rising, during the summer months, to from 65° to 70° Fahr.

Where a plentiful supply of well water at a temperature of from 50° to 54° Fahr. can be obtained, the provision of means for artificial cooling become of minor importance for this special purpose, and can be dispensed with.

When, however, the water supply is at a comparatively high temperature, such as that above indicated, it would of course be totally impossible to cool the worts down to the ordinary pitching temperatures of from 57° to 59° Fahr., or to control the fermentation in the tuns or squares with water at such a temperature passing through the attemperators, and, moreover, on the completion of the fermentations it would be likewise quite impracticable to cool the finished beers down to the temperature desirable for racking.

In Fig. 70 is shown the arrangement of an apparatus for cooling water for refrigerating and attemperating purposes in a brewery, by means of an ammonia absorption machine of the Pontifex-Wood type.

In the illustration H is the water-service pipe from the company's main, or from other source of supply; I is the cooled water-pipe leading from the cooler D up to the ice-water tank J, in which the cooled or refrigerated water is stored to be drawn off as may be required for refrigerating or attemperating. A thermometer is fitted on the pipe I at the outlet from the cooler, and a regulating cock or valve on the pipe H, by which the supply can be so adjusted as to admit of the cooled water being delivered at any predetermined temperature. The water from the supply pipe H is run direct through the coil of the cooler D of the machine (which is placed on the ground floor of the brewery, and sufficiently near the steam boilers to admit of a supply of steam being obtained for use in the generator), from whence it passes reduced to a temperature of 45° or 50° Fahr., or to any other desired lower temperature, to the tank J, which is at a sufficient elevation to command the refrigerators and

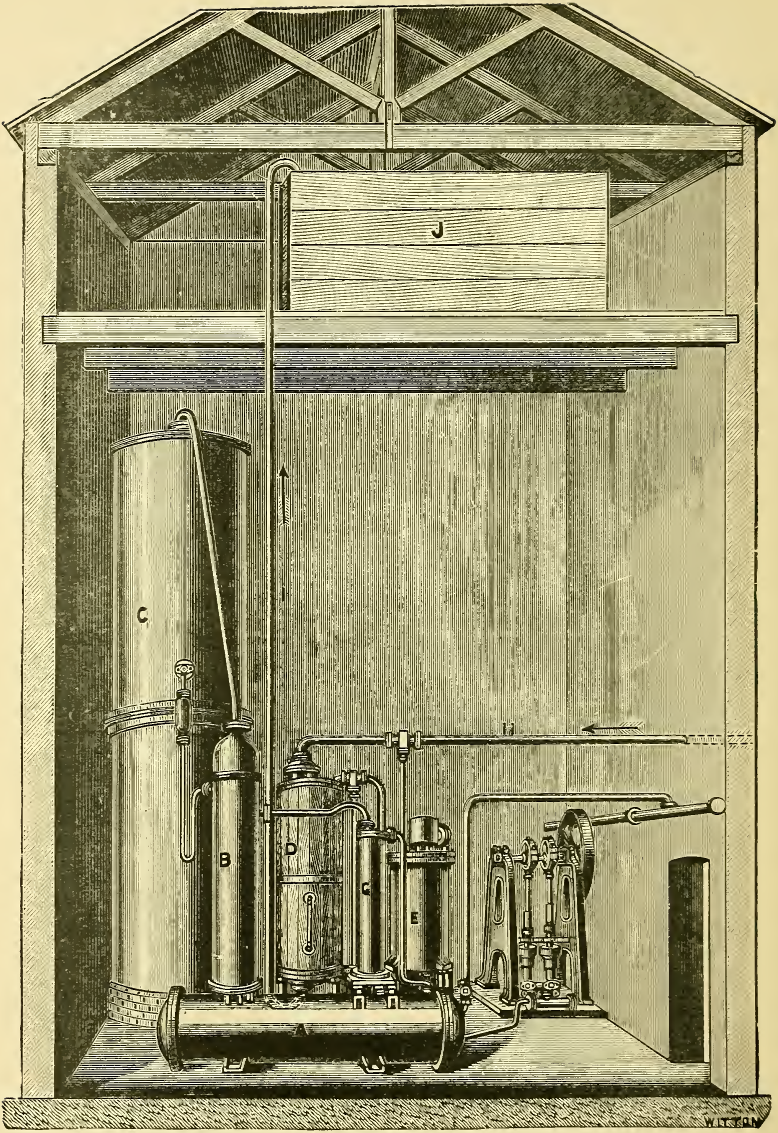

Fig. 70.

attemperators, and from which, as above-mentioned, it can be drawn off as wanted. The tank J is fitted with a suitable lid or cover, and is preferably constructed of wood, or of iron lagged with wood and sawdust.

A full description of the Pontifex-Wood ammonia absorption machine, having reference to the letters upon the drawing (Fig. 70), will be found on page 108.

In working an arrangement of this description the machine is started in the morning sufficiently early to admit of the ice water tank J being filled up by the time the refrigerators are set to work. The machine is kept in operation until the refrigerating is done, and for a sufficient length of time after to admit of the tank J being filled up again, so as to provide a sufficient supply of ice water for the use of the attemperators during the night and until the machine is again started next day. It is stated by the makers that when the tank J is properly constructed as regards insulation, it has been constantly found in practice that the rise in temperature of the water is not more than 1° Fahr. during a stoppage of from twelve to twenty-four hours. The ice water from the tank J is forced through the attemperators, due provision being made for enabling the supply to each of them being suitably regulated, or cut off altogether if desired, independently of the others. The pump for circulating the ice water through the attemperators should be self-acting, and provided with an automatic regulating device, thereby enabling it to act efficiently whether one or all the attemperators be at work.

The results obtained by the use of this arrangement in a brewery are, in addition to a marked improvement in the quality of the beer, that there is a complete control over the refrigeration and fermentation, the beer refrigeration can be performed in a very much shorter time, and, consequently, the day's work completed sooner, and lastly, that the waste occasioned by the necessity for passing the greatest possible quantity of the comparatively hot water through the refrigerators and attemperators is obviated. This latter item alone is by no means insignificant, the saving where water companies' water is employed for refrigerating and attemperating being generally more than half. In large breweries where several machines are employed, they are kept running continuously day and night.

An ordinary refrigerator for cooling hot beer wort consists of a shallow vat wherein is mounted a continuous tube or pipe, through which the cooling water is forced in a direction opposite to that taken by the said wort. The object of thus running the wort in one direction and the water in another is to insure the delivery end of the wort being exposed to the coldest portion of the stream of water. In another form the wort passes through a coil of pipe arranged in a vat, through which a circulation of cooling water is kept up. A more complicated arrangement is that wherein boxes are arranged to project alternately from opposite sides of a double walled vertical case; through the latter and which boxes the wort is caused to take a zigzag course by suitable check-plates extending centrally into the said boxes. The cooling water takes a like sinuous or zigzag course on the exterior of the said boxes. A wort or beer-cooler, employed in many large breweries, is a large shallow, covered vat, fitted with a volute formed by a wide strip of metal set on edge between the upper and lower plates or heads, to which it is attached, in such a manner as to form a helix with two distinct spaces. Through one of these spaces the refrigerating liquid, or medium, is circulated, suitable inlet and outlet passages being provided, and through the other the wort or beer to be cooled. Brotherhood's refrigerator consists of a number of long boxes placed side by side or otherwise, each box having a flow and return passage for the cooling water, and copper tubes through which the wort passes. Hollow covers at the ends of the boxes afford communication between one tier of tubes and another.

Mash tuns are likewise constructed in which the vertical shaft carrying the rake or stirrer is formed hollow, as also the arms of the said rake, which latter are perforated with a number of small holes. Through the above-mentioned hollow shaft and perforated arms steam is first passed to boil the wort, and subsequently air, reduced to a low temperature in order to cool or refrigerate it. In a refrigerating or cooling apparatus on a somewhat similar principle, air, previously reduced to a low temperature, is forced into the perforated false bottom of a vat, from whence it escapes, through the said holes or perforations, and passes up through the wort or beer contained therein.

Numerous other arrangements are also in use in this country and abroad. Two of which, of American origin, are as follows:—In the first the hot wort is delivered into a trough of a V shape in transverse section, from the bottom of which it trickles over a series of horizontal pipes arranged in line vertically, and through which the cooling water is passed, the cooled wort being finally collected in an U-shaped trough for delivery to the fermenting tun.

The second, which is extensively used in America for cooling or refrigerating hot beer wort, is that known as the "Baudelot Cooler." This apparatus is constructed for use both with a brine circulation and direct expansion. In the first case, the upper portion, or half of a set of tubes or coils, arranged horizontally, is cooled by the ordinary well or main water, and the lower part or half thereof by a circulation of cold brine or ice water. In the second arrangement the upper part or half of the said pipes or coils is similarly cooled, but the lower portion or half is cooled by direct expansion of the gas or vapour.

The ordinary practice is to first slightly reduce the temperature of the hot wort by exposing it in the large tank known as the cool-bed or cool-ship, which is generally located on the top of a building and roofed over, the sides being only enclosed by lattice work, so as to allow a free circulation of air, and then permit it to flow slowly down over the tubes or coils of the "Baudelot Cooler."

The Pontifex-Wood brine refrigerator (Fig. 74), a description of which will be found on page 201, with reference to its application to the cooling of water for use in margarine factories, is also very successfully employed for cooling beer worts.

Another, and also a very important, use for a refrigerating machine in breweries is that of cooling the air in the fermenting and yeast rooms, an arrangement for which purpose, on the brine circulation systems, is shown in Fig. 71. This cooling is necessary during hot weather, even in cases where an unlimited supply of cold water for refrigerating and attemperating is obtainable, inasmuch as the water can only be applied to the cooling of the beer itself in the fermenting vessels, and not to the head of yeast above. The result of this is that, although the fermenting beers can be kept well under control by the use of the attemperators, the yeast above is frequently found to be going wrong by reason of the excessive temperature of the atmosphere of the room.

In employing a refrigerating machine for this purpose, in connection with the arrangement shown in Fig. 71, brine reduced in the cooler or refrigerator to about its own temperature, that is from 10° to 20° Fahr., or very much lower if desired, is circulated through rows of pipes B fixed over the tuns A, or the squares, to be cooled in the fermenting rooms, and also in the yeast rooms, the said system of pipes being reduced by the brine to below freezing point, and the atmosphere of the rooms from contact with the latter to 45° or 50° Fahr., or any other desired point. By this means an October temperature, that is to say, one of 50° Fahr. or less, can be obtained during the hottest summer weather.

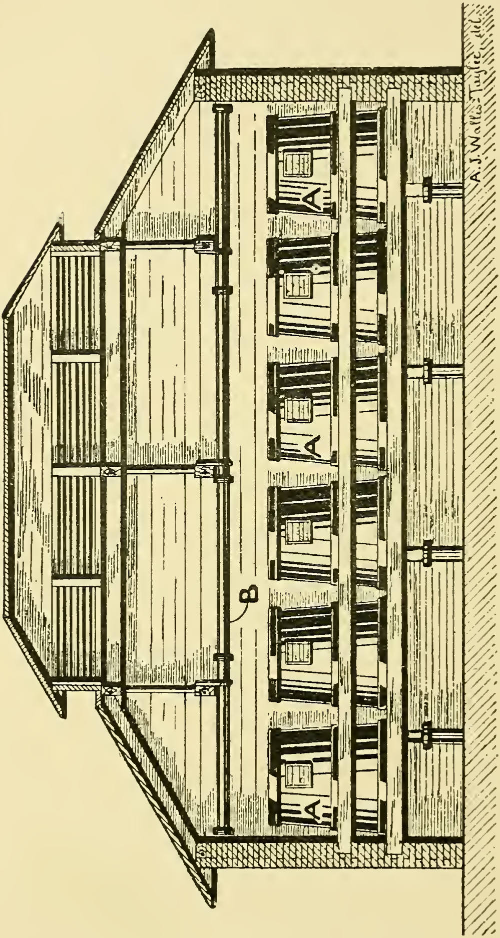

Fig. 71.

Fig. 72 shows an arrangement for cooling a fermenting room on the direct expansion principle, fitted with the De la Vergne patented pipe system, a detailed description of which will be found on pages 153, 155 and 156.

The speed of the flow of brine through the various circulations (Fig. 71) can be regulated at will by means of stopcocks or valves provided on the several branch mains, and that of the gas or vapour (Fig. 72) by the expansion valve, and consequently, also the temperature of the fermenting rooms. In simple

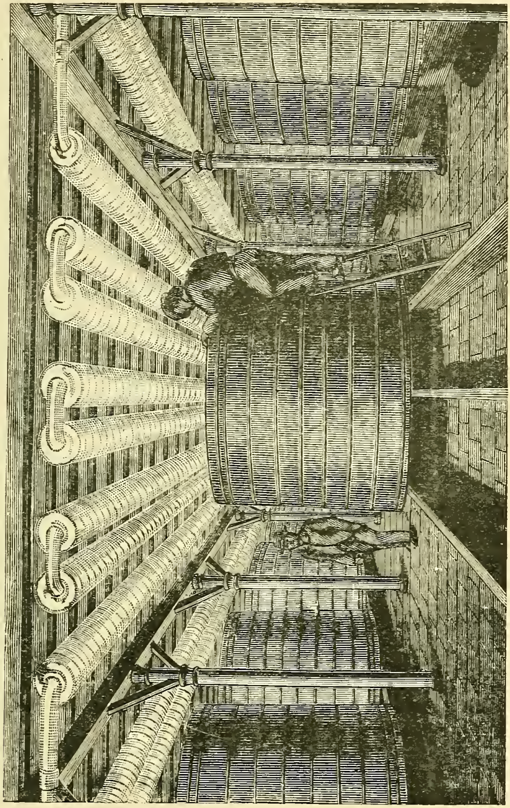

Fig. 72.

arrangements, such as that illustrated in Fig. 71 and Fig. 72, the brine mains B (Fig. 71), and the direct expansion pipes (Fig. 72), cool the entire area of the fermenting room, that is to say, a separate brine circulation (Fig. 71) or coil of vapour pipes (Fig. 72) is run over each row of rounds or tuns, and all are cooled at once. Where a number of large squares have to be cooled, however, a more elaborate arrangement is preferably employed, and the sides and tops of the squares are boxed in or enclosed with partitions formed of light boarding, under which a separate circulation of brine or vapour pipes to each square is fixed. The latter plan enables the temperature of the air over each square to be regulated separately and independently of the others, and the brine or vapour to be shut off completely from empty squares, thereby lessening the work of the refrigerating machine. It also further economises the work of the latter, inasmuch as only the air directly over each vessel has to be cooled.

In working a refrigerating machine on the brine circulation principle, for these cooling purposes, in a brewery of moderate dimensions, it is usually run during the daytime, and when it is shut off at night, and the fermenting rooms are closed up, the large amount of cold stored up in the brine in the pipes over the fermenting vessels, is, as a rule, found to be sufficient to keep the atmosphere of the rooms down to the desired temperature during the night; except, however, in very hot weather, when the machine has usually to be run continuously. In very large breweries also it has generally to be kept working day and night.

In some instances, a refrigerating machine is employed for the combined purposes of cooling water for use in refrigerating and attemperating, and of cooling the air in the fermenting and yeast rooms. In an arrangement of this description, at the top of the brewery building, or at a sufficient elevation to command the refrigerators and attemperators, is fixed a suitable ice-water tank, and above this tank a brine refrigerator, which latter may consist of horizontal rows of brass or copper pipes, through which a branch circulation of cold brine from the mains is run, whilst over them the supply water at 60° or 65° Fahr. or other temperature, is allowed to trickle or flow slowly. This water is thus reduced by the cold brine within the pipes to about 33° Fahr., or to any other desired temperature, after which it is passed into the ice or cold water tank, from which it is drawn through pipes as required for refrigerating and attemperating. This arrangement admits, by the simple opening, closing, or regulating of the stop-cocks or valves, of the whole or any desired proportion of the power of the machine being applied to the cooling of air, or to the cooling of water, or to both operations at the same time.

Lager beer fermenting rooms, and store cellars, can be cooled by a plan substantially similar to that shown in Fig. 71, for cooling the air in fermenting and yeast rooms in ordinary breweries. In the case of lager beer, however, where the whole of the fermenting rooms are kept at a temperature of about 42° Fahr., and the stores at about 38° Fahr., a proportionately larger number of brine cooling pipes are required.

Another obvious application of refrigerating machines in breweries, though one of secondary importance, is that of making small quantities of ice, either for use in keeping yeast cool, or to send out to public-houses, or for private use. This can be very easily accomplished with machines having a brine circulation. If only opaque ice be required, all that is necessary is to place galvanised iron pails, moulds, or cans of the shape of which the blocks of ice are desired, and filled with water, in the brine tank, and the said water will be frozen in a few hours into solid blocks of ice, which can then be loosened by dipping in warm water, and turned out of the said cans, the latter having a slight taper, to admit of this being more readily performed. When, however, clear, transparent crystal ice is desired, it is necessary to use de-ærated water, or to keep the water in motion whilst freezing, and some special apparatus is consequently required, such as will be found described in the chapter on ice-making.

Further important applications of refrigerating machinery to manufacturing purposes are :—In candle works, for the extraction of the solid stearine and paraffin. And in paraffin oil works, for enabling refiners to extract in an economical manner in the presses a greater quantity of paraffin than is obtainable in any other manner, and also to obtain a product of a superior quality.

An ordinary arrangement for the extraction of solid paraffin from shale oil is shown in Fig. 73, wherein A A are the cooling drums or cylinders, B B the troughs or receptacles intended to contain the oil to be treated, and C C scrapers for removing the partly solidified oil from the drums or cylinders A.

The operation of the apparatus is exceedingly simple, a circulation of brine, first reduced to about 10° or 12° Fahr., or other desired temperature, in the usual manner, is afterwards

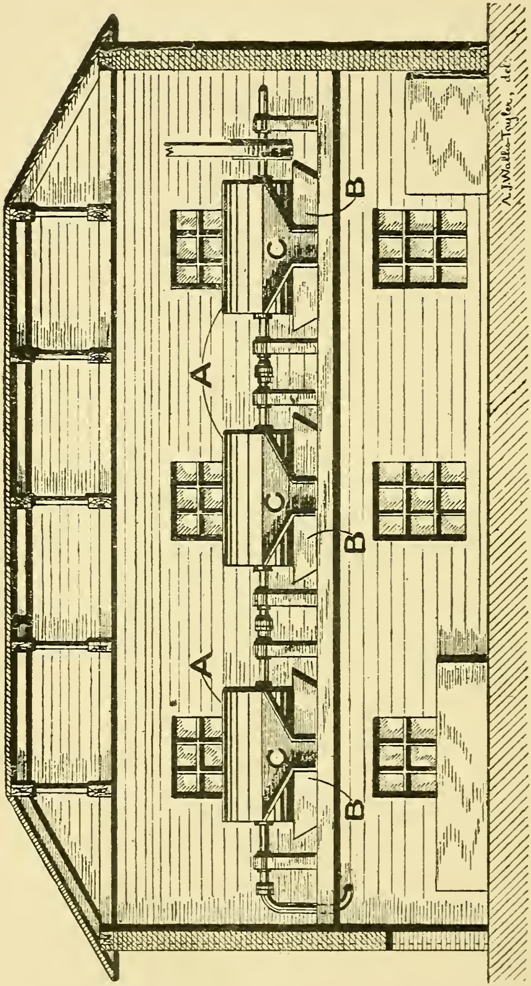

Fig. 73.

passed through the set of cooling drums or cylinders A, entering each of the latter at one of the hollow trunnions or gudgeons, and leaving at the other. The lower portions of the drums or cylinders A project, as shown in the drawing, into the open shallow troughs B, one of which is placed below each drum, and in which the oil to be cooled and treated is placed. The surfaces of the drums or cylinders A during their revolutions dip into this oil, and become coated with a thin film of it, which is cooled by the circulation of the cold brine from the machine, and reduced in temperature during the continuance of the revolution, until it is finally removed in a pasty condition by the scrapers C, one of which is arranged to press against the periphery of each of the said drums or cylinders. The remaining oil is then drawn away by plunger pumps, and forced through filter presses, which separate the paraffin wax crystals or scales from the oil.

The employment of a refrigerating machine of one type or another in a works engaged in the production of paraffin is, and indeed has been for some years past, deemed indispensable, and but few manufacturers now endeavour to do without it. Indeed, the development of the industry dates from the time when an ether machine of the Harrison type was first used for this purpose, which, as already mentioned, was in 1861.*

In manufactories of artificial butter, as also in other butter and cheese factories and dairies, but more especially in the former, refrigerating machines play an important part, both for ensuring an ample supply of cold water, and for cooling stores or chambers, the former being an essential for successful manufacture in hot weather, and the latter enabling butter and margarine to be kept in prime condition until a favourable opportunity for disposing of it presents itself.

In the manufacture of artificial butter a variety of ingredients are first melted and amalgamated together at about blood heat in churns, and the resultant mass is then mixed with and run out into ice-cold water contained in open troughs. This sudden application of intense cold crystallises and granulates the artificial butter, which is then skimmed off, and at the same time it also washes out the butter milk, which otherwise, by its rapid decomposition, would taint the butter.

Primarily, and indeed still to a considerable extent, the means adopted for reducing this water to the requisite temperature is

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* For further information regarding the most recent and approved practice in paraffin cooling, see "Journal of the Society of Chemical Industry," of 29th May, and 30th November, 1885.

