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Methods of Pumping Water from Deep Wells

Mech. Engineering
B. S.

1903

METHODS OF PUMPING WATER FROM DEEP WELLS

BY

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THESIS FOR THE DEGREE OF BACHELOR OF SCIENCE

IN MECHANICAL ENGINEERING

IN THE
COLLEGE OF ENGINEERING
OF THE
UNIVERSITY OF ILLINOIS
PRESENTED JUNE, 1903

UNIVERSITY OF ILLINOIS

June 1, 1903 190

THIS IS TO CERTIFY THAT THE THESIS PREPARED UNDER MY SUPERVISION BY

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ENTITLED METHODS OF PUMPING WATER FROM DEEP WELLS.

IS APPROVED BY ME AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE DEGREE

OF Bachelor of Science in Mechanical Engineering.

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Methods of Pumping Water From Deep Wells.

I N T R O D U C T O R Y

Methods of Pumping Water from Deep Wells.

The pumping of water has come to be a very important factor in modern civilization. Towns and cities must have water for household purposes, for power plants, and for extinguishing fires. In many cases it might be taken from surface streams or lakes, but as the same mains furnish the supply for all purposes, it has to be obtained from a source that is pure. Deep wells usually furnish pure water, and as they seem to be the most practicable means in level parts of the country, most cities and towns of sufficient size have one or more of them. Some means must be devised by which the water can be brought to the desired level. Many different schemes have been tried, but it is the object of this thesis to describe and compare the methods in use at the present time. A report of some tests made on the Downie Deep Well Pump and on the Air Lift used in the pumping station of the University of Illinois will also be made.

H I S T O R I C A L

The art of raising water must of necessity have been one of the first of the mechanical arts engaging the attention of man, for no progress in civilization can be had without a convenient and ample supply of good and wholesome water. The earliest people must have obtained their water supply from permanent springs and streams; but the growth in population, the increase in wealth, and a higher civilization required a broader development of the land, and it was during this period of development that the ingenuity of man was exercised in originating schemes and appliances for the lifting and distributing of water.

Little is known of the early history of the art. Cities were supplied from aqueducts which brought the water from a higher altitude. The earliest known method of raising water was by buckets attached to cords, lowered and raised by hand. As the possession of a well or source of supply of this precious fluid placed the owner in a very high standard regarding wealth, we cannot doubt that the method to obtain the same was of minor importance, and, therefore the best means known would certainly be employed.

The Egyptian wheel was a common machine over all Asia, and in remote corners remains in use yet. It consists of a

wheel with shovels fastened on the rim which raise the water a short distance when it revolves. There were many schemes used in which the wheel was the principal part. One form had buckets, on the periphery of the wheel, which filled with water when at the bottom and poured it out into a trough at the top. Another form was made up of a hollow wheel enclosing spiral blades which radiated from a hole in the center. The wheel was revolved in such a way as to scoop up the water and as the revolution continued the water ran around on the blades and out of the hole in the center.

A scheme similar in principle but by which the lift was greater, was composed of an endless chain with buckets attached at regular intervals. This chain ran over a wheel at the top and dipped into the water at the bottom of the lift. The buckets filling at the bottom and emptying as they came across the top of the wheel. The modern chain pump is a development of this idea.

The Archimedean screw is also one of the oldest known water raising machines. It consists essentially of a tube wound spirally around an inclined shaft, and taking part in the rotation of the shaft. The pitch of the screw and the inclination of the shaft are so chosen that a portion of each thread will always point downwards; a certain quantity of water will then be contained in the lower part of each thread. At each revolution of the shaft a quantity equal to that contained in the bottom of the thread will be poured out at the top.

Another form of a water screw consists of a hollow barrel in which a double or triple screw is made to revolve. These were the earliest methods used and there was nothing that implied our modern pump till many years later.

The first scheme that suggested the pump was made up of a tube which projected below the water surface, a rope and a bundle of hay. The rope went down on the inside of the tube and at the lower end was fastened to a bundle of hay. The lower part of the tube filled with water and the bundle of hay was pulled up even with a spout in the tube. Thus the column above the hay was lifted and discharged through the spout. The hay was pushed down with a stick and the operation repeated. Not only would the water above the bundle be lifted, but that below would follow also. That below, however, would be forced out again when the bundle was pushed down. To prevent this a valve was placed at the lower end of the tube, but in this case a lateral passage was necessary. It is called the pump of Cteribus; the valve being the great refinement.

