THE STEAM JACKET

PRACTICALLY CONSIDERED

THE STEAM JACKET

PRACTICALLY CONSIDERED AS AN EFFICIENT FUEL ECONOMISER.

A TREATISE ON THE

ECONOMICAL USE OF STEAM FOR ENGINE-BUILDERS, ENGINE-DRIVERS, MILL-MANAGERS, AND STEAM-USERS GENERALLY.

BY

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AUTHOR OF

"THE HISTORY AND DEVELOPMENT OF STEAM LOCOMOTION ON COMMON ROADS."

WITH SIXTY-THREE ILLUSTRATIONS.

Second Edition, Revised and Enlarged.

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PREFACE TO THE FIRST EDITION.

THE origin of this little book may soon be told. Some years ago, the author purposed writing a letter to one of the engineering journals on the Steam-Jacket, in reply to a correspondent who sought information on the subject. A large amount of matter was collected, but, owing to the time devoted to the search, he was led to relinquish the idea of the letter. But he continued the study, with a view, at some distant date, of writing a book on the steam-jacket. When busily engaged with this work, it was found that little or nothing had been said about the misapplication of the steam-jacket; while experience showed that a large number of the so-called steam-jackets were steam-jackets in name only. The utility of four out of every six jackets that were examined must have been impaired by imperfections. In the present treatise the author has shown the defects in many steam-jacketed cylinders, and also given some of the principles relating to their proper design and application. As this book furnishes the only information on this neglected subject, he trusts that the contents may prove of some service to designers and makers of steam-engines. Mention may be made here that the scarcity of engineering books written by practical men,* has served as an incentive to energy, hoping that this first literary venture, emanating from the drawing-office and works, may meet with some measure of support and approval.

Our cleverest engineers, and those most competent to write good practical books which would be of permanent value to the rising generation of engineers, are so busily engaged in the manufacture of engines, that they have not the time to write about them, for the very reason that the manufacture of engines is a far more profitable undertaking than the production of books relating to engines.

In many engineering books, the efforts of the authors are spread over such a large surface that the information given is too superficial to be of any real value: where a few lines are devoted to the explanation of each detail of the steam-engine for instance, in all probability those few lines fail to supply the information needed, and serve no good purpose to the inquiring mind. Who does not remember reading numerous books of this class in the hope of finding some valuable notes, and, after wading through the contents, have had to close them in disappointment?

Take, for illustration, the valuable detail we are studying—the steam-jacket. In many works on the steam-engine it is not even mentioned; in some, two or three paragraphs only are devoted to its consideration; and those few who have written more lengthily have treated it, like many more engineering subjects, in a theoretical style, so that the literature is adapted for students only, and is perfectly useless in the

* "Well written, practical books, from the pens of competent practical men, are as scarce and nearly as valuable as gold."—*The Engineer*, 17th May 1872.

workshop, and, in the majority of cases, of very little real service in the drawing-office.

If authors would confine themselves to the study of one detail, and thoroughly ventilate it, their remarks could not fail to be of practical service; indeed, this is just the style of book relating to the steam-engine of which there is the greatest need.

It may be owing to this dearth of literature, in a great measure, that accounts for such widespread ignorance respecting the use of the steam-jacket prevailing among engineers. It is to many a perplexing paradox. When engine-makers, who do *not* apply it, evidence some hazy notions respecting its utility, there is no occasion for surprise. But, when we find engineers at the head of one of the largest portable engine firms (who profess to have jacketed their earliest engines, and still continue the practice) saying that the cylinder is protected from "*cold* and *radiation*" by means of a jacket of steam, clearly showing that the function of the steam-jacket is not understood by the writers, it does cause some astonishment. They can be excused on the ground above named, viz., the fragmentary nature of the information relating to this subject. One writer says:—"Almost every engineer knows now-a-days that a cylinder should be kept as hot as possible; but very few makers of steam-engines understand the precise reasons why a cylinder should be kept hot. Most people imagine that the condensation takes place by conduction through the metal of the cylinder to the outside."

We have related at page 71 an instance wherein an engine-maker thought a steam-jacket was not required, because the cylinders were well lagged and felt comparatively cool on the surface.

As a consequence of the prevalence of these mistaken notions, it follows that very little, if any, good has resulted from the voluminous discussions on steam-jacketing. The practical conclusion of the whole matter appears to be :—*The fact of the utility of the steam-jacket, when properly applied, cannot be gainsaid*, but, owing to numerous cases of internal mal-arrangement, its efficiency is impaired or destroyed, occasioning in some quarters a doubt respecting its advantage.

W. FLETCHER.

BASINGSTOKE.

PREFACE TO THE SECOND EDITION.

THE first edition of *The Abuse of the Steam-Jacket Practically Considered,* is exhausted. It is believed that a second edition of the work is required. The first edition was not only favourably reviewed by many of the technical journals, but the author received some friendly letters from (previously unknown) correspondents, thanking him for the work, and acknowledging the service rendered by it to designers of steam-engines particularly. *The Electrical Review*, in commenting on one of the author's articles on this subject, said:—"Mr. Fletcher has been discussing jackets for many years, and there is still very good cause to continue the discussion. It is much to be feared that numerous learned disquisitions have appeared on the behaviour of steam in the cylinder, which have been argued out with a great array of mathematics from results whose true meaning has been entirely obscured by faulty construction. Papers like this of Mr. Fletcher's might well be kept in type, and used at periodical intervals, as corrective of that depravity of design which lends so much force to the arguments in favour of the totality of the specially human failing to go wrong where it is as easy to go right."* It is gratifying also to know that a perusal of the little book led to a set of standard engine cylinder patterns

* *The Electrical Review*, 2nd June 1893.

being modified in design, so as to accord with the requirements of efficient steam-jacketing. In issuing the second edition, the scope of the work has been extended, and it now forms a complete treatise on steam-jacketing. All the matter of value contained in the first edition has been retained, and the information brought down to date.

The abuse of the steam-jacket occupies a prominent position in the work. The author confesses that hopes were entertained years ago that the production of faulty steam-jacketed cylinders would have ceased before now.

But some of the abortions illustrated in the book represent the latest practice, and, as several of the cylinder sections have figured very prominently in our illustrated journals, they were evidently looked upon by their producers as being worthy of notice.

Until these inefficient steam-jackets cease to be built and tested, the contentions respecting cylinder condensation and steam-jacketing will never be settled.*

It is astonishing to find how much has been recently written on steam-jacketing, and how little information of a practical kind has been imparted. During recent years much valuable space has been devoted by our technical journals to useless contentions and theoretical investigations, but no one, it is believed, has given any practical suggestions respecting the requirements of thorough steam-jacketing.† An

* We have referred to a test carried out at Paisley, the small economy of which is probably due to the small size of the pipe supplying the jackets with steam : a very common fault among engine-makers.

† Since the issue of the first edition, many writers have given the results of their investigations ; there is not now the dearth of literature on this subject that existed a few years ago.

attempt has been made to set forth some rules which may help the designer to produce steam-jackets, that cannot fail to be beneficial.

If all the engines which have recently been tested had been built in accordance with these requirements, the results of such tests would have been so convincing an evidence in favour of steam-jacketing, that no further discussion would be needed.

Trials carried out on thoroughly steam-jacketed engines are still wanted, but no tests of engines pretending to give results of jacketed and unjacketed runs are of any real service, unless the conditions laid down in this book for obtaining beneficial results are complied with. Before any comparative figures are accepted of jacketed and unjacketed engine trials, sections of the cylinders, jackets, steam-supply and drain-pipe arrangements should be clearly illustrated, which is the only safeguard against fraud; for, too often in the past, faulty jackets have been tried—consequently showing a low economy—and these adverse results have been turned to account by a few engineers who profess to believe that steam-jackets are of little service. But, in every case where properly jacketed engines have been thoroughly tested, the results have proved, beyond a shadow of a doubt, the advantage and economy of steam-jacketing.

This book closes with the results of such trials in a tabular form, carried out on many different types of engines during the last fifty years; and the economy gained by jacketing is shown to have ranged from 10 to 42 per cent.

The work has been written at odd moments out of work hours, and no one more than the author is sensible of its faults, but it is hoped that this book may meet with a favourable reception, and be of service to everyone in any way connected with the steam-engine.

The author is indebted to the proprietors of *Engineering* and *The Mechanical World* for many of the illustrations. He wishes to tender his thanks also to Messrs. Crosby, Lockwood & Son for allowing an illustration to appear from Haeder and Powles' *Handbook of the Steam-Engine;* to Messrs. Hopkinson for a similar privilege; and to the Council of the Inst. of Mechanical Engineers for permission to quote some tables from the Second Report on the Value of the Steam Jacket. He wishes to acknowledge, with thanks, the blocks lent by Messrs. Robey & Co. and Messrs. Hornsby & Sons, and for the permission to use some blocks from Mr. Chas. Day's work on "The Indicator, &c.," which appeared in *The Practical Engineer.*

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207 Woodbridge Road, Ipswich,
February, 1895.

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THE STEAM-JACKET PRACTICALLY CONSIDERED.

CHAPTER I.

HISTORY OF THE STEAM-JACKET.

THE Steam-Jacket is one of the numerous details of the modern steam-engine which owes its origin to the illustrious Watt, and, like many other of his valuable inventions, it was the outcome of several years of earnest thought and experiment, commencing from the time that the steam-engine first became the subject of his study, until the jacket was included in the well-known patent specification of 1769.

While Mr. Watt was repairing the model of a Newcomen steam-engine in 1763, it occurred to him that a large portion of steam must be condensed without doing any work by being turned into a cold cylinder, this condensation representing a considerable loss. He aimed at reducing this waste, and said to himself :—
" Let me make an engine, working by a piston, in which the cylinder shall be continually hot and perfectly dry."

He therefore set to work with this object in view, by making his cylinders of substances that would receive and give out heat slowly. A small engine was soon constructed with a 6-inch cylinder "made of wood, soaked in linseed oil, and baked to dryness." By numerous experiments made with this engine he found that this reduced the internal condensation; but, owing to other reasons not named, but easily conceived, he was obliged to abandon wood as a material for the construction of his cylinders. He next surrounded his metal cylinders with an outer wooden case, and filled the intervening space with ashes. Another engine was made in 1765, the inner "cylinder of which was formed of copper—not bored, but hammered, and not very true:" it was enclosed in a wooden jacket or steam-case. Mr. Watt preferred sheet-copper to cast-iron for his cylinders, for the convenience of adjusting them: the castings in those days could not be depended upon, and to procure a round and parallel hole in a cylinder was an impossibility. Mr. Watt, when speaking to Dr. Roebuck about one of his model engines (with a steam-jacket round the cylinder), complains "that the cylinder had been so badly bored that it was ⅛th of an inch larger at one end than the other," and only a trifle better were those that were considered a good job; for, on one occasion, Mr Boulton, in writing to his partner, said in effect, "that the completion of the bore of a cylinder by a new boring-bar * was most satisfactory; the piston fitted so nicely that there was scarcely room for the insertion of a half-crown at the worst part." Mr. Watt applied his first steam-jacket, most probably, to the engine erected at a coal-mine on the estate of the Duke of Hamilton, at Kinniel. The cylinder

* Invented by W Murdock.

of this engine was made of cast-iron, 18 inches diameter, inclosed in a wooden steam-case. This being a sort of experimental engine, it was continually altered and improved, until it was brought to considerable perfection. During the erection of this engine Mr. Watt applied for a patent to secure the profits of his ingenuity, which was enrolled in April 1769.*

The steam-jacket was introduced into Cornwall about 1776: it was applied to an engine having a 30-inch cylinder, erected at a mine near Chacewater. In 1783 Mr. Watt writes:—"We have altered all the engines in Cornwall but one, and many in other parts of England:" and, from that time to this, the steam-jacket has held its own in that county, notwithstanding the attempts which have been made to discontinue it, these attempts being attended with a palpable loss of power.

It has recently been asserted that Watt imperfectly understood the theory of the steam-jacket. We cannot stay here to dispute this point. We may say, however, with all our glittering theory and much vaunted knowledge, we do not jacket our cylinders so wisely or so well as Watt did more than a hundred years ago. Whatever theoretical knowledge Watt possessed on this subject is of little moment, but it is

* The following are Mr. Watt's own words concerning his invention: —"My methods of lessening the consumption of steam, and, consequently, fuel in fire-engines, consists in the following principles: First, that the vessel in which the powers of steam are to be employed to work the engine, which is called the cylinder in common fire-engines, and which I call the steam vessel, must, during the whole time the engine is at work, be kept as hot as the steam which enters it; first, by enclosing it in a case of wood or any other materials that transmit heat slowly; secondly, by surrounding it with steam or other heated bodies; and, thirdly, by allowing neither water, or other substances colder than the steam, to enter or touch it during that time."

well known that he displayed remarkable ability in all his steam-jacketing arrangement. He was quite clear respecting the beneficial results obtained from the steam-jacket, for he says:—"We have also

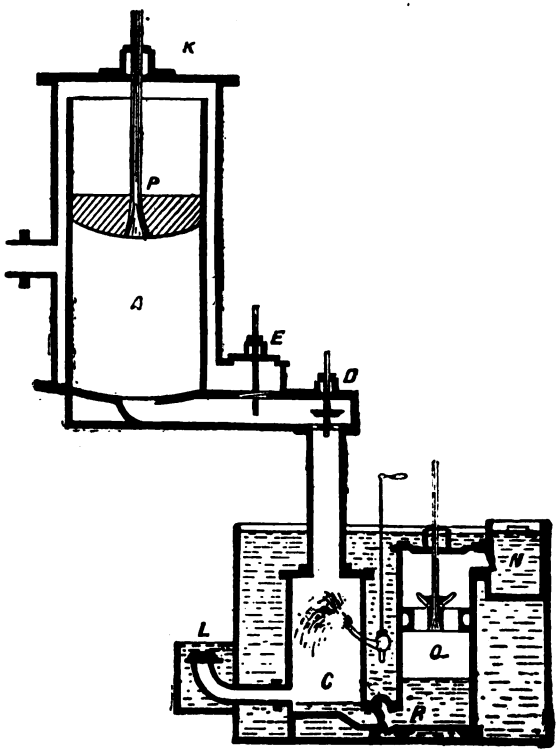


Fig. 1. Watt's first steam-jacketed cylinder.

executed some engines without the outside cylinders (jackets) altogether; but we have no reason to applaud our economy, as the consumption of coal was considerably greater." It is well known that Watt could only introduce his steam-engines by giving them away, and contenting himself with one-third of the saving in fuel compared with the Newcomen engines of the period. A careful study of Watt's methods for lessening the consumption of steam cannot but prove of interest.

In Watt's first steam-jacketed cylinder, the steam would constantly press upon the top of the piston in the same way as the atmosphere had previously done in Newcomen's engines.

Fig. 1 shows this interesting steam-jacketed cylinder, from which it will be seen that, during the up-stroke of the piston, by closing the valve communicating with the condenser, and admitting steam into the bottom of the cylinder, the piston would be placed in equilibrium, and so be carried to the top of the cylinder by the weight of the pump-rods. To produce the down-stroke, the passage between the steam-jacket and the bottom of the cylinder being closed, and that between the bottom of the cylinder and the condenser being opened, a vacuum was created under the piston, and the steam acting upon the top of it, would drive it to the bottom of the cylinder; the piston-rod passed through a stuffing-box in the top of the steam-jacket.

Fig. 2 shows Watt's later steam-jacketed cylinder; the steam-case was put together round the cylinder in segments united by bolts. In the earlier instances the steam for the internal cylinder was taken from the jacket, but in the illustration the steam was drawn from the main steam-pipe: * the jacket was drained by means of a long syphon pipe, which conveyed the condensed steam from the bottom of the jacket into the hot well of the condenser. A socket-joint, packed with hemp and tallow, was provided in the steam-case, to allow a little end-wise movement in case of

* The steam inlet to the jacket is not shown in the drawing.

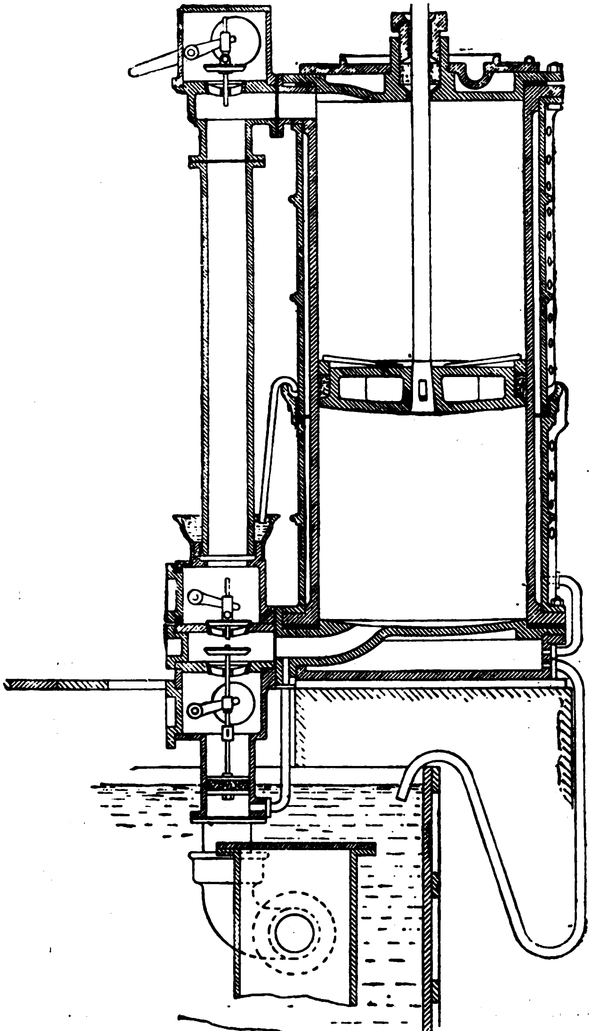


Fig. 2. Watt's second steam-jacketed cylinder.

any difference in the expansion of the jacket or the cylinder.

In Watt's later engines the steam-jacket was supplied with steam direct from the boiler, the inlet being placed at the top, and made of ample area. The jacket was drained effectively: the drain returned the condensed steam from the lowest part of the jacket to the water space of the boiler by gravitation.

We have dwelt at some length on Watt's examples of steam-jacketing, so as to make our historical notes more complete, and, we trust, of greater interest.

In another part of the book we illustrate a modern Cornish pumping-engine steam-jacketed cylinder, showing the steam-supply pipe, the drain-pipe, and the method of lagging adopted by some engine-builders (see fig. 42).

Although Mr. Watt left the steam-jacket very much as we have it to-day, yet there have been numerous alterations suggested in the interval that has elapsed between his day and ours. Some of these suggestions are really improvements, others are attempts to introduce various means in lieu of the jacket for attaining the same end; while many display a great amount of ignorance on the part of the inventors, and, as a consequence, their so-called improvements are worse than useless. We have only space for noticing one or two of these absurdities in passing, confining ourselves very briefly to the steam-jacket's career.

In 1781 W. Murdock made a model locomotive for common roads, the cylinder of which was placed on the top of and partly let into the steam-space of the copper boiler (see fig. 3). When Murdock was testing the powers of this interesting little engine one very dark night, on a narrow road at Redruth, after lighting the spirit lamp under the boiler the locomotive started off with a fizzing sound, at such a pace

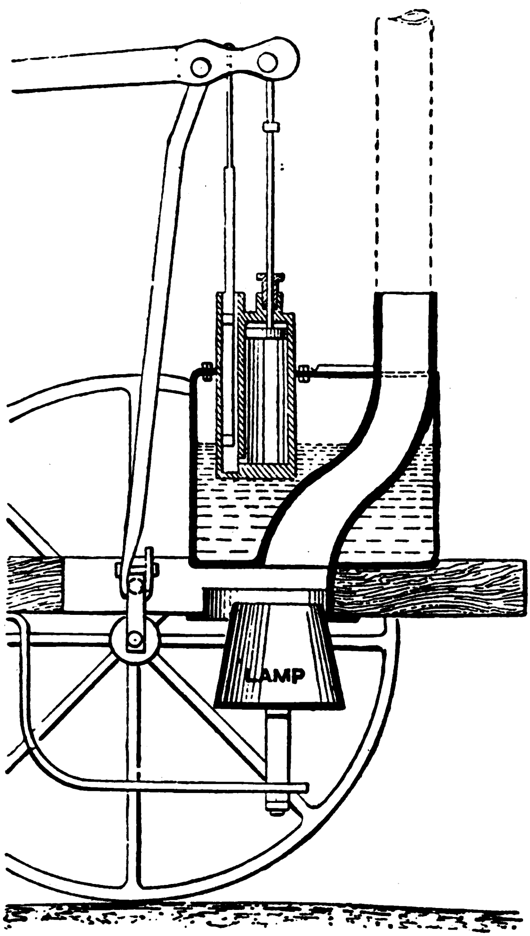


Fig. 3. Murdock's cylinder inserted in the boiler.

as to leave its inventor in full chase after it. During this experimental trip "he heard distant despair-like sounds: it was too dark to perceive objects, but he found the cries for assistance proceeded from the worthy pastor, who, going into town on business, was met on this lonely road by the fiery monster, whom he took for the evil one *in propria persona.*" Murdock took out a patent in 1799 for some improvements in steam-engines, among the rest a new method of forming jacketed cylinders. The cylinder casing was cast in one piece, to which the cover and bottom of the steam-cylinder were attached. The liner placed within was fixed to the case at one end by conical joints, and by a packed or caulked joint at the other. Three years later Trevithick and Vivian obtained a patent for a "high-pressure engine, the cylinder of which was enclosed within the boiler; the nozzle, steam-pipe, and bottom were cast in one piece to resist the strong steam" (fig. 4). In 1803 they made a common road locomotive, the cylinder being fixed within the boiler horizontally. In 1804 they constructed a high-pressure engine for moving carriages on rails, which proved a success; this engine was employed in a mine at Methyr Tydfil, and drew carriages containing 10½ tons at the rate of 5½ miles an hour; its cylinder was let into the boiler vertically. It was suggested that "placing the cylinder inside the boiler saved the expense of a jacket, and effectually kept up the temperature of the cylinder to that of the steam."

Arthur Wolff employed steam of still higher pressure, and, to keep up the temperature of his cylinders, a separate fire was made under the steam-jacket, which was fitted with a safety-valve. In 1804 he obtained another patent for raising the cylinder to any temperature, without admitting high pressure steam into the jacket, by the use of oil, fat, wax, or other substances that melt without being turned into vapour.

About this time Henry Maudslay constructs the most elegant engine of its day: the cylinder was en-

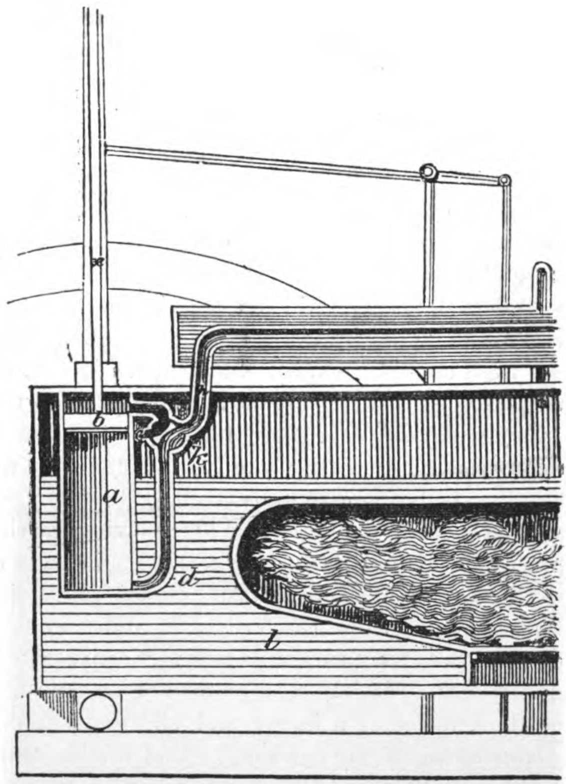


Fig. 4. Trevithick's cylinder inserted in the boiler.

closed in a casing of copper, and the annular space filled with wool.

Early in 1813 the celebrated "Puffing Billy," designed by W. Headley and constructed by J. Foster, commenced to run on the Wylam Railway; this patriarchal locomotive may be seen in the Patent

Museum at South Kensington. The working cylinders on each side are dropped into wrought-iron jackets: some engineers have assumed that these were *bonâ fide* steam-jackets, but there is now no doubt that these jackets did not serve such a useful purpose, but were used as receivers, into which the exhaust steam was admitted previous to its passing into the chimney, a pipe being provided for this purpose.

In 1814 Thomas Tyndall obtained a patent for an engine adapted to give motion to carriages, in which the exhaust was led into a case surrounding the cylinder, to *preserve its heat.* The absurd notion of keeping the outside of a cylinder at the same heat as the inside, by means of the comparatively cool exhaust, was not confined to the Puffing Billy's designer, or the individual just named, but this idea has been repeatedly mentioned by so-called steam-engine improvers since that date. It has three or four times been embodied in inventors' specifications, the most notable instance being in Mr. J. Beattie's patent specification of 1858, actually forty-four years after Tyndall's day; and, in another instance, as recently as 1862. Surely this wasteful fallacy does not still prevail among engineers, but there are plenty of cylinders in our day, which, if not totally encircled by the exhaust steam, are so badly arranged as to be very nearly so.

About the year 1825 Captain S. Grose erected a Cornish pumping-engine, in which he considerably increased the pressure of steam, and obtained very good results; the cylinder was carefully steam-jacketed, and, with a view to prevent any loss of heat from radiation, the cylinder, nozzles, and steam-pipe were carefully clothed with non-conducting materials. He subsequently erected an 80-inch cylinder engine, in which these improvements were introduced, and this

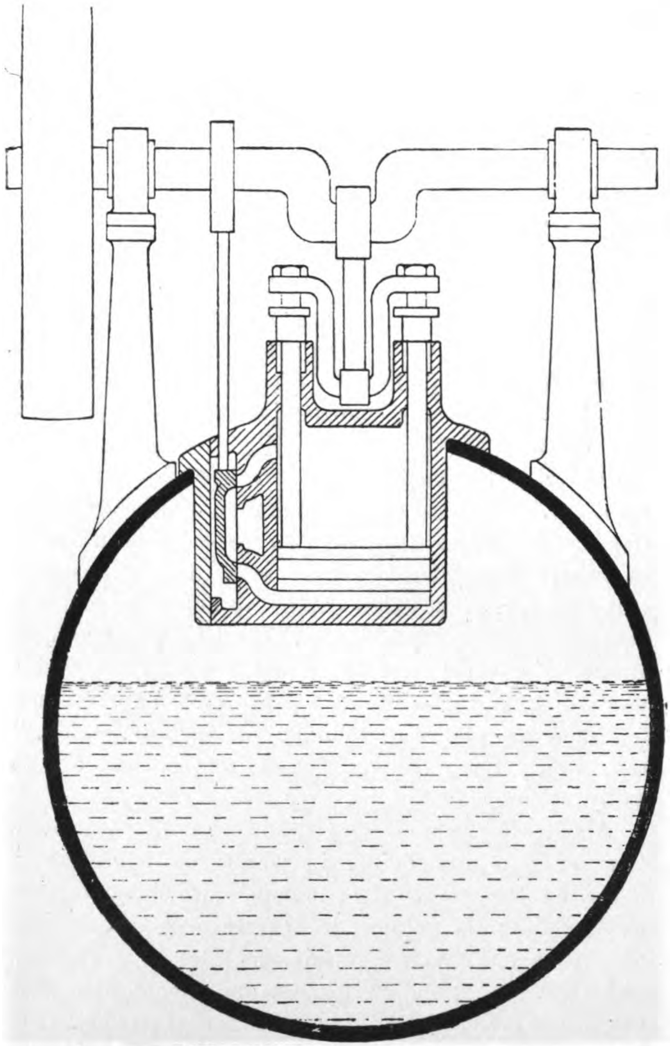


Fig. 5. Cambridge's portable engine cylinder.

engine being manufactured and erected with peculiar care, did an extraordinary duty in 1828.

W. F. Flaycraft, in 1830, uses superheated steam, and he heats the cylinder by a fire.

During the year 1842 P. M. Parsons keeps the cylinders of locomotive engines warm by allowing steam to have passage between the jacket and the cylinder.

To Cambridge, of Market Lavington, must the honour be accorded for having first attempted to heat the cylinders of portable engines, his first engine being made in 1843: it was his practice to place the cylinders vertically on the top of the boilers, and let them into the steam-space like Murdock's little road engine (see fig. 5). Cambridge built a large number of engines, which were sold in various counties in England. He hardly made two engines alike. The vertical engines with the cylinders let into the boiler eventually gave place to the engine placed horizontally on the top of the boiler: some engines made by Cambridge of this design are still at work.

The portable engines made by Messrs. R. Hornsby, in 1850, were fitted with the cylinder inside the steam space of the boiler, similar to the method adopted by Trevithick in his steam carriages. Messrs Hornsby make compound portable engines on this system to this day. Fig. 6 shows the latest arrangement: the two cylinders and valve-chests are inserted in the elevated steam-space at the fire-box end of the boiler; the whole steam-dome being well lagged, making a very efficient steam-jacket.

In 1853 Clayton and Shuttleworth obtained a patent for their portable engines fitted with the steam-cylinder placed within the smoke-box, and also steam-jacketed, a combination that had not been used before.

In 1854 Frederick Martini patented a method of supplying the jackets of steam-engines with steam of a higher pressure than that which is being admitted into the working cylinder. He says :—" If the steam

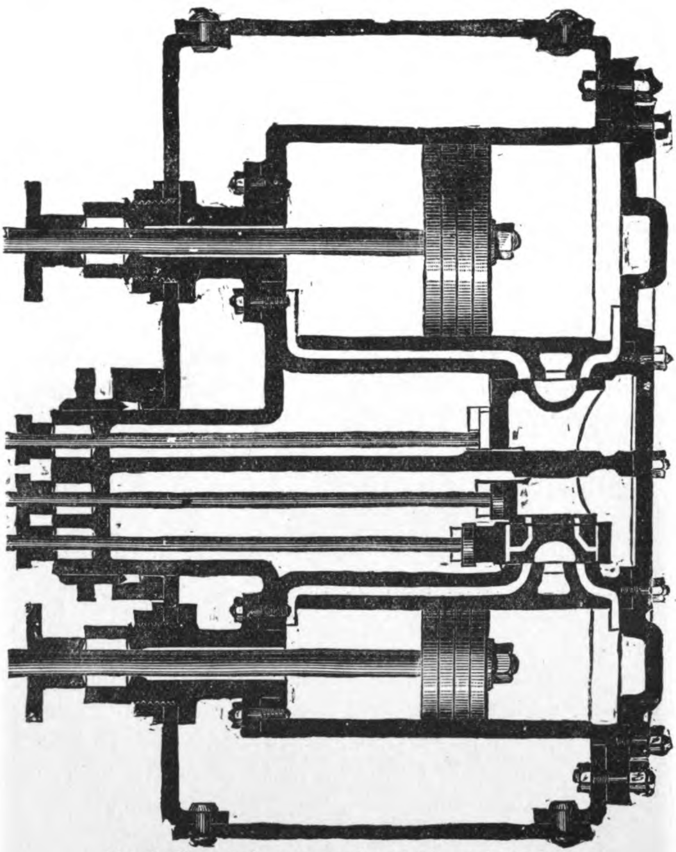


Fig. 6. Hornsby's compound portable engine cylinder.

in the cylinder has a pressure of three atmospheres, that in the steam-jacket should have a pressure of five atmospheres. The steam to produce this effect should be generated in a small, strong, separate boiler." It is curious to find the same thing re-patented thirty years afterwards, viz., 1884. Here are the inventor's own words :—" A method of increasing and maintaining the heat of steam used for working engines. It is usual to apply to the cylinders of steam-engines steam-jackets for the purpose of maintaining the heat of the working steam, and many attempts have been made to superheat the steam before it reaches the cylinder. These expedients are more or less ineffective, because the steam in the jacket is not hotter than the steam entering the cylinder, and because superheating apparatus are generally complex and far from durable. Now, according to our invention, we remedy these defects by employing a separate boiler, which may be comparatively small, and generating in it steam at a higher pressure and temperature than that of the working steam in the main boilers. We employ either the steam or the hot water of this auxiliary boiler for circulating through the jackets encasing the working cylinders. Thus, by conduction from the hotter fluid, the heat of the working steam is increased and maintained."

This is a slight digression—we will now proceed with the historical notes. A few months after Martini's patent, Oliver Maggs placed the cylinders of his portable engines in the base of the chimney to prevent the loss of heat.

Several other agricultural engineers, besides those already named, commenced to jacket the cylinders of their portable engines about this time. Tuxford's prize portable at the R.A.S.E. Show at Carlisle, in 1855, had a jacketed cylinder.

Steam-jacketed or heated pistons were introduced in 1856 by C. B. Normand, who says :—" In engines acting expansively, the cylinder is often jacketed, which protects the sides and ends only; to remedy this defect, the piston-rod and piston are made hollow, and steam at its maximum pressure is introduced into the piston."

Robey & Co., in 1857, used jacketed cylinders on their portable engines, and the Reading Iron Works Co. also obtained three prizes at the R.A.S.E. Show at Worcester, in 1863, with engines having steam-jacketed cylinders.

Mr A. E. Cowper, in 1862, patented a method of re-heating the steam of compound engines during its passage from the high-pressure to the low-pressure cylinder, viz., by inclosing the receiver in a steam-jacket.

In 1863 Newton proposed to line the interior of cylinders with metal surfaces, heated by steam from an auxiliary boiler at about 100° F. above the working pressure in the boiler: the linings of the cylinder lids were made of two circular steel plates $\frac{1}{10}$th of an inch thick, kept $1\frac{1}{4}$ inches apart, and filled with steam; the barrel of the cylinder was got up in a similar manner.

At the Royal Agricultural Society's trials of fixed engines at Bury St. Edmunds, in 1867, the first prize engine had a steam-jacketed cylinder and covers; the second prize engine had the cylinder only, jacketed. At the same trials of single cylinder portable engines, the first prize engine had a steam-jacketed cylinder inclosed inside the smoke-box; the second prize engine had a steam-jacketed and carefully clothed cylinder on the top of the boiler. There was an engine with an exhaust jacket partly round the cylinder, which burnt just twice as much coal per hour as the first prize engine did.

During the trials of vertical engines and boilers combined, at the Oxford Show of the Royal Agricultural Society, in 1870, it was shown that the engines having the cylinders not steam-jacketed, and the boilers not clothed, burnt from 50 to 250 per cent. more coal per horse-power than those having the cylinders jacketed and the boilers lagged.

We have traced merely in outline the first century of the steam-jacket's history, viz., from 1770 to 1870; during this period the most conflicting opinions have been entertained by engineers concerning its value; at one time it enjoyed very little favour, and was only fitted to engines of one class; at another time it was the rule to jacket nearly all engines; while at another period it was all but abandoned for all classes of engines, its application being very exceptional indeed; it can, however, be easily shown that whenever doubts have been entertained by persons respecting the utility of the steam-jacket, these misgivings have been occasioned by an imperfect knowledge of the function of the jacket: for instance, Tredgold, the foremost engineer and writer of his day, held erroneous notions respecting the theory of the jacket; consequently, his opinions on this subject are of no value whatever; and numerous other smaller writers and less known engineers have been similarly misinformed, and have thus lightly esteemed the services of the steam-jacket as an economizer. We have also noticed, in passing, some of the plans that have been suggested for effecting the same ends by other means than steam-jacketing; not one of which, however, has been successfully applied: among many others the use of hot-air jackets may be mentioned.

To give full particulars of the various methods of perfect steam-jacketing that have been introduced between 1870 and the present time would require more space than has been occupied by this chapter, for it is now the custom to thoroughly steam-jacket the cylinders of all classes of engines, save one, manufactured by firms of repute, and some of the means adopted by the best makers to secure the highest efficiency are worthy of more extensive imitation ; for, notwithstanding our increased knowledge, there is still room for much improvement in the so-called cheap productions of some makers, which are designed in such a manner that economy of fuel is out of the question: let us hope, however, that such engines will soon become more rare, because of a decreased demand for such abortions existing among buyers.

By numerous tests, carried out on all classes of engines, under all circumstances, the steam-jacket has proved itself beyond a shadow of a doubt to be of immense service in promoting economy; hence the steam-jacket is to-day more universally applied than ever it was, because its value is more universally understood.

CHAPTER II.

Cylinder Condensation.

Losses from External Radiation and Conduction.

The working steam within the cylinder of a steam-engine is robbed of its heat and liquefied by the four following causes:—

(1) Some heat passes through the metal of the cylinder body and ends, which is absorbed by the metal of the bed-plate or engine-frame in contact with the cylinder.

(2) Heat is rapidly transmitted through the walls and lids of the cylinder to the atmosphere, unless it is checked or prevented by the application of non-conducting and non-radiating materials.

(3) The greatest amount of heat, however, is wasted by the internal surfaces of the cylinder being cooled down during the exhaust by exposure to the atmosphere or to the frigorific influence of the condenser: this metal has to be warmed up by the incoming steam during every stroke of the engine, representing an enormous loss in unjacketed cylinders.

(4) Steam is condensed resulting from the performance of work: this liquefaction takes place inside the cylinders of unjacketed engines, and within the jackets of steam-jacketed engines.

I. Some heat passes through the metal of the cylinder body and ends, and is absorbed by the metal of the bed-plate or engine-frame in contact with the cylinder. Very little need be said respecting the heat transmitted from the cylinder to the bed-plate, because, in modern engines, a very small proportion of the one is in contact with the other. The loss from this source may be reduced to a minimum by a judicious arrangement of the materials on the part of the engine designer. But, even in badly-arranged engines, the loss of heat conducted from the cylinder to the frame must be very slight. It has, however, been proposed to place strips of non-conducting materials between the parts of the cylinder in contact with the engine bed-plate, so as to prevent this useless expenditure of heat.

II. Heat is rapidly transmitted through the walls and lids of the cylinder to the atmosphere, unless it is checked or prevented by the application of non-conducting and non-radiating materials.

Much heat is conducted through the cylinder sides and ends, and lost by radiation if left exposed. Radiation is the transmission of heat by direct rays from a hot body through space, just as light is from a luminous body. The rapidity with which heat radiates varies, other things being equal, as the square of the temperature of the hot body is in excess of the temperature of the cold one, so that a body if made twice as hot will lose a degree of temperature in a quarter of the time; if made three times as hot, it will lose a degree of temperature in one-ninth of the time; and so on, in all other proportions.*

The loss by radiation is not affected by the form of the radiant body: a cube or cylinder will radiate the same amount of heat with equal areas under the same

* "Treatise on Heat," by Thomas Box.

conditions. The amount of heat emitted by radiation will vary exceedingly with the nature of the surface, being increased by darkness and roughness, and diminished by smoothness and polish.

The loss of heat from a dull black surface by radiation being 100, that for polished metal does not exceed 5.

A few years ago many engine cylinders were left totally exposed, notwithstanding that Watt in his time had clearly gained a marked economy by carefully clothing his cylinders. Most of the portable engines exhibited and tested at the Crystal Palace, in 1851, had exposed cylinders: it is not surprising to find that the average consumption of coal during these trials was 14 lbs. per ind. horse-power per hour; and we have mentioned elsewhere that at the trials carried out by the Royal Agricultural Society at Oxford in 1870, the engines with unjacketed cylinders and unlagged boilers burnt from 50 to 250 per cent. more fuel per horse-power than some other engines having the cylinders steam-jacketed and clothed, and the boilers carefully coated with some non-conducting material.

Some experiments, made by Mr. D. K. Clark, show that, in the case of exposed cylinders of locomotive engines, the loss from radiation may rise to as much as 40 per cent. of the whole steam consumed, and by careful clothing this loss may be reduced to 2 per cent.

Few engines at the present day, however, are seen with unlagged cylinders, and these few belong to low-priced and abortive types used on steam-cranes, ships-winches, direct-acting pumps, &c. We regret to say that the steam-engines having unlagged cylinders are often found working out of doors, exposed to all weathers: the waste of steam in such cases must be enormous. It is very unfortunate that there should be any demand for low-priced wasteful engines, when well-designed and excellent engines of all classes may now be had at very reasonable rates, fitted with steam-jacketed and carefully-clothed cylinders: the rest of the details are also arranged by competent engineers for working economically.

Happily, these examples of second-rate construction are becoming every day more exceptional; the standard of efficiency is gradually being raised; steam-jacketing and lagging are more general now than ever they were heretofore.

There are an immense number of non-conducting compositions introduced for the purpose of preventing the radiation of heat from boilers, steam-pipes, and cylinders.

