EVANSVILLE WATER WORKS.

REPORT OF THE EXPERT

John Willmuth Hill

ON THE

CONTRACT TRIALS

OF THE

Gaskill Compound Pumping Engine

BUILT BY

THE HOLLY MANUFACTURING COMPANY,

LOCKPORT, N. Y.,

FEBRUARY, 1881.

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PRELIMINARY REPORT

ON THE

CONTRACT TEST TRIALS

OF THE

GASKILL COMPOUND PUMPING ENGINE,

BUILT BY

THE HOLLY MANUFACTURING COMPANY

FOR THE

CITY OF EVANSVILLE,

FEBRUARY, 1881.

HENRY S. BENNETT,
GEORGE A. BITTROLFF,
NICHOLAS ELLES,
} *Committee on Water Works.*

GENTLEMEN:—Acting under your instructions, in behalf of the *City of Evansville*, I have made test trials of the engines recently erected in your pumping house by the *Holly Manufacturing Company*, of Lockport, N. Y., for your city water supply, and have to report to you thereon as follows:

The engines, two in number, are of the compound condensing type, with cylinders set parallel, and centers separated eight feet. The high pressure cylinder has a diameter of twenty-four (24) inches, and the low pressure cylinder a diameter of forty-one (41) inches. Each piston has a stroke approximately thirty-six (36) inches. The pistons of each engine are connected to cranks set at quarters on the fly wheel shaft mounted in bearings on the gallows frame overhead.

The contract between the city of Evansville and the Holly Man-

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ufacturing Company provides for "two sets of duplex pumping engines, each of four millions (4,000,000) gallons capacity each twenty-four (24) hours at a piston speed of one hundred and eight (108) feet per minute."

With engines pumping direct into the distributing mains, it is impossible to measure the water delivered through the force pipe by any of the usual methods, and as the supply is drawn from the river (Ohio) through long lines of suction pipe connected to the suction of the pumps, and subject to wide differences of head, it becomes practically impossible to measure the water on the suction side of the pumps. I have therefore adopted the only convenient method for determining the capacity of the engines, that of calculating the discharge and deducting therefrom a minimum slip.

The data for this purpose were taken by myself in the presence of your superintendent (Roberts) and a representative of the Holly Manufacturing Company, and are as follows:

Engine No. 1—

H. P.	cylinder	pump	piston,		diam.,	17.98	inches.
"	"	"	"	rod,	"	3.376	"
L. P.	"	"	"		"	18.00	"
"	"	"	"	rod,	"	3.422	"
H. P.	"	"	"	stroke,		35.965	"
L. P.	"	"	"	"		35.985	"

From which I estimate the capacity of engine No. 1 as

$$\frac{2(17.98^2 \times .7854) - (3.376^2 \times .7854) \times 35.965}{231} = 77.653$$

gallons, calculated capacity of the pump worked by the piston of H. P. cylinder per revolution, and

$$\frac{2(18^2 \times .7854) - (3.422^2 \times .7854) \times 35.985}{231} = 77.850$$

gallons, calculated capacity of the pump worked by the piston of the L. P. cylinder, per revolution, and aggregate calculated capacity of both pumps, per revolution,

155.503 gallons.

The mean stroke in feet of both pumps is

$$\frac{35.965+35.985}{2\times 12}=2.9978$$

corresponding to

$$\frac{108\times 60\times 24}{2.9978}=25938.01$$

revolutions per day of twenty-four hours at "contract" piston speed of one hundred and eight (108) feet per minute, and capacity with an estimated slip of four (4) per cent. of calculated discharge.

$$155.503\times 25938.01\times .96=3{,}872{,}101 \text{ gallons.}$$

Engine No. 2—

H. P. cylinder pump piston,		diam.,	17.99	inches.
" " " "	rod,	"	3.376	"
L. P. " " "		"	18.00	"
" " " "	rod,	"	3.422	"
H. P. " " "	stroke,		36.023	"
L. P. " " "	"		35.967	"

From which I estimate the capacity of engine No. 2 as

$$\frac{2(17.99^2\times .7854)-(3.376^2\times .7854)\times 36.023}{231}=77.882$$

gallons, calculated capacity of the pump worked by the piston of the H. P. cylinder, per revolution, and

$$\frac{2(18^2\times .7854)-(3.422^2\times .7854)\times 35.967}{231}=77.811$$

gallons, calculated capacity of the pump worked by the piston of the L. P. cylinder, per revolution, and aggregate calculated capacity of both pumps, per revolution,

155.693 gallons.

The mean stroke in feet of both pumps is

$$\frac{36.023+35.967}{2\times12}=2.9995$$

corresponding to

$$\frac{108\times60\times24}{2.9995}=25932.6$$

revolutions per day of twenty-four hours at "contract" piston speed of one hundred and eight (108) feet per minute, and capacity with an estimated slip of four (4) per cent. of calculated discharge,

$$155.693\times25932.6\times.96=3,874,628 \text{ gallons.}$$

The contract provides that the duty shall be eighty millions (80,000,000) foot pounds, per hundred (100) pounds of coal burned under the boilers, with an evaporation from the temperature of feed of nine pounds of steam per pound of coal; and that the duty shall be estimated from the calculated discharge of pumps per revolution, the revolutions of engine during the trial, and the total head pumped against as the numerator of a fraction; the denominator of which shall be the net water delivered as steam to the engine divided by nine hundred (900). "The weight of water pumped to be taken at 8.34 pounds per gallon."

"Each engine to be operated continuously for twenty-four (24) hours for duty trial."

The duty trial of engine No. 1 commenced at 11:15 A. M., January 27th, and terminated at 11:15 A. M., January 28th.

The counter reading at beginning of trial, was	1392
And, at end of trial, was	27762
Difference—revolutions	26370

The head pumped against in feet, was—

By gauge on force pipe	135.6931
" difference between center of gauge on force pipe and mean level of water in river during trial	29.055
" friction head suction pipe	2.3806

By friction head force pipe	.161
" " " 20″ elbow in force pipe	·0155
" allowance for resistance of water passages in pumps	2.3
Total head	169.6052

The calculated discharge of pumps per revolution of engine has been stated as 155,503 gallons.

The water weighed to the boilers during whole trial was 65228 pounds, from which is deducted the following quantities:

Drawn off to Calorimeter	172.125
Leakage between weighing tank and boilers	50.322
Entrained in the steam, 1.93 per cent	1254.607
Total deduction	1477.054

and net steam delivered to the engine becomes 63750.946 pounds, corresponding to an expenditure of 7083.44 pounds of coal, upon the evaporation stipulated in the contract.

From which I estimate the duty of engine No. 1 as

$$\frac{155.503 \times 26370 \times 8.34 \times 169.6052}{70.8344} = 81,885,917.12$$

The duty trial of engine No. 2 commenced at 10:45 A. M., January 29th, and terminated at 10:45 A. M., January 30th.

The counter reading at beginning of trial was	501
And at end of trial	27986
Difference—revolutions	27485

The head pumped against in feet was

By gauge on force pipe	141.372
" difference between center of gauge on force pipe and mean level of water in river during trial	32.437
" friction head suction pipe	2.5925
" " " force "	.1737
" " " 20″ elbow in force pipe	.0169
" allowance for resistance of water passages in pumps	2.3
Total head	178.8921

The calculated discharge of pumps per revolution of engine has been stated as 155.693 gallons.

The water weighed to the boilers during whole trial was 68238 pounds from which is deducted the following quantities:

Drawn off to calorimeter	168.875
Leakage between weighing tank and boilers	50.322
Entrained in the steam, 4.7489 per cent	3230.145
Total deduction	3449.342

and net steam delivered to the engine becomes 64788.658 pounds corresponding to an expenditure of coal under the terms of the contract, of 7198.74 pounds

From which I estimate the duty of engine No. 2 as

$$\frac{155.693 \times 27485 \times 8.34 \times 178.8921}{71.9874} = 88,688,866.4$$

In regard to the capacity guaranteed for the engines, I am inclined to believe, in view of the stipulated dimensions of pumps and piston speed, that the incorporation in the contract of four millions (4,000,000) gallons capacity was unintentional, as the prescribed data of the contract prohibits this discharge.

You will observe that both engines have exceeded the contract duty, one by *nearly two millions*, and the other by more than *eight and one-half millions.*

In the general report, which I shall submit at an early date, will be given all the data taken during the trials, together with an inquiry into the precise performance of the engine, as developed from the indicator diagrams.

JOHN W. HILL.

EVANSVILLE, *February* 2, 1881.

GENERAL REPORT.

The engines are mounted in an iron well casing 16.5 feet diameter at the bottom, 17.5 feet diameter at the top, and 52 feet deep; constructed of .5 inch boiler plate, with rings of 4x4 inch angle iron, set three feet apart from top to bottom of well. The bottom of the well casing consists of a circular disc of .5 inch plate iron, riveted to a radial spider of I beams 30 inches deep and 8.5 inches width of flange. The inner ends of the I beams are bolted to lugs on a cast iron center, 36 inches diameter and same depth as the beams.

Around the iron well casing, for a depth of 16 feet from the coping, an annular wall 25 inches thick, of brick work in cement, is built upon a shelf or rim of plate iron attached to the iron well casing, by brackets.

The load on the bottom of the well casing consists of the casing itself, the annular wall of masonry above referred to, and the engines.

The weight of the well casing I estimate at forty-eight tons (of 2,000 pounds).

The weight of the brick work, supported by the well casing, I estimate at one hundred and twenty tons, and the weight of the engines complete is given me by the designer, Mr. Gaskill, as one hundred and twenty-five tons. From which I obtain the load per square foot of well bottom as

$$\frac{293}{213.83} = 1.37 \text{ tons.}$$

The steam end of the engines is mounted upon a heavy frame work of cast iron, arranged to effect a general distribution of the load around the annular wall, and the shell of the well casing.

Two heavy cast iron beams span the top of the well, to the under sides of which are bolted the steam cylinders; the upper sides of the beams having planed seats for the reception of the feet of the inclined columns of the gallows frame.

Wrought iron tie rods, extend from the upper outer corners of the frame down to the centers of the beams placed across the well, and carry the center loads upon the beams, to the heads of the outer inclined posts, and down to the coping on the annular wall.

The steam cylinders are each provided with two admission and two exhaust valves, of the double seat poppet variety. The steam and exhaust valve chambers are arranged one immediately over the other in the same casting.

The steam valves are worked by a liberating gear which can be adjusted by hand to vary the cut-off, and when connected with the pressure regulators, furnished with the engines, automatically adjusts the point of cut-off to the load and steam pressure. The exhaust valves have a fixed rise and fall.

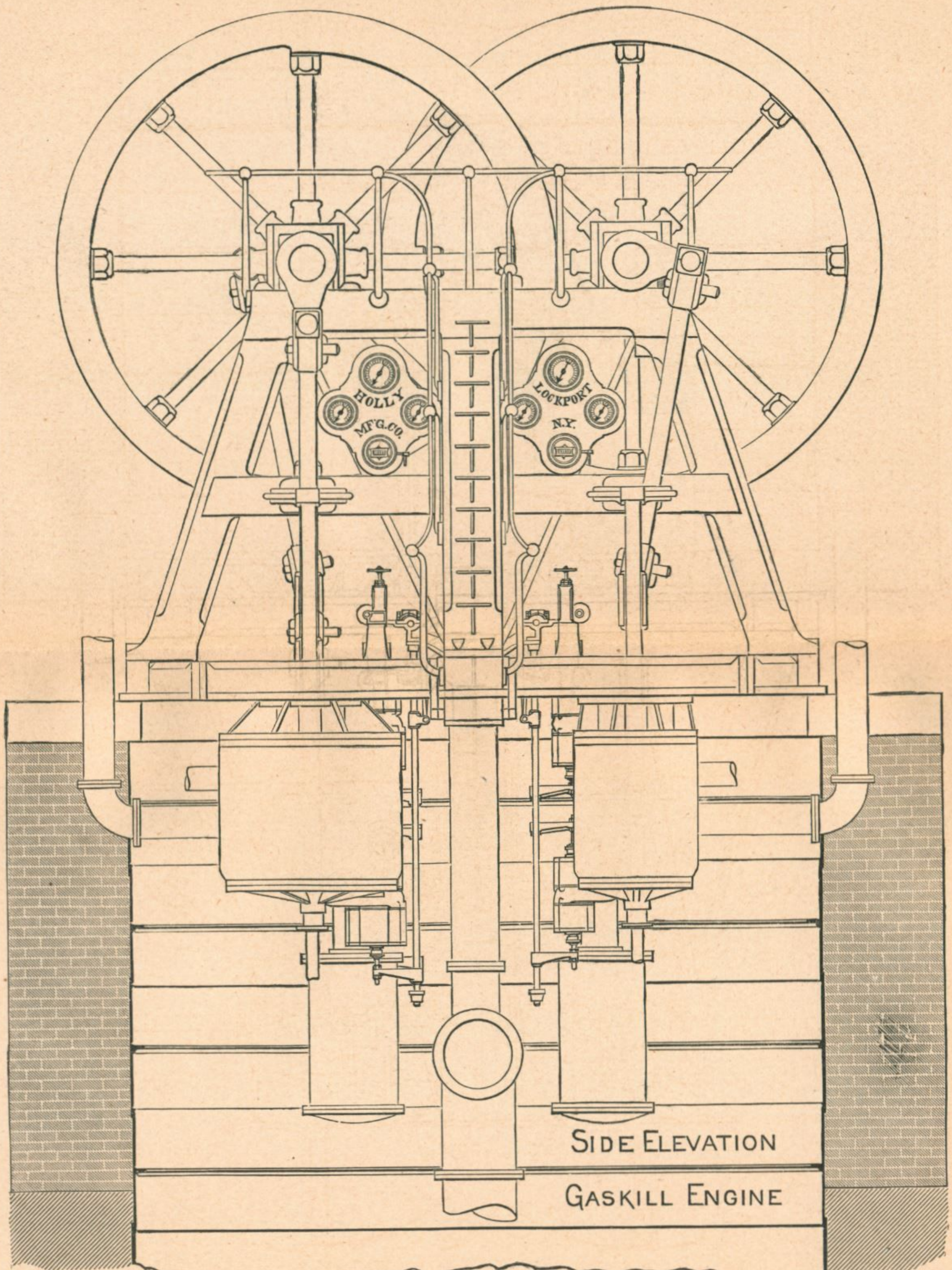
The valves of each steam cylinder are operated by a gang of four cams revolving on a shaft mounted in standard bearings on the bed plates, and driven through an angular shaft, and miter wheels from the fly wheel shaft overhead.

The piston rods pass through both heads of the steam cylinders; through the upper heads to cross heads, traveling on square wrought iron guide bars, and through the lower heads to the pumps at the bottom of the well casing. The piston rods are uniform in diameter from end to end, and are guided for every four feet between the steam and water cylinders.

The receivers are placed below and between the two cylinders of each engine.

The steam pipes, steam cylinders, and receivers are all heavily lagged with a plastic covering.