Fig 1

Fig 2

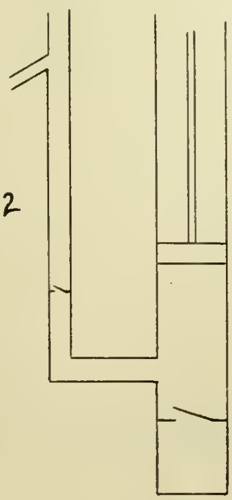
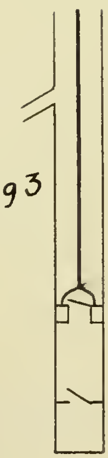


Fig 3



Sketches of the earliest pumps.

The Encyclopaedia Britannica defines a pump as an hydraulic machine for raising water by means of the pressure of the atmosphere. In Figure 2 when the piston is pulled up the pressure in the chamber B is lessened. When the pressure within the chamber has become small enough, the pressure of the atmosphere on the surface of the water outside causes the valve c to be lifted and the water to flow in. The pump is the last step of the progress of the ingenuity of man in inventing methods of drawing water. Nothing like it has been found in any of the rude nations either in America or the islands of the Pacific Ocean. It was unknown in ancient China, and does not appear to have been known to the Greeks and Romans in earlier times.

The first application of steam was in the operation of mechanical toys. About one hundred and thirty years before the Christian era, Hero, the elder, who flourished in Alexandria in the reign of Ptolemy Philadelphus, and was eminently distinguished for his learning and for the number and ingenuity of his mechanical inventions, was the first to give an account of the application of the vapor of water. In his work, entitled "Spiritalia" he describes a machine which operates by the force of steam. It consists of a caldron or vace, C. containing boiling water, with a pipe P reaching nearly to the bottom. As the steam accumulates it presses on the surface of the water, and will force it in a jet through the pipe,

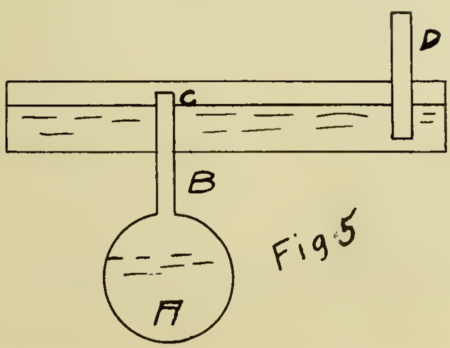


Fig 5

till the whole is ejected or converted into steam. A fountain is thus formed capable of supporting the ball B. This is the first known application of steam to the raising of water.

Another method somewhat similar but differing in the fact that it raises cold water is shown in Figure 5. A boiler A has a neck or tube B, through which the steam passes to the upper part of the cistern C, and, pressing on the surface of the water it contains forces the water upward and out of the pipe D. This principle was used in various contrivances and for a long while it was the most advanced form of water elevator..