" It should carefully be borne in mind, although it is constantly forgotten, that whether the protective material is, or is not a first-rate non-conductor, unless its qualities as a non-radiator are also good, it cannot prove wholly satisfactory." * By increasing the thickness of low conductors the loss of heat becomes rapidly less, but, " with moderately good conductors, the loss with all thicknesses is greater than by a naked cylinder, and the thicker the casing the greater the loss." † A 12-inch cylinder, filled with steam at 212° and exposed to external air, will lose twenty-four times as much heat per square foot run, if left naked, than if it were lagged with felt or wood 6 inches thick, or eleven times more if left naked than with 2 inches of lagging. According to the table quoted from Box's " Treatise on Heat," given on the next page, it will be seen that the best material, as

* *The Engineer*, 10th March 1876.

† " Treatise on Heat," by Thomas Box.

far as non-conduction goes, is grey blotting-paper; the quantity of heat transmitted per square foot in one hour by a block of this material 1 inch thick being only ·274 of a unit, while a plate of iron of the same thickness transmitted 233 units per square foot, the difference in temperature at the opposite sides of the plate being one degree.

TABLE I.—*Conducting Power of Materials, being the quantity of heat in units transmitted per square foot per hour by a plate* 1 *inch thick, the two surfaces differing in temperature* 1°. *From the Experiments of Péclet.*

Copper, ...	515
Iron, ...	233
Zinc, ...	225
Lead, ...	113
Marble, grey, fine-grained, . .	28
Stone, calcareous, fine, . . .	16·7
Glass, ...	6·6
Baked clay, brickwork, . . .	4·83
Plaster, ordinary, ...	3·86
Brick-dust, sifted, ...	1·33
Coke, pulverised, ...	1·29
Cork, ...	1·15
Chalk, in powder, ...	·869
Charcoal of wood, in powder, . .	·636
Straw, chopped, ...	·563
Wood ashes, ...	·531
Mahogany dust, ...	·523
Canvas of hemp, new, . . .	·418
Calico, new, ...	·402
White writing-paper, . . .	·346
Cotton-wool and sheep wool (any density),	·323
Eiderdown, ...	·314
Blotting-paper, grey, . . .	·274

It must be borne in mind that Table I. gives only the conducting power of materials, and does not refer to radiation.

The power of radiation is influenced by the surface of materials; roughness increases the radiation, while smoothness diminishes it. Table II. shows this very clearly.

TABLE II.—*The Radiating Power of Bodies, being the units of heat emitted per square foot per hour for a difference in temperature of 1°. From the Experiments of Péclet.*

Silver, polished,	·026527
Copper, polished,	·03270
Tin, polished,	·04395
Zinc and brass, polished,	·04906
Tinned iron, polished,	·08585
Sheet-iron, polished,	·09200
Sheet-lead,	·13286
Sheet-iron, ordinary,	·56620
Glass,	·59480
Cast-iron, new,	·64800
Chalk,	·6786
Cast and sheet-iron, rusty,	·6868
Wood sawdust, fine,	·7215
Building-stone, plaster, wood, brick,	·7358
Sand, fine,	·7400
Calico,	·7461
Woollen stuffs, any colour,	·7522
Silk stuffs, oil-paint,	·7583
Paper, any colour,	·7706
Lamp-black,	·8196
Water,	1·0853
Oil,	1·4800

Silicate cotton or slag-wool possesses advantages as a non-conductor of heat: it is largely used by the Admiralty. Some railway companies have adopted it for covering their locomotive boilers. The following relative conducting powers are interesting:—

Silicate cotton, ...	100
Hair-felt, ...	117
Cotton-wool, ...	122
Sheep's wool, ...	136
Charcoal, ...	143
Sawdust, ...	163

The following experiment was recently carried out to test the heat-resisting qualities of silicate cotton. A cake, 2 inches thick, covered on both sides with a wrought-iron plate ¼ of an inch thick, was placed over a fire; when the bottom plate was made red-hot, the top plate was warm but not hot.

Very few people have any idea of the extent to which heat can be retained by non-conducting substances. In one of the mines of the Comstock Lode (America), a shaft burned out, and, five months after, when the *débris* of the fire was cleared away, locks at the bottom of the shaft were found to be still red-hot.* In this we have an example of the effects of properly covered cylinders, steam-pipes, &c., by good non-conducting materials.

Air spaces are often recommended as effective non-conductors of heat, but it has been remarked by Professor Ordway that the air spaces should be filled up with a material that will act as entangler, because air at such a temperature as 311° F., for instance, corresponding to a steam pressure of 180 lbs. per square inch, is of little or no value as a non-conductor, unless something

* Address by Mr. J. C. Bayles of New York, in 1876.

is used to prevent the air from moving. A small quantity of hair-felt or wool will play the part of entangler. There are many non-conducting compositions which are unsatisfactory—they are anything but non-radiators. If such materials are covered with cold-rolled steel-sheets this defect will be remedied, as these smooth steel plates stand pretty high among the non-radiators. The smoother and brighter the sheets that are used for lagging cylinders, steam-chests, and pipes, the more satisfactory they are as non-radiators.

Many engine-makers coat their cylinders with a good non-conducting composition, and cover the whole with bright steel plates, which act perfectly for retaining the heat. We now wish to combat an opinion which is firmly established in the minds of many users of steam, viz., that the outside temperature of a non-conducting composition applied to hot surfaces is a measure of its non-conducting efficiency. It has been proved that the act of measuring the temperature, either on the outside by placing the hand upon the covering, or even by thermometer readings, are unreliable and misleading. Good non-conductors will not allow the heat to escape quickly, but retain it in the surface just as tenaciously as in the interior, because they are also good non-radiators, in which case the supply of heat from the steam inside is greater than the loss of heat from the surface, and, consequently, the outside feels warm. Inferior non-conductors, however, give the heat from the surface quicker to the surrounding space than it can be supplied from the interior source of heat; thus it can happen that the outside surface feels cooler, when, in fact, it loses more heat than the better covering.*

One of the oldest non-conducting compositions which

* Mr. Albert Haake in *The Practical Engineer*, 14th June 1889.

is in use at the present time is that manufactured by Messrs. F. Leroy & Co. It has been improved from time to time, and is now, as heretofore, giving satisfaction. Messrs. Leroy can show some composition which has been ten years on steam-heated surfaces without the least apparent change.

A non-conducting coating for cylinders, steam-pipes, &c., is described in a recent issue of the *Revue Industrielle* as being conveniently applied and cheap, while it can be prepared by any steam-user. It consists of a mixture of wood sawdust, with common starch, used in a state of thick paste. If the surfaces to be covered are well cleaned from all trace of grease, the adherence of the paste is perfect for either cast or wrought-iron, and a thickness of 1 inch will produce the same effect as that of the most costly non-conductors. For copper pipes there should be used a priming coat or two of potter's clay, mixed thin with water, and laid on with a brush. The sawdust is sifted to remove too large pieces, and mixed with very thin starch. A mixture of two-thirds of wheat starch with one-third of rye starch is the best for this purpose. It is the common practice to wind string spirally around the pipes to be treated, keeping the spirals about $\frac{3}{8}$ inch apart to secure adhesion for the first coat, which is about $\frac{1}{4}$ inch thick. When this is set, a second and third coat are successively applied ; and so on, until the required thickness is attained. It is stated that twenty shillings worth of starch will go as far in this way as £40 spent in many commercial non-conductors of heat.

The conduction and radiation of heat from cylinders may be very much reduced, if not practically prevented, by a liberal application of non-conducting and non-radiating materials, which are so easily obtainable.

In another part of the book we refer to the method of protecting Cornish engine cylinders. And we give another example of careful clothing, as carried out by an American firm also.

The following note refers to the lagging of the triple-expansion engine, made by Messrs. Sulzer Bros., Winterthur, which has given such remarkable results, recorded later on:—"The jackets are well covered with an insulating substance, and are clothed with polished steel-sheets and bright cast-iron covers."

CHAPTER III.

CYLINDER CONDENSATION—*continued.*

Losses from Internal Condensation.

III. THE greatest amount of heat, however, is wasted by the internal surfaces of the cylinder being cooled down during the exhaust by exposure to the atmosphere, or to the frigorific influence of the condenser: this metal has to be warmed up by the incoming steam during every stroke of the engine, representing an enormous loss in unjacketed cylinders.

This liquidation of steam inside unjacketed engine-cylinders is caused by the rapid conducting powers of cast-iron of which the cylinder, piston, and cylinder lids are made, for these surfaces most readily absorb and emit heat.

To explain more fully how this internal condensation takes place, let us imagine the case of a non-condensing steam-engine with the cylinder unjacketed, the piston of which is being moved towards one end by the incoming steam. At the other end the exhaust port is open to the atmosphere, so that the temperature of the surfaces of the piston, cylinder-walls, lids and steam passages being thus exposed, are reduced to the same temperature as the exhaust steam (or, say, of boiling water) by the time the piston has completed its stroke.

The admission port opens, and steam of 60 or 80 lbs. pressure enters the cylinder: while this is taking place a considerable quantity of heat is extracted from the incoming steam to warm up the cylinder; hence a large portion of the steam which first enters the "cylinder is condensed by the piston-face and cylinder-lid, and its place is immediately supplied from the boiler. Ten lbs. of steam might be sufficient if no condensation occurred; but condensation does take place, and a further quantity of steam is admitted to keep up the pressure. Instead of 10 lbs. per stroke being required, we may have an admission of 15 lbs. to 20 lbs. One portion of the steam goes to heat up the cylinder, the rest to fill up the space behind the piston." It has been well said by *The Engineer* that "nothing can be more efficient as a condenser than the thin space due to clearance intervening between the cylinder-lid and the piston-face, both reduced to the temperature of the exhaust steam." When the slide-valve closes, we have not steam alone, but steam and hot water; expansion now commences, and the pressure is gradually reduced; the water lying in the cylinder, which was condensed during the admission of the steam, is now in contact with the heated walls of the cylinder, while the pressure in the cylinder has diminished to, say, 5 or 6 lbs. pressure: the result of this is, that the water which was condensed by the cool metal is in part re-evaporated, and the terminal pressure of the steam is slightly raised in consequence. It has often been asserted that all the power that was lost by condensation is regained by evaporation, but this is a mistake, for the power was lost when the steam was at its highest pressure, and regained at some other pressure very much lower, and much too late to be of any real service, while the cylinder is cooled by the loss of heat in boiling off this water.

Thus, without steam-jackets, a large quantity of steam passes through the cylinder in the form of water without doing any work. Indeed, the cylinder acts to some extent as "a condenser at the beginning, and as a boiler at the end of the stroke." This waste of steam varies in different types of engines; for instance, in fast-running engines the loss is considerably less than for slow-moving engines, because so much less time is allowed for the cooling of the metal. In long-stroke engines of medium diameter of cylinder, the piston and lids (for they certainly are the greatest agents of condensation) contribute less to this waste than for short-stroke engines of large diameter of cylinder. The higher the steam pressure used, the greater the difference of the temperature of the metals at admission and exhaust, therefore the larger the loss. The most wasteful are slow-moving, unjacketed, expansive condensing engines, for the "evil influence of the condenser on unjacketed cylinders is a matter of notoriety."

The quantity of steam thus condensed in various classes of engines has been approximately estimated. For information concerning this liquidation in locomotive engine-cylinders, we will quote the following by Mr. D. K. Clark, who says:—"I made a large number of trials and observations, and I conclusively proved that the loss of steam by condensation in outside cylinders of locomotive engines was enormous; the loss increased with the degree of expansion or the shortness of the cut-off, until, for a cut-off of $\frac{1}{7}$th *half*, the steam was condensed when admitted into the cylinder." The same author says, in his work *Steam and the Steam-Engine*, p. 268:—"In the cylinders of ordinary steam-engines the extra consumption and waste of steam devoted to the heating of the cylinders in the first part of the stroke is above 12 per cent. of the whole steam consumed for a period of admission of one-third of the stroke." From indicator diagrams, taken by Mr. E. A. Cowper, which are illustrated in the *Cyclopædia of Useful Arts*, the amount of loss from the want of a steam-jacket is clearly demonstrated. These figures show the pressure really attained, to-

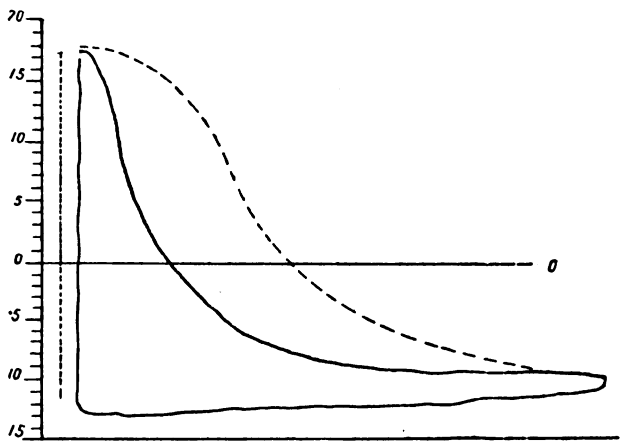


Fig. 7.

gether with the true expansion curve for the whole quantity of steam that entered the cylinder dotted in, and which dotted curve would have been described if the cylinder had been steam-jacketed. The difference between these curves represents the amount of loss from the lack of steam-jacketing: in one diagram this loss amounts to 11·7 per cent.; in another to 19·66 per cent., there being rather more variation of temperature in this case, owing to there being more expansion; in the next figure the loss is 27·27 per cent.; *whilst in the last diagram, which we reproduce by fig. 7, the loss rises to the formidable proportions of* 44·58 *per cent.*

Professor Rankine, in his work on the Steam-Engine, says:—" In some experiments the quantity of steam wasted through alternate liquefaction and evaporation in the cylinder has been found to be greater than the quantity which performed the work."

From articles which appeared some time ago in *The Engineer* on " Condensation in Steam-Engine Cylinders," it is shown that 9 lbs. of steam per horse-power per hour are lost in the cylinder of a steam-engine through internal condensation: cylinder 3 feet diameter and 5 feet stroke, the engine making 30 revolutions per minute, the absolute pressure of steam being 75 lbs. per square inch, and steam is admitted through one foot of the stroke, and expanded through 4 feet.

The consumption of steam in practice of such an engine would be 27 lbs. per horse-power per hour. The theoretical quantity of steam needed per horse-power per hour is stated to be only 13·7 lbs.: we must therefore in some way account for the difference of 13·3 lbs.

Theoretical quantity required per ind. horse-power per hour, . . .	13·7
Loss by leakage per ind. horse-power per hour, ...	1·0
External condensation, &c., per ind. horse-power per hour, ...	0·3
	15·0

The remaining 12 lbs. of steam is condensed inside the cylinder—3 lbs. will be condensed by the mere performance of work. After making all these allowances, there yet remains 9 lbs of steam per indicated horse-power per hour; and this 9 lbs. is assumed to be liquefied by the unjacketed cylinder as we have explained.

This internal condensation may be made clear to the eye by the aid of indicator cards, which are reproduced for this purpose. "This conduction of heat to and from the metal of the cylinder has the effect of lowering the pressure at the beginning and raising it at the end of the stroke; the lowering effect being, on the whole, greater than the raising effect. The general

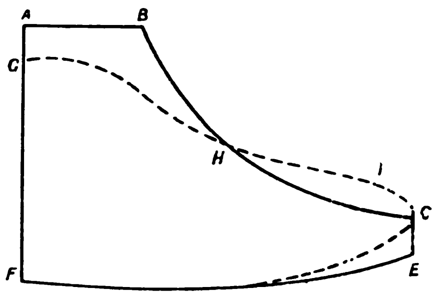


Fig. 8.

nature of the change thus produced in the diagram is shown by the dotted line G, H, I, C, F, in fig. 8.

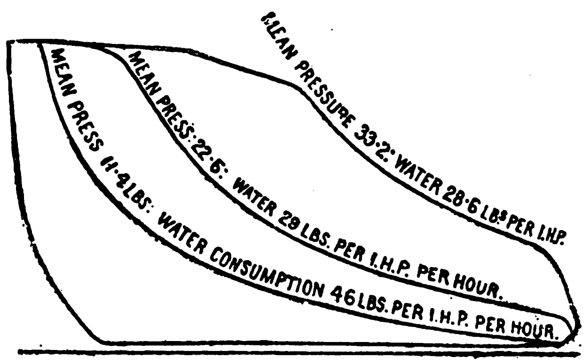
Mr. D. K. Clark, in his little work *Steam and the Steam-Engine*, 1885, says:—" When steam is admitted into the cylinder while the latter is colder than the steam, a very sensible condensation of the steam takes place during admission, in the process of heating the cylinder to the temperature of the steam, which continues to a certain extent during the period of expansion. A portion of this heat, though but a small part, passes off and is lost; the remainder is retained by the cylinder until it is re-absorbed by the precipitated steam during the expansion of the remaining steam, if it be long enough continued; that is, until the temperature of the latter falls below that of the cylinder. This is a destructive process, occasioning an absolute loss of steam; and the amount of steam thus injuriously precipitated, and but partially revived, increases rapidly in proportion as the steam is earlier cut off and expansion is extended." This condensation and re-evaporation is exemplified in a diagram taken from an outside-cylinder locomotive, and reproduced at p. 269 of Mr. Clark's book, to which we must refer our readers. Dotted lines show the expansion curve which would have been described with a constant weight of steam; the full lines show the expansion curve produced by the indicator; the fall of the pressure at the beginning, and the rise at the end of the stroke are shown by the full lines, producing an effect similar to the diagram already given at fig. 8.

Outside cylinders have not many supporters on English railways. The chief drawback is the great loss of heat from internal condensation. Proof of this can be derived from Mr. D. K. Clark's paper "On the Behaviour of Steam in the Cylinders of Locomotives during Expansion,"* from which it would appear that the difference of initial condensation between inside and outside cylinders, taken from six inside and fifteen outside engines, is, on an average something like 16 per cent.

"In many text-books on the steam-engine, the fact that increased work can be obtained from a given quantity of steam by utilizing its expansive property is fully gone into; but, unfortunately, this statement is not unfrequently given without any qualification; consequently, many people believe that the earlier the

* *Minutes of Proceedings Inst. C.E.*, vol. lxxii., p. 275.

cut-off in any cylinder the greater the economy. This, however, is only true within certain limits, as it is found that, after a certain point in any engine, the loss introduced by cylinder condensation more than counterbalances the gain by increased expansion. We give two most instructive diagrams to show the increased water consumption owing to internal condensation in unjacketed cylinders. Fig. 9 shows three diagrams taken from a horizontal non-condensing engine by a



—Diagrams showing reduced economy as cut-off gets earlier owing to increased cylinder condensation.

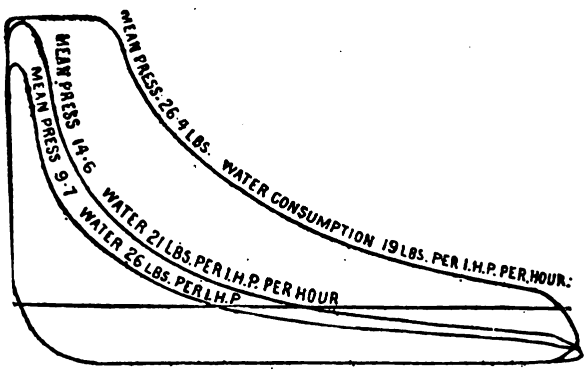
Fig. 9.

well-known maker. The calculated water consumption is given on each curve. From these it will be seen that, instead of decreasing as the cut-off got earlier, the water consumption increased; proving that, although the steam was expanded to a greater extent, the gain thus obtained was outweighed by the increased condensation losses." * Fig. 10 shows three diagrams

* The diagrams and remarks are taken by permission from a series of papers on "The Indicator and its Diagrams," by Mr. Chas. Day, Wh.Sc., which recently appeared in *The Practical Engineer.*

from an unjacketed condensing engine; the water consumption is given at each grade of expansion, again showing the losses that take place by attempting to work at high rates of expansion in an unjacketed cylinder. The adoption of a good steam-jacket in both these instances would have considerably reduced the water consumption at all grades of expansion.

We regret to say that small unjacketed vertical engines are now being most extensively adopted for



—Diagrams from condensing engine, illustrating same point as fig. 9.

Fig. 10.

driving dynamos for electric-lighting purposes, and the amount of steam consumed by some of these wasteful abortions is, we believe, never realised by the users, and known only to those who have tested the engines, or to others who have had the privilege of stoking the boiler supplying them with steam. Professor Unwin's tests of the three small steam-engines sent for competition in the trials of the Royal Agricultural Society's meeting at Plymouth, 1890, was a serious revelation to many, showing, as he did, by the results, the extreme wastefulness of the engines working without steam-jacketed cylinders, and using sloppy steam from vertical boilers. The following table shows the figures:*—

TABLE III.

SUMMARY OF RESULTS.	No. 1.	No. 2.	No. 3.
Boiler.			
Water evaporated per lb. of coal from feed temperature, ... lb.	8·726	7·65	5·978
Equivalent evaporation from and at 212°, .	10·42	9·065	7·136
Water evaporated per sq. ft. of heating surface per hour, ... lb.	3·09	9·71	7·80
Engine.			
Piston speed in feet per minute, ...	298·1	263·0	240·3
Indicated horse-power, ...	5·641	5·175	6·201
Brake horse-power, ...	5·042	3·997	5·003
Steam.			
Steam used per indicated horse-power per hour, ... lb.	35·75	64·73	57·75
Coal.			
Per indicated horse-power, ... lb.	4·099	8·461	9·66

It will be seen from the table that the compound engine No. 1 required 35·75 lb. of steam per indicated horse-power, while the others required 64·7 lb. and 57·7 lb. respectively. The real ratios of expansion were No. 1, 4·4; No. 2, 1·2; and No. 3, 1·6.

These facts have been very clearly brought out by Professor Unwin in his report, from which the two instructive diagrams (figs. 11 and 12) are copied.† "Each diagram is constructed from the mean of the measurement of three or four good diagrams, taken

* *Engineering*, 14th November 1890.

† Figs. 11 and 12 are inserted by the kind permission of the Proprietors of *Engineering*.

during the trial, and is thus representative of the average conditions of working. On each diagram is

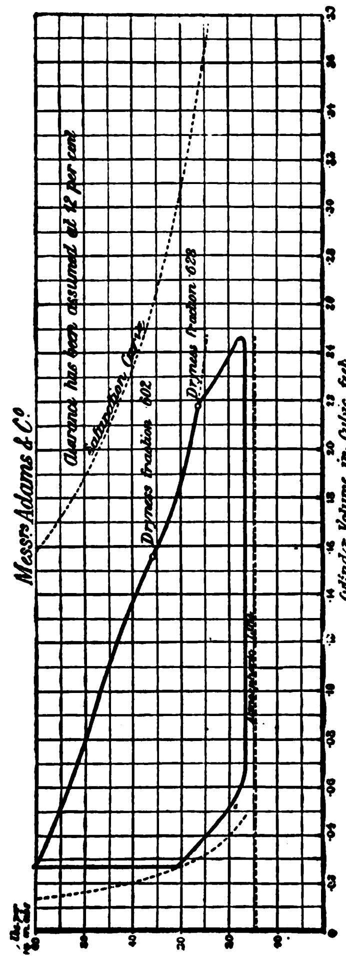


Fig. 11.—Diagram from small engine at the Plymouth Trials.

drawn a dotted saturation curve, obtained by calculating the volume of steam admitted to the cylinder at each stroke, and set out on the supposition that none of it is condensed. The space between the actual and the ideal expansion curves represents the loss at any moment by cylinder condensation or by the wetness of the steam." Fig. 11 reveals that with a boiler pressure of 75 lbs. the highest cylinder pressure in the No. 3 engine was only 60 lbs. About 40 per cent. of

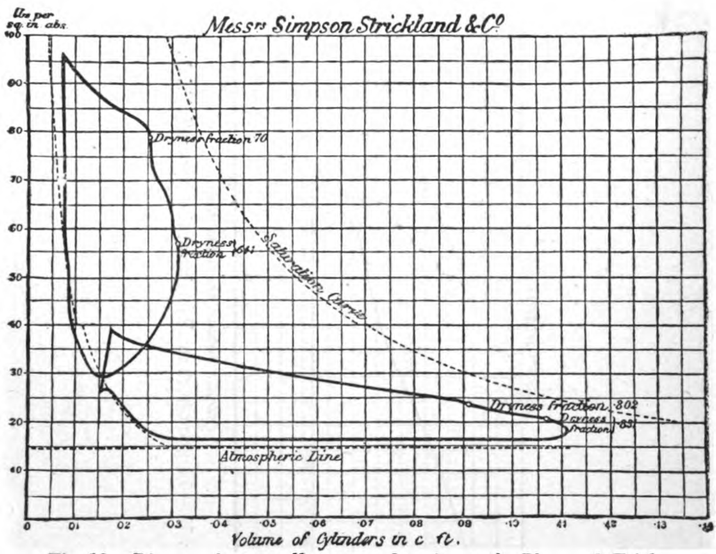


Fig. 12.—Diagram from small compound engine at the Plymouth Trials.

the steam admitted did nothing but warm the cylinder walls. The diagram of engine No. 2, not given here, shows less than half the steam that calculation demonstrates should be in the cylinder. Fig. 12 shows a great amount of loss in the No. 1 engine from condensation and re-evaporation. The steam-jacket is most beneficial in small steam-engines; the extra cost is very trifling, and we think that it is a great pity

TABLE IV.

Summary of Results.		Simple Engines.			Compound Engines.		
		Foden.	M'Laren.	Paxman.	Foden.	M'Laren.	Paxman.
Water evaporated per lb. of coal from feed temperature,	lbs.	10·10	9·34	8·74	9·06	9·38	9·88
Equivalent evaporation from and at 212°, ...	lbs.	11·79	10·79	10·01	10·81	11·21	11·38
Piston speed in feet per minute (declared), . . .		280	325	264	260	354	312
Indicated horse-power, ...		13·88	23·43	19·82	18·63	24·02	22·72
Brake horse-power, ...		11·08	16·71	16·69	17·27	20·77	20·06
Steam used per brake horse-power per hour, ...	lbs.	25·63	23·91	23·58	17·37	19·75	17·78
Coal used per brake horse-power per hour, ...	lbs.	2·842	2·727	2·638	1·977	2·267	1·874

that such engines as the above should be manufactured without steam-jackets.

By way of contrast, we now give similar figures obtained from three of the small simple and compound engines tested at the Royal Agricultural Show at Newcastle in 1887. The boilers in these tests were of the locomotive type, the cylinders were steam-jacketed, and the feed-water was heated. The Newcastle results are just as creditable as the Plymouth results are disgraceful.

We leave the tables to speak for themselves.

It has already been said that some of the waste of steam in the Plymouth engines is due to the wet steam produced by the vertical boilers. From experience we have had in boiler testing, we are led to believe that many of the evaporative tests of vertical boilers are inaccurate. Much of the water said to be evaporated has never been evaporated at all; but is carried with the steam into the cylinder to aggravate the great waste arising from the heating and cooling action of an unjacketed cylinder.* We give the following table to show that, when a boiler supplied dry steam, a

* Since writing the above, we have read Mr. John M'Laren's paper on "The Economical Use of Steam in Colliery Engines," in which he says: —"Tubular, or water-tube boilers, are largely used on the Continent and in America, and they are coming into somewhat limited use in this country. Their economy, however, is doubtful, and, in actual tests, a great disparity in results has been noted, the evaporation varying from 7 to 10 lbs. of water per lb. of coal; but, even with the higher evaporation, their economy is not by any means established, as it is well known that their construction induces priming to a greater or less extent, so that the duty obtained from the boiler is more apparent than real. *In priming, the steam, of course, carries a certain amount of water in the form of spray in suspension, which is an absolute disadvantage to the engine, though it makes the evaporation of the boiler appear very good.*"

Judging by the Sulzer engine trials, given later on, the water-tube boiler certainly made *dry* steam.

smaller quantity was required to do the same amount of work than when the steam was wet.

TABLE V.—*Small Vertical Engine and Boiler Trials.*

TYPE OF VERTICAL BOILERS.	Horizontal fire-tubes.	Horizontal water-tubes.	Horizontal cross-tube and uptake.	Horizontal fire-tubes.
Steam pressure above atm., . lbs.	80	80	80	80
Duration of test in hours, . . .	3·941	3·641	3·65	4·208
Brake horse-power, ...	10·15	10·35	10·54	10·38
Water required per brake horse-power per hour, ... lbs.	50·64	48·87	45·57	44·73
Water evaporated from and at 212° per lb. of coal, ...	10·28	9·31	8·88	9·83
Coal required per brake horse-power per hour, ... lbs.	8·39	8·92	8·72	7·69

The same engine was tested with each boiler: the brake and conditions were alike in all the trials. It will be seen that the boiler in the fourth column produced dry steam, whereas the boiler in the first column supplied wet steam to the engine. Less dry steam was required per hour to develop more power on the brake, with a reduced coal consumption also.

The engine was not fitted with a steam-jacketed cylinder: a simple governor and equilibrium throttle-valve were used. The engine and boilers were similar to the simple engines tested at Plymouth. The results are anything but satisfactory: they are given here for the purposes named above, and also to show the excessive wastefulness of these small unjacketed steam-engines.

Leaving these small steam-engines, we will now turn our attention to some large compound condensing-engines.

We cannot do better than quote what the late Mr. Rich said respecting this part of our subject.* In compound engines, with the cylinders not steam-jacketed, working at a low speed, water is always present in the low-pressure cylinder at a temperature

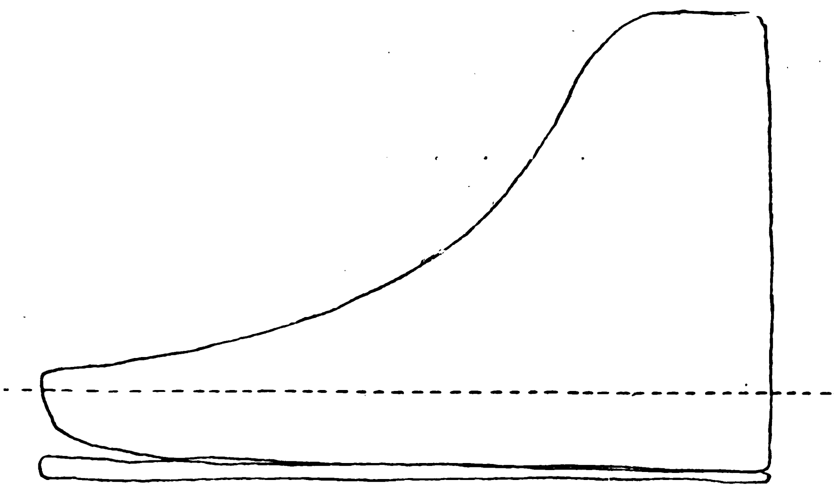


Fig. 13.

considerably below that of the steam exhausted by the high-pressure cylinder. The result is, that so much steam is condensed by this water and the cold cylinder walls on its first admission, as to make an enormous fall between the final pressure in the high-pressure cylinder and the initial in the low-pressure cylinder ; and, at the same time, the low-pressure

* "The Comparative Merits of Engines for Pumping," by Mr. W. E. Rich, M.Inst.C.E., 1884.

diagrams are greatly reduced in their dimensions; sometimes to so large an extent as to become almost worthless. An example of such a diagram is given in fig. 13.

In experiments made in 1877 on an engine of the compound principle, with unjacketed cylinders, Mr. Rich found that, unless special arrangements are made for removing this water, the low-pressure cylinder itself, and the water within it, will frequently remain

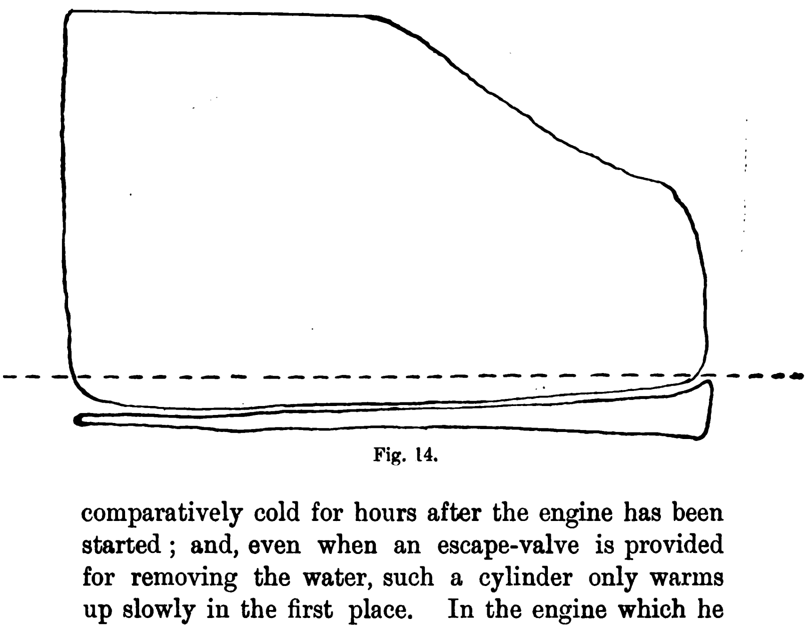


Fig. 14.

comparatively cold for hours after the engine has been started; and, even when an escape-valve is provided for removing the water, such a cylinder only warms up slowly in the first place. In the engine which he tested he found that, at one hour thirty minutes after starting, the water in the cylinder top when steam was being admitted had only a temperature of 150°; at two hours fifteen minutes it was 155°; at three hours five minutes it was 175°; at four hours fifty-five minutes it was 192°; but, having once gained such a temperature as the last-named, its further advance was very rapid, if the escape-valve remained open; and the engine appeared suddenly to work more freely, and to be capable of developing considerably more power than before. For instance, the escape-valve, fitted to the top of the low-pressure cylinder, was opened to discharge the water above the piston on one occasion when the temperature of that water was 187°; two minutes later its temperature was 198°; three minutes later 204°. Twelve minutes

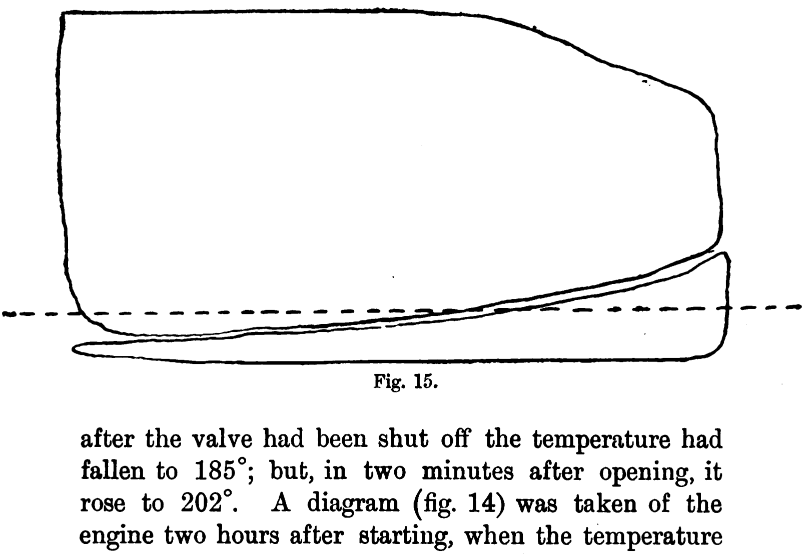


Fig. 15.

after the valve had been shut off the temperature had fallen to 185°; but, in two minutes after opening, it rose to 202°. A diagram (fig. 14) was taken of the engine two hours after starting, when the temperature of the water in the cylinder was 150°; and a diagram (fig. 15) five hours after starting, when it had risen to above 200°. In the first case the low-pressure cylinder shows a mean indicated pressure of only 4·43 lbs. per square inch, and it does only 24 per cent. of the whole work of the engine; while in the second case, it indicates 8·32 lbs. per square inch and does 41 per cent. of the whole work of the engine. Messrs. Easton and Anderson had adopted steam-jackets largely previously; but these experiments so thoroughly convinced them of the great importance of having steam-jackets in all cases on both cylinders, that they have since made no compound engines without them.

From Mr. Rich's paper on "Engines for Pumping," we take two more diagrams (figs. 16 and 17) to exemplify the effect of steam-jacketing, and the injurious effect

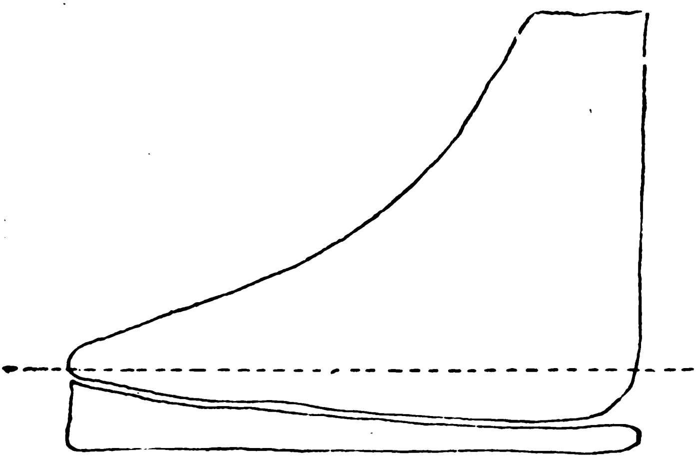


Fig. 16.

of any moisture left in the cylinder. Fig. 13 was given as an extreme case of high expansion in unjacketed cylinders where the low-pressure diagram was considered to be worthless. The two diagrams (figs. 14 and 15) were also from unjacketed cylinders working slowly at 12 to 13 revolutions per minute; the first taking one hour and a half, and the second five hours after starting, without materially altering the load. Figs. 16 and 17 were from steam-jacketed cylinders of the same comparative volumes, viz., 4 to 1, and working under very similar circumstances. Comparing the highly expansive diagrams (figs. 13 and 16), it will be seen how much larger the low-pressure card was in the jacketed cylinder (fig. 16); and the same remark applied on comparing figs. 14, 15, and 17. In fig. 14 the maximum steam pressure indicated in the low-pressure cylinder was below the atmosphere; while in fig. 17 it was 15 lbs. above the atmosphere. These diagrams confirmed graphically

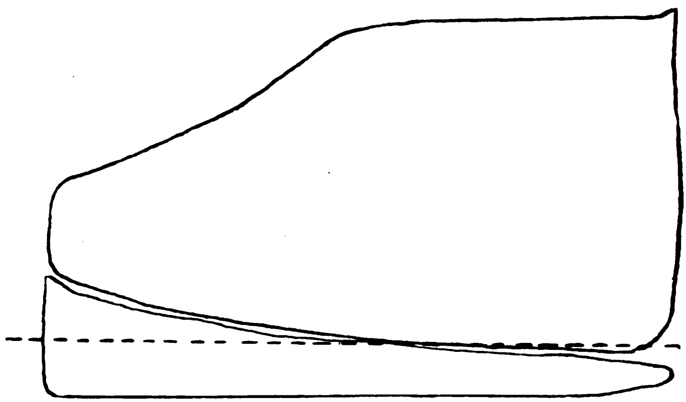


Fig. 17.

the many other evidences of the immense gain due to steam-jackets, especially in slow-speed engines.*

It is a well-known fact that the condensation of steam in the triple-expansion engine under ordinary circumstances is greater than in any other type of engine. Sir Frederick Bramwell in one case found that 45 per cent. of the whole steam that came to the engine was condensed in the high-pressure cylinder of a triple-expansion engine. Other engineers have re-

* Discussion on Mr. Rich's paper on "Engines for Pumping," 1884.

corded as much as 30 to 32 per cent. lost by condensation in the high-pressure cylinder of the same type of engine. One writer has said that " under all circumstances he has found the high-pressure cylinder of triple-expansion engines drowned with water. It was impossible to get a dry diagram from it." Another authority writes as follows :—" I always find the high-pressure cylinder wet. I cannot account for it in any other way than I believe that *all marine boilers* send a very large quantity of water into the cylinder, and what is termed cylinder condensation is really priming."* The steam-jacketing of many triple-expansion engines is badly carried out. Take the Sulzer engine as a model for efficient steam-jacketing. The ends are well jacketed and drained; and, above all, the pistons and cylinder covers exposed to the incoming steam have a smooth surface. Let Mr. Croll's suggestions be carried out, and we shall have less trouble with cylinder condensation in the triple-expansion engine.

The remedies for checking the loss of heat by external radiation and conduction were dealt with in Chapter II. But the greater losses of internal condensation are not so easily remedied: the many proposals for reducing these wastes must be dealt with separately in another chapter, leading up to thorough steam-jacketing,—the only successful means at present employed for reducing these sources of loss.

Work Condensation.

IV. Steam is condensed resulting from the performance of work: this liquefaction takes place inside the cylinders of unjacketed engines and within the jackets of steam-jacketed engines.