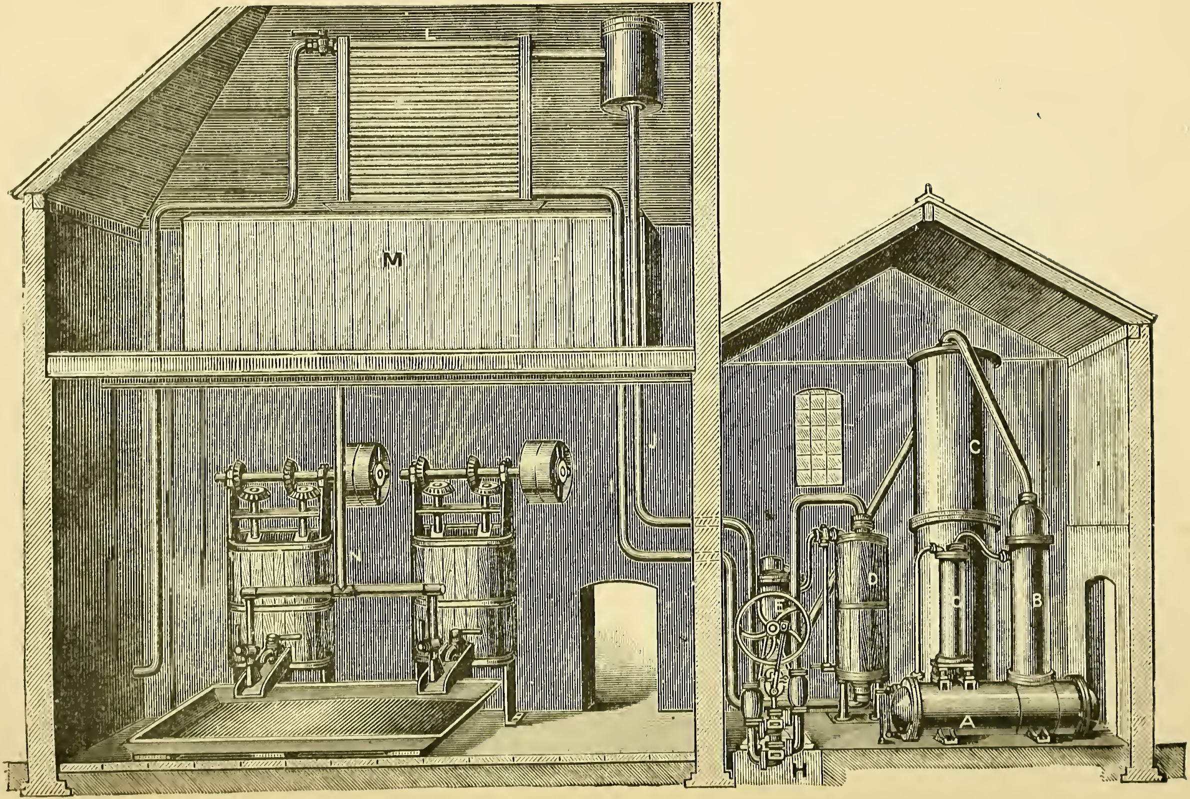

Fig. 74.

the application of natural ice, which is placed in tanks partially filled with water, and by melting imparts its cold to the latter. This plan, however, is open to several serious objections, amongst which may be mentioned :—The excessive cost of the ice and of the necessary labour for handling it ; the impossibility of thus obtaining as low a temperature as is desirable, the best result being the mean of the two temperatures of the ice and the water ; the non-attainment of a regular temperature continuously ; and finally that the natural ice is always more or less dirty, and renders the cooled water so also, and consequently soils and spoils the colour and appearance of the artificial butter.

Figs. 74 and 75 illustrate an installation of an ammonia absorption refrigerating machine in an artificial butter factory, and Fig. 76 that of an ammonia compression refrigerating machine in a dairy.

In the first of these arrangements (Fig. 74) an ammonia absorption machine of the Pontifex-Wood type is employed. The operation is very simple, a circulation of brine is forced by the brine pump H first through the coils of the cooler D wherein the expansion of the ammonia gas cools it down to about 20° Fahr., and secondly through the pipe I to the bottom of the refrigerator L, the construction of which latter is more clearly shown in the enlarged view thereof, Fig. 75. It consists of sets or rows of horizontally arranged copper or brass tubes, secured at their extremities in return heads, and through which the cold brine from the cooler D passes. Over these tubes the supply water is allowed to trickle into the cooled or ice-water tank M, from which it is drawn off as required for the use of the churns through the pipes N. In this manner a steady and constant supply of clean cooling water at a temperature as low as $32\frac{1}{2}$° Fahr. is ensured. The brine returns to the pump H from the top of the refrigerator L through the pipe J.

In factories where the practice of using water cooled down only to 39° or 40° Fahr. prevails, the brine refrigerator L can be dispensed with, and the water to be cooled may be simply run through the pipes in the cooler D as in the arrangement in a brewery for cooling water for refrigerating and attemperating, shown in Fig. 70.

A full description of the Pontifex-Wood ammonia absorption machine, reference being made to the letters on Fig. 74, will be found on page 108.

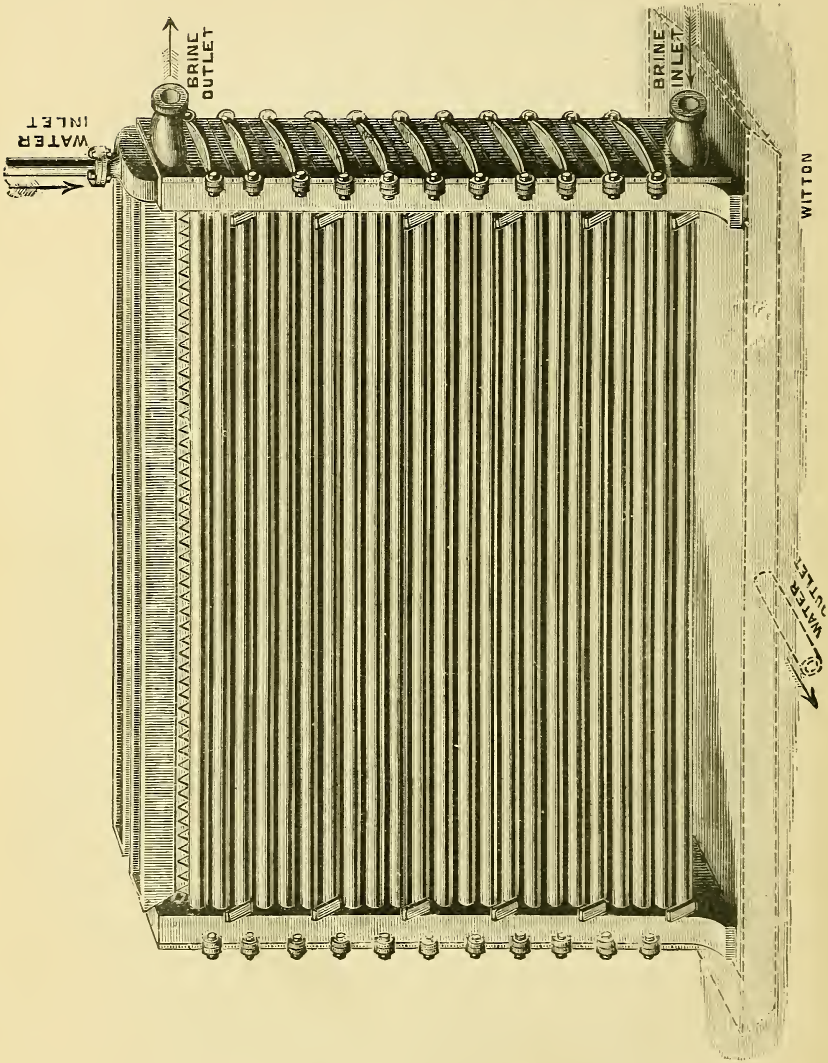

Fig. 75.

In the second arrangement (Fig. 76) an ammonia compression machine of the Kilbourn improved type, driven by means

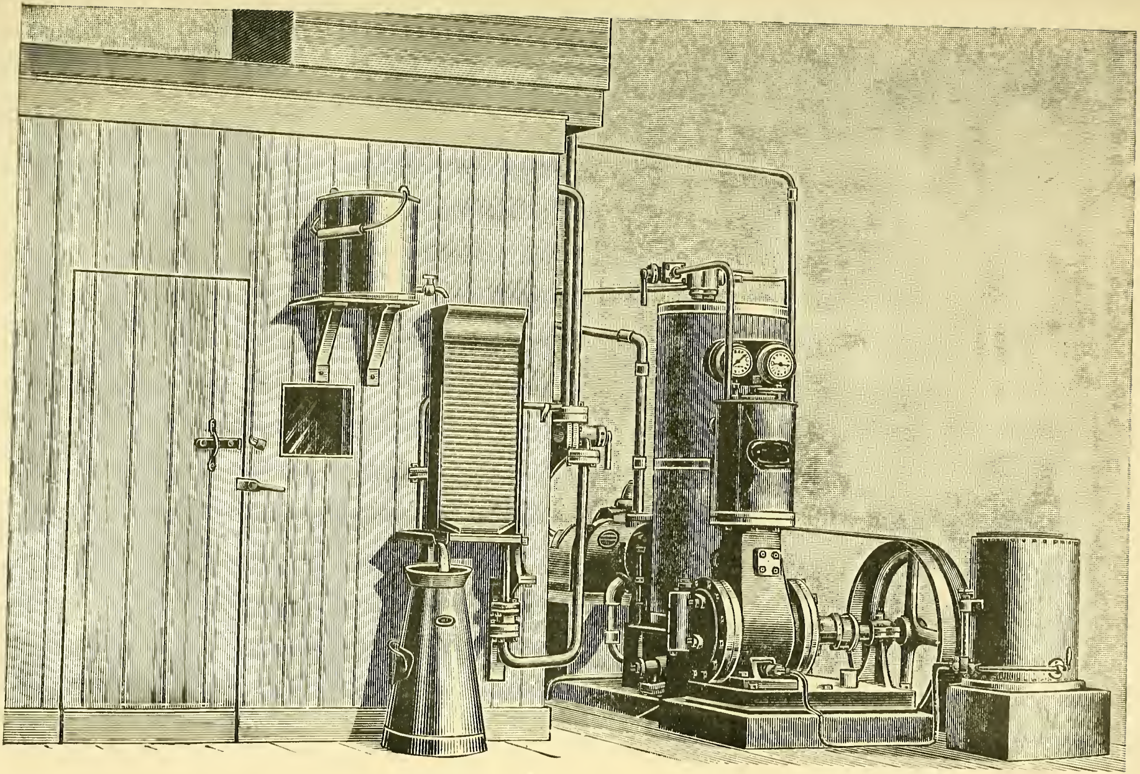

Fig. 76.

of belt gearing from a gas-engine, is used. The cream-cooler is fixed against the wall of the cold-store or chamber, a portion of which latter only is shown in the drawing. The said cream-cooler is constructed of tinned copper, and is fitted with small wrought-iron coils without internal joints, similar coils being likewise provided in the water-cooling tank, a portion of which is shown on the top of the cold-store or chamber. The refrigeration is effected on the direct system, the ammonia gas or vapour being permitted to expand into the coils of pipe in the cold-store or chamber and of the cream and water-coolers.

An ordinary form of milk or cream cooler consists simply in a pan fitted with a false bottom, through the space or clearance between which and the real bottom, a circulation of cold or refrigerated water is maintained.

Amongst the numerous other applications of refrigerating machinery mention may be made of the following :—

In dynamite factories, for maintaining the dynamite at a low temperature during the process of nitrating.

In manufactories of photographic accessories, for cooling the gelatine dry plates.

In the establishments of wine-growers and merchants, for reducing the temperature of the must or unfermented wine, and for the obtainment of an equable temperature in the cellars, etc.

In distilleries, for keeping the spirits in the store tanks cool during hot weather, and thereby obviating the very serious loss that is otherwise experienced through evaporation.

In chocolate and cocoa manufactories, to enable the cooling room to be maintained at a low temperature in summer, and the process to be worked continuously all the year round. A great saving is likewise effected by the rapid solidification which is rendered possible, and the waste thus avoided ; and furthermore as the chocolate leaves the moulds readily and intact, a considerably fewer number of the latter are required to do the same amount of work.

In sugar factories and refineries, for the concentration of saccharine juices and solutions by freezing or congealing the watery particles, which are then removed, leaving the residuum of a greater strength.

In chemical works, for the reduction of mother liquors at low temperatures, thus hastening crystallisation, and augmenting the amount of crystals produced, as well as reducing the cost of production. In addition, however, to substances the crystallisation whereof is facilitated by cold, it can be also advantageously employed for the congelation of various chemicals, and for other purposes.

In india-rubber works, for the curing and hardening of blocks of india-rubber, thereby facilitating the cutting of same into sheets for the manufacture of various elastic articles. The material in that state admitting of its being worked up in a much superior manner, and, moreover, at a far lower cost. In glue works for drying the gelatine, and so admitting of the use of less concentrated solutions. And also in numerous other industries, in which it would be impracticable to carry out many of the manufacturing processes in the summer months, without the employment of some artificial means for cooling.

For the freezing of loose ground in quicksand soils, in order to facilitate sinking colliery shafts, well-sinking, tunnelling, or putting in foundations, wherever the amount of water is too great to be pumped, or in cases where the removal thereof would damage existing foundations, to avoid the necessity for expensive underpinning, etc. This may be effected either by means of ammonia or cold-air machines.

In the case of a quicksand in a well, a coil of pipes, of a somewhat larger diameter than the lining of the well, is usually sunk into the quicksand, and the latter frozen by a circulation of cold brine through the said coil. The necessary excavation can then be proceeded with, and as soon as the lining is put in, the circulation of brine is stopped and the coil withdrawn.

During the construction of a tunnel for foot passengers through a hill in Stockholm, this method was employed for driving the tunnel through about 80 ft. of loose ground, consisting of gravel mixed with clay and water which possessed so little cohesion as to render the ordinary method of excavation impossible. The refrigerator employed was a cold-air machine of the Lightfoot type, capable of delivering 25,000 cubic ft. of air per hour, and the arrangement consisted in forming the innermost end of the tunnel into a freezing chamber by means of a partition wall made of a double layer of wood filled in between with charcoal. After the refrigerator was run continuously for sixty hours the gravel was frozen into a hard mass to a depth varying from 5 ft. near the bottom of the tunnel to 1 ft. near the top. The work was proceeded with in 5 ft. lengths, the excavation commencing at the top, and a temporary iron wall of plates 12 in. square was built up against the face from the top downwards as the cutting away of the gravel was proceeded with; the arching of the tunnel was completed as quickly as possible close up to this temporary iron wall while the ground was still frozen. After being fairly started it was found sufficient to run the cold-air machine on the average from ten to twelve hours every night, except after heavy rains, when much water percolated through the gravel. After two 5 ft. lengths had been excavated the partition was moved forward. The daily progress whilst employing the freezing process was on an average about 1 ft.

A full description of the construction of this tunnel is given in the *Engineer* of 9th April, 1886. And in the issue of 30th November, 1883, of the same journal, will be found an interesting account of the Poetsch method of sinking colliery shafts by freezing the soil by means of an arrangement consisting of a series of vertical iron pipes placed in a circle.

A very interesting account of the more recent applications of the Poetsch process in France has also been given in a paper upon the use of freezing machinery for sinking through water-bearing strata by F. Schmidt,* of which an abstract is subjoined.

The Poetsch process was first employed in the Houssu coal-fields of Hainault in 1885, having been introduced into France at a later date, viz., 1890, and since extensively employed for sinking pits through the tertiary and cretaceous strata above the coal measures at Vendin-Sens, Dourges, Courrières, Vicq-Anzin, and Flines lez Raches, the pits being respectively 82 and 84, 47, 45, 102 and 102, and 70 metres in depth.

The latter was the most difficult undertaking. The permeable strata to be got through was 70 metres, blue marls affording a bearing for tubing at 72 to 79 metres; the tertiary sands and clays were 25 metres and the chalk about 50 metres in thickness. At the junction of these formations a heavy sheet of water was encountered, which gave from a single bore-hole a flow of 1,200 cubic metres, which rose to 2 metres above the surface; a second one in the lower portion of the chalk between 65 and 70 metres also overflowed. Two brick towers were constructed round the mouth of the pit, viz., an inner one of 6 metres and an outer one of 11 metres in diameter, and rising the one 1·6 metre and the other 2·6 metres above the level of the surface, with the object of arresting these feeders, but were found to be ineffectual and incapable of maintaining the water

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* "Bulletin de la Société de l'Industrie Minérale," vol. ix., 1895, pp. 273–416.

level constant by reason of a lateral flow joined to subsidence which was set up in the overlying strata of sand, the arresting of which necessitated the sinking of a special bore-hole so as to trap the spring at a distance of 25 metres eastward from the pit, by which means a steady head of 1·6 metre of water was got in the towers, and the freezing operation could be commenced.

The freezing circuits were twenty-two in number, contained in bore-holes 75 metres deep, one of which was located in the centre of the pit, which was 4·2 metres in diameter, the remaining twenty-one being arranged in a ring 6 metres in diameter. An ammonia-compression machine of the Fixary type was used for the production of the necessary cold; it was driven by a 500 × 900 millimetre single-cylinder engine, making 80 revolutions per minute, and capable of producing cold equal to 1 ton of ice made per hour.

In thirty-eight days from the 1st September, 1894, upon which date the freezing machine was started, the ice-wall was completed, and the sinking commenced on the 25th October, the relief or special bore-hole being stopped for good on the 5th November. At the upper strata the ground was broken up by means of picks and wedges, but at a lower level blasting by means of compressed powder was employed. The central tube was disused and removed as the sinking progressed. When a depth of 14·8 metres was reached two oak seating rings, the one 22 by 24 centimetres and the other 22 centimetres square, were secured in position for the first line of tubbing, which was composed of segments of oak 16 centimetres to a height of 2·6 metres above the surface level, with a 16 centimetre backing of concrete increased to 70 centimetres near the surface. A second seating with curbs of 22 by 24 centimetres and 22 by 20 centimetres was fixed at 25·93 metres, and a third at 43·82, which latter had three seating rings respectively of 22 by 28 centimetres, 22 by 24 centimetres, and 22 by 22 centimetres in section, the tubbing rings being of 18 centimetres, with the same thickness of concrete behind. By April, 1895, the pit was sunk to a depth of 70 metres, and on the 1st May the building of the tubbing was completed. Light was provided by incandescent electric lamps supplied with electricity from a dynamo situated in the same building as the freezing machine.

The cost of sinking in frozen ground per metre was as follows:—

	Francs.
Freezing	1,550
Sinking	150
Tubbing	650
Concreting and sundries	50
	2,400 per metre.

The Poetsch method of sinking has been also lately successfully employed at the coal-field of Ligny-les-Aire in a sinking through a permeable covering of about 86 metres, and in the repair of the cylinder pits of the Fontinette Canal lift. These pits, which were of 4 metres in diameter, were sunk by compressed air and tubbed with cast iron between 1883 and 1887. In 1893, however, owing to an irregular subsidence of the ground, they became leaky, and it was decided to replace the iron lining by one of brickwork of 80 centimetres in thickness, thus reducing the diameter from the original 4 metres to 3·7 metres, with a considerable increase in the bottom bearing of the press, which was to consist of a cylindrical block of brickwork 5·307 metres in diameter and 2 metres in height. In the carrying out of these repairs it was decided to adopt the freezing process in preference to using compressed air, so as to avoid any chance of disturbing the ground and thus causing damage to the neighbouring buildings.

The work was commenced at the right-hand press, the boat-cradle being secured at its highest level by means of two supporting girders of 40 metres in depth; the piston was disconnected; and twenty bore-holes arranged on a circle of 6·307 metres in diameter, or 99 centimetres apart, and one placed centrally, were provided for freezing. These bore-holes were about 2 metres deeper than the bottom of the new foundation, and lined with tubes of 150 millimetres in bore and of 5 millimetres in thickness, formed of steel. The freezing tubes were likewise of steel and 125 millimetres in diameter, and the inside brine supply pipes of iron and 33 millimetres in diameter; the collecting rings were of 100 millimetres bore by 5·050 metres diameter on the admission, and 5·7 metres diameter on the return circuit.

Mr. Schmidt does not think that the methods of working proposed by Mr. Gobert and Mr. Koch are likely to afford as favourable results as are obtainable by the original method. The first of these gentlemen proposes to volatilise the liquified ammonia in the freezing circuits; and the latter depends entirely upon gaseous expansion.

The paper also contains descriptions of the combined method of freezing and fire-setting in frozen ground used for prospecting for gold in the alluvial deposits of the Siberian rivers during the winter.

The following extracts are taken from an account of Mr. Gobert's system* given in "The Colliery Manager's Handbook":—

This is a modification of the Poetsch congelation method, and is specially applicable to the sinking of shafts through shifting sands and water-bearing strata.

Fig. 76*a* is a vertical section and Fig. 76*b* a plan showing the refrigerating plant and the shaft to be sunk, the two being as near each other as possible, and the shaft being lightly roofed over as a protection from the weather. The power of the steam-engine required varies with the diameter and depth of the shaft to be sunk, and need not exceed 40 horse-power unless the shaft is deep. The steam-engine and compressor are placed horizontally side by side, and connected to the same shaft, with a fly-wheel and pulley for belting between them.

Liquid ammonia is forced by the compressor through the series of wrought-iron tubes of the condenser, first to the reservoir, which acts as a kind of governor, and then by the lower of the two pipes seen in the vertical section to the system of congelation tubes round the shaft. Great heat results from compressing the gaseous into liquid ammonia, and in order to abstract it, the condensers have a relatively large surface, and cold water is caused to circulate freely round them. This water is kept in a state of agitation by means of the small water wheels with floats, shown in the drawings, driven by belts off the pulley on the main shaft.

The machinery, by means of the upper of the two pipes seen in the vertical section, exhausts gaseous ammonia from the congelation tubes, sunk vertically beneath the surface of the earth round the site of the shaft, and forces it, condensed into a liquid form, first through the apparatus for separating the oil (see Fig. 76*b*), and then into the condenser.

The compressor piston is freely lubricated with mineral oil, and some of the ammonia comes into contact with and is absorbed by it. The mixture might choke the tubes of the condensers, and possibly even reach the congealing tubes, if

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* For further description and illustration of the system see "The Colliery Manager's Handbook," by Caleb Pamely, M.E., published by Crosby Lockwood and Son, London.

the two substances were not separated. This is effected chiefly

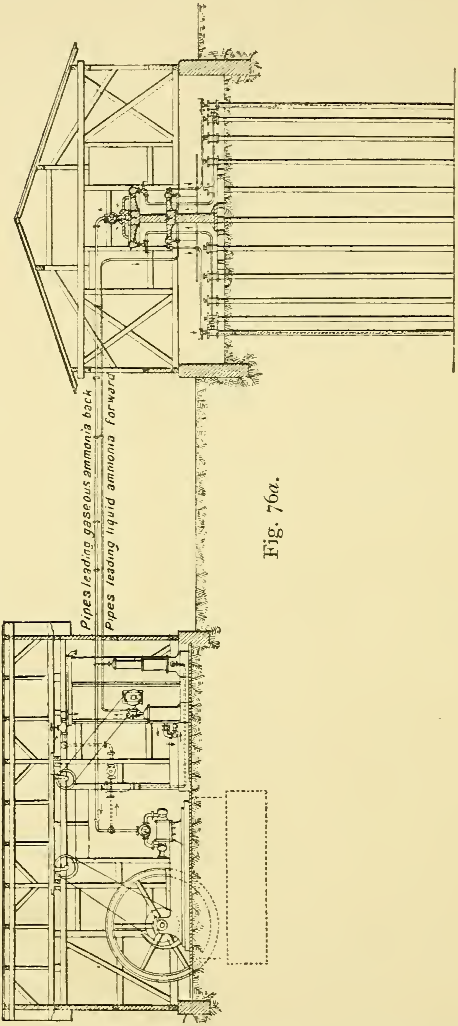

Fig. 76*a*.

by the oil-separator, but, as an additional precaution, a space is provided at the bottom of each congelation tube for the reception of any oil that may be carried there. The oil retained in the separator is not effectually separated from the

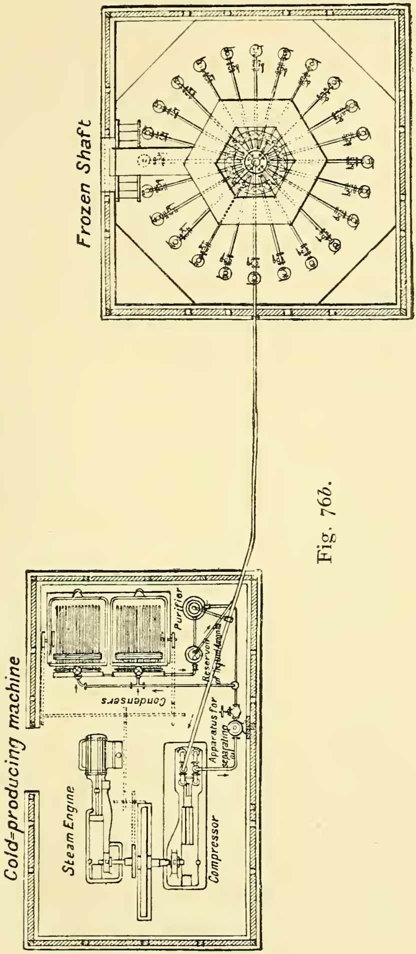

Fig. 76*b*.

ammonia, but is slightly mixed with it; this ammonia, however, is recovered in the purifier, where it is driven off by distillation. The distillation is effected by means of a worm through which steam from the boiler circulates; the ammonia vapour is led by a small curved pipe, seen in Fig. 76*a*, into the main pipe, leading the gaseous ammonia from the shaft to the compressor.