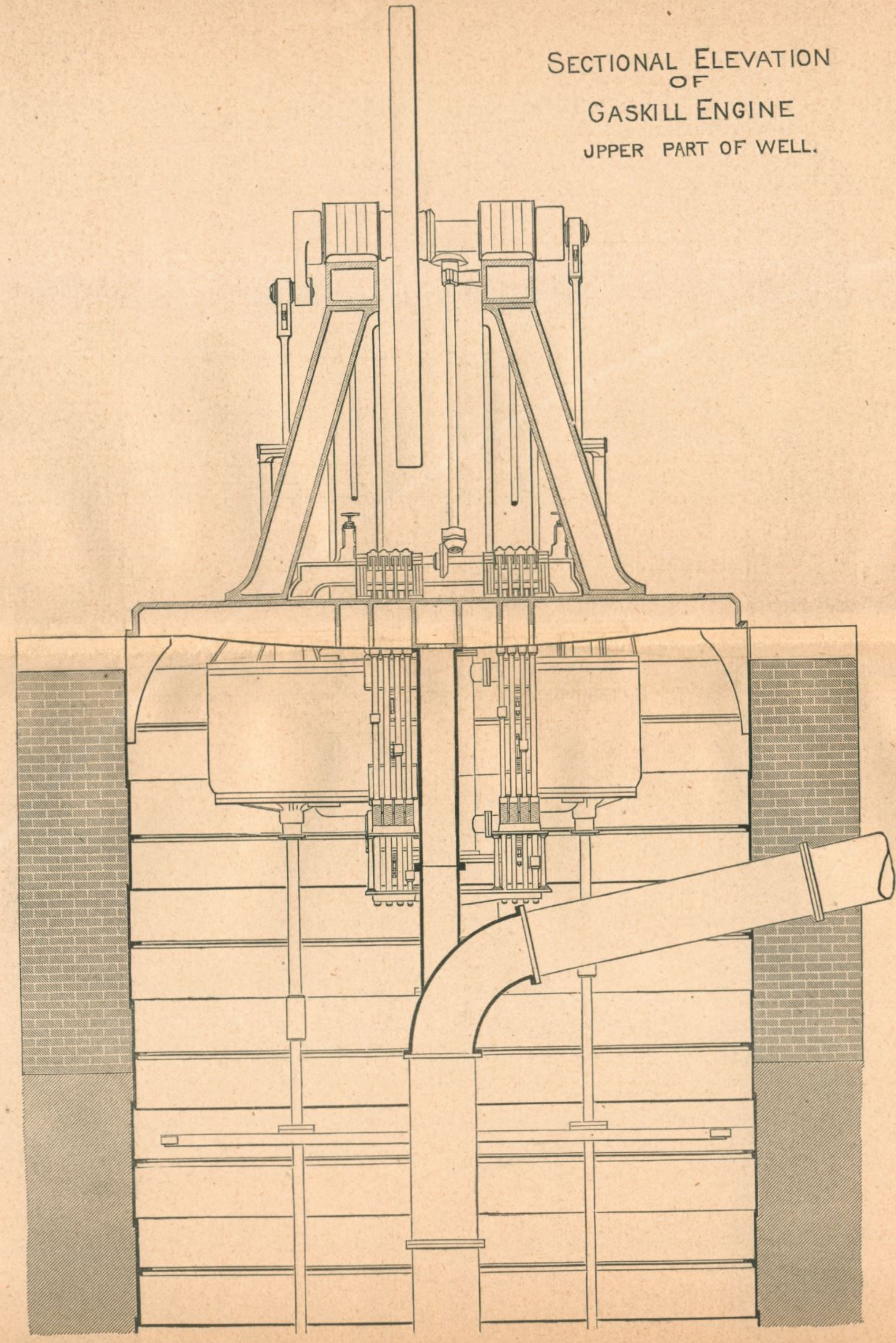
The low pressure cylinders are fitted with the "Bulkley" injector condenser. This form of condenser was adopted to avoid the use

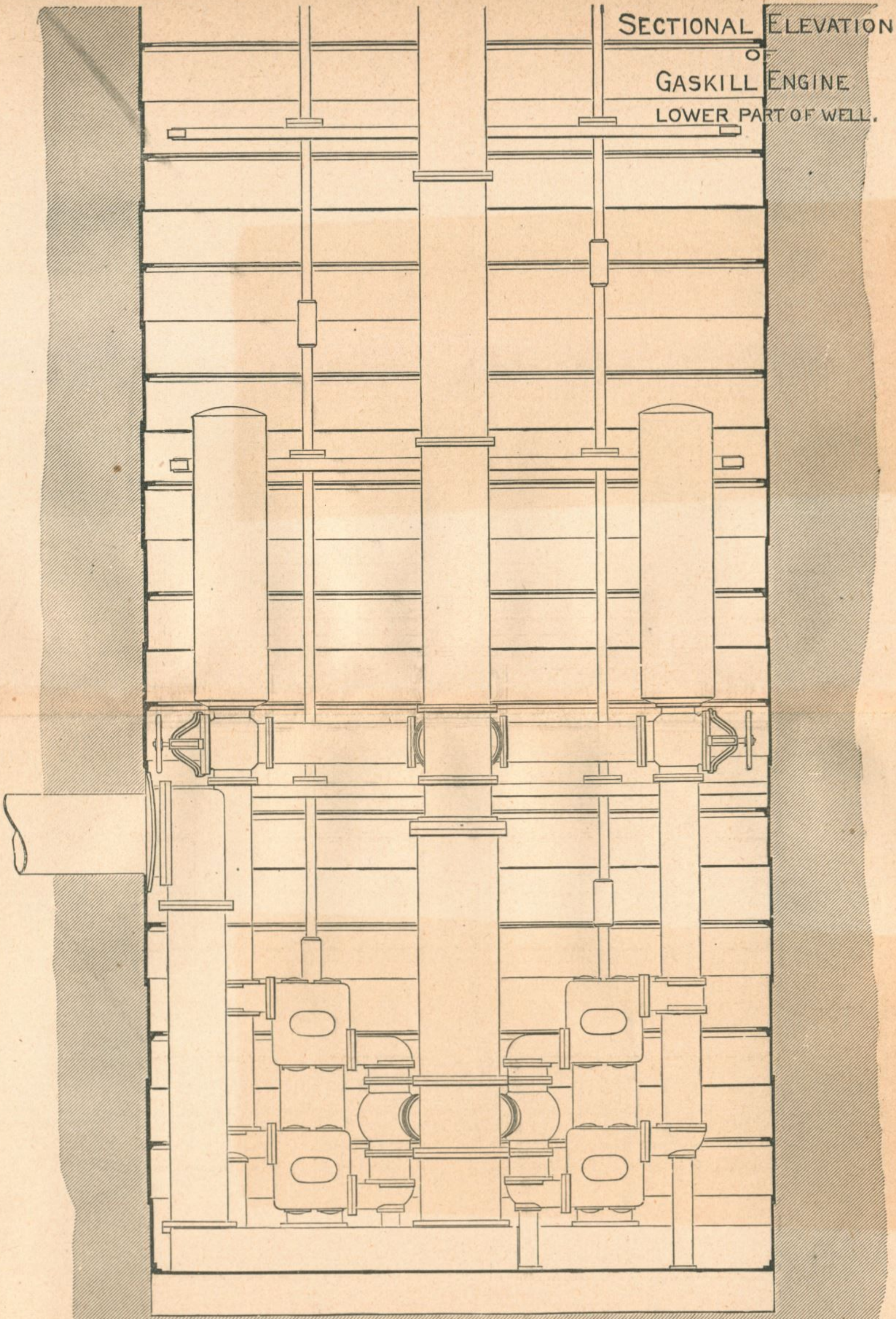


SIDE ELEVATION

GASKILL ENGINE

SECTIONAL ELEVATION
OF
GASKILL ENGINE
UPPER PART OF WELL.




SECTIONAL ELEVATION
OF
GASKILL ENGINE
LOWER PART OF WELL.

of an air pump, which would be liable to clog in the valves with the debris draw through the suction pipe from the river.

The pumps—two to each engine—are of the double acti piston variety, with receiving and discharge valves at each end.

The pump cylinders are nominally 18 inches diameter, and the water pistons have the same motion as the corresponding steam pistons. The pump valves are rubber discs set in iron shells, which rise and fall on central guide stems.

The force pipe rises in the center of the well casing to within eight and one-half feet of the coping of the annular foundation wall, where it is turned at right angles into the pump-house yard, to connect with the distribution mains.

Air vessels upon the discharge side are provided for each pump, and an air vessel common to all pumps, is connected with the suction pipe.

The engines are compactly arranged, with very little polish, and no attempt at attractive display. Strength and utility seem to have been carefully considered in the design of all parts.

The boilers furnishing steam during the trials, were those previously in use at the works, the contract of the Holly Manufacturing Company being limited to the engines.

In the next table are given all the principal dimensions of engines and boilers.

DIMENSIONS OF ENGINES.

CYLINDERS.

	Engine No. 1.	Engine No. 2.
Diameter of H. P. steam cylinder	24″	
" " L. P. " "	41″	
" " H. P. engine pump	17.98″	17.99″
" " L. P. " "	18.00″	18.00″
" " H. P. piston and pump rod	3.76″	3.376″
" " L. P. " " " "	3.422″	3.422″
Stroke of H. P. steam and water pistons	35.965″	36.023″
" " L. P. " " " "	35.985″	35.967″
Clearance, H. P. cylinder, one end	.0394	
" L. P. " " "	.030-	

STEAM VALVES.

STYLE.	Double-beat.
H. P. cylinder admission upper seat diameter	7.625″
" " " lower " "	6.875″
" " exhaust upper " "	7.750″
" " " lower " "	8.500″
L. P. " admission upper " "	11.250″
" " " lower " "	10.125″
" " exhaust upper " "	11.875″
" " " lower " "	12.875″
H. P. " all valves lift	.5625″
L. P. " " " "	.8125″

STEAM SUPPLY PIPE.

Diameter	8″

RECEIVER.

Volume cu. ft.	17.9617

FLY WHEELS AND MAIN SHAFTS.

Diameter of fly wheel		12.33′
" " " shaft		10.00″
Length " " "		7.375′
" " " " cen' to cen' journals		4.271′
Weight of fly wheel	pounds,	13000.
" " engine complete	tons,	125

PUMP CONNECTIONS.

Suction pipe	410′	24″
" "	1300′	16″
" "	200′	16″
Force "	90′	20″
Valve chambers, area of connecting nozzles	sq. ins.	108
Receiving and discharge valves, area each	"	254.46

RATIO OF VOLUMES.

(Exclusive of clearance.)

L. P. to H. P. cylinder	2.9568
L. P. and H. P. cylinders to H. P. cylinder	3.9568
Receiver to H. P. cylinder	1.9443
" " L. P. "	.6576

AIR VESSELS.

Suction pipe	20″ diam.	8′ high
Force "	24″ "	6′ "

DIMENSIONS OF BOILERS.

STYLE.		Return-flue.
Number of boilers used for trials		2
Diameter of shells		48″
Length " "		16′
Flues, each boiler		12–6″
Heating surface, shells	sq. ft. 301.593	
" " flues	" 603.187	
" " heads	" 27.238	
" " total	sq. ft.	932.018
Grate, width each furnace		5′
" length " "		4.5′
" surface, total sq. ft		45
Cross section of flues, both boilers	sq. ft.	4.704
Ratio heating to grate surface		20.7115
" grate surface to cross section of flues		9.5663

The contract between the city of Evansville and the Holly Manufacturing Company, relieved of the usual verbiage, provides for: "Two sets of pumping engines, each of four million gallons capacity each twenty-four (24) hours, at a piston speed of one hundred and eight (108) feet per minute.

"Said engines to be compound condensing" * * *

"All working parts to be made heavy, and the pump barrels to be one and one-half (1½) inches thick, so that they may be bored out when worn." * * *

"There shall be valves on each pump, so arranged that the water may be shut off from both suction and discharge." * * *

"The said party of the second part (Holly Manufacturing Company) will make a duty test of said machinery." * * *

"The said engines to be run for twenty-four (24) consecutive hours, and the duty to be calculated as follows:"

"The pumps to be carefully measured, and their contents calculated from such measurement. The number of revolutions as recorded by the counter and the pressure or head in feet fixed by the pressure gauge."

"The weight of water agreed as per Haswell, to be 8.34 pounds per gallon."

"The number of gallons from all the pumps to be multiplied by the revolutions made by the engines during the tests; this product multiplied by the height in feet which the water is lifted to, as shown by the pressure gauge; and this multiplied by the weight of water in pounds."

"The total to be divided by the number of pounds of best anthracite coal consumed during the trial, under a guaranteed evaporation of nine (9) pounds of water (steam) for one pound of coal. * * * The usual allowance to be made for friction through the suction pipe, and for suction lift."

"Under the above conditions the party of the second part agrees to perform a duty of eighty million foot pounds" (for every hundred pounds of coal charged).

The measurement of pumps I have already given in the preliminary report.

The trials were made in the following manner:

1. The coal was weighed in the boiler house in uniform charges of five hundred (500) pounds, in the barrows provided for that purpose, each charge remaining upon the scale, until called for by the firemen.

The number of the barrow, weight, and time of delivering each charge was noted in the log.

The fires and ash pits were cleaned previous to the trial, and the ash clinker and unburnt coal drawn from the furnaces upon cleaning of the fires during the runs, were weighed and charged against the coal for the same periods.

The condition of fires and water level at the boilers were noted at the beginning of the trials, and the same conditions subsisted at the close of the trials.

2. The steam pressure at the boilers, the steam pressure at the engine, the temperatures of injection, overflow and feed water, vacuum in the condenser, and the water pressure in the force pipe, were read regularly every fifteen minutes.

3. The water delivered to the boilers was weighed in a tank mounted upon a platform scale, from which it was drawn into a supplemental tank placed below, and connected with the suction of the feed pump.

The feed water was drawn from the mains into an exhaust heater connected with the donkey engine, and the temperature elevated by a jet from the boiler furnishing steam to the feed pump.

The level of water in the supplemental tank was regulated by an overflow tube; the excess of water, from which, was caught in a pail and returned to the weighing tank. This level obtained at the commencement, at the end, and at the expiration of every fifteen minutes interval during the trials.

The level of water in the supplemental tank having been established at the commencement of the trials, the weighing tank was filled with water from the heater, and weighed; at the close of the first, and of all the intervals for the trials, the level of water in the supplemental tank was first restored, the flow from the weighing tank then suppressed, and the weighing tank and contents again weighed.

The difference between the weight of the full tank, and of the partially emptied tank, represents the weight of water supplied to the boiler during the interval. The feed pump took steam from an independent boiler.

4. The engine counter, barometer, and temperature of atmosphere in the engine room were read hourly.

5. Calorimeter observations of the quality of steam supplied to the engines, were made hourly.

6. Indicator diagrams from both ends of each cylinder were taken hourly during the trial.

7. The readings of the friction heads in the suction pipe were taken hourly.

This measurement was had by means of a tin float in a vertical pipe connected with the suction pipe to the river. A silk thread attached to the float passed up and over a light grooved wheel of brass, turning on a stud, secured to a temporary post, sprung between two of the angle iron rings of the well casing.

Below the wheel and opposite the tube containing the float, a scale graduated to half inches, was located; a lead plate on the silk thread traveled up and down in front of the scale and indicated with relation to an arbitrary zero point, the position of the float in the vertical pipe.

At the close of the first trial (Engine No. 1), the engine was stopped, and the level of water in the float tube allowed to assume the level of the water in the river. A true zero was then established by marking the scale opposite the index point on the lead plate. Changes in the level of the river occurred, and the readings are all referred to a mean zero for each trial.

8. The stage of water in the river was noted regularly every third hour during the trials, and at beginning and end of trials, on the U. S. government gauge at the foot of Main street.

The readings of the guage are from an arbitrary zero, to which the position of the water pressure guage on the force pipe is referred.

The tables of data from the trials have been arranged in the following order :

Engine No. 1—

Tables 1 to 4—Observations engine and boiler rooms.

Table 5—Calorimeter observations.

Table 6—Indicator diagrams from upper end of H. P. cylinder.

Table 7—Indicator diagrams from lower end of H. P. cylinder.

Table 8—Indicator diagrams from upper end of L. P. cylinder.

Table 9—Indicator diagrams from lower end of L. P. cylinder.

Engine No. 2—

Tables 10 to 13—Observations engine and boiler rooms.

Table 14—Calorimeter observations.

Table 15—Indicator diagrams from upper end of H. P. cylinder.

Table 16—Indicator diagrams from lower end of H. P. cylinder.

Table 17—Indicator diagrams from upper end of L. P. cylinder.

Table 18—Indicator diagrams from lower end of L. P. cylinder.

In the tables of general observations, columns 1 and 2 contain the date and time by clock of the readings. Columns 3 and 4 contain the pressures by guages at the boilers and at the engines.

Columns 5 and 6 contain the pressure of atmosphere by barometer and the vacuum realized in the condenser. The barometer used was a compensated Aneroid known to be in good adjustment.

Columns 7, 8, and 9 contain the pressure in the force pipe, the readings of the float gauge in the suction pipe, and the trihoral stage of water in the Ohio river, from which the engines pumped.

The readings of columns 8 are not the original observations at the float gauge, but are corrected to read from a mean zero for entire trial. The head in the river having steadily declined during both trials, the readings are slightly in error, in that the early readings are less, and the later readings are more than they should be. The mean reduction of head is, however, unaffected by the discrepancies.