* Mr Mudd, West Hartlepool.

The phenomenon of the liquefaction of steam by expansive working was detected in 1849 by Professor Rankine in England and Professor Clausius in Germany, about the same time, but quite independently of each other. This condensation, due to the work done by the steam, is explained in the following passage from Rankine on *The Steam Engine*:—

"When steam or other saturated vapour in expanding performs work by driving a piston, and receives no heat from without during the expansion, a portion of it must be liquefied is confirmed by experience in actual steam-engines; for it has been ascertained that the greater part of the liquid water which collected in unjacketed cylinders, and which was once supposed to be wholly carried over in the liquid state from the boiler (a phenomenon called priming), is produced by liquefaction of part of the steam during its expansion. This liquefaction does not, when it first takes place, directly constitute a waste of heat or energy, for it is accompanied by a corresponding performance of work. It does, however, afterwards, by an indirect process, diminish the efficiency of the engine; for the water which becomes liquid in the cylinder, probably in the form of mist and spray, acts as a distributer of heat and equalizer of temperature, abstracting heat from the hot and dense steam during its admission into the cylinder, and communicating that heat to the cool and rarefied steam which is on the point of being discharged; and thus lowering the initial pressure and increasing the final pressure of the steam, but lowering the initial pressure much more than the final pressure is increased; and so producing a loss of energy which cannot be estimated theoretically. Accordingly, in all cases in which steam is expanded to more than three or four times its initial volume, it has in practice been found advantageous to envelop the cylinder in a steam-jacket. The liquefaction which would otherwise have taken place in the cylinder, takes place in the jacket instead, where the presence of the liquid water produces no bad effect; and that water is returned to the boiler." *

The fact of the partial condensation of saturated steam expanding without receiving heat from external sources is not dependent for proof upon theory only.

The expansion may be accomplished in a glass cylinder, when a cloud or mist will be observed to form, which is due to condensation, since dry steam is invisible.† We give particulars of Mr. Cowper's experiments with glass cylinders in another chapter.

This film of moisture acts as a most excellent medium for the interchange of heat between the steam and the cylinder walls. Perfectly dry steam is a very indifferent radiator and conductor of heat, while moist steam is comparatively good in both respects. Now, the presence of water in the cylinder, by increasing the moisture of the steam, aids in the rapid transmission of heat from the latter to the metal sides; and, *vice versa*, the power of the sides in transmitting heat to the exhaust steam is enormously increased by the presence of a film of water, which, as fast as it evaporates, takes up heat from the metal with great rapidity. The presence of water in the cylinder always exists when the expansion is carried beyond a certain limit; and this is one of the reasons why excessive expansion in a non-compound engine is unattended by any economy.‡

At some trials of small steam-engines at Glasgow

* *A Manual of the Steam Engine and other Prime Movers*, 1876.

† *Economy in the Use of Steam*, by the late Mr. F. Salter, 1874.

‡ *The Steam Engine*, Holmes, 1887.

in 1888, one of the makers attempted to use a very high range of expansion with 80 lb. steam, namely, about thirteen, that is to say, cut-off took place at about one-thirteenth of the stroke, and they made the still greater mistake of passing the exhaust steam from a cylinder expanding through such a range round the cylinder jacket. It seems scarcely credible, but it is true. The diagram (fig. 18)* is from the engine. It shows what an enormous quantity of steam will pass into a cylinder when the cut-off is too early and the heat of the cylinder not maintained by means of a steam-jacket. The loss, however, in this instance

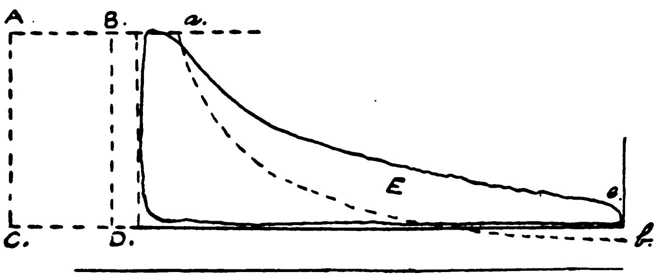


Fig. 18.

was aggravated by the exhaust jacket. For the sake of getting at some information as to what was going on in this cylinder, we have assumed that the total clearance and port spaces amounted to 5 per cent. of the volume of the cylinder. This adds to the diagram the space included within the line B, D. But, even with this 5 per cent. and the cut-off at *a*, the hyperbolic curve for that volume of steam falls, as shown by the dotted curve *a b*, a long distance below the actual indicator diagram, so that the whole of the area E is more than can be accounted for by

* We are indebted to *The Engineer* for this diagram.

dry steam cut-off at the point *a*, even when 5 per cent. clearance is added. This gives some idea of the extent to which this maker turned their cylinder into a condenser, but a better idea may be gained, when it is pointed out that, in order to obtain the curve *a e* of the indicator diagram, a further quantity of steam, represented by the rectangle A, B, C, D, would be necessary, and must have entered the cylinder, been condensed, and re-evaporated. The engine in question used 42 lb. of water per brake horse-power per hour.*

The indicator diagram (fig. 18) shows a large amount of initial condensation, owing to the cooling action of the exhaust jacket. In fact, all the sources of loss were brought into play in this instance of faulty designing. We have inserted the diagram in this place to show the folly of attempting to work with such a great range of expansion without a proper steam-jacket.

After Professor Rankine's clear statement respecting work condensation, little more need be added. We have here a species of liquefaction which cannot be prevented, and the higher the efficiency of the engine the greater the amount of work condensation: but the water resulting from this liquefaction, if left in the cylinder, is a source of waste; some of it is boiled away as expansion proceeds, and the rest is sent to the condenser, or into the drain from the exhaust pipe; in any case this is a waste of heat. Whereas, in a steam-jacketed cylinder, the jacket steam prevents the condensation taking place in the cylinder, the liquefaction taking place in the jacket, where the hot water produces no harm but is returned to the boiler to be re-evaporated to do more work.

We have gone more fully into initial condensation,

* *The Engineer*, 3rd August 1888.

because it is a cylinder waste which is entirely preventable. Most of the cards illustrating initial losses show the inevitable waste of attempting to work expansively in an unjacketed engine. "The hot water of initial and work condensation must be got rid of during each exhaust stroke; such water, if allowed to remain, not only makes the engine noisy, but it will absorb an immense amount of potential heat from the incoming steam in the next steam-stroke, and thus the economic performance of the engine will be greatly reduced."* Work condensation always takes place, and we need not further explain the waste attending it, since a simple remedy in the steam-jacket is provided for removing the loss.

* *Engines for Pumping*, by the late Mr. W. E. Rich, 1884.

CHAPTER IV.

Means Proposed for Preventing Internal Cylinder Condensation.

The following methods have been proposed and tried for reducing cylinder condensation:—

(1) The use of superheated steam.
(2) Hot-air jackets.
(3) Hot-water jackets.
(4) Non-conducting cylinders.
(5) Turned and polished pistons and cylinder-covers.
(6) Steam-jackets.

1. **Superheated steam** is formed by imparting further heat to ordinary or saturated steam. It is also formed by the free expansion of saturated steam.

In practice, steam is superheated in its course from the boiler to the cylinder by being made to pass through tubes which are heated on one side by the products of combustion on their way to the chimney.

" Superheating conduces to economy, but the extent to which it can be carried is practically limited to a few degrees, owing to the injurious chemical action of such steam upon the metal of the cylinder, and the excessive friction caused by the high temperature."* The chief object of superheating, however, is not so much to secure economy as to prevent one great cause of inefficiency, viz., the use of wet steam. But high-pressure steam cannot be sufficiently superheated to thoroughly cure initial condensation. Mr. Holmes "shows that superheating the boiler steam is impracticable for modern high-pressure engines."†

When boilers are given to priming, some heat may with advantage be added to the steam after it is formed, so as to insure its being thoroughly dry before it enters the cylinder. When low-pressure steam was used, a moderate amount of superheating could be adopted with advantage; but, even then, considerable risk attended the use of the superheating apparatus. The ordinary superheating apparatus is costly and cumbersome, while the excessive wear and tear to which it is subjected soon renders it useless. By the least amount of neglect on the part of the engine-driver, the steam may be so much overheated as to cause an enormous amount of injury to the piston and cylinder.

Nevertheless, the use of superheated steam is strongly advocated by some engineers; consequently, we occasionally hear of improved superheaters being introduced. When experiments on the use of superheated steam had been carried out years ago, the engines had not the excellent metallic packing ‡ they now have. Mr. Henry Davey recently said:—If the use of superheated steam were now to be reverted to, he thought the difficulties would not again be met with that had been experienced years ago, when it was tried and discarded. There was a great deal to

* *The Steam-Engine*, Northcott.

† *The Steam-Engine*, Holmes, 1887.

‡ *See* Appendix for particulars of the United States Metallic Packing, as made at the Soho Engineering Works, Bradford.

be done, he believed, in the direction of superheated steam.*

2. Hot-air jackets.—Hot-air jackets are now very rarely used. Many plans have been tried for heating the cylinder in the flues of the boiler, &c., all of which have failed. In portable engines, about thirty years ago, the plan of placing the cylinder in the top of the smoke-box was tried and abandoned for obvious reasons. But, in the portable engines made by another firm, the cylinders were similarly placed, and surrounded by steam-jackets as well, which entirely removed all inconveniences arising from the action of the hot gases on the working steam.

Some years ago a writer in *The Engineer* proposed to draw a moderate quantity of heated air into the jackets of small portable engines by means of the exhaust steam, so as to effectually prevent condensation in the cylinder.† In 1885 a patent was taken out, among other things, for the employment of a steam jet for drawing the hot gases through the cylinder-jacket. In many locomotive engines the cylinders are placed inside the smoke-box, but, as they are at the bottom, they are not so likely to be overheated by the hot gasses on their passage to the chimney. A little time ago we saw a tandem compound traction engine the low-pressure cylinder and valve chest of which were placed in the base of the chimney, so that the hot gases from the smoke-box could keep up the heat of the working steam, but the usual injurious effects were experienced, viz., destroyed lubrication: consequently the plan was quickly abandoned. Mr.

* Messrs. M'Phail & Simpson's superheating apparatus has been put to the test with the most satisfactory results as regards the economy of steam and durability of the apparatus itself. *See* Appendix for more information respecting this.

† *The Engineer*, 13th May 1870.

Northcott says:—"There are practical difficulties in using the hot gases in the jacket, chiefly arising from their high temperature and from the deposit of soot and tarry matter upon the surfaces of the jacket. The former leads to excessive friction in the cylinder, and the latter to the choking of the passages and the non-transfer of heat."*

3. Hot-water jackets.—A few inventors have, at intervals, proposed to jacket the cylinders with hot water, but we are not aware that the plan has ever been tried. A patent was taken out in 1831 for supplying the jackets with a solution of potash and water, kept heated. The use of many other fluids has been suggested, which we cannot refer to here, *The Engineer* proposes the use of hot water, as the following extract shows:—"It should be borne in mind that the great source of waste of fuel is condensation within the cylinder; and that it is only by preventing this waste that any very marked advance can be made on existing practice. If the jacket could be kept hot by heat that would otherwise be wasted, it would be a perfect remedy. We suggested some years ago the use of hot water as the heating medium, the water being raised to the necessary temperature in the flues. For example, it is by no means unusual to find the water in a Green's economizer raised to a temperature of 340°, while the maximum temperature in the cylinder does not exceed 300°, and the average temperature is much less. Now, if the feed-pump drew the water from the economiser† and forced it through the cylinder-jacket, and thence into

* *The Theory and Action of the Steam-Engine*, W. H. Northcott.

† The saving of steam by the application of Green's economiser is happily well known. It is interesting, however, to see this proposal to render it still more valuable as a steam economiser.

the boiler, an excellent result would no doubt be obtained. Again, if the jacket were traversed by the water-coils of a Perkins' heating apparatus, while the fire-coils were located in the boiler flues, a similar result would be more simply attained. Various methods of applying this principle will suggest themselves, the difficulties and objections which stand in the way being very small."* A correspondent to *The Engineer*, 27th August 1886, proposes another method of jacketing with hot water, as under:—"The best system of jacketing that can be adopted is to cast spiral ribs round the cylinder liner, and take water in at one end and out at the other, the water flowing round the cylinder and then through a system of tubes heated by the waste heat from the boiler. There would then be a constant circulation of hot water maintained round the cylinder. A device so cheap and simple would be sure to work well." We have stated these proposals fully in the hope that some one will put the system to a practical test, so as to ascertain if it will more efficiently prevent the condensation of steam in the cylinders of steam-engines than steam-jacketing does.

4. Non-conducting cylinders.—It is a well-known fact that much of the condensation of steam that takes place in unjacketed cylinders is owing to the cast-iron of which the cylinder, the piston, and lids are made, being such a rapid conductor of heat. It necessarily follows that, if a non-conducting material could be used for this purpose, this evil would be removed. For instance, suppose the cylinder was made of a non-conductor and non-absorber of heat, the steam would not be robbed of its heat and condensed on entering the cylinder, simply because the material

* *The Engineer*, 3rd January 1879.

would not part with its heat when exposed to the atmosphere during the exhaust. If it were possible to construct a cylinder of such a character, then would steam work with a maximum efficiency, and we should have the nearest possible approach to a perfect steam-engine.

Many methods have been proposed for the construction of non-conducting steam-engine cylinders. Some of these must be named presently.

But, to make this part of our subject as clear as possible, we quote as under:—"In order to avoid or reduce condensation in steam cylinders, we must construct them either of a material which will conduct heat so slowly that only a small portion of its total weight will alter in temperature; or of a material having so low a specific heat that any moderate quantity of caloric will suffice to raise it through the required range of temperature; or, finally, of a material which will combine both these characteristics. Wood would satisfy the first condition very fairly, but it is obviously inapplicable to the required purpose."*

Watt used a wood cylinder, which no doubt answered admirably for checking condensation of steam, but it practically failed as a substitute for metal for the construction of cylinders, as related in Chapter I.

It is suggested that a non-conducting cylinder could be made of lignum-vitæ in staves, powerfully compressed, and forced into a heavy cast-iron case; the material would be found almost if not quite insusceptible of being injured by the steam. It is suggested that, in case a wood-lined cylinder does not succeed in practice, there could be no difficulty whatever in lining cylinder-lids and covering piston-faces with wood; and, considering the enormous area pre-

* *The Engineer*, 2nd June 1871.

sented to the steam by these surfaces in short-stroke engines of much power, it is evident the result would be almost as good as though the entire cylinder were composed of non-conducting materials.*

Smeaton used wood-lined pistons and heads: we fear, however, that Smeaton's device cannot be made successful at modern temperatures and pressures.

A near approach to thermal neutrality might be had in a cylinder consisting of an inner tube of very thin steel and an outer casing of cast-iron, the space between the two being filled up with compressed paper or charcoal. The lids should be got up in the same way.† A patent was taken out for the above plan sixteen years after it was proposed in *The Engineer*. The inventor says :—" The internal surfaces are covered with a layer of non-conducting composition, such as a mixture of asbestos and cement; the wearing surfaces are covered with sheet steel."‡ Lead has often been proposed as a suitable material for covering the pistons and cylinder-covers. The conductivity of lead is but three-fourths that of cast-iron. Of course, a lead cylinder cannot be used because it is too soft. In order to use lead for the body of the cylinder, the working surface should be composed of a thin steel tube, placed in an outer casing of cast-iron, the space between being filled up with lead run in and compressed by hydraulic power. We believe that some experiments were made with an engine having the piston and lids covered with lead-plates, but some difficulty was experienced, owing to the relative expansions of the two metals being so different.

" There does not appear, however, to be any obstacle

* *The Engineer*, 3rd January 1873.

† *The Engineer*, 8th July 1870.

‡ Patent No. 15390, 25th November 1886.

in the way of using porcelain or slate for the intended purpose: plates of the material about an inch thick could easily be let into the cylinder lids and piston, and secured by cement in seats cast for the purpose in the metal. The experiment would be well worth trying. Any expedient, in short, which holds out fair promise of neutralizing the enormous condensing powers of the piston-face and cover would be worth testing. To the prevention of this condensation we can alone look for further progress in the direction of economy."*

At a meeting of the Institute of Mechanical Engineers, a paper was some time ago read on triple-expansion engines, when Professor Kennedy said:—"If slag-glass liners to the cylinders could be used, or if in some other way we could make them non-conducting, it would get rid of the present abomination of sending in 20 per cent. of the steam as water, or converting it into water as it entered the cylinder."

A few months ago M. Dwelshauvers Dery, Professor of Applied Mechanics at the University of Liège, published in the *Revue des Sciences pures et appliquées* a very interesting article on this subject, from which we quote. The writer refers to the question recently agitated by Mr. Thurston, the well-known American scientist.

"The improvement consists in clothing with an insulated heat-resisting covering, not the outside, but the inside of the cylinders—that is, the metallic surface which is brought into direct contact with the steam, in order to avoid the loss which is occasioned by the direct contact between the iron and the steam.

"The economic principle is as follows:—

"A steam-engine attains its maximum efficiency when the whole of the heat given out by the steam

* *The Engineer*, 1st April 1881.

to the metallic walls during its admission is returned by the walls during its expansion; in other words, when all the water arising from the condensation of steam during admission is re-vaporized during expansion, and the metal is dry on the inside from the commencement of the exhaust.

"To carry out this principle to the greatest satisfaction, the action of the walls is to be suppressed (taken off), or, what is more exact in practice, the condensation should be reduced as much as possible by making the cylinder of metal which is a bad conductor, and which presents but feeble heat capacity. But, as this metal does not exist, refuge must be found in a superficial covering, which shall possess these qualities and be durable likewise, and which shall cover the whole of the surface that is brought into contact with the steam.

"Mr. Thurston's proposed method of covering is as follows:—The surfaces to be covered are subjected for several days to the action of diluted nitric acid. Then a spongy substance is obtained, made probably by a mixture of carbon and silicate, and treated with insulating varnish. Layers of linseed oil, which adhere solidly and fill up the pores, are spread all over to complete the insulation. Experience has shown that the economy will be considerable, even with a coating far removed from the ideal. The supplementary heat lost in the metal by the initial condensation is diminished, and, at the same time, the useful return during the expansion is increased, while the saving in clear loss during exhaust is reduced.

"In 1866 Mr. Emery proposed porcelain. Mr. Babcock has tried bismuth and other metals. Mr. Thurston had his attention directed to the process he suggests by the examination of corrosion in condensers and air-pumps, which corrosions are due in great measure to the action of oily acids. Mr. Hill made an analysis, and sought to convert the spongy mass into an insulating substance. He has succeeded, aided by Mr. Chamberlain, who has applied to the task all the resources of experimental analysis, in order to give it a solid base.

"In conclusion, an engine using steam sufficiently superheated, with such a degree of expansion that the metal will be dry at the end of the stroke, and provided with an exterior protecting covering and with an interior insulating layer, as advocated by Mr. Thurston, will realise the most perfect type of steam-engine possible."*

We shall bring this part of the subject to a close by referring to a series of interesting experiments carried out by Mr. Emery with glass and iron cylinders.

Mr. Emery carried out 250 experiments, so that the results arrived at must be reliable. He says:—

"I constructed two cylinders of like dimensions, one of glass, the other of iron, in such a manner that either could be attached to a valve which regularly admitted steam from a boiler to the cylinder, and permitted its exhaust to enter into a condensing coil lying in a tub of water. The capacity of the two cylinders was made exactly the same, as shown by transferring water from one to the other. When put in turn in the condition of a steam-engine cylinder, the iron cylinder used (averaging the experiments) fully twice as much steam as the glass one, shown by the fact that twice the quantity of water came through the condensing coil for the same number of movements of the valve. Steam of same pressure was used in both cylinders, and the experiments were many times re-

* *The Mechanical World*, 15th April 1892.

peated, with the same results. The glass cylinder saved half the steam."

We think it is a great pity that some of the simple methods of coating the cylinder-lids and piston with non-conducting materials have not been thoroughly tried ; pottery, slate, or glass appear to be very suitable, because, in addition to their being bad conductors of heat, they are capable of presenting a smooth surface. It is a well-known fact that the cylinder-covers and piston-faces are invariably rough, and these rough castings just cooled by the exhaust steam form a perfect condenser: the rougher the surface the greater the condensation. If pottery ware cannot be tried, there is no valid reason why smooth steel-plates should not be secured to the lids and piston with a thickness of slag-wool, or some other non-conductor between the steel plates and the castings.

5. Polished piston and cylinder-covers.—A most useful and interesting paper was recently read by Mr. Croll before the Institute of Naval Architects, in which some simple methods for preventing initial condensation in triple-expansion engines are recorded; and as this is so closely connected with this part of our subject, we shall devote some space to Mr. Croll's sensible suggestions. He says :—" Supposing a piston to begin its stroke with a temperature lower than the steam entering, it is evident that the steam will first heat both the piston and cover faces, and, in doing so, deposits a film of water upon them. After the steam is cut off and the pressure lowered, the deposited water will partly become steam again; but then the exhaust is opened and the pressure still further lowered: the remainder will evaporate much more rapidly, and, in doing so, cool the piston cover and cylinder walls, so that with the following stroke the cycle is again repeated.* In a low-pressure cylinder of a modern marine engine, when the diameter is one and a half times the stroke, we find the exposed surface of piston and cover is 50 per cent. greater than that of the working surfaces of the barrel, and it is to the former that I wish to direct your attention. The greater the re-evaporative power of the material in contact with the steam the greater will be the cooling of the surfaces, and the greater the initial condensation; the re-evaporative power of a body is increased by an increase of surface: a fairly smooth surface may, nevertheless, have a much greater area exposed than the geometrical plane which it is taken to represent. The total condensation in a steam-engine is a question of very thin films of water, and the structure of the surfaces exposed to the steam merits our closest attention."

As far as can be seen from Mr. Croll's experiments, a polished surface is far superior to that of ordinary cast-iron as it comes from the mould, and a rough steel casting is about the worst material that could be chosen; it appears therefore advisable to carefully turn and polish, as far as possible, all the parts of the steam cylinder which come in contact with steam performing work. Mr. Croll's paper concludes as under:—

"1. I made a disconnecting paddle-engine, in which each wheel could be driven by a perfectly independent compound engine; in the starboard engine all the parts were turned and polished; in the port engine all the parts exposed to the steam were left rough. The port engine was troubled with water; the starboard engine was apparently dry.

* The laws of condensation and evaporation are so clearly stated that we insert them here in connection with the remedy.

"2. In my experience, excessive condensation has always occurred in connection with rough steel pistons and covers; in one case this was so marked that the top of the piston would not give a card at all, which I attributed to the cover being of rough cast-steel and combining with the top of the piston to absorb the heat of the steam.

"3. Torpedo boat engines that have turned and polished pistons, and, in some cases, polished covers, are quite remarkable for the economy of steam at nearly all powers; and, at all events, are very free from water in the cylinders.

"4. The highest results known to me are obtained by the land engines made by Messrs. Sulzer: the piston and covers are turned, the consumption of steam, 11·73 lbs. per indicated horse-power per hour, has been obtained in the vertical triple-expansion engines. If we wish to make machinery which will give the highest results in economy, we must turn and polish the surfaces of the piston and covers, or seek a method of coating them over with a metallic layer which will diminish their tendency to absorb and reject heat."

Several other means have been proposed and tried for diminishing the liquefaction of steam in unjacketed cylinders beside the five plans we have adverted to.

It may be useful if we refer to these, and afterwards pass on to deal with the steam-jacket, the only successful means at present devised for reducing internal condensation in steam-engine cylinders.

Many patents have been taken out for circulating heated oils and other substances that melt without being converted into vapour round the working barrel of the cylinder.

It has been suggested to prevent cylinder condensation by the use of air expanded by heat combined with the working steam. Steam is condensed and loses its pressure with frightful rapidity when in contact with a cold surface; whereas air under the same circumstances parts with its heat with extreme sluggishness as compared with steam. There are many difficulties to be surmounted before engines using heated air or air combined with steam can successfully compete with the steam-engine. At the present time very little is heard of some of the schemes for using air and steam combined that were to the front a few years ago. Some time since, a piston was introduced by Mr. T. Sturgeon. The object in view was to jacket the piston and also use it as a heater to raise the temperature of the cylinder: the steam was admitted into the piston through holes in the top and drained by means of cocks. This body of live steam, carried along between the walls of the piston, and in direct contact with the inner surface of the cylinder, would, it was urged by the inventor, heat the cylinder far more effectively than the external jacket could do, and would also present a hot surface of the piston to the steam, while the exhaust was not interfered with or acted upon by the hot steam except the part immediately in front of the piston. In compound engines it is recommended that, in addition to the jacketed pistons, an external steam-jacket should be applied to the high-pressure cylinder.

The losses arising from initial condensation may be reduced by compression. The closing of the exhaust port before the end of the stroke, and the consequent compression of the steam then remaining in the cylinder, has a useful effect on the working of an engine by providing an elastic cushion at the end of

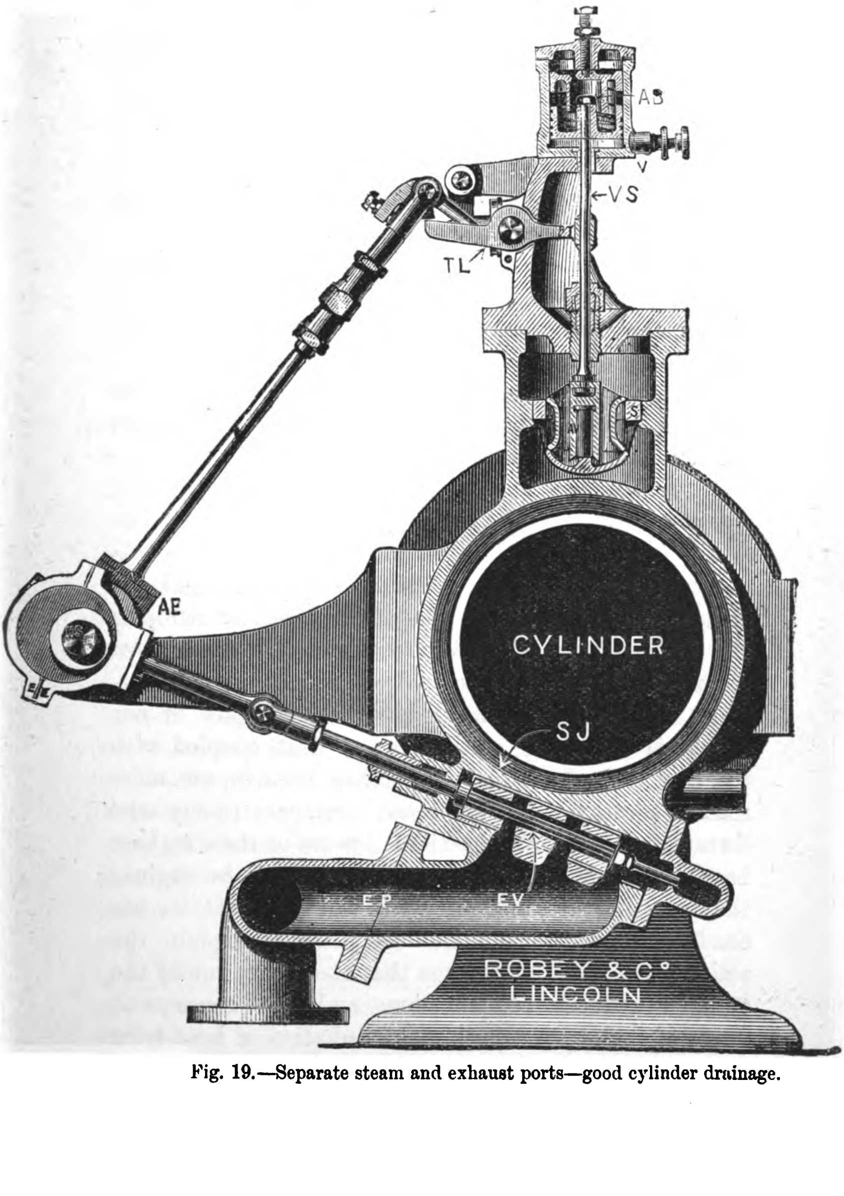


Fig. 19.—Separate steam and exhaust ports—good cylinder drainage.

the stroke, which secures smooth running at high speeds. "In quick-speed engines the imprisoned steam may advantageously be compressed up to the initial pressure."* Experiments have been made, and the results have shown a gain in economy by increasing the compression which has the effect of heating the cylinder-cover and piston, and preventing condensation of steam on admission.

It has been said that the jackets around the body of the cylinder are of no use without compression, and the greater the compression the greater the economy secured by the employment of steam-jackets.

A high piston speed has the effect of reducing the cylinder condensation by lessening the time allowed for the transfer of heat.

The Steam-Jacket.

6. Steam-Jackets.—The last method, and the most successful means at present employed for reducing the condensation of steam within the cylinders of steam-engines, must now be dealt with.

It is somewhat remarkable that, in spite of our increased knowledge of the laws of heat, coupled with the fact that the steam-jacket has been in use more than a century, there are many engineers to-day who do not understand its function. Some of these makers have applied the steam-jacket for years on the engines they manufacture, and they will tell you that its use conduces to economy. But ask them to explain the action: they will inform you that the jacket round the cylinder reduces condensation, and the consequent waste of fuel, by preventing the radiation of heat from the working steam. These people "share in the

* *The Theory and Action of the Steam-Engine*, Northcott.

mistake of the greatest writer that probably we have ever had upon the steam-engine (we allude to Tredgold), who, clear as he was in almost every point connected with that subject, was, in respect of this particular of steam-jacketing, in error, and was led from that error to condemn Watt's practice of the steam-jacket as a mistake. For Tredgold, not appreciating the theory of the steam-jacket, held that it was a mere contrivance for keeping the cylinder warm; and that, although it did this, it did it by the waste of more steam than would have been wasted in the unjacketed cylinders; the excess being (in Tredgold's judgment) that due to the extra size of the jacket over and above that of the cylinder which it enveloped."* It is owing to this incorrect notion of the theory of the jacket being abroad that some engineers (who do not jacket their cylinders) give as their reason the hackneyed phrase—that the loss from radiation may just as well come from the steam in the cylinder as from the steam in the jacket; whereas, the loss in unjacketed cylinders arising from condensation is not measured by the radiation at all, but is a much greater loss, as we have already explained in the previous chapters.†

The true function of the steam-jacket appears to be :—

(1) To keep the cylinder barrel and covers hot, so as to prevent the alternate heating and cooling of the metal of the cylinder. The steam enters a cylinder

* Report on the Trials of Traction Engines at Wolverhampton, by Sir F. J. Bramwell and James Easton.

† Some little time ago a well-known engine-maker was asked if the cylinder of a steam-engine we were looking at was steam-jacketed. He, placing his hand on the cylinder lagging of the working engine, said: "There is no need for a steam-jacket as the loss of heat is very slight."

as hot as itself: there is then no initial condensation.

(2) To prevent the liquefaction of steam within the cylinder, resulting from the performance of work, this condensation is transferred to the steam in the jacket where the presence of hot water produces no bad effect, but is returned to the boiler.

(3) To prevent the loss of heat during the exhaust, the cylinder liner being hot and dry, very little heat is transmitted to the atmosphere or to the condenser, as fully explained later on.

The steam-jacket conduces to economy by permitting higher grades of expansion to be used with economy. We have already shown that the greater the range of expansion the greater the loss without the steam-jacket.

Let us now more fully, and as clearly as possible, explain the action of the steam-jacket. By its means the cylinder is constantly kept at the same temperature as the steam within the boiler: the sides and ends of the cylinder being hot and dry, no steam will be condensed during the admission; therefore the initial pressure will, as nearly as possible, coincide with the full boiler pressure. No steam having been condensed during admission, it follows that no water will have to be evaporated arising from this cause; hence the enormous loss of heat produced by this boiling process will be entirely prevented. During expansion, the sides of the cylinder being hotter than the working steam, the latter is slightly superheated; hence no condensation can take place within the cylinder during expansion. Again, the sides of the cylinder being hot and dry, it follows that very little heat will be lost during the exhaust, because it is a well-known fact that dry cast-iron parts with its heat very slowly, compared with the same surface covered with damp steam, and what little heat is transmitted from the metal during this exposure to the atmosphere or condenser, as the case may be, is quickly repaid by the jacket causing a slight condensation in the steam-jacket. Mr. Northcott says:—" Heat passes from the jacket to the expanding steam, sufficient in many cases to keep the steam in the saturated state throughout the stroke."

To prevent the liquefaction of any steam within the cylinder resulting from the performance of work, we must impart as much heat to the steam as it loses in performing its task; and this is precisely what the jacket does. The whole theory of its action may be summed up in the following words, quoted from *The Engineer*:—" All the liquefaction due to the performance of work by the steam within the cylinder is transferred to the steam within the jacket. The water resulting from this liquefaction is restored to the boiler, where it is re-evaporated, and flows to the cylinder to do more work; whereas, if the liquefaction had taken place within the cylinder, the resulting water would have been re-evaporated there instead of within the boiler, and the resulting steam, although obtained at just the same expenditure of power, would, instead of doing work on the piston, do it in heating the condensing water. It thus appears that, in a properly jacketed engine, *the true seat of the entire energy of the engine is in the jacket, and not in the cylinder;* and, startling as the statement may appear at first sight, it is none the less virtually true, that it is *in the jacket, and not in the cylinder, that all the work of the steam is performed.* It follows, as a consequence, that the condensation which takes place in the jacket does not in any way represent loss of fuel, except in so far as that condensation is a result of radiation and conduction through the sides of the cylinder to the condenser during the time the exhaust port is open, and of radiation to the external atmosphere."*

But we have shown that the loss from radiation from the outside of the cylinder may be entirely prevented by proper clothing, and that very little heat will be wasted by conduction from the jacket to the atmosphere or the condenser during the exhaust, seeing that the sides of the cylinder will always be dry. We may, therefore, safely infer that most of the condensed steam collected from a properly-applied, perfectly-clothed, and well-drained steam-jacket will be the result of work condensation. We are sorry to confess, however, in every-day practice, there are few cylinders arranged so as to reap the full benefits of thorough steam-jacketing. In another part of the book we have named some of the requirements for obtaining the best results. But, in passing, we may point out some of the causes of the enormous losses that take place in so-called jacketed cylinders. In such engines it is impossible for the steam-jacket to effect the saving in steam that we have assumed should be saved.

"In most cases met with in practice, the barrels only of engine cylinders are jacketed; but, at the moment of admission, or even at the point of cut-off with high rates of expansion, a very small proportionate part of the hot jacket is exposed to the steam,"† and it is impossible for such a jacket to prevent the initial condensation of the steam. In many engines tested, this and other evils are allowed to pass, account-

* *The Engineer*, 17th November 1871.

† *The Theory and Action of the Steam-Engine*, Northcott.

ing for the enormous amount of condensation frequently met with. We have heard of some experiments with triple-expansion engines where the losses from internal condensation amounted to 25 to 30 per cent.* There are other engines of the same type so well cared for by the designer that the loss from condensation only amounted to 5 to 6 per cent.

To prevent the losses named above, the cylinder liners should be thoroughly enveloped in a large body of steam (see fig. 50).

The steam ports should be short and heated: better still if separate steam and exhaust ports are provided. The clearance should be reduced to the utmost limit. The covers and pistons must be smooth, and carried out in accordance with Mr. Croll's directions.

In short-stroke engines of large diameter the pistons must be heated.

The working steam should be perfectly dry. A good separator should be applied to remove all water from the working steam. The presence of water in any quantity in steam appears to take all the life out of it.

"The admission of wet steam into a steam-jacketed cylinder is also productive of great loss, owing to the evaporation of the contained water during the stroke by heat abstracted from the jacket."†

In many cases the jackets may be supplied with steam of a higher pressure than the steam employed in the cylinder. It has been proved by practical experience that the greatest attainable economy has been secured by this arrangement of steam-jacketing.

It must be clearly understood that it is only by

* In Chapter III. larger losses are referred to.

† *The Theory and Action of the Steam-Engine*, Northcott.

thorough steam-jacketing that the beneficial results we have stated can be realised. If the rules we have laid down in other parts of the work were carefully observed, the steam-jackets would in every case yield an ample amount of economy of steam to well repay for the trouble taken. Perhaps we have had, thus far, too much theorising respecting the steam-jacket. Our only course to get at the real value of jacketing is by means of reliable tests. Surely the accurate trials, carried out under the direction of the Institute of Mechanical Engineers, should be sufficient to convince every one of the economical value of the steam-jacket. The most economical engines are always provided with real steam-jackets. Sulzer's vertical triple-expansion engine is an example, as given further on in this chapter. In 1890 Professor Unwin said: "that a steam jacket was always, in every case, useful. He had taken the trouble to go through fifty experiments of a parallel character, with and without the jackets, and in only one case did he find that there was not a very distinct economy gained by the use of the jacket, and that he attributed rather to an experimental error." *

Mr. Cowper says:—"A little experiment, which I made many years ago, gave a very palpable demonstration of the action of the steam in a cylinder which was not steam-jacketed.

"A glass tube, closed at the outer end, was fixed to a cylinder, so as to form part of it. At the commencement of each stroke the incoming steam condensed upon the interior surface of the glass tube, forming a dew or film of moisture, visible from the

* Lecture on the Objects and Methods of Steam-Engine Trials, delivered before the London Association of Foreman Engineers, March 1890.

outside, which remained throughout the first part of the stroke ; during the latter part of the stroke, when the steam had been cut off and was expanding, and consequently falling in temperature, the dew disappeared by re-evaporation.

" The glass was then heated from the outside by means of hot coals, and, as long as the external heat was maintained, no condensation took place. Thus the walls of an unjacketed cylinder being at an intermediate temperature between that of the incoming steam and that of the exhaust, condense a portion of the steam whilst the latter is at its full pressure, sacrificing the power which should have been given by the steam so condensed; and when the re-evaporation from the surface takes place, through the natural reduction of temperature of the expanding steam *below* that of the walls, the piston is approaching the end of the stroke. In the case of a steam-jacketed cylinder, not only is radiation from the outer surface of the walls prevented, but heat is continually supplied at the full temperature to the outer surface, to be conveyed by conduction through the metal to the inner surface. The walls thus heated from the outside cause no condensation of the incoming steam; and, whilst the steam is expanding, its pressure is kept up somewhat above the natural curve by the slight superheating and drying action of the hot walls."*

" We know now that we cannot work with the expansive engines to any good purpose without a steam-jacket."†

The effect of the steam-jacket on the indicator diagram is very manifest. Fig. 20 represents a beautiful card taken from a steam-jacketed Corliss

* *The Steam-Engine*, by the late E. A. Cowper, Esq., 1884.

† Sir F. J. Bramwell, Bart.

engine: the initial pressure shown on the diagram is within half a pound of the boiler pressure; the cut-off is one-thirteenth of the stroke. This diagram shows a perfection of valve arrangement, valve setting, and general efficiency, which it would be difficult to equal.* The expansion curve coincides very nearly with the theoretical curve: this being so, the diagram shows little evidence of internal condensation: this result is brought about by the cylinder ends and body being thoroughly enveloped in steam of the full boiler pressure. We may point out also that the boilers supplying the engine are noted for producing dry steam.

Fig. 21 shows a pair of figures from a Woolf beam rotative pumping-engine, during a trial conducted by Mr. John Taylor, M.Inst.C.E.; the cylinders were steam-jacketed, and the steam-main thoroughly drained.

Fig. 22 shows a pair of figures from the same engines, on another trial, when the jackets were shut off, and the steam-main not thoroughly drained. The indicated horse-power

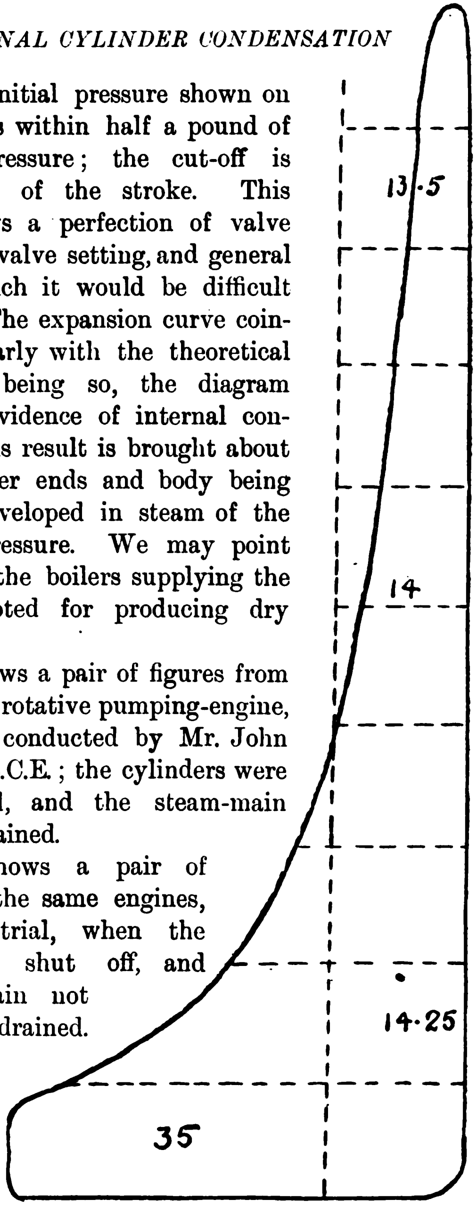


Fig. 20.