Over the centre of the area forming the intended shaft are two pipe-rings, the lower of which is in connection with the ingoing pipe and receives the liquid ammonia, and afterwards distributes it by the radial pipes to the vertical congelation pipes sunk in a circle below the surface of the earth. The upper ring is in connection with the return pipe, and forms a receiver for the collection of the gaseous ammonia from separate orifices in the same congelation tubes after it has by evaporation in these tubes produced the desired refrigerating effect. The gaseous ammonia is drawn from the upper ring pipe to the condenser through the return pipe.

The liquid ammonia is not allowed to fall to the bottom of the tube and collect in a mass, but in order to cause the evaporation of the greatest possible amount of liquid in a given space of time, the small pipe for leading the freezing liquid through the tube is made to assume either a wavy or a spiral form, as shown in Figs. 76*c* and 76*d*, in which A represents the congealing tube, B the pipe for leading the freezing liquid, and C small holes for allowing the liquid to escape into the tube, at points more or less frequent, as may be desired. The injecting pipe is led down nearly but not quite to the bottom of the congealing tube, and both pipe and tube are closed at the bottom. The entrance of the congealing liquid into the injecting pipe is carefully regulated and descends slowly in a thin stream, the flow being retarded by the waves or spirals, and giving up a part of itself at intervals.

The source of heat necessary for evaporating the liquid is the higher temperature of the surrounding strata, and this heat passes not only through the thickness of the congealing tube, but also across the frozen wall which soon surrounds it. By this arrangement the liquid to be evaporated escapes into the congealing tube at all depths simultaneously, and the whole source of heat available is thus utilised at the same time for evaporating the freezing liquid. In other words, the refrigeration is effected simultaneously at all points.

The diameter, number, and arrangement of the holes in the injecting pipe, and also the pitch of the spirals or undulations, are varied in accordance with the depth in order to produce a

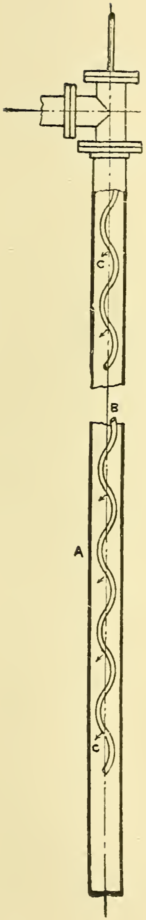

Fig. 76*c*.

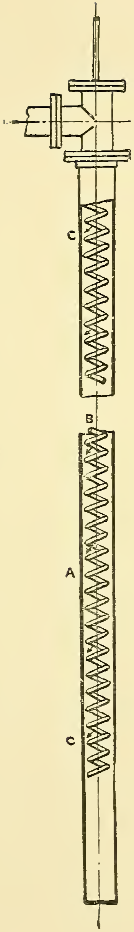

Fig. 76*d*.

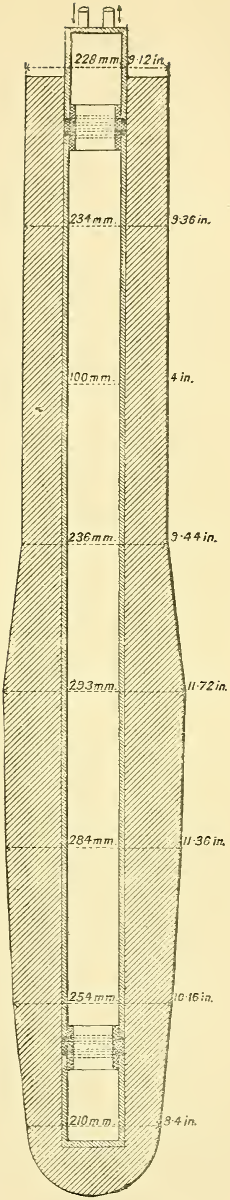

Fig. 76*e*.

To face p. 207*c*.]

greater freezing effect at special points, or a uniform freezing, in accordance with the requirements. A congelation may therefore be arranged to have the frozen column of larger diameter at the bottom than at the top, on the supposition that the measures are of uniform consistency, in order that its stability may be maintained while the shaft is being sunk through it.

The arrows in Figs. 76*a* and 76*b* show the course of the ammonia in its passage, as a liquid, from the compressor to the condensers, and then on to the congelation tubes, and also its return, in a gaseous state, from the congelation tubes to the compressor, to be again liquefied, and so on. The same ammonia serves indefinitely, with the addition of a small quantity to compensate for waste.

The process requires a large quantity of cold water for use at the condensers, but this must not be drawn from any point so near the site of the shaft as to create a current, which might oppose and retard the congelation by licking or washing the congelation tubes, thus depriving them of their refrigerating effect, which would be carried away instead of going into the surrounding sand.

When the wet sand or loose material has been frozen round the tubes, sinking may be commenced with a small windlass placed between the collecting and distributing rings and the circumference of the circle of congelation tubes. The men enter, and the excavated material is removed, laterally, near the surface, between two congelation tubes, where also access is obtained for the segments of tubbing.

More important winding apparatus must of course replace the windlass when the sinking has reached a depth of two or three fathoms; then, if the arrangements have been made judiciously and due precautions taken, the frozen mass will be so large as to require slighter refrigerating power to maintain it than that required for its production. This allows of the removal of one or two radial pipes for distributing the ammonia in order to allow of more space for the working of a winding engine.

A great advantage claimed for the Gobert modification is that if the congelation tube be surrounded with water and there be a defective joint, the water will simply enter the tube, on account of the pressure therein being less than that outside. If such an accident occurs at all it is usually after congelation has proceeded for some time and the tube is already surrounded with ice; there will then be no interruption in the work. The liquid ammonia always enters the tubes at a temperature above freezing point, and in practice varies from between 20° and 35° Cent. (68° to 95° Fahr.). The cold produced is due to the liquid ammonia becoming volatilised in the tubes.

It is of course impossible to entirely guard against leaky joints. The thrust of the superincumbent measures severely tries them, but special attention has been given to the design of the joints in order to increase their power to resist the strains to which they may be subjected. The method of connecting the ends of congelation tubes has been by screwing one end into another without internal sockets. The thinning of these tubes at the joints frequently causes them to break in being withdrawn from the ground.

The form of joint used by Mr. Gobert is shown in Fig. 76*e*. Its chief feature is an internal collar, or ring, shown by crossed hatchings in the section. This collar has an outside flange of the same outside diameter as that of the tubes which it serves to connect. The flange is undercut on both sides so as to be of dovetailed section. Each end of a tube is also bevelled or curved off so as to afford with the collar flange a groove wider inside than out, holding and compressing the lead ring or washer instead of forcing it outwards, thus affording an absolutely tight joint when the ends of the tubes are screwed on to the collar. In some cases, especially for joining the smaller sizes of tubes, the internal collar is made without a flange, and then only one lead washer is used placed between the ends of the tubes, which must be bevelled and curved just the same as when the collar is flanged. On the tubes being screwed up, they squeeze the washer between them, just as the gland of a stuffing-box compresses the packing. The outer lines of the section, Fig. 76*e*, shows the form and extent to which a tube was covered with ice after having been immersed for 32 hours in a tank filled with water; the ice weighed 62 kilogs. (137 lbs.) at the end of the operation. If the tube had been immersed in wet sand instead of clear water, the congelation would have been more rapid. One of the two smaller tubes shown at the top of the congelation tube serves to introduce the liquid ammonia, while the other carries off the gas to the upper ring-pipe.

Instead of ammonia, any other liquid susceptible of easily assuming the gaseous state, such as liquid carbonic acid or liquid anhydrous sulphurous acid, may be employed with a suitable modification of the engine.

Refrigerating machinery is also used in tropical and other warm climates for cooling the atmosphere of hospitals and large public buildings.

For cooling the holds of vessels carrying live cattle, in which manner an uniform temperature of about 70° Fahr. can be maintained throughout the entire voyage (instead of its rising to over 100° as it otherwise would), thus entirely obviating the heavy losses of cattle usually experienced from the high temperature and bad ventilation. It might also be advantageously applied, on large passenger steamers, to cool and ventilate the saloons and state-rooms, as also the engine rooms, &c., when in hot latitudes.

And finally, for producing artificial surfaces of ice in enclosed places, so as to provide skating rinks upon which this pastime may be enjoyed during the mildest winters, or at any season of the year. Such an application may be now seen at the Niagara Hall, London, of which the following is a brief description :—

The plant consists of ammonia compression machines of the De La Vergne type, the ice-making capacity of which are of 12 tons per day each. The rink itself when in every-day use requires the expenditure of a refrigerating power equal to that consumed in the manufacture of 8 tons of ice per day, and the balance of power, which is considerable, is employed in the manufacture of block ice, and in maintaining large cold stores or chambers in connection with the rink at the required temperature.

The congelation or freezing of the water to form the ice surface of the rink is effected by a network of pipes which are laid upon the floor of the said rink, and through which brine, reduced to a sufficiently low temperature in the refrigerator of the machine, is kept in constant circulation by means of a suitable brine pump. The non-congelable liquid or brine employed in this instance is a strong solution of calcium chloride.

The operation of the ammonia compression machines employed for this purpose differs in no way from the description already given when dealing with that type of machine.

CHAPTER XII.

ICE-MAKING.

THE specific gravity of ice made from de-ærated water is, according to De Mairan, ·926; its specific heat is ·504; at a temperature of 32° Fahr. 1 cubic in. = ·033449 lb., 1 cubic foot = 57·789872 lbs.; 1 lb. = 29·896259 cubic in., or ·0174 cubic ft. The equivalent of a ton of ice is 318,080 thermal units,* that is to say that this is the amount of heat that would be required to convert 1 ton of ice at a temperature of 32° Fahr. into a ton of water at a temperature of 32° Fahr.; or, on the other hand, it is the amount of heat that it is necessary to extract from 1 ton of water at a temperature of 32° Fahr. in order to convert it into a ton of ice at a temperature of 32° Fahr. The amount of heat that would have to be abstracted from a ton of water at 60° Fahr. to form a ton of ice at 32° is 382,144 units.

When the manufacture of artificial ice first assumed the proportions of an industry no great thought was given to the quality of the product, and consequently all, or the greater part, of the ice so made was opaque.

Soon, however, a demand for a superior article arose, and it became necessary to introduce means for the production of clear, transparent, crystal ice; the result being numerous inventions and patented devices of more or less efficacy.

The reason why the blocks of ordinary artificial ice are formed opaque is that the rapidity of the freezing process prevents the air contained in solution in the water from escaping, and this opacity increases towards the centres of the blocks, and is less in hot climates than in colder ones because the quantity of air held in the water decreases as its temperature is raised. Not only is this opacity objectionable by reason of

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* A Thermal unit is that amount of heat necessary to raise the temperatures of 1 lb. of water 1° by the Fahrenheit scale when at 32°. Mech. eq. 772 ft. pounds.

the less pleasing appearance of the ice, but also on account of the far inferior keeping qualities of the article.

Five methods may be employed for preventing this opacity and forming clear, transparent, crystal ice, viz., by freezing the water slowly at comparatively high temperatures; by agitating the water in cans, moulds, or cases during the process of freezing, so as to admit of the escape of the contained or imprisoned air; by forming thin slabs of ice on what is known as the wall or plate system; by freezing water in shallow stationary cells; and finally by de-ærating or depriving the water of its air before placing it in the moulds or cells.

The first of these plans, besides, at best, only producing blocks of ice partially clear, was so extremely slow, and required the use of such a large number of cans or moulds, and correspondingly large tanks, as to thereby render the first cost of the apparatus ruinously high, and it was consequently soon abandoned altogether; a modification of the same method wherein the temperature of the liquid or medium used for abstracting the heat from and freezing the water was gradually decreased, having likewise experienced the same fate.

The second method, or agitation, can be more or less successfully carried out in a number of different ways, but has, likewise, certain drawbacks; for instance, complication of mechanism, increased first cost of plant, &c.

The third and fourth methods, or the wall or plate and shallow stationary cell systems, are also objectionable, by reason of the extent of the plant required and the slowness of the process.

The fifth method or that wherein the water is first de-ærated, that is to say, the air is expelled from the water before it is placed in the cans, moulds, or cases, is, all things considered, perhaps the most satisfactory, and is in extensive use in many works where large quantities of ice are made.

In the plate or wall system, which was invented by Twining and Harrison, in 1850—1856, one or more hollow or cellular plates, or walls, of sheet or cast iron are fixed in a properly insulated tank, which contains the fresh water to be frozen, and a circulation of cold brine is kept up through the said hollow plates or walls. The brine is either cooled in a brine-cooler or refrigerator by evaporating-coils connected to the gas-pump or compressor, in the case of an ammonia-compression machine, or to the absorber in an ammonia-absorption machine, in the usual or ordinary manner; or the said refrigerating coils may be placed within the said hollow or cellular walls or plates themselves. In a short time ice will begin to form on both sides of the plate, and layers of ice become gradually built up thereon. To remove these layers or slabs of ice, the cold brine is withdrawn, and warm or tepid brine passed into the hollow or cellular plates or walls, when the said slabs are melted or thawed off and detached therefrom.

The stationary cell system when employed to make clear or transparent ice without agitation, or using water that has been deprived of its air, consists of a number of shallow pan-shaped cells having hollow walls, through which a circulation of cold brine is kept up. The ice is removed therefrom as in the plate or wall system.

Transparent ice is also formed in deep cells provided with agitators. In the latter case a number of cellular or hollow walls of wrought or cast-iron are fixed in a suitably insulated tank or cistern, the water to be frozen being placed between the said walls, and the refrigerated brine circulated through the hollow walls of the cells therein. The ice gradually forms on the outside, and increases in thickness until the two opposite layers meet and join, but the freezing may be stopped at any time and the ice removed; this latter operation can be very conveniently effected by passing brine at a higher temperature through the cells.

Amongst the numerous different methods devised for agitating the water whilst it is freezing, mention may be made of the following:—The insertion into the can or case of a metal or other bar which has imparted to it a vertical reciprocating motion through a revolving shaft and cam or wiper, or by a crank on the said shaft, or the placing in the said can or case of a wooden or other paddle which is moved to and fro, or of an endless screw or spiral which is rotated by any suitable mechanism. The introduction into the can or case of a pipe extending to within a short distance of the bottom thereof, and through which a current of cold air is forced, which rising in bubbles through the water, produces a circulation in the latter. The imparting of a rocking or oscillating motion to the can or case itself during the freezing operation.

The main objection to those arrangements wherein some form of agitator, or the above-mentioned air tube, is inserted into the can or case, is the necessity for withdrawing them, at or near the termination of the freezing operation, to prevent them from being frozen into the blocks of ice.

In the last-named method, the gear for imparting motion to a large number of cans or cases is found to be exceedingly cumbersome, and has besides to be disconnected, to allow of their being lifted from the ice-making tank or cistern to remove the finished blocks of ice therefrom.

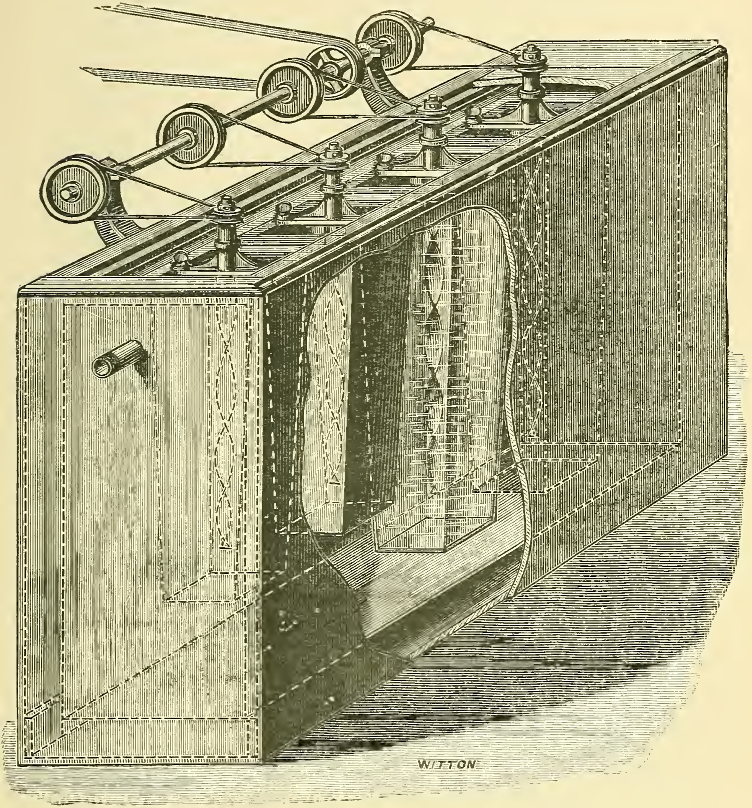

Fig. 77.

Fig. 77 shows a patented arrangement of Pontifex and Wood's for making clear or transparent pyramids of ice suitable for table decoration, &c. The ice-making or brine tank is formed of iron, wood lagged, and the intervening space is filled with sawdust. The ice-moulds or cases are made of galvanised wrought-iron, and are of a suitable pyramidical form; and the agitators consist of spirals or endless screws, which are kept constantly revolving, during the freezing of the block, by gut or other bands gearing on pulleys, fixed upon the vertical spindles carrying the said spirals or endless screws, and upon an horizontal shaft supported in bearings in brackets secured to the side of the tank, to which latter shaft rotary motion is imparted, through belt gearing from any available source of power, as is very clearly shown in the drawing. When the block is nearly frozen solid the agitators must be withdrawn, for which purpose the brackets carrying the spiral, or endless screws, are so secured to the tank as to be readily removable therefrom.

By arresting the freezing action before the block is frozen quite solid the central hollow can be filled up with fruit, flowers, or other objects, and afterwards the congelation completed, thus producing very beautiful effects.

Fig. 78 is a perspective view showing a can ice-box, which is the oldest and simplest method of making clear or crystal ice. The construction of the apparatus, which is of the Pontifex-Wood improved type, will be very readily apparent from the drawing. The agitators, which are very readily removable, are operated through rods running upon rollers, to which rods a reciprocating motion is imparted from a rocking shaft mounted at one end of the tank, through suitable connecting-rods. The ice-making tank is similar in construction to that shown in Fig. 77, but is of larger dimensions, and is filled with brine, a circulation of which is kept up from the coils of pipes in the cooler of the refrigerating machine by a brine-pump, in the usual manner. The ice-cans or moulds are formed of galvanised iron, and the blades of the agitators are of wood. To remove the finished blocks of ice from the moulds or cans they are dipped for a few seconds in a tank containing warm water, which may be derived from that running to waste from any convenient source. The sizes of the blocks of ice made, vary from 2 ft. × 2 ft. × 6 in. in thickness up to 3 ft. 6 in. × 3 ft. 6 in. × 12 in. in thickness, and in weight from 1 cwt. up to 6 cwts., according to the dimensions of the cans employed.

Puplett's agitators for liberating the air from the water during freezing are also reciprocated by crank mechanism. They are, moreover, so arranged that as the ice grows, and it becomes

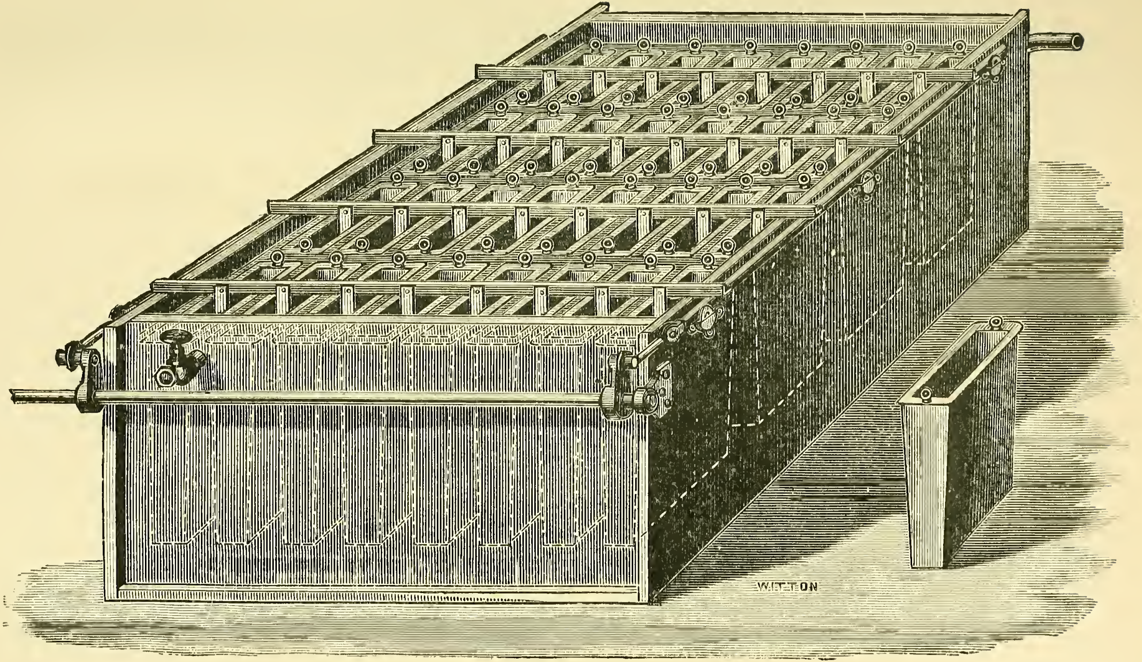

Fig. 78.

necessary or desirable to reduce the width of the paddles or agitator-blades, the latter can be feathered by giving them a quarter-turn in + shaped slots.

This system of making clear, crystal, transparent ice has, as already stated, several objectionable features, which may shortly be summed up as follows:—

The blades of the agitators occupying the centres of the cans or moulds whilst the blocks are freezing, have to be withdrawn at the finish, in order to prevent their becoming frozen into the blocks, consequently the spaces occupied by them during their traverse have to be congealed without agitation, with the result that each block has a narrow core of semi-transparent or almost opaque ice in the centre, which, to a slight degree, spoils its appearance, although the keeping qualities of the ice are not affected thereby. If, however, any impurities are contained in the water they become frozen up in the blocks and show through them, to the considerable detriment of their appearance.