Columns 10, 11, 12, and 13 contain the temperatures, of atmosphere in the engine room, of injection to the condenser, of overflow from the condenser, and of the feed water to the boilers.

Columns 14 and 15 contain the continuous reading of counter and hourly revolutions of engine.

Columns 16 contain the weights of feed water to the boilers, by intervals. Columns 17 and 18 contain the number of the barrow, and the weight of coal delivered to the firemen, by charges.

The readings of all the pressure gauges are given in pounds; the readings of barometer and vacuum gauge are given in inches; the readings of the float gauge in the suction pipe, and of the river gauge, are given in feet; the charges of water and coal to the ers are given in pounds.

The means and totals for both trials are given at the foot of tables 4 and 13.

The heads against which the engines worked during the trials were obtained in the following manner:

Engine No. 1—

Head by guage on the force pipe,

$$58.997 \times 2.3 = 135.6931 \text{ feet.}$$

The vertical distance from the center of the pressure gauge on the force pipe to the zero mark on the government gauge was 60.53 feet, and the mean level of water in the river from same datum, during the trial, was 31.475 feet, and vertical distance from center of pressure gauge to mean level of water in the river,

$$60.53-31.475=29.055 \text{ feet.}$$

The mean reading of the float gauge in the suction pipe, referred to mean level of water in the river, was

2.3806 feet.

The pressure gauge was connected with the force pipe at a point 90 feet from the center of the pumps, and the frictional resistance of the force pipe, calculated by Weisbach's formula, was

$$\frac{155.503 \times 26370 \times .96}{7.4851 \times 86400}=6.08709 \text{ discharge}$$

in cu. ft. per second by the pumps, and

$$\frac{6.08709}{2.182}=2.7896 \text{ velocity in}$$

feet through force pipe, then

$$\frac{(2.7896^2)}{64.4} \times \frac{(\ 90\ )}{1.666} \times (.0144+\frac{.01716}{\sqrt{2.7896}}=.1610 \text{ foot}$$

The frictional resistance of the 20-inch elbow in the force pipe, with an estimated radius of bend to center of orifice of 1.25 diameters, was

$$2.7896^2 \times .002=.0155 \text{ foot.}$$

The usual allowance for frictional resistances of water passages into and from the pumps is one pound or

2.3 feet

and the total head, as given in the preliminary report,

$$135.6931+29.055+2.3806+.1610+.0155+2.3=169.6052 \text{ feet.}$$

Engine No. 2—

Head by gauge on the force pipe,

$$61.4661 \times 2.3=141.372 \text{ feet.}$$

The vertical distance from center of pressure gauge on the force pipe to zero mark on the government gauge, as before, 60.53 feet, and mean level of water in the river from the same datum during trial was 28.093 feet, and vertical distance from center of pressure gauge to mean level of water in the river,

$$60.53 - 28.093 = 32.4370 \text{ feet.}$$

The mean reading of float gauge in the suction pipe, referred to mean level of water in the river, was

2.5925 feet.

The frictional resistance of the force pipe was

$$\frac{155.693 \times 27485 \times .96}{7.4851 \times 86400} = 6.3522 \text{ discharge in}$$

cu. ft. per second by the pumps, and

$$\frac{6.3522}{2.182} = 2.911186 \text{ velocity in feet}$$

through the force pipe, then

$$\frac{(2.911186^2)}{64.4} \times \frac{(\ 90\ )}{1.666} \times \left(.0144 + \frac{.01716}{\sqrt{2.911186}}\right) = .17375 \text{ foot.}$$

The frictional resistance of the 20-inch elbow in the force pipe was

$$2.911186^2 \times .002 = .01695 \text{ foot,}$$

and usual allowance for frictional resistances of water passages

2.3 feet,

and total head, as given in the preliminary report,

$$141.370 + 32.437 + 2.5925 + .1737 + .0169 + 2.3 = 178.8921 \text{ feet.}$$

In the tables of calorimeter data are given the weights of water heated, weights of steam condensed, initial temperature of water, final temperature of water, range of temperature of water heated, and steam pressure corresponding with each observation. At the foot of the tables are given the means of temperatures, range, and pressure, and totals of water heated and steam condensed.

In the tables of indicator diagrams are given the initial, terminal, counter at mid stroke, and mean effective pressures; and decimals of cut-off, release, and exhaust closure for the diagrams from the high pressure cylinders; and initial, terminal, counter at mid stroke, and mean effective pressures, and vacuum realized in the cylinder in pounds below atmosphere; and decimals of release, and exhaust closure, for the diagrams from the low pressure cylinders.

The spring used in the indicators with which the high pressure diagrams were taken measured 59.625 pounds per inch of movement of the pencil, and the spring of the indicator on the low pressure cylinder measured 11.8125 pounds per inch of pencil movement.

The readings given in the tables, excepting the mean effective pressures, are as measured on the cards, with 60 and 12 pound scales, respectively.

The mean readings at the bottom of each table of diagrams are corrected to agree with the measured strength of springs.

During the trial of engine No. 1, the mean initial pressure high pressure cylinder was 95.405 pounds, with diagram readings corrected for error of spring; and for engine No. 2 same pressure was 95.37 pounds.

The gauge pressure at the boilers for engine No. 1 was 95.745 pounds, and the pressure in the pipe 92.953 pounds, to which must be added the weight of a column of steam, nine feet high, or .016 pound.

The gauge pressure at the boilers for engine No. 2 was 95.427 pounds, and pressure in the pipe 92.281 pounds.

It will be observed that the pressures in the pipe are less than the initial pressures in the cylinders. The springs used in the indicators were sent to the Buckeye Engine Company, to be weighed, and registered immediately after the trials, with the results as given above. No means were to be had at Evansville to prove the steam gauges, and their precise error can not be stated.

I believe that the values of the springs, reported to me by the Buckeye Engine Company, are correct, and that both steam gauges indicated considerably *less* than the true pressures.

TABLES OF DATA

FROM

ENGINE AND BOILER ROOM.

ENGINE No. 1.

TABLE I.

ENGINE NO. 1.

GENERAL OBSERVATIONS.

1	2	3	4	5	6	7	8	9
		STEAM PRESSURE.		VACUUM.		PUMPING HEADS.		
DATE.	TIME.	Boilers,	Pipe at Engine.	Barom'er.	Gauge on Condenser.	Gauge on Force Pipe, Pounds.	Gauge on Suc'n Pipe, Feet.	Gauge at River, Feet.
Jan. 27.	11:15 A. M.	96	94	30.26	20.0	59.5	....	31.90
	:30	95	92	....	23.5	62.5	....	....
	:45	97	94	....	24.0	64.0	....	....
	12:00	96	93	....	22.5	61.0	....	....
	:15 P. M.	95	92	30.24	22.0	57.0	....	....
	:30	95	92	....	23.0	57.5	1.908	....
	:45	96	93	....	23.5	58.0	....	......
	1:00	96	93	....	24.0	57.5	....	....
	:15	96	94	30.23	22.5	56.0	....	....
	:30	96	94	....	23.5	54 5	2.533	....
	:45	95	93	....	23.5	53 0	....	....
	2:00	97	94	....	23.0	53.0	....	. ...
	:15	96	93	30.20	22.5	52.0	....	31.80
	:30	95	92	....	23.5	52.0	2.220	....
	:45	96	93	....	24 0	51.0	....	....
	3:00	95	92	....	23.5	52.0	....	....
	:15	96	93	30.21	24.0	52.0	....	....
	:30	95	93	....	24.0	53.0	2.200	....
	:45	95	93	....	24.0	54.0	....	....
	4:00	95	92	....	24.0	54.0	....	....
	:15	95	92	30.21	23.5	53.0	....	....
	:30	94	91	....	24.0	52.5	2.283	....
	:45	97	94	....	24.0	56.0	....	....
	5:00	95	92	....	23.5	54.0	....	....
Jan. 27.	:15	95	92	30.21	24.0	55.0	....	31.70

TABLE I.

ENGINE NO. 1.

GENERAL OBSERVATIONS.

10	11	12	13	14	15	16	17	18
Temperatures.				Revolutions.		Water to Boilers, Pounds.	Coal.	
Air.	Injection.	Overflow.	Feed Wat.	Engine Register.	Revolut'ns per hour.		Barrow.	Weight Delivered.
51.0	34	92	132	1392	....	....	No. 2.	500
....	34	89	129	....	....	718	....	....
....	34	88	124	....	1119	919	....	....
....	34	88	122	....	....	700	....	....
52.0	35	85	123	2511	....	606	....	....
....	35	86	132	....	....	782	....	....
....	35	86	131	....	1101	540	No. 1.	500
....	35	86	141	....	....	1020	....	....
55.0	35	85	138	3612	....	474	....	....
....	35	83	134	....	....	750	....	....
....	35	82	134	....	1134	908	....	....
....	35	82	127	....	....	576	....	....
57.0	35	82	126	4746	....	632	....	....
....	35	82	127	....	....	680	No. 2.	500
....	35	81	128	....	1100	604	....	....
....	35	82	130	....	....	516	....	....
57.0	35	82	132	5846	....	620	....	....
....	35	82	133	....	....	550	....	....
....	35	83	134	....	1086	700	....	....
....	35	83	136	....	....	689	....	....
55.0	35	82	136	6932	....	560	....	....
....	35	82	137	....	....	663	....	....
....	35	83	137	....	1093	716	No. 1.	500
....	35	83	135	....	....	378	....	....
54.0	35	83	138	8025	....	876	....	....

TABLE II.

ENGINE NO. 1.

GENERAL OBSERVATIONS.

1	2	3	4	5	6	7	8	9
		STEAM PRESSURE.		VACUUM.		PUMPING HEADS.		
DATE.	TIME.	Boilers.	Pipe at Engine.	Barom'er.	Gauge on Condenser.	Gauge on Force Pipe, Pounds.	Gauge on Suc'n Pipe, Feet.	Gauge at River, Feet.
Jan. 27.	5:30 P. M.	95	92	....	23.5	54.0	1.991	....
	:45	95	92	....	24.5	57.0	....	....
	6:00	96	93	....	24.5	57.5	....	....
	:15	97	93	30.22	24.5	58.0	....	....
	:30	90	85	....	24 0	50.0	2.200	....
	:45	96	93	....	24.5	56.0	....	....
	7:00	95	92	....	24.5	60.0	....	....
	:15	96	94	30.22	24.0	59.5	....	....
	:30	95	93	....	24.0	59.0	2.241	....
	:45	95	93	....	24.5	60.0	....	....
	8:00	95	92	....	24.5	58.0	....	....
	:15	95	92	30.28	24 5	60.0	....	31.60
	:30	96	93	....	24.5	65.0	2.491	....
	:45	95	92	....	24.5	65.0	....	....
	9:00	95	92	....	24.5	65.0	....	....
	:15	95	92	30.28	24.5	63.0	....	....
	:30	96	93	....	25.0	67.0	2.506	....
	:45	95	92	....	24.5	60.5	....	....
	10:00	96	93	....	24.5	62.0	....	....
	:15	97	94	30.29	24.5	64.0	....	....
	:30	96	93	....	24.0	59.0	2.283	....
	:45	95	92	....	24.5	59.0	....	....
	11:00	97	94	....	24.0	61.0	....	....
Jan. 27.	:15	96	93	30.29	24.5	59.0	....	31.50

TABLE II.

ENGINE NO. 1.

GENERAL OBSERVATIONS.

10	11	12	13	14	15	16	17	18
Temperatures.				Revolutions.		Water to Boilers, Pounds.	Coal.	
Air.	Injection.	Overflow.	Feed Wat.	Engine Register.	Revolut'ns per hour.		Barrow.	Weight Delivered.
......	35	83	134	......	......	490	......	......
......	35	84	134	......	1079	690	......	......
......	35	84	135	......	......	868	No. 2.	500
54.0	35	84	133	9104	......	432	......	......
......	35	80	136	......	......	960	......	......
......	35	82	134	......	1094	612	......	......
......	35	84	132	......	......	508	No. 1.	500
54.0	35	84	133	10198	......	728	......	......
......	35	84	132	......	......	700	No. 2.	500
......	35	85	137	......	1095	616	......	......
......	35	82	118	......	......	478	......	......
55.0	35	84	117	11293	......	588	No. 1.	500
......	35	86	101	......	......	720	......	......
......	35	86	101	......	1111	421	......	......
......	35	85	109	......	......	902	......	......
54.0	35	85	113	12404	......	696	No. 2.	500
......	35	88	118	......	......	920	......	......
......	35	85	110	......	1103	596	......	......
......	35	86	101	......	......	722	......	......
53.0	35	86	94	13507	......	534	......	......
......	35	84	95	......	......	850	......	......
......	35	83	95	......	1078	680	......	......
......	35	84	102	......	......	500	No. 1.	500
53.0	35	84	118	14585	......	839	......	......

TABLE III.

ENGINE NO. 1.

GENERAL OBSERVATIONS.

1	2	3	4	5	6	7	8	9
		STEAM PRESSURE.		VACUUM.		PUMPING HEADS.		
DATE.	TIME.	Boilers.	Pipe at Engine.	Barome'r.	Gauge on Condenser.	Gauge on Force Pipe, Pounds.	Gauge on Suc'n Pipe, Feet.	Gauge at River, Feet.
Jan. 27.	11:30 P. M.	95	92	....	23.5	58.0	1.991	....
	:45	95	92	....	24.0	59.0	....	....
	12:00	96	93	....	24.5	58.0	....	....
Jan. 28.	:15 A. M.	96	93	30.29	24.0	60.0	....	....
	:30	96	92	....	24.0	61.0	2.189	....
	:45	96	93	....	24.0	62.0	....	....
	1:00	96	93	....	24.5	60.0	....	....
	:15	96	93	30.30	24.5	62.0	....	....
	:30	97	94	....	24.0	62.0	2.179	....
	:45	95	93	....	24.0	62.0	....	....
	2:00	97	94	....	24.0	63.0	....	....
	:15	96	93	30.30	23.5	62.5	....	31.40
	:30	95	92	....	24.0	62.0	2.345	....
	:45	96	93	....	24.5	62.5	....	....
	3:00	95	92	....	21.5	62.0	....	....
	:15	96	93	30.30	23.5	60.0	....	....
	:30	95	92	....	24.0	59.5	2.616	....
	:45	97	94	....	23.5	61.0	....	....
	4:00	96	93	....	23.5	62.0	....	....
	:15	97	94	30.30	24.0	64.5	....	....
	:30	95	92	....	23.0	62.0	2.450	....
	:45	96	94	....	24.5	64.5	....	....
	5:00	96	93	....	24.5	63.0	....	....
Jan. 28.	:15	97	94	30.30	24.0	62.5	....	31.30

TABLE III.

ENGINE NO. 1.

GENERAL OBSERVATIONS.

10	11	12	13	14	15	16	17	18
Temperatures.				Revolutions.		Water to Boilers, Pounds.	Coal.	
Air.	Injection.	Overflow.	Feed Wat.	Engine Register.	Revolut'ns per hour.		Barrow.	Weight Delivered.
....	35	83	118	....	....	496	....	....
....	35	84	116	....	1071	778	....	....
....	35	85	117	....	....	738	....	....
52.0	35	86	117	15656	....	647	No. 2.	500
....	35	85	118	....	....	620	....	....
....	35	85	118	....	1064	544	....	....
....	35	85	119	....	....	750	....	....
54.0	35	86	117	16720	....	750	....	....
....	35	85	114	....	....	518	....	....
....	35	85	116	....	1074	734	No. 1.	500
....	35	86	112	....	....	1000	....	....
54.0	35	86	109	17794	....	464	....	....
....	35	85	107	....	....	642	....	....
....	35	85	105	....	1086	522	....	....
....	35	85	108	....	....	538	No. 2.	500
53.5	35	84	115	18880	....	1015	....	....
....	35	83	120	....	....	900	....	....
....	35	85	119	....	1103	742	....	....
....	35	85	116	....	....	456	....	....
46.0	35	85	114	19983	....	370	No. 1.	500
....	35	86	115	....	....	884	....	....
....	35	86	117	....	1088	1054	....	....
....	35	86	118	....	....	827	....	....
49.5	35	85	117	21071	....	714	....	....