* *The Engineer's Practical Guide*, J. Hopkinson.

shown in the two cases is almost identical, and the initial pressure of steam nearly the same; but the great loss, arising chiefly from the want of steam-jackets, is shown by the smaller rate of expansion in the second case, viz., 9·3, as compared with 15·76 times.*

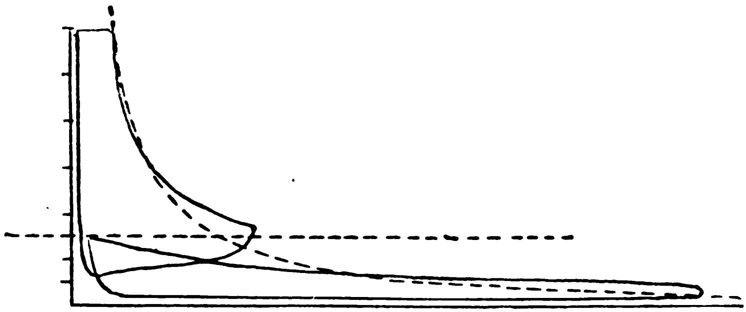


Fig. 21.

Fig. 23 shows a Rankinised diagram taken from a large side-by-side compound engine. The steam passes from the high-pressure cylinder through a steam-jacketed receiver: both cylinders are steam-jacketed.

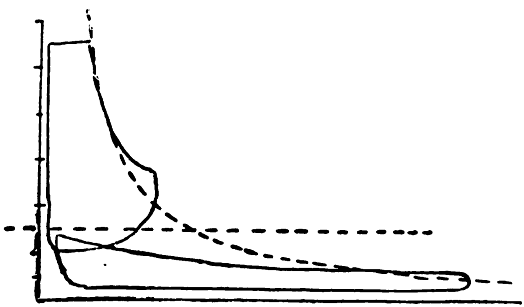


Fig. 22.

It will be seen that the shaded portion, representing the loss of power as against the theoretically attain-

* *The Steam-Engine*, by the late E. A. Cowper: a lecture delivered at the Inst. of Civil Engineers in 1884.

able maximum, is unusually small, showing that a very high efficiency has been attained.* We now must refer to an interesting trial, carried out by Professor Goodman and Mr. W. Hartnell, of a triple-expansion engine, made by Messrs. J. & H. M'Laren, Leeds.

Fig. 24 shows the combination of three cards and their relation to the theoretical curve, which is shown by the dotted curved line. The high-pressure clear-

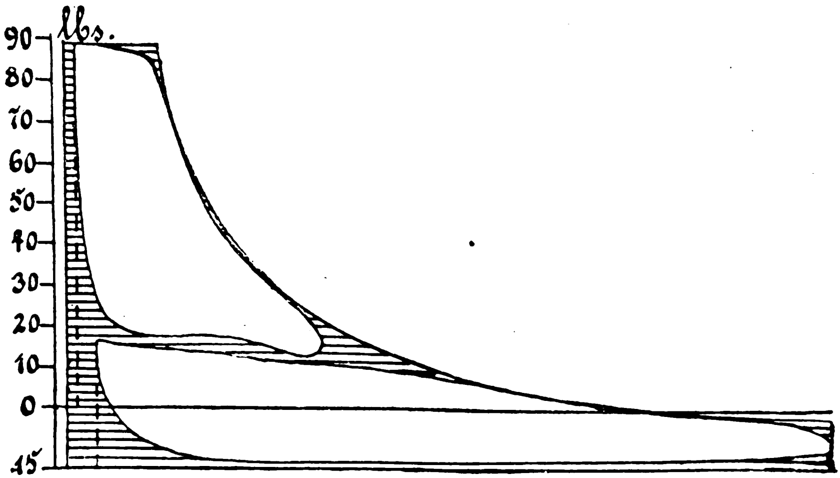


Fig. 23.

ance is shown at A, the intermediate-pressure clearance at B, and the low-pressure clearance at C.

The results obtained are so good that we give some of the figures.

The engines were of the vertical inverted cylinder pattern, marine style, surface-condensing, with cylinders 9 inches, 14¼ inches, and 22½ inches diameter by 2 feet stroke, working down on a three-

* *The Mechanical World*, 9th March 1889.

throw crank set at angles of 120 degrees. The high-pressure and intermediate cylinders are jacketed with live steam supplied direct from the main steam-

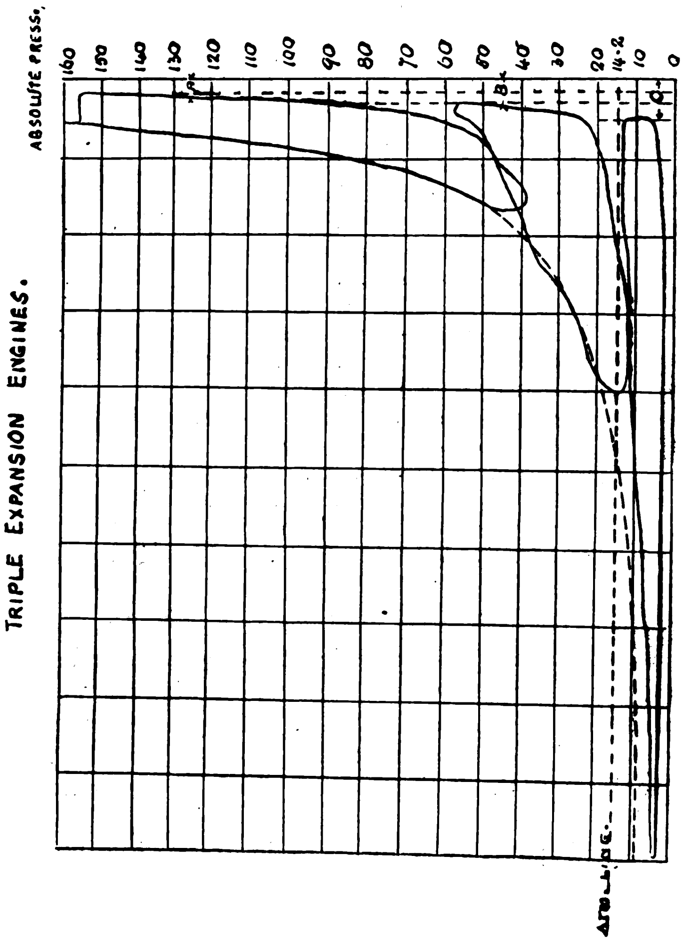


Fig. 24.

pipe. The condensed water from the jackets is allowed to escape through efficient patent steam-traps.

TABLE VI.—*Trial of a Triple Expansion Engine, made by Messrs. J. & H. M'Laren.*

Duration of trial, . . .	4·1 hours
Indicated horse-power, . .	121·85 I.H.P.
Brake horse-power, . .	106·9
Steam press in boiler absolute, .	171·2 lbs. per sq. in.
Vacuum in condenser, . .	28 inches.
Feed-water used per indicated horse-power per hour, including jackets, . . .	13·6 lbs.
Feed-water used per brake horse-power per hour, . .	15·5 lbs.
Steam used in jackets per indicated horse-power per hour, ...	1·24 lbs.
Coal burnt per indicated horse-power per hour, . . .	1·35 lbs.
Water evaporated per lb. of coal from a mean temp. of 110° F., . . .	10·11 lbs.
Water evaporated per lb. of coal from and at 212° F., .	11·34 lbs.

Indicator gear was fixed on each cylinder, but, instead of one indicator being fixed at each end of each cylinder, only three instruments in all were used, viz., one on each cylinder. T pipes were used, one branch being carried to the top and the other to the bottom, the indicator being fixed in the centre. This was very unfortunate, as a considerable loss of indicated power was thus sustained. It has been found by actual experiment that this arrangement may involve a loss of as much as 8 per cent., as compared with having the indicators close up to their work at each end of the cylinder. The boilers are of the multitubular type. The whole was covered in to prevent, as far as possible, any loss of heat by radiation. As the results obtained in previous trials with the same engine were so exceptionally good, it was determined to ask Professor Goodman of the Yorkshire College, and Mr. Wilson Hartnell of Leeds, to run an independent test, so that the figures published might be accepted as above suspicion.

Referring once more to the diagrams (fig. 24), the influence of the jacket is shown very clearly in this diagram, for, while the actual line almost coincides with the theoretical line in the case of the jacketed cylinders, it falls considerably short of it in the case of the low-pressure cylinder, which was not jacketed at all.*

We now refer to some trials of a triple-expansion condensing mill engine of the inverted type, made by Messrs. Sulzer Bros. of Winterthur. We cannot do better than quote some particulars of the tests from *The Mechanical World* for 27th April 1894. This engine is a *thoroughly steam-jacketed engine,* having, in addition to other refinements for economising steam, the piston and cylinder covers turned and polished, as cited by Mr. Croll in previous pages of this chapter.

"The exceptionally high economy of this engine will doubtless lead some of our engine-builders to dispute the accuracy of the trials included in the description; but, before doing so, it may be well that they should know that the trials referred to were not made by the engine-builders, but on behalf of the owners, who naturally desired independent evidence that the conditions of the contract had been fulfilled. Further, the engine was tested under practically every-day

* "The Economical Use of Steam in Colliery Engines," a paper read before the Federated Inst. of Mining Engineers by Mr. John M'Laren, 28th May 1891.

conditions of work, and after it had been running for some considerable time. The results obtained are, as far as we are aware, the best yet placed to the credit of any mill engine; but, if certain theories are correct, we ought to be able to improve upon this performance by adopting the Corliss cylinder—with sensibly less clearance spaces than is possible with double-beat valves." *

This engine has, in spite of the double-beat valves, with the increased clearance and a moderate steam pressure, achieved results which out-distance any trustworthy records of the best horizontal Corliss mill engines yet published. No steam separators were used, but we should imagine that the steam must have been dry. "The mechanical efficiency of large compound-condensing and triple-expansion engines is seldom more than 85 or 88 per cent., but in this case an efficiency of 92·45 is obtained." †

"According to the contract, the engine was not to require more than 12·125 lbs. of steam per indicated horse-power per hour when developing 1100 indicated horse-power, it being understood that the water condensed in the steam-pipes was to be deducted, but not the water condensed in the jackets.

"From the above trials it is seen that, with the engine loaded to 1228·51 indicated horse-power (nearly the maximum load), the steam used per hour is only 11·94 lbs. With the engine loaded 1138·7 and 1163·7, or a mean of 1151, and nearer to the normal power, the mean steam consumption is 11·74 lbs.

"The feed-water was measured in standard barrels and fed to the boilers by a separate steam-pump. The economiser was disconnected during the trials. The steam pressure during the trials was almost

* *The Mechanical World*, 27th April 1894. † *Ibid.*

uniformly 151 lbs. per square inch, and the initial pressure in the high-pressure cylinder 147 to 150 lbs., so that the loss of pressure is very small. The mechanical efficiency of the engine was 92·45 per cent., the makers guaranteeing 92 per cent. Steam is furnished by three Babcock and Wilcox water-tube boilers.

" In December 1893, a set of three trials were made to determine the economy of the engine. The following is an abstract of the report :—

TABLE VII.

DATE OF TRIAL.	Dec. 2.	Dec. 5.	Dec. 6.
Duration of trial—hours,	4·7	5·15	5·033
Mean number of revolutions per minute,	76·31	75·9	76·0
Mean pressure in high-pressure cylinder—lb. per sq. inch,	48·48	47·309	46·57
Mean pressure in intermediate cylinder,	14·84	13·48	14·12
Mean pressure in low-pressure cylinder,	9·37	8·48	8·82
Indicated horse-power—high-pressure cylinder,	450·11	436·88	430·63
Indicated horse-power—intermediate cylinder,	320·36	289·48	303·74
Indicated horse-power—low-pressure cylinder,	458·04	412·34	429·34
Total indicated horse-power of engine,	1228·51	1138·70	1163·71
Feed-water consumed—total lb.,	69,445·5	69,445·5	69,445·5
Condensed water from steam pipe,	573·1	623·9	610·6
Total net steam consumption,	68,872·4	68,821·6	68,834·9
Steam consumption per hour,	14,654·1	13,363·2	13,676·3
Steam consumption per indicated horse-power per hour,	11·94	11·735	11·75

"To compare these results with the best results obtained here, some allowance has to be made for the slightly different values of the horse-power in the two countries. But, even with this deduction, the steam consumption is only 11·9 lbs. per indicated horse-power per hour—probably the best result yet obtained from a mill engine."*

It is very evident that these excellent results were due to the following, among other reasons :—

(1) All *three* cylinders were thoroughly enveloped in high-pressure steam, the barrels and ends are well steam-jacketed and lagged. (2) The steam-jackets and cylinders are well drained. (3) The inside of the cylinder-lids and both faces of the pistons are smooth, as already noted. (4) The admission of steam into the cylinder is regulated automatically by an excellent governor arrangement and valve gear, which varies the cut-off to suit the load. (5) The lubrication of the cylinders and all the working parts has been most efficiently carried out. (6) General excellence of the design ; and (7), The steam used was undoubtedly dry.

Messrs. Sulzer Bros. have long been known as builders of high-class economical engines, and the table and particulars which we have been enabled to place before our readers are well calculated to sustain the high reputation which they so deservedly enjoy.

In a valuable paper on "The most Economical Temperature for Steam-Engine Cylinders," by Mr. Bryan Donkin, the following remarks occur, which are well worthy of careful note :—

"If engineers and others using steam-engines wish to work economically and with smaller boilers, they must arrange to keep their cylinders and covers as

* *The Mechanical World*, 27th April 1894.

hot as the entering steam; otherwise the cylinder becomes unintentionally an efficient condenser, with a large area of cooling surface. Properly applied, steam-jackets are economical, because they raise the temperature of the walls touched by the steam. Those who cannot steam-jacket the whole cylinder should at least jacket the two covers, which are the most important surfaces. Well-arranged jackets, with properly sized pipes for entering steam and exit water, without places for air to collect, are an excellent investment, and pay a good interest on the small additional cost."

CHAPTER V.

The Abuse of the Steam-Jacket.

Faulty Designing.

> "The steam-jacket to a cylinder is a static economiser. It has no working parts, does not move, and, if properly made at first, will never cost one farthing for repairs or renewal."—*The Engineer.*

The steam-jacket, when properly designed and applied, is of undoubted benefit in promoting the economy of steam. Yet, owing to various causes which we shall presently name, it is in a great many cases rendered not only ineffective but positively detrimental.

Mr. Northcott says:—"The steam-jacket may be quite ineffectual or somewhat worse than ineffectual, if without the means of removing air and water from it."

Mr. Holmes says:—"Many cases have occurred in practical experience in which jacketing has been carried out so as to be positively injurious instead of beneficial." It will serve no good purpose to close our eyes to the fact that there must be many engineers at the present time who entertain mistaken notions respecting the function of the steam-jacket, to account for the number of modern steam-engines now being turned out from English, American, and Continental works, fitted with jackets, which, to say the least, are of doubtful advantage, owing to faulty designing. Some engineers who entertain very hazy notions on this subject have not been backward in airing their theories on steam-jacketing in their steam-engine catalogues. While engine-builders display a lack of knowledge on this subject, it is not surprising that steam-users and engine-drivers either hold curious notions or are totally uninformed on the subject. This may be in some measure accounted for by the paucity of the literature devoted to the consideration of steam-jacketing; and scarcely any reference had been made to the maltreatment of the steam-jacket previous to the publication of the author's little book on the subject.* We believe the want of information of a practical type is one of the chief causes of this endless contention respecting the utility of the steam-jacket. There are, however, some indications that more interest is being taken in the practical part of the subject. So we may reasonably hope that, before long, it will receive all the attention from the hands of steam-engine makers which it really deserves. In the meantime, however, the economising influence of the steam-jacket is, in numerous instances, counteracted, if not totally destroyed, arising from :—

1. **Faulty designing.**
2. **Defective construction.**
3. **Inattention on the part of the engine-driver.**

The steam-jacket constitutes a very important and valuable detail of the steam-engine: yet, in its design

* *The Abuse of the Steam-Jacket Practically Considered, &c.* London: E. & F. N. Spon, 125 Strand. 1878.

and construction, it has not received a tithe of the attention that other parts of equal, or less importance, have; consequently, it is, in far too many instances, little better than a sham, and serves to exhibit the carelessness or ignorance of the designer. Now, a defect in the design of any other part of an engine would very likely be quickly detected, or it may by its imperfect action cripple the engine; but a badly designed steam-jacket may work untold mischief undiscovered for years. It may be that the drainage is faulty, and the jacket is acting as a surface condenser; thereby aggravating to an alarming extent the very evil it was intended to diminish. When we remember the numerous abortive steam-jackets that have come under our notice during the last few years, we are at no loss to account for the opinions of engineers, respecting the utility of the jacket, being so diametrically opposed. Many of the people who denounce the steam-jacket are those who, being ignorant of its function, are unable to design it properly, and they have evidently tested engines which have had so-called *steam*-jackets applied, that were in reality *water*-jackets, acting as small condensers, or otherwise; and the unsatisfactory results obtained have not, of course, influenced them to alter their creed.

It is somewhat surprising that there should be any designers left who do not understand the requirements of efficient steam-jacketing. Yet it is not an unusual occurrence to meet with engineers who understand everything connected with the steam-engine except the jacket round the cylinder, and this simple device is to them shrouded in mystery: the moment they attempt to explain its function they become hopelessly entangled.

The notion these people evidently cherish concerning the steam-jacket is, that it is simply a ring round or partly round the cylinder into which the steam is conveyed: it being quite immaterial whereabouts in this ring the steam is taken in, or from whence it is drawn. The Editor of *Engineering* some time ago very wisely remarked:—"That to secure the advantages of steam-jacketing, it is not sufficient to merely place around the cylinder a casing that *may* contain steam; care must be taken that this jacket always *does* contain steam."

"Few but those who have actually tried it, fully appreciate how soon a jacket may be rendered ineffective by the accumulation of air or water."

No one who has given the slightest attention to this subject, can have failed to notice that, notwithstanding the many cylinders which are said to be jacketed, very few are really *steam*-jacketed, thoroughly and efficiently.

Mr. M. D. Stapfer, in a paper on Steam-Jackets, read before the Scientific Industrial Society of Marseilles, says:—That there are "few engines which have not their jackets partly obstructed." Practical experience confirms the truth of this statement, as will be gathered from the instances of careless jacketing which have come under our notice, now to be recorded. These examples of miserable designing have mostly been discovered in the repairing shop: no more favourable opportunity can be secured for detecting the weak points in the design and construction of engines than while they are undergoing repairs.

We will now show, by the aid of illustrations, how the steam-jacket may be rendered of no service through careless designing.

Our mode of procedure will be to state some of the necessary requirements of efficient steam-jacketing, and test our cylinder sections by these principles, so as to ascertain whether the steam-jackets are properly designed or not.

1. *The steam-jacket should completely encircle the cylinder from end to end.*—We have several cylinders

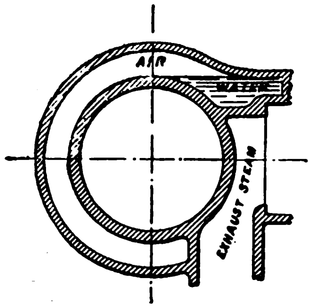


Fig. 25.—Faulty design.

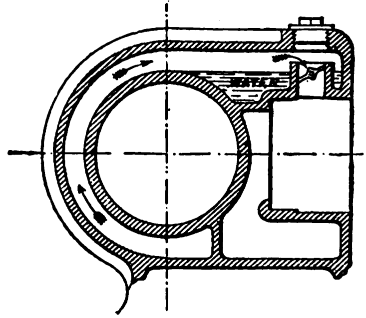


Fig. 26.—Faulty design.

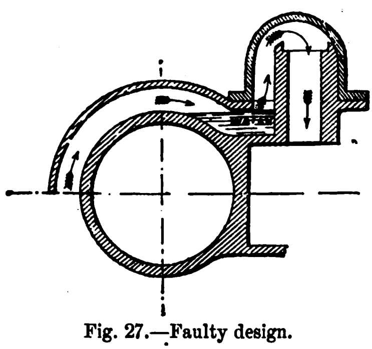


Fig. 27.—Faulty design.

illustrated, in which the steam-jacket is only taken partly round the cylinder: in some cases only two-thirds round it. Figs. 25, 26, 27 and 47 show examples of this fault, which generally occur in those instances where the cylinder and the jackets are combined in one casting. In cylinders that have the liners cast separately and afterwards inserted into the casing or jacket, this point is fully and invariably carried out, as will readily be understood by referring to figs. 30, 31, and 36.

2. *The exhaust-chamber should present as small an area of surface to jacket steam as possible, and in no case should the exhaust steam be made to travel partly round the cylinder, either in contact with the steam in the jacket,*

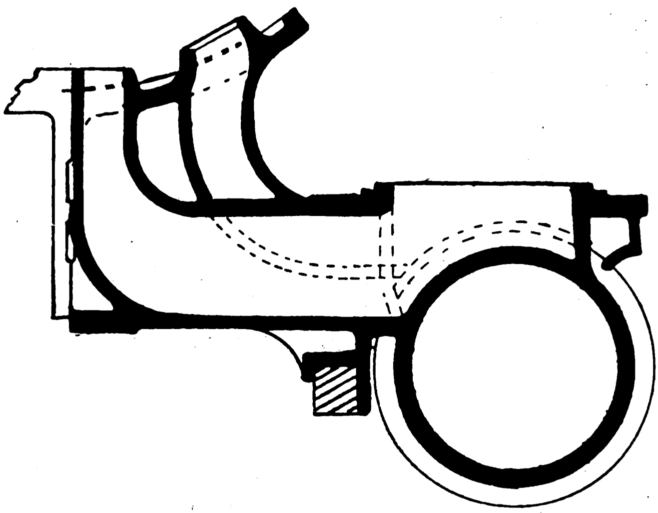


Fig. 28.

or the working body of the cylinder.—More steam is dissipated by large exhaust-passages than some would suppose: the steam in the cylinder or in the jacket is cooled at every stroke of the engine, and thus counteracts to a great extent the good effects of the jackets. At one time it was a very usual thing to jacket cylinders with exhaust steam. Some eminent engineers have carried this fallacious idea into practice. Surely these persons have not imagined that the damp and cool exhaust steam (which possesses a notorious propensity for absorbing heat) would impart warmth through the cylinder sides to steam of a much higher temperature within the cylinder. In order to show the hazy notions entertained about steam-jacketing, we are tempted to refer to a little episode which happened a few years ago between two rival steam-engine makers. One firm was in possession of a patent for a steam-jacketed cylinder for traction engines, in which the steam in its passage to the working cylinder was made to traverse round the jacket-casing (by the way, however, not a desirable plan, in spite of its being a patent). Six years afterwards, another firm made a steam-jacketed cylinder, but, instead of the steam from the boiler being carried round the working barrel, the *exhaust steam* was led into the jacket-casing previous to its exit into the chimney. At first sight the sectional drawings of the two cylinders appear to be alike, but they are totally opposite in reality. The curious part is, however, that the last-named exhaust-jacketed cylinder was considered by the former firm to be an infringement of their patent, showing that the persons who possessed the steam-jacket had little knowledge of the subject, or they would have repudiated the notion of considering such an abortion as an exhaust-jacket to be an infringement of their rights.

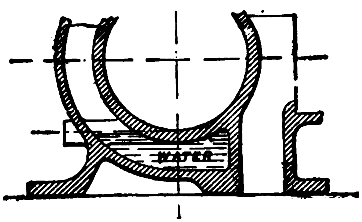


Fig. 29.—Steam-jacket badly drained.

Headley's celebrated Puffing Billy of 1813, had its cylinders provided with sham jackets; but it appears somewhat curious that the next case, and the only case of jacketed cylinders for locomotives (save in the compounded ones of recent date), should also turn out to be a similar counterfeit. We now refer to Beattie's patent improvements in locomotive cylinders, introduced in 1858, which were nothing more than exhaust-jackets. Cylinders intentionally provided with a jacket to be supplied with steam from the exhaust may, now-a-days, be rare; still, there are many cylinders, if not inten-

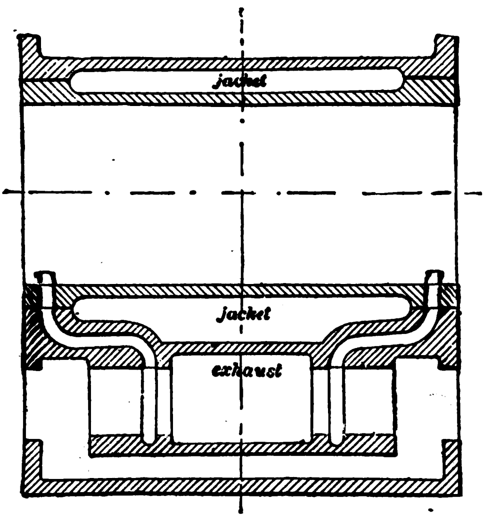


Fig. 30.—American portable engine cylinder.

tionally exhaust-jacketed, yet a large proportion of their surface is accidentally exposed to the action of the exhaust steam.

Non-jacketed cylinders have generally a large portion of their outside surface exposed to the exhaust steam. The metal of the cylinder being a good conductor, much of the working steam inside is robbed of its heat and wasted in continually warming up this metal, to be constantly cooled on the outside by the action of the damp spent steam and the atmosphere. Much heat is dissipated in this process, and more or less condensation within the cylinder is the result.

When cylinders are steam-jacketed, this surface in contact with the exhaust draws a large amount of heat from the steam in the jacket. To prevent this waste the exhaust should be made to pass quickly away from the cylinder by as direct and short a course

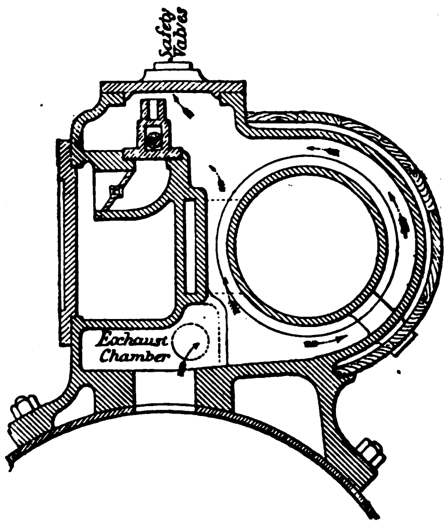


Fig. 31.—Traction engine cylinder.

as practicable, allowing the smallest possible surface of the cylinder to be touched by it in its passage to the atmosphere. Figs. 25, 26, 29 and 30 show a large portion of the working barrel exposed to the exhaust steam.

Fig. 28 shows an American locomotive cylinder, the working steam in which is uselessly spending heat in drying the exhaust: this is a serious drawback in many of the outside cylinders as arranged on foreign railways. In experiments, such cylinders reveal an enormous amount of condensation. In some English outside cylinder locomotives the exhaust is in contact with no less than 292 square inches of the exterior of the barrel. The exhaust in other engines does not touch the exterior of the barrel: they have been specially designed to avoid loss of heat. Fig. 35 shows an otherwise neatly-designed Corliss engine-cylinder with a grave defect; the whole of the bottom part of the steam-jacket is in contact with an enormous exhaust

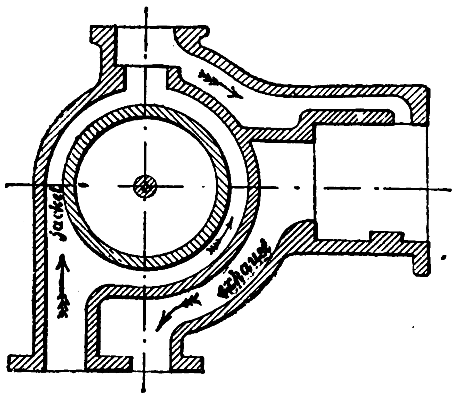


Fig. 32.—Faulty design.

chamber. To a certain extent fig. 33 is defective in this respect. How much better it would have been if the exhaust steam had been taken away through the cylinder foot at each end, and thus have saved considerable steam. Fig. 36 shows the exhaust passing down the foot of a cylinder of an excellent type. Fig. 32 represents a sectional end elevation of a horizontal engine cylinder, in which the exhaust steam is made to traverse nearly half-way round the outside of the jacket; a common and pernicious practice with some continental engineers. Fig. 30 illustrates a sectional plan of an American portable engine cylinder wherein a large proportion of the jacket surface is exposed to the exhaust steam. Fig. 37 shows the commonest form of exhaust chamber with the same fault.

Fig. 38 gives a better method of conducting the waste steam away, so that the exhaust chamber scarcely touches the space occupied by the jacket steam.

These exhaust passages may appear in themselves to be trifling matters to write about, but economy is

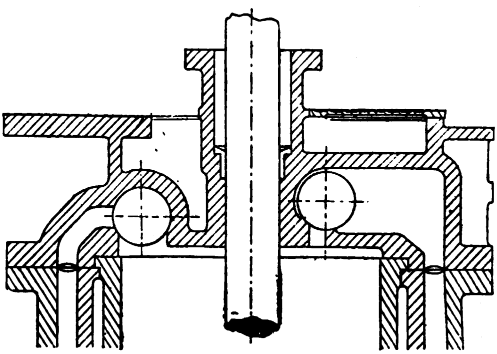


Fig. 33.

brought about by our attention to a number of small details, each of which in itself seems insignificant.

3. *The jacket must be supplied with steam of the full boiler pressure. The supply pipe must be of ample area in order to secure these results.*—In days gone by these essential requirements must have been understood, for it has not been unusual to insert the cylinder inside the steam-space of the boiler.

Murdock's little locomotive of 1784 was thus jacketed; so were Trevithick and Vivian's high-pressure engines (figs. 3 and 4). Cambridge's portable engines of 1843 had their cylinders inserted vertically in the steam-space of the boiler (fig. 5). Hornsby's portable engines of 1850 had, and some that are made in our times, have the steam cylinders placed horizontally

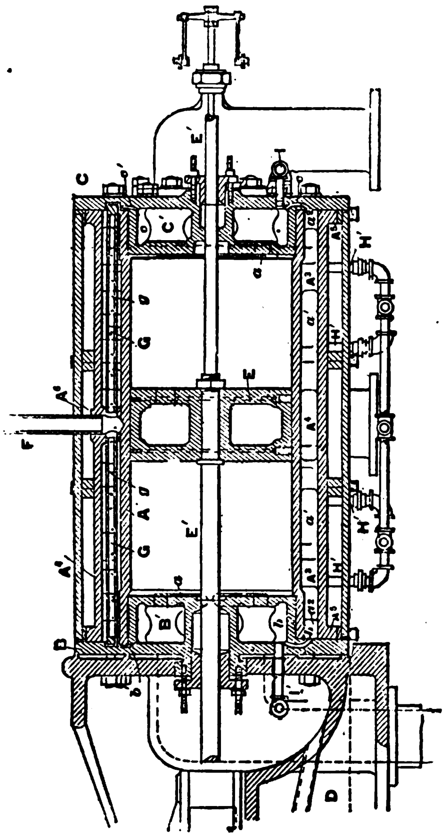


Fig. 34.—An Efficient Steam-Jacket.

within an elevated steam chamber at the fire-box end of the engine (see fig. 6). Clayton and Shuttleworth had the steam-jacketed cylinders inserted in the top of the smoke-box, the steam in the jacket preventing any over-dryness in the working cylinder, and the heat of the escaping gases in the smoke-box keeping up the heat of the jacket steam. Having named the requirements necessary for securing the jacket's steam-supply being properly attended to, let us see how these essential conditions to effective steam-jacketing are complied with by the engine-makers of the present generation. The steam-supply pipes for the jackets

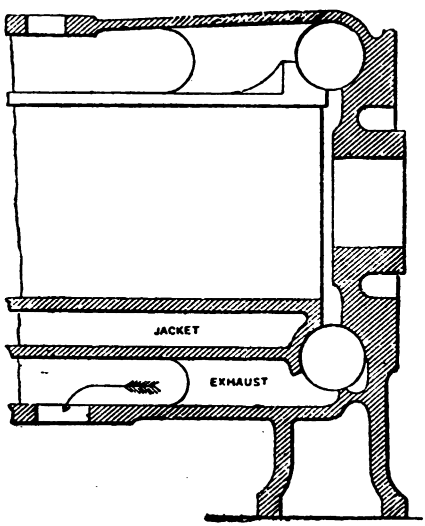


Fig. 35.—Faulty exhaust outlet.

of marine engines, instead of always being open to the boiler, are generally provided with cocks, and the engineer can have steam in the jackets or not as he pleases.

A large number of horizontal fixed-engines have their jackets supplied with steam from the slide-valve chest. These examples have not steam of the full boiler pressure in their jackets, and the supply being affected by the stop-valve, the cylinders are not heated gradually, and hot ready for work. Therefore the engine has to be started very slowly and run with the stop-valve partly open for several minutes in order to warm up the cylinder and to give the condensed steam from the cold cylinder time to run away. In not a few

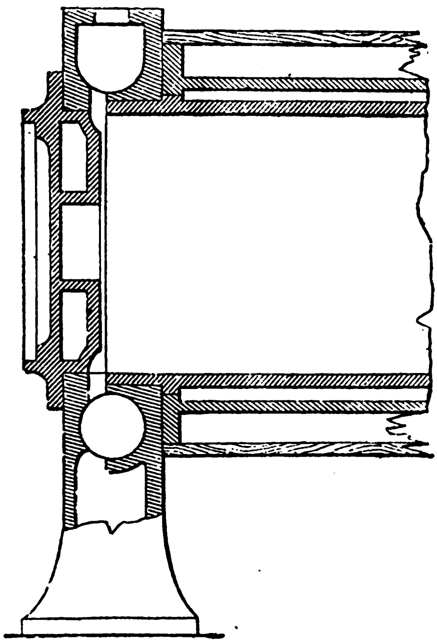


Fig. 36.—Approved design.

cases cylinders of this type have been cracked by having the steam turned on suddenly. Figs. 39 and 40 show sectional views of a horizontal stationary engine cylinder, with the steam-jacket supply taken from the valve-chest, with all its attendant faults; but the makers of this cylinder, being anxious to display some originality of a questionable type, have carefully carried the steam-supply through the exhaust chamber also, in order to further reduce the temperature of the jacket steam, which is already much lower than the steam in the boiler.

When engines have their jackets filled with steam from the supply pipe above the stop-valve, these

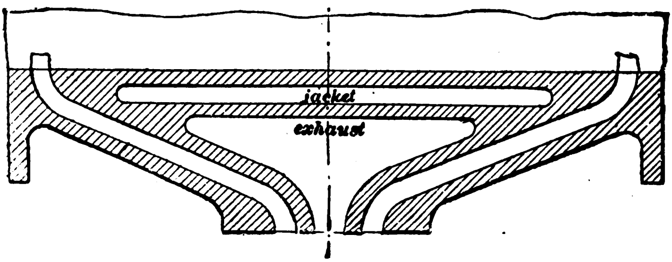


Fig. 37.—Large exhaust port.

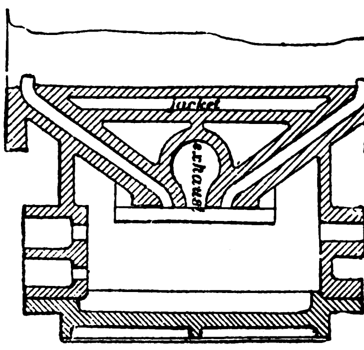


Fig. 38.—Approved exhaust outlet.

supply pipes are in many cases much too small to efficiently feed a large steam-jacket; and these pipes are generally exposed instead of being neatly clothed or arranged beneath the lagging. We recently saw a ¼-inch copper pipe fitted to a 16-inch cylinder: such a means of jacketing could not be of much service.

The following remarks respecting small steam-supply pipes to jackets occur in the second report of the Research Committee on "The Value of the Steam-Jacket." Experiments were made at Messrs. J. & P.

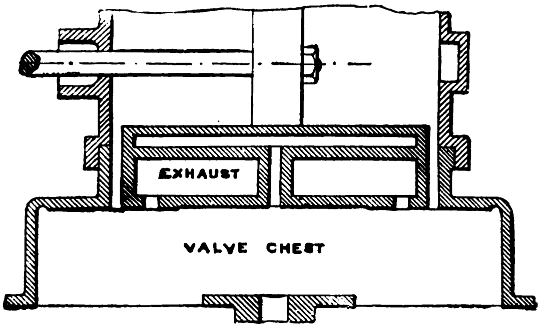


Fig. 39.—Faulty steam-jacket supply.

Coats' Thread Works, Paisley, in 1889 by Mr. Michael Longdridge, on a pair of single-cylinder condensing horizontal Corliss engines. Cylinders 25·06 inches diameter; 48 inches stroke: the body and both ends of each cylinder were jacketed. Steam was supplied to the jackets from the main steam-pipe through ¾-inch pipes. The economy resulting from steam in the ends or cylinder-lids was

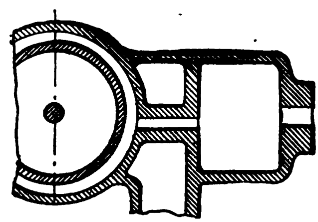


Fig. 40.—Faulty steam-jacket supply.

only 1·3 per cent.; and the gain resulting from steam in all the jackets was very low, viz., 2·5 per cent. "For the size stated of the engine, such small pipes were, of course, inadequate to supply sufficient steam to jackets. It would be interesting to know whether the poor economy obtained in that instance by the use of jackets was due to the want of sufficient pressure of steam in the jackets, and therefore to the low temperature in the jackets."*

The worst and most common examples of inefficient steam-jacketing are those wherein the working steam is made to traverse round the jacket previous to entering the cylinder; a practice which in the Cornish engine has been abandoned,† and should be rejected

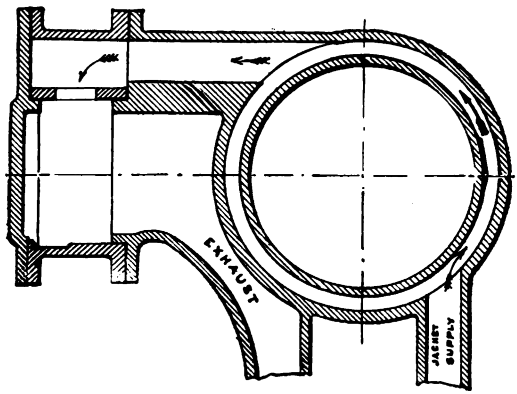


Fig. 41.—Faulty design.

in all engines, seeing that the steam is robbed of its heat and condensed before it reaches the cylinder; the water resulting from this refrigeration being carried with the steam into the cylinder.

Figs. 27, 32, and 41 are illustrations of this class: the jacket may be said "to drain itself through

* Mr. W. Schönheyder, p. 497 of Inst. of Mechanical Engineers. Second Report on "The Value of the Steam-Jacket."

† In the earlier Cornish jacketed engines the steam for the engine was taken from the steam-jacket, but this plan has subsequently been discontinued, and the steam-pipe is now always made to lead direct from the boilers to the top nozzle. Fig. 42 shows this clearly.