The unavoidable freezing of the blocks at different speeds frequently results, with careless watching, in some of the agitator blades or paddles getting frozen in prematurely, and broken off. The cans or moulds are sometimes filled too full of water, which, in consequence of the expansion due to freezing, runs over into the brine solution and dilutes it, in some cases to such an extent as to cause it to freeze or congeal at the ordinary working temperature of the machine.

The additional weight of the cans or moulds which have to be lifted with the blocks of ice entails an extra expenditure of labour, and the constant handling thereof renders their lives short, and necessitates a large stock, and frequent repairs and renewals.

To obviate the first of these objections, wooden frames have been sometimes placed in the centres of the moulds or cans, inside which the agitators are adapted to work, a block of ice being frozen up at each end. This, however, gives rise to further serious objections, the wooden frames having to be removed from the moulds or cans with the ice blocks, detached therefrom by means of chisels, and again replaced in the moulds, and a certain quantity of dirty water has moreover to be pumped out of each of the latter before the withdrawal of the ice block and frame therefrom, both of which operations entail much additional labour. The unequal rate of freezing of the blocks causes some of them to come out of an uneven shape and under their proper weight, owing to the large holes in their centres.

Every apparatus for making ice on this system should be fitted with an arrangement for automatically supplying to each can or mould a sufficient predetermined charge, and no more. In the absence of this, however, a gauge should be used, and the greatest care in filling the cans should be exercised. The moulds or cans should not be filled to more than within 6 in. of the top.

On the other hand, again, the can system has several well-defined advantages which certainly deserve full consideration. For instance, the first cost of the simple apparatus is low as compared to many others; the blocks of ice produced being, as a rule, of an uniform given size and weight, the necessity for weighing them is dispensed with, and they are very convenient to load and pack; should a can become leaky it can be placed on one side for repairs and a spare one inserted in its place without delay; and, lastly, the construction of every part of the apparatus is so simple that it can be made or repaired by any ordinary engineer without special knowledge of ice-making machinery.

Many ingenious, but complicated and expensive, mechanical arrangements have been also devised for facilitating the handling of the cans or moulds, and so lessening the labour of moving them, a brief description of some of which will be found at the end of this chapter.

In 1885 Carl Linde patented an invention designed to overcome the objection to having to remove the agitators when the freezing of the blocks of ice is nearly completed, by providing suitable means whereby an horizontal flow of water is determined throughout the whole depth of the mould from one end to the other during congelation, by external mechanism.

In Fig. 79 is illustrated an improved ice-making tank or box on the wall or plate system, also designed by Pontifex and Wood. The construction and operation of an apparatus of this type have been already briefly described at the commencement of this chapter. The hollow or cellular walls, which are formed of galvanised iron, are, as will be seen from the drawing, fixed vertically to the hollow cast-iron ends of the tank. The agitators are similar in construction to those shown in Fig. 78, and are reciprocated in a like manner. The cold brine is circulated through the hollow ends and hollow or

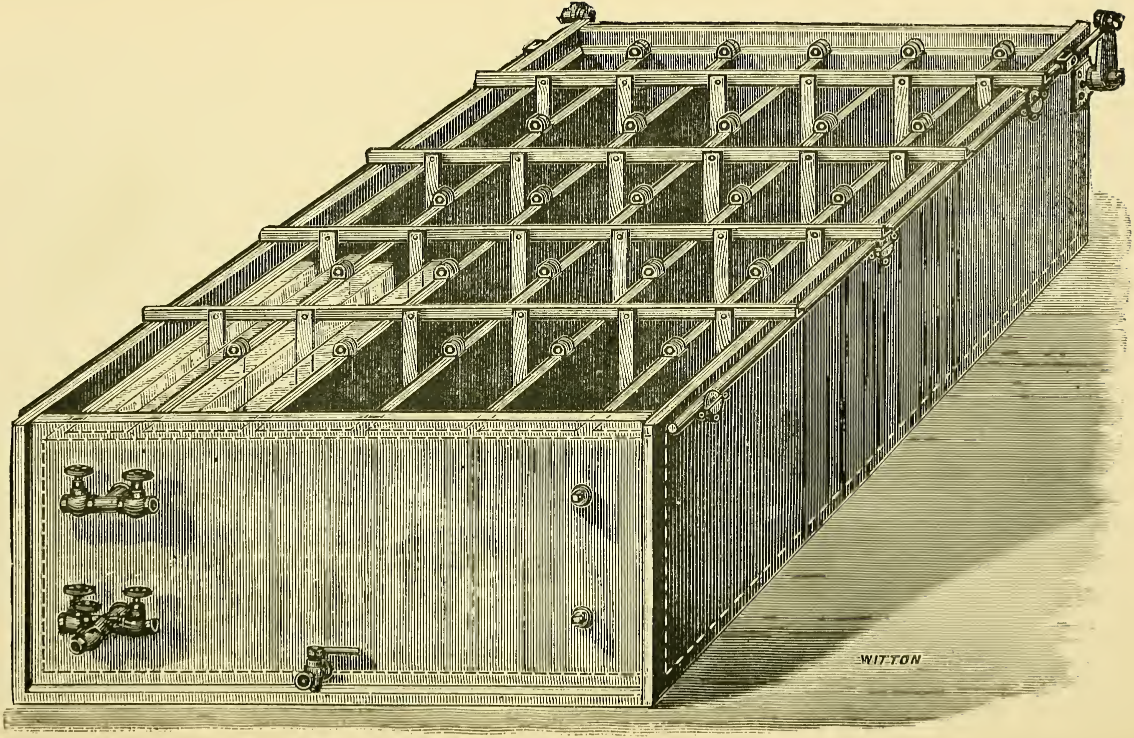

Fig. 79.

cellular walls, and suitable cocks and connections are provided which admit, when the freezing is finished, of the cold brine being completely drained out of the said hollow or cellular walls into the cold brine tank, and warm brine being introduced, by a small pump, from a warm brine tank heated by a coil of pipes, so as to melt or thaw the ice slabs off the walls or plates, and leave them ready for removal.

The hollow or cellular walls are, moreover, so constructed as not to reach quite to the bottom of the ice-making tank, and in this space all the impurities voided by the water settle. The freezing is generally continued until the slabs of ice extend to within a quarter of an inch of the blades of the agitators, when the cold brine is shut off and turned on to another tank from which the ice has been just removed.

The agitators are lifted out, and the slabs of ice, which when melted off the walls or plates are generally 14 ft. in length, 3 ft. in depth, and from 6 to 10 in. in thickness, are sawn into convenient lengths, and raised from the surplus water in the ice-making tank, in which they remained floating, by means of an overhead traveller, by which they are deposited, either directly into a cart for removal, or upon a platform from which they are dragged or otherwise delivered into the ice store. When the slabs are detached from the walls or plates, the hot brine is shut off and completely drained out of the latter, the water again filled up to the usual level, the agitators are replaced, and the circulation of cold brine is again turned on.

The water must be entirely run out of the tank about once every week, and the sediment and dirt at the bottom thoroughly cleared out.

The ice made by this apparatus is of very superior quality, being of great purity, and of a most attractive, brilliant, clear, appearance, and it is in great demand for use in restaurants, clubs, etc., fetching a higher price than other makes.

There are, however, certain drawbacks to its use, the principal one of which is, that the ice cannot be obtained in blocks of uniform size and weight without an expenditure of considerable labour in cutting them into shape. In case of any necessity for repairs arising, moreover, the whole of one of the ice-making tanks or boxes has to be shut off, and is thrown out of use.

The plate or wall system, besides, is necessarily very slow from the fact of the freezing process going on on one side only, instead of from four opposite sides conjointly, as in the can system, wherein the four surfaces growing gradually together in the centre finally unite into a solid block of ice the width of the can. If, therefore, a slab or block of ice of an equal thickness is to be formed on a plate or wall congealing only from one side, the time occupied in freezing it will be quadrupled.

The advantages over the can system may be enumerated as follows: The ice made is, as above mentioned, of a very superior quality. The liability of any of the agitator blades becoming frozen in, and broken off, is very slight. Only the ice itself having to be handled the weight to be manipulated is considerably reduced. The ice-making tanks can be shut off when the ice is finished, and left until it is convenient to remove the ice, thus admitting of night shifts of labourers being dispensed with. Owing to there being no parts, like the movable cans or moulds, liable to rapid deterioration, less expenditure on repairs is required. No possibility exists of the brine solution being weakened by the accidental spilling of water into it, as in the former system.

The plan wherein stationary cells are employed consists in the provision of fixed or stationary shallow pans, or moulds, having hollow walls, the intervening spaces being open at the top. These cells or moulds are filled with water, and a circulation of cold brine is passed through the said hollow walls, and the said water frozen, after which the cold brine is stopped off and completely drained out of the hollow walls, and warm brine is caused to circulate therethrough, melting or thawing off and loosening the blocks, which can then be easily removed from the said cells or moulds, which are then refilled and the operation repeated. In this system an entire tank has to be emptied at once, as in the plate or wall system; therefore, in order to make the operation continuous, at least two tanks must be provided.

If the cells are constructed deep in proportion to their width, that is to say, substantially similar in form to the moulds or cases used in the can system, then the freezing or congealing of the water will be as rapid as in the latter, but agitation, de-ærated water, or other means will have to be used if crystal ice is required. If, however, they are made shallow, and pan-shaped, then the freezing being almost entirely done from the bottom will be extremely slow, as it is in the plate or wall system where the formation of ice is also effected upon one side only.

The advantage of forming the cells shallow is that clear, transparent crystal ice can be made in them without agitation. or using water for freezing that has been de-ærated or deprived of its air. The slowness of freezing is, however, on the other hand, a great drawback, and is the chief objection to the use of the shallow stationary cell system, as the congelation of a block of ice on this plan, of equal thickness to one formed in a deep can or mould, or in a deep stationary cell, takes about four times as long, it is evident that the apparatus requisite for an equal output must become cumbersome and expensive.

Fig. 80 is a perspective view showing a Pontifex-Wood patent cell ice-making tank or box the main novel feature in which is the arrangement of the agitators externally to the spaces where the blocks or slabs of ice are formed. The apparatus consists in a tank with a galvanised wrought-iron hollow or double bottom, two galvanised cast-iron hollow cross walls or partitions, and a number of short galvanised cast-iron longitudinal hollow walls fixed at right angles to the said cross walls, and so that there is a space or clearance left between their adjacent ends in the middle of the tank, and between the other ends, and the extremities of the tank, in which open spaces are placed the agitators. The movements of the latter give an impulse to the water, causing it to rush in waves between the longitudinal walls, and wash out all the impurities thrown off or voided by the water during the freezing process, which impurities settle at the bottom of the open spaces. In this arrangement the two layers of ice gradually growing in thickness between each two longitudinal walls, at last meet and freeze together, so as to form a solid block or slab of ice of a given size and weight.

To remove the blocks of ice they are first loosened or melted off in a similar manner to that employed in the ordinary plate or wall system, after which they are gently started away from the cross walls to enable the ice-grips to grasp each end, and are then lifted out by an overhead traveller in the usual way.

The only ones of the hereinbefore-mentioned objections to which this arrangement seems open are, that, when an ice-making tank or box is in need of any repairs it has to be completely shut off, and the capacity of the apparatus is thus reduced for the time being; and, owing to the space occupied by the agitators being lost for ice-making purposes, the size of the apparatus required for a given output has naturally to be somewhat increased.

The advantages claimed by the inventors are as follows:—The blocks of ice are produced of an uniform size and weight,

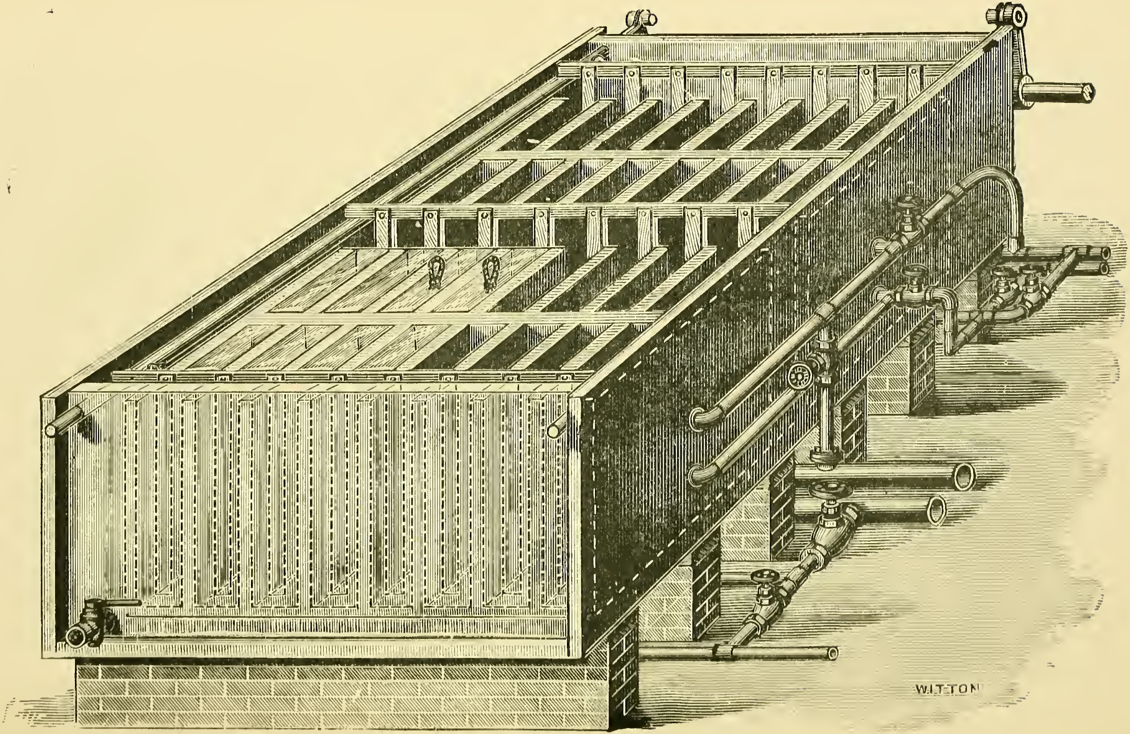

Fig. 80.

and are convenient to manipulate, load, and pack. The ice is of superior purity and appearance, and the slabs are of great thickness and durability. There is no liability to breakage of any of the blades of the agitators. There are no cans or moulds to handle or repair. The walls are fixed and the general arrangement is of very great strength and practically indestructible. Only the actual ice itself has to be handled, therefore less weight has to be moved in comparison with the can system. No cutting up and consequent waste, or weighing of the ice is required, as in the wall or plate system. When an ice tank or box is finished, it can be shut off by simply turning the cocks, and left till it is convenient to remove the ice. Thus all the tanks or boxes can be set so as to be completed during the day, and no night shift of labourers is required. And, finally, the water cannot spill into the brine and weaken it, as it does in the can system, unless considerable care be exercised.

The sizes of the blocks of ice made in these boxes run from 3 ft. 6 in. by 3 ft. 6 in. by 9 in. in thickness up to 3 ft. 6 in. by 3 ft. 6 in. by 1 ft. 9 in. in thickness, and the weight likewise varies in a corresponding ratio from about 4½ cwts. up to 10½ cwts. each. Very thick blocks are not, however, found to be commercially successful, inasmuch as they take too long a time to freeze or congeal.

As in the ordinary wall or plate system every plant working with the above described ice-making tanks or boxes, in order to render the process continuous, must have a set comprising two or more of the latter. Thus a 4-ton plant has two boxes, a 6-ton three boxes, a 9-ton three boxes, a 15-ton either three or four boxes, and a 24-ton either six or eight boxes.

Hill's method of making clear or crystal ice (British Patent No. 16253 of 1889) is shown in Figs. 80*a* and 80*b*, which represent respectively a plan of the ice-making tank or box partly in horizontal section and with the lid or cover removed, and a vertical section on the line *x x* of the previous figure. The apparatus comprises a vessel or tank P, which is provided with a lid or cover (Fig. 80*b*), and with a jacket or casing Q, the intervening space between the said jacket or casing and the tank P being filled with any suitable non-conducting material as at Q^1. When clear ice is to be made, the liquid to be frozen is continuously circulated in the said vessel or tank P by means of a rotating screw R, or other suitable device. Into the vessel or tank P project freezing vessels or chambers S, so that the water in the vessel or tank P will be frozen on the exterior of the chambers s, and the hollow blocks of ice thus formed can be very readily removed therefrom. For this latter purpose the chambers s are made slightly conical or taper from their outer to their inner ends, and rings s^1 are fitted loosely thereon to further facilitate the removal of the hollow blocks of ice. Either the direct expansion or brine circulation may be used for freezing purposes. In the first case the liquid ammonia is forced into the chambers s through a pipe s^2, and is then allowed to expand and return to an absorber, the weak liquor, which cannot be vaporized without the application of heat, being allowed to return to the ammonia

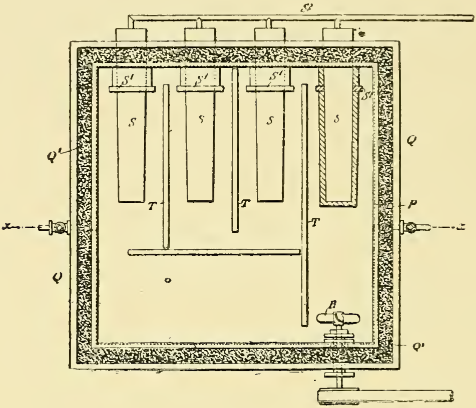

Fig. 80*a*.

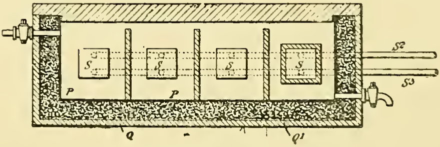

Fig. 80*b*.

boiler through a pipe s^3. In the second case brine reduced to a very low temperature by any suitable process is caused to circulate through the chambers S, for the purpose of freezing the water on the exterior thereof.

To ensure the proper circulation of the water to be frozen in the vessel or tank P, partitions T are provided in the latter, which are so arranged that they can be readily removed to permit the withdrawal of the hollow blocks of ice from the chambers S.

In another arrangement, shown in horizontal section in Fig. 80*c*, and in vertical transverse section on the line *x*′ *x*′ of the latter in Fig. 80*d*, a series of the freezing chambers S at each side of the tank P are provided, leaving a space between them of slightly greater length than the blocks of ice to be produced, so that the blocks from one series of chambers can be first removed and then those from the other series, and space in the ice box or tank is thus economised. Several rows or series of the freezing chambers S placed one above another in the freezing or ice vessel or tank may be employed, as shown in Fig. 80*d*.

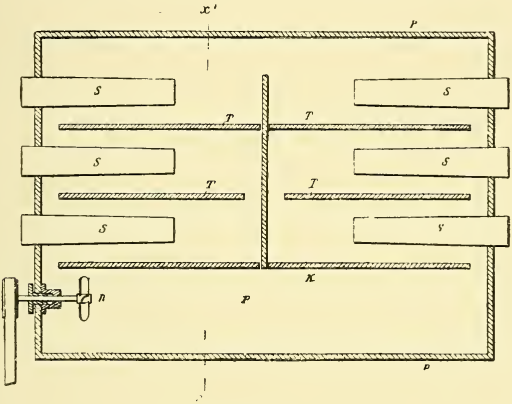

Fig. 80*c*.

Where clear ice is required in blocks of, say, 5 cwts., the Pulsometer Engineering Company, Limited, use a special form of tank, composed of hollow cells forming squares the size of practice to utilise the exhaust steam from the engine for the purpose of ice-making, as described on page 49; and as this exhaust steam contains an admixture of more or less of the lubricating oil from the engine cylinder, it must be deprived of this before being thus used. This is very easily accomplished by passing the said exhaust steam through steam-filters of very simple construction, and after the steam has been thus filtered it is condensed, and the resultant water is again thoroughly filtered so as to, as completely as possible, deodorise it. The can ice produced from this de-ærated or air-freed water still contains a very thin stratum or core of porous ice in the centre, but it is insignificant, and not sufficient to injure the appearance of the blocks to any appreciable extent.

Another method of utilising the exhaust or waste steam for de-ærating or producing water freed of its air, is by employing it for the evaporation or distillation of other water in a suitable still or apparatus, as, for example, a Haslam distilling apparatus, or in a single effect, or, for very large plants, a multiple effect, evaporator of the Yaryan type.

The Haslam distilling apparatus is constructed upon the triple-effect principle, and comprises a first boiling pan, a second boiling pan, a condenser, a feed-water heater, and a distilled-water receiving tank or vessel. When no exhaust or waste steam is available the plant also includes a suitable steam-boiler.

Fig. 81 is a perspective view, partly in section, illustrating a complete single effect distilling apparatus of the Yaryan type, which are made in various sizes, adapted to produce from 3 tons to 48 tons of distilled water per twenty-four hours. The apparatus consists essentially of a cylindrical evaporator, having an horizontal body or shell of wrought iron, with a separator similarly constructed at one end, and a number of straight, solid-drawn tubes (according to the capacity of the machine) so fixed in tube plates provided at both ends of the said shell or body as to be capable of being readily withdrawn therefrom for cleaning purposes. These tubes are connected at their ends by return heads, so as to throw them into sets or series, thus practically forming coils of pipe of any desired length. The water to be distilled is passed through these coils or sets of pipes, the exhaust steam being admitted to the space round them, and the steam or vapour from the said evaporating coils passes through the separating chamber, which is fitted with baffle or check plates, as shown in the drawing, to the con-

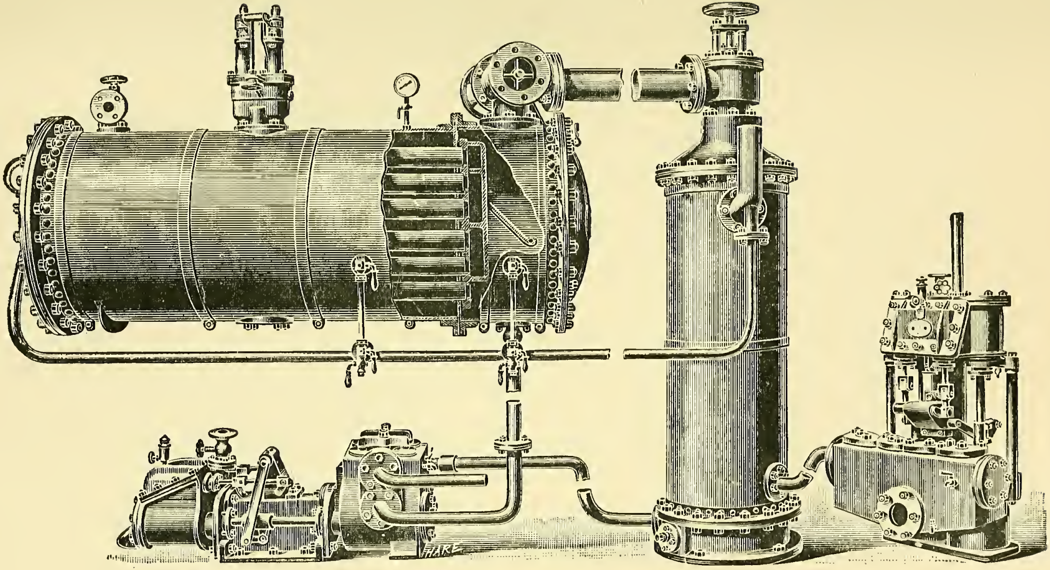

Fig. 81.

denser, which latter also forms an interchanger and heats the water to be distilled.