TABLE IV.

ENGINE NO. 1.

GENERAL OBSERVATIONS.

1	2	3	4	5	6	7	8	9
		STEAM PRESSURE.		VACUUM.		PUMPING HEADS.		
DATE.	TIME.	Boilers.	Pipe at Engine.	Barome'r.	Gauge on Condenser.	Gauge on Force Pipe, Pounds.	Gauge on Suc'n Pipe, Feet.	Gauge at River, Feet.
Jan. 28.	5:30 A. M.	98	95	....	23.5	62.5	2.366	....
	:45	97	95	....	23.0	64.0	....	....
	:00	98	95	....	23.5	62.5	....	....
	:15	96	93	30.31	22.5	62.0	....	....
	:30	96	94	....	22.5	63.0	2.325	....
	:45	97	94	....	23.5	61.5	....	....
	7:00	97	94	....	23.0	62.0	....	....
	:15	98	95	30.32	22.0	60.0	....	....
	:30	97	93	....	21.5	59.5	2.825	....
	:45	95	92	....	22.0	57.0	....	....
	8:00	95	92	....	21.5	56.0	....	....
	:15	96	93	30.32	22.0	53.0	....	31.10
	:30	95	92	....	22.5	54.0	2.825	....
	:45	95	92	....	24.0	57.5	....	....
	9:00	97	94	....	25.5	63.0	....	....
	:15	96	93	30.33	24.5	57.0	....	....
	:30	95	92	....	22.0	57.0	2.845	....
	:45	95	92	....	14.0	54.0	....	....
	10:00	95	93	....	24.0	59.0	....	....
	:15	95	92	30.34	22.5	58.0	....	....
	:30	95	93	....	24.5	59.0	2.929	....
	:45	97	94	....	24.0	60.0	....	....
	11:00	97	94	....	24.5	64.5	....	....
Jan. 28.	:15	95	93	30.34	23.0	60.0	....	30.90

Mean pressure in the boilers........................ .... 95.745
" " " pipe.. 92.953
" barometer. 30.274
" vacuum in condenser 23.600
" pressure in the force pipe.................................. 58.992
" gauge on suction pipe, referred to mean zero..... 2.3806
" river gauge.. 31.475

TABLE IV.

ENGINE NO. 1.

GENERAL OBSERVATIONS.

10	11	12	13	14	15	16	17	18
Temperatures.				Revolutions.		Water to Boilers, Pounds.	Coal.	
Air.	Injection.	Overflow.	Feed Wat.	Engine Register.	Revolut'ns per hour.		Barrow.	Weight Delivered.
...	35	87	118	...	...	606	No. 2.	500
...	35	87	118	...	1079	554	...	...
...	35	87	113	...	...	837	...	...
46.0	35	87	110	22150	...	756	...	...
...	35	87	99	...	...	582	...	...
...	35	87	87	...	1086	938	...	...
...	35	87	77	...	...	341	No. 1.	500
46.5	35	87	80	23236	...	623	...	...
...	35	87	80	...	...	630	...	...
...	35	87	80	...	1104	924	...	...
...	35	86	83	...	...	927	...	...
43.5	35	85	84	24340	...	500	...	...
...	35	85	90	...	...	522	...	...
...	35	86	93	...	1145	618	...	...
...	35	89	92	...	...	812	...	...
45.0	35	84	91	25485	...	830	No. 2.	500
...	35	82	90	...	...	600	...	...
...	35	104	92	...	1137	470	...	...
...	35	85	96	...	...	630	...	...
46.0	35	85	109	26622	...	916	...	...
...	35	85	119	...	...	834	...	...
...	35	83	131	...	1140	796	No. 1.	500
...	35	85	131	...	...	664	...	...
46.0	35	84	132	27762	...	388	...	...

Mean temperature of air.................................... 51.563
" " " injection.................................... 34.964
" " " overflow.................................... 84.948
" " " feed water.................................... 116.177
Revolutions during trial.................................26370
" per minute.................................... 18.3125
Water weighed to boilers.................................65228
Coal " " 9000–359.............................. 8641

TABLE V.

ENGINE NO. 1.

CALORIMETER.

1	2	3	4	5	6	7	8	9
		WATER TO TANK.			TEMPERATURES.			
DATE.	TIME.	From Mains.	From Steam Pipe.	STEAM CONDENSED.	Initial.	Final.	Range.	PRESSURE IN BOILERS.
Jan. 27.	11:20 A. M.	98	2	5.5	45 0	106.5	61.5	97
	12:20 P. M.	98	2	5.375	48.5	106.5	58.0	97
	1:20	98	2	5.5	49.5	109.0	59.5	97
	2:20	98	2	5.0	52.0	106.5	54.5	96
	3:20	98	2	5.25	49.0	106.0	57.0	95
	4:20	98	2	5.0	50.0	104.0	54.0	96
	5:20	98	2	5.0	73.5	126.0	52.5	96
	6:20	98	2	5.5	52.0	108.0	56.0	98
	7:20	98	2	5.0	47.0	102.5	55.5	96
	8:20	98	2	5.375	50.0	111.0	61.0	94
	9:20	98	2	5.5	48.0	106.5	58.5	96
	10:20	98	2	5.0	47.5	101.5	54.0	95
	11:20	98	2	5.0	48.0	103.0	55.0	96
Jan. 28.	12:20 A. M.	98	2	5.0	46.0	100.0	54.0	94
	1:20	98	2	5.125	48.0	104.0	56.0	96
	2:20	98	2	5.125	47.5	113.5	56.0	94
	3:20	98	2	5.0	46.5	101.0	54.5	95
	4:20	98	2	5.125	46.0	102.0	56.0	96
	5:20	98	2	5.25	46.0	102.0	56.0	97
	6:20	98	2	5.0	45.5	100.0	54.5	95
	7:20	98	2	5.125	47.0	102.0	55.0	97
	8:20	98	2	5.125	50.0	106.0	56.0	95
	9:20	98	2	5.25	45.0	102.0	57.0	95
Jan. 28.	10:20	98	2	5.0	46.0	101.5	55.5	94

Weight of water heated..2400
" " steam condensed.. 124.125
Mean initial temperature.. 48.896
" final " 105.458
" range, " 56.562
" steam pressure.. 95.710

TABLE VI.

ENGINE NO. 1.

DIAGRAMS—HIGH PRESSURE CYLINDER, UPPER END.

1	2	3	4	5	6	7	8	9
		Pressures.				Valve Motion.		
Date.	Time.	Initial.	Terminal.	Counter at Mid Stroke.	Mean Effective.	Cut-off.	Release.	Exhaust Closure.
Jan. 27.	11:50 A. M.	95.00	19.00	12.25	44.794	.276	.990	.985
	12:50 P. M.	95.00	16.00	10.50	42.951	.237	.990	.985
	1:50	95.00	12.00	9.00	37.281	.202	.990	.985
	2:50	95.25	11.00	9.25	35.438	.178	.990	.985
	3:50	95.00	11.00	8.75	36.289	.186	.990	.985
	4:50	97.00	12.75	10.50	36.856	.190	.990	.985
	5:50	93.50	12.00	10.00	36.147	.194	.990	.985
	6:50	96.75	12.50	10.50	36.005	.190	.990	.985
	7:50	95.00	11.50	10.50	35.297	.190	.990	.985
	8:50	94.25	12.00	12.00	33.737	.194	.990	.985
	9:50	96.50	11.50	11.00	33.879	.181	.990	.985
	10:50	96.00	13.00	10.25	36.572	.196	.990	.985
	11:50	95.25	14.00	11.00	37.706	.203	.990	.985
Jan. 28.	12:50 A. M.	97.00	15.00	11.50	39.975	.221	.990	.985
	1:50	96.25	14.00	11.00	39.124	.220	.990	.985
	2:50	96.50	14.50	11.75	39.691	.221	.990	.985
	3:50	96.50	14.50	11.00	39.266	.214	.990	.985
	4:50	97.00	15.25	12.00	39.407	.220	.990	.985
	5:50	97.25	16.00	12.50	41.393	.226	.990	.985
	6:50	98.50	15.50	12.50	41.250	.227	.990	.985
	7:50	96.25	14.00	11.00	38.132	.207	.990	.985
	8:50	96.00	14.25	11.25	38.557	.211	.990	.985
	9:50	97.25	15.00	12.25	39.266	.214	.990	.985
	10:50	96.00	13.00	12.50	36.289	.204	.990	.985

Mean initial pressure, corrected for error of spring..... 95.40
" terminal " " " " 13.63
" counter " " " " 10.96
" effective " " " " 38.129
" cut-off in decimal of stroke. .... .208
" release " " .... .990
" exhaust closure in decimal of return stroke...... .985

TABLE VII.

ENGINE NO. 1.

DIAGRAMS—HIGH PRESSURE CYLINDER, LOWER END.

1	2	3	4	5	6	7	8	9
		Pressures.				Valve Motion.		
Date.	Time.	Initial.	Terminal.	Counter at Mid Stroke.	Mean Effective.	Cut-off.	Release.	Exhaust Closure.
Jan. 27.	11:50 A. M.	96.00	32.00	14.00	47.204	.294	.995	.985
	12:50 P. M.	95.50	28.00	12.25	44.227	.255	.995	.985
	1:50	95.50	25.00	11.50	40.825	.213	.995	.985
	2:50	96.00	23.50	10.75	40.116	.209	.995	.985
	3:50	94.50	25.50	11.00	42.248	.237	.995	.985
	4:50	97.00	27.00	12.75	42 526	.237	.995	.985
	5:50	94.25	26.00	12.00	43.093	.243	.995	.985
	6:50	97.00	27.50	12.00	45.786	.256	.995	.985
	7:50	95.00	33.00	14 50	51.173	.337	.995	.985
	8:50	95.00	36.50	16.75	53.300	.385	.995	.985
	9:50	96.00	30.50	14.25	49.046	.309	.995	.985
	10:50	94 50	29.50	13.00	47.487	.302	.995	.985
	11:50	95.50	28.00	13.00	44.085	.259	.995	.985
Jan. 28.	12:50 A. M.	97.00	28.75	13.00	46.070	.264	.995	.985
	1:50	96.50	29.50	13.50	46.779	.278	.995	.985
	2:50	97.50	29.75	13.25	48.197	.292	.995	.985
	3:50	95.00	29.00	13.00	46.779	.283	.995	.985
	4:50	97.75	30.00	14.00	47.770	.280	.995	.985
	5 50	97.00	29.00	14.00	45.645	.273	.995	.985
	6:50	98.00	28.50	14.00	46.212	.278	.995	.995
	7:50	96.50	29.00	14.00	45.077	.271	.995	.985
	8:50	96.00	29.50	15.00	45.644	.287	.995	.985
	9:50	96.25	28 00	15.00	44.936	.280	.995	.985
	10:50	95.00	30.00	15.50	46.779	.297	.995	.985

Mean initial pressure, corrected for error of spring..... 95.41
" terminal " " " " 28.69
" counter " " " " 13.33
" effective " " " " 45.877
" cut-off in decimal of stroke.......................... .276
" release " " .... .995
" exhaust closure in decimal of return stroke....... .985

TABLE VIII.

ENGINE NO. 1.

DIAGRAMS—LOW PRESSURE CYLINDER, UPPER END.

1	2	3	4	5	6	7	8	9
		Pressures.					Valve Motion.	
Date.	Time.	Initial.	Terminal.	Counter at Mid Stroke.	Mean Effective.	Vacuum at Mid Stroke.	Release.	Exhaust Closure.
Jan. 27.	11:50 A. M.	30.00	13.20	3.75	18.072	11.11	.986	.993
	12:50 P. M.	27.10	12.15	3.35	16.593	11.51	.986	.993
	1:50	26.75	11.70	3.30	15.722	11.56	.986	.993
	2:50	26.30	11.40	3.25	15.560	11.61	.986	.993
	3:50	26.90	11.65	3.00	16.194	11.86	.986	.993
	4:50	27.25	11.60	2.75	16.757	12.11	.986	.993
	5:50	27.35	11.75	3.30	16.358	11.56	.986	.993
	6:50	28.00	11.75	3.75	16.429	11.11	.986	.993
	7:50	29.75	12.30	3.50	17.555	11.36	.986	.993
	8:50	30.90	12.50	3.30	18.377	11.56	.986	.993
	9:50	30.50	12.60	3.70	17.837	11.16	.986	.993
	10:50	28.90	12.15	3.00	17.626	11.86	.986	.993
	11:50	28.20	12.00	2.95	17.156	11.91	.986	.993
Jan. 28.	12:50 A. M.	28.65	12.25	3.00	17.837	11.86	.086	.993
	1:50	29.50	12.75	5.20	17.320	9.66	.986	.993
	2:50	29.45	12.75	3.00	18.306	11.86	.986	.993
	3:50	29.25	12.35	2.90	18.259	11.96	.986	.993
	4:50	29.70	12.75	2.80	18.564	12.06	.986	.993
	5:50	29.40	12.50	2.90	17.532	11.96	.986	.993
	6:50	30.40	13.25	3.50	18.775	11.36	.986	.993
	7:50	28.75	12.50	4.10	16.922	10.76	.986	.993
	8:50	29.75	12.50	4.35	16.851	10.51	.986	.993
	9:50	30.00	12.25	4.10	17.297	10.76	.986	.993
	10:50	30.25	12.10	4.25	16.804	10.61	.986	.993

Mean initial pressure, corrected for error of spring..... 28.43
" terminal " " " " 12.32
" counter " " " " 3.64
" effective " " " " 17.251
" vacuum realized, " " " 11.22
" release in decimal of stroke.............................. .986
" exhaust closure in decimal of return stroke....... .993

TABLE IX.

ENGINE NO. 1.

DIAGRAMS—LOW PRESSURE CYLINDER, LOWER END.

1	2	3	4	5	6	7	8	9
		PRESSURES.					VALVE MOTION.	
DATE.	TIME.	Initial.	Terminal.	Counter at Mid Stroke.	Mean Effective.	Vacuum at Mid Stroke.	Release.	Exhaust Closure.
Jan. 27.	11:50 A. M.	28.25	17.00	5.75	13.670	9.11	1.000	.870
	12:50 P. M.	26.30	15.60	5.60	12.814	9.26	1.000	.870
	1:50	24.50	14.60	5.00	12.274	9.86	1.000	.870
	2:50	24.25	14.35	4.50	12.227	10.36	1-000	.870
	3:50	24.70	14.90	4.75	12.274	10.11	1.000	.870
	4:50	25.35	15.00	5.00	12.673	9.86	1.000	.870
	5:50	24.75	14.86	5.30	11.805	9.56	1.000	.870
	6:50	25.75	15.25	4.75	12.861	10.11	1.000	.870
	7:50	26.75	16.00	4.20	13.730	10.66	1.000	.870
	8:50	27.30	16.35	5.20	13.612	9.66	1.000	.870
	9:50	26.70	15.75	4.80	13.401	10.06	1.000	870
	10:50	26.20	15.45	4.65	13.190	10.21	1.000	.870
	11:50	25.75	14.85	5.25	12 251	9.61	1.000	.870
Jan. 28.	12:50 A. M.	26.90	15.80	5.00	13.424	9.86	1.000	.870
	1:50	26.95	16.00	4.85	13.612	10.01	1.000	.870
	2:50	27.20	15.90	5.80	13.941	9.06	1.000	.870
	3:50	26.70	15.75	4.85	13.730	10.01	1.000	.870
	4:50	27.35	16.35	5.65	13.377	9.21	1.000	.870
	5:50	27.30	16.25	5.00	13.753	9.86	1.000	.870
	6:50	27.60	16.60	4.80	14.574	10.06	1.000	.870
	7:50	26.90	15.50	6.00	12.133	8.86	1.000	.870
	8:50	27.50	16.25	5.60	12.978	9.26	1.000	.870
	9:50	27.50	15.75	4.75	13.753	10.11	1.000	.870
	10:50	27.75	15.60	5.00	12.932	9.86	1.000	.870

Mean initial pressure, corrected for error of spring..... 26.09
" terminal " " " " 15.62
" counter " " " " 5.24
" effective " " " " 13.125
" vacuum realized, " " " 9.62
" release in decimal of stroke.............................. 1.000
" exhaust closure in decimal of return stroke....... .870

TABLES OF DATA

FROM

ENGINE AND BOILER ROOM.