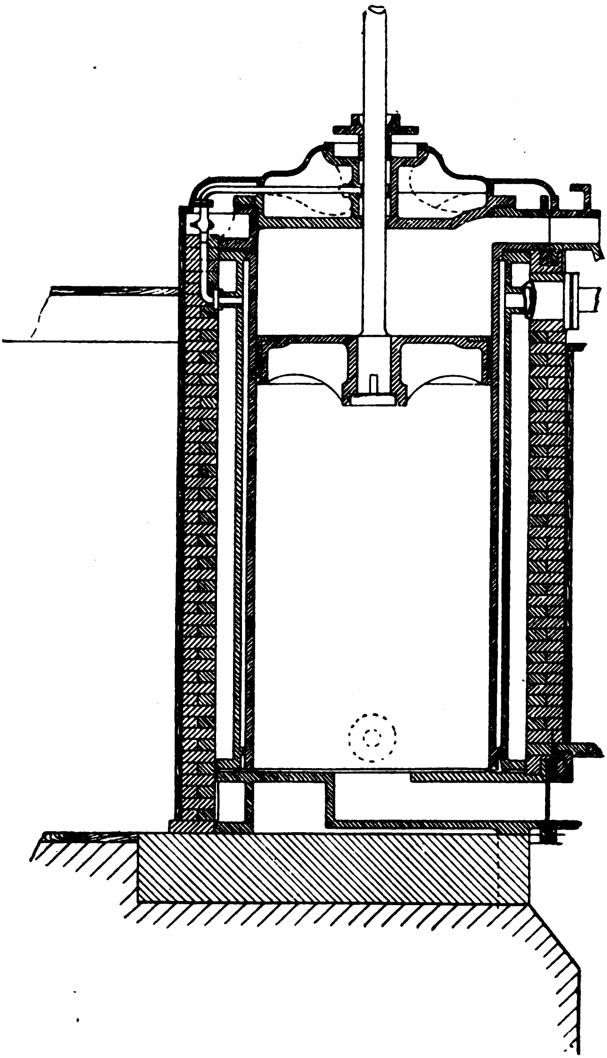


Fig. 42.

the cylinder." * In many compound engines of large sizes the steam on its way to the high-pressure cylinder passes round the jacket of the small cylinder, does work in that cylinder, and then makes its escape to reach the low-pressure cylinder by the same circuitous route. Jacketing the high and low-pressure cylinders with such steam must cause an immense loss; and, strange to say, there are hundreds of cylinders on all classes of engines in which this species of jacketing obtains.

We noticed in one of the engineering journals a compound side-by-side horizontal engine, in which the steam on its way to the high-pressure cylinder traversed the outside of an interheater, then round the outside of the high and low-pressure cylinders in the manner indicated above. The editor of the journal says:—"We must say that we think this plan of transmitting heat to the working steam at the expense of steam just about to do work is not at all an advisable one. The almost inevitable result is to make the steam so wet that the benefits gained by jacketing and re-heating are more than counterbalanced."

We are of opinion that, with such a plan of steam-jacketing, and one which is sadly too common, no advantage, but positive loss, results, so we need not be astonished to hear doubts raised occasionally respecting the jacket's utility; thus demonstrating the truth of our previous remarks regarding the

* It will be seen, however, that this arrangement promotes the circulation of the steam in the jacket. The cylinders of traction engines are generally arranged in this manner; the jacket space is made unusually large so as to act as a steam dome, as per fig. 31: the drainage is also well carried out as shown by fig. 55. But, where the jacket space round the cylinder is contracted as in the figures referred to, the plan must possess the faults we have named.

ignorance displayed by engine-makers relative to this subject.

Mr. Northcott in *The Theory and Action of the Steam-Engine*, says :—" In all cases the jacket should be distinct from the cylinder, as when the steam is passed through a jacket on its way to the cylinder, the water condensed in the jacket is carried with the steam into the cylinder, and the result is much the same as would be produced without the jacket."

In order to obtain the very best results, not only has it been the rule to obtain steam of the same temperature in the jacket as the initial steam in the cylinder, but recently cases have occurred wherein the jackets have been supplied with steam of a higher pressure than the working steam in the cylinder. There is no reason in many places why such a system of jacketing should not be carried into effect. In another part of the work we give some particulars which show the advantages of jacketing with high-pressure steam. In Hopkinson's *Engineer's Guide*, the following sentence occurs :—" It is clear then, that to secure the greatest attainable economy by steam-jacketing, they must be supplied with steam of a much higher temperature, and higher in proportion as the metal is thicker through which the heat must be transmitted."

4. *Not only should high-pressure steam be used in the jacket, but, if we are to realise the best results, we must have the working steam as dry as possible, because all wet steam admitted into the cylinder is evaporated during the stroke by heat abstracted from the jacket.*— The steam-pipes from the boiler should have provisions for draining, so as to prevent the condensed steam from being carried into the cylinder. We believe that priming boilers are more numerous than some

people imagine, and much of the water we are sometimes troubled with probably comes from this source, causing an enormous loss of power. A good water-

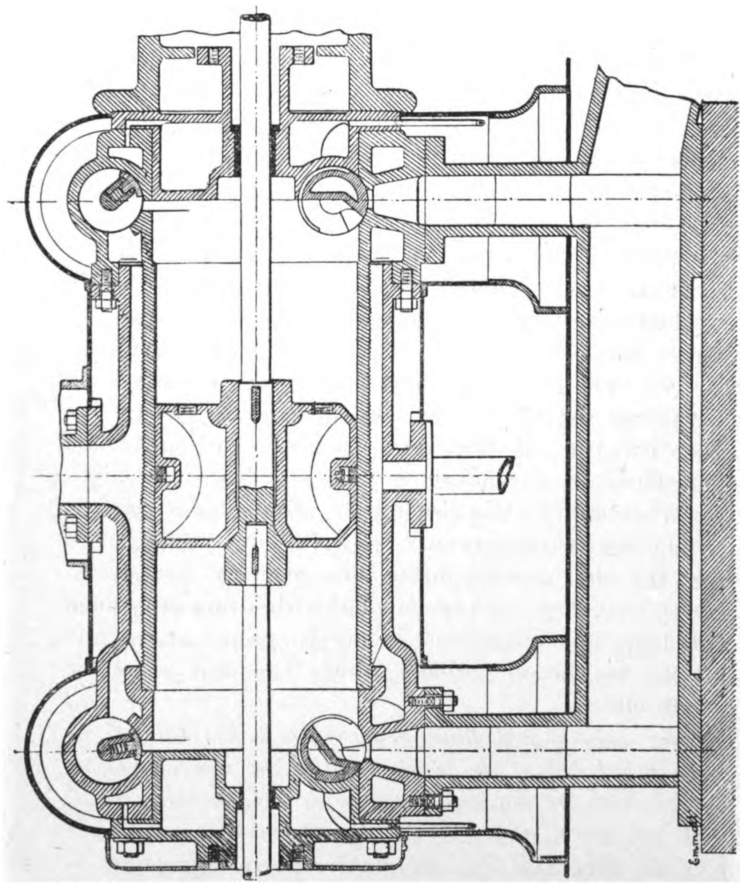


Fig. 43.

collector should be provided on all steam pipes: the pipes should be carefully clothed. In fig. 28 the steam-pipe of this locomotive cylinder is not only exposed to the cold air, but it is also partly in contact with the exhaust pipe, and the working steam is uselessly spending its heat in drying the exhaust

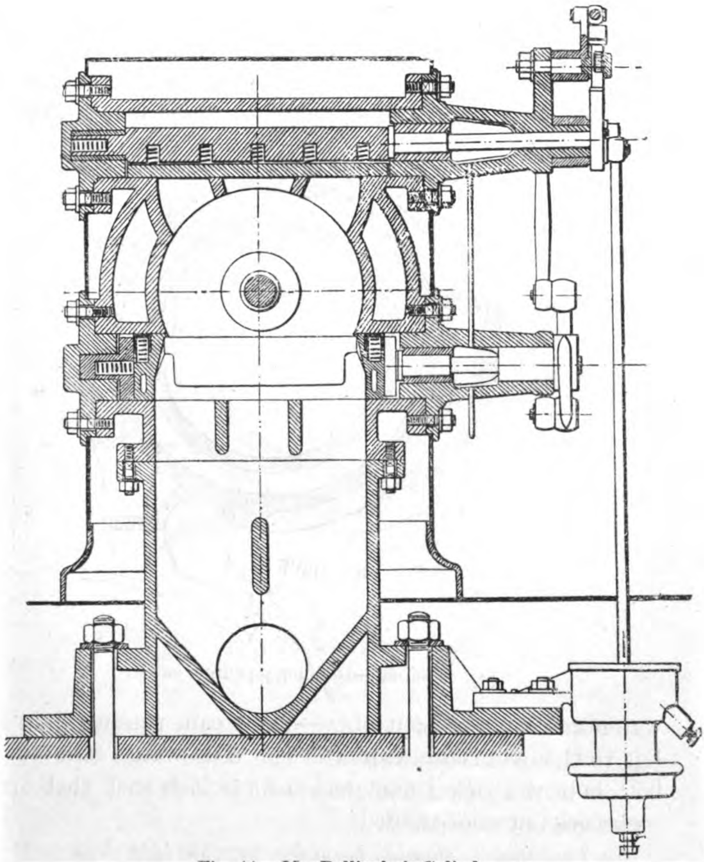


Fig. 44.—Mr. Bollinckx's Cylinder.

steam. Respecting this wet steam supply, Mr. Northcott says:—Owing to this cause "it is not unusual to see engine diagrams in which the expansion curve rises considerably above even the hyperbolic curve." In all such cases the loss must be very considerable.

In Mr. Bollinckx's cylinder, shown by figs. 43 and 44, " to prevent water being taken into the cylinder with steam, the well-known system of 'knocking the water out of it' is used. The steam before entering the cylinder passes into the jacket—it enters at the top, and, striking the metal of the liner, it has the

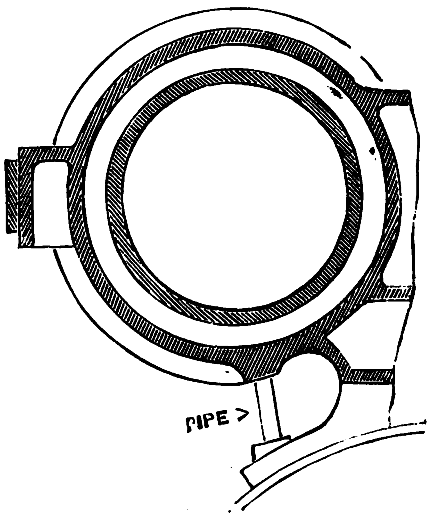


Fig. 45.—Draining pipe from jacket.

water knocked out of it—dry steam passing right and left to the admission valves. The water falls to the bottom of the jacket, and the result is such that drain-cocks are not needed."*

5. *The jacket should be open to the boiler at all times, and not affected by the stop-valve; it will thus be heated gradually as the steam is raised, and always hot ready for work;* therefore, no steam will be required

* *The Engineer*, 18th December 1885.

for blowing through the cylinder for warming it. When the jacket steam is taken from the steam chest, as referred to previously, this fault obtains. In small engines it is not necessary to provide any means for shutting off the steam from the jacket, but large engines are generally fitted, so that the steam may be turned off; care, however, should be taken to arrange these cocks or appliances so that they may not be tampered with by being turned off or on, to suit the fancy of a meddlesome engine-driver. Fig. 62 shows

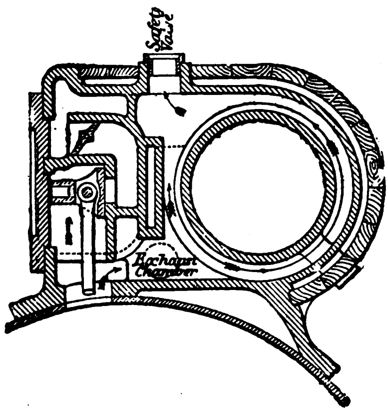


Fig. 46.—Portable engine cylinder.

the steam supply for the jacket independent of the stop-valve. Any water collecting in the steam pipe should pass into the jacket rather than into the cylinder.

6. *The steam-supply pipe should enter the jacket at such a point that a thorough circulation of the steam within may be secured and maintained, and the accumulation of air at any part made impossible.*

Figs. 25 and 47 show sections of cylinders, the jacket of which is only taken partly round the cylinder; no circulation of the steam takes place in the jacket, and air collects at the top. The following incident occurred at a trial of portable engines, which appears to prove that air does sometimes accumulate at the highest point of the jacket, and prevent the jacket becoming heated by the steam, notwithstanding that some tell us that such cannot be the case.

A correspondent in *Engineering* says :—" The cylinder of one engine was steam-jacketed : being on the top of the boiler, the admission of the steam was direct to the jacket : it might be supposed that the

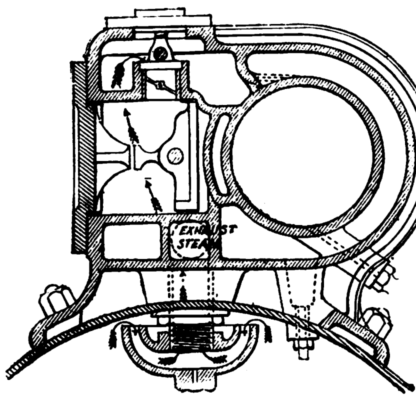


Fig. 47.—Traction engine cylinder—deficient circulation.

jacket would be heated as the steam rose ; the jacket felt quite cold with sixty pounds pressure of steam in the boiler, until the safety-valve (which was on the top of the cylinder, in communication with the jacket) being eased a little, a current was formed in the steam, showing clearly that the air must be expelled before they can be heated properly."

At the present time, there are hundreds of portable engines being sent out by celebrated makers, having the most worthless so-called steam-jackets, but, in reality, they are air-jackets, because no trouble has been taken to cause any circulation of the jacket steam.

The cylinders are bushed in the usual manner: a small hole is drilled into a pocket at one end of the cylinder at the lowest part of the annular space. Through this hole the steam supply to the jackets is taken, but, as there is no other opening into the jacket, it is impossible for it to be of any service, because the greater part of the space will be filled with air. Such jackets must be an immense source of loss; the steam in the working cylinder not only derives no benefit, but positively has to warm up the stagnant air in the jacket. We cannot denounce such counterfeits too strongly; it would be far better for some makers not to attempt to steam-jacket their cylinders at all, unless the jacketing can be properly designed so as to be an advantageous agent for economising fuel.

Another portable engine-maker supplies steam to the jackets of their compound cylinders in a similar manner to the above, but the jackets are in communication with tubular stays, connecting the cylinder and crank-shaft brackets together, and some circulation of the steam is set up in the jackets by means of a circulating pipe from the stay to the boiler; in other words, steam passes through the stay from the jacket to the boiler. Another plan is to place the safety-valves on the top of the cylinder in communication with the jacket steam, and also open to the boiler, as is done on most road locomotive cylinders, (figs. 31, 46, and 58).

Mr. Mair, a great authority on steam-engine testing, recently said respecting faulty steam-jackets:—"In some cases the jackets are only air-traps. The steam should enter the jacket in such a position so as to prevent this accumulation of air." We illustrate at fig. 43 a section of a cylinder made by Mr Bollinckx of Brussels, to which reference has previously been made. Mr. Bollinckx, "it is worth notice, attaches the greatest importance to taking steam in at the *top* of the jacket. It is to the neglect of this precaution, he holds, that the unsatisfactory results now and then obtained with jackets is due." *

If the jacket steam cannot be taken in at the top and drained from the bottom, an air-valve will answer the purpose, placed on the highest part of the jacket; but we strongly recommend the safety-valves being placed on the top as just named.

In a description of a triple-expansion condensing engine by Mr. F. Schichau of Ebling, Prussia, in *Cassier's Magazine* for May 1893, the following remarks occur :—

"The first two cylinders have steam-jackets supplied with steam at boiler-pressure, and *the jackets have small air-valves to prevent air binding*, and traps for draining off the water of condensation."

Figs. 58 and 59 show sections of a compound traction-engine cylinder. The steam for the jacket is taken to the top from which the stop-valve draws its supply; the drain is at the lowest point. Two safety-valves are also placed on the top of the jacket. It is impossible for air to be trapped in such a steam-jacket.†

Messrs. M'Intoch, Seymour & Co., of Auburn, New York, exhibited a 1200 horse-power double tandem compound engine at the World's Fair. The following account of the methods adopted for securing good

* *The Engineer*, 18th December 1885.

† We are indebted to *Engineering* for figs. 58 and 59.

circulation in the jackets may be of interest. "The high-pressure cylinders are provided with steam-jackets, and the receivers between the cylinders are filled with copper-heating coils, presenting a large amount of heating surface, and tending to give perfectly dry steam at the entrance to the low-pressure cylinders.

"The builders argue that the cause of inefficiency of steam-jackets on high-pressure cylinders, as ordinarily made, is lack of proper circulation through

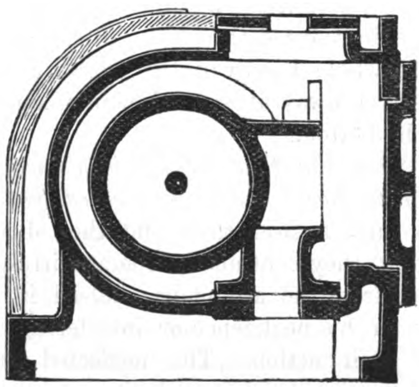


Fig. 48.—Mr. Halpin's Cylinder.

the jackets, and that a very rapid circulation is necessary to render them of service. By the present arrangement, the temperature of the steam in the receiver being much lower than that in the coil, a very considerable amount of condensation takes place in the receiver coil, and as this is fed from the high-pressure cylinder jacket only, a brisk circulation is insured in the latter. The pipes from the high-pressure cylinders to the receivers are also fitted with steam separators to catch any water which may be carried along by the passing steam."*

We are pleased to find that our foremost engineers are beginning to recognise the importance of obtaining a thorough circulation of the steam within the jacket. In order to obtain this result, Mr. Chas. T. Porter of Montclare, U.S.A., has recently, among other patents connected with the steam-engine, shown a method of distributing the jacket steam by means of a perforated pipe (see fig. 34). Mr. Porter says:—"To insure that the current shall move through every part of each jacket without permitting air to accumulate anywhere, the steam is introduced through a perforated pipe extending the whole length of the jacket on the upper side, and taken away at several points equally distributed at the bottom."†

7. *It is essential that the provisions made for the drainage of the jacket should be most efficient and complete.*—To fully answer their end, they should be so planned that they continually operate, irrespective of any control from the attendant; indeed, it should be impossible for his negligence or interference to hinder or impair their action. This neglected drainage is the most prevalent, and, by far, the most serious evil which the steam-jacket has to contend with. It is an abuse which is perhaps working greater mischief than all other detrimental causes combined.

By the defective arrangements, and, in some cases, the total omission of any provisions made for the drainage of the jacket, an otherwise well-designed steam-jacket can be transformed from an economising agent to the veriest sham,—acting as a surface-condenser instead of a heat-preserver, and thereby

* *Cassier's Magazine*, July 1893.

† *Iron Age*, 3rd May 1894.

aggravating to an alarming extent the very evil it was intended to diminish. In spite of our engineering boasts, we may with advantage take notice of the methods pursued by our forefathers in this respect. Let us take the case of the steam-jacketed Cornish engine of a hundred years ago, for an instance of careful jacketing.

The jacket was supplied with steam by means of a sufficiently large pipe, connecting the highest part of the boiler with the highest part of the jacket space,

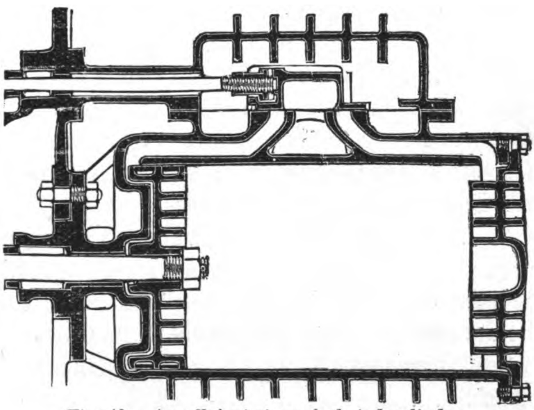


Fig. 49.—An efficient steam-jacketed cylinder.

and the drain-pipe at the bottom of the jacket led the condensed steam into the water-space of the boiler. The boilers were placed on a lower level than the engines, so that the drainage was effected by gravitation: the drain-pipe was of ample size and was always open to the boiler below the water-line. Where such a method of drainage cannot be carried out in such like engines, an efficient steam-trap should always be connected to the lowest part of the steam-jacket. We have some steam-traps that will deliver the drainage direct to the boiler, described later on.

Many years ago Mr. Maw suggested the use of a small pump for constantly drawing the water of condensation from the jackets and forcing it into the boiler. "We think this mode of draining the jackets would be preferable to any arrangement dependent upon the attention of the driver, while it has the advantage of returning the water to the boiler at practically the temperature of the steam.

"The utilisation of the water of condensation as hot-feed would be quite an appreciable economy." *

While on the subject of the proper drainage of jackets, we quote the following respecting some first-class compound marine engines :—"The steam for the jackets is taken direct from the boilers, and the drain-pipes are carried below the water-level of the boilers, so that the steam-jackets of the cylinders form a part of the boilers while they are in use."†

Very little difficulty should be experienced in properly draining the steam-jackets of agricultural engine cylinders where these are placed upon the top of the locomotive type of boilers. But here is an instance of carelessness in this simple matter of the drainage.

A few years ago, some repairs were being done to a ten horse-power expansive portable engine, made by a celebrated firm.

The cylinder and covers were jacketed, the lids being supplied with steam from the circumferential jacket by means of three or four holes drilled through the end of the cylinder; and, opposite these, similar holes were provided in the covers. After removing these lids we found all the holes in each one filled—we may say plugged with red lead one inch thick,

* *Engineering*, 29th April 1881.

† *The Engineer.*

for evidently every time the cover-joints had been made, a fresh layer was added in each hole, to account for the thickness of lead named. After clearing out the holes, which was no easy matter, as the lead was rammed in very tightly, we saw that the jackets of the covers were *full of water*, and, judging from appearances, they had been in this state for years; it is almost needless to remark that this is a very poor plan for supplying jacketed covers with

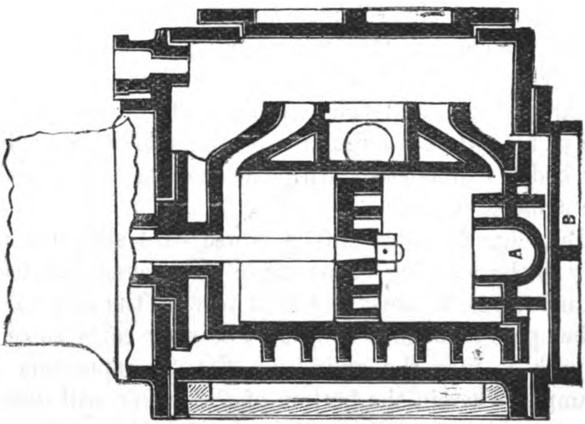


Fig. 50.—An efficient steam-jacket.

steam. But this is not all, for, when the holes were being cleared out in the ends of the cylinder, it was discovered that the circumferential jacket also was half full of water. The drainage of this steam-jacket had been entirely overlooked by the designer, for it was impossible to prevent the accumulation of water in it without altering the arrangement considerably. Fig. 54 shows a method of drainage adopted on a portable engine by means of holes drilled up the holding-down bolts, which cannot be recommended. Fig. 55 shows a good drainage arrangement independent of the steam-supply, an improvement on fig. 46.

But we have known many instances wherein the bottom part of the jacket has been drained, but, owing to defects in the design, water has found some shelf or pocket where it may lodge in the higher part of the jacket space. Figs. 25, 26 and 27 are examples of this species of defective drainage.

In figs. 26 and 27, for instance, the steam is made to pass round the cylinder body over water to reach the steam-chest; this water, lying in contact with the cylinder wall, tends to waste the heat of the working steam, and causes other evils on the top of the jacket, while a large area of the side of the cylinder body is in contact with the cooling influences of the exhaust steam.

But fig. 27 represents a worse case still, for, not only is the working steam made to traverse round the cylinder, but it must, before it reaches the stop-valve, either pass through a body of water, or carry some of it with it into the cylinder. Fig. 29 represents an example, wherein the bottom of the jacket will *always contain some water*, because the jacket drain-cock is in a line with the cylinder drip-cocks, several inches above the bottom of the jacket, the levers of the three cocks being coupled together; not only so, but the fact of the drain-cock being connected to the drip-cocks, shows that the condensed steam will never be blown out except when the cylinder-cocks are opened: and the attendant may only do this two or three times a day, which is not nearly often enough, as the water within the jacket should be got rid of as quickly as it is formed. The injurious effects occasioned by such an improper arrangement will be apparent to all; for

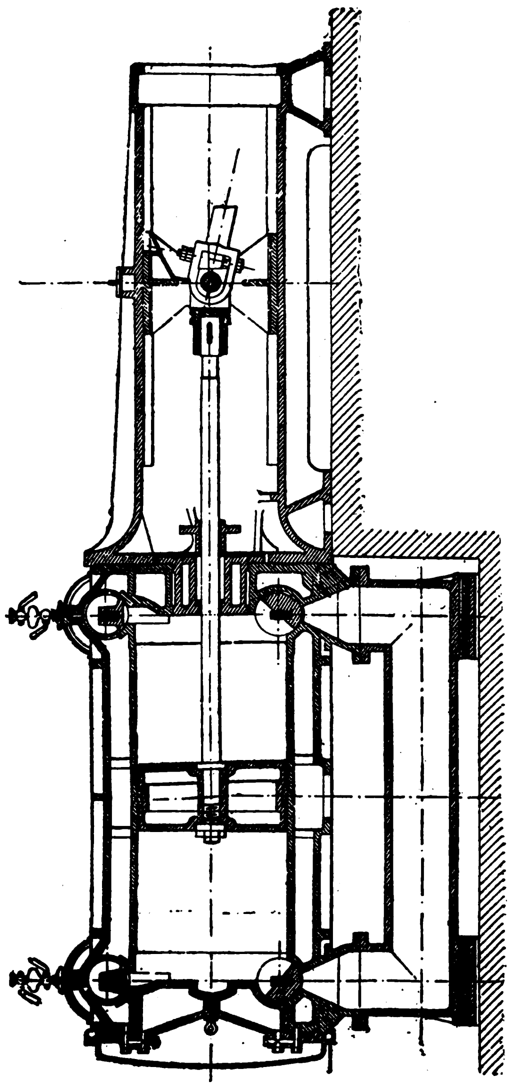


Fig. 51.—Frikart Compound Engine.

it is more than probable that the jacket will often be full of water.

In designing all classes of cylinders, care should be taken to avoid all shelves or pockets, either at the top or bottom of the steam-jacket, where water may find a lodging place. Several engineers entertain an erroneous impression respecting the drainage of steam-jackets; they fancy that, if the drain-pipes are occasion-

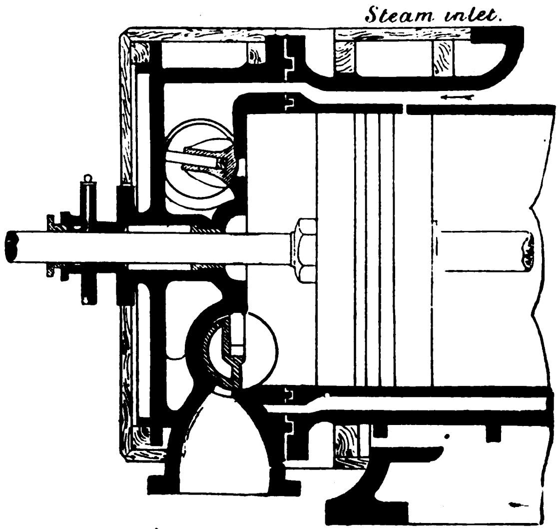


Fig. 52.

ally opened, that will be sufficient. It must be distinctly understood that *no occasional blowing out will do;* the condensation of the jacket steam is continuous, hence the water resulting from this incessant cause should be removed as quickly as it is formed.

Fig. 45 shows a good plan adopted by another firm for draining the steam-jackets of their compound portable engines. Two pieces of steam-pipe are cast into the lower part of the jacket passing through the foot of the cylinder, opening up a communication between the lowest part of the jacket and the boiler. Let us hope, however, that these pipes are provided for the drainage only, and not for the supply of the jacket; for, if so, the remarks made on previous pages apply to this cylinder also.

In figs. 53 * and 63, the high and low-pressure cylinders and the intermediate receiver are immersed in steam of the full boiler pressure: the drainage is well carried out. Fig. 63 has two drainage pipes at the lowest part of the cylinder foot, not shown in the drawing. The safety-valves are placed on the top. We have previously referred to Mr. Porter's efficient steam-jacket. It will be seen from fig. 34 that the condensed steam is drained from the jacket round the cylinder and the spaces in the cylinder heads by means of four separate exit pipes, so as to insure perfect circulation and drainage.

8. *The working barrel of the cylinder should be made as thin as possible, and of the best conductor of heat.*—"The thickness of the metal of the cylinder, that is, between the steam in the jacket and the internal surface of the cylinder, is of very great importance, because the transmission of heat, both in time and quantity, is inversely as the distance passed through, and, therefore, the shorter such distance, the more efficacious will be the steam in the jackets."†

It is a well-known fact that many makers of portable engines cast the walls and partitions of their cylinders of such a thickness as to seriously interfere with the transfer of the heat from the jacket to the

* We are indebted to Messrs. Crosby Lockwood for permission to use this block.

† Hopkinson's *Engineer's Guide.*

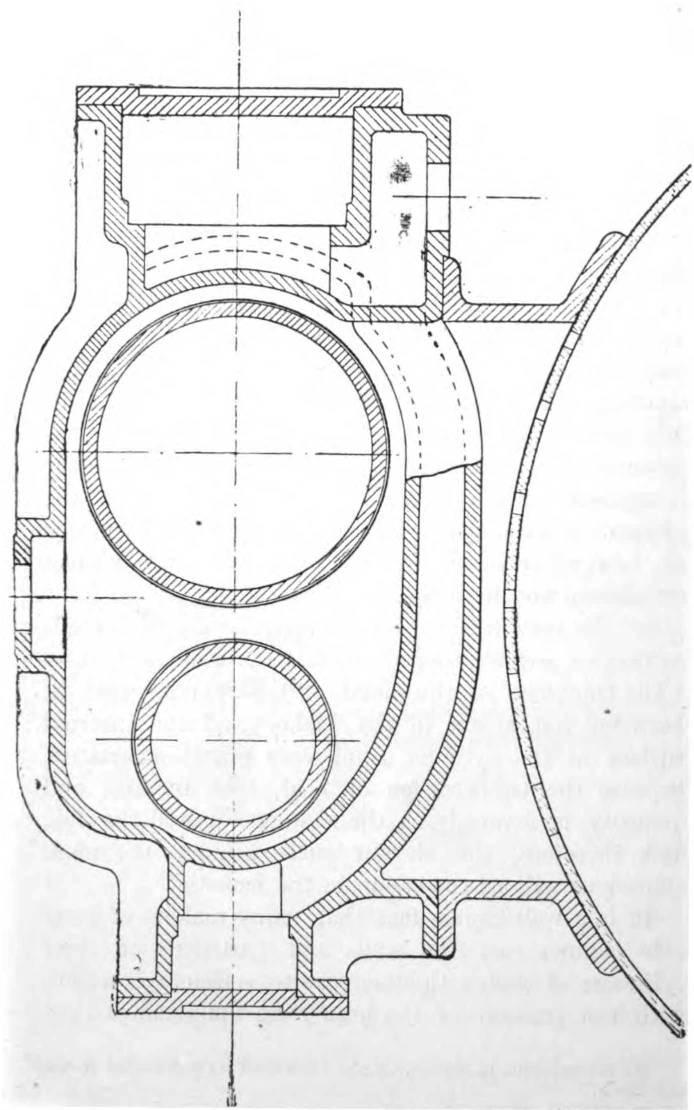


Fig. 53.—Compound portable engine cylinder from Haeder & Powles on *The Steam-Engine.*

cylinder; these thick walls are introduced to lessen the risk from defective castings in the foundry, for the steam-jacket and cylinder when made in one, is a somewhat complicated and troublesome casting to make. Herein consists one of the most valuable advantages of casting the cylinder and bush separately; the bush may be made as thin as possible, and as hard as practicable, reducing the wear to a minimum, so that repeated re-boring will not be necessary, and, perhaps, under some conditions, re-boring may not be required at all.

We may remark in passing, that the bush system of steam-jacketing is now generally adopted for all classes of engines. It possesses the following advantages over the old system of casting the steam-jacketed cylinder in one piece:—

(1) Reduced cost for moulding.

(2) Minimum risk from defective castings, as all the walls or partitions can be examined and tested before the liner is inserted.

(3) The liner can be cast in very hard metal and the shell in softer metal. The liner may also be made of any other material than cast-iron, such as steel, hard brass, phosphor-bronze, &c. The liner may be made as thin as practicable and of equal thickness throughout.

(4) One pattern of cylinder casing may be used for several sizes of engines, the liners being made to suit the different pistons.

Figs. 30, 31, 36, and 46 show the liner system of cylinder construction clearly.

The Editor of *The Engineer* some time ago suggested the use of hard brass or gun-metal liners for high-pressure cylinders. "Properly made, the material is much harder than cast-iron, and will take a beautiful surface; while this material, being an excellent conductor of heat, would comply with one of the fundamental conditions of eminent success in using the jacket." Phosphor-bronze is now largely used for all manner of purposes: it would not only be in keeping with the spirit of the times to propose this material to be used for cylinder liners, but it has, likewise, several favourable properties to recommend it, the chief being its conductivity, which is more than three times greater than cast-iron. Fig. 43 shows an excellent method of construction.

Steel liners for steam-jacketed cylinders were first used on portable engines by Mr. Barrett of Reading. They are now used in America for Corliss engines of large dimensions.

It is only recently that they have been applied to marine engines: the credit of their introduction is due to Mr. Allen of Sunderland, who read a paper on this subject before the Institution of Engineers and Shipbuilders of Scotland, containing an interesting account of their successful application to several high-pressure cylinders. We believe that steel liners are not adopted in the merchant marine engines of the present day, because of their extra first cost.

Messrs. Sir Joseph Whitworth & Company have, during the last twenty years, supplied some hundreds of their fluid-pressed steel liners to the war-ships of various governments. They are prepared to make these liners from one-quarter of an inch in thickness up to any diameter.

Previous to the introduction of steel liners in the Admiralty service, fractured cylinders were of frequent occurrence,—in fact, cracked cylinders were the rule rather than the exception; and when the liners did not crack, they scored, but, since steel has been used, few have failed, and not one of Messrs. Whitworth's liners have cracked.

It has been the custom for some time past, with several firms, to make their cast-iron liners as thin as practicable, and as hard as possible. In order to give the necessary strength to the liners, there were added a series of ribs placed longitudinally and transversely at suitable distances apart on the outside of the liner. We have a liner shown in fig. 50, transversely ribbed for a totally different purpose, as we shall explain. The outer casing of the cylinder is cast in one with the steam-chest, which completely encloses the cylinder liner as clearly shown. When steam is admitted to the outer casing it supplies the valve-box, the circumferential jacket, and the cylinder-covers, which are all in communication with each other. The flange of the engine frame answers for the front cylinder-cover, to which the liner and the outer casing are separately bolted. There are two back covers, one, A, for the liner, and a second one, B, for the casing, the space between the two being open to the jacket steam. The outside of the liner is provided with a number of ribs, which completely encircle its circumference, except on the part taken up by the ports and the valve-face: these ribs are applied for the purpose of absorbing the heat from the jacket steam and transmitting it to the interior, to keep up the heat of the working steam. The inside cover, A, is similarly ribbed on both sides, the piston being made to correspond with it. It has been stated that these heat ribs produce no useful effect unless they project into the inner casing, to which they are intended to carry the heat, as well as the outer space from which they borrow the heat. This, of course, can only be carried into effect in the case of the cylinder-cover. But this point has been decided by Mr. Halpin, the inventor of the ribbed cylinders. In a letter received from Mr. Halpin, the following remarks occur:—"I have subsequently made several experiments, and find that, by perfect ribbing, the amount of heat transmitted in the ribbed cylinders is 3·28 times that transmitted in the plain cylinders." Fig. 49 shows a section of a low-pressure cylinder liner and valve-chest, the whole of which is inclosed within a steam casing. We look on this system of steam-jacketing as the most efficient in existence. Mr. Halpin carried out some experiments with a small stationary compound engine, both the cylinders of which were got up in the style shown: the results of the trial was without a parallel, proving beyond a shadow of a doubt the substantial benefits to be derived from the application of real steam-jackets to the cylinders of steam-engines. Fig. 48 shows the end view of a small stationary engine cylinder. Fig. 43 shows the barrel provided with heat ribs also.

9. *In large engines of short stroke, not only should the covers be jacketed, but the piston should be heated, for it is a well-known fact that the jacket round the barrel is powerless to extend its influence into a great body of steam.*—In these cases the covers and pistons expose a larger area of heating surface if fitted with steam than the circumferential jacket does.* It has been said:—"The action of a steam-jacket in securing economy is greater as the diameter of the cylinder is smaller. Some marine engines have been fitted with

* Mr. Lavington E. Fletcher recently said:—"He was of opinion that steam was very much misused, from the fact that the cylinders and receivers, &c., were not sufficiently steam-jacketed, and the boiler pressure maintained in the jackets during the whole time the engine was at work; they should not be content with having only the sides of the cylinders jacketed, but also the ends, which, in his opinion, was equally important. This question of jacketing must receive attention as the pressure of steam used increases."

steam-jacketed pistons, the steam being admitted by a sliding tube.

In a large marine engine we noticed sometime ago, the pistons were provided with balancing cylinders fixed to the bottom covers of each cylinder. The balancing cylinders had hollow piston-rods through which steam was admitted to the interiors of the main pistons, while the effective pressure of steam on the under sides of the balancing pistons was increased by the upper ends of the balancing cylinders being placed in communication with the condensers.*

10. *With regard to jacketed cylinder-covers, the utmost care must be bestowed on their steam-supply and drainage,* for nearly all the jacketed covers are defective in this matter. In the majority of cases these communications simply consist of a few holes drilled through the ends of the cylinder into the jacket, and similar holes to correspond drilled opposite them in the faces of the covers (as described from practice at p. 119.)

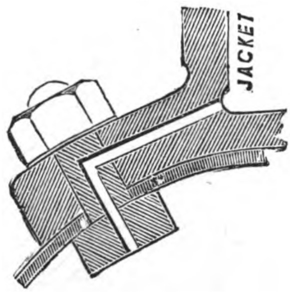


Fig. 54.—Faulty jacket-drain.

There should always be some provision made for preventing these holes becoming choked up with red lead when the cover-joint is being made, for, unless this be attended to, they will undoubtedly soon become obstructed; few engine-drivers would take

* Mr. John Phillips said :—" Some years ago he remembered being told of some vessels that had been wanting a little in speed, and their speed had been increased to the required amount by simply putting boiler steam inside the pistons."

the trouble to keep them clear, and no one could guarantee to always keep them open, no matter how carefully the joint was made. One very simple plan is to provide a plug opposite each communication hole, which may, before the joint is made, be taken out, and a bar or bolt passed through it into the communication hole at the time that the joint is being made.

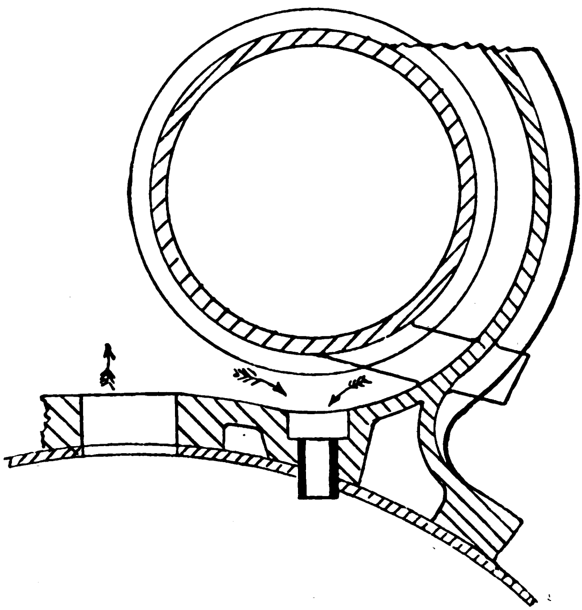


Fig. 55.—Jacket drain-pipe.

Red lead is thus prevented from entering the holes and of obstructing the passage of both steam and water.

Fig. 57 shows the arrangement described. A second plan is also inserted, by fig. 56, which consists of a short piece of tube screwed into the cover. If cylinder-cover joints are made with red lead, some provision of this kind is necessary. When the engines are new, the joints are made with brown paper, or they are carefully faced and made with a little tallow only: the precaution then becomes unnecessary. Figs. 43 and 51 show methods of supplying jacketed cylinder-covers with steam: their proper drainage is also illustrated.

11. *There is room for improvement in most steam-engines in the matter of the clearance, which should be reduced to a minimum.*—The steam-ports should be kept as short as possible. By making the steam-

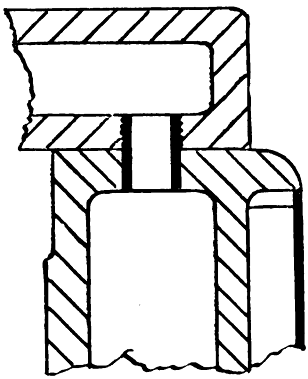


Fig. 56.