The distinctive feature of this system is film evaporation, that is, the blowing of the whole mass of the liquid to be evaporated into spray, and its rapid motion through the sets or series of tubes during the process. This latter point is of great importance, and is the chief reason of the great efficiency of this type of apparatus. The result is due to the fact that there is a very considerable gain in absorption of heat by the liquid under treatment as its velocity increases, owing to the fact that new particles of the said liquid are being constantly brought into contact with the heated surfaces, and naturally the more rapid its motion over the latter the more frequently will this occur.

When in operation there will be a vacuum of from 12 ins. to 15 in. in the separator, and the steam pressure in the evaporator should be about 15 lbs. per square inch: the latter may, however, be increased to about 40 lbs. per square inch.

The feed taken from the circulating discharge is usually drawn into the tubes by reason of the vacuum in the separator; if, however, condensation is carried out at atmospheric pressure, it is forced in owing to the head of water due to the height of the circulating discharge, or to a loaded valve.

The advantages of an apparatus of this type for producing pure distilled water for ice-making are obvious, inasmuch as it admits of its being obtained free from the slighest trace of oil, by the use of exhaust or waste steam only, and that without any necessity for filtering. The dispensing with filtering is of some importance, as each time the distilled water is passed through a new filter it takes up a considerable quantity of air, and consequently until all the air has become expelled from the said filter the water is in no way superior to ordinary undistilled water, and the ice made from it is opaque and porous. The condensed exhaust steam, after having performed its duty in the evaporator, may be either run into a hot-well to be used for boiler feeding purposes, or it may be run to waste.

Fig. 82 illustrates one of the Mirrlees, Watson, and Yaryan Company's larger forms of distilling apparatus, which is suitable for installations turning out considerable quantities of ice per twenty-four hours. As will be seen from the drawing it is a sextuple or six-effect apparatus. On the right are situated the air, circulating, brine, fresh water, and feed pumps, which are all driven off one engine, and are, with the latter, the only moving parts. Next is placed the distilling condenser (between two heaters in which the feed-water becomes partially heated

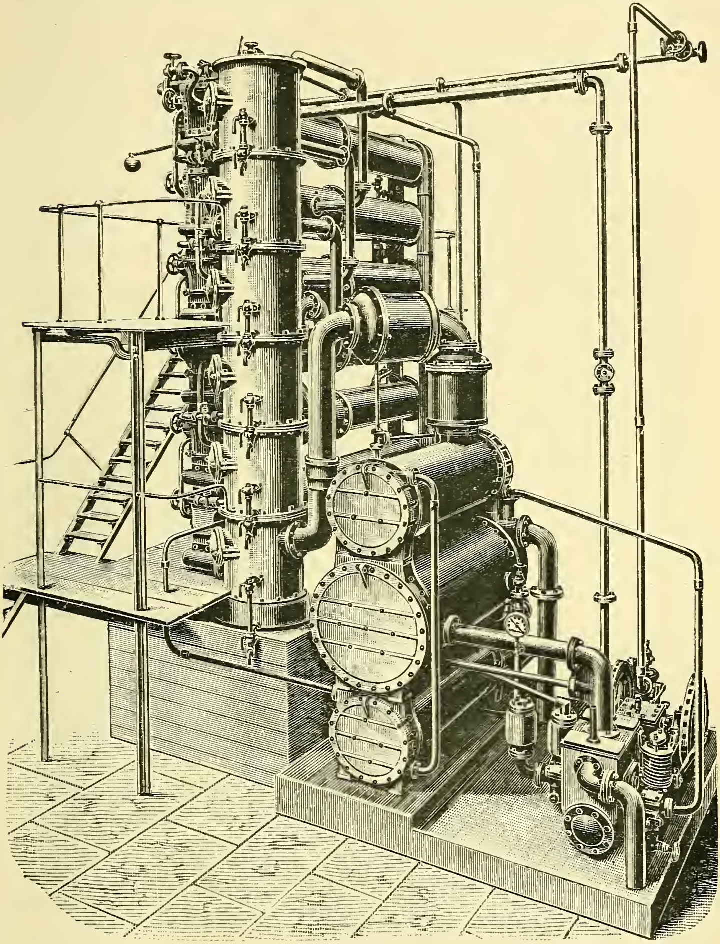

Fig. 82.

on its way to the evaporator); and finally, on the left, six separators placed in a vertical column, with the corresponding six effects arranged horizontally in the rear.

In operation there will be a pressure of from 40 to 60 lbs. in the first effect, and a vacuum of about 27 inches in the distilling condenser, the apparatus being so proportioned that this difference of pressure will distribute itself automatically between the several effects. The feed for the evaporator being taken from the circulating water of the distilling condenser, a certain amount of heat, which would otherwise be rejected, is utilised at the very commencement of the operation, and the efficiency of the apparatus is further increased and heat economised by a multiple effect system of heating the feed before reaching the evaporating vessel. The first stage of heating the feed referred to is effected by exposing it to the vapour given off by the water evaporated in the last effect while this vapour is on its way to the distilling condenser, and then to the vapour from the several effects constituting the evaporating apparatus, until it receives its final increment of heat from the steam employed to heat the first effect, into which the feed enters at or about the boiling point of that effect.

The feed entering the first, passes down through all the effects of the apparatus. The water resulting from the condensation which takes place on the different heating surfaces, together with that from the last effect, being eventually delivered as cold distilled water. Usually the water resulting from the condensation of the steam employed to heat the first effect is separated from that produced in the remainder of the apparatus, as being likely to be slightly contaminated, and is reserved for feeding the boiler supplying steam to the apparatus, pumping engines, &c. On the number of effects used in combination with the system of evaporating water in continuous motion depends the great economy of fuel which is obtained in apparatus of this type. The only labour required in connection with the apparatus is that for stoking the boilers, and the necessary attention to the feeding of these, and to the working of the pumps. All parts of the apparatus are readily accessible, hinged doors at the end of each effect giving easy access to the interior of these for cleaning purposes when required.

An exceedingly compact and efficient form of portable Yaryan distilling apparatus has also been designed by the same firm, which is entirely self-contained and is easily movable, being mounted upon an independent carriage supported upon strong iron wheels. The apparatus comprises two Yaryan evaporators arranged to work as a double effect, a distilling condenser in connection therewith, a suitable feed water-tank, a pump for feeding the water to be distilled through a heater into the first effect or vessel, and a tail or circulating pump for condensing the steam given off from the second effect or vessel in the said distilling condenser. The steam required for working the apparatus is supplied from a portable boiler fitted with a donkey feed-pump, &c., and also mounted upon iron road wheels.

The advantages of a portable distilling apparatus capable of being shifted with great facility from one source of water supply to another, or to any desired location in the works, are obvious. And the compactness of the installation renders it very easily manageable, one skilled attendant and a boy being sufficient for a machine having a capacity to produce 85 gallons of pure fresh water per hour from strong brine averaging twice the density of ordinary sea water. Exhaustive tests proved most conclusively that the efficiency of the plant was fully equal at the termination of each run to what it was at the commencement, which abundantly demonstrated the self-cleaning powers of the apparatus when treating water so strongly charged with salts. The evaporative duty was 4¾ lbs. of water per pound of common wood fuel; with coal, however, the duty would be about double per pound of coal consumed, and naturally when treating impure water of less density than the said brine, or comparatively pure water for de-ærating purposes, the amount of pure de-ærated water obtained per pound of fuel consumed would be proportionately larger.

In the case of a single effect distilling apparatus the above fuel consumption would be doubled to produce the same amount of distilled water, and the more effects that are employed up to a certain point the greater the economy, a six-effect apparatus being found capable of producing 36 lbs. of pure distilled water for each pound of fuel consumed, that amount being over and above what was evaporated in the boiler which was returned to the latter.

It is obviously, therefore, advisable wherever the demand for the de-ærated water warrants it, to employ a multiple effect distilling apparatus.*

In most factories, however, the exhaust steam from the

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* A detailed description of the larger forms of multiple effect Yaryan evaporators, with reference to their use for the evaporation and concentration of saccharine juices and solutions, will be found in a treatise on "Sugar Machinery," by the same author.

engines will be available for use in the apparatus, and the expenditure on fuel for raising steam, specially for use in the evaporator, is saved.

The evaporator should be opened every two or three weeks, and if scale is found on any of the tubes, these should be withdrawn and clean ones inserted in their place. The best means to employ for removing the scale from the tubes is to pass them over a slow fire, care, however, being taken not to apply more heat than is necessary to bring off the said scale.

As the refrigeration of cold stores or chambers, so also the manufacture of ice with modern machines may be divided into two main systems, that is to say, the one wherein brine previously reduced in temperature in the cooler or refrigerator of the machine is used for freezing the water, and the other wherein the said freezing or congelation is effected by the direct expansion of the refrigerating agent.

It will be readily seen that the latter system enables a very considerable amount of apparatus, essential in the first, to be entirely dispensed with; prevents the loss of efficiency due to a second transmission of heat; and, moreover, avoids the mess and inconvenience so frequently occasioned by a careless or unskilful use of the brine solution.

Much greater difficulties, however, have to be surmounted before the direct expansion system can be successfully applied to ice-making, than is the case with the cooling or refrigerating of cold stores or chambers. In the latter, indeed, all that is required to ensure complete success is a perfectly gas-tight system of pipes, and as a pipe of no very great diameter form- the safest, surest, and least expensive method of imprisoning or confining a gas of a searching nature, it consequently follows that no insurmountable difficulty is here experienced. But the freezing or congelation of water is quite another matter, and requires straight surfaces, as it is not only very difficult to remove the ice that becomes formed round pipes, but a very considerable portion of it is also wasted in so doing. Hitherto attempts to construct straight surfaces with sufficiently gas-tight joints have proved a failure.

In another system, wherein an imitation of the natural process is attempted, the water to be frozen is exposed in well insulated rooms or chambers to a temperature far below freezing point. This plan, however, is not found to answer commercially owing to the extreme slowness with which the freezing or congealing of the water is effected, by reason of the low specific heat of air and its poor capacity for conduction, a fault which cannot be got over even by increasing the cooling surfaces of the rooms to an abnormal degree.

The method of making ice without the use of either a primary or secondary cooling agent, that is to say, by freezing the water in vacuo, has been already dealt with when describing the Carré, Windhausen, Harrison, and other vacuum machines. Briefly, the principle upon which they work is that if water be exposed in a practically perfect vacuum it is rapidly turned into vapour, and this change requiring a large quantity of heat which must be provided by the water itself, that portion of the water which is not vaporised becomes frozen solid. As already mentioned, however, the ice thus made is more in the form of granulated snow, and, being brittle, charged with air, and possessing no durability, it is practically of very little or no market value.

A combination of the direct expansion and the brine system was described in the specification of Lightfoot's 1885 patent, which, as already mentioned, consists of a combined refrigerating and ice tank, wherein moulds were to be arranged between coils or pipes through which the vaporised freezing medium was to be caused to circulate, the said moulds and pipes being surrounded by brine, or uncongealable fluid, not mechanically circulated.

A factory for making ice consists of more or less solid buildings in accordance with the particular regulations of the locality, capital at command, etc. Fig. 83 shows an arrangement of the ice-tank, or box-room, but in addition to this the factory will comprise a machine-room, boiler-room, ice store, offices, loading platforms, etc.

The arrangement shown in the drawing is intended for making ice on the can system, and the ice-boxes are precisely similar to that illustrated in Fig. 78. Above the ice-boxes is provided a travelling hoist, or crane by means of which the cans, or moulds, can be conveniently raised one by one from the said ice-boxes, when the water in the said cans has been frozen, and transferred to the platform shown on the right-hand side of the drawing. On or beneath this platform are provided a suitable number of thawing or relieving tanks filled with warm, or tepid water, at about 70° Fahr., and into this the can or mould is dipped for a few seconds, after which the block of ice can be readily turned out on a tip-table, and the said can or mould is again filled with water and returned into the brine-

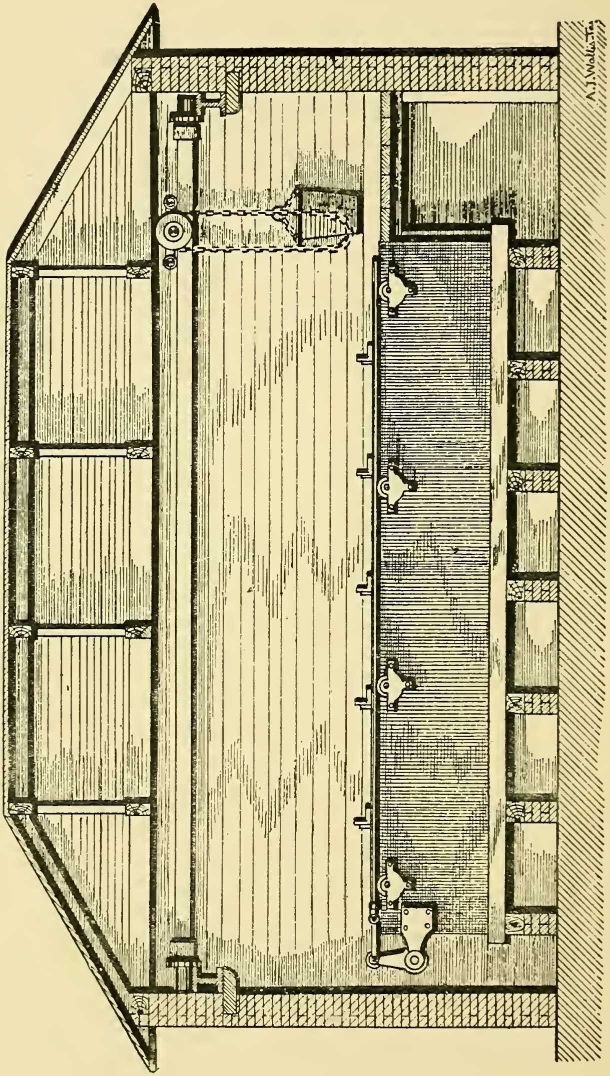

Fig. 83.

tank to recommence freezing. The ice blocks, or cakes, are in some instances turned out of the cans or moulds at, or delivered to, the upper end of an inclined plane, or runway, down which they pass to the ice-store, or ante-chamber leading thereto. The waste water tanks, etc., are located beneath the ice-making tanks or boxes. For another ice factory see folding plate.

As has been already mentioned, numerous contrivances for minimising the work of handling the cans or moulds and the blocks of ice have been devised.

Puplett and Rigg's patent of 1887 comprises an arrangement for facilitating the lifting of the cans or cases, and removing the ice. This labour-saving contrivance consists in an apparatus for connecting two or more of the cans, moulds, or cases together, and comprises a frame which is provided with trunnions or gudgeons so situated as to be slightly above the centre of gravity of the said cans or moulds. At one end of each of these frames a quadrant, worm and worm wheel, or some other convenient means, are provided, for enabling the frame and moulds therein to be inclined to any required angle. To admit of the frames being raised from the ice-making tank or box by the overhead traveller the latter is fitted with links adapted to engage with the above-mentioned trunnions or gudgeons. The frame, and moulds or cans, being nearly balanced on their trunnions, the labour of discharging the ice therefrom is greatly reduced, and the operation is moreover considerably expedited. The quadrant or worm gearing is usually so arranged as to engage with a suitable device fixed on to the links of the overhead traveller; but mechanical contrivances can be dispensed with, and the frame containing the moulds tipped by hand, which operation, owing, as above mentioned, to its being almost balanced, can be so accomplished without any difficulty.

Ice-delivery machines and other labour-saving appliances are also manufactured by the Pulsometer Engineering Company, Limited, and others.

Whatever the arrangement, however, for drawing the ice, one thing is absolutely necessary to ensure economical working, and that is the strictest regularity. It is, of course, understood that the machinery should also be kept working at as uniform a speed as possible, and that all temperatures should be maintained as normal as practicable.

Suitable ice elevators are also required for raising the blocks of ice from one level of the factory to another. Amongst numerous devices for this purpose, mention may be made of the following; viz., That wherein an endless chain, provided with hooks, is employed to grab the blocks of ice, and drag them up an incline, which latter may be made in sections, so as to admit of the ice being discharged at different elevations. The hooks are set in position to engage with the blocks of ice by a spring bar upon the frame carrying the driving-wheel. In another arrangement the blocks of ice are shoved up a fixed spiral incline, by arms or levers projecting radially from a shaft, located vertically in the centre of the said incline, and rotated in any convenient manner.

Ordinary hydraulic or steam platform lifts, communicating between the different floors of the factory, may be located wherever found to be necessary and convenient.

A number of loose tools are likewise required in an ice-factory for manipulating the ice, such as ice-saws, hatchets, hooks and picks, hoisting tongs, etc., etc.

It is advisable to have hydrants in suitable positions throughout the buildings, and this precaution is especially desirable where ammonia machines are in use, the extreme affinity of ammonia for water rendering the latter (as already mentioned) the best remedy to employ for killing the said ammonia should any considerable quantity become accidentally spilt.

The ice store is usually refrigerated by means of a brine or direct expansion coil, and the ante-room thereto should be cooled in a similar manner. It may be taken that, as usually stored, a ton of ice will occupy about 50 cubic feet. The top layer should be covered with dry sawdust or shavings.

In some places it is found advisable and advantageous to add to the ice factory buildings, one or more cold stores or chambers, wherein perishable products can be preserved for parties desiring such accommodation.

The management of ice-making and refrigerating machines has been dealt with in the preceding chapters, so far as the space at command would allow. That of the steam-engines or other motors employed for driving these and of the miscellaneous accessory machines and apparatus will, of course, in no way differ from those used for other purposes, and instructions for the proper care and working thereof are outside the province of this work.*

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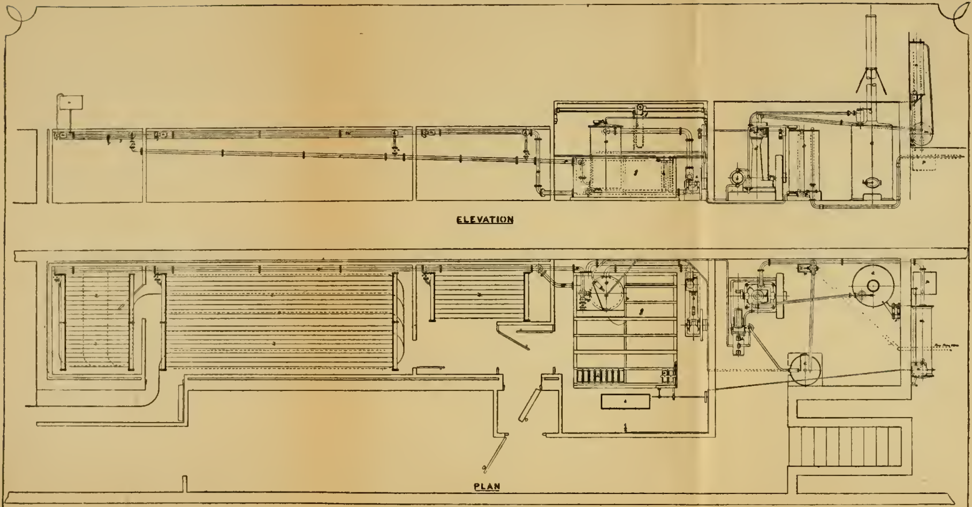
* For detailed information regarding friction, and the management and lubrication of the rubbing parts of machinery see "Bearings and Lubrication," by the same author.

ICE FACTORY WITH COLD STORES ATTACHED.

[To face p. 231.



— PUPLETT'S PATENT —
— 6.TON ICE MAKING & REFRIGERATING PLANT —
— WITH IMPROVED DE-AERATING APPARATUS FOR MAKING —
— PURE & CRYSTAL ICE —
BRINE CIRCULATION SYSTEM

CHAPTER XIII.

COST OF WORKING.

THE cost of producing cold with any of the hereinbefore described machines must of necessity vary in different localities in accordance with the prices of material and labour, and even in the same district with the fluctuations in the market, consequently any estimates made thereof can only apply to the particular case in point, and in others can be taken as approximate only.

The main items of expense in the production of cold by artificial means, are fuel and skilled and other labour for operating the machinery, and in the manufacture of ice, for handling the latter. The degree of economy of working to which the apparatus has been brought, and the point to which the operation thereof has been rendered automatic, will naturally tend to minimise the cost of the production of cold and of ice-making, and the latter will also vary inversely with the power of the machine, as the consumption of fuel and the number of attendants necessary to work the machinery do not increase in a ratio corresponding to the size thereof, and consequently those having the larger outputs require proportionately fewer operatives. The saving, moreover, under this latter head is the greatest in the more expensive skilled labour. For instance, an ammonia machine on either the absorption or compression principle, with a capacity of 1 ton of ice per twenty-four hours, requires the services of two engine-drivers and two labourers; whilst the same number of attendants can likewise work a 2 or a 5-ton machine, and the addition of a single labourer will be sufficient for either a 7½, 10, or 12-ton machine, and of three labourers for a 28-ton machine. The same skilled attendants are sufficient for a machine having an output of 50 tons per twenty-four hours.

According to calculations made by Mr. F. Colyer, M.Inst.C.E., in 1884, from observations of the working of a Pontifex-Wood ammonia absorption machine of a capacity of 20 tons of can ice per twenty-four hours, the cost of making ice, taking coals at London price, is 4s. 9d. per ton. If, however, two machines were used the price would be reduced to 3s. 5d. per ton, and with coals at Glasgow price the cost would be further lowered and would stand respectively at 3s. 7d. and 2s. 10d.

The cost of cooling water 10° by the same machine he estimated to be ·15 of a penny per barrel cooled.

The calculations from which these figures were deduced includes the cost of labour, coals, water, oil and sundries, repairs, loss of ammonia, 5 per cent. interest on capital invested, and an allowance of 4 per cent. for depreciation.

The cost of producing clear block ice in this country with an ammonia machine working on the absorption principle is given at a somewhat higher figure * by Mr. Lightfoot, viz., for a machine of 15 tons capacity per twenty-four hours about 4s. per ton, and this estimate, moreover, is made, on the assumption that good coals can be obtained at 15s. per ton, and is exclusive of any allowance for repairs and depreciation.

The cost of producing ice with a Pontifex-Wood improved ammonia absorption machine, is stated by the makers to be, for a machine having a capacity of 24 tons per twenty-four hours, allowing for labour, coals, oil, chemicals, and water (taking coals at 10s. a ton and water at 6d. per 1,000 gallons), 2s. 0¾d. per ton. With coals at 20s. a ton it rises, however, to 2s. 10½d. per ton. For a machine with a capacity of 15 tons per twenty-four hours, it is respectively, with coals at the above prices, 2s. 7¾d. and 3s. 7¾d. per ton. For a machine with a capacity of 9 tons per twenty-four hours, 3s. 4d. and 4s. 5½d. per ton. For a machine with a capacity of 6 tons per twenty-four hours, 4s. 5½d. and 5s. 8d. per ton. And for a machine with a capacity of 4 tons per twenty-four hours, 5s. and 6s. 3d. per ton.