ENGINE No. 2.

TABLE X.

ENGINE NO. 2.

GENERAL OBSERVATIONS.

1	2	3	4	5	6	7	8	9
		STEAM PRESSURE.		VACUUM.		PUMPING HEADS.		
DATE.	TIME.	Boilers.	Pipe at Engine.	Barom'er.	Gauge on Condenser.	Gauge on Force Pipe, Pounds.	Gauge on Suc'n Pipe, Feet.	Gauge at River, Feet.
Jan. 29.	10:45 A. M.	96	93	30.10	21.0	58.5	....	29.20
	11:00	95	92	....	21.0	62.0	....	....
	:15	95	92	....	21.0	62.5	1.842	....
	:30	96	93	....	20.5	62.5	....	....
	:45	96	93	30.09	20.5	64.0	....	....
	12:00	95	92	....	20.5	63.0	....	....
	:15 P. M.	95	91	....	25.0	66.0	2.300	....
	:30	95	92	....	20.5	58.0	....	......
	:45	95	93	30.04	21.0	60.0	....	....
	1:00	96	93	....	26.0	62.0	....	....
	:15	95	92	....	21.5	56.0	1.623	....
	:30	95	92	....	21.5	57.5	....	....
	:45	96	93	29.98	21.5	61.0	....	29.00
	2:00	95	92	....	21.5	63.0	....	....
	:15	96	93	....	21.5	63.0	1.571	....
	:30	95	92	....	21.5	64.5	....	....
	:45	95	92	29.96	20.5	64.0	....	....
	3:00	96	93	....	21.0	63.5	....	....
	:15	95	92	....	20.5	57.5	1.831	....
	:30	95	92	....	21.0	62.0	....	....
	:45	95	92	29.92	20.5	62.5	....	....
	4:00	96	93	....	20.5	62.0	....	....
	:15	96	93	....	21.0	63.0	2.144	....
	:30	95	91	....	20.5	62.0	....	....
Jan. 29.	:45	95	91	29.90	20.0	61.0	....	28.70

TABLE X.

ENGINE NO. 2.

GENERAL OBSERVATIONS.

10	11	12	13	14	15	16	17	18
Temperatures.				Revolutions.		Water to Boilers, Pounds.	Coal.	
Air.	Injection.	Overflow.	Feed Wat.	Engine Register.	Revolut'ns per hour.		Barrow.	Weight Delivered.
60.0	44	92	122	501	......	......	No. 1.	500
......	44	92	122	......	......	1034	......	......
......	44	92	121	......	1142	746	......	......
......	44	92	122	......	......	810	......	......
55.0	44	92	123	1643	......	700	......	......
......	44	92	127	......	......	752	......	......
......	44	93	125	......	1168	620	......	......
......	44	87	120	......	......	836	......	......
62.0	44	88	114	2811	......	540	No. 2.	500
......	44	87	105	......	......	722	......	......
......	44	88	98	......	1126	732	......	......
......	44	86	97	......	......	742	......	......
63.5	44	87	99	3937	......	802	......	......
......	45	88	101	......	......	534	......	......
......	45	89	108	......	1107	640	......	......
......	45	89	113	......	......	488	......	......
62.0	45	89	122	5044	......	690	......	......
......	45	88	133	......	......	1104	No. 1.	500
......	45	88	133	......	1138	818	......	......
......	45	88	136	......	......	560	......	......
62.5	46	88	125	6182	......	724	......	......
......	46	88	117	......	......	644	......	......
......	46	88	105	......	1129	634	......	......
......	46	88	99	......	......	566	No. 2.	500
62.0	46	87	93	7311	......	614	......	......

TABLE XI.

ENGINE NO. 2.

GENERAL OBSERVATIONS.

1	2	3	4	5	6	7	8	9
		STEAM PRESSURE.		VACUUM.		PUMPING HEADS.		
DATE.	TIME.	Boilers.	Pipe at Engine.	Barom'er.	Gauge on Condenser.	Gauge on Force Pipe, Pounds.	Gauge on Suc'n Pipe, Feet.	Gauge at River, Feet.
Jan. 29.	5:00 P. M.	96	92	....	20.5	62.5	....	
	:15	95	92	....	21.0	64.0	1.383	....
	:30	95	92	....	21.0	63.0	....	....
	:45	96	92	29.84	21.5	62.5	....	....
	6:00	96	93	....	21.5	65.0	....	....
	:15	95	92	....	21.0	64.5	1.425	....
	:30	96	93	....	21.5	65.0	....	....
	:45	97	94	29.82	20.5	65.0	....	....
	7:00	95	92	....	21.0	63.5	....	....
	:15	97	94	....	20.5	63.5	1.904	....
	:30	96	93	....	20.5	62.5	....	....
	:45	95	92	29.82	20.5	63.0	....	28.40
	8:00	95	91	....	20.5	60.5	....	....
	:15	97	94	....	20.0	62.0	2.383	....
	:30	93	90	....	19.5	57.5	....	....
	:45	95	91	29.82	19.5	58.0	....	....
	9:00	94	91	....	20.0	58.0	....	....
	:15	96	94	....	19.5	62.0	2.623	....
	:30	96	93	....	19.5	62.0	....	....
	:45	95	92	29.83	19.5	59.0	....	....
	10:00	94	90	....	20.0	60.0	....	....
	:15	95	91	....	19 0	59.0	2.583	....
	:30	97	94	....	19.5	62.0	....	....
Jan. 29.	:45	95	92	29.83	19.0	59.0	....	.... 28.10

TABLE XI.

ENGINE NO. 2.

GENERAL OBSERVATIONS.

10	11	12	13	14	15	16	17	18
Temperatures.				Revolutions.		Water to Boilers, Pounds.	Coal.	
Air.	Injection.	Overflow.	Feed Wat.	Engine Register.	Revolut'ns per hour.		Barrow.	Weight Delivered.
....	46	88	87	....	....	844	....	....
....	46	88	85	....	1114	722	....	....
....	46	88	88	....	....	724	....	....
62.0	46	89	91	8425	....	618	No. 1.	500
....	46	89	101	....	....	324	....	....
....	46	88	123	....	1069	894	....	....
....	46	89	126	....	....	1166	....	....
62.0	46	89	148	9494	....	606	....	....
....	47	89	144	....	....	488	No. 2.	500
....	47	89	138	....	1088	794	....	....
....	47	88	135	....	....	658	....	....
65.5	47	88	128	10582	....	960	....	....
....	47	88	124	....	....	840	No. 1.	500
....	47	89	121	....	1135	642	....	....
....	47	85	119	....	....	900	....	....
67.0	47	90	118	11717	....	520	....	....
....	47	87	121	....	....	680	....	....
....	48	88	122	....	1151	420	No. 2.	500
....	48	88	129	....	....	904	....	....
67.0	48	87	125	12868	....	848	....	....
....	48	87	121	....	....	452	....	....
....	48	89	116	....	1167	634	....	....
....	48	87	111	....	....	726	No. 1.	500
68.0	48	88	110	14035	....	788	....	....

TABLE XII.

ENGINE NO. 2.

GENERAL OBSERVATIONS.

1	2	3	4	5	6	7	8	9
		STEAM PRESSURE.		VACUUM.		PUMPING HEADS.		
DATE.	TIME.	Boilers.	Pipe at Engine.	Barome'r.	Gauge on Condenser.	Gauge on Force Pipe, Pounds.	Gauge on Suc'n Pipe, Feet.	Gauge at River, Feet.
Jan. 29.	11:00 P. M.	96	93	....	20.0	62.0	....	....
	:15	96	93	....	19.5	62.0	2.821	....
	:30	95	92	....	19.5	57.0	....	....
	:45	95	91	29.83	19.5	60.0	....	....
	12:00	97	94	....	20.0	62.5	....	....
Jan. 30.	:15 A. M.	98	94	....	20.0	63.5	2.685	....
	:30	95	92	....	20.0	62.0	....	....
	:45	95	92	29.83	19.5	62.5	....	....
	1:00	95	93	....	20.0	62.5	....	....
	:15	95	93	....	20.0	60.0	3.050	....
	:30	96	93	....	19.5	60.0	....	....
	:45	97	94	29.83	20.0	62.0	....	27.80
	2:00	96	93	....	19.0	59.5	....	....
	:15	102	99	....	18.5	62.5	3.165	....
	:30	90	85	....	20.5	55.5	....	....
	:45	98	95	29.82	19.5	62.0	....	....
	3:00	86	82	....	20.0	55.0	....	....
	:15	95	91	....	19.5	59.0	3.154	....
	:30	94	89	....	19.5	57.0	....	....
	:45	95	91	29.81	20.0	61.5	....	....
	4:00	96	93	....	20.0	62.5	....	....
	:15	95	91	....	19.5	60.0	2.853	....
	:30	96	94	....	19.0	61.0	....	....
Jan. 30.	:45	94	90	29.80	19.5	57.5	....	27.50

TABLE XII.

ENGINE NO. 2.

GENERAL OBSERVATIONS.

10	11	12	13	14	15	16	17	18
Temperatures.				Revolutions.		Water to Boilers, Pounds.	Coal.	
Air.	Injection.	Overflow.	Feed Wat.	Engine Register.	Revolut'ns per hour.		Barrow.	Weight Delivered.
....	48	87	112	....	....	755	....	....
....	48	87	113	....	1152	468	....	....
....	48	87	120	....	....	1000	....	....
68.0	48	87	125	15187	....	562	....	....
....	48	87	132	....	....	890	No. 2.	500
....	48	87	136	....	1162	572	....	....
....	48	87	146	....	....	1100	....	....
67.0	48	86	146	16349	....	544	....	....
....	48	86	147	....	....	392	....	....
....	48	88	143	....	1175	480	No. 1.	500
....	48	88	134	....	....	612	....	....
66.5	48	91	121	17524	....	992	....	....
....	48	88	119	....	....	248	No. 2.	500
....	48	90	115	....	1173	1248	....	....
....	48	85	110	....	....	1096	No. 1.	500
65.5	48	88	108	18697	....	346	....	....
....	48	86	104	....	....	1266	....	....
....	48	87	103	....	1166	406	....	....
....	48	88	103	....	....	534	No. 2.	500
66.0	48	87	102	19863	....	428	....	....
....	48	88	102	....	....	712	....	....
....	48	89	104	....	1164	1084	....	....
....	48	87	109	....	....	814	No. 1.	500
66.5	48	89	117	21027	....	722	....	....

TABLE XIII.

ENGINE NO. 2.

GENERAL OBSERVATIONS.

1	2	3	4	5	6	7	8	9
		STEAM PRESSURE.		VACUUM.		PUMPING HEADS.		
DATE.	TIME.	Boilers.	Pipe at Engine.	Barome'r.	Gauge on Condenser.	Gauge on Force Pipe, Pounds.	Gauge on Suc'n Pipe, Feet.	Gauge at River, Feet.
Jan. 30.	5:00 A. M.	94	90	....	19.5	61.0	....	....
	:15	95	91	... .	19.5	61.0	3.071	....
	:30	95	92	....	19.0	60.5	....	....
	:45	96	93	29.80	19.5	62.0	....	....
	6:00	95	93	....	19.5	60.0	....	....
	:15	95	92	....	18.5	59.5	3.623	....
	:30	96	93	....	20.0	61.5	....	....
	:45	95	92	29.80	20.0	62.0	....	....
	7:00	96	93	....	20.0	61.5	....	....
	:15	97	94	....	19.0	61.0	3.915	....
	:30	95	93	....	19.0	60.0	....	....
	:45	95	92	29.81	19.0	59.0	....	27.20
	8:00	95	93	....	19.5	61.0	....	....
	:15	97	94	....	19.5	60.0	3.738	....
	:30	95	93	....	20.0	61.0	....	....
	:45	95	93	29.80	20.0	62.5	....	....
	9:00	96	93	....	20.5	65.0	....	....
	:15	97	94	....	20.0	60.0	3.290	....
	:30	96	93	....	20.0	70.0	....	....
	:45	96	93	29.81	20.0	64.0	....	....
	10:00	95	92	....	20.0	64.0	....	... .
	:15	95	91	....	20.0	64.0	3.238	....
	:30	98	94	....	20.0	64.0	....	....
Jan. 30.	:45	96	93	29.80	20.0	65.0	....	26.90

Mean pressure in the boilers....................................	95.427
" " " pipe....................................	92.281
" barometer.	29.864
" vacuum in condenser..................................	20.224
" pressure in the force pipe..............................	61.4661
" gauge on suction pipe, referred to mean zero.....	2.5925
" river gauge..	28.0937

TABLE XIII.

ENGINE NO. 2.

GENERAL OBSERVATIONS.

10	11	12	13	14	15	16	17	18
Temperatures.				Revolutions.		Water to Boilers, Pounds.	Coal.	
Air.	Injection.	Overflow.	Feed Wat.	Engine Register.	Revolut'ns per hour.		Barrow.	Weight Delivered.
....	48	87	124	....	....	740	....	....
....	48	87	129	....	1144	890	....	....
....	48	88	131	....	....	326	....	....
66.5	48	88	134	22171	....	664	....	....
....	48	87	136	....	....	570	No. 2.	500
....	48	88	141	....	1162	1010	....	....
....	48	87	143	....	....	714	....	....
68.0	48	87	145	23333	....	546	....	....
....	48	87	144	....	....	384	....	....
....	48	87	145	....	1206	1112	....	....
....	48	88	143	....	....	314	....	....
66.0	48	87	141	24539	....	612	No. 1.	500
....	48	88	141	....	....	744	....	....
....	48	88	138	....	1179	1138	....	....
....	48	87	138	....	....	540	....	....
66.5	48	88	140	25718	....	1086	....	....
....	48	78	140	....	....	370	....	....
....	48	81	146	....	1090	1177	....	....
....	48	64	142	....	....	417	....	....
66.0	48	87	134	26808	....	532	No. 2.	500
....	48	88	122	....	....	1048	....	....
....	48	88	117	....	1178	542	....	....
....	48	89	113	....	....	700	....	....
67.5	48	88	112	27986	....	587	....	....

Mean temperature of air.. 64.365
" " " injection.. .... 46.896
" " " overflow.................................. 87.635
" " " feed water.............................. 121.917
Revolutions during trial... 27485
" per minute.. 19.0866
Water weighed to boilers........ 68238
Coal " " 9000–84.......................... 8916

TABLE XIV.

ENGINE NO. 2.

CALORIMETER.

1	2	3	4	5	6	7	8	9
		Water to Tank.			Temperatures.			
Date.	Time.	From Mains.	From Steam Pipe.	Steam Condensed.	Initial.	Final.	Range.	Pressure in Boilers.
Jan. 29.	11:00 A. M.	98	2	5.25	74.5	127.0	52.5	95
	12:00	98	2	5.125	48.5	104.0	55.5	97
	1:00 P. M.	98	2	5.0	47.5	101.0	53.5	95
	2:00	98	2	5.0	50.0	103.0	53.0	94
	3:00	98	2	5.0	52.5	105.5	53.0	95
	4:00	98	2	5.125	52.0	107.0	55.0	95
	5:00	98	2	5.0	51.0	105.0	54.0	97
	6:00	98	2	5.0	51.5	104.5	53.0	95
	7:00	98	2	5.0	49.0	102.5	53.5	93
	8:00	98	2	5.0	56.0	110.0	54.0	99
	9:00	98	2	5.125	52.0	107.5	55.5	93
	10:00	98	2	5.0	52.0	106.5	54.5	95
	11:00	98	2	5.125	51.0	106 0	55.0	94
	12:00 A. M.	98	2	5.0	53.0	106.5	53.5	96
Jan. 30.	1:00	98	2	5.0	52.0	105.5	53.5	96
	2:00	98	2	5.0	50.75	104.25	53.5	96
	3:00	98	2	5.0	53.0	106.0	53.0	90
	4:00	98	2	5.0	52.5	105.5	53.0	95
	5:00	98	2	5.0	49.0	103.0	54.0	91
	6:00	98	2	5.0	51 0	105.0	54.0	94
	7:00	98	2	5.0	53.5	107.0	53.5	94
	8:00	98	2	5.0	54.0	106.0	52.0	95
	9:00	98	2	5.0	51.0	105.5	54.5	95
	10:00	98	2	5.125	48.5	103.0	54.5	97

Weight of water heated.................................2400
" " steam condensed.................................. 120.875
Mean initial temperature.................................. 52.323
" final " 106.115
" range, " 53.792
" steam pressure.................................. 94.833

TABLE XV.