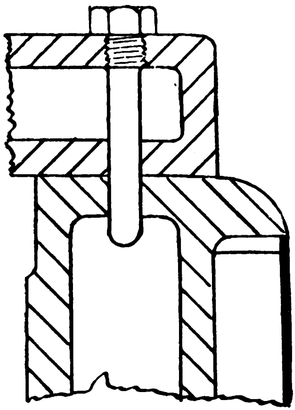


Fig. 57.

Jacketed cylinder-covers.

chest longer than the cylinder, as shown by fig. 39, the steam-ports in many engines can be kept straight and very short. It is owing to this reduction of the clearance in the Corliss engine, which has, without doubt, contributed in no small measure to the economical working and success of this excellent type of engine.

Another valuable feature of this type of engine consists in having separate steam and exhaust ports, for Mr. Joule has pointed out that the almost universal practice of making the steam enter and leave the cylinder by the same port tends to the waste of heat, especially with high rates of expansion.

Few engines at one time had separate steam and exhaust ports, but it is becoming a general practice to have separate admission and exit ports, the latter being, as a rule, at the bottom for efficiently draining

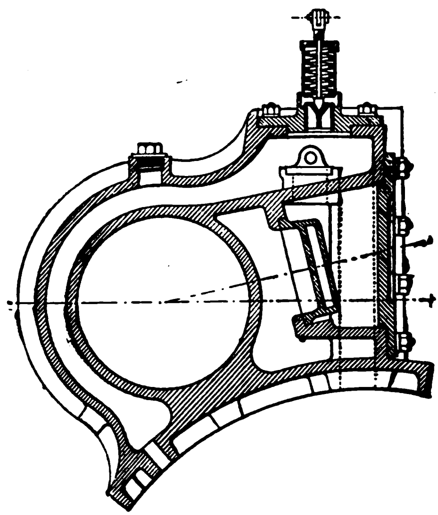


Fig. 58.—Cylinder for Compound Tramway Locomotive, by Messrs. Aveling & Porter.*

the cylinder during the exhaust. Fig. 19 is a good arrangement. Figs. 33, 35, 36, 43, and 52 show sections of Corliss cylinders with short ports. By placing the valves in the cylinder-covers this waste in port space is certainly reduced to the utmost limit, as shown by figs. 33 and 52, but the arrangement possesses some disadvantages, which need not be mentioned here.

* We are indebted to *Engineering* for the illustrations, fig. 58 and fig. 59.

In many stationary engines the steam-ports and slide valve-chests are made of an undue size, in order to bring the slide-rods in a line with the eccentrics on the crank-shaft. The position of the eccentrics is ruled by the length of the main bearing, the thickness of the crank-arm or disc, and the length of the crank-pin. Fig. 37 shows the fault referred to.

The large steam-chests on many steam-engines

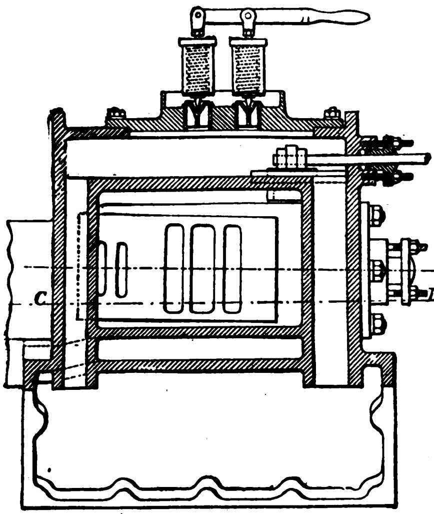


Fig. 59.—Cylinder for Compound Tramway Locomotive, by Messrs. Aveling & Porter.

are badly protected against the radiation of heat. Fig. 52 shows an effective method of protecting the cylinder.

In a trial of stationary engines some years ago, one maker very wisely filled up the useless space of the slide-valve box with blocks of hard wood. Some of the little vertical engines used for electric lighting and other purposes have enormous clearance spaces.

These engines use high-pressure steam, and run at very high speeds: need we wonder, therefore, at their wastefulness? See Professor Unwin's report on the Plymouth Trials of Small Steam-Engines, given in Chapter III.

12. *The last but not least part of our duty is to emphatically denounce all steam-jackets that are left exposed to the atmosphere or unlagged:* indeed it should be, amid all our present knowledge, totally unnecessary to mention this as one of the needful conditions of successful jacketing; but, much as we regret it, we are bound to confess that there are many engines turned out of hand with steam-jacketed cylinders unlagged, chiefly on low-priced portable and vertical engines, intended in not a few instances for out-door service. Need we wonder that some makers say that they have tried the jacket, and find very little difference in the coal consumption during the test of an engine with the cylinder steam-jacketed and the surface of the jacket left totally exposed, and one with the cylinder unjacketed, but carefully clothed and lagged over the whole surface; for, what is gained inside of the cylinder by the application of the steam-jacket, is partly counteracted by the loss of heat radiated from the unlagged jacket. Radiation of heat from the cylinder and other parts of the engine is a very direct source of loss. Some experiments, made by Mr. D. K. Clark, show that, in the case of exposed cylinders, the loss from this cause may rise to as much as 50 per cent. It is impossible to wholly prevent escape of heat; but, by casing or lagging the cylinder and steam-pipes with an efficient non-conducting material, the loss, we are told, may be reduced to as little as 2 per cent.

We have dealt very fully with cylinder clothing compositions elsewhere, but we may imitate, with advantage and profit, an American example of effective cylinder clothing. We refer to the 1400 horse-power Corliss engine at the Philadelphia Exhibition. The

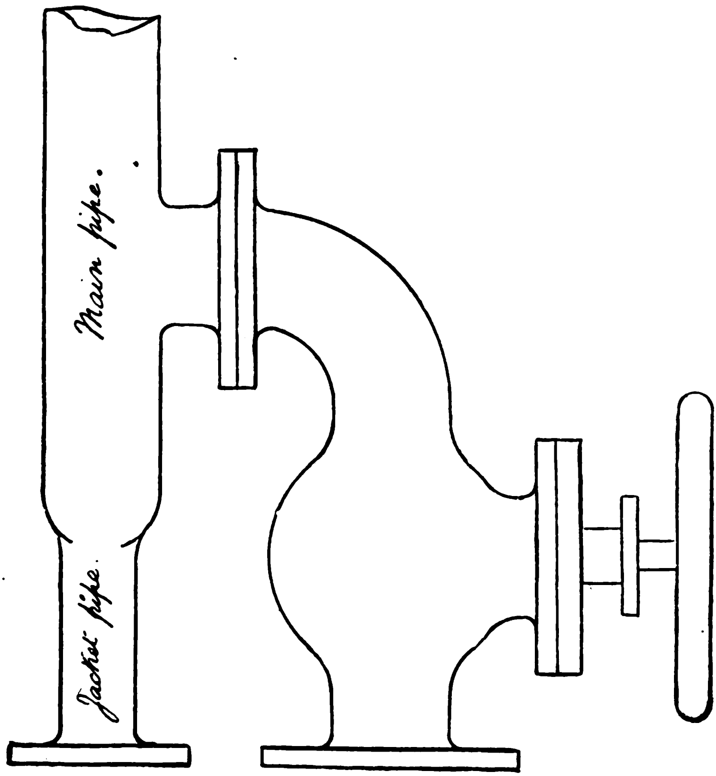


Fig. 60.

cylinders were steam-jacketed and covered with hair felting and lagging, the former $\frac{3}{4}$-inch thick, the latter 1-inch thick; outside this there was an air-space $\frac{1}{2}$-inch thick between it and the polished iron casing.

By fig. 42 we illustrate the method of protecting the steam-jacketed Cornish engine cylinder.

The steam-jacket is surrounded by another casing of wood, the space between the two being filled with some bad conductor of heat, such as sawdust, ashes, or slag-wool. The whole is inclosed by a casing of brickwork, or by an air-tight cavity formed by building a thickness of brickwork at a few inches

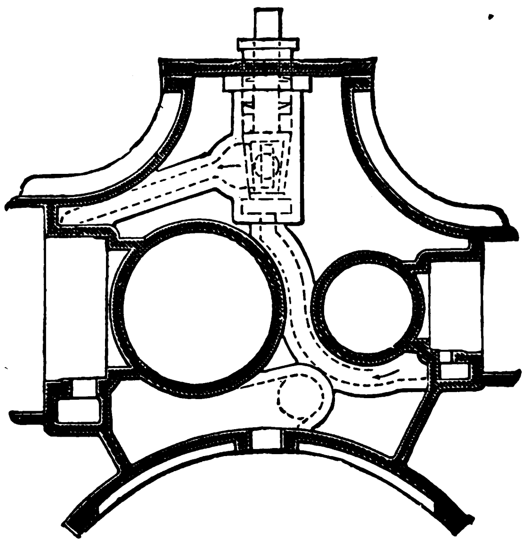


Fig. 61.—Compound traction engine cylinder.

distance, which is plastered on the outside and covered with wood panelling. The cylinder cover and bottom are also protected from the cooling influences of the air; the former being fitted with a false cap inclosing a thick layer of non-conducting composition. A small branch pipe, shown by the illustration, supplies steam to the stuffing-box.

The following sentence bearing on this subject is quoted from Hopkinson's *Guide*:—"To prevent the escape of heat by radiation, it is only necessary that the cylinder, and all parts of the metal which receive heat from the steam by contact or conduction, should have a clean metallic surface. Whoever has been much about steam-engines will have often felt that a dirty cylinder and engine generally, seemed to make the engine-room insufferably hot. Such is really the fact. If any one should doubt the statement that a clean polished metallic surface radiates less heat than a black and dirty one, let him try the experiment, and he will doubt no more. Cleanliness, therefore, is the handmaid of economy, and, at the same time, pleasant withal to look upon."

With these facts before us, it is our duty, previous to accepting any of the startling figures said to be the results of a practical and accurate engine test for and against steam-jacketing, to ascertain for ourselves:—(1) That the engineers and attendants engaged in the test understand the function of the jacket, and know how to use it, should it be so arranged that its action may be interfered with by them. (2) That the so-called jacket is really an efficient *steam-jacket*, possessing all the necessary requirements for obtaining the best possible results; in fact, it is a farce to merely say that the cylinder is steam-jacketed, but exact sectional drawings of the cylinder, and complete description of the supply and drainage pipes should be given, for, without such information, the publication of a lot of tables and figures teach nothing, and are of no practical value whatever.

Whenever the steam-jacket has been well applied and properly tested, its utility has been proved beyond a doubt, but, in too many instances we fear, some of the miserable counterfeit jackets we have alluded to, instead of the real article, has been tried, which explains the mistaken notions in vogue as to its utility, and the nonsense that is occasionally expressed in some quarters respecting it.

In this chapter we have alluded to several steam-saving appliances that are absolutely needed to make all steam-jacketed cylinders complete, and thoroughly effective:—such as steam-collectors, steam-traps, return steam-traps, dry steam generators, &c. More particulars of these fuel-economising agents are given in the Appendix.

CHAPTER VI.

THE ABUSE OF THE STEAM-JACKET—*continued.*

Defective Construction.

LET us see how the steam-jacket may be abused by mal-construction.

It has been our lot to have had (in addition to the designing of new engines) the superintendence of repairs to numerous portable, traction, and other engines for some years, during which time we have had a favourable opportunity for noticing the weak points in the construction of the engines of different makers; and it would be an easy matter to place on record the description of some very curious steam-jackets that have during this time been discovered; but such a catalogue of makeshifts and mistakes would not answer any good purpose were they recorded. We have chosen out of a great number, three cases under this head, to show how bad workmanship may interfere with or destroy the utility of the jacket; the first is the record of a cylinder having a flaw in it, attributable to incompetent moulding; the second case is the result of carelessness during the erection of an engine; while the third is an account of a badly-turned and bored cylinder liner and jacket, which were made in separate castings, and, when put together, being a very indifferent fit, did not constitute a tight joint between the two when tested under steam.

It is well known by practical men that there is considerable difficulty in procuring a sound casting from the foundry of a cylinder when cast with a steam-jacket round it: hence, to reduce this risk, the walls of the cylinder are made excessively thick: some makers of portable engines use a cast-iron wall of quite an inch thick for a cylinder but 9-inch bore. We need not be surprised to learn that these users of thick cylinder walls are somewhat disappointed in the results arrived at during the use of such jackets: for it has often been affirmed that these thick walls seriously interfere with the efficiency of the steam-jacket, as we have already alluded to.

The Engineer says that:—"The steam-jacket is useless if the walls of the cylinder are so thick that heat cannot be freely transmitted from the steam outside to the steam inside—the fault lies not in the jacket, but in the manner of making it: we must not condemn steam-jackets, however, because of incompetent moulders." In cases where the jacket and the cylinder are cast together, and the walls and partitions are of varying thicknesses, and, particularly, when there are any lumps of metal left in corners and other parts of the cylinder, the partitions are very likely to be "spongy," caused by the "drawing" of the metal during cooling; in some instances, a place of this sort is not detected until the engine is tried, or has been at work some time, when the flaw has commenced to allow steam to leak from one part of the cylinder to another, sometimes blowing from the jacket into the steam-chest or the supply-ports, which, of course, seriously interferes with the working of the engine. The only remedy in this case, and the one very often resorted to, is to cut off the steam supply from the boiler to the jacket. Here is the record of a troublesome steam-jacketed cylinder of this description being doctored, which we heard from the lips of the facetious party who effected the "cure," as he was pleased to call it; and, as we entertain not a doubt respecting the accuracy of the story, it will serve as a case in point for this part of the subject. A new eight-horse portable engine, made by a small firm, was sent out to a customer, having a faulty place in one of the walls of the cylinder between the steam-jacket and the slide valve-chest, which had either not leaked during the trial on the works, or it had not been discovered; but, unfortunately, very soon after the engine was put to work, it began leaking so rapidly that it was impossible to stop the engine when required, as there was provided no means of shutting off the steam from the jacket round the cylinder.

Complaints were at once despatched to the makers, who sent out a fitter "to look to the stop-valve gear," and ascertain the cause of the annoyance, and put the engine to rights; he soon found out that the stop-valve gear was in order, and that the steam gained access to the valves above the stop-valve through this faulty place in the cylinder partition.

After dropping the steam, taking off the steam-chest cover, and convincing himself that no patch could be put over the flaw, an idea (of which he is ever proud) at once suggested itself, and he took the cylinder off the boiler to put his happy thought into practice. Now the jacket of this cylinder was supplied with steam by means of a piece of 1-inch piping screwed through the arch plate of the boiler into the bottom of the jacket. By a little manœuvring, he managed to take out this pipe from the inside without the engine-driver, who was helping him, noticing the act; he then told this assistant that he had found out the cause of all the trouble, or, to use his own words, "I have found out a 'mare's nest,'" pointing to the hole through which the supply pipe had been screwed. "This hole has no business to be here, and must be stopped up;" his ignorant and confiding mate nodding assent.

He screwed and rivetted a plug into it, re-made the cylinder joint and the connections, steamed the engine, pronounced her cured, then took his leave of the driver, who, no doubt, is just as satisfied with his engine with a "dummy" jacket round the cylinder as he was with a real one, seeing that he has always been totally unaware of the jacket's existence, much less its use.

So long as this jacket *remains* as an air-space, it would be of some slight service in checking the radiation of heat from the working steam within the cylinder; but it is very probable that some of the steam, finding its way through the flaw from the valve-chest into this jacket space, would be condensed; in the course of time, therefore, the water resulting from this condensation would fill the jacket up to the level of the flaw, there being no means of escape at the bottom. It is needless to mention that the jacket in this state, viz., half filled with water, instead of being of some slight *service*, would be a positive evil.

Most of the jackets that are abused by incompetency, laziness, or carelessness, are rendered useless, owing to the accumulation of water in them, the water-jacket being by far the commonest type.

Here is the record of another type of jacket. The outside casing around one of the cylinders of a double portable engine, by another maker, was accidentally cracked during the erection of the engine (cracked cylinders are evidently not solely confined to the engines of Her Majesty's Navy), and, as a patch could not be put on the outside because the cylinders of this firm are not arranged for lagging—lagging being an admirable cloak for hiding such like "bodges," notwithstanding its utility, the following plan was adopted in this dilemma; the jacket space was filled up and rammed with rust cement through the core holes in the end, and the pipe for supplying the jacket of this cylinder was, like the one in the last case, plugged up, to prevent the possibility of any steam leaking through the cement and out at the crack.

We have heard of hot-air jackets, smoke-jackets, water-jackets, exhaust-jackets, and steam-jackets, but this is a novel one, viz., a cement-jacket,—a makeshift, truly, of doubtful utility.

Another instance of a leakage from the jacket to the cylinder, of rather a different nature, occurred on a large horizontal fixed engine made by a very small firm. The cylinder and bush were separate castings, the latter turned and the former bored to suit, but, owing to incompetency, or great carelessness on the part of the turner, the joint, after the bush was inserted, leaked all round when under steam. The cylinder was then put under a rusting process, or, to use the workmen's term, it was "pickled" in sal-ammoniac and water for some days; but all to no purpose, for, when steamed again, it leaked into the cylinder at each end. The engine was, we are told, sent away in this plight, for, unfortunately no diagrams were taken, so that this carelessness was not revealed to those who might have condemned such mal-construction, and have also prevented the engine being sent away in this manner.

Referring to the trials carried out on the steam-vessel "Meteor," Mr. List said:—"Steam-jackets were necessary. He warned our engineers to see that the liners were steam tight, as cases have occurred in which the liners of marine engines did not make a good joint in the casing. Such a piece of bad workmanship would neutralise any advantage that might accrue from the steam-jackets.

CHAPTER VII.

THE ABUSE OF THE STEAM-JACKET—*continued.*

Inattention on the Part of the Engine-Driver.

THE steam-jacket may be abused by carelessness on the part of the attendant, whenever its right action depends on his control. In large engines of one or two types the condensed steam from the jackets is generally carried away by means of a pipe having a cock in it, placed within the reach and under the control of the engine-driver, which is an unsatisfactory arrangement, because the chances are that the cock may not be opened at all, or not nearly often enough; an ignorant driver thus having it in his power to transform an efficient jacket into an efficient condenser, the result causing an enormous waste. It is very essential that the supply and drain pipes for the jackets should be so arranged that it is quite unnecessary for the engineer to interfere with them, or, as some one recently put it, "quite independent of a lazy or careless engineer." It is equally important that the opening and closing of these pipes should not be left to the discretion of the attendant, because of his love of meddling with, and experimenting upon, every detail of the engine under his charge; for, in these individuals, as in most other mechanics, where there is a minimum supply of knowledge, there is generally to be found a maximum amount of conceit, and no sooner is an engine placed under their charge than they find out a number of imaginary defects and details requiring improvement: this tampering with the engines very often ends in disaster.*

The following is an amusing instance, illustrating this trait in their character, given in a little book entitled: *The Engine Room, Who should be in it, &c.*, by an Old Hand, which we quote, although it is a slight digression.

"When at Galatz, in 1867, a boat was sent from the I——, of N——, with a request from her captain to ours to allow me to go on board of her, as they could not start the engines: our captain being agreeable, I went. On getting on board the captain introduced me to the engine-room, where, in the faces of all, was a look of half bewilderment. The captain, being a true representative of the north country vernacular, said to the chief: 'Winna she gan yet; what's wrang

* Since writing the above remarks respecting the omission of duty by the engine-driver, and the delight he generally evinces for trying his hand at the improvement of parts, &c., causing steam-jackets either to be neglected altogether or else shut off, we have read Sir Frederick J. Bramwell's two excellent lectures on "The Steam-Engine," Macmillan, wherein he mentions the engine-driver's power in many cases to frustrate the designer's intentions, and, consequently, to waste his employer's fuel. Here is the sentence referred to:—"I do not think that the economy of the compound engine really lies in its principle, but that its economy in practice arises from another thing altogether, and that is this, that by making a double cylinder engine you put it out of the power of an ignorant engine-driver to do away with that which you want—high expansion; he must get high expansion; he is compelled to use it whether he likes it or not; whereas, with the single cylinder expansive engine, he has the power to follow the dictates of his own ignorance, and, as a matter of observation, I have hardly ever seen such an engine left to the control of an engine-driver but it invariably worked at the lowest possible grade; and, as I have said, I believe that this withdrawal of control is, to a large extent, the secret of the success of the compound cylinder engine."

wi' her?' 'She's a' het,' says the chief. 'Dinna ye think the improvement hes out te de wi't?' says the captain. 'Na, na,' says the chief, 'it hes nout te de wi't, she's fu' o' san.' During this colloquy the reversing wheel was turned repeatedly, but to no purpose. I asked the captain what improvement he alluded to; he told me that his engineer had got some undefined notion from the engineer of another steamer, that the only way to save his coals was to 'gie her sma' steam,' and that he had done something 'wi' the slides,' but what that was he could not say. It was proposed by the captain, at my suggestion, to lift the casing cover. What a look of offended dignity the chief assumed! Much against his will, the steam was blown off, &c., &c., and the cover lifted, when the reason of the engines not starting was at once apparent. Three-quarters of an inch of wrought iron had been pinned (and very badly) on to the ends of each slide valve! I asked the chief if he had done anything with the eccentrics. 'Dune out wi't sheaves? Na, na, they're a' reet.' The economical pieces were taken off, and she proceeded the following day. I learnt this chief was 'a converted fireman.'"

Our steam-ship companies have vastly improved their machinery, adopting compound engines with steam-jacketed cylinders. The steam-supply and the drainage-pipes of these jackets are fitted with cocks. But, while they have taken care to introduce first-rate machinery into their vessels, they have entrusted these engines to the tender care of drivers who, whatever knowledge they possess of marine engines and machinery in general, display the utmost lack of information respecting the steam-jacket; and the following accounts, while showing how they manipulate the drainage cocks of the jackets placed under their charge, unmistakably reveal this lack of knowledge.

One or two authorities on marine engineering have expressed doubts as to whether the jackets on board our steam-vessels received proper attention at sea. To confirm these doubts a writer in *Engineering* gives the results of his observations, extending over several years, in connection with the steamers of a large company,* from which we gather the following particulars. Mr. Coath says :—" My interest in the *use* and *abuse* of the steam-jacket having been powerfully aroused some years ago, I have availed myself of every opportunity since for observing in how far the benefits appertaining to the use of a steam-jacket are actually obtained in practice; or, in other words, in how far steam-jackets are 'used' or 'abused.' From my notes I find that up to date my observations extend to **twenty-three** steamers, in which, with **two** exceptions, I find the steam-jacket more or less abused, and, in some cases, to such an extent as to render its existence a cause of positive loss, so that, under the circumstances, it would have been better not to have applied it at all.

" My *modus operandi* has been, in course of conversation with a chief, or naval engineer, to elicit how he manages 'his jacket.'" The results of these observations are briefly as follows :—

In thirteen steamers *he found the drain-pipe full open to the condenser,* and the steam-supply cock to the jacket partly open.

In three steamers the jackets were only used on starting to warm up the cylinders, and, when the engines were well under way, the steam-supply was totally closed, *and the outlet opened to the condenser.*

* Mr. D. D. Coath in *Engineering*, 7th July 1882.

In two cases the inlet was left wide open, *and the drain-pipe kept closed, and the condensed steam was blown out once a watch.*

In three instances no trouble was taken with the jacket, because the engineer-in-chief could not see what difference it made.

In two steamers the engineer said :—"I work with the jacket steam full open, and regulate the drain so as to as nearly as possible keep the jacket free from water without wasting steam by passing through."

It will be seen from the above remarks that, in about 70 per cent. of the cases observed, the existence of the jacket is a positive evil,—indeed, in the first cases named, this evil amounts to surrounding the cylinder by the condenser, for the so-called steam-jacket virtually forms part of the condenser.* In the third case it amounted to the partial use of a water-jacket.

The following paragraph is quoted from a letter, signed A. M., in *Engineering*, for 10th April 1874. "Those engineers who advocate the disuse of steam-jackets do it merely to save trouble to themselves, never thinking of the amount of money they cost their owners; so long as the engine gives no bother, a few revolutions is nothing to them. We heard of an amusing instance the other day of an engineer, when asked as to his steam-jackets, answered that they were shut off to keep the engine-room cooler; and of another, when the maker of the engines visited the engine-room, he found the jacket space filled with water, doing the duty of a condenser on a small scale. The maker of the engines put the question :—Of what use is my spending so much money on steam-jacketing

* See Mr. Bryan Donkin's experiments, recorded in the next chapter.

when owners will not see the intention carried out, although it is for their own benefit?"

It is perfectly astounding to think that the ridiculously simple matter of attending to the steam-jacket's proper drainage should be so ignorantly tampered with by so-called engineers of the present day. By this lack of knowledge, or meddlesome interference on the part of engine-drivers, the designer's purposes are frustrated, causing the intended steam-jacket to be transformed into a water-jacket or a surface-condenser, and resulting in such an extravagant waste of steam, which could not be equalled by the neglect or the mismanagement of any other detail of the steam-engine.

The steam-jackets of our marine engines, by having their drain-pipes imperfectly fitted and interfered with, instead of conducing to economy are made to act as wasteful dissipators of steam, the amount of such loss being beyond computation.

One writer says:—"I should advise those who have steam-jackets round the cylinders of their engine, to see that the drains and supply are properly placed, that is to say, independent of a careless or lazy engineer.

Messrs. R. Napier & Son take the steam from the boilers, and drain to the boilers; the cocks or valves are opened when the ship leaves the dock or wharf, and are not closed until arrival at destination." Mr. Rich says:—"Purchasers and users of steam-engines frequently did not appreciate the advantages to be derived from steam-jackets, and would not incur the extra cost; and, even when steam-jackets were supplied, they were too often tended by engine-drivers, who, from ignorance or negligence, failed to realise the possible advantages. Indeed, from personal observation, he believed that not even one-half of the steam-jackets in existence were worked efficiently."*

We have pointed out the manner in which the steam-jacket has been rendered of little or no value on account of faulty designing, defective construction, and inattention. It would seem, judging by past experience, that *incompetent designing* is by far the most common cause of the inefficiency of the steam-jacket. If any one will take the trouble to examine the steam-jacket on various classes of engines, he will find more examples of wretched scheming than could be found connected with any other detail of the steam-engine. From this it is self-evident that the requirements of efficient jacketing are rarely understood, but this ignorance may be partly accounted for from the fact that little or nothing has been written on this part of our subject: the steam-jacket has been mentioned by various writers on the steam-engine,—there has also been much written at various times respecting its utility—but very little has been said concerning the requirements necessary to render it of service: in other words, no one has, to our knowledge, stated how the steam-jacket should be arranged and applied.

In order, therefore, in some measure to supply this want, in Chapter V. we have enumerated many of the chief points of importance which it is necessary should be strictly attended to, both by **Designers, Manufacturers,** and **Owners** of steam-jacketed cylinders, in order to produce and keep them in efficient working condition, so that the object for which they are applied, viz., the economy of fuel, may be fully realised.

As the greatest responsibility rests with the

* "Engines for Pumping:" paper read before the Inst. of Civil Engineers by W. E. Rich, Esq., M.I.C.E., 1884.

draughtsman, how very important it is that he should endeavour to thoroughly and conscientiously work out the details of engines, ever aiming at the highest results, remembering that every detail of machinery illustrates the mind, and, to some extent, the character of the designer; yes, to engineers, these parts of engines express more intelligibly than words can even, the designer's thoughtfulness and wisdom, or his haste and ignorance; the smallest detail unmistakably exhibits every evidence of care that has been bestowed in the drawing office on its production. Let us all, therefore, aim at perfect efficiency and complete success.

> "'Tis not in mortals to command success;
> We will do more—deserve it."

By careful designing we may, to a large extent, perform our part of the "duty that devolves upon scientific mechanical men, viz., that of preventing the scandalous waste of fuel that now, alas, too frequently occurs."

CHAPTER VIII.

PRACTICAL PROOF OF THE EFFICIENCY OF THE STEAM-JACKET.

IT is by actual experiments alone that the value of the steam-jacket can be shown, for very little dependence can be placed upon the results arrived at by theoretical investigations, this being unfortunately one of those questions where figures may be made to represent almost anything the theorist pleases.

Watt did not ascertain the value of the steam-jacket by calculation, but by actual tests; and, strange to say, the very first theory raised against its use, viz., Tredgold's, proved to be incorrect.

Numerous experiments have been made during the last fifty years on all classes of engines, and, whenever engines have been accurately tested with and without steam in the jackets, the results invariably prove the economy of thorough steam-jacketing.

It has often occurred that, when the jackets of steam-engines have been shut off for a short time by accident or for repairs, it has been necessary, in order to keep up the speed of the engine, to alter the expansion valve, so as to give a later cut-off, and, consequently, the boilers have had to be fired harder to keep up the steam. We could give numerous cases of this kind, proving the value of the steam-jacket, when no such proof was sought or expected to be realised.

Watt, in his early practice, discarded the steam-jacket for a short time, but resumed it again, because he found its discontinuance caused a perceptible waste of fuel. It is a well-known fact that, in Cornwall, any attempt made to discontinue the use of the steam-jacket round the cylinder has been attended with a palpable loss of power, although the radiation of heat seemed to be effectually prevented by the use of the best non-conducting substances. "Trevithick stated that there was 40 per cent. increase in the duty of Watt's engines, when worked expansively, from putting a steam-jacket on the cylinders." *

In some experiments on a small-beam condensing engine at Mr. Penn's flour-mill at Lewisham, in 1849, Mr. Farey said Mr. Penn's comparative trials with and without steam in the steam-case had shown the advantage of supplying steam around the cylinder to be very considerable, although the steam pressure used in this instance was only 6 lb.† Mr. Edward Humphries conducted some experiments at Woolwich Dockyard nearly forty years ago, in which the weight of feed-water used per horse-power was carefully noted, which showed that there was a positive loss in attempting to work with any degree of expansion in the unjacketed, slow-going, large cylinder geared engines in use in the British Navy at that time, and adopted in the American Navy up to a more recent date. At a meeting of the Manchester Association of Engineers, held a few years ago, a paper was read on the "Steam Jacket," and, during the discussion, the

* Scott-Russell on *The Steam-Engine*, 1841.

† Mr. Bryan Donkin in the discussion on Rich's paper on "Pumping Machinery," read before the Institution of Civil Engineers.

following fact was related by one of the members:—"When the steam was turned off from the jacket of an engine, used by the Fairbairn Engineering Company, they found that they lost power, and the boilers would not supply sufficient steam, the stokers were unable to keep up the steam; when the jackets were turned on again, the engine and boilers easily performed their allotted task."

The following extract from a letter from Mr. Pinchbeck appeared in *Engineering*, which clearly shows the advantages of steam-jacketing:—"It so happened that the steam-trap connected with the steam-jacket required repairing, and, to do this, the steam had to be shut off: while these repairs were going on, I found the consumption of coal per day increased from about 14 cwts. to nearly 20 cwts.; I also found the engine incapable of performing the same amount of work as it did when the steam-jacket was in use; I had, therefore, to alter the cut-off valve to admit more steam. As soon as the repairs were effected, the steam was re-admitted into the jacket, upon which the consumption fell again to 14 cwts. per day after the expansion valve had been put back to its previous position. This experiment left no doubt in my mind as to the economical advantage of the steam-jacket, and it will take a very great deal of *argument* to create a doubt that I am mistaken."

The following is quoted from Hopkinson's *Engineers' Guide*:—"If the steam be for a short time shut off from the jackets of the engines of Sir T. Salt, Bart., and Co.'s, of Saltaire, unknown to the stokers, they discover by the heavier firing required that something is amiss, and soon begin to inquire what is the matter."

Although these instances show the advantages of steam-jacketing, and are practical proofs of its efficiency, yet we will now give the results of actual and accurate trials of engines of every type, which furnish more weighty testimony in favour of thorough steam-jacketing.

Combe, a French engineer, as far back as 1843 appears to have been one of the first to make a careful feed-water experiment on a small condensing engine, with a cylinder 15¾-inch diameter. The result was an economy in feed-water of 42 per cent., due to this cylinder being steam-jacketed. Expansion was about 20 to 1; pressure of steam 57 lbs.*

Mr. Hirn, about 1854, made some experiments on a compound-condensing beam-engine, indicating about 104 horse-power and 80 horse-power, with and without steam in the jacket, and found an economy in the feed-water of 24 per cent. in favour of using steam in the jacket. Expansion, 4 to 1; the steam pressure was 60 lbs. per square inch.†

Mr. Gordon M'Kay, U.S.A., about 1858, made experiments with a little steam-engine (non-condensing) with a cylinder only 2 inches in diameter, and found the economy due to steam-jacketing this cylinder was 20 per cent. The steam pressure was 115 lbs. per square inch.‡

Messrs. Bryan Donkin & Co. have, from time to time, carried out a large number of accurate experiments to show the economy of using the steam-jacket, and we shall make use of the tables of results they have published very soon. In 1859 and 1870 they carried out experiments on a compound-condensing beam-engine, with cylinders 7½-inch and 14-inch diameter. The economy due to steam-jacketing these

* Mr. Bryan Donkin in the discussion of Mr. Rich's paper on "Pumping Machinery," read before the Institution of Civil Engineers, 1884.

† *Bulletin de la Societe de Mulhouse*, No. 133, 1855.

‡ *Journal of the Franklin Institute*, 1859.

two cylinders was found to be 30 to 38 per cent. The feed-water was carefully measured. Expansion, 10 to 1; and the steam pressure was 45 lbs. per square inch. In two other experiments the expansion was kept 9 to 1. The steam pressure was 45 lbs. per square inch. The temperature of the condensing water was also kept the same, and the results were 24¼ lbs. of steam required per indicated horse-power per hour with steam in the jackets, and 39½ lbs. without steam in the jackets.

In 1867 the following particulars were obtained during a trial of an eight horse-power nominal portable engine, fitted with a steam-jacket, and provided with the means for turning steam into the jacket or not as required. The weight suspended upon the brake was exactly the same in both experiments. Coal allowed in both experiments was 1 cwt. Actual horse-power developed on the brake = 16 horse-power. *Without* steam in the jacket 20,665 revolutions were made; running time, 2 hours 11 minutes. *With* steam in the jacket 24,920 revolutions were made; running time 2 hours 20 minutes. The barrel of the cylinder only was steam-jacketed, and not the covers.

The next table shows the results obtained from careful experiments made in 1868 by Mr. Farey and Mr. B. Donkin, jun., upon a double cylinder-jacketed condensing beam steam-engine of 30 horse-power nominal, constructed by Messrs. B. Donkin & Co., Bermondsey, London. The dimensions of the engine are as follow:—

	Ft.	In.
Diameter of high-pressure cylinder,	–	$13\frac{3}{16}$
Stroke of high-pressure cylinder, .	3	$3\frac{3}{8}$
Diameter of low-pressure cylinder, .	–	24
Stroke of low-pressure cylinder, .	4	6

TABLE VIII.

30 HORSE-POWER NOMINAL COMPOUND ENGINE.	With Steam in Jackets.	Without Steam in Jackets.
Indicated horse-power diagrams, taken every half-hour,	46·21	27·78
Pressure of steam in boiler-house (mean),	40·9 lbs.	$41\frac{1}{4}$ lbs.
Duration of experiment, in hours,	10	10
Revolutions of engine per minute (mean),	32·48	32·02
Vacuum in condenser by mercurial gauge (mean),	27 in.	$27\frac{1}{4}$ in.
Condensing Water. Temperature. Going in from a deep artesian well,	53°	53°
Condensing Water. Temperature. Coming out, taken photographically (mean),	89·54°	90·91°
Condensing Water. Temperature. Degrees of heat put into condensing water,	36·54°	37·91°
Condensing Water. Quantity. Quantity of water per minute measured over a tumbling bay 6 inches wide; height recorded photographically, in pounds,	408·32	404
Condensing Water. Heat Units. Units of heat per minute = weight of water × rise of temperature,	14,920	15,329
Condensing Water. Heat Units. Units heat per minute per indicated horse-power,	322·87	552
Water from Steam Jackets. Temperature. Taken every quarter of an hour,	207°	None
Water from Steam Jackets. Quantity from a Steam Trap. Total pounds weighed,	$1,783\frac{1}{2}$	
Water from Steam Jackets. Quantity from a Steam Trap. Pounds per minute,	2·97	
Feed-water. Temperature. Taken every ten minutes (mean),	$74\frac{1}{2}°$	$68\frac{3}{4}°$
Feed-water. Quantity. Total water evaporated in pounds,	$10,404\frac{1}{2}$	9,094
Feed-water. Quantity. Pounds per hour,	1,040·4	909·4
Feed-water. Quantity. Pounds per minute,	17·34	15·157
Description of boiler:—Vertical tubular,	...	Same boiler
Total quantity of coal burnt, accurately weighed in pounds,	1,204	1,058
Pounds of water evaporated per pound coal burnt,	8·72	8·6
Pounds of coal per indicated horse-power per hour,	2·61	3·8
Pounds of water evaporated from temperature of $74\frac{1}{2}°$ per indicated horse-power per hour,	22·51	32·72
Rates of expansion, allowing for clearances, about,	11 to 1	14 to 1
Number of indicated diagrams taken, four always taken at once, two at top and two at bottom of the cylinders,	84	88
Temperature of outer air, fine day, in degrees	67	61
Temperature of steam engine-house, in degrees	76	74
Height of barometer, in inches	30	30·1
Lubrication, in pints	Tallow, $1\frac{1}{2}$; Oil, 1	Tallow, 2; Oil, 1

Comparing 32·72 lbs. with 22·51 lbs. = 10·21 saved per indicated horse-power per hour; and, comparing 10·21 lbs. with 32·72 lbs. = 31 per cent. less feed-water or steam by the use of the jackets and very much more power.

It is impossible to have more convincing proof of the efficiency of the steam-jacket than that given in the very interesting experiments, carried out in 1869, by Messrs. Donkin and Farey, on a beam engine working as a high-pressure non-condensing engine at Messrs. Donkin's factory, given in *Engineering*, 16th October 1874, from which we quote the following particulars:—These experiments are valuable, seeing that they "show the effect of steam-jacketing on a non-condensing engine working at moderate degrees of expansion, and under conditions which agree with those existing in a large number of engines which are to be found at work at small factories, &c." The cylinder is $7\frac{5}{16}$-inch diameter and 2 ft. $2\frac{1}{8}$-inch stroke, and steam-jacketed. The cylinder and piston were in good working order and free from leakage when the experiments were made. The revolutions made by the engine were registered by a counter, and the indicator diagrams were taken by two indicators driven from the parallel motion direct, and the springs of which had been carefully tested. The expression "full steam" corresponds to a cut-off at about two-thirds of the stroke.

"The great thing shown by the results, however, is the decided effect exercised by the steam-jacket, even when working with full steam, or with full steam throttled. Under each of these two conditions it effected a saving of nearly 18 per cent., while when working with a cut-off at three-eighths the stroke, the saving rose to nearly 28 per cent. The great increase

TABLE IX.—*Experiments on a Beam Engine, working as a High-Pressure Non-Condensing Engine, at Messrs. B. Donkin & Co.'s. Works, London, S.E.*

	Cut off at ⅜ths of Stroke.		Full Steam.		Full Steam Throttled.	
	With Jackets.	Without Jackets.	With Jackets.	Without Jackets.	With Jackets.	Without Jackets.
Number of experiments, ...	1	2	3	4	5	6
Duration of experiments, ... in hours	4½	4½	2¾	2¾	3	3
Total indicated horse-power, ...	6·41	4·94	10·57	8·90	4·52	5·04
Pressure of steam in boiler-house, . in pounds	45	45	45	45	45	45
Revolutions per minute, ...	48·31	44·81	51·17	46·82	45·63	47·00
Total quantity of water from jackets, in pounds	240	nil	·131	nil	141	nil
Quantity of feed-water evaporated from boiler, ... in pounds	1625·6	1593·7	1545·9	1530·0	1004·0	1259·0
Quantity of feed-water evaporated per indicated horse-power per hour, . . . in pounds	56·35	71·69	53·18	62·51	74·04	83·28
Number of indicator cards taken, ...	38	38	22	22	26	24
Temperature of outer air, ... in deg. F.	43	35½	32½–33½	31½–32½	37	35½
Temperature of engine-house, . . in deg. F.	62	59–66	65½–74	59–63	67–80	61–65
As shown by Indicator, } Initial pressure of steam in pounds	42	39	44½	41	25	27
As shown by Indicator, } Final pressure of steam in pounds	8	6½	27	25½	10½	14
Mean pressure of steam in cylinder for calculating indicated horse-power, . . in pounds	23·97	19·93	37·31	34·30	17·89	19·35
Feed-water required per hour, calculating indicated horse-power, ... in pounds	331·2	324·1	532·16	526·36	304·68	389·68
Feed water required per indicated horse-power per hour, ... in pounds	51·66	65·62	50·34	59·14	67·40	77·31

in the mean cylinder pressure, due to the use of the steam-jacket, is also remarkable, and, altogether, the results are of much interest."