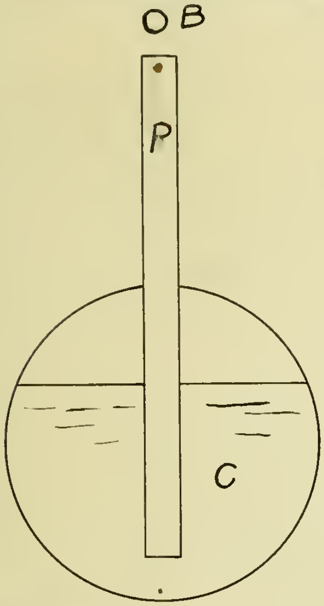
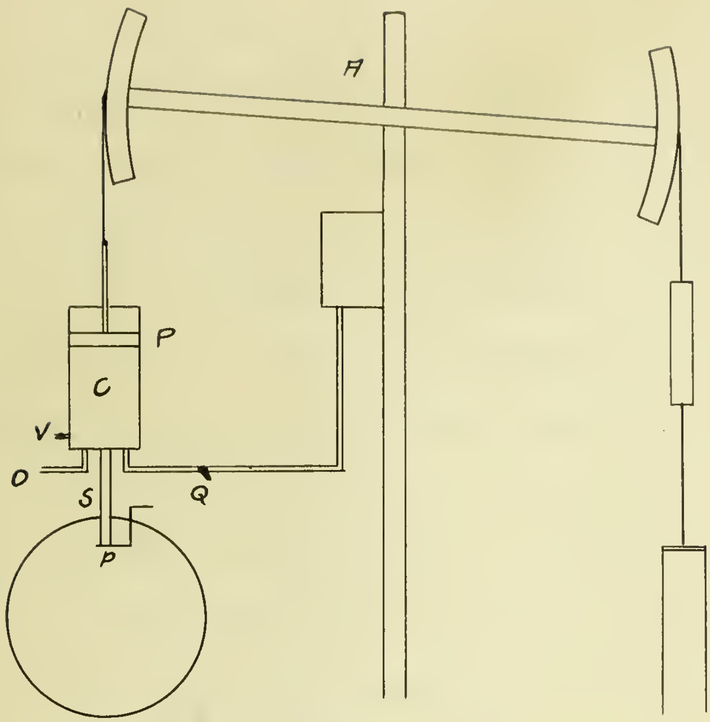


Fig 4

Notwithstanding the imperfection of these machines, it now became sufficiently evident that steam could be used effectively for raising water, and the want of some cheap and powerful agent for that purpose, rendered the working of deep mines so expensive as to be almost ruinous to the proprietors, though otherwise highly productive. These incentives produced farther research and experiments, and in the year 1805, Thomas Newcomer, a smith, of Dartmouth obtained a patent on a machine which might be called the first steam engine of the piston type. It was used to raise water from mines. B represents the boiler, with its furnace for producing steam.



A small height above the boiler is a steam cylinder C of metal, bored to regular diameter, and closed at the bottom, the top remaining open. A pipe S connects the boiler and piston. The lower aperture of this pipe is shut by the plate p which fits tight. It is attached to a handle on the outside of the boiler. The piston P is fitted to the cylinder and packed with soft rope soaked in tallow for lubrication. The piston rod is connected to a chain which is fastened at the upper end of the arched head of the lever arm A. The chain on the other end of the arm is fastened to the pump rod. The bottom of the cylinder is connected by a pipe to a tank of water.
When the piston is at the bottom of the cylinder and the steam valve p is closed the pressure of the atmosphere keeps it there. The pump rod is loaded so that it is just a little heavier than the piston. The steam valve is opened and the

steam allowed to enter. The load on the pump rod and the steam cause the piston P to ascend. When it reaches the top of the cylinder the valve p is closed and the cock Q is opened admitting a jet of cold water, which condenses the steam, forming a partial vacuum, and the piston descends by the pressure of the atmosphere. raising water by the pump from the mine. The air which the steam and injection water contained is forced out through the snifting valve V, by the force of descent, and the water flows out the eduction pipe O; and by the repitition of the operations of alternately admitting steam and injection water the work of raising water is effected.

The next step in the development of the steam pump was brought out by Leupold, a German. His engine differed in the fact that by means of a four way steam cock the steam was admitted to two cylinders alternately which in turn worked two plungers and caused a continuous flow of water up the main pipe.

Many contrivances and schemes were used , each one being what the maker considered an improvement over the last invention. Some were good while others were bad, but it was the rivalry between these early inventors that led up to the modern pumping engine of to-day. Most of these earlier pumps were able to raise water a short distance only, but as the demands became greater, the height to which water could be raised also became greater, until there is to-day almost no limit to the height.

One of the modern high duty pumping engines of to-day gives a duty of 130,000,000 ft. lb. per 1000 pounds of steam used.

The air lift pump is said to have been invented in the eighteenth century, and in use at Freiberg Saxony. Seimens in England experimented with the air lift in the middle of the nineteenth century, and it was patented as an air ejector by McKnight in 1864. It seems to have been dropped for awhile till Dr. J. G. Pohle' was granted several patents on air lifting devices. His first system required a depth of water in the well more than equal to a height to which the water was to be lifted. The original system has, however, been modified and improved on special points with small gains of efficiency. Dr. Pohle' also introduced compounding till it is possible now to lift water to great heights either from mines or deep wells. The Compressed air and the Electrical pump are of very recent origin.