According to Mr. Lightfoot † the action of, and losses experienced in working an ammonia absorption machine are as follows:—

"Assuming the action of the economiser to be perfect—which, of course, is a condition never met with in practice—all the heat given out by the steam in the generator-coils would be found in the water issuing from the condenser, less that portion directly lost by radiation and conduction. In this case

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* "Proceedings, Institution of Mechanical Engineers," 1886, p. 221.

† "Proceedings, Institution of Mechanical Engineers," 1886, pp. 220, 221

the total heat expended would be that required to vaporise the ammonia, and the water, which, in the form of steam, unavoidably passes off with the ammonia to the rectifier and condenser: plus the heat lost by radiation and conduction. In the refrigerator the liquid ammonia in becoming vaporised will take up the precise quantity of heat that was given off during its cooling and liquefaction in the condenser, less the amount due to difference in pressure, and less also the small amount due to the difference in temperature between the vapour entering the condenser and that leaving the refrigerator. Again, when the vapour enters into solution with the weak liquor in the absorber, the heat taken up in the refrigerator is given to the cooling water, subject to slight corrections for differences of pressure and of temperature. Supposing there were no losses, therefore the heat given up by the steam in the generator, plus that taken up by the ammonia in the refrigerator, would be precisely equal to the amount taken off by the cooling water from the condenser, plus that taken off from the absorber. The sources of loss are: Inefficiency of the economiser; radiation and conduction from all vessels and pipes that are above normal temperature; useless evaporation of water which passes into the rectifier and condenser; conduction of heat into all vessels and pipes that are below normal temperature; water passing into the refrigerator along with the liquid ammonia.

"It will have been seen that the heat demanded from the steam is very much greater in the absorption system than in the compression. This is chiefly due to the fact that in the absorption system the heat of vaporisation acquired in the refrigerator is rejected in the absorber; so that the whole heat of vaporisation required to produce the ammonia vapour prior to condensation, has to be supplied by the steam. In the compression system the vapour passes direct from the refrigerator to the pump, and power has to be expended merely in raising the pressure and temperature to a sufficient degree for enabling liquefaction to occur at ordinary temperatures. On the other hand, a great advantage is gained in the absorption machine by using the direct heat of the steam without first converting it into mechanical work; for in this way its latent heat of vaporisation can be utilised by condensing the steam in the coils, and letting it escape in the form of water. Each lb. of steam passed through can thus be made to give up some 950 units of heat; while in the steam-engine using 2 lb. of coal per indicated horse-power per hour, about 160 units only are utilised per lb. of steam, without allowance for mechanical inefficiency. In the absorption machine also the cooling water has to take up about twice as much heat as in the compression system, owing to the ammonia being twice liquified, namely, once in the condenser and once in the absorber. It is usual to pass the condensing water first through the condenser and then through the absorber."

The cost of ice production with machines of the ammonia compression type is somewhat less on the whole than with those working on the absorption principle.

The estimate given by the Pulsometer Engineering Company as the approximate amount per ton of clear or crystal ice is, cost of coals 1s., all labour, including that of getting the ice out of the tanks, 1s. 3d., and cost of ammonia lost through leakage, &c., ¼d. per ton of ice made, or a total cost of 2s. 3¼d. per ton. If an allowance of, say, 10d. per ton be added to this for interest and depreciation, repairs to machinery, cost of water supply and sundries, this would increase the cost of production to about 3s. 2d. per ton.

Mr. Lightfoot states * that one ton of coal is capable of producing as much as 12 tons of ice in well-constructed ammonia compression apparatus, having a capacity of 15 tons per twenty-four hours; and with coals at 15s. a ton, he estimates the cost of making ice by the ammonia-compression system at about 3s. 9d. per ton, for a production of 15 tons per twenty-four hours, exclusive, however, of any allowance for repairs and depreciation.

The estimate given for the total cost of ice per ton, made by a Frick ammonia-compression machine, is, for a daily production of 15 tons, 5s. 2d. per ton of ice. This calculation, however, is got out at the much higher rate of wages paid in America, and if due allowance be made for this, and also for the falling off in efficiency of the machine, due to the greater heat of the climate in summer, the cost per ton in this country would probably be something under 4s. If the capacity of the machine be 100 tons of ice per day, the cost per ton falls to 3s. 11d., or allowing for the larger item for labour, about 2s. 10d. here.

In an ether compression machine Mr. Lightfoot accounts for the work as follows †:—Friction. Heat rejected during compression. Heat acquired by the refrigerating agent in passing

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* "Proceedings, Institution of Mechanical Engineers," 1886, p. 221.

† "Proceedings, Institution of Mechanical Engineers," 1886, p. 214.

through the pump. Work expended in discharging the compressed vapour from the pump. Against this he sets the work done by the vapour in entering the pump. Assuming that vapour alone enters the pump, the heat rejected in the condenser he states to be :—Heat of vaporisation acquired in the refrigerator, with the correction necessary for difference in pressure. And the heat acquired in the pump, less the amount due to the difference between the temperature at which liquefaction occurs, and that at which the vapour entered the pump, and less also the amount lost by radiation and conduction between the pump and the condenser.

The mechanical work expended in compressing ammonia is to be accounted for in a precisely similar manner to that expended in the compression of ether.

Notwithstanding, however, that the degree of compression is so much greater with ammonia than with ether, the energy expended in the compression, heating, and delivering of the gas is less, owing to the much smaller weight of ammonia required to produce a given refrigerating effect, the weights being in the reverse ratio of the heats of vaporisation, or as 1 to 5·45. For this reason the cost of making ice with ether is far higher than with ammonia, and assuming the coal consumption per indicated horse-power to be 2 lb. per hour, and the price of coals fifteen shillings a ton, the total cost of producing transparent block ice in this country on the ether system would be about 5s. per ton, exclusive of any allowance for repairs and depreciation. The production of ice would be about 8·3 tons per ton of coal consumed.

On the other hand, however, as already mentioned, either machines, by reason of their low working pressures in the condensers, offer considerable advantages in hot climates, especially in the case of machines with small outputs.

The expense of producing ice with the Tellier and Pictet machines is about the same. The results obtained with Pictet's special liquid (combination of carbon dioxide and sulphur dioxide) is stated to equal a production of 35 tons of ice per ton of coal, but this is in all probability far in excess of any result obtained in actual working.

It will be obvious that the arrangement made for the use of any particular machine acting on the principle of the abstraction of heat by the evaporation of a separate refrigerating agent of a more or less volatile nature, must have a very considerable effect upon its economical working, and it is doubtless owing to the superiority of the fixing and manipulation of the installation that so much better results are occasionally obtained in one case than in another, as, these things being equal, all first-rate machines of this class are about the same in point of economy. In relation to this it must also be borne in mind that the thickness of the blocks of ice that are being made exercises an important influence upon the time occupied in their production, for whereas a block 3 in. thick can be frozen in eight hours, a block 9 in. in thickness will require thirty-six hours. The time varying also, of course, more or less with the temperature of the brine.

The cost of making a ton of opaque and porous ice with a vacuum machine such as the Windhausen is estimated * by Dr. Hopkinson at 4s. The amount of water required (including that used for cooling purposes) is stated † by Mr. Pieper to be from 10 to 12 tons per ton of ice produced, and the fuel consumption 1 ton of coal for every 12 tons of ice. The fuel is required for the generation of steam to drive the vacuum pump, and the air pump, of the concentrator. The total heat which must be abstracted to produce a ton of ice from a ton of water at a temperature of 60° Fahr. is 382,144 units. The Windhausen machine is heavy, and takes up a considerable floor space, and the necessary outlay for keeping it in an efficient state of repair, even under the most favourable circumstances, must be heavy.

The cost of making opaque ice by means of the Harrison (1878) patent vacuum apparatus would undoubtedly be lower than with the Windhausen machine, as the larger part of the friction, which forms a very considerable item of the loss in the latter, is got rid of, and a corresponding saving of fuel is thus effected. The expenditure of fuel for concentrating the acid is also entirely eliminated, much less water is required for cooling purposes, and the first cost and subsequent outlay for repairs, &c., are likewise much less. It is stated that the inventor expected to be able to produce opaque ice on a large scale at a cost of about 1s. per ton.

The outlay per ton of ice made on the system of abstracting the heat by the rapid melting or liquefaction of a solid is the greatest, and so much so that for producing ice on a commercial scale in this climate it is completely out of the running. The cost of making 15 tons of ice per twenty-four hours, with

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* "Journal of the Society of Arts," 1882, vol. xxi., p. 20.

† "Transactions of the Society of Engineers," 1882, p. 145.

an apparatus working on a substantially similar principle to that of Sir William Siemens', is stated to be 7s. per ton with good coals at 15s. a ton, and not making any allowance whatever for depreciation, interest, repairs, &c.

This estimate, moreover, is based upon the erroneous assumption that 1 lb. of coal is capable of evaporating 20 lbs. of water, and it is undoubtedly far too low. According to Mr. Lightfoot*:—

"Nearly the whole of the coal is used for evaporating the water in recovering the salt, the quantity being given at 2½ tons of coal for every 15 tons of ice. If, however, this has been calculated on an evaporative duty of 20 lbs. of water per lb. of coal, the amount actually used will probably be about 5 tons of coal, which would make the cost per ton of ice 9s. 3d. instead of 7s. On the other hand, it must be remembered that under certain climatic conditions much of the water could be evaporated in the open air, without the use of fuel, in which case the coal consumption, and therefore the cost of ice production, would be greatly lessened."

As regards the capacity, etc., of cold-air machines, those of the Haslam type vary from an ice equivalent of one-third of a ton, requiring 4 indicated horse-power at average speed, or 9 indicated horse-power at maximum speed, and delivering 2,000 cubic ft. per hour (capacity of compressor in cubic ft. per hour 2,500), up to an ice equivalent of 60 tons, requiring 460 indicated horse-power at average speed, or 566 indicated horse-power at maximum speed, and delivering 300,000 cubic ft. of air per hour (capacity of compressor in cubic ft. per hour 353,000). This latter machine is of the quadruple duplex condensing type.

It has been stated† by Mr. Lightfoot that with the best machines of large size then (1886) made, a weight of 1,000 lbs. of air per hour could be reduced from 60° above to 80° below zero, the cooling water being at 60° Fahr., with an expenditure of about 18 indicated horse-power. That is to say, that an abstraction of 916 units of heat is effected to each pound of coal used, with an engine consuming 2 lbs. of coal per indicated horse-power per hour.

For Haslam's formula to enable the amount of air delivered by a cold-air machine per hour to be ascertained, the revolutions, and size of the compressor being known, see page 254.

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* "Proceedings, Institution of Mechanical Engineers," 1886, p. 204.

† "Proceedings, Institution of Mechanical Engineers," 1886, p. 230.

CHAPTER XIV.

USEFUL TABLES AND MEMORANDA.

EVAPORATION OF LIQUIDS.—*Lightfoot.*

Liquid or gas.		Water.	Anhydrous Ammonia.	Sulphuric ether.	Mythylic ether.	Sulphur dioxide.	Pictet's liquid.
Specific gravity of vapour, compared with air = 1·000		0·622	0·59	2·24	1·61	2·24	—
		Fahr.	Fahr.	Fahr.	Fahr.	Fahr.	Fahr.
Boiling point at atmospheric pressure . . .		212°	−37·3°	96°	−10·5	14°	−2·2°
Latent heat of vaporisation at atmospheric pressure .		966	900	165	473	182	—
Absolute vapour tensions in lbs. per square inch at different temperatures.	Fahr.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
	− 40°	—	—	—	—	—	—
	− 20°	—	19·4	—	12·0	5·7	11·6
	0°	—	30·0	1·5	18·7	9·8	15·4
	+ 20°	—	47·7	2·6	28·1	16·9	22·0
	+ 32°	0·089	61·5	3·6	36·0	22·7	27·0
	+ 40°	0·122	73·0	4·5	42·5	27·3	31·3
	+ 60°	0·254	108·0	7·2	61·0	41·4	44·0
	+ 80°	0·503	152·4	10·9	86·1	60·2	60·0
	100°	0·942	210·6	16·2	118·0	84·5	79·1
	120°	1·685	283·7	23·5	—	117·5	99·7
	140°	2·879	—	33·5	—	—	—
	160°	4·731	—	45·6	—	—	—
	180°	7·511	—	62·0	—	—	—
	200°	11·526	—	81·8	—	—	—
	212°	14·7	—	96·0	—	—	—

Table giving weights of aqueous vapour held in suspension by 100 lbs. of pure dry air when saturated, at different temperatures, and under the ordinary atmospheric pressure of 29·9 in. of mercury.—*Box and Lightfoot.*

Temperature.	Weight of vapour.	Temperature.	Weight of vapour.
Fahr. degs.	lbs.	Fahr. degs.	lbs.
−20	0·0350	102	4·547
−10	0·0574	112	6·253
0	0·0918	122	8·584
+10	0·1418	132	11·771
20	0·2265	142	16·170
32	0·379	152	22·465
42	0·561	162	31·713
52	0·819	172	46·338
62	1·179	182	71·300
72	1·680	192	122·643
89	2·361	202	280·230
92	3·289	212	Infinite

N.B.—The weight in lbs. of the vapour mixed with 100 lbs. of pure air at any given temperature and pressure is given by the formula

$$\frac{62{\cdot}3\,E}{29{\cdot}9 - E} \times \frac{29{\cdot}9}{p}$$

Where E = elastic force of the vapour at the given temperature, in inches of mercury (to be taken from Tables)

p = absolute pressure in inches of mercury

= 29·9 for ordinary atmospheric pressure.

PROPERTIES OF SATURATED AMMONIA GAS.—*Yaryan.*

Temperature Fahr.	Pressure from vacuum in lbs. per sq. in.	Heat of vaporization.	Volume of vapour per lb. cubic ft.	Volume of liquid per lb. cubic ft.	Gauge pressure per sq. in.
−40	10·69	579·67	24·38	·0234	0·
−35	12·31	576·69	21·21	·0236	0·
−30	14·13	573·69	18·67	·0237	0·
−25	16·17	570·68	16·42	·0238	1·47
−20	18·45	567·67	14·48	·0240	3·75
−15	20·99	564·64	12·81	·0242	6·29
−10	23·77	561·61	11·36	·0243	9·07
− 5	27·57	558·56	9·89	·0244	12·87
0	30·37	555·5	9·14	·0246	15·67
+ 5	34·17	552·43	8·04	·0247	19·47
+10	38·55	549·35	7·20	·0249	23·85
+15	42·93	546·26	6·46	·0250	28·23
+20	47·95	543·15	5·82	·0252	33·25
+25	53·43	540·03	5·24	·0253	38·73
+30	59·41	536·92	4·73	·0254	44·71
+35	65·93	533·78	4·28	·0256	51·23
+40	73·00	530·63	3·88	·0257	58·30
+45	80·66	527·47	3·53	·0260	65·96
+50	88·96	524·30	3·21	·02601	74·26
+55	97·63	521·12	2·93	·02603	82·93
+60	107·60	517·93	2·67	·0265	92·90
+65	118·03	515·33	2·45	·0266	103·33
+70	129·21	511·52	2·24	·0268	114·51
+75	141·25	508·29	2·05	·0270	126·55
+80	154·11	504·66	1·89	·0272	139·41
+85	167·86	501·81	1·74	·0273	153·16
+90	182·8	498·11	1·61	0·274	168·10
+95	198·37	495·29	1·48	0·277	183·67
+100	215·14	491·50	1·36	0·279	200·44

TO CONVERT DEGREES CENTIGRADE OR REAUMUR INTO DEGREES FAHRENHEIT.

Let F = degrees Fahrenheit; C = degrees Centigrade; and R = degrees Reaumur.

$$F = \frac{9\,C}{5} + 32 \qquad F = \frac{9\,R}{4} + 32 \qquad C = \frac{5\,(F - 32)}{9}$$

$$R = \frac{4\,(F - 32)}{9}$$

COMPARISON BETWEEN THE SCALES OF CENTIGRADE AND FAHRENHEIT THERMOMETERS.

Centigrade.	Fahrenheit.	Centigrade.	Fahrenheit.
−73	−100·0	−24	−11·2
−72	−97·6	−23	−9·3
−71	−95·8	−22	−7·6
−70	−94·0	−21	−5·8
−69	−92·2	−20	−4·0
−68	−90·4	−19	−2·2
−67	−88·6	−18	−0·4
−66	−86·8	−17	+1·4
−65	−85·0	−16	+3·2
−64	−83·2	−15	+5·0
−63	−81·4	−14	+6·8
−62	−79·6	−13	+8·6
−61	−77·8	−12	+10·4
−60	−76·0	−11	+12·2
−59	−74·2	−10	+14·0
−58	−72·4	−9	+15·8
−57	−70·7	−8	+17·6
−56	−68·8	−7	+19·4
−55	−67·0	−6	+21·2
−54	−65·3	−5	+23·0
−53	−63·4	−4	+24·8
−52	−61·6	−3	+26·6
−51	−59·8	−2	+28·4
−50	−58·0	−1	+30·2
−49	−56·2	−0	+32·0
−48	−54·4	+1	+33·8
−47	−52·6	+2	+35·6
−46	−50·8	+3	+37·4
−45	−49·0	+4	+39·2
−44	−47·2	+5	+41·0
−43	−45·4	+6	+42·8
−42	−43·6	+7	+44·6
−41	−41·8	+8	+46·4
−40	−40·0	+9	+48·2
−39	−38·2	+10	+50·0
−38	−36·4	+11	+51·8
−37	−34·6	+12	+53·6
−36	−32·8	+13	+55·4
−35	−31·0	+14	+57·2
−34	−29·2	+15	+59·0
−33	−27·4	+16	+60·8
−32	−25·6	+17	+62·6
−31	−23·8	+18	+64·4
−30	−22·0	+19	+66·2
−29	−20·2	+20	+68·0
−28	−18·4	+21	+69·8
−27	−16·6	+22	+71·6
−26	−14·8	+23	+73·4
−25	−13·0	+24	+75·2

COMPARISON OF VARIOUS HYDROMETER SCALES.—*Varyan.*

Degrees Beaumé.	Specific Gravities.		Degrees Densimetric 15·5° C.	Degrees Twaddell 60 Fahr. T° = 200 (Sp. gr. — 1).	Degrees Brix. Official Prussian Hydrometer 15·6° C. Sp. gr. = $\frac{400}{400-\text{Bx}^\circ}$	Degrees Beck 12·5° C. Sp. gr. = $\frac{170}{170-\text{Bk}^\circ}$	Degrees Brix Saccharimetric (per cent. Sugar).	Gay-Lussac (Centigrade). Sp. gr. = $\frac{100}{100-\text{C}^\circ}$
	Standard adopted by U.S. Chem. Mfg. Ass. 15.5°. Sp. gr. = $\frac{145·04}{145·04-\text{B}}$	Modulus 144·38. Custom in France.						
0	1·000	1·0000	0·0	0·0	0·0	0·0	0·0	0·0
1	1·007	1·0070	0·7	1·4	2·8	1·2	1·8	0·4
2	1·014	1·0140	1·4	2·8	5·5	2·3	3·6	1·4
3	1·021	1·0215	2·1	4·2	8·2	3·5	5·4	2·1
4	1·028	1·0285	2·8	5·6	10·9	4·6	7·1	2·7
5	1·036	1·0380	3·6	7·2	13·9	5·9	9·0	3·5
6	1·043	1·0435	4·3	8·6	16·5	7·0	10·7	4·1
7	1·051	1·0510	5·1	10·2	19·4	8·3	12·6	4·8
8	1·058	1·0585	5·8	11·6	21·9	9·3	14·3	5·5
9	1·066	1·0665	6·6	13·2	24·8	10·4	16·1	6·2
10	1·074	1·0745	7·4	14·8	27·5	11·7	18·0	6·9
11	1·082	1·0825	8·2	16·4	30·3	12·9	19·8	7·6
12	1·090	1·0905	9·0	18·0	33·0	14·1	21·5	8·3
13	1·098	1·0990	9·8	19·6	36·0	15·2	23·3	8·9
14	1·107	1·1075	10·7	21·4	39·0	16·4	25·2	9·7
15	1·115	1·1160	11·5	23·0	41·3	17·6	27·0	10·3
16	1·124	1·1245	12·4	24·8	44·2	18·8	28·9	11·0
17	1·133	1·1335	13·3	26·6	46·5	20·0	30·7	11·7
18	1·142	1·1425	14·2	28·4	49·7	21·2	32·6	12·4
19	1·151	1.1515	15·1	30·2	52·5	22·3	34·4	13·1
20	1·160	1.1607	16·0	32·0	55·2	23·5	36·2	13·8
21	1·169	1·1705	16·9	33·8	57·8	24·6	38·0	14·5
22	1·179	1·1795	17·9	35·8	60·7	25·8	40·0	15·2
23	1·188	1·1895	18·8	37·6	63·3	26·9	41·7	15·8
24	1·198	1·1995	19·8	39·6	66·1	28·1	43·6	16·5
25	1·208	1·2095	20·8	41·6	68·9	29·3	45·5	17·2
26	1·218	1·2195	21·8	43·6	71·6	30·4	47·3	17·9
27	1·229	1·2300	22·9	45·8	74·5	31·7	49·4	18·6
28	1·239	1·2405	23·9	47·8	77·2	32·8	51·2	19·3
29	1·250	1·2515	25·0	50·0	79·3	34·0	53·2	20·0
30	1·261	1·2625	26·1	52·2	82·8	35·2	55·1	20·7
31	1·272	1·2735	27·2	54·4	85·5	36·4	57·0	21·4
32	1·283	1·2850	28·3	56·6	88·3	37·5	58·9	22·1
33	1·295	1·2960	29·5	59·0	91·1	38·8	60·9	22·8
34	1·306	1·3080	30·6	61·2	93·7	39·9	62·7	23·4
35	1·318	1·3200	31·8	63·6	96·5	41·0	64·7	24·1

COMPARISON OF VARIOUS HYDROMETER SCALES.—*Yaryan.—Continued.*

Degrees Baumé.	Specific Gravities.		Degrees Densimetric 15·5 C.	Degrees Twaddell 60 Fahr. 1° = 200 (Sp. gr.—1).	Degrees Brix. Official Prussian Hydrometer 15·6° C. Sp. gr. = $\frac{400}{400-Bx^\circ}$	Degrees Beck 12·5° C. Sp. gr. = $\frac{170}{170-Bk^\circ}$	Degrees Brix Saccharimetric (per cent. Sugar).	Gay-Lussac (Centigrade). Sp. gr. = $\frac{100}{100-C^\circ}$
	Standard adopted by U.S. Chem. Mfg. Ass. 15·5°. Sp. gr. = $\frac{145{\cdot}04}{145{\cdot}04-B}$	Modulus 144·38. Custom in France.						
36	1·330	1·3320	33·0	66·0	99·2	42·2	66·7	24·8
37	1·342	1·3445	34·2	68·4	101·9	43·3	68·6	25·5
38	1·355	1·3570	35·5	71·0	104·7	44·6	70·7	26·2
39	1·368	1·3700	36·8	73·6	107·6	45·8	72·7	26·9
40	1·381	1·3830	38·1	76·2	110·3	46·9	74·7	27·6
41	1·394	1·3955	39·4	78·8	113·5	48·0	76·7	28·3
42	1·408	1·4100	40·8	81·6	115·9	49·3	78·8	28·9
43	1·421	1·4240	42·1	84·2	118·5	50·4	80·8	29·6
44	1·436	1·4380	43·5	87·0	121·3	51·5	82·9	30·3
45	1·450	1·4525	45·0	90·0	124·1	52·8	85·1	31·0
46	1·465	1·4675	46·5	93·0	126·7	53·9	87·2	31·7
47	1·479	1·4827	48·0	96·0	129·7	55·1	89·4	32·4
48	1·495	1·4980	49·5	99·0	132·4	56·3	91·5	33·1
49	1·510	1·5135	51·0	102·0	135·1	57·4	93·6	33·8
50	1·526	1·5300	52·6	105·2	137·9	58·6	..	34·5
51	1·542	1·5460	54·2	108·4	140·6	59·8	..	35·2
52	1·559	1·5630	55·9	111·8	143·4	61·0	..	35·9
53	1·576	1·5800	57·6	115·2	146·2	62·2	..	36·6
54	1·593	1·5965	59·3	118·6	148·9	63·3	..	37·2
55	1·611	1·6150	61·1	122·2	151·7	64·5	..	37·9
56	1·629	1·6335	62·9	125·8	154·5	65·7	..	38·6
57	1·648	1·6520	64·8	129·6	157·3	66·9	..	39·3
58	1·666	1·6715	66·7	133·4	160·0	68·0	..	40·1
59	1·686	1·6910	68·6	137·2	162·8	69·2	..	40·7
60	1·706	1.7110	70·6	141·2	165·5	70·4	..	41·4
61	1·726	1·7315	72·6	145·2	168·3	71·5	..	42·1
62	1·747	1·7525	74·7	149·4	171·0	72·7	..	42·8
63	1·768	1·7740	76·8	153·6	173·8	73·8	..	43·4
64	1·790	1·7950	79·0	158·0	176·5	75·0	..	44·1
65	1·812	1·8185	81·2	162·4	179·3	76·2	..	44·8
66	1·835	1·8420	83·5	167·0	182·0	77·4	..	45·5
67	1·859	1·8660	85·9	171·8	184·8	78·6	..	46·2
68	1·883	1·8910	88·3	176·6	187·5	79·7	..	46·9
96	1·907	1·9151	90·7	181·4	190·2	80·9	..	47·6
70	1·933	1·9410	93·3	186·6	193·0	82·1	..	48·3
72·5	2·000	2·0085	100·0	200·0	200·0	85·0	..	50·0

PRESSURE OF WATER.