In 1870 Messrs. B. Donkin & Co. made experiments with a single cylinder condensing-engine, cylinder 7¼-inch. diameter. The economy due to steam-jacketing the cylinder was about 19 per cent. The feed-water was measured. Steam pressure, 45 lbs. per square inch. Expansion, 2 to 1.*

In 1871 experiments were carried out on a large single cylinder condensing pumping-engine, when a gain of about 13 per cent. was recorded, due to steam-jacketing. Steam pressure, 35 lbs. per square inch.

The improvements which have been made in portable engines during the last few years, both in design and construction, are well known to everyone; these improvements have resulted in increased economy of fuel. A large percentage of this increased efficiency is due to the now almost universal practice of steam-jacketing, combined with careful lagging of the cylinders. In the following Table (No. X.) we have reproduced the sizes, particulars, and results of trials of four portable engines tested, among many others, at the Royal Agricultural Society's Show at Cardiff, 1872. Two of these engines were fitted with steam-jacketed cylinders, the other two were not jacketed. The difference in the valve gearing is noticed in the table. Particulars of the *prize engines are not given* in the table, or the results would have been more marked than they already are; but, knowing that the prize engines had been specially built for racing, and contained several details too refined and fragile for every-day use, we prefer to give particulars of four com-

* Mr. B. Donkin, in the discussion on Mr. Rich's paper on "Pumping Machinery," read before the Institute of Civil Engineers, 1884.

mercial engines. It is impossible to state what proportion of the decided advantage in economy, which the jacketed engines showed over those unjacketed, was attributable to the steam-jacket; undoubtedly, the valve gear in some measure contributed to the improvement.

TABLE X.—*Four Portable Engines tested at Cardiff*, 1872.

R.A.S.E. Catalogue Number,	5024	4959	4834	2950
Nominal horse-power,	8	8	8	8
Maximum steam pressure in lbs.,	80	80	70	70
Heating surface in fire-box in square feet,	26·3	35·4	28·6	27·4
Heating surface in tubes in square feet,	257·2	133·0	142·0	102·4
Total heating surface in sq. ft.,	283·5	168·4	170·6	129·8
Diameter of cylinder in inches,	8½	8⅝	9	9½
Length of stroke in inches,	12	12	12	13
Cylinder,	Jacketed.	Jacketed.	Unjacketed.	Unjacketed.
Valve gear,	Automatic expansion	Automatic expansion	Ordinary slide-valve.	Ordinary slide-valve.
Mean boiler pressure in lbs.,	80	80	63	70
Indicated initial pressure in lbs.,	74	73	41·6	47·2
Indicated mean pressure in lbs.,	31·23	33·9	19·6	25·8
Mean revolutions per minute,	168	114·2	122·6	116·1
Mean indicated horse-power at actual speed,	18	13·6	9·1	13·8
Coal used per hour in lbs.,	47·2	38·8	75·5	67·2
Coal used per indicated horse-power per hour,	2·62	2·85	8·3	4·8
Weight of steam used per indicated horse-power per hour,	25·9	29·7	35·5	37·5
Time actually running in hours,	4·9	4·20	1·29	2·30

However, no engineer now would attempt to run an unjacketed single cylinder portable engine in a trial against a steam-jacketed one, no matter how many refinements in the valve gearing the unjacketed engine might possess.

Messrs. B. Donkin & Co., about 1872, found in a compound-condensing engine an economy due to the steam jackets of 25 per cent., the engine indicating 140 horse-power with jackets, and 90 horse-power without jackets. Steam pressure, 40 lbs. per square inch: expansion 4 to 1.

Particulars of the following tests made in November, 1873, were published in *Engineering*, 10th April 1874.

Compound-Condensing Marine Engine made by Messrs. Napier & Sons.

Steam-Jackets off.	Steam-Jackets on.
Pressure in boilers, 58 lbs. Vacuum, 27-inch. Revolutions per minute, 58. Cut-off high-pressure cylinder, ·55. Indicated horse-power, 1031·65.	Pressure in boilers, 58 lbs. Vacuum, 27-inch. Revolutions per minute, 63. Cut-off high-pressure cylinder, ·55. Indicated horse-power, 1184·44.

The consumption of coal is invariably kept the same during the day of trial; the weather also is studied, so that, if possible, the ship may be under the same conditions during the trial. The correspondent who supplied the information says:—"I am aware of other eminent makers who get similar results from steam-jacketing. I hope the above results will convince those of your readers who waver as to the benefits of steam in the jackets."

The same correspondent, at a later date, says:—"In exhaustive trials, conducted under my own care, the saving arising from the use of the steam-jackets amounted to 15 per cent. As to the benefits arising from steam-jackets during a voyage of fifty days, I have seen the gain to be from 25 to 30 knots per day."

We now give particulars of trials carried out during the early part of 1874, by Mr. Hallawer.* These experiments were made on a couple of Corliss engines, of identical dimensions and design, the only difference

* *Bulletin de la Société Industrielle de Mulhouse.*

being that the cylinder of one was steam-jacketed and the other was not.

Diameter of cylinders, 20·08 inch. Length of stroke, 41·73 inch. Speed, 55 revolutions per minute. Cut-off, one-tenth of the stroke.

The initial pressure was practically the same in both cylinders; the cut-off was alike in both engines, yet a far higher mean pressure was obtained in the engine fitted with a steam-jacketed cylinder, as is always the case, owing to the influence of the jacket; the consumption of water per effective indicated horse-power in the two engines being nearly as 4 to 3.

Two Separate Corliss Engines.	Engine with Cylinder Jacketed.	Engine with Cylinder not Jacketed.
Absolute initial pressure in cylinder,	74·3 lbs.	73·3 lbs.
Absolute ind. horse-power developed,	101·18	69·01
Effective ind. horse-power developed,	83·15	56·32
Water consumed per absolute indicated horse-power per hour, .	17·88 lbs.	23·58 lbs.
Water consumed per effective indicated horse-power per hour, .	21·93 lbs.	28·92 lbs.

The above results, as will be seen at once, obtained from an entirely different type of engine, afford further evidence of the benefits derived from steam-jacketing.

The following Table (No. XI.) is extracted from the record of some experiments, made by Mr. Charles Emery, on the engines of the United States Coast Survey steamer "Bache," in the year 1874. The engines were compound, the high-pressure cylinder having a diameter of 15·98 inch., the low-pressure cylinder being 25 inch., and the stroke of both being 24 inch. During part of the trials, the large engine was used alone as a simple single-cylinder engine, with and without steam in the jackets. During the remainder of the trial the engines were worked compound, the large cylinder with and without jackets; the high-pressure cylinder had no jacket. From an inspection of this Table (No. XI.), we see that, under all circumstances, whether the engine was worked simple or compound, a considerable saving was effected by the use of the steam-jacket, when corresponding rates of expansion are compared. For instance, when worked compound, about 3 lbs. of water was saved per indicated horse-power per hour, being at the rate of about 13 per cent.; while in the case of the simple engine worked at the higher rates of expansion, as much as 22·5 per cent. was saved. Mr. Emery carried out tests on other marine engines at about the same period, and the results, as given in the published statements, conclusively proved the efficiency of the steam-jacket. We are indebted to Mr. Holmes's excellent treatise "On the Steam-Engine" for Table XI., and the remarks.

Messrs. B. Donkin & Co., in 1875, during experiments made on a compound-condensing horizontal engine, the high-pressure cylinder 6 inch. diameter, low-pressure cylinder 10 inch. diameter, found that by applying steam to the jackets of both cylinders, the consumption of steam was reduced 32 per cent. Steam pressure, 43 lbs. per square inch; expansion, 8 to 1.

From particulars given in *Bulletin de la Société de Mulhouse*, 1878, of a test carried out on a single cylinder Corliss condensing engine, diameter of cylinder 24 inch., the results recorded in favour of steam-jacketing the cylinder ranged from 21 to 30 per cent.; steam pressure was 60 lbs. per square inch; expansion, 6 to 1.

TABLE XI.

	Simple Engine.							Compound Engines.						
	Without Jackets.			With Jackets.				Without Jackets.			With Jackets.			
Boiler pressure, ...	81	79·6	78·1	80·8	81	79·5	30·9	82	80·3	80·3	81·4	80·3	80·2	80·1
Vacuum in condensers, . .	24	22·78	24·2	24·66	25·28	25·5	24	24	24·3	24·65	24·5	26·5	26·5	26·6
Revolutions per minute, . .	37·3	44·9	47	39·9	46·2	53·8	45·3	42·6	47·7	49·3	38·9	48·2	53·2	56·3
Indicated horse-power, . .	47·2	71·8	89·1	54·8	74·6	116	66	55·9	77	85	46·4	77·4	99·2	110·5
Ratio of expansion, . . .	11·8	7·6	5·3	12·6	8·57	5·1	2·18	9·14	6·65	5·63	16·8	9·2	6·97	5·7
Water used per indicated horse-power, including drainage from jackets and reservoir in lbs., ...	35	29·6	26·25	27·1	24	23·15	34	23·76	23·04	23·2	25·1	20·7	20·33	20·36
Ditto, as calculated from diagrams in lbs., . . .	21	17·75	17·35	16·4	15·57	16·25	24	12·7	12·3	12·3	18·5	15·7	14·8	15·25

The following trustworthy and interesting particulars of experiments made on a pair of condensing engines, belonging to the world-known establishment of Sir Titus Salt, Bart., Sons & Co., Saltaire, are copied from a reliable source:—They are beam engines of the simple principle, in pairs of two cylinders each. The cylinders are each 50 inch. diameter by 7 feet stroke, with a speed of 30 revolutions per minute, making a piston speed of 420 feet per minute. The valves are the Corliss type, with Inglis & Spencer's patented improvements, and made by Messrs. Hick, Hargreaves & Co. The cylinders are steam-jacketed, both around the cylindrical part and at the top and bottom, so that they are entirely surrounded with steam at the boiler pressure.

These experiments were made by Mr. George Salt, to determine the difference in the economy of the engines with and without the jackets:—

	With the Jackets.	Without the Jackets.
Water from the condensation of steam in the jackets for the week, in tons,	16·85	...
Coal used for the week, in tons, . .	72	84
Water evaporated for the week, in tons,	510·2	584·7

The proportion of coal and steam consumed in these cases was 7 without steam in the jackets to 6 with steam in the jackets. The weight of water evaporated without steam in the jackets amounts to 584·7 tons per week, all of which passes through the cylinders, while with steam in the jacket it was 501·2 − 16·84 = 484·35 tons per week only passed through the cylinders. This leads to the inevitable conclusion that, without steam in the jackets, not only is there a greater aggregate consumption of steam in the ratio of 7 to 6, but also that $584{\cdot}7 - 484{\cdot}35 = 100{\cdot}35$—being a little more than one-sixth of the whole quantity consumed—is permanently condensed in the cylinders, and passes out in the state of water, not being re-evaporated. The condensation from the jackets was 16·85 tons, or a little more than one-thirteenth of the whole consumption.

Messrs. Donkin & Co. proved that it was most essential in a compound engine that the low-pressure cylinder should be thoroughly steam-jacketed, in order to secure the best results, the economy resulting from the application of a steam-jacket to the low-pressure cylinder being under some conditions four times as great as that obtained by jacketing the high-pressure cylinder alone.

We now give some very interesting particulars of trials, carried out in 1881 on a Corliss engine, having a cylinder 24-inch. diameter and 48-inch. stroke. Ratio of total clearance space to volume swept by the piston, 2·48 per cent.

(1) Both sides and ends of the cylinder were steam-jacketed, the jackets receiving steam by a pipe quite detached from the supply-pipe to the valve-chest. The jackets had two steam-traps, one automatic and one requiring to be emptied by hand.

(2) Arrangements were made by which the piston also could be steam-heated, the condensed steam being discharged through an automatic trap.

(3) The engine was one of a pair, exactly similar, working on opposite ends of the same shaft, with cranks at right angles to each other. The second engine was not tested, but was kept at work, so that the speed might be maintained constantly without changing the cut-off in the engine under trial.

Steam was supplied to the engines by two similar but quite separate boilers, the steam-pipe of each inclining downwards from the engine-room the whole distance to the boiler-house, so as to allow the steam condensed in the pipes to run backwards into the boiler. The following Table (No. XII.) gives the results of experiments on the consumption of steam, based on the direct measurement of the feed-water:—

TABLE XII.

Date.	Duration of experiment in hours.	Mean boiler pressure in pounds.	Mean number of revolutions per minute.	Mean indicated horse-power.	Feed-water supplied per indicated horse-power per hour.	REMARKS.
April 8	10·71	66·2	49·2	126·6	24·98	No steam in jacket
April 10	10·66	67·7	50·0	157·1	19·85	Steam in jacket only
April 11	10·76	66·8	50·0	158·7	18·96	Steam in jacket only
May 6	5·68	67·7	49·9	81·9	27·21	No steam in jacket
May 6	5·07	68·1	50·4	100·8	18·96	Steam in jacket only
May 7	10·87	67·9	50·4	103·7	18·51	Steam in jacket and piston
May 8	10·59	67·2	51·2	134·2	18·53	Steam in jacket and piston

April 8, the steam-jacket was not used, the governor was fixed, the speed kept constant; April 10 and 11, the steam-jacket in use, piston not heated, governor fixed, the speed kept constant; May 6 (morning), the steam-jacket was not used, the piston not heated; May 6 (afternoon), the steam-jacket was in use, the piston was not heated; May 7, the jacket was in use and the piston was heated; May 8, steam in both jacket and piston, but work reduced to a minimum.

Working under average conditions:—April 8, without the jacket, the engine developed 127·6 horse-power, with a consumption of 24·7 lbs. of steam per indicated horse-power per hour. Under exactly similar conditions, except the jacket in use, on April 10, the work rose to 157·13 horse-power, and the consumption fell to 19·85 lbs. of steam per indicated horse-power per hour, showing 19·6 per cent. gained by the jackets.

This was in spite of a somewhat defective action of the steam-traps, which, being put right on the next day (April 11), the consumption fell to 18·96 per indicated horse-power per hour, a gain of 23·5 per cent. Comparing the mean of the two days' work in each case, we find that the same engine did 23·7 per cent. more work with the jackets than without them, with a saving of steam per indicated horse-power per hour of 21·6 per cent. Comparing the working of the engine on the morning and afternoon of 6th May, when the power was smaller, the results are even more striking.

The power is raised from 81 indicated horse-power to 100·3 indicated horse-power, or 23·7 per cent., while the water used per indicated horse-power per hour has fallen from 27·2 to 18·96 lbs., or 30·2 per cent. No economy appears to have resulted from heating the piston. The above trials were conducted by MM. Walker Meunier (chief engineer of the Association Absaciene des Propriétaires d'Appareils á Vapeur) and G. Keller, of the same society. The engine tested was a Corliss engine, made by Messrs. Berger Andre & Co., of Thaun.

We have pleasure in giving the results in favour of steam-jacketing, extracted from a most valuable paper, "On the Independent Testing of Steam-Engines and the Measurements of Heat Used," by Mr. M. J. G.

Mair, M.I.C.E.* By this system of testing—viz., the practical measurement of heat units, among many other things which can be settled is the relative values of compound or simple engines, and the saving by the use of steam-jackets absolutely proved.

Out of ten trials made on various types of engines, we give a few particulars of five trials:—

TABLE XIII.

	B.	C.	D.	E.	F.
Date of trial, ...	Aug. 1881	Aug. 1881	Dec. 1881	Dec. 1881	Dec. 1881
Type of engine, . . .	Com. Woolf Beam		Compound Woolf Beam		
Time running in hours and minutes, ...	6·0	10·0	10·0	11·0	10·0
Total number of revolutions from counters, . . .	6,421	11,772	20,238	22,584	20,710
Revolutions per minute, . .	17·84	19·62	33·73	34·22	34·52
Indicated horse-power, . .	75·9	75·2	267·86	267·94	267·91
Total horse-power, . . .	87·36	85·09	284·25	282·55	288·69
Water drained in jackets in pounds, ...	Not in use	1345	3502	4284	Not in use
Total number of expansions, .	9·30	15·76	9·64	9·56	7·77
Absolute boiler pressure in pounds per square inch, .	58	62	84·8	88·14	88·95
Percentage of supply from boiler passed through the jackets, .	Not in use	9·9	7·1	8·3	Not in use
Percentage of water present in the cylinder at cut-off, . .	51·1	40·8	37·6	37·7	34·0
Percentage of water present in the cylinder at end of high-pressure stroke, ...	35·1	18·1	24·3	21·5	28·0
Percentage of water present in the cylinder at end of low-pressure stroke, ...	38·8	8·7	17·5	14·3	35·2
Percentage of total heat through engine lost by the cooling action of the condenser, .	24·4	3·1	11·3	9·4	22·5
Thermal units per indicated horse-power per minute, .	519·5	338·8	348·1	341·8	378·1
Thermal units per total horse-power per minute, . . .	451·4	299·3	328·1	324·2	350·9
Pounds of dry saturated steam per ind. horse-power per hour,	26·62	17·34	17·73	17·39	19·24
Maximum theoretical efficiency,	0·254	0·276	0·340	0·339	0·341
Actual efficiency, ...	0·082	0·126	0·122	0·125	0·113
Pounds of coal used per indicated horse-power per hour,	2·66	1·76	1·86	1·83	2·02
Radiation per cent., . . .	1·6	2·7	1·2	1·3	1·2

Trials B and C.—A Woolf beam rotative engine, working a deep-well pump direct from the beam. It

* See *Minutes of Proceedings of the Institution of Civil Engineers*, Vol. LXX. p. 313, &c.

was made by Messrs. Simpson & Co., and had been at work six months before the trials were made. The cylinders were 34 inch. in diameter by 5 feet 6 inch. stroke, and 22 inch. in diameter by 3 feet 7 inch. stroke, with their covers and bases jacketed with boiler steam. Two trials were made with this engine, one trial with, and the other without, steam in the jackets: the results of both trials are given in Table XIII.

Trials D, E, F.—A Woolf beam engine driving a flour mill. It was made by Messrs. Simpson & Co. The cylinders 38 inch. in diameter by 5 feet 6 inch. length of stroke, and 24½ inch. in diameter by 3 feet 5 inch. length of stroke, were steam-jacketed on the barrels only. Three trials were made with this engine, two with, and one without, the jackets. The results of these trials are given in Table XIII.

Mr. Mair says:—" Trials B and C are interesting, as showing the great loss that existed when the steam-main was not thoroughly drained and the jackets shut off, 519·5 thermal units being used in that case, against 338·8 thermal units when the main was better drained and the jackets were on. The water present at the cut-off was 51·1 per cent., the loss by the cooling action of the condenser being reduced in the latter case when the jackets were on from 24·4 per cent. to 3·1 per cent.

" In the next trials, D, E, and F, it will be noticed that the best results, 348·8 thermal units, were obtained when 8·3 per cent. of steam passed through the jackets, against 348·1 when only 7·1 per cent. passed, the water present at the toe of the low-pressure diagram being 14·3 per cent. against 17·5 per cent., and the loss due to the cooling action of the condenser 9·4 per cent. instead of 11·3 per cent. When the jackets were shut off 378·1 thermal units were used, or a loss of 10½ per cent., the loss due to the cooling action of the condenser being 22·5 per cent. Had the cylinders been better jacketed—that is, the covers and bottoms, in addition to barrels,—the loss through shutting off the jackets would undoubtedly have been greater in proportion."

It will be seen from these results that great advantage was in each case gained by the jackets being at work, and they were productive of economy. On the

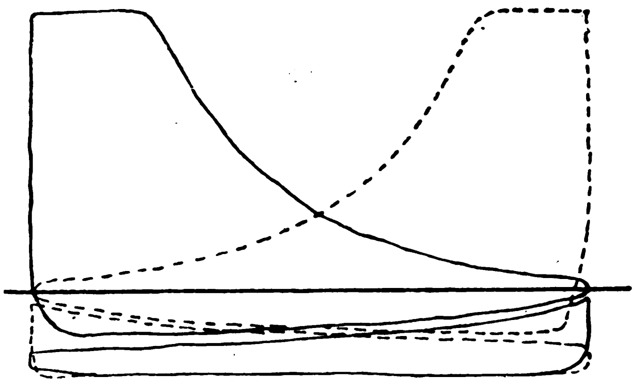


Fig. 62.—Scale 1/30.

Chatham Waterworks.	Steam in Jackets.
Indicated horse-power, high-pressure	35·4
Indicated horse-power, low-pressure	39·8
Total indicated horse-power	75·2
Consumption of steam per indicated horse-power	17·34 lbs.

B and C trials, the gain was 34¾ per cent. by using jackets and draining the steam-main, and on the D, E, and F trials it was seen how the better discharge from the jacket increased the efficiency, and how 10½ per cent. was lost by their being shut off.

In the discussion which followed the reading of Mr.

Rich's very interesting paper on "Pumping Engines," before the Institution of Civil Engineers, 1884, Mr. Mair furnished two sets of diagrams taken from the same engines at the Chatham Waterworks, illustrating the economy of the steam-jacket. Fig. 62 shows diagrams from the engine with steam in the jackets, when the total indicated power developed by the engine was 75·2, and the consumption of steam per indicated horse-power per hour was 17·34 lbs. Fig. 63 shows diagrams from the same engine without

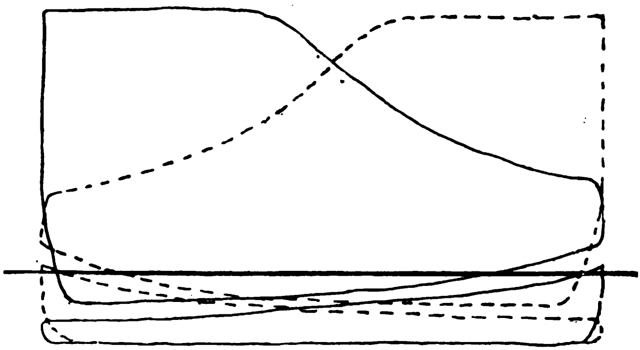


Fig. 63.

Chatham Waterworks. No Steam in Jackets.

Indicated horse-power, high-pressure	44·6
Indicated horse-power, low-pressure	31·3
Total indicated horse-power	75·9

Consumption of steam per indicated horse-power, 26·62 lbs.

steam in the jackets, when a much later cut-off was required to develop a total of 75·9 indicated horse-power, and the consumption of steam rose to 26·62 lbs. per indicated horse-power per hour. The speed and the boiler pressure were kept exactly the same in both cases.

Mr. E. A. Cowper, M.I.C.E., in his lecture "On the

Steam-Engine," read before the Institution of Civil Engineers in 1884, refers to trials carried out by Mr. Rennie, extending over two periods of four weeks each, with and without steam in the jackets, of a 40 horse-power stationary engine, when the coal consumption showed a gain of 31 per cent. in favour of steam-jacketing.

We have now reached the conclusion of the results of engine tests carried out to ascertain the value of steam-jacketing, collected and published by the author of this work in 1889.*

Soon after their appearance, the first of the two excellent reports of the Research Committee on "The Value of the Steam-Jacket," was published—followed three years later by the second report. We are able in the present chapter, by the kind permission of the Council of the Institution of Mechanical Engineers, to add a few abbreviated tables of results, carried out on various classes of engines from these reports. We have supplemented the whole by reproducing Mr. Donkin's valuable and exhaustive tests on the experimental vertical engine at Bermondsey.

It will be seen from the tables recorded in this chapter, that, whether the engines have been simple or compound, condensing or non-condensing, of large or small proportions, an economy has always resulted from thorough steam-jacketing. But "the smaller the cylinder, the greater is the percentage of gain from the use of the jacket." † It may be of service to point out here that, in testing the same engine with and without steam in the jackets, the results from the jacketed engine would show a greater gain than those recorded, because the empty steam-jackets round the

* *The Mechanical World.*

† Second Report on "The Value of the Steam-Jacket," p. 420.

cylinder will cause the so-called non-jacketed engine to give a much better result than another engine would, without this empty ring. It is a well-known fact that the annular space acts as an excellent non-conductor to the working steam inside the cylinder barrel. It would be useful, therefore, to have some tests carried out on two engines of precisely the same design, and working under exactly the same conditions, one cylinder steam-jacketed and lagged, the other cylinder not steam-jacketed, and lagged in the same manner.

On p. 164 we have given the results of two trials made on a couple of Corliss engines of identical dimensions and design, the only difference being that the cylinder of one was steam-jacketed and the other was not.

The results of the above experiments are very interesting, because they show the exact value of steam-jacketing without the non-jacketed cylinder having the advantage of a liner with an air-jacket.

Sir Frederick Bramwell, Bart., "mentioned a practical test, wholly unpremeditated and unconcerted, of the value of steam-jackets, which had occurred in his own experience. Some thirty years ago he had designed a tandem compound engine for some saw-mills, with steam-jacketed cylinders high enough up for the jacket water to be returned by gravitation to the boiler. After the engine had worked ten years, it happened one day that it could not be made to go. Having been sent for, he found on examination that everything appeared to be right; and he had no notion what was the matter, until, by good luck, he put his hand upon the return pipe from the jackets and felt that it was quite cold. On being taken off, it was found that, after all those years, the drain-pipe had become choked up with a deposit of lime. It was cleaned and put on again, and then the engine worked as well as ever." * The above fact speaks for itself, and we could furnish many other similar experiences, but we must now give the tables of results which prove to demonstration the efficiency of steam-jacketing.

In Table XIV. we give the results of four out of twenty-four experiments carried out by M. Delafond at the Creusot Works, France. The experiments were made on a single cylinder non-condensing Corliss engine; cylinder, 21·65 inch. diameter, 43·31 inch. stroke: the body only was jacketed. The jackets were supplied with steam by a small pipe from the main steam-pipe, and were automatically drained.

In the next table six out of forty-six experiments are given. These figures show the results obtained by M. Delafond from the same engine with the condenser at work. It is very interesting to compare the results obtained from the same engine working first as non-condensing and afterwards with the condenser at work.

We now record two experiments made on a compound surface-condensing three cylinder vertical engine. Cylinders 19-, 25- and 25-inch. diameter, 24-inch. stroke: only the bodies of the cylinders were jacketed. Experiments made at the London Hydraulic Power Pumping Station in 1887, by Professor Kennedy and Mr B. Donkin. Steam supply to jacket by small pipe. Steam from small cylinder expanded into two large cylinders. Table XVI.

The experimental engine at University College, London, with which the trials recorded in Table XVII. was carried out, is of the compound tandem type, manufactured by Messrs. Bryan Donkin & Co.

* Second Report of the Research Committee on "The Value of the Steam-Jacket," 1892.

TABLE XIV.

Single Cylinder Corliss Engine.	Without Steam in Jackets.	With Steam in Jackets.	Without Steam in Jackets.	With Steam in Jackets.	Without Steam in Jackets.	With Steam in Jackets.
Duration of experiment in hours,	1·3	1·3	1·1	1·2	1·2	1
Boiler pressure, lbs. per square inch above atmosphere,	110	110	78·2	78·2	49·8	49·8
Number of expansions,	6·2	7·1	5·4	5·1	2·5	2·8
Indicated horse-power,	147·5	143	121	137	147	141·5
Feed-water, lbs. per ind. horse-power per hour,	28·38	22·80	27·58	23·65	27·20	25·21
Feed-water, percentage less with jackets,	...	19·7	...	14·25	...	7·32
Duration of experiment in hours,	1·3	1	0·5	0·5	0·4	0·5
Boiler pressure, lbs. per square inch above atmosphere,	110	110	78·2	78·2	49·8	49·8
Number of expansions,	6·2	6·2	2·9	3·1	1	1
Indicated horse-power,	445	447·5	209	204	145	147·5
Feed-water, lbs. per ind. horse-power per hour,	28·38	22·13	24·18	21·95	46·82	46·26
Feed-water, percentage less with jackets,	...	22·0	...	9·23	...	1·19

TABLE XV.

Single Cylinder Corliss Condensing Engine.	Without Steam in Jackets.	With Steam in Jackets.	Without Steam in Jackets.	With Steam in Jackets.	Without Steam in Jackets.	With Steam in Jackets.
Duration of experiment in hours,	1	1	0·8	0·7	1·1	1·3
Boiler pressure, lbs. per square inch above atmosphere,	110	110	88·9	88·9	35·6	35·6
Number of expansions,	13·5	11·3	4·8	5·9	2·2	2·3
Indicated horse-power,	109	141	194	193	160	162
Feed-water, lbs. per ind. horse-power per hour,	23·24	17·05	20·43	17·50	22·73	22·08
Feed-water, percentage less with jackets,	...	26·6	...	14·3	...	2·9
Duration of experiment in hours,	0·6	0·7	1·25	1·2	0·3	0·4
Boiler pressure, lbs. per square inch above atmosphere,	110	110	64	64	35·6	35·6
Number of expansions,	6·4	6·4	3·9	4·4	1	1
Indicated horse-power,	186	212	172	175	182	199
Feed-water, lbs. per ind. horse-power per hour,	21·99	17·59	18·37	17·66	35·87	33·01
Feed-water, percentage less with jackets,	...	20·0	...	3·9	...	8·0

Cylinders 6-inch. and 10-inch. diameter, 12-inch. stroke: only the bodies of the cylinders were jacketed. Experiments made at Bermondsey from 1875 to 1881

TABLE XVI.

Compound Surface Condensing Engine.	Without Steam in Jackets.	With Steam in Jackets.
Duration of experiment in hours,	9	9
Boiler pressure lbs. per square inch above atmosphere, . .	80	80
Number of expansions, - . .	7	7
Indicated horse-power, . .	157	168
Feed-water lbs. per indicated horse-power per hour, . .	23·93	20·25
Feed-water percentage less with jackets, ...	...	15·4

by Messrs. Farey, B. Donkin, jun., and Salter. The whole steam-supply to the cylinders passed through the jackets when in use, which were drained by traps. When not in use the jackets were open to the air.

It is impossible to over-estimate the value of the test carried on in the compound engine, the results of which are given in Table XVII.

There are many engineers, while admitting the utility of the steam-jacket when applied to the simple engine, yet they question the economy of applying a jacket to both the cylinders of a compound engine. They agree that one of the cylinders should be jacketed, but they are very much divided when it comes to the question as to which of the two cylinders should be steam-jacketed. For instance, one writer says:—"There is reason to believe that the loss by condensation which takes place in the jackets of low-pressure cylinders is so great as to justify the use of unjacketed low-pressure cylinders." * Mr. Stapfer, in

* *The Engineer*, 3rd December 1873.

1874, said:—" In compound engines, only the small cylinder and the reservoir (receiver) should be jacketed."

TABLE XVII.

Average Results from three experiments *with* steam in the high-pressure jacket alone, and four experiments *without* steam in either jacket.

High-pressure jacket alone, with or without steam.	Without.	With.
Indicated horse-power,	8·75	7·86
Thermal units rejected per indicated horse-power per minute,	563	419
Thermal units, percentage less with steam in high-pressure cylinder alone,	...	25·5

Average Results from seven experiments *with* steam in low-pressure jacket alone, and four experiments *without* steam in either jacket.

Low-pressure jacket alone, with or without steam.	Without.	With.
Indicated horse-power,	8·75	9·89
Thermal units rejected per indicated horse-power per minute,	563	400
Thermal units, less with steam in low-pressure cylinder alone,	...	29·0

Average Results from eight experiments *with* steam in both jackets, and four experiments *without* steam in either jacket.

Both jackets, with or without steam.	Without.	With.
Indicated horse-power,	8·75	9·4
Thermal units rejected per indicated horse-power per minute,	563	372
Thermal units, percentage less with steam in both jackets,	...	33·9

Mr. Rich says:—" Their firm were so convinced of the great importance of having steam-jackets in all cases on *both* cylinders, that they have since made no large compound engines without them."* Mr. Bryan Donkin comes to our aid, and proves to demonstration by these useful tests that, if the utmost economy is to be realised by compounding, both the high and low-pressure cylinders should be steam-jacketed. It will, however, be seen from the figures that the jacket on the low-pressure cylinder was more productive of good than the jacket on the high-pressure cylinder. Yet it is valuable to have both cylinders thoroughly steam-jacketed and well drained.

The next table gives particulars of tests carried out by Professor A. B. W. Kennedy on the same engine with which the trials recorded in Table XVII. were made. The cylinders are 6-inch. and 10-inch. in diameter. An expansion valve of the Meyer type is fitted to the high-pressure cylinder, by means of which the cut-off can be made to take place at any point in the stroke. Both cylinders are jacketed, and during the trials the steam circulated through both jackets before entering the high-pressure valve-chest.

TABLE XVIII.

Compound Condensing Engines.	Jackets not in Use.	Both Jackets in Use.	Jackets not in Use.	Both Jackets in Use.	Jackets not in Use.	Both Jackets in Use.
Duration of experiment in hours, . .	2	2·2	2·0	1·75	1·8	2·0
Absolute boiler pressure,	39·4	48·3	80	82·1	94·6	94·0
Ratio of expansion, .	3·23	3·56	8·95	11·10	8·25	8·43
Indicated horse-power,	7·25	9·74	6·90	8·45	10·37	13·03
Feed-water per ind. horse-power per hour,	41·60	31·75	42·98	27·86	38·0	23·48
Feed-water, percentage less with steam in jackets, . . .	...	23·7	...	35·2	...	38·2

* "The Comparative Merits of Engines for Pumping:" a paper read before the Institution of Civil Engineers by Mr. Rich, 1884.

Record of two experiments on the same engine, *with* and *without* steam in the jackets, are given in Table XIX.—Triple-expansion condensing vertical inverted engine, on three uncoupled cranks, with cylinders provided with Meyer expansion gear. Cylinders 5-, 8- and 12-inch. diameter; 10-, 10- and 15-inch. stroke. All the bodies, ends, and valve-chests of the three cylinders were jacketed, as also were both re-

TABLE XIX.

Triple Expansion Engine.	Without Steam in Jackets.	With Steam in Jackets.
Duration of experiment in hours,	4·0	4·1
Boiler pressure, lbs. per square inch above atmosphere,	188	192
Number of expansions,	15	26·5
Indicated horse-power,	73·9	72·1
Feed-water per indicated horse-power per hour in lbs.,	16·42	13·56
Feed-water, percentage less with steam in jackets,	...	17·4

ceivers, and part of the steam-pipe, steam being admitted to the last three jackets throughout both of the experiments.* Steam was supplied to each of the fifteen jackets by a separate pipe, and all the jacket water was drained through the first receiver into the boiler. In the high-pressure cylinder 64·7 per cent. of the internal surface is jacketed, in the intermediate cylinder 67·1 per cent., and in the low-pressure cylinder 75·2 per cent. Three independent brakes were used to absorb the power.

Experiment on a triple-expansion engine at the

* Experiments made at Owens College, Manchester, in January and April, 1889, by Professor Osborne Reynolds (Institution of Civil Engineers, vol. xcix., 1889).

Waltham Abbey Pumping Station of the East London Waterworks, by Mr. Henry Davey and Mr. William B. Bryan.—The diameter of the cylinders are 18-inch. 30·5-inch., and 51-inch., respectively. The stroke of each of the three cylinders is 36-inch. Each piston cross-head is connected to its crank by a single connecting rod, and to a pump-plunger by a pair of pump-rods. There are thus three steam-cylinders, three pump-plungers, three connecting-rods, and three pairs of pump-rods. Each of the three cylinders is provided with an ordinary slide-valve, actuated by a separate eccentric on the crank-shaft. The slide-valve on the high-pressure cylinder is actuated direct by its eccentric, and is provided with a Meyer expansion valve, by means of which the speed of the engine was regulated during the experiment. The slide-valves on the intermediate and low-pressure cylinders are actuated through variable expansion links, but the positions of these remained unchanged throughout the experiment.

The bodies and both ends of all three cylinders are steam-jacketed, the cylinders forming liners in the body jackets. Steam is supplied to these jackets through a pipe connected to the main steam-pipe on the boiler side of the stop-valve. The steam to the jackets enters at the top on one side, and at the bottom on the opposite side; and, in ordinary working, the high-pressure jackets discharge directly into the boiler, while the intermediate and low-pressure jackets discharge through steam-traps into the hot-well. The jackets of the high-pressure cylinder receive steam at full boiler pressure; and, by means of reducing valves, the pressures in the jackets of the intermediate and low-pressure cylinders are maintained a little higher than the pressures in their respective steam-chests.

Each cylinder is therefore jacketed with steam a little above its own initial pressure. See Table XX.

TABLE XX.

Triple Expansion Engine.	Without Steam in Jackets.	With Steam in Jackets.
Duration of experiment in hours,	8	8
Boiler pressure, lbs. per square inch above atmosphere, . .	130	130
Number of expansions, . .	22	30
Indicated horse-power, . .	140	138
Feed-water per indicated horse-power per hour, . . lbs.	17·22	15·45
Feed-water, percentage less with jackets, ...	...	10·3
Coal per indicated horse-power per hour in lbs., ...	2·09	1·79

The following steam-jacket experiments were made on a single cylinder vertical experimental engine at Bermondsey, by Mr. Bryan Donkin, jun. The cylinder is 6-inch. diameter, and the stroke 8-inch. The slide-valve is provided with a Meyer variable expansion valve. The body and both ends of the cylinder are jacketed, as is also the valve-chest cover; and steam is supplied to each of the four jackets direct from the boiler by a separate pipe. By a special arrangement, the water from the cylinder body-jacket was divided into two portions, and the weights of these are given separately. The first portion consists of the steam condensed on the inner vertical surface of the jacket, and is due to the heat passing through the walls into the cylinder, almost all of which is usefully employed in keeping the temperature of the cylinder nearly equal to that of the steam in the jacket. The other portion consists of the steam condensed on the outer vertical surface of the jacket, and is due to the heat uselessly radiated outwards owing to imperfect external covering. This loss should, of course, be reduced to a minimum, and in these experiments a layer of good non-conducting material was placed round the cylinder for this purpose. Observations of the temperatures of the cylinder walls were made throughout the trials. These temperatures were taken by small thermometers inserted in $\frac{1}{8}$-inch holes, drilled into the metal walls and filled with mercury. It will be seen from Tables XXI. to XXV., that the temperature of the cylinder walls was much higher with steam in the jackets than without.

Experiments were made not only with and without steam in the jackets, but also with all the jackets filled with water, which was allowed to assume a normal temperature before commencing the trial; a trial was also made with a vacuum in the body jacket. When no steam is admitted into the jackets the air in them gets gradually hotter, being heated by the cylinder walls, until it reaches a normal temperature. The same thing occurs when cold water is admitted into the jackets; it gradually becomes hotter, and then remains at a constant temperature.

Experiments were made at two different speeds—about 218 and 115 revolutions per minute. In order to shorten the duration of the trials, the engine was fitted with a surface-condenser to measure the feed-water, and it was found that trials lasting for half an hour agreed satisfactorily with those of three hours' duration.

The steam pressure and cut-off were kept constant throughout the whole of the experiments, with the exception of No. 24, in which the cut-off was varied. A brake was used to absorb the power.

Five experiments were made on this engine, four condensing and one non-condensing. Experiment No. 21 consisted of four trials at about full speed, with steam in all the jackets; without steam in any of the jackets; with water in all the jackets; and with a vacuum in the body jacket. Experiment No. 22 consisted of two trials at about half speed, with and without steam in all the jackets. Experiment No. 23 consisted of two non-condensing trials at about full speed, with and without steam in all the jackets. Experiment No. 24 consisted of twelve trials, all at full speed, made in pairs, one unjacketed and one jacketed, with six different degrees of expansion, in order to determine how the changes in the ratio of expansion would effect the value of the steam-jackets. In Experiment No. 25 steam was admitted to the body jacket and shut off again during the experiment, without stopping the engine, in order to ascertain the effect of this upon the speed of the engine, the load on the brake being kept constant.

In all the experiments, the feed-water always included the whole of the jacket water.

Experiment No. 21.—*Four trials with different media in jackets.*—The details of this experiment are given in Table XXI. These four trials were all made at a mean speed of about 218 revolutions per minute, condensing, and at a cut-off of three-sixteenths. The first trial was made without steam in any of the jackets, that is, with hot air in all the jackets, and lasted for 34 minutes. The consumption of feed-water was at the rate of 41·23 lbs. per indicated horse-power per hour.