S T E A M   P U M P I N G

The consideration of the subject of deep well water supply is beginning to attract considerable attention. Within the boundaries of our state, containing 55,000 square miles, there are 275 thriving towns of over 1000 inhabitants each, upon whose attention the necessity of a pure water supply has been or will be forced. The specifications for a well should be given as careful attention as the machinery by which the water is raised. The expense of operation and maintenance of pumping plants for cities, towns and villages varies very much

in different localities.

The natural conditions surrounding the source of water supply, must have a controlling influence on the nature and design of the pumping machinery used to develop it. The limits of possible suction lift varies with the elevation of the locality above the sea level. The available suction head at any place may be determined by the formulae

$$\text{Log. } F = 1.53084 - \frac{H}{64,000}$$

F = height in feet of a column of water which will balance average atmosphere pressure. H = height of station above sea level. About two feet must be deducted from this head for minimum atmospheric pressure, and a further deduction must be made for the loss in head in the suction pipe and suction chambers of the pump.

These various deductions leave the maximum possible suction lift from about 27 feet at sea level to 24 feet at an elevation of 1500 feet above sea level. It is usually desirable to set pumping machinery nearer the water when possible. When the water surface is still lower suction lift becomes impossible, and other methods must be utilized. The most obvious method of reaching water, when it is below the reach of suction is to sink the pump to such a depth below the surface, that it will be within suction distance of the water, and where the distance is not too great this can be done. The most usual method however, is to place the working barrel near or beneath the surface of the water. This furnishes an abundance of water

to the working cylinder at all times.

The motor end of pumping machinery usually requires more particular and constant attention, both on account of its lack of means of lubrication necessarily provided by the nature of the work performed by the water end, and on account of the greater intricacy of arrangement, and frequently the greater speed of the parts in the motor end of the machine. In most deep well practice the motor is placed on the surface within ready access and near the source of power. This has given rise to various types of vertical machinery, which has supplied the condition of such situationswith greater or less satisfaction. Some types are driven from a shaft while others are direct driven. The piston and water flanges being on opposite ends of the same rod.

Pumping engines are divided into several classes, namely; low duty, medium duty, high duty and higher duty. Competition is so great along this line in the last few years that most all pumping engines are designed especially to suit the condition of the place in which they are to be put. The superiority or inferiority of a pumping engine depends upon the fitness of the machine for the work to be done; and there mustbe considered first cost, cost of repairs and maintenance, duty or steam economy, and the probable amount of lost time or time out of service to insure proper condition . Charles A. Hague, in a paper read before the American Water Works Association says, "The first requisite of a pumping engine is to pump water, to pump it continuously and unfailingly, and if unreliable

in this respect, it does not matter what it can do."

The question of valve area in a pump is one which has given rise to many arguments and misstatements; but the fact of the matter is that the area of the valve is a factor in the quantity of water to be pumped regardless of the ratio or percentage it happens to bear to the area of the plunger. For example a large plunger moving slowly will pump the same amount of water as a proportionly smaller plunger moving more rapidly, but the same amount of valve area will serve both plungers if the quantity of water remains the same, although it will be claimed for the smaller plunger that it has a much larger percentage of valve area than its larger and slower moving neighbor; whereas the practical advantage is with the larger plunger even with its apparent small percentage of valve area.