ENGINE NO. 2.

DIAGRAMS—HIGH PRESSURE CYLINDER, UPPER END.

1	2	3	4	5	6	7	8	9
		Pressures.				Valve Motion.		
Date.	Time.	Initial.	Terminal.	Counter at Mid Stroke.	Mean Effective.	Cut-off.	Release.	Exhaust Closure.
Jan. 29.	11:15 A. M.	96.00	25.50	3.50	60.572	.397	.993	.951
	12:15 P. M.	96.00	22.00	1.50	57.271	.349	.993	.951
	1:15	97.00	22.50	2.00	57.988	.349	.993	.951
	2:15	95.50	25.00	3.00	60.715	.373	.993	.951
	3:15	97.00	24.00	3.00	59.317	.349	.993	.951
	4:15	95.00	23.00	3.00	56.697	.349	.993	.951
	5:15	96.00	23.00	4.00	55.979	.344	.993	.951
	6:15	94.00	22.00	4.50	54.974	.351	.993	.951
	7:15	97.00	24.00	4.75	56.840	.349	.993	.951
	8:15	98.00	23.00	4.50	58.562	.344	.993	.951
	9:15	96.50	23.00	6.50	54.831	.353	.993	.951
	10:15	93.00	21.50	5.50	54.400	.349	.993	.951
	11:15	94.00	22.60	6.00	53.539	.349	.993	.951
Jan. 30.	12:15 A. M.	96.00	23.00	6.00	54.974	.349	.993	.951
	1:15	96.00	23.50	7.00	55.548	.349	.993	.951
	2:15	102.50	24.00	7.00	58.132	.349	.993	.951
	3:15	97.75	23.00	7.00	54.831	.349	.993	.951
	4:15	97.25	23.00	6.00	55.117	.349	.993	.951
	5:15	95.25	22.50	6.00	54.544	.349	.993	.951
	6:15	97.00	22.00	5.25	55.548	.349	.993	.951
	7:15	98.00	23.00	7.00	55.405	.349	.993	.951
	8:15	99.00	23.25	6.50	55.979	.349	.993	.951
	9:15	98.00	29.00	7.00	61.577	.409	.993	.951
	10:15	95.00	23.50	5.75	54.543	.380	.993	.951

Mean initial pressure, corrected for error of spring..... 95.92
" terminal " " " " 23.22
" counter " " " " 5.06
" effective " " " " 56.578
" cut-off in decimal of stroke. .... .356
" release " " .... .993
" exhaust closure in decimal of return stroke...... .951

TABLE XVI.

ENGINE NO. 2.

DIAGRAMS—HIGH PRESSURE CYLINDER, LOWER END.

1	2	3	4	5	6	7	8	9
		Pressures.				Valve Motion.		
Date.	Time.	Initial.	Terminal.	Counter at Mid Stroke.	Mean Effective.	Cut-off.	Release.	Exhaust Closure.
Jan. 29.	11:15 A. M.	94.50	32.00	4.25	64.735	.431	.976	.981
	12:15 P. M.	96.00	27.00	3.50	61.002	.380	.976	.981
	1:15	96.00	27.00	2.75	61.433	.373	.976	.981
	2:15	95.50	29.00	4.00	63.156	.397	.976	.981
	3:15	97.00	28.00	4.00	63.012	.373	.976	.981
	4:15	91.00	26.50	4.50	59.998	.368	.976	.981
	5:15	95.00	28.00	5.75	61.577	.357	.976	.981
	6:15	94.00	27.00	6.50	59.423	.359	.976	.981
	7:15	98.00	29.50	7.00	61.720	.373	.976	.981
	8:15	98.00	29.00	6.00	62.151	.385	.976	.981
	9:15	96 50	29.00	8.75	59.711	.385	.976	.981
	10:15	93.00	26.50	8.00	57.127	.380	.976	.981
	11:15	93.50	27.00	8.00	57.414	.385	.976	.981
Jan. 30.	12:15 A. M.	96.00	28.00	8.20	58.850	.385	.976	.981
	1:15	96.00	28.00	9.50	58.562	.385	.976	.981
	2:15	102.50	30.00	9.50	62.869	.385	.976	.981
	3:15	97.50	27.00	9.00	59.423	.385	.976	.981
	4:15	95.50	28.00	8.75	58.849	.385	.976	.981
	5 15	93.25	28 00	9.00	57.988	.385	.976	.981
	6:15	96.25	27.50	8.00	60.428	.385	.976	.991
	7:15	98.00	28.50	9.50	59.711	.385	.976	.981
	8:15	98.00	29.00	9.00	59.711	.385	.976	.981
	9:15	92.50	30.00	3.50	68.453	.445	.976	.981
	10:15	93.50	29.50	7.75	58.132	.433	.976	.981

Mean initial pressure, corrected for error of spring..... 94.82
" terminal " " " " 28.11
" counter " " " " 6.82
" effective " " " " 60.643
" cut-off in decimal of stroke.......................... .387
" release " " .... .976
" exhaust closure in decimal of return stroke....... .981

TABLE XVII.

ENGINE NO. 2.

DIAGRAMS—LOW PRESSURE CYLINDER, UPPER END.

1	2	3	4	5	6	7	8	9
		PRESSURES.					VALVE MOTION.	
DATE.	TIME.	Initial.	Terminal.	Counter at Mid Stroke.	Mean Effective.	Vacuum at Mid Stroke.	Release.	Exhaust Closure.
Jan. 29.	11:15 A. M.	18.20	12.25	5.00	10.181	9.66	.996	.967
	12:15 P. M.	16.10	11.30	3.25	10.460	11.41	.996	.967
	1:15	16.90	12.20	4.10	10 460	10.56	.996	.967
	2:15	18.20	12.70	4 40	11.018	10.26	.996	.967
	3:15	17.80	12.40	4.75	10.483	9.91	.996	.967
	4:15	18.30	12.40	4.60	10.390	10.06	.996	.967
	5:15	19.20	12.95	4.75	10.971	9.91	.996	.967
	6:15	19.70	12.75	4.75	11.088	9.91	.996	.967
	7:15	19.80	13.25	5.15	11.041	9.51	.996	.967
	8:15	19 30	13.00	5.30	10.460	9.36	.996	.967
	9:15	21.20	12.50	5.75	10.902	8.91	.996	.967
	10:15	19 85	11.90	5.75	10.041	8.91	.996	.967
	11:15	20.04	12.40	5.25	11.227	9.41	.996	.967
Jan. 30.	12:15 A. M.	21.00	12.40	4.80	11.436	9.86	.996	.967
	1:15	21.00	12.30	5.35	10.925	9.31	.996	.967
	2:15	22.10	13.00	6.20	11.227	8.46	.996	.967
	3:15	21.50	12.40	6.00	10.785	8.66	.996	.967
	4:15	21.30	12.50	5.60	11.041	9.06	.996	.967
	5:15	21.65	12.30	5.60	11.064	9.06	.996	.967
	6:15	20.10	11.95	5.25	10.751	9.41	.996	.967
	7:15	21.70	12.70	5.75	10.995	8.91	.996	.967
	8:15	21.65	12.60	6.10	10.925	8.56	.996	.967
	9:15	22.20	13.65	5.20	13.110	9.46	.996	.967
	10:15	21.45	12.50	5.20	11.738	9.46	.996	.967

Mean initial pressure, corrected for error of spring..... 19.69
" terminal " " " " 12.54
" counter " " " " 5.31
" effective " " " " 10.950
" vacuum realized, " " " 9.35
" release in decimal of stroke.............................. .996
" exhaust closure in decimal of return stroke....... .967

TABLE XVIII.

ENGINE NO. 2.

DIAGRAMS—LOW PRESSURE CYLINDER, LOWER END.

1	2	3	4	5	6	7	8	9
		Pressures.					Valve Motion.	
Date.	Time.	Initial.	Terminal.	Counter at Mid Stroke.	Mean Effective.	Vacuum at Mid Stroke.	Release.	Exhaust Closure.
Jan. 29.	11:15 A. M.	19.10	14.65	6.30	8.833	8.36	.971	.959
	12:15 P. M.	16.60	13.65	4.25	9.832	10.41	.971	.959
	1:15	17.45	14.20	6.00	8.856	8.66	.971	.959
	2:15	18.30	15.10	5.15	10.483	9.51	.971	.959
	3:15	17.80	14.60	5.20	9.763	9.46	.971	.959
	4:15	18.25	14.65	5.10	9.995	9.56	.971	.959
	5:15	19.00	14.60	5.35	10.158	9.31	.971	.959
	6:15	19.40	14.25	5.25	10.460	9.41	.971	.959
	7:15	19.70	14.15	5.80	9.809	8.86	.971	.959
	8:15	19.00	13.95	5.95	9.507	8.71	.971	.959
	9:15	21.00	13.95	6.00	10.320	8.66	.971	.959
	10:15	18.75	13.30	6.15	9.182	8.51	.971	.959
	11:15	20.45	13.90	6.25	9.995	8.41	.971	.959
Jan. 30.	12:15 A. M.	20.50	13.90	5.60	10.483	9.06	.971	.959
	1:15	21.00	14.00	6.00	10.065	8.66	.971	.959
	2:15	21.80	14.45	6.80	10.181	7.86	.971	.959
	3:15	21.50	13.95	6.45	10.018	8.21	.971	.959
	4:15	20.50	13.50	6.60	9.321	8.06	.971	.959
	5:15	21.00	13.80	6.30	9.763	8.36	.971	.959
	6:15	17.35	13.10	6.75	8.414	7.91	.971	.959
	7:15	21.50	14.20	6.25	10.344	8.41	.971	.959
	8:15	21.30	13.90	7.15	9.251	7.51	.971	.959
	9:15	22.35	15.15	6.25	11.250	8.41	.971	.959
	10:15	22.15	14.70	6.10	10.785	8.56	.971	.959

Mean initial pressure, corrected for error of spring..... 19.51
" terminal " " " " 14.16
" counter " " " " 6.10
" effective " " " " 9.877
" vacuum realized, " " " 8.56
" release in decimal of stroke.......................... .971
" exhaust closure in decimal of return stroke...... .959

PERFORMANCE OF THE ENGINES.

The net area of H. P. piston of both engines is

$$452.39-8.952=443.438 \text{ sq. inches,}$$

and net area of L. P. piston of both engines is

$$1320.26-9.19=1311.07 \text{ sq. inches.}$$

The mean effective pressure on the piston of the H. P. cylinder of engine No. 1 for whole trial was

$$\frac{38.129+45.877}{2}=42.003 \text{ pounds.}$$

and average piston speed

109.7994 feet per minute,

and power developed

$$\frac{443.438\times42.003\times109.7994}{33000}=61.972 \text{ horse power.}$$

The mean effective pressure on the piston of L. P. cylinder of engine No. 1 for whole trial was

$$\frac{17.251+13.125}{2}=15.188 \text{ pounds,}$$

and average piston speed

109.7994 feet per minute,

and power developed

$$\frac{1311.07\times15.188\times109.7994}{33000}=66.253$$

horse power, and total power developed

128.225

Of this work

$$100\times\frac{61.972}{128.225}=48.33 \text{ per cent. was}$$

done in the high pressure cylinder, and

$$100\times\frac{66.253}{128.225}=51.67 \text{ per cent. was}$$

done in the low pressure cylinder.

The net steam delivered per hour to the engine for whole trial was

$$\frac{63750.946}{24}=2656.29 \text{ pounds,}$$

and coal per indicated horse power per hour upon the evaporation stipulated in the contract,

$$\frac{2656.29}{128.225\times 9}=2.3017 \text{ pounds.}$$

The duty represented by the work in the steam cylinders of the engine was

$$\frac{(443.438\times 42.003)+(1311.07\times 15.188)\times 26370\times 2\times 35.975}{12\times 70.8344}=86,021,597.4$$

The duty developed in accordance with the terms of the contract is given in the preliminary report as 81,885,917.12, and percentage of total power utilized,

$$\frac{81,885,917.12}{86,021,597.4}\times 100=95.192$$

from which it appears that the frictional resistances of engine and load absorbed 4.808 per cent. of total power developed.

The mean effective pressure on the piston of the H. P. cylinder of engine No. 2 for whole trial was

$$\frac{56.578+60.643}{2}=58.6105 \text{ pounds,}$$

and average piston speed

114.5038 feet per minute,

and power developed

$$\frac{443.438\times 58.6105\times 114.5038}{33000}=90.18 \text{ horse power.}$$

The mean effective pressure on the piston of the L. P. cylinder of engine No. 2 for whole trial was

$$\frac{10.950+9.877}{2}=10.4135 \text{ pounds,}$$

and average piston speed

114.5038 feet per minute,

and power developed

$$\frac{1311.07 \times 10.4135 \times 114.5038}{33000} = 47.373$$

horse power, and total power developed

137.554

Of this work

$$100 \times \frac{90.180}{137.554} = 65.56 \text{ per cent.}$$

was done in the high pressure cylinder, and

$$100 \times \frac{47.373}{137.554} = 34.44 \text{ per cent.}$$

was done in the low pressure cylinder.

The net steam delivered per hour to the engine for whole trial was

$$\frac{64788.658}{24} = 2699.53 \text{ pounds,}$$

and coal per indicated horse power per hour upon the evaporation stipulated in the contract

$$\frac{2699.53}{137.554 \times 9} = 2.1805 \text{ pounds.}$$

The duty represented by the work in the steam cylinders of the engine was

$$\frac{(443.438 \times 58.6105) + (1311.07 \times 10.4135) \times 27485 \times 2 \times 35.995}{12 \times 71.9874} = 90{,}802{,}152.8$$

The duty developed in accordance with the terms of the contract is given in the preliminary report as 88,688,866.4, and percentage of total power utilized

$$\frac{88{,}688{,}866.4}{90{,}802{,}152.8} \times 100 = 97.671,$$

from which it appears that the frictional resistance of engine and load absorbed 2.32 per cent. of the total power developed.

The friction load is low for engine No. 1, and surprisingly low for engine No. 2.

The frictional resistance of the reciprocating members is always lower in a vertical engine than in an inclined or horizontal engine, for the reason that in the latter types of engine, the weight of the parts develop a certain friction in addition to that of the packing rings and stuffing boxes.

From the few experiments which I have made upon vertical pumping engines with steam and water pistons set up sufficiently to avoid leakage, I find the least friction load approximately *five per cent.* of the duty developed in the steam cylinders.

The engines in this instance (Evansville) were under the control of the contractors previous to and during the trials, and no doubt every effort was made to reduce the friction to the smallest possible percentage of the indicated load.

The lubrication of all parts was excellent, and the difference of 4.8 per cent. between the indicated work of engine No. 1 and the duty, by the terms of the contract, may be accepted as the frictional resistance of the working parts of the engine, exclusive of the frictional resistances already accounted for in the preliminary report.

The difference of 2.32 per cent. between the indicated load and the duty, by the contract, in the case of engine No. 2, is not sufficient to cover the frictional resistances of engine and load with steam and water pistons practically tight, and steam or water leaks past the pistons must have existed during the trial.

No attempt was made to ascertain the condition of pistons, it being presumed that the contractors in their own behalf would place the engines in the best working order.

The duty of engine No. 2 is materially better than that of engine No. 1, and it is not likely that the difference, if any, in the steam leaks, was prejudicial to the economy of engine No. 2. It is therefore fair to presume that the reduced friction must have been largely due to the difference in condition of the packing in the water pistons of the two engines.

It will be observed that the contract between the city of Evansville and the Helly Manufacturing Company stipulated a method of trial for duty which eliminated the actual delivery of water from the problem, the water delivered to be estimated from the areas and piston travel of pumps.