Worthington Pumping Engine Company.

The pressure of water in pounds per square inch for every foot in height to 270 ft. By this Table, from the pounds pressure per square inch the feet head is readily obtained, and *vice versâ.*

Feet Head.	Pressure per sq. in.	Feet Head.	Pressure per sq. in.	Feet Head.	Pressure per sq. in.	Feet Head.	Pressure per sq. in.	Feet Head.	Pressure per sq. in.	Feet Head.	Pressure per sq. in.
1	0·43	46	19·92	91	39·42	136	58·91	181	78·40	226	97.90
2	0·86	47	20·35	92	39·85	137	59·34	182	78·84	227	98·33
3	1·30	48	20·79	93	40·28	138	59·77	183	79·27	228	98·76
4	1·73	49	21·22	94	40·72	139	60·21	184	79·70	229	99·20
5	2·16	50	21·65	95	41·15	140	60·64	185	80·14	230	99·63
6	2·59	51	22·09	96	41·58	141	61·07	186	80·57	231	100·06
7	3·03	52	22·52	97	42·01	142	61·51	187	81·00	232	100·49
8	3·46	53	22·95	98	42·45	143	61·94	188	81·43	233	100·93
9	3·89	54	23·39	99	42·83	144	62·37	189	81·87	234	101·36
10	4·33	55	23·82	100	43·31	145	62·81	190	82·30	235	101·79
11	4·76	56	24·26	101	43·75	146	63·24	191	82·73	236	102·23
12	5·20	57	24·69	102	44·18	147	63·67	192	83·17	237	102·66
13	5·63	58	25·12	103	44·61	148	64·10	193	83·60	238	103·09
14	6·06	59	25·55	104	45·05	149	64·54	194	84·03	239	103·53
15	6·49	60	25·99	105	45·48	150	64·97	195	84·47	240	103·96
16	6·93	61	26·42	106	45·91	151	65·49	196	84·90	241	104·39
17	7·36	62	26·85	107	46·34	152	65·84	197	85·33	242	104·83
18	7·79	63	27·29	108	46·78	153	66·27	198	85·76	243	105·26
19	8·22	64	27·72	109	47·21	154	66·70	199	86·20	244	105·69
20	8·66	65	28·15	110	47·64	155	67·14	200	86·63	245	106·13
21	9·09	66	28·58	111	48·08	156	67·57	201	87 07	246	106·56
22	9·53	67	29·02	112	48·51	157	68·00	202	87·50	247	106·99
23	9·96	68	29·45	113	48·94	158	68·43	203	87·93	248	107·43
24	10·39	69	29·88	114	49·38	159	68·87	204	88·36	249	107·86
25	10·82	70	30·32	115	49·81	160	69·31	205	88·80	250	108·29
26	11·26	71	30·75	116	50·24	161	69·74	206	89·23	251	108·73
27	11·69	72	31·18	117	50·68	162	70·17	207	89·66	252	109·16
28	12·12	73	31·62	118	51·11	163	70·61	208	90·10	253	109·59
29	12·55	74	32·05	119	51·54	164	71·04	209	90·53	254	110·03
30	12·99	75	32·48	120	51·98	165	71·47	210	90·96	255	110·46
31	13·42	76	32·92	121	52·41	166	71·91	211	91·39	256	110·89
32	13·86	77	33·35	122	52·84	167	72·34	212	91·83	257	111·32
33	14·29	78	33·78	123	53·28	168	72·77	213	92·26	258	111·76
34	14·72	79	34·21	124	53·71	169	73·20	214	92·69	259	112·19
35	15·16	80	34·65	125	54·15	170	73·64	215	93·13	260	112·62
36	15·59	81	35 08	126	54·58	171	74·07	216	93·56	261	113·06
37	16·02	82	35·52	127	55·01	172	74·50	217	93·99	262	113·49
38	16·45	83	35·95	128	55·44	173	74·94	218	94·43	263	113·92
39	16·89	84	36·39	129	55·88	174	75·37	219	94·86	264	114·36
40	17·32	85	36·82	130	56·31	175	75·80	220	95·30	265	114·79
41	17·75	86	37·25	131	56·74	176	76·23	221	95·73	266	115·22
42	18·19	87	37·68	132	57·18	177	76·67	222	96·16	267	115·66
43	18·62	88	38·12	133	57·61	178	77·10	223	96·59	268	116·09
44	19·05	89	38·55	134	58·04	179	77·53	224	97·03	269	116·52
45	19·49	90	39·98	135	58·48	180	77·97	225	97·46	270	116·96

DIAMETERS, AREAS, AND DISPLACEMENTS.

Worthington Pumping Engine Company.

Diameter.	Area.	Displacement in Imperial Gallons per foot of Travel.	Diameter.	Area.	Displacement in Imperial Gallons per foot of Travel.	Diameter.	Area.	Displacement in Imperial Gallons per foot of Travel.
⅛	·0122	·0005	7¼	41·28	1·783	18¼	261·5	11·297
¼	·0490	·0021	7½	44·17	1·908	18½	268·8	11·612
⅜	·1104	·0047	7¾	47·17	2·037	18¾	276·1	11 927
½	·1963	·0084	8	50·26	2·171	19	283·5	12·247
⅝	·3068	·0132	8¼	53·45	2·309	19¼	291·0	12·571
¾	·4417	·0190	8½	56·74	2·451	19½	298·6	12·900
⅞	·6013	·0259	8¾	60·13	2·597	19¾	306·3	13·232
1	·7854	·0339	9	63·61	2·747	20	314·1	13·569
1⅛	·0940	·0429	9¼	67·20	2·903	20½	330·0	14·256
1¼	1·227	·0530	9½	70·88	3·062	21	346·3	14·960
1⅜	1·484	·0641	9¾	74·66	3·225	21½	363·0	15·681
1½	1·767	·0763	10	78·54	3·393	22	380·1	16·420
1⅝	2·073	·0895	10¼	82·51	3·564	22½	397·6	17·176
1¾	2·405	·1038	10½	86·59	3·740	23	415·4	17·945
1⅞	2·761	·1192	10¾	90·76	3·920	23½	433·7	18·735
2	3·141	·1356	11	95·03	4·105	24	452·3	19·539
2⅛	3·546	·1531	11¼	99·40	4·294	24½	471·4	20·364
2¼	3·976	·1717	11½	103·8	4 484	25	490·8	21·202
2⅜	4·430	·1913	11¾	108·4	4·682	25½	510·7	22·062
2½	4·908	·2120	12	113·0	4·881	26	530·9	22·935
2⅝	5·411	·2337	12¼	117·8	5·088	26½	551·5	23·824
2¾	5·939	·2565	12½	122·7	5·300	27	572·5	24·732
2⅞	6·491	·2804	12¾	127·6	5·512	27½	593·9	25·656
3	7·068	·3053	13	132·7	5·732	28	615·7	26·598
3⅛	7·669	·3313	13¼	137·8	5·952	28½	637·9	27·567
3¼	8·295	·3583	13½	143·1	6·182	29	660·5	28·533
3⅜	8·946	·3864	13¾	148·4	6·410	29½	683·4	29·522
3½	9·621	·4156	14	153·9	6·649	30	706·8	30·533
3⅝	10·32	·4458	14¼	159·4	6·886	31	754·8	32·607
3¾	11 04	·4769	14½	165·1	7·132	32	804·2	34·741
3⅞	11·79	·5193	14¾	170·8	7·388	33	855·3	36·949
4	12·56	·5426	15	176·7	7·633	34	907·9	39·221
4¼	14·18	·6125	15¼	182·6	7·888	35	962·1	41·562
4½	15·90	·6868	15½	188·6	8·147	36	1017·9	43·973
4¾	17·72	·7655	15¾	194·8	8·415	37	1075·2	46·448
5	19·63	·8480	16	201·0	8·683	38	1134·1	48·993
5¼	21·54	·9348	16¼	207·3	8·955	39	1194·6	51·607
5½	23·75	1·026	16½	213·8	9·236	40	1256·6	54 259
5¾	25·96	1·121	16¾	220·3	9·516	41	1320·3	57·037
6	28·27	1·221	17	226·9	9·802	42	1385·4	59·849
6¼	30·67	1·325	17¼	233·7	10·095	43	1452·2	62·735
6½	33·18	1·433	17½	240·5	10·389	44	1520·5	65·686
6¾	35·78	1·545	17¾	247·4	10·687	45	1590·4	68·688
7	38·48	1·662	18	254·4	10·990	46	1661·9	71·794

In estimating the capacity of Worthington (and other duplex) Pumps (*i.e.*, the delivery in gallons per minute or per hour) at a given rate of piston speed, it should be noted that they have *two* double-acting water plungers: its capacity, therefore, is double that of any ordinary double-acting pump of same size, or four times as large as a single-acting pump.

TABLE OF POWER REQUIRED TO RAISE WATER FROM DEEP WELLS.—*Appleby.*

Gallons of water raised per hour	200	350	500	650	800	1,000
Height of lift for 1 man working on crank, in feet	90	52	36	28	22	18
Height of lift for 1 donkey working on gin, in feet	180	102	72	56	45	36
Height of lift for 1 horse working on gin, in feet	630	357	252	196	154	126
Height of lift for 1 horse-power steam engine, in feet . . .	990	561	396	308	242	198

TABLE GIVING QUANTITY OF WATER DISCHARGED PER MINUTE BY BARREL PUMPS.—*Hutton.*

Diameter of pump.	Length of stroke.	Single barrel.		Double barrel.		Treble barrel.	
		30 strokes per min.	40 strokes per min.	30 strokes per min.	40 strokes per min.	30 strokes per min.	40 strokes per min.
Inches.	Inches.	Galls.	Galls.	Galls.	Galls.	Galls.	Galls.
1½	9	1¾	2¼	3½	4½	4½	6¾
2	9	3	4	6	8	9	12
2½	9	4¾	6¼	9½	12	14	19
3	9	6¾	9	13¾	18	20	27
3½	9	9¼	12½	18¾	25	28	37
4	9	12¼	16	24½	32	36	48
4½	9	15½	20¾	32	42	46	62
5	9	19	25½	38	50	57	76
5½	9	23¼	32	46½	62	69	92
6	9	27½	37	55	73	82	110
2	10	3½	4½	6	9	10	13
2½	10	5¼	7	10	14	15	22
3	10	7½	10	15	20	22	30
3½	10	10½	13¾	20	27	32	42
4	10	13½	18	27	36	40	54
4½	10	17	23	34	45	52	68
5	10	22	28	42	56	63	84
5½	10	25½	34	51	68	77	102
6	10	30½	40	62	82	92	122
2	12	4	5	8	10	12	16
2½	12	6¼	8	12	17	19	25
3	12	9	12	18	24	27	36
3½	12	12½	16	24	33	37	50
4	12	16¼	22	32	43	49	65
4½	12	20½	27	42	55	62	82
5	12	25¼	33	50	68	76	100
5½	12	30¾	42	62	82	92	123
6	12	36½	49	73	97	110	146
6½	12	43	57	86	114	129	172
7	12	50	66	100	134	149	199
7½	12	57	76	114	152	171	229
8	12	65	87	130	174	195	262
9	12	82	110	165	220	246	330
10	12	102	131	202	268	303	404
12	12	146	195	294	390	440	588

HYDRAULIC RAM PROPORTIONS OF THE SUPPLY PIPES AND DELIVERY PIPES TO THE NUMBER OF GALLONS.—*Hutton.*

Number of gallons to be raised in 24 hours	500	1,000	2,500	4,000	6,000
Diameter of fall or supply pipe, in inches	1½	2	2½	3	4
Diameter of rising main or delivery pipe, in inches . . .	¾	1	1½	2	2

EFFICIENCY OF HYDRAULIC RAMS.—*Hutton.*

Number of times the height to which the water to be raised is contained in the fall	4	5	6	7	8	9	10	11	12	13	14	15	16	18	19	20	25
Efficiency per cent. . .	75	72	68	62	57	53	48	43	38	35	32	28	23	17	15	12	0

POWER REQUIRED TO DRIVE CENTRIFUGAL PUMPS.

Diameter of suction and delivery pipes in inches.	Quantity of water delivered per minute, in gallons.	Horse-power required for every foot in height the water is raised.
1	16	·01
2	50	·02
3	100	·05
4	200	·08
5	300	·16
6	500	·25
7	700	·35
8	800	·40
9	1,000	·50
10	1,500	·75
11	1,800	1·
12	2,000	1·01
13	2,300	1·08
14	2,500	1·20
15	3,000	1·31
16	3,500	1·60
17	3,800	1·75
18	4,200	2·

FRICTION IN PIPES.

Friction loss in pounds pressure for each 100 ft. in length of cast-iron pipe discharging the stated quantities per minute.—*G. A. Ellis, C.E.*

Imperial Gallons.	Sizes of Pipes, inside diameters.															U.S. Gallons.
	3/4″	1″	1¼″	1½″	2″	2½″	3″	4″	6″	8″	10″	12″	14″	16″	18″	
4	3·3	0·84	·31	·12												5
8	13·	3·16	1·05	·47	·12											10
12	28·7	6·98	2·38	·97	·27											15
16	50·4	12·30	4·07	1·66	·42											20
20	78·	19·00	6·40	2·62	·67	·21	·10									25
25		27·5	9·15	3·75	·91	·30	·12									30
29		37·	12·4	5·05	1·26	·42	·14									35
33		48·	16·1	6·52	1·60	·51	·17									40
37			20·2	8·15	2·01	·62	·27									45
41			24·9	10·00	2·44	·81	·35	·09								50
62			56·1	22·40	5·32	1·80	·74	.21								75
83				39·	9·46	3·20	1·31	·33	·05							100
103				48·1	14·9	4·89	1·99	·51	·07							125
124					21·2	7·00	2·85	·69	·10	·02						150
145					28·1	9·46	3·85	·95	·14	·03						175
166					37·5	12·47	5·02	1·22	·17	·05	·01					200
207					47·7	19·56	7·76	1·89	·26	·07	·03					250
249						28·06	11·20	2·66	·37	·09	·04	·005				300
290						33·41	15·20	3·65	·50	·11	·05	·007				350
332						42·96	19·50	4·73	·65	·15	·06	·01				400
373							25·00	6·01	·81	·20	·08	·02				450
415							30·80	7·43	·96	·25	·09	·04	·017	·009	·005	500
621								14·32	2·21	·53	·18	·08	·036	·019	·011	750
830									3·88	·94	·32	·13	·062	·036	·020	1,000
1,037										1·46	·49	·20	·091	·046	·028	1,250
1,245										2·09	·70	·29	·135	·071	·040	1,500
1,450											·95	·38	·181	·095	·054	1,750
1,660											1·23	·49	·234	·123	·071	2,000
1,867												·63	·297	·153	·086	2,250
2,075												·77	·362	·188	·107	2,500
2,490												1·11	·515	·267	·150	3,000
2,905													·607	·365	·204	3,500
3,320													·910	·472	·263	4,000
3,735														·593	·333	4.500
4,150														·730	·408	5,000
4,980															·585	6,000

The frictional loss is greatly increased by bends or irregularities in the pipes.

DIMENSIONS, ETC., OF STANDARD WROUGHT-IRON PIPE.

Nominal size in inches.	Inside dia. in inches.	Inside dia. extra strong in ins.	Inside dia. extra double-strong in ins.	External dia. in inches.	Internal area in inches.	External circumference in inches.	Length in ft. per sq. ft. outside surface.	Weight per ft. in lbs.	No. of threads per inch.
⅛	·27	·20	—	·40	0·0572	1·272	9·44	·24	27
¼	·36	·29	—	·54	0·1041	1·696	7·075	·42	18
⅜	·49	·42	—	·67	0·1916	2·121	5·657	·56	18
½	·62	·54	·24	·84	0·3048	2·652	4·502	·85	14
¾	·82	·73	·42	1·05	0·5333	3·299	3·637	1·12	14
1	1·04	·95	·58	1·31	0·8627	4·134	2·903	1·67	11½
1¼	1·38	1·27	·88	1·66	1·496	5·215	2·301	2·25	11½
1½	1·61	1·49	1·08	1·90	2·038	5·969	2·01	2·69	11½
2	2·06	1·93	1·49	2·37	3·355	7·461	1·611	3·66	11½
2½	2·46	2·31	1·75	2·87	4·783	9·032	1·328	5·77	8
3	3·06	2·89	2·28	3·50	7·388	10·996	1·091	7·54	8
3½	3·54	3·35	2·71	4·00	9·887	12·566	0·955	9·05	8
4	4·02	3·81	3·13	4·50	12·730	14·137	0·849	10·72	8
5	5·04	—	—	5·56	19·990	17·475	0·629	14·56	8
6	6·	—	—	6·62	28·889	20·813	0·577	18·77	8
7	7·02	—	—	7·62	38·737	23·954	0·505	23·41	8
8	7·98	—	—	8·62	50·039	27·096	0·444	28·35	8
9	9·00	—	—	9·68	63·633	30·433	0·394	34·07	8
10	10·01	—	—	10·75	78·838	33·772	0·355	40·64	8

COMPARISON OF BRITISH MEASURES WITH U. S. STANDARDS.

United States Standard.		British Standard.
	1 gill	= ·833565 imperial gill.
4 gills	= 1 pint	= ·833565 „ pint.
2 pints	= 1 quart	= ·833565 „ quart.
4 quarts	= 1 gallon	= ·833565 „ gallon.

An imperial gallon = 4·5435 litres = 1·19968 U. S. standard gallons.

An imperial gallon contains (Act of Parliament, 1878), 10 lbs. of water at a temperature of 62° Fahr. Its accepted volume is 277·274 cubic in.

USEFUL INFORMATION.

A gallon of water contains 231 cubic in., and weighs 8⅓ lbs. (U. S. standard).

A cubic foot of water contains 7½ gallons, and weighs 62½ lbs.

The friction of liquids and vapours through pipes increases as the square of the velocity.

Sensible heat of a liquid is the amount indicated by the thermometer when immersed in it.

Specific heat is the amount of heat absorbed to produce sensible heat.

Latent heat is the amount of heat required for the conversion into vapour after a liquid has reached its boiling point.

The latent heat of vapour is given off whilst condensing to a liquid; the sensible heat is retained.

One U. S. gallon = ·133 cubic ft.; ·83 imperial gallon; 3·8 litres.

An imperial gallon contains 277·274 cubic in.; ·16 cubic ft.; 10·00 lbs.; 1·2 U. S. gallons; 4·537 litres.

A cubic in. of water = ·03607 lb.; ·003607 imperial gallon; ·004329 U. S. gallon.

A cubic foot of water = 6·23 imperial gallons; 7·48 U. S. gallons; 28·375 litres; ·0283 cubic metre; 62·35 lbs.; ·557 cwt.; ·028 ton.

A lb. of water = 27·72 cubic in.; ·10 imperial gallon; ·083 U. S. gallon; ·4537 kilo.

One cwt. of water = 11·2 imperial gallons; 13·44 U. S. gallons; 1·8 cubic ft.

A ton of water = 35·9 cubic ft.; 224 imperial gallons; 298·8 U. S. gallons; 1,000 litres (about); 1 cubic metre (about).

A litre of water = ·22 imperial gallon; ·264 U. S. gallon; 61 cubic in.; ·0353 cubic ft.

A cubic metre of water = 220 imperial gallons; 264 U. S. gallons; 1·308 cubic yard; 61,028 cubic in.; 35·31 cubic ft.; 1,000 kilos; 1 ton (nearly); 1,000 litres.

A kilo of water = 2·204 lbs.

A vedros of water = 2·7 imperial gallons.

An eimer of water = 2·7 imperial gallons.

A pood of water = 3·6 imperial gallons.

A Russian fathom = 7 ft.

One atmosphere = 1·054 kilos per square in.

One ton of petroleum = 275 imperial gallons (nearly).

One ton of petroleum = 360 U. S. gallons (nearly).

A column of water 1 ft. in height = ·434 lb. pressure per square in.

A column of water 1 metre in height = 1·43 lbs. pressure per square in.

One lb. pressure per square in. = 2·31 ft. of water in height.

One U. S. gallon of crude petroleum = 6·5 lbs. (about).