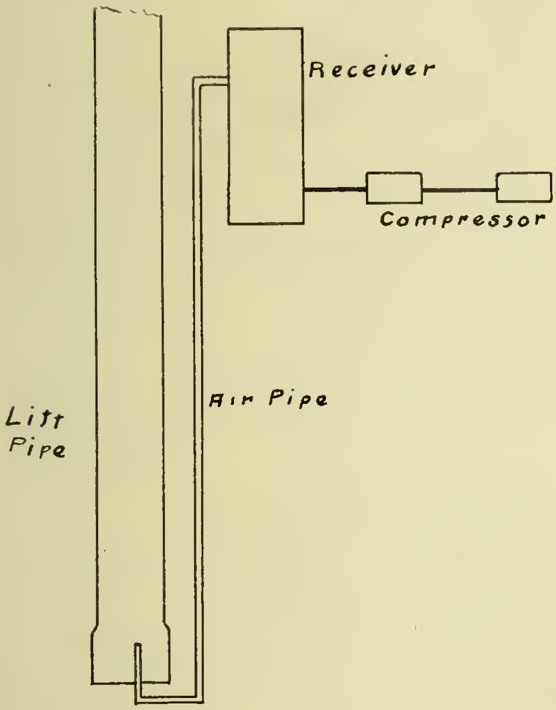
The speed of the plunger is another item of argument and contention, but as a rule the experimentors are the most ardent advocates of high speed. The tendency to-day is no doubt more and more toward higher speeds in feet travelled per minute. High speed coupled with a high rate of reciprocation is only a subterfuge of the manufacturer to enable him to lower his figures by offering a small engine to do the work of a large one. The best practice agrees that a low rate of revolution is the best.

The difference in class and cost of pumping engines for any certain service is comprised mainly in the steam end. The most ordinary class of non-condensing steam pump will require

from three to four times as much steam and consequently coal as a high class compound condensing high duty engine. A triple expansion engine if equally well designed will require still less fuel and a quadruple less still. But in service best adapted to a compound engine the triple and quadruple engine will fall far enough behind in efficiency to wipe out the gain. The higher the class the closer the conditions must be observed.

In such a machine as the high pressure steam pump taking steam at full stroke is at its best the lowest type of steam engine, and its consumption of steam will not be materially affected under a wide diversity of conditions; but when we raise the class and begin to expand steam, the higher we go, and the more the expansion is multiplied the more delicate the machine with reference to balance between power and load. The question of duty of a pumping engine has received much attention and is held to represent the efficiency.

AIR LIFT PUMPING



The accompaning figure illustrates a compressor, receiver air and lift pipe as usually operated in deep wells, in which the pressure in the air pipe must be greater than the hydrostatic pressure of the water at the bottom of the pipe, and in quantities sufficient to make the ascending column of air and water in the flow pipe lighter in its total height than a solid column of water of the depth of the mouth of the flow pipe below the surface of the water; thus making this principle in pumping water essentially a differential gravity system.

The air lift pump proper consists of only two plain open mouthed pipes, the larger one with an enlarged end piece constituting the water pipe, and the smaller one let into the enlarged end picce of the discharge pipe constitutes the air inlet pipe, through which the compressed air is conveyed. There are no valves, buckets, plungers, rods or other moving

parts used within the pipes or well. Compressed air is forced down the air pipe into the enlarged end at the bottom of the water pipe; hence by the inherent expansive force of the compressed air, layers of bubbles of air are formed in the water pipe which lift and discharge the water layers through the upper end of the discharge pipe. At the beginning of the operation the water surface on the outside and that on the inside of the pipe are at the same level; hence the pressures per square inch are equal at the submerged end both inside and outside. As the air is forced in the alternate layers of water and air cause the pressure on the inside to become less than on the outside.

Owing to the difference of pressure the water flows continuously from the outside to within by gravity force, and its ascent through the pipe is without shock, jar, or noise of any kind.

The air sections or strata of compressed air form closed bodies in their ascent and allow neither slipping or back flow of water. As each air stratum progresses on its way to the outlet, the air expands in proportion as the overlying weight of water is diminished by its discharge, so that the air section which may have been 50 # at the start comes to the same tension as the atmosphere, thus proving that the whole of its energy has been expended in doing work.

The Pohle "air-lift" pump has been found to give an efficiency of 80% from the air receiver in pipes of large diameter, and about 70% in pipes of smaller diameter. The

efficiency of the air lift remains the same till the pipes rust through whereas the efficiency of the plunger pump begins to decrease as soon as it is started, especially if the water contains acid, sand, or other injurious substance.

The secret of the air lift pump is in the high velocity with which the air and water are discharged. Without the high velocity there would be no piston like action except perhaps in small tubes where capillary attraction takes the place of velocity. There being no moving parts there is nothing to get out of order or wear out. When the air is shut off the water in the pipes flows back and thus there is no danger of freezing up. The absence of valves makes it a good pump to use in the lifting of sewage. It is also adapted for use in vinegar works, dye works, sugar refineries, etc. The capacity of the pump seems to be unlimited, and, with the proper proportions of air and water will work efficiently in pipes of several feet in diameter. It has been estimated that a 30 inch pipe will deliver 16,660 gallons per minute, equal to 1,000.000 gallons per hour.