With pump pistons, stuffing boxes, and valves, in proper condition, there is no objection to this method of determining the quantity of water delivered by the pumps, but with loose pistons or leaky valves through which, or past which, water would slip on the return stroke, a serious objection arises, in that the pumps will be credited with a larger delivery of water than they are properly entitled to under the terms of the contract. For the area of the pump pistons into their travel, means neither more nor less than the quantity of water actually pumped, plus the customary allowance for slip.

As stated in the preliminary report, no convenient means could be adopted to measure the water delivered to or from the pumps. The engines pumped directly into the distributing mains, and any cutting of the force pipe would have deprived the city of water for several days.

The terms of the contract were such that a duty calculated from the actual delivery of water, with the usual allowance for loss of action in the pumps, would not have complied therewith, and the only object in measuring the actual delivery of water would have been to compare duties by the usual methods of determination, and by the method adopted by the contract in this instance.

I have estimated the weight of steam accounted for by the diagrams as follows:

The volume of the low pressure cylinder to release, of engine No. 1, was

$$\frac{1311.07\times35.985\times.993}{1728}=27.111$$

cu. ft. of steam present in the cylinder per stroke of piston at the opening of the exhaust to the condenser. The exhaust valves closed a short time before the termination of the return stroke, and the volume of steam retained for cushion was

$$\frac{1311.07\times35.985\times.0635}{1728}=1.734$$

cu. ft. of steam in the cylinder at exhaust closure. The clearance is given in the table of dimensions as 3.07 per cent. of piston displacement, and

$$\frac{1311.07\times35.985\times.0307}{1728}=.838$$

cu. ft. of steam contained in the clearance space.

The mean terminal pressure from the tables of diagrams (L. P. cylinder) for engine No. 1 was 13.97 pounds, corresponding to a weight per cu. ft. of

$$\frac{62.382}{25.62+\frac{49513}{25.45+.72}}=.03621 \text{ pound.}$$

The mean pressure subsisting in the cylinder when the exhaust valves closed was 4.44 pounds, corresponding to a weight per cu. ft. of

$$\frac{62.382}{25.62+\frac{49513}{9.044+.72}}=.01224 \text{ pound.}$$

The weight of steam present at release per stroke of piston was

$$(27.111+.8382)\times.03621=1.01204 \text{ pounds,}$$

and weight of steam per stroke retained for cushion,

$$(1.734+.8382)\times.01224=.031483 \text{ pound.}$$

and net steam accounted for by the diagrams for whole trial,

$$.98056\times2\times26370=51714.734 \text{ pounds.}$$

The weight of steam condensed in the jackets was 2017.9 pounds, and of the total weight of steam delivered to the engine 53732.634 pounds were accounted for.

The net weight of steam delivered to the engine during the same interval was 63750.946 pounds, and water entrained in the steam 1254.607 pounds, and percentage of steam accounted for

$$\frac{53732.634}{65005.553} \times 100 = 82.658.$$

The volume of steam at release, not including clearance, in the low pressure cylinder of engine No. 2 was

$$\frac{1311.07 \times 35.967 \times .9835}{1728} = 26.839 \text{ cu. ft.}$$

As in the case of Engine No. 1, the exhaust valves closed before the termination of the return stroke, and volume of steam retained for cushion, per stroke of piston, was

$$\frac{1311.07 \times 35.967 \times .037}{1728} = 1.009 \text{ cu. ft.}$$

The clearance was .0307 of piston displacement, or

$$\frac{1311.07 \times 35.967 \times .0307}{1728} = .8377 \text{ cu. ft.}$$

The mean terminal pressure for engine No. 2 was 13.35 pounds, corresponding to a weight per cu. ft. of .03467 pound.

The mean pressure subsisting in the cylinder, when the exhaust valves closed, was 5.705 pounds, corresponding to a weight per cu. ft. of .01545 pound.

The weight of steam present at release per stroke of piston was

$$(26.839 + .8377) \times .03467 = .96055 \text{ pound,}$$

and weight of steam retained for cushion

$$(1.009 + .8377) \times .01545 = .02853 \text{ pound,}$$

and net steam accounted for by the diagrams for whole trial,

$$.93202 \times 2 \times 27485 = 51233.139 \text{ pounds.}$$

The weight of steam, condensed in the jackets, was 1401.7 pounds, and of the total weight of steam delivered to the engine 52634.839 pounds were accounted for.

The net weight of steam delivered to the engine, during the same interval, was 64788.658 pounds; and water entrained in the steam, 3230.145 pounds, and percentage of steam accounted for,

$$100 \times \frac{52634.839}{68018.8} = 77.383$$

In estimating the weight of steam accounted for, I have included the water entrained; for while this may have entered the H. P. cylinder as liquefaction, it is very probable that a considerable portion of it was evaporated during expansion, and was manifest at release in the low pressure cylinder, as vapor. In other terms, if the jackets were removed, and it was known that no portion of the water entrained was evaporated during expansion, then I should expect a smaller quantity of steam at release than has been found by calculation.

It will be noticed, in the preliminary report, that I have charged the engines with coal upon the net weight of steam delivered, and that any loss or gain by the small percentage of water in the steam, when it entered the cylinder, is neglected.

The mean initial pressure for trial of engine No. 1, was, by the diagrams, 95.405 pounds, and mean pressure of atmosphere by barometer, 14.86 pounds, and absolute pressure at which the steam entered the cylinder, 110.265 pounds.

The mean terminal pressure was, by the diagrams, 13.97 pounds, and expansion, by pressures,

$$\frac{110.265}{13.97} = 7.893$$

The volume of the high pressure cylinder is 9.229 cubic feet, and the volume of clearance, .3638 cubic feet. The cut-off was, by the diagrams, .242 of piston stroke, and volume of steam, at cut-off, in the high pressure cylinder,

$$(9.229 \times .242) + .3638 = 2.5972 \text{ cu. ft.}$$

The volume of the low pressure cylinder, to release, was 27.111 cubic feet, and clearance, .8382 cubic feet; then expansion, by volume, was

$$\frac{9.229 + .3638 + 27.111 + .8382}{2.5972} = 14.455$$

The mean initial pressure for trial of engine No. 2, was, by the diagrams, 95.37 pounds, and mean pressure of atmosphere, by barometer, 14.66 pounds; and absolute pressure at which the steam entered the cylinder, 110.03 pounds.

The mean terminal pressure was, by the diagrams, 13.35 pounds, and expansion, by pressures,

$$\frac{110.03}{13.35} = 8.242$$

The volume of high pressure cylinder is 9.244 cubic feet, and volume of clearance .3644 cubic feet. The cut-off was, by the diagrams, .3715 of piston stroke, and volume of steam cut off in the high pressure cylinder,

$$(9.244 \times .3715) + .3644 = 3.7984 \text{ cu. ft.}$$

The volume of the low pressure cylinder, to release, was 26.839 cubic feet, and clearance, .8377 cubic feet; then expansion, by volumes, was

$$\frac{9.244 + .3644 + 26.839 + .8377}{3.7984} = 9.816$$

Considering the low percentage of water entrained in the steam (especially in the trial of engine No. 1), and the use of steam jackets on both cylinders, the discrepancy between the expansion by pressures and by volumes, would indicate a condition of the steam end of the engines not calculated for maximum economy.

A leakage through the steam valves of the high pressure cylinder, with the exhaust valves of the low pressure cylinder tight, would account for the difference in that the volume of steam expanded is greater than the volume of steam cut off, by the amount of leakage.

In the accompanying diagrams, I have developed a mean diagram of expansion and work for each engine.

The vertical projection is on the line of pressures, and the horizontal projection is on the line of volumes, the latter including clearances.

Isothermal and adiabatic curves have been drawn from initial pressure and point of cut-off upon both diagrams.

The data and formula for the construction of the diagrams are given in the margin.

The excess of the diagram from the high pressure cylinder of engine No. 1, beyond the isothermal curve, seems to indicate a very material leakage of the steam valves; for the steam entered the cylinder practically at saturation, and the condensing effect of the piston rods was balanced by the abstraction of heat from the jackets.

The diagram worked for engine No. 2, indicates leakage after cut-off, in the high pressure cylinder, probably past the piston, as the extremely low friction load can scarcely be accounted for by looseness of the water pistons alone.

The steam, condensed in the jackets during the trials, was caught in a tight tub, which was filled to a uniform gauge point, and dumped as often as required, the temperature of the contents and time of dumping being noted.

During the trial of engine No. 1, the tub was filled and dumped twenty times, for a period of twenty-three hours and twenty-three minutes, with a mean temperature of contents of 156.75 F.

The weight of water contained in the tub, to the gauge point, at 40 F., was 100.5 pounds. The relative weights of a given volume of water at 40 F., and at 156.75 F., are as 1 to .978, whence weight of water drawn from the jackets becomes

$$\frac{100.5 \times 20 \times .978 \times 24}{23.38} = 2017.9 \text{ pounds.}$$

The number of times the tub was filled and dumped, during the trial of engine No. 2, for a period of twenty-three hours and thirty-five minutes, was fourteen, at a mean temperature of 153.72 F., corresponding to an expenditure of

$$\frac{100.5 \times 14 \times .9785 \times 24}{23.58} = 1401.7 \text{ pounds.}$$

The same pipe which supplied steam to the engines, also supplied the jackets, and, of the total quantity of water drawn from the jackets, a certain percentage came from the pipe as water entrained in the steam, and to estimate the percentage of total steam found in the jackets as liquefaction—to the known weight of net steam charged to the engine must be added the weight of water entrained, or 1254.607 pounds for engine No. 1, and 3230.145 pounds for engine No. 2, whence the percentage of steam accounted for in the jackets of engine No. 1 becomes

$$\frac{2017.9}{65005.553} \times 100 = 3.1042$$

and for engine No. 2,

$$\frac{1401.7}{68018.8} \times 100 = 2.0606$$

Precise information, upon the value of steam jacketing cylinders, is very meager. From experiments by Mr. Emery, upon the Coast Survey steamer "Bache," it appears that the gain in economy, by the use of the steam jacket on the larger cylinder of a compound engines was eleven to twelve per cent. The expenditure of steam in the jacket, in this case, varied from four to seven per cent.

In the trial of the Lynn engine (Leavitt Compound), the jacket water was caught and weighed, and amounted to 2.93 per cent. of the total steam expended; whilst at Lawrence, with a pair of engines substantially like those at Lynn, and by the same designer, the jacket water, according to Mr. Hoadley, amounted to nearly ten per cent. of the total steam expended.

In Mr. Emery's experiments, upon the Revenue Cutter Gallatin, of the total steam expended in the engine, the jacket water represented 7.142 per cent.

Recapitulating the results of the experiments noted:

Gaskill Compound Pumping Engine No. 1	3.104
" " " " No. 2	2.0606
Lynn " " "	2.93
Steamer Bache, Compound	5.5
" Gallatin, Single Cylinder	7.142
Lawrence Compound Pumping Engine	9.71

it appears that the expenditure of steam, in maintaining the jackets, is least in the Gaskill (Evansville) pumping engine, and greatest in the Leavitt (Lawrence) pumping engine.

No experiments were made by the experts, at Lawrence, to determine the efficiency of the engine without the jackets, nor were such experiments made at Evansville, and no relation of the jacket water, to the extra economy due the use of the jacket, can be stated in either instance.

PERFORMANCE OF THE BOILERS.

The total water weighed to the boilers, during the twenty-four hours trial of engine No. 1, was 65228 pounds, of which quantity 50.322 pounds was caught and weighed as leakage in the suction pipe to the feed pump; of the remainder

$$65177.678 \times .019332 = 1257.929 \text{ pounds}$$

was entrained in the steam; and net steam, from the temperature of feed (116.117 F.), was 63919.749 pounds.

The coal charged, during the same interval, was 8641 pounds, and evaporation, per pound of coal, was

$$\frac{63919.749}{8641} = 7.397 \text{ pounds}$$

at a mean boiler pressure of 95.745 pounds, corresponding to an evaporation from, and at 212 F., of,

$$\frac{7.397 \times 1100}{996} = 8.423 \text{ pounds.}$$

The contract under which the engines were tested provides that the coal shall be charged upon an evaporation per pound, of nine pounds of steam from the temperature of the feed; less coal represented by steam expended in the calorimeter; hence,

$$\frac{(7.397 \times 8641) - 168.803}{9} = 7083.438 \text{ pounds}$$

of coal, upon which the duty is based.

The rate of evaporation, from the temperature of feed, during the trial of engine No. 1, was

$$\frac{63919.749}{24 \times 932.018} = 2.858 \text{ pounds}$$

per hour, per square foot of heating surface.

The total water weighed to the boilers, during the trial of engine No. 2, was 68238 pounds, of which quantity 50.322 pounds was lost by leakage in the suction pipe, leaving 68187.678 pounds actually pumped as feed. The water entrained in the steam was 4.7489 per cent., and net steam, from temperature of feed (121.917 F.), was

$$68187.678 - (68187.678 \times .047489) = 64949.514 \text{ pounds.}$$

The coal burned, during the trial, was 8916 pounds, and evaporation

$$\frac{64949.514}{8916} = 7.285 \text{ pounds}$$

at a mean pressure of 95.427 pounds, corresponding to an evaporation from, and at 212 F., of

$$\frac{7.285 \times 1094.05}{996} = 8.251 \text{ pounds,}$$

and coal charged to the engine, under the terms of the contract,

$$\frac{(8.916 \times 7.285) - 160.854}{9} = 7198.74 \text{ pounds.}$$

The rate of evaporation from the temperature of the feed, during the trial of engine No. 2, was

$$\frac{64949.514}{24 \times 932.018} = 2.903 \text{ pounds.}$$

The rate of combustion, per square foot of grate, was, for trial of engine No. 1,

$$\frac{8641}{24 \times 45} = 8.001 \text{ pounds per hour,}$$

and for trial of engine No. 2,

$$\frac{8916}{24 \times 45} = 8.255 \text{ pounds per hour.}$$

The ash pits were cleaned before each trial began, and the accumulations of ash and clinker during the intervals between the cleaning of fires previous to the trials, and the same operation during the trials, were collected and weighed, with the following results.

The ash and clinker, weighed back during the trial of engine No. 1, for a period ef eleven hours and forty-five minutes, was 788 pounds; and the accumulation, during the trial of engine No. 2, for a period of nineteen hours and thirty minutes, was 831 pounds. From which I obtain the percentage of combustible, as the coal was fired,

$$100 \times \frac{788 \times 24}{8641 \times 11.75} = 18.63$$

for the trial of engine No. 1, and

$$100 \times \frac{831 \times 24}{8916 \times 19.5} = 11.47$$

for the trial of engine No. 2.

The coal fired, anthracite, was from the same pile, and the non-combustible should have been approximately alike for both trials.

In cleaning the fires, even with great care in handling the rake, more or less unburnt coal will be drawn from the furnace with the clinker, and the lowest percentage of non-combustible shown by the trials, is necessarily in excess of the actual non-combustible in the coal.

The larger percentage of non-combustible, during the trial of engine No. 1, is evidently due to the careless manipulation of the rake, and the withdrawal of a considerable quantity of unburnt coal along with the clinker.

The actual percentage of non-combustible in the coal was, probbly, *eight* or *nine;* from which I should regard the coal as of good quality, although not the best.

In conclusion, I desire to thank your committee, the engineer and secretary of the works, and the representatives of the Holly Manufacturing Company, for the efficient aid given me during the trials.

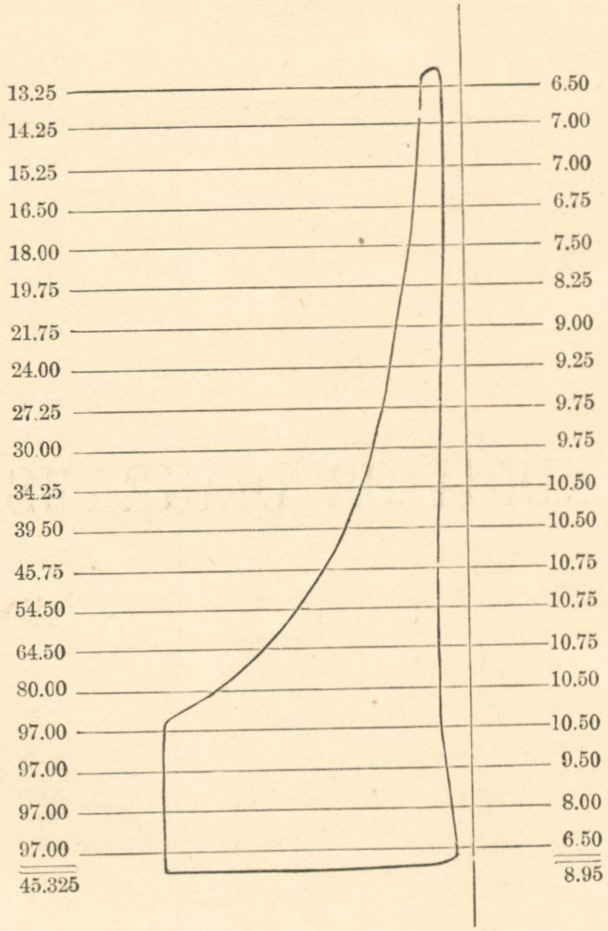
All of which is respectfully submitted.