Brine for Use in Refrigerating and Ice-making Plants.

A brine suitable for the above purpose can be made with from 3 to 5 lbs. of chloride of calcium, or muriate of lime, in accordance with its degree of purity, dissolved in each gallon of water. The density of this solution is about 23° Beaumé, its weight about 13½ lbs. per gallon, and the freezing point is —9° Fahr. As the above standard of density must be kept up, in order to prevent the brine from becoming congealed in the refrigerator, or the ice-making tanks or boxes, it is desirable to test it periodically with a salinometer.

In the best American practice first quality medium ground salt, preferably in bags for convenience of handling, is employed, the proportions being about 3 lbs. of salt to each gallon of water. The brine is made in a brine mixer, consisting of a water-tight box or tank about 4 ft. × 8 ft. × 2 ft., having a suitably perforated false bottom, and a small compartment, partitioned off at one extremity, communicating with the main compartment through an overflow situated at the upper end of the said partition, and fitted with a large strainer, to prevent the passage into the said compartment of salt or foreign bodies. The water is admitted through a perforated pipe situated beneath, and running the full length of the false bottom, and the brine is removed through a pipe from the upper part of the end compartment, at the lower extremity of which latter pipe is a strainer-box and strainer through which the brine passes before delivery into the brine-tank. A salt gauge, salinometer, or hydrometer is also placed in the said end compartment.

The salt should be dissolved in the water until it reaches a density of about 90° by the hydrometer. To facilitate dissolution it is desirable to stir the salt in the mixer with some handy implement, the said salt being shovelled in as fast as it can be got to dissolve.

By the use of this mixer the settlement of salt on the bottom, and on the coils in the brine tank, which inevitably results when the dissolution is effected directly in the latter, is avoided.

To maintain the strength of the brine it is recommended to suspend bags filled with salt in the brine tank, or to pass the return brine through the above-described brine maker or mixer.

FORMULA FOR CALCULATING THE AMOUNT OF AIR DELIVERED PER HOUR BY COLD-AIR MACHINES, WHEN THE REVOLUTIONS AND THE SIZE OF THE COMPRESSORS ARE KNOWN.

This is given as follows by Messrs. Haslam in their Catalogue of ice-making and refrigerating machinery :—

$$\text{Air discharged per hour} = \frac{A \times N \times 2R \times S \times 60}{1728} \times C$$

Where A = Area of each compressor in inches.
N = Number of compressors.
2R = Strokes per minute (or twice the revolutions).
60 = Minutes per hour.
S = Stroke in inches.
1,728 = Cubic inches in one foot.
C = Factor of efficiency which is taken as ·8 for short strokes, and ·85 for long strokes.

INFORMATION REQUIRED BY MANUFACTURERS TO ENABLE THEM TO ESTIMATE FOR THE COST OF A REFRIGERATING PLANT.

1. The length, breadth, and height of the cellars, rooms, or stores to be refrigerated. If the ceiling or roof is vaulted, the height to the centre and spring of the arch will be required. Full particulars of the means of insulation adopted; or if none exist, of the materials from which the chambers are built.
2. Whether it is desired to refrigerate on the direct expansion, or on the brine circulation system.
3. The temperature desired to be maintained in each chamber or store.
4. The nature of the substance which it is desired to refrigerate.
5. In the case of a packing-house, or an abattoir, the largest number of carcasses to be cooled daily, and their average weight.
6. In the case of a freezing chamber for beef, mutton, or other produce, the number of carcasses, &c., to be frozen in each 24 hours, and their average weight.
7. When a liquid is to be cooled, the number of gallons, or

barrels, to be dealt with per hour, and from what temperature down.

8. The nature, quantity, and temperature of the water supply available for use.

9. Rough dimensioned plan of the establishment showing the most convenient spot to locate the refrigerating machine.

INFORMATION REQUIRED BY MANUFACTURERS TO ENABLE THEM TO ESTIMATE FOR THE COST OF AN ICE-MAKING PLANT.

1. Number of tons of ice that it is desired to produce per 24 hours.

2. If clear, crystal, transparent ice is required, or whether opaque ice will do for the purpose.

3. The nature, quantity, and temperature of the supply of water procurable for use.

4. Whether there is an available source of steam supply on the premises; and if spare steam-power, then how many horse-power could be utilised.

5. When the installation is to be erected in existing buildings, a rough dimensioned plan of same.

6. Where an estimate of cost of making ice is required, price and quality of fuel; wages of engine drivers, stokers, and common labourers, for 12 hours day work, and for 12 hours night work; if water has to be bought, cost of same.

LOSS OF PRESSURE BY FRICTION OF COMPRESSED AIR IN PIPES.

F. A. Halsey.

Diameter of Pipe.	Cubic feet of Free Air compressed to a Gauge Pressure of 60 lbs. per Square Inch and passing through the Pipe per Minute.									
	50	75	100	125	150	200	250	300	400	600
	Loss of Pressure in Pounds per Square Inch for each 1,000 Feet of Straight Pipe.									
ins.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
1	10·40									
1¼	2·63	5·90								
1½	1·22	2·75	4·89	7·65	11·00					
2	·35	·79	1·41	2·20	3·17	5·64	8·78			
2½	·14	·32	·57	·90	1·29	2·30	3·58	5·18	9·20	
3		·11	·20	·31	·44	·78	1·23	1·77	3·14	7·05
3½				·15	·21	·38	·59	·85	1·51	3·40
4						·20	·31	·45	·80	1·81
5							·10	·15	·26	·59
6										·23

FRICTION OF AIR IN TUBES.—*Unwin*, "*Min. Proceedings Inst. C.E.*"

k = coefficient of friction = $\frac{a}{v} + b$, a and b being constants, and v = velocity of air feet per second.

Diameter of tube, ft.	1·64	1·07	·83	·338	·266	·164
Value of a . .	·00129	·00972	·01525	·03604	·0379	·04518
,, b . .	·00483	·0064	·00704	·00941	·00959	·01167
,, k if $v = 100$	·00484	·0065	·00719	·00719	·00997	·01212

COEFFICIENTS FOR EFFLUX OF AIR FROM ORIFICES.

Molesworth.

Vena contracta	·98
Conical converging	·9
Cylindrical rounded at ends	·9
Cylindrical throughout	·8
Thin plates	·6

CENTRIFUGAL FANS.—*Molesworth.*

D = Diameter of fan.
V = Velocity of tips of fan in feet per second.
P = Pressure in lbs. per square inch.

$$V = \sqrt{P \times 97300}.$$

$$P = \frac{V^2}{97300}.$$

POWER REQUIRED FOR FANS.—*Molesworth.*

P = Pressure of blast in lbs. per square inch.
A = Area of the sum of the tuyeres in square inches.
V = Velocity of tips of fan in feet per second.
HP = Indicated horse-power required.

$$HP = \cdot 000016\ V^2\ A\ p.$$

PROPORTIONS OF FANS.—*Molesworth.*

Length of vanes $= \frac{D}{4}$. Width of vanes $= \frac{D}{4}$.

Diameter of inlet $= \frac{D}{2}$. Eccentricity of fan $= \frac{D}{10}$.

Length of spindle journal = 4 diameters of spindle.

SOLUBILITY OF AMMONIA IN WATER AT DIFFERENT TEMPERATURES AND PRESSURES.—*Sims.*

1 lb. of water (also unit volume) absorbs the following quantities of ammonia.

Absolute Pressure in lbs. per sq. in.	32° F.		68° F.		104° F.		212° F.	
	lbs.	vols.	lbs.	vols.	lbs.	vols.	grms.	vols.
14·67	0·899	1·180	0·518	0·683	0·338	0·443	0·074	0·97
15·44	0·937	1·231	0·535	0 703	0·349	0·458	0·078	0·102
16·41	0·980	1·287	0·556	0·730	0·363	0·476	0·083	0·109
17·37	1·029	1·351	0·574	0·754	0·378	0·496	0·088	0·115
18·34	1·077	1·414	0·594	0·781	0·391	0·513	0·092	0·120
19·30	1·126	1·478	0·613	0·805	0·404	0·531	0·096	0·126
20·27	1·177	1·546	0·632	0·830	0·414	0·543	0·101	0·132
21·23	1·236	1·615	0·651	0·855	0·425	0·558	0·106	0·139
22·19	1·283	1·685	0·669	0·878	0·434	0·570	0·110	0·140
23·16	1·336	1·754	0·685	0·894	0·445	0·584	0·115	0·151
24·13	1·388	1·823	0·704	0·924	0·454	0·596	0·120	0·157
25·09	1·442	1·894	0·722	0·948	0·463	0·609	0·125	0·164
26·06	1·496	1·965	0·741	0·973	0·472	0·619	0·130	0·170
27·02	1·549	2·034	0·761	0·999	0·479	0·629	0·135	0·177
27·99	1·603	2·105	0·780	1·023	0·486	0·638	..	..
28·95	1·656	2·175	0·801	1·052	0·493	0·647	..	..
30·88	1·758	2·309	0·842	1·106	0·511	0·671	..	..
32·81	1·861	2·444	0·881	1·157	0·530	0·696	..	..
34·74	1·966	2·582	0·919	1·207	0·547	0·718	..	..
36·67	2·070	2·718	0·955	1·254	0·565	0·742	..	..
38·60	..	..	0·992	1·302	0·579	0·764	..	..
40·53	..	..	..	..	0·594	0·780	..	..

TEMPERATURES ADAPTED FOR THE COLD STORAGE OF VARIOUS ARTICLES.—*Ice and Refrigeration, &c.*

Articles.	degs. Fahr.	Articles.	degs. Fahr.
Meats (fresh)	34	Eggs	33-35
,, (canned)	35	Poultry (frozen)	28-30
Fish (fresh)	25-30	,, (to freeze)	18-22
,, (dried)	35	Game (frozen)	25-28
Oysters	33-35	,, (to freeze)	15-28
,, (in tubs)	25	Oil	35
,, (in shells)	33	Syrup	35
Butter	32-38	Honey	45
Butterine	35	Beer (in barrel)	33-42
Oleomargarine	35	,, (bottled)	45
Cheese	32-33	Cider	30-40

TEMPERATURES ADAPTED FOR THE COLD STORAGE OF VARIOUS ARTICLES.—*Continued.*

Articles.	degs. Fahr.	Articles.	degs. Fahr.
Ginger ale	36	Asparagus	34
Wines	40-45	Sauerkraut	35-38
Apples	32-36	Potatoes	36-40
Bananas	40-45	Onions	34-40
Berries (fresh)	36-40	Nuts	35
Cranberries	34-36	Peas (dried)	40
Canteloupes	40	Corn (dried)	35
Dates, figs, &c.	55	Beans (dried)	32-40
Fruits (dried)	35-40	Chestnuts	33
Grapes	36-38	Wheatflour	40
Hops	33-40	Oatmeal	40
Lemons	36-40	Buckwheat flour	40
Oranges	45-50	Sardines (canned)	35
Peaches	45-55	Fruits (canned)	35
Pears	34-36	Meats (canned)	35
Watermelons	34	Cigars	35
Parsnips	34	Furs (undressed)	35
Celery	32-34	Furs, woollens, &c.	25-32
Carrots	34	Tobacco	35
Cabbage	34	Sugar, &c.	40-45

ROUGH ESTIMATE OF REFRIGERATION IN BREWERIES.

A ready method of obtaining a rough estimate in tons of the amount of refrigeration required in a brewery is to divide the capacity of the brewery in barrels by 4.

AMOUNT OF REFRIGERATING PIPES NECESSARY FOR CHILLING, STORAGE, AND FREEZING-CHAMBERS.

Chilling-rooms or Chambers, refrigerators on the direct expansion system, 1-ft. run of 2-in. piping for each 14 c. ft. of space; on the brine-circulation system, 1-ft. run of 2-in. piping for each 8 c. ft. of space.

Freezing-rooms or Chambers, refrigerated on the direct expansion system, 1-ft. run of 2-in. piping for each 8 c. ft. of space; on the brine-circulation system, 1 ft. run for each 3 c. ft. of space.

Storage-rooms or Chambers, refrigerated on the direct expansion system, 1-ft. run of 2-in. piping for each 45 c. ft. of space; on the brine-circulation system, 1-ft. run of 2-in. piping for each 15 c. ft. of space.

TABLE SHOWING PROPERTIES OF SATURATED STEAM.—*Varyan.*

Absolute Pressure from Vacuum.		Above Atmosphere.		Temperature.	Total Heat in British Units.	Heat of Vaporization or Latent Heat.
lbs. per Square In.	Inches of Mercury.	lbs. per Square In.	Inches of Mercury.	Deg. Fahr.		
1	2·0355	−13·7	−27·886	101·99	1113·1	1043·0
2	4·0710	−12·7	−25·851	126·27	1120·5	1026·1
3	6·1065	−11·7	−23·815	141·62	1125·1	1015·3
4	8·142	−10·7	−21·780	153·09	1128·6	1007·2
5	10·178	−9·7	−19·744	162·34	1131·5	1000·8
6	12·213	−8·7	−17·709	170·14	1133·8	995·2
7	14·249	−7·7	−15·673	176·90	1135·9	990·5
8	16·284	−6·7	−13·638	182·92	1137·7	986·2
9	18·320	−5·7	−11·602	188·33	1139·4	982·5
10	20·355	−4·7	−9·567	193·25	1140·9	979·0
11	22·319	−3·7	−7·531	197·78	1142·3	975·8
12	24·426	−2·7	−5·496	201·98	1143·6	972·9
13	26·462	−1·7	−3·460	205·89	1144·7	970·1
14	28·497	−0·7	−1·425	209·57	1145·8	967·5
14·7	29·922	0·0	0·000	212·00	1146·6	965·8
15	30·533	0·3	0·611	213·03	1146·9	965·1
16	32·568	1·3	2·646	216·32	1147·9	962·8
17	34·604	2·3	4·682	219·44	1148·9	960·6
18	36·639	3·3	6·717	222·40	1149·8	958·5
19	38·675	4·3	8·753	225·24	1150·7	956·6
20	40·710	5·3	10·788	227·95	1151·5	954·6
21	42·746	6·3	12·824	230·55	1152·3	952·8
22	44·781	7·3	14·859	233·06	1153·0	951·0
23	46·787	8·3	15·895	235·47	1153·7	949·2
24	48·852	9·3	18·930	237·79	1154·4	947·6
25	50·888	10·3	20·966	240·04	1155·1	946·0
26	52·923	11·3	23·007	242·21	1155·8	944·6
27	54·972	12·3	25·043	244·32	1156·5	943·1
28	57·008	13·3	27·079	246·36	1157·1	941·7
29	59·044	14·3	29·115	248·34	1157·7	940·3
30	61·080	15·3	31·143	250·27	1158·3	938·9
31	63·116	16·3	33·187	252·15	1158·8	937·5
32	65·152	17·3	35·223	253·98	1159·4	936·3
33	67·188	18·3	37·239	255·76	1159·9	935·0
34	69·224	19·3	39·295	257·50	1160·4	933·7
35	71·260	20·3	41·321	259·19	1161·0	932·6
36	73·296	21·3	43·367	260·85	1161·5	931·5
37	75·331	22·3	45·319	262·47	1162·0	930·3
38	77·367	23·3	47·397	264·06	1162·5	929·2
39	79·403	24·3	50·463	265·61	1163·0	928·2

Table showing Properties of Saturated Steam.—*Varyan.*—*Continued.*

Absolute Pressure from Vacuum.		Above Atmosphere.		Temperature.	Total Heat in British Units.	Heat of Vaporization or Latent Heat.
lbs. per Square In.	Inches of Mercury.	lbs. per Square In.	Inches of Mercury.	Deg. Fahr.		
40	81·439	25·3	51·499	267·13	1163·4	927·0
41	83·475	26·3	53·534	268·62	1163·9	926·0
42	85·511	27·3	55·583	270·08	1164·3	925·0
43	87·547	28·3	57·619	271·51	1164·8	924·0
44	89·583	29·3	59·655	272·91	1165·2	923·0
45	91·619	30·3	61·691	274·29	1165·6	922·0
46	93·655	31·3	63·727	275·65	1166·0	921·0
47	95·691	32·3	65·763	276·99	1166·4	920·1
48	97·727	33·3	67·799	278·30	1166·8	919·2
49	99·763	34·3	69·835	279·58	1167·2	918·3
50	101·799	35·3	71·871	280·85	1167·6	917·4
55	111·98	40·3	82·050	286·89	1169·4	913·1
60	122·16	45·3	92·230	292·51	1171·2	909·3
65	132·34	50·3	102·410	297·77	1172·7	905·5
70	142·52	55·3	112·59	302·71	1174·3	902·1
75	152·70	60·3	122·77	307·38	1175·7	898·8
80	162·88	65·3	132·95	311·80	1177·0	895·6
85	173·06	70·3	143·13	316·02	1178·3	892·5
90	185·24	75·3	153·31	320·04	1179·6	889·6
95	193·42	80·3	163·49	323·89	1180·7	886·7
100	203·06	85·3	173·67	327·58	1181·9	884·0
105	213·78	90·3	185·85	331·13	1182·9	881·3
110	223·96	95·3	194·03	334·56	1184·0	878·8
115	234·14	100·3	203·67	337·86	1185·0	876·3
120	244·32	105·3	214·39	341·05	1186·0	874·0
125	254·50	110·3	224·57	344·13	1186·9	871·7
130	264·68	115·3	234·75	347·12	1187·8	869·4
135	274·86	120·3	244·93	350·03	1188·7	867·3
140	285·04	125·3	255·11	352·85	1189·5	865·1
145	295·22	130·3	265·29	355·59	1190·4	863·2
150	305·40	135·3	275·47	358·26	1191·2	861·2
160	325·76	145·3	295·83	363·40	1192·8	857·4
170	345·82	155·3	316·19	368·29	1194·3	853·8
180	366·48	165·3	336·55	372·97	1195·7	850·3
190	386·84	175·3	356·91	377·44	1197·1	847·0
200	407·20	185·3	377·27	381·73	1198·4	843·8

FRACTIONS OF AN INCH AND DECIMAL EQUIVALENTS.

Fractions.	Inch.	Fractions.	Inch.	Fractions.	Inch.
1-32	·03125	3-8	·375	23-32	·71875
1-16	·0625	13-32	·40625	3-4	·75
3-32	·09375	7-16	·4375	25-32	·78125
1-8	·125	15-32	·46875	13-16	·8125
5-32	·15625	1-2	·5	27-32	·84375
3-16	·1875	17-32	·53125	7-8	·875
7-32	·21875	9-16	·5625	29-32	·90625
1-4	·25	19-32	·59375	15-16	·9375
9-32	·28125	5-8	·625	31-32	·96875
5-16	·3125	21-32	·65625		
11-32	·34375	11-16	·6875		

MEAN ANNUAL TEMPERATURES OF PRINCIPAL CITIES OF THE WORLD.

Cities.	Mean annual temperature.
England.	
Birmingham	48·2
Bristol	51·7
Liverpool	50·8
London	50·8
Manchester	48·8
Scotland.	
Edinburgh	47·1
Glasgow	49·8
Ireland.	
Belfast	52·1
Dublin	50·1
East Indies.	
Bombay	81·3
Calcutta	82·4
Madras	81·9
West Indies.	
Havanna	79·1
North America.	
Baltimore	54·9
Boston	48·4
Chicago	45·9
Cincinnati	54·7

Cities.	Mean annual temperature.
Mexico	60·9
Montreal	44·6
New Orleans	69·1
New York	51·8
Philadelphia	52·1
Quebec	40·3
San Francisco	55·2
St. Louis	55·0
Washington	56·2
South America.	
Buenos Ayres	62·8
Lima	73·3
Quito	60·9
Rio Janeiro	77·2
Valparaiso	64·0
Australasia.	
Melbourne	57·0
Sydney	65·8
France.	
Bordeaux	57·0
Boulogne	54·4
Marseilles	58·3
Paris	51·3
Austro-Hungary.	
Buda-Pesth	47·5
Vienna	51·0

MEAN ANNUAL TEMPERATURES OF PRINCIPAL CITIES OF THE WORLD.—*Continued.*

Cities.	Mean annual temperature.
Germany.	
Berlin	48·2
Breslau	46·7
Dresden	49·1
Frankfort	49·6
Hamburg	48·0
Leipsic	46·4
Munich	48·4
Vienna	51·0
Italy.	
Florence	59·2
Genoa	61·1
Milan	55·1
Naples	60·3
Palermo	63·1
Rome	60·5
Turin	53·1
Venice	55·4
Spain and Portugal.	
Barcelona	63·0
Madrid	58·2
Lisbon	61·4
Switzerland.	
Geneva	52·7
Holland.	
Amsterdam	49·9
Rotterdam	51·0

Cities.	Mean annual temperature.
Belgium.	
Brussels	50·7
Norway and Sweden.	
Christiania	41·5
Stockholm	42·3
Denmark.	
Copenhagen	46·6
Turkey.	
Bucharest	46·4
Constantinople	56·5
Russia.	
Moscow	40·0
St. Petersburg	39·6
Warsaw	44·2
Palestine.	
Jerusalem	62·6
Egypt.	
Cairo	72·2
Barbary.	
Algiers	64·3
Tunis	68·8

LEAKS IN AMMONIA APPARATUS.

Leaks are readily detected by the smell of the escaping ammonia gas when the machine is being filled; at a later stage, when working, their detection is not so easy. During the operation of the machine when the liquor or brine in the tanks commences to smell of ammonia it indicates a considerable leakage. It is recommended to test the liquor or brine periodically with Nessler's solution or otherwise

Nessler's reagent, which is the best to use for the discovery of traces of ammonia in water or brine, consists of 17 grms. of mercuric chloride dissolved in about 300 cc. of distilled water, to which is added 35 grms. potassium iodide dissolved in 100 cc.

of water, and constantly stirred until a slight permanent red precipitate is produced. To the solution thus formed is added 120 grms. of potassium hydrate dissolved in about 200 cc. of water, allowed to cool before mixing; the amount is then made up to 1 ltr., and mercuric chloride added until a permanent precipitate again forms. After standing for a sufficient time, the clear solution can be placed in glass-stoppered blue bottles and kept in a dark place.

If a few drops of this reagent be added to a sample of the suspected brine or water in a test-tube, or other small vessel, and the slightest trace of ammonia is present, a yellow colouration of the liquid will take place; a large quantity of ammonia will produce a dark-brown.

When the leaks are comparatively insignificant they can be closed in the usual way, by solder, using as a flux muriatic or hydrochloric acid killed with zinc. In some instances electric welding may be resorted to with advantage, or the leak may be closed by means of a composition of litharge and glycerine mixed into a stiff paste, bound with sheet-rubber, and covered with sheet-iron clamped firmly in position. When, however, the leak is at all serious it is usually the better plan to at once put in a new coil, or a new length of pipe.

LEAKS IN CARBONIC ACID MACHINES.

To detect these, smear the joints with a solution of soap and water, and any leakage of gas will be evidenced by the formation of bubbles. Carbon dioxide or carbonic acid being a completely inodorous gas, great precautions are required to prevent the occurrence of leakage.

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See pages 165 to 171 for results of experiments with various other substances.

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