It often happens that one well will not yield enough water, but a number of wells will give the desired quantity. By the deep well pump method each well would require a separate "steam head," separate sets of rods and other paraphernalia, which with the condensation of steam in the pipes connecting it to the source, would be very costly in the first outlay, and very wasteful of power in its maintenance, to say nothing

of the loss of time taken for repairs. By the Pohle process one air compressing plant is required, and this may be placed under the eyes of the engineer; from whence the air may be conveyed to the several wells all of which may be pumped simultaneously and economically.

The compound air lift is as yet undeveloped. No tests have been made and it is impossible to state its efficiency It differs from the simple lift in that the water is lifted from one level to a higher level by simple lifts. If the compounding is carried far enough, there is no limit to which the water cannot be raised.

There are many different kinds of pumps on the market to-day. The surrounding conditions determine which kind is the best fitted for the work and the most economical in installation and maintenance. Centrifugal and Rotary pumps are used for lifts that are not very great. They are made up of two or more solids of revolution that cause the spaces occupied by the water to be increased and diminished by their motion. Compressed air pumps are of recent origin and are not yet much used. Electrical pumps are also of recent origin. There are a few pumps of this kind throughout the country, but data and information cannot be had concerning them till they become better known.

With many industrial institutions the use of steam for pumping water is incidental; that is to say, it constitutes but a fractional part of the total use of steam and possesses an incidental relation to the productions of the institution. Consequently, the installation of this portion of a plant often receives little or no skilled consideration, and frequently a cheap and inferior grade of machinery is introduced without regard to the economy of operation. Although in such a plant the consumption of fuel and steam may be enormous in proportion to the amount of work done, still the drain upon the resources is not felt, or may be tolerated on account of the comparative insignificant amount of power consumed, But let the consumption of water be large as in those operations requiring water in large amounts for cooling, brewing, refrigeration or other

similar purposes, and the distribution of it be from several points more or less isolated; then the pumping expense becomes an important factor in the economical working of the establishment, and the low grade pumping engine develops to the fullest extent its abnormal appetite for steam. Such things cannot continue in this day and age when the growth of economical devices is so rapid and the competition between manufacturing firms is so close.

In the pumping station of the University of Illinois there are two wells. One well contains a "Downie Double Acting Steam Pump," the other an "Air Lift Pump." The Downie pump, the air lift and the two air pumps used in the tests are shown in the accompaning photographs.

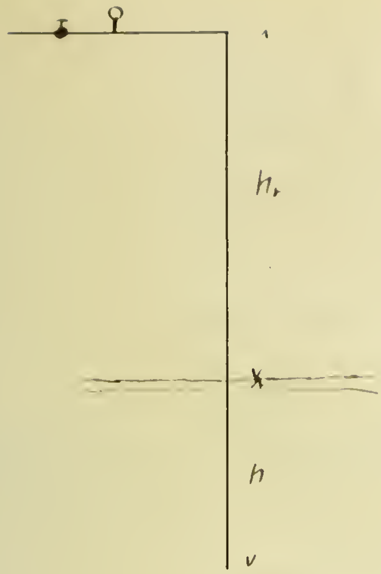
The pump is of the standard Downie pattern. Its double action gearing being its particular feature. The photograph shows the gearing in about mid stroke. The drop pipe of the well is 100' 5-3/4" long, the working barrel 6' 6", check 11", strainer 1' 9-1/2" making the total length 109' 8-1/4". The well is 145' deep. The drop pipe is surrounded by a cast iron casing having a larger diameter.

The air pumps used were the New York Air Brake Company's air pump number 1876, and the Westinghouse Air Brake Company's number 60,838. Each pump was tested separately to find the number of pounds of air delivered per pound of steam. The pumps were then connected with the air lift and the amount of water pumped determined.

During the test run on the Downie pump the water was pumped into a tank of known area. The height of water at beginning of test was carefully noted and also at the end of test. It was thus possible to obtain the number of cubic feet of water pumped into the tank.