JOHN W. HILL.

CINCINNATI, *March* 4, 1881.

INDICATOR DIAGRAMS.

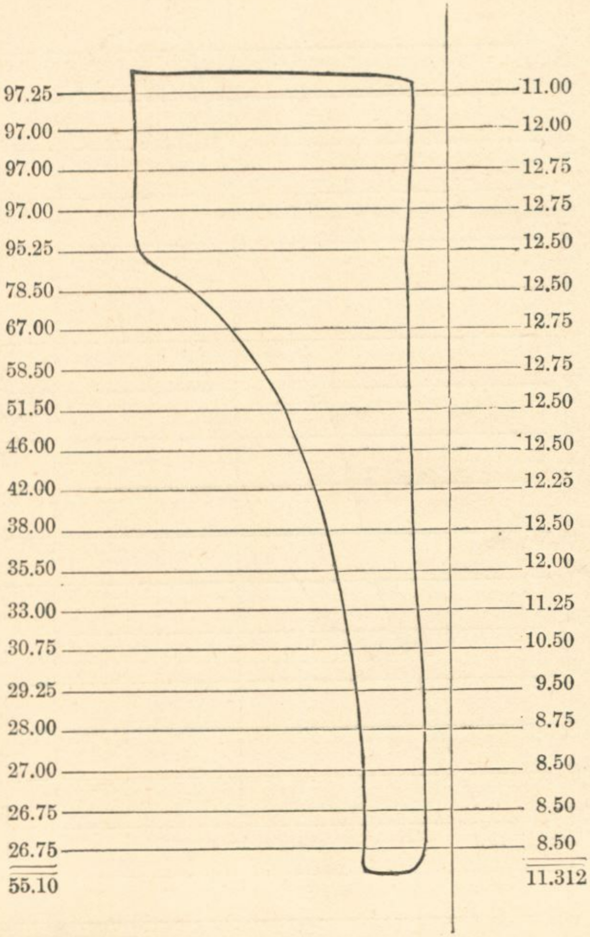
ENGINE No. 1.
H. P. Cylinder Upper End.
DIAGRAM 6.



Mean effective pressure corrected for error of Spring
By ordinates 36.147 By planimeter 36.856

ENGINE No. 1.
H. P. Cylinder Lower End.

DIAGRAM 6.



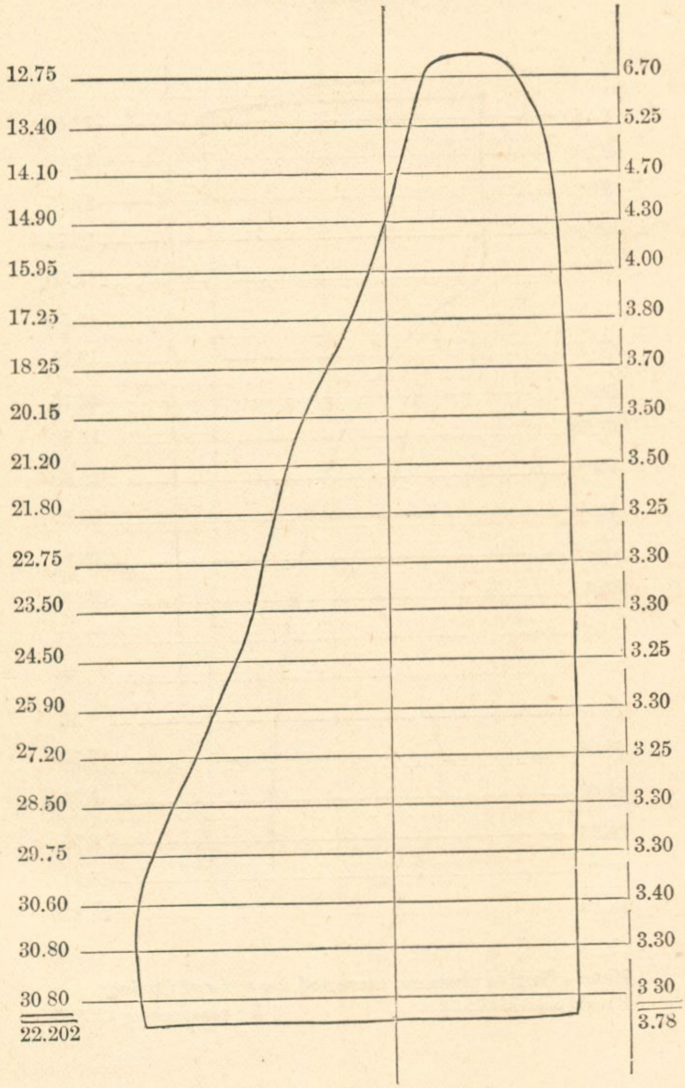
Mean effective pressure corrected for error of Spring

By ordinates 43.514 By planimeter 42.526

ENGINE No. 1.

L. P. Cyliner Upper End.

DIAGRAM 10.



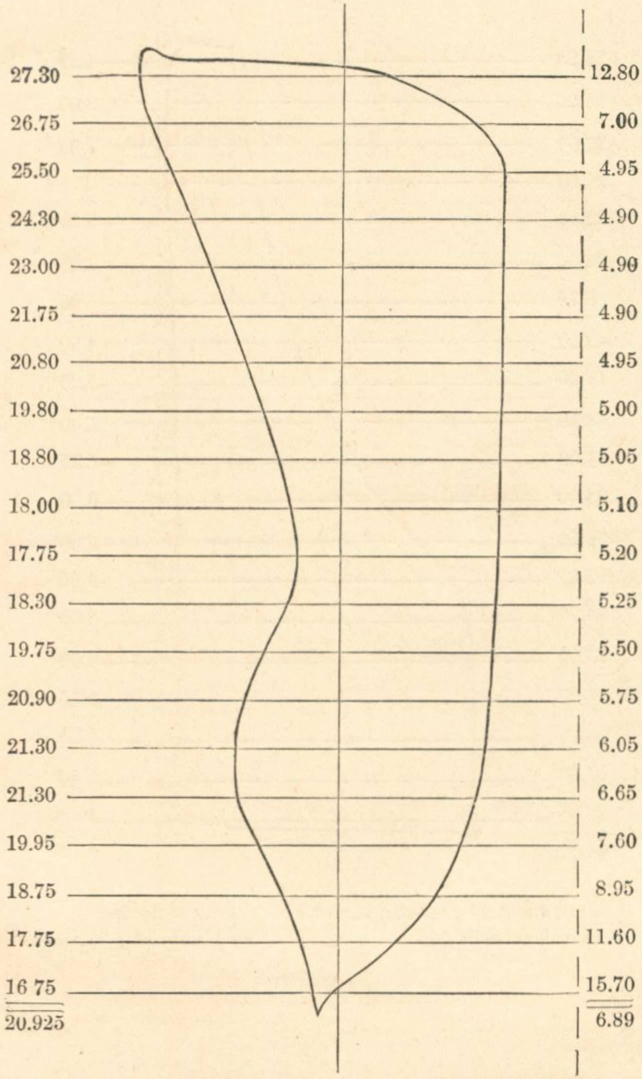
Mean effective pressure corrected for error of Spring

By ordinates 18.306 By planimeter 18.377

ENGINE No. 1.

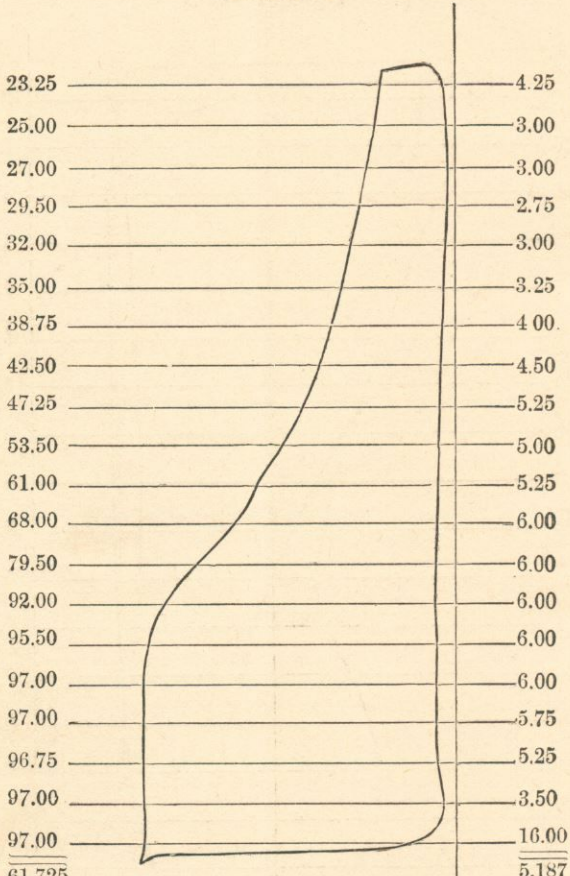
L. P. Cylinder Lower End.

DIAGRAM 10.



Mean effective pressure corrected for error of spring
By ordinates 13.947 By planimeter 13.612

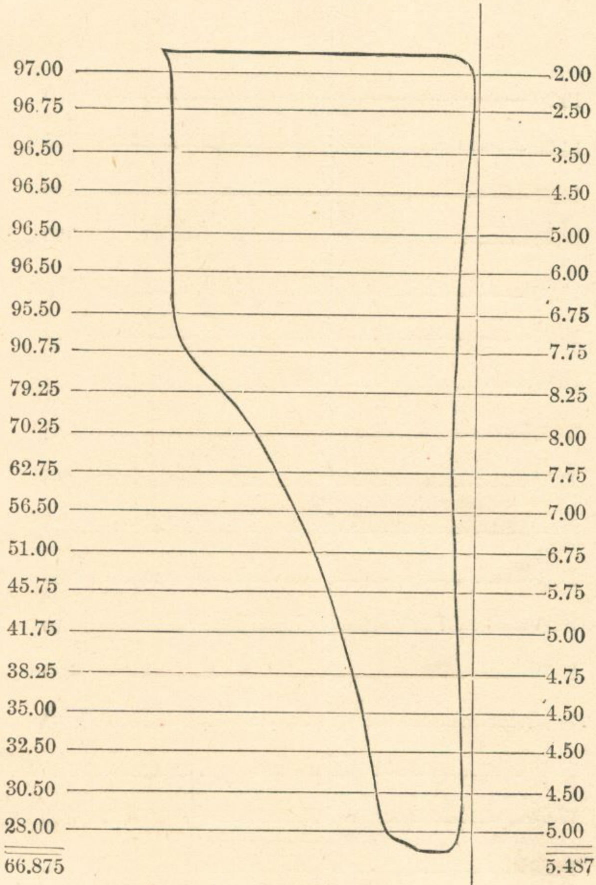
ENGINE No. 2.
H. P. Cylinder Upper End.
DIAGRAM 20



Mean effective pressure corrected for error of Spring

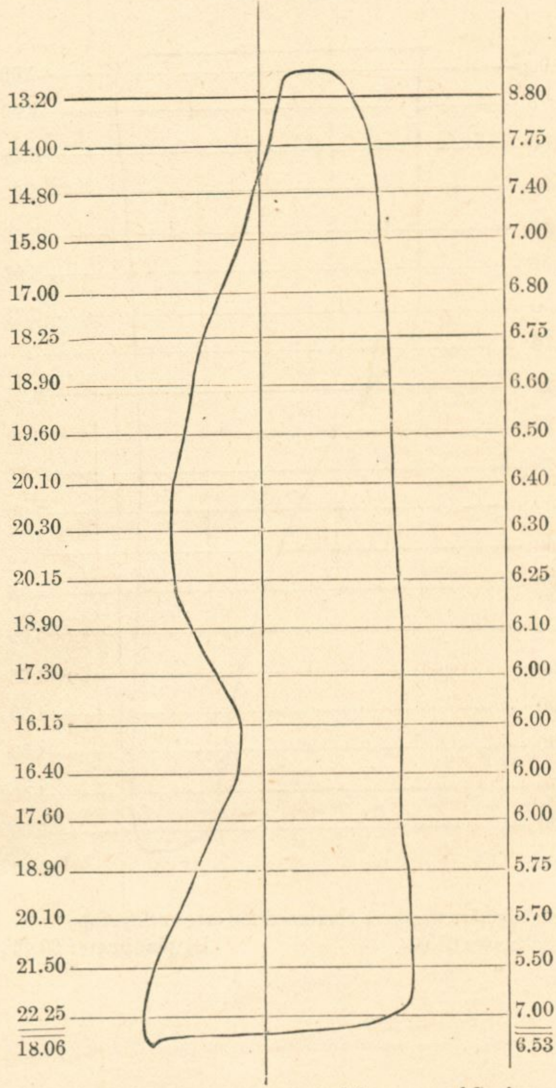
By ordinates 56.016 By planimeter 55.548

ENGINE No. 2.
H. P. Cylinder Lower End.
DIAGRAM 20.



Mean effective pressure corrected for error of Spring
By ordinates 61.004 By planimeter 60.428

ENGINE No. 2.
L. P. Cylinder Upper End.
DIAGRAM 16.

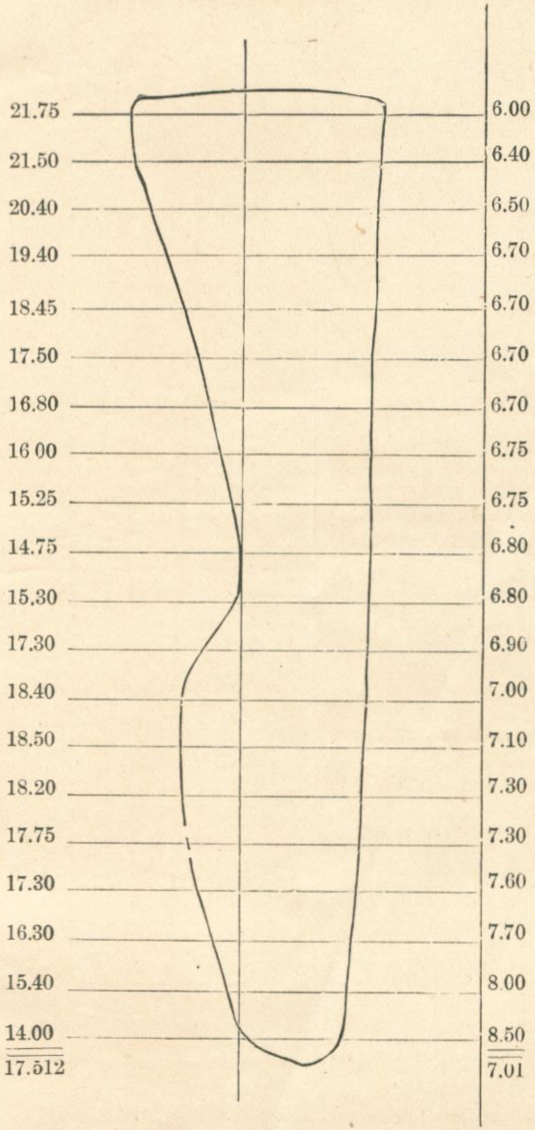


Mean effective pressure corrected for error of Spring
By ordinates 11.458 By planimeter 11.227

ENGINE NO. 2.

L. P. Cylinder Lower End.

DIAGRAM 16.



Mean effective pressure corrected for error of spring
By ordinates 10.436 By planimeter 10.181