The second trial was made with steam in all the jackets, and lasted for 52 minutes. The consumption of feed-water, including jacket-water, was at the rate of 28·39 lbs. per indicated horse-power per hour, showing a saving in feed-water of $41{\cdot}23-28{\cdot}39=$

12·84 lbs. per indicated horse-power per hour, or a decrease in consumption of 31·1 per cent., due to the action of steam as compared with hot air in the four jackets. The mean temperature of the internal part of the cylinder walls was 28° higher with steam in the jackets than with hot air. The condensed water from the various jackets was as follows:—

Jacket.	Condensed water.	
Body jacket, inner wall, .	0·69 lb.	per I.H.P. per hour.
,, ,, outer wall, .	0·68 lb.	,,
Top-end jacket, . .	0·15 lb.	,,
Bottom-end jacket, . .	0·41 lb.	,,
Valve-chest jacket, . .	0·18 lb.	,,
Total jacket-water, . .	2·11 lbs.	,,

The total quantity of steam condensed in the jackets was, therefore, 2·11 lbs. per indicated horse-power per hour, which is equivalent to 7·44 per cent. of the total feed-water. Thus, for every pound of steam condensed in the jackets, there was a net saving in feed-water consumption of 6·1 lbs. The following table shows the effect of the different jackets on the feed-water consumption, as determined by another experiment:—

Arrangement of Jacketing.	Feed-water, including Jacket-water.		
	Consumption per indicated Horse-power per hour.	Saving due to Steam-jackets.	
		Per indicated Horse-power per hour.	Percentage of 41·2.
Without steam in any of the jackets, . . .	41·2 lbs.	...	...
With steam in two *end* jackets only, . .	37·0 lbs.	4·2 lbs.	10·2 per cent.
With steam in *body* jacket only, ...	30·1 lbs.	11·1 lbs.	26·9 ,,
With steam in *all four* jackets, . . .	28·4 lbs.	12·8 lbs.	31·1 ,,

The third trial was made with hot water in all the jackets, and lasted for 22½ minutes, the water in the jackets being allowed to assume a normal temperature before the observations were commenced. The consumption of feed-water was at the rate of 46·27 lbs. per indicated horse-power per hour, showing a difference in feed-water consumption of $46·27 - 41·23 = 5·04$ lbs. per indicated horse-power per hour, or an increase of 12·2 per cent., due to the presence of hot water in the jackets, as compared with hot air. In the fourth trial, which lasted for 26 minutes, a vacuum of 12·85 lbs. per square inch below the atmosphere was maintained in the body jacket by putting it in direct communication with the condenser, the other three jackets being open to the air. The consumption of feed-water was at the rate of 38·01 lbs. per indicated horse-power per hour, showing a saving in feed-water of $41·23 - 38·01 = 3·22$ lbs. per indicated horse-power per hour, or a decrease of 7·8 per cent., due to maintaining a vacuum in the body jacket, as compared with hot air in all the jackets. This trial with a vacuum in the body jacket, and was made with the intention of lowering the temperature of the cylinder walls, but a little reflection showed that there was no medium to convey the heat from the hot metal walls to the cooler condenser.

The walls were found to remain at a temperature of 264° F., without parting with their heat, although exposed to the much lower condenser temperature of 130° F.

This has since been confirmed by further experiments, and shows a practical result which is not unimportant. The cylinder walls were rather hotter with a vacuum in the body jacket than with hot air in all the jackets, and external radiation was probably diminished.

Experiment No. 22.—Two trials at half-speed with and without steam in jackets.—The details of this experiment are given in Table XXII.

The trials were made at a mean speed of about 116 revolutions per minute, condensing, and at a cut-off of three-sixteenths.

With the exception of the speed, which was a little more than half, all the conditions were the same as those for the first two trials of Experiment No. 21.

The trial without steam in any of the jackets lasted for 36 minutes. The consumption of feed-water was at the rate of 46·25 lbs. per indicated horse-power per hour. The trial with steam in all the jackets lasted for 28 minutes. The consumption of feed-water, including jacket-water, was at the rate of 30·43 lbs. per indicated horse-power per hour, showing a saving in feed-water of 46·25 − 30·43 = 15·82 lbs. per indicated horse-power per hour, or a decrease in the consumption of 34·2 per cent., due to the action of steam, as compared with hot air in the jackets.

The mean temperature of the internal part of the cylinder wall was 31° higher with steam in the jackets than without; and for those two trials the temperatures were a few degrees higher than in the first two trials of Experiment No. 21, when the speed was about double, all the other conditions being the same. The total condensed water from the jackets was as follows:—

Jacket.	Condensed water.	
Body jacket, inner wall, .	0·68 lb.	per I.H.P. per hour.
Body jacket, outer wall, .	0·68 lb.	,,
Top-end jacket, . . .	0·32 lb.	,,
Bottom-end jacket, . .	0·50 lb.	,,
Valve-chest jacket, . .	0·25 lb.	,,
Total jacket-water, . .	2·43 lbs.	,,

The total quantity of steam condensed in the jackets was therefore 2·43 lbs. per indicated horse-power per hour, which is equivalent to 7·99 per cent. of the feed-water. Thus, for every lb. of steam condensed in the jackets, there was a net saving in feed-water of 6·5 lbs.

Comparing these results with the first two trials in Experiment No. 21, in which all the conditions were the same, with the exception of speed, the effect of the steam-jackets at the reduced speed is seen to be increased by about 3 lbs. per indicated horse-power per hour, thus:—

Speed of Engine.	Saving due to Steam-Jackets.	
218 revs. per minute, .	12·84 lbs. per I.H.P. per hour.	
116 revs. per minute, .	15·82 lbs.	,,
Increase in saving at reduced speed .	2·98 lbs.	,,

Experiment No. 23.—Two non-condensing trials with and without steam in jackets.—The details of this experiment are given in Table No. 23. The trials were made at about full speed. With the exception that, in this case, there was no vacuum in the condenser, all the conditions were the same as those for the first two trials of Experiment No. 21.

The trial without steam in any of the jackets lasted for 38¾ minutes. The consumption of feed-water was at the rate of 62·64 lbs. per indicated horse-power per hour.

The trial with steam in all the jackets lasted for 44 minutes. The consumption of feed-water, including jacket water, was at the rate of 35·69 lbs. per indicated horse-power per hour, showing a saving in feed-water of 62·64 − 35·69 = 26·95 lbs. per indicated horse-power per hour, or a decrease of 43·0 per cent. due to the action of steam as compared with air in the four jackets. The mean temperature of the internal part of the cylinder walls was 44° higher with steam in the jackets than without. The total condensed water from the jackets was as follows:—

Jacket.	Condensed water.	
Body jacket, inner wall, .	0·75 lb.	per I.H.P. per hour.
Body jacket, outer wall, .	0·81 lb.	,,
Top-end jacket, . . .	0·22 lb.	,,
Bottom-end jacket, . .	0·53 lb.	,,
Valve-chest jacket, . .	0·25 lb.	,,
Total jacket-water, . .	2·56 lbs.	,,

The total quantity of steam condensed in the jackets was therefore 2·56 lbs. per indicated horse-power per hour, which is equivalent to 7·17 per cent. of the feed-water. Thus, for every pound of steam condensed in the jackets, there was a net saving in feed-water consumption of 10·5 lbs. Comparing these two non-condensing trials with the first two trials in Experiment No. 21, which were condensing, and had all the other conditions the same, the useful effect of the jackets was increased from 31·1 per cent. to 43·0 per cent. when the engine was worked without a vacuum, thus:—

	Saving due to Steam-Jackets.	
Engine Working, .	per I.H.P. per hour.	per cent.
Condensing, . .	12·84 lbs.	31·1
Non-condensing, .	26·94 lbs.	43·0

Experiment No. 24.—*Twelve trials with and without steam in the jackets, at various rates of expansion.*—The details of these trials are given in Table XXIV. They were all made condensing, at a speed of 218 revolutions per minute, and with a steam-pressure of about 50 lbs. per square inch above the atmosphere. The trials were made in pairs, jacketed and unjacketed, at six different degrees of cut-off,—1-16th, 1-12th, 1-8th, 3-16ths, 5-16ths, and half-stroke,— all the other conditions remaining as far as possible the same.

From Table XXIV. it will be seen that with the greatest number of expansions, 6·8 at 1-16th cut-off, the saving due to the jackets was 40·4 per cent., while with the smallest number of expansions, 1·8 at one-half cut-off, the saving was only 23·1 per cent.; or, speaking generally, the saving in steam consumption due to the use of steam-jackets increases with the number of expansions.

The great difference in the temperatures of the cylinder walls with and without steam in the jackets is clearly noticeable; this difference decreases considerably as the number of expansions decreases.

At a speed of about 220 revolutions per minute, the cut-off giving the minimum steam consumption, the steam in jackets was found to be at 1-8th of the stroke, equal to 4·8 expansions. The consumption of feed-water, including jacket-water, per indicated horse-power per hour in this case was 25·2 lbs. At the same speed, without steam in the jackets, the best cut-off was found to be at 5-16ths of the stroke, equal to 2·6 expansions. Here the steam used was 38·7 lbs. per indicated horse-power per hour.

The drier the steam at release, the greater is the economy, the maximum economy being obtained with the steam practically dry at release.

Experiment No. 25.—*To determine the effects of the steam-jacket on the speed of the engine, and temperature of the cylinder walls, &c.*—Throughout this experiment the condenser was kept in action, steam was cut off at 3-16ths, and the steam pressure and load on the

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TABLE XXI.—*Experiment on a Single-Cylinder Vertical Surface-Condensing Engine, with and without Steam, &c., in Jackets, at Bermondsey, by Mr. Bryan Donkin, jun.*

1	Medium in jackets	Air.	Steam.	Water.	Vacuum.*
2	Duration of Trial, ... hours	0·57	0·87	0·38	0·43
3	Valve-chest pressure, lbs. per square inch above atmosphere, lbs.	49·7	50·1	50·2	50·2
4	Steam-jacket pressure, lbs. per square inch above atmosphere, . lbs.	0	51·8	53·6	−12·9
5	Number of expansions, ...	3·77	3·75	3·75	3·77
6	Revolutions per minute, mean, ... revs.	220	216·3	218	213·5
7	Piston speed, feet per minute, mean, ... feet	293	288	291	285
8	Indicated horse-power, mean, ... I.H.P.	6·56	6·83	6·32	6·36
9	Mean temperature in body-jacket space, ... F.	252·5°	298·5°	247·0°	248·0°
10	,, ,, of cylinder wall, in six holes, ... F.	260·5°	290·5°	249·5°	264·3°
11	,, ,, ,, ,, 0·06 inches from piston, . F.	255·8°	284·0°	250·0°	266·0°
12	,, ,, initial in cylinder, ... F.	...	297·0°	...	...
13	,, ,, terminal in cylinder, ... F.	...	223·9°	...	...
14	,, ,, during steam stroke in cylinder, ... F.	...	260·4°	...	...
15	Percentage of feed-water present in cylinder as steam at cut-off, per cent.	42·6	61·2	...	...
16	Percentage of feed-water present in cylinder as stream at release, per cent.	63·7	89·2	...	...
17	Jacket-water, lbs. per indicated horse-power per hour, total, . lbs.	...	2·11	...	...
18	,, in percentage of feed-water, ... per cent.	...	7·43	...	...
19	Feed-water, lbs. per indicated horse-power per hour, total, . lbs.	41·23	28·39	46·27	38·01
20	,, percentage less with steam in jackets, . . per cent.	...	31·1 p.c.	...	...

* Body jacket in communication with condenser, air in other three jackets.

TABLES XXII. AND XXIII.

	Engine working Condensing or Non-Condensing		XXII. Condensing.		XXIII. Non-Condensing.	
1	Jackets with or without steam,		Without.	With.	Without.	With.
2	Duration of trial,	hour	0·60	0·47	0·65	0·73
3	Valve-chest pressure, lbs. per square inch above atmosphere,	lbs.	49·5	50·2	49·9	50·2
4	Steam-jacket pressure, lbs. per square inch above atmosphere,	lbs.	0·0	51·2	0·0	53·3
5	Number of expansions,		3·75	3·75	3·75	3·75
6	Revolutions per minute, mean,	revs.	116·8	114·9	220·7	212·4
7	Piston speed, feet per minute, mean,	feet	156	153	294	283
8	Indicated horse-power, mean,	I.H.P.	3·92	3·72	3·80	4·19
9	Mean temperature in body-jacket space,	F.	250·0°	299·0°	246·0°	299·5°
10	,, ,, of cylinder wall, in six holes,	F.	262·5°	295·0°	250·0°	297·0°
11	,, ,, ,, ,, 0·06 inches from piston,	F.	260·0°	291·0°	252·0°	296·0°
12	,, ,, initial in cylinder,	F.	292·2°	296·3°	289·2°	297·7°
13	,, ,, terminal in cylinder,	F.	235·3°	228·2°	230·1°	221·1°
14	,, ,, during steam stroke in cylinder,	F.	263·7°	262·2°	259·6°	259·4°
15	Percentage of feed-water present in cylinder as steam at cut-off,	per cent.	33·0	57·6	42·1	72·1
16	Percentage of feed-water present in cylinder as stream at release,	per cent.	59·1	88·3	71·5	95·2
17	Jacket-water, lbs. per indicated horse-power per hour, total,	lbs.	...	2·43	...	2·56
18	,, in percentage of feed-water,	per cent.	...	7·99	...	7·17
19	Feed-water, lbs. per indicated horse-power, per hour, total,	lbs.	46·25	30·43	62·64	35·69
20	,, percentage less with steam in jackets,	per cent.	...	34·2 p.c.	...	43·0 p.c.

TABLE XXIV.—*Experiment on a Single-Cylinder Vertical Surface-Condensing Engine, with different Rates of Expansion, with and without Steam in Jackets, at Bermondsey, by Mr. Bryan Donkin, jun.*

	Trial letter	*a*	*b*	*c*	*d*	*e*	*f*	*g*	*h*	*i*	*k*	*l*	*m*	
1	N Jackets not in use; J all four Jackets in use	N	J	N	J	N	J	N	J	N	J	N	J	1
2	Duration of trial . . . minutes	33·25	58·0	30·5	97·75	28·0	92·25	34·25	52·25	31·0	41·75	24·25	22·0	2
3	Steam-chest pressure, lbs. per square inch above atmosphere . . . lbs.	49·0	49·9	49·5	49·3	49·8	49·3	49·8	50·2	50·7	48·5	49·1	51·1	3
4	Steam-jacket pressure, lbs. per square inch above atmosphere . . . lbs.	..	55·2	..	51·3	..	53·4	..	51·9	..	50·0	..	52·4	4
5	Cut-off in percentage of stroke . . . per cent.	6·25	6·25	8·33	8·33	12·5	12·5	18·75	18·75	31·25	31·25	50·0	50·0	5
6	Number of expansions	6·8	6·8	6·0	6·0	4·8	4·8	3·7	3·7	2·6	2·6	1·8	1·8	6
7	Revolutions per minute, mean . . . revs.	219	222	222	219	214	217	220	216	214	219	224	205	7
8	Piston speed, feet per minute, mean . . . feet	292	296	296	292	285	289	293	288	285	292	299	273	8
9	Indicated horse-power, mean . ind. horse-power	4·06	4·36	4·48	5·18	5·46	5·86	6·56	6·83	7·77	8·27	9·61	9·81	9
10	Mean temperature in body-jacket space . . F.	225°	301°	227°	295°	238°	297°	252°	299°	267°	03°	260°	296°	10
11	,, ,, of cylinder wall . . . F.	232°	298°	237°	295°	246°	292°	260°	290°	270°	290°	272°	288°	11
12	Mean temperature of cylinder wall 0·6 in. from piston . . . F.	236°	297°	240°	294°	246°	287°	255°	284°	274°	281°	275°	284°	12
13	Mean temperature inside cylinder . . . F.	217°	307°	224°	299°	232°	299°	244°	278°	250°	281°	255°	279°	13
14	Percentage of feed-water present in cylinder at cut-off . . . per cent.	35·4	65·9	33·9	58·2	38·1	66·5	42·6	61·2	50·5	70·8	58·5	77·4	14
15	Percentage of feed-water present in cylinder at release . . . per cent.	59·0	107·9	62·8	92·2	63·4	96·6	63·7	89·2	73·9	85·1	68·5	87·9	15
	Jacket-water, lbs. per indicated horse-power per hour.		lbs.		lbs.		lbs.		lbs.		lbs.		lbs.	
16	Jacket-water from inner surface of body-jacket	..	0·57	..	0·51	..	0·53	..	0·69	..	0·64	..	0·49	16
17	,, ,, outer surface of body-jacket	..	0·68	..	0·64	..	0·51	..	0·61	..	0·53	..	0·45	17
18	,, ,, other three jackets	..	1·07	..	1·42	..	1·25	..	0·81	..	0·79	..	0·54	18
19	,, total from all four jackets	..	2·32	..	2·57	..	2·29	..	2·11	..	1·96	..	1·48	19
20	Jacket-water, total, in percentage of feed-water . . . per cent.	..	8·5	..	9·6	..	9·1	..	7·4	..	6·8	..	4·8	20
21	Feed-water, total per ind. horse-power per hour, lbs.	45·6	27·2	44·6	26·7	41·0	25·2	41·2	28·4	38·7	28·8	39·3	30·7	21
22	Feed-water, lbs. saved per lb. of jacket-water with steam in jackets	..	7·9	..	7·0	..	6·9	..	6·1	..	5·1	..	6·2	22
23	Feed-water, percentage less with steam in jackets per cent.	..	40·4	..	40·1	..	38·5	..	31·1	..	25·4	..	23·1	23

brake were kept constant. Only the body jacket was used, steam being shut off from the other three. The object of the experiment was to determine the effects on the speed of the engine and the temperature of the walls, &c., when steam was admitted to the body jacket and shut off from it again without stopping the engine. Starting at 11.30 A.M., after normal working

TABLE XXV.

			A.M.	A.M.	P.M.
1	Time of observations, . .		11.41	14.47	12.37
2	Body-Jacket off or on, . .		off.	on.	off.
3	Steam-Jacket pressure, lbs. per square inch above atmosphere .	lbs.	0·0	55·0	7·5
4	Revolutions per minute	revs.	140	265	190
5	Piston speed, feet per minute, mean . .	feet	187	353	253
6	Indicated horse-power, mean . . .	I.H.P.	4·00	7·51	5·06
7	Temperature in body-jacket . . .	F.	240°	301°	246°
8	Temperature of jacket-wall, mean . .	F.	233°	295°	240°
9	Temperature of cylinder-wall, mean . .	F.	250°	284°	250°
10	Temperature in cylinder, maximum . .	F.	239°	253°	242°
11	Temperature in cylinder, minimum . . .	F.	235°	252°	240°
12	Temperature in cylinder (in steel cup) maximum	F.	256°	286°	262°
13	Temperature in cylinder (in steel cup) minimum	F.	253°	286°	261°

conditions had been reached, the engine was worked for eleven minutes without steam in the jacket, and allowed to attain a constant speed of 140 revolutions per minute, and a constant temperature of the cylinder, after which, at 11.41 A.M., steam was admitted to the jacket without stopping the engine. Six minutes afterwards, at 11.47 A.M., when the engine had acquired an increased speed of 265 revolutions per minute, and the temperatures had also again become constant, steam was shut off from the jacket, with the result that the speed and temperatures gradually decreased. Fifty minutes afterwards, at 12.37 P.M., the speed was found to have fallen to 190 revolutions

TABLE XXVI.—*Summary of Experiments carried out on Single Cylinder Non-Condensing Engines.*

Date.	Authority.	Type of Engine.	Pressure of Steam.	Ratio of Expansion.	Indicated Horse-Power.	Gain per cent. due to Jackets.
			lbs.			
1846	Thomas and Laurens	...	...	...	120	8 to 10
1859	M'Kay	...	115	...	...	23·0
1867	Fletcher, W.	Portable	60	4 to 1	16	20·0
1869	Donkin	Beam	45	5 to 1	...	18 to 28
1872	Cardiff Trials	Portable	80	6 to 1	9 to 18	23 to 27
1874	Hallaner	Corliss	73	10	101	24·0
1874	Donkin	Beam	45	2·7 to 1	4·94	21·4
1874	Donkin	Beam	45	1	8·90	14·9
1874	Donkin	Beam	45	1	5·04	11·1
1874	Cornut	Corliss	...	18 to 21	78·9	19·5
1874	Cornut	Corliss	...	7 to 8	136	13·8
1874	Cornut	Ingliss	...	10	...	19·1
1875	Emery	Marine	68·5	3·5 & 4·1	201	10·3
1878	Salt	Corliss	...	...	...	14·2
1881	Meunier and Keller	Corliss	67	...	81 to 100	20 to 30
1881-3	Borodin	Locomotive	65	3·4	55·7	9·3
1881-3	Borodin	Locomotive	54·9	3·3	44·6	16·0
1881-3	Borodin	Locomotive	75·3	5·1	45·7	22·4
1883	Delafond	Corliss	...	1 to 3·9	158	6·8
1883	Delafond	Corliss	...	4·4 to 7·1	171	16·8
1890	Donkin	Vertical	50 to 53	3·75	4·19	43·0

per minute; and had the experiment been continued long enough, it would have decreased to 140 revolutions per minute, as at the commencement. Every two minutes throughout the experiment, observations were made of speed, jacket pressure, and the various principal temperatures.

The principal results are also given in Table XXV.

It will be seen how quickly the temperatures in the cylinder increased after steam was admitted to the jacket; and, on the contrary, how they decreased, though less quickly, after the steam-supply was shut off; the only heat then available being that shut into the jacket-space and that remaining in the metal

TABLE XXVII.—*Summary of Experiments carried out on Single Cylinder Condensing Engines.*

Date.	Authority.	Type of Engines.	Pressure of Steam.	Ratio of Expansion.	Indicated Horse-Power.	Gain per cent. due to Jackets.
			lbs.			
1842	Thomas and Laurens	...	53	6	...	30 to 32
1843	Combes	...	50 to 58	20	6 to 7	41·7
1860	Isherwood	Vertical	55·7	5·3	1·13	31·2
1860	Isherwood	Beam	12·0	1·7	361	2·7
1870	Donkin	Cornish	36	4	161	12·9
1870	Donkin	Beam	45	1·8	9·3	19·4
1873	Hirn and Halleur	Corliss	80	10	83·1	23·7
1873	Rennie	Beam	17	3·4	41·6	32·4
1875	Loring and Emery	Marine	15·4	2	97·9	16·3
1877	Fletcher, L.	Marine	30 to 60	4·7	192	15·5
1878	Meunier and Keller	Corliss	67·2	5·7	158	21·5
1878	Meunier and Keller	Corliss	68·1	12·4	100·3	30·3
1879	Farcot	Corliss	61·8	15	166	17·1
1882	Mair	Pumping	42	4·3	123	16·6
1883	Delafond	Corliss	110	11·3	141	26·6
1883	Delafond	Corliss	110	6·4	212	20·0
1886	Guzzi	...	56·6	...	25·5	16·8
1888	Doerfel	Corliss	62·2	5	159	12·3
1889	Longdridge	Corliss	61	4·2	488	2·5
1890	Unwin	Horizontal	59·61	4	37·96	17·0
1890–1	Donkin	Vertical	50·2	3·75	3·72	34·2
1890	Donkin	Vertical	49·9	6·8	4·36	40·4

of the cylinder-walls. The speed of the engine decreased considerably as this heat was gradually exhausted.

Superheating.—Subsequent experiments have been carried out, using slightly superheated steam both in the jackets and in the cylinder. With only from 35° to 58° F. of superheating, and using this steam in all four jackets as well as in the cylinder, there was an economy of about 26 per cent. due to the jackets, in comparison with the result obtained when using the same steam in the cylinder alone, and shutting off the jackets. The engine was working, condensing, at 1-16th cut-off, and at a speed of 200 revolutions per minute. The increase in temperature

TABLE XXVIII.—*Summary of Experiments carried out on Compound Condensing Engines.*

Date.	Authority.	Type of Engine.	Pressure of Steam.	Ratio of Expansion.	Indicated Horse-Power.	Gain per cent. due to Jackets.
1855	Hirn	Beam	55·8	4·3	102·6	23·5
1859	Donkin	Beam	41·0	5·5	19·8	28·6
1868	Donkin	Beam	40·9	11	46·2	31·2
1870	Donkin	Beam	45·0	10·3	16·5	38·6
1874	Emery	Marine	80·3	7	99·2	11·7
1875–81	Donkin	Tandem	42·0	8·5	7·86	25·5
1875–81	Donkin	Tandem	42·0	9·0	9·89	29·0
1875–81	Donkin	Tandem	42·0	9·3	9·46	33·9
1881	Mair	Beam	47·3	15·8	75·2	34·9
1887	Kennedy and Donkin	Vertical	80	7	168	15·4
1887	Kennedy	Tandem	82·1	11·10	8·45	35·2
1887	Kennedy	Tandem	94	8·43	13·03	38·2
1888	Mair Rumley	Beam	49	...	168	8·6
1890	Ollgaard	Beam	51·25	14·6	81·2	18·6
1890	English Davey and Co.	Horizontal	50·2	12·6	113·4	19·0
1891	Denton	...	150	15	...	20·0
	Triple Expansion Engines.					
1889	Reynolds	Vertical	192	26·5	72·1	17·4
1889	Davey and Bryan	Vertical	130	30	138·0	10·3

of the cylinder-walls when the jackets were in use was about 50° F.

Conclusions.—With the same quality and temperature of steam in these experiments, the hotter walls yielded the better results. With walls of the same temperature, the drier and hotter the steam the greater was the economy. The best result with all the jackets in use was obtained with 1-8th cut-off, or 4·8 expansions; the consumption was 25·2 lbs. of steam per indicated horse-power per hour, including jacket-water; and the dryness-fraction at release was 96·6 per cent., showing that, in this case, the exhaust steam was practically dry, and neither superheated nor wet.

We now give Tables XXVI., XXVII., and XXVIII., which show at a glance the percentage of economy gained by thorough steam-jacketing in all types of engines during the last fifty years. It will be seen from this summary of results that, whether the engines have been simple or compound—condensing, or non-condensing, of large or small proportions—at all pressures and rates of expansion, where jackets have been properly applied and tested, an increased economy has resulted therefrom.

We shall bring our remarks to a close by referring to the use of steam of a higher pressure for supplying the jackets than that used in the working cylinder. The employment of high-pressure steam for jacketing is not a modern idea. Mr. Combe, in 1843, "first noticed the condensation on admission, which he believed could be prevented by exposing the cylinder to a greater heat than that supplied by the boiler."*

While many engineers have proposed the adoption of high-pressure steam for use in the jackets, Mr. P. Guzzie, an Italian engineer, has recently put the system to a test. He generates steam for the jackets in a Perkins' type of boiler, steam of 220 lbs. pressure, having a temperature of 390° F., being used. The condensed steam from the jackets is drained back into

* Mr. J. C. Mair.

the boiler. Two comparative tests show the advantages of the arrangement :—

	Jacket Press, 176 lbs.	Jacket Press, 56 lbs.
Date of experiment, ...	24 Feb., 1886	20 Feb., 1886
Duration of test, ...	6 hrs. 18 min.	7 hrs. 11 min.
Boiler pressure, per square inch, .	56 lbs.	56 lbs.
Mean indicated horse-power, .	25·9	25·67
Water used per indicated horse-power per hour, . . .	19·6 lbs.	28·5 lbs.

The first was made with a steam pressure of 12·75 atmospheres in the jacket; the second with boiler steam in the jacket. The engine was one of 50 effective horse-power, with a single cylinder and condenser, an arrangement most conducive to excessive condensation or loss of steam in the cylinder, especially when working with a small admission of steam to less than half its power, and under these circumstances a consumption of 19·6 lbs. of steam per indicated horse-power per hour is a very good result.

In any case, there is a difference of 17 per cent., not between jacketed and unjacketed cylinders, but between high-pressure and boiler-pressure steam employed in the jacket. The advantage of this principle is thus clearly demonstrated, and the application in a similar way could in many instances be easily carried out. Mr. Thurston says :—" The final results of experience up to date, may be summed up in the statement that, when a jacket is properly designed, constructed, and attached, and when it is properly manipulated, it may always be expected to give good economical results."

APPENDIX.

In order to realise the utmost economy from steam-jacketing, it is absolutely necessary that the engine should be provided with several appliances that will help to secure these results. It may be useful to refer to some of these at greater length than we were able to do in the body of the book.

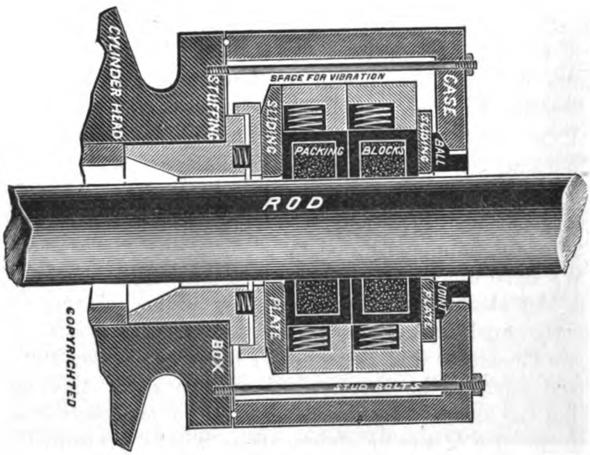
We purpose also in this place to make a few observations on some other appliances for economising steam, apart from steam-jacketing altogether, in the hope that these notes will enhance the value of the book.

We have urged the importance of providing the engines with dry steam, both for the supply of the steam-jackets and the working cylinders. Messrs. M'Phail & Simpson's Steam Generator and Superheater has, in some severe tests, proved itself to be the needful apparatus for thoroughly drying the steam. By its use the enormous losses arising from the use of wet or sloppy steam will be prevented (see p. 57).

Another useful appliance is Mr. J. Royle's Water Separator fitted with an expansion trap. This combined apparatus intercepts and discharges the water arising from condensation in the steam pipes, and ensures dry steam only passing to the cylinder of the engine. Heavy wet steam is well known to materially interfere with economical use in the cylinder. Another advantage arising from the use of the Separator is that all knocking in the cylinder is avoided, owing to the presence of water between the piston and the cylinder-cover; a fertile source of many break-downs. All bursting of joints through the pipes being water-logged on starting is also avoided.

No steam-jacketed cylinder can be complete unless it is provided with a reliable steam-trap. We have had several years' experience with Messrs. Lancaster & Tonge's Steam-traps, and can recommend them. Let it be remembered that a steam-jacket is worse than useless unless it is thoroughly drained.

Another steam-trap is the "Syphonia," made by Mr. J. Royle: this trap also gives good results, and has several special features of advantage that are well worthy of careful notice by steam-users.



United States Metallic Packing.

Messrs. Llewellin & James are the makers of Farrar's steam-trap, from the use of which we have heard some good accounts.

The Return Steam-trap, made by Messrs. Dawson and Co., not only clears the steam pipes or steam-jackets of water, but returns this hot water to the boiler, which is a clear saving, as we have stated in another place (see p. 117).

The chief objection arising from the employment of superheated steam is the trouble experienced with the ordinary packing used in the stuffing-boxes for the piston-and valve-rods. But this trouble is entirely removed by the adoption of the United States Metallic Packing. It is very evident that superheated steam will again be thoroughly put to the test on many types of engines, so that a larger demand for this packing will be experienced (see illustration).

Messrs. Green & Son's Economiser is so well known and largely adopted that little need be said in its favour. Wherever one or any number of boilers of the Cornish, Lancashire, or other types (which are set in brickwork) are adopted, the economiser should be fixed so as to heat the feed-water to a high temperature by the waste flue gases in their exit to the chimney-stack, thereby effecting a considerable saving in coal (see p. 58).

In non-condensing engines the feed-water can be heated to nearly boiling point by means of the exhaust steam, previous to its discharge into the atmosphere. Messrs. Shore & Son's Heater is suitable for this purpose. In some jet-condensing engines we have fixed a water-heater between the cylinder and the condenser, so that the exhaust steam in its passage was made to traverse through the heater; the feed-water being forced through the heater in the usual manner.

Another method of utilising the exhaust steam, so as to effect considerable economy, cannot be secured more easily than by the application of the now well-known and appreciated Exhaust Steam Injector, made by The Patent Exhaust Steam Injector Coy. One user says:—"During my forty years' experience with all sorts of boiler feeders, I have never known anything to equal the Exhaust Steam Injector." It can be used on boilers working at high pressures; it removes back pressure in the engine cylinder; forces the feed-water into the boiler at a high temperature; and is a most economical and reliable steam-saving appliance.

We are very pleased to be able to call attention to Messrs. Whyte & Cooper's Evaporative Condenser. This system of condensation is invaluable where the supply of water is limited or costly, a good vacuum being maintained with a consumption of water which is altogether unattainable by any other method of condensation.

With regard to the saving in coal, or in steam used per indicated horse-power, say, for example, a simple high-pressure engine uses 34 lbs. of steam per indicated horse-power per hour; by the addition of a condenser the weight of steam is reduced to 24 lbs. per indicated horse-power per hour, the engine doing quite the same work as before, with a coal saving of 30 per cent.; but then the water required for the condenser to suit this case would only be 18 lbs. per indicated horse-power per hour, so that a saving in water of 47 per cent. would be effected. With the high-pressure engines 34 lbs. of water, in the shape of exhaust steam, is blown away as waste per indicated horse-power; with the condenser 18 lbs. is evaporated from the condenser per indicated horse-power.

One correspondent says:—"The Evaporative Condenser uses very little water, gives a good hot engine-feed, and the vacuum averages at least 26½ inches. To-day the vacuum stands at 28 inches. I wish I had got your Cooler a few years sooner, as I should have saved by it a great deal of money which I could ill afford to lose."

Wherever water is scarce and fuel expensive these simple condensers shall be adopted.

There are steam-engines in every neighbourhood, the economy of which is capable of being vastly improved. In many of these cases it would pay a good percentage to apply Dr. Proell's Patent Automatic Expansion Apparatus to the engines. It is easily applied to existing slide-valve engines, and special forms are made for newly-built engines, which are thereby made equal in regularity of speed and economy of steam to the best Corliss engines.

In a previous part of the book we have recommended the use of Phosphor-Bronze for steam-jacketed cylinder liners. We believe that a considerable saving would accrue from the use of these phosphor-bronze liners: they can be made as hard as desirable, the material gives a smooth surface, while its conductivity is more than three times as great as that of cast iron. We have used phosphor-bronze slide-valves with excellent results. It is impossible to name the many purposes to which this metal is now applied (see p. 126).

We have to notice two distinct arrangements of forced draught; this is an appliance that has come to the front during recent years. Mr. Granger's Forced Draught can be applied to all classes of boilers, and will increase their steaming capacity from 20 to 25 per cent. The saving effected by Granger's system of forced draught may be put as follows:—The average of several experiments has shown that one ton of cheap fuel, such as slack, smudge or small coal of fair heating power, will raise as much steam when urged with a forced draught as one ton of good steam coal will raise with ordinary draught. Now, as the one fuel is from 40 to 50 per cent. cheaper than the other, there is a gross saving to that extent, and from this must be deducted a small percentage for the steam consumed in working the nozzles. In cases where the boiler power is greatly deficient, ordinary small steam coal may be used, which, with the powerful draught, will increase the steaming capacity from 20 to 25 per cent.

The second system of Forced Draught we have to notice is Messrs. Meldrum Bros. This firm has been for some time closely identified with the advances made in the profitable use of inferior fuel in boiler furnaces. Undoubtedly their system of forced draught has been very largely employed.

The firebars used have air-spaces less than $\frac{1}{8}$ inch in width, so that nothing but the finest dust can fall through. In many cases it has been found possible to dispense with one or two out of a range of boilers, in consequence of the increased evaporation obtained from the others. A great point is that the draught is forced, and is perfectly under control. Any kind of waste fuel can be burned to advantage. "In some cases," says *The Mechanical World*, "under special conditions the economy effected has been most remarkable, notably in the care of the West Hartlepool Iron and Steel Coy., who formerly used to send refuse out to sea at a cost of about 1s. 6d. a ton. This now suffices to raise all the steam required in the works."

Messrs. Meldrum Bros. have 2300 of these furnaces at work, which speaks for itself.

Feed-Water Filters are coming into general use, and are found to be most beneficial. The one made by Messrs. Copley, Turner & Co. may with confidence be recommended.

The filter removes grease, metallic oxides, and other objectionable materials found in feed-water. By its use the burning and collapsing of furnaces is prevented; its use also serves to reduce the quantity and thickness of the scale; and the removal of these non-conductive deposits causes a considerable economy of fuel.

In another part of the book we have spoken very highly of the cylinder and jacketing arrangements carried out by M. Bollinckx. We must admit that the design, workmanship, and efficiency of these engines are worthy of all praise. M. Bollinckx's productions have been most favourably noticed in recent issues of *The Engineer*. The firm deservedly enjoys a very high reputation for the excellence of the work turned out.

In these days of scientific inquiry, when nothing appears to be taken for granted, no steam user of any importance can afford to be without a steam-engine indicator. There are doubtless hundreds of engines which are considered by their owners as being fairly economical, which, if indicated, would prove themselves to be anything but economical: many of these engines could be improved without much expense. Engines should always be indicated after alterations and repairs. It is necessary that steam users should know the amount of power absorbed by the engine and the shafting: this can readily be ascertained by taking a friction diagram. The indicator will show the amount of back-pressure in the cylinder; it will show any wire drawing owing to contracted steam-ports or small steam pipes; it will reveal defective valve-setting and many other faults of construction that we cannot stay to name. If the information received from the cards of a properly used indicator be acted upon, this instrument may then be termed a steam economiser. Messrs. Hopkinson & Coy.'s Indicator is a reliable instrument, and is used by a large number of engineers.

There is one more essential steam economising agent that must not be overlooked. It is very necessary that a perfectly steam-tight piston should be used, and being tight it must also be as near frictionless as possible. A leaking piston in a simple engine is a direct source of loss. In compound engines the leakage from the high-pressure piston is not lost, but does some work in the low-pressure cylinder. But a leaking piston is an inexcusable waste of fuel, because the remedy is so easily effected. Messrs. Lancaster & Tonge have made this subject their particular study with good results. While on the question of pistons, we may quote some remarks made by Mr. Butterworth recently:—"Before leaving the subject of steam-jackets, it may be said that they have an important bearing on the efficient lubrication of a cylinder. It is well known that most metals when working together under water actually generate more friction than when working dry, so that if a film of water be already present, it will prevent the oil adhering to the walls of the cylinder, and cause increased wear. The following may be taken as an indirect proof of this. In the high-pressure cylinder of a marine engine 22 inch. diameter, 36 inch. stroke, running 150 revolutions per minute, a set of piston rings were fitted, and, after working twelve months, were overhauled and found to have scarcely worn at all, although the steam-pressure was 160 lbs. per square inch. At the same time, by the way, the boilers of the ordinary tubular marine type were thoroughly scraped and cleaned, with the result that the steam was more rapidly generated on the next voyage, causing priming to ensue, with the result that the piston rings were worn out in three weeks. All the conditions were the same, so that it leaves no doubt that the water washed the oil from the cylinder walls and took its place, causing the rings to gall and wear away rapidly."*

As steam-pressures increase, the use of balanced slide-valves will become more general. Messrs. Lancaster and Tonge's Serpent Coil is specially adapted for piston-valves, the peculiarity of which is, that they work over ports, the steam thus acting on the outer circumference of the rings and tending to close them in. If the steam is able to do so, the piston valve will then leak and cause great loss. By means of the Serpent Coil the makers guarantee to obtain a resistance to collapse of over 200 lbs. per square inch, and, at the same time, have an outward pressure to compensate

* *The Practical Engineer*, 21st December 1894.

for wear of less than 3 lbs. per square inch. The Serpent Coils have worked in some instances for two years without showing signs of wear.

There are other means of saving fuel besides the ones we have touched upon, but we cannot stop to name them.

We have dwelt upon the principal methods of economising steam in engines and boilers. The book has been written in the hope that some of the iniquitous waste of coal, that now, alas, is constantly taking place, may be prevented: should our remarks bear fruit we shall be rewarded.

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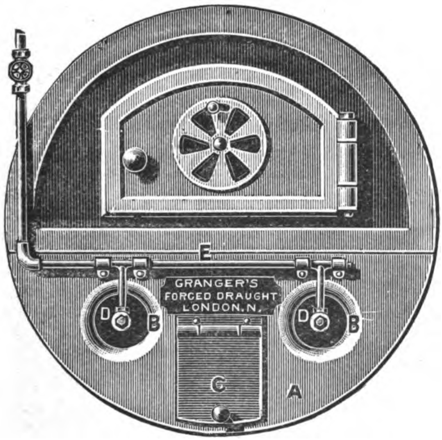

Can be applied to all classes of Boilers, and will increase their steaming capacity 20 to 25 per cent.

All Steam Users having over-worked Boilers will derive great benefit from this system.

It also burns **SLACK, DUST COAL, REFUSE FUEL, &c.,** to great advantage, thus

REDUCING THE COST OF RAISING STEAM 25 TO 50 PER CENT.

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