The steam was allowed to exhaust into tanks of cold water set on scales. The weight of a tank of cold water was noted and then the steam allowed to exhaust into it till the water became warm. The steam was then made to exhaust into the other tank of cold water whose weight was known. The weight of the tank of warm water was noted and after emptying was again filled with cold water while the steam was exhausting into the second tank. The tanks were thus used alternately. The difference in weight between the tank of cold and the tank of warm water gave the weight of the exhaust steam. The sum of these differences gave the total amount of steam used during the test.

The depth of the water below the surface was determined by putting a small pipe of known length down the well so that it extended below the water surface. Compressed air was forced down the pipe till all the water was forced out at the bottom. A valve was then closed to prevent more air from going down. The reading on a gauge then gave the pressure necessary to balance a column of water equal in height to the distance from the surface of the water to the end of the air pipe. The accompaning figure shows the arrangement of the valve and gauge.



P = pressure in lb. per sq. in.

h = feet

h = 2.304 P   2.304 x 5 = 11.52ft

Length of pipe 85' 10-3/4"

85. 979

h_1 = 85.979' − 11.52 = 74.459'

Distance from surface to top of lift 21' 7". H = total lift

= 74.459 + 21.583 = 96.042'

or 96'.

If x = the number of cubic feet of water pumped, 62.5X the number of pounds pumped. The number of foot pounds of work done is equal to the total weight in pounds times the lift in feet. The number of pounds of steam taken to do this work is also known, therefore the duty or foot pounds of work done per 1000 pounds of steam can be determined.

In testing the air pumps, the steam used was determined in the same manner as in the test the Downie pump. The pump was made to pump against a constant pressure. A valve was put in the air pipe and a gauge between the valve and the pump so that the gauge reading was kept constant by regulating the valve. The air was pumped into a receiver with mercury wells. The volume of receiver and pipes was known. The pressure and the temperature at the beginning and the end of the test were noted. It was then possible to determine the number of pounds of air in the receiver at the given period by the formula

P V = M R T

Where:-

P = pressure in lb. per square ft.

V = volume in cubic ft.

M = weight in lb.

R = 53.35 = constant for air.

T = temperature, degrees absolute.

If the values obtained at the beginning of test be substituted in the formulae and then those obtained at the end, the difference in the values of M will be equal to the number of pounds of air pumped into the receiver in the given time. With the steam used known, and the weight of air pumped known the weight pumped per pound of steam is easily obtained. Both pumps were tested in this way. They were first made to pump against 40 lb pressure and then against 50 lb. pressure. They were then connected with the lift and made to work under the same conditions. The amount of water raised into a tank of known size was noted. Thus it was possible. knowing the amount of air pumped per lb. of steam in both pumps and the amount of water raised in a given time, to find the duty of the lift.

The two air pumps were not able to furnish air enough to run the lift at a pressure of more than 35 lb. so they were run so as to deliver the maximum amount of air per pound of steam. The Westinghouse pump was made to pump against 50 pounds pressure, and the New York pump against 40 pounds pressure. *If* The New York pump used 984 lb. of steam, and the Westinghouse used

614 lb. of steam per hour to pump the maximum amount of air per pound of steam it can be correctly assumed that they will, working under the same conditions, deliver the same amount of air per pound of steam when turned on the lift. Therefore they will use 1598 lb. of steam per hour. Thus, knowing the steam used, the lift in feet and the pounds of water pumped the duty is determined.

TEST ON DOWNIE PUMP.

Time	Weight Tank I Start	Weight Tank I Finish	Weight Tank II Start	Weight Tank II Finish	S.P.M.	Depth in tank	Duty.
9:57	700	744	509	542	30	2' 2"	
	573	600.5	485.5	520	"		
	690	727.5	482	523	"		
	645	679	552.5	582.5	"		
10:57	656	695	506.5	529	"		
Steam	355#						11,893,440 ft. lb.
11:16	640.5	678.5	486	515	30	2' 1 7/16"	
	671	707	481	512	"		
	635	682	496	528	"		
	602	637.5	489	519	"		
12:16	645.5	680	477	512.5	"		
	Steam 369						11,811,840 ft. lb.
4:34	703	754	502	540.5	30	2' 2 1/2"	
	714	750	529	566	"		
	747	786	520	561	"		
	698	740	520	552.5	"		
5:34	705	756			"		
	Steam 368						11,689,760 ft lb.

Time	Weight Tank I Start	Weight Tank I Finish	Weight Tank II Start	Weight Tank II Finish	S.P.M.	Depth in tank	Duty.
1:12	614	648.5	485	509	20	1' 3 7/16"	
	624.5	651	465	503	"		
	716	751	483	515	"		
2:12	728	760	482.5	509	"		
	Steam 249#						10,046,400 ft lb.
2:20	661.5	700	482.5	504.5	20	1' 3 7/8"	
	664	700	473.5	500	"		
	655	694	444	476.5	"		
3:20	628	670	483	502	"		
	Steam 256						10,048,320 ft lb.
1.55	711	755	502	532.5	20	1' 3 3/4"	
	709	754	517	546	"		
	723	763	538	568	"		
2.55	715	756.5			"		
	Steam 220#						10,063,920

Time	Weight Tank I Start	Weight Tank I Finish	Weight Tank II Start	Weight Tank II Finish	S.P.M.	Depth in tank	Duty
1:34	627	668.5	518	566	10	$4\frac{9}{16}''$	
2:34	657.5	695	550	587	10		
	Steam 163#						4,359,072 ft.lb.
2:40	705	751	523	561	10	$4\frac{7}{16}''$	
3:40	698	743	541	568	"		
	Steam 156						4,608,000 ft.lb.
4:00	715	755	504	532	10	$4\frac{1}{2}''$	
5:00	713	757	527	564	"		
	Steam 149						4,886,400 ft.lb.

TEST ON NEW YORK AIR PUMP.

PUMPING AGAINST 40 lb. PRESSURE

	Time	T	P	V	M	Steam	lb. air per lb. steam
		°	#	cu. ft.	#	#	
Start	9:25	83	5	89	1.44	0	
Finish	9:30	87	23.5	89	6.35	67	.073 #
Start	11:45	83	5	89	1.44	0	
Finish	11:50	90	23	89	6.14	61	.0718

PUMPING AGAINST 50 lb. PRESSURE.

	Time	T	P	V	M	Steam	lb. air per lb. steam
		°	#	cu. ft.	#	#	
Start	1:15	84	5	89	1.43	0	
Finish	1:20	90	29	89	7.75	82	.0772 #
Start	2:30	84	5	89	1.432	0	
Finish	2:35	92	30	89	7.85	82	.0784

TEST ON WESTINGHOUSE AIR PUMP

Pumping against 40 lb. pressure.

	Time	T	P	V	M	Steam	lb. of air per lb. steam
		°	#	cu. ft.	#	#	
Start (1)	9:05	96	5	88.9	1.2 5	0	
Finish (2)	9:10	102	26	88.9	6.1 2	50	.0975#
Start (1)	9:45	94	5	88.9	1.2 7	0	
Finish (2)	9:50	102	27	"	6.3 5	52.5	.0963

Pumping against 50 lb pressure.

	Time	T	P	V	M	Steam	lb. of air per lb. steam
Start	10:30	94°	5	88.9	1.2 7	0	
Finish	10:35	101	25	88.9	5.9 3	60	.0777
Start	1:05	95°	5	88.9	1.2 6	0	
Finish	1:10	102	27	88.9	6.3 5	65	.0782

TEST ON AIR LIFT

Time	Steam per hour	Water per hour	Duty
1 hour	1598	28272 #	1,728,000 ft.lb.
"	1598	28272	1,728,000 ft.lb.
"	1598	28061	1,680,000 ft.lb.
"	1598	27851	1,632 000 ft.lb.

The Downie Pump seems to give the highest duty at the maximum speed. Although at a medium speed of twenty strokes per minute the duty is only decreased from 11,800,000 ft. lb. the maximum speed of thirty strokes per minute, to about 10,000,000 ft. lb., It seems to fall off very rapidly as the speed is decreased below this point. At a maximum speed of ten strokes per minute the duty is only 4,600,000 ft. lb. Thus indicating that to get the maximum duty from the pump it is necessary to run it at full speed.

The air lift gives a duty of about 1,600,000 ft. lb. It therefore appears that the Downie pump is by far the most economical.