Theoretical Discussion of the action of the Hancock Inspirator. with Experiments.

A Thesis by

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Before entering upon the plan and discussion of the work which I intend to pursue, I will refer to the Thesis of Mr. Schwamb of 1878, in which will be found a full description of the Hancock Inspirator, and of its mode of operation which it will be needless for me to repeat.

From a perusal of Mr. Schwamb's paper, I find that he has made experiments, which are as follows:-

The first six experiments were made with a view of finding the change of temperature of the water, produced by varying the opening of the forcer valve.

The quantities of water and steam used were not ascertained, but only the effect on the heat given to the feed. All the readings of the steam-pressure, lift, and temperature of entering water were kept as nearly constant as possible; the amount of opening of the valve only, being changed. It was found as would be supposed, that the more steam used to force the water, the higher the resulting temperature of the feed. —

Three experiments were made to give the capacity of the lifter alone. From these no special result was obtained.

By a number of experiments with

and without the steam pipe jacketed, the advantage of the former method was shown.
In the comparison made between two experiments, it was seen that more water was drawn in the case of jacketed pipes, all other conditions remaining nearly the same.—
Two experiments were made to find the weight of steam used per pound of feed-water.—
From the result of six experiments is shown the effect of changing the pressure against which the feed is forced. From these was deduced the fact that no practical difference is caused in the weight or the temperature of the feed

water, by a difference in the boiler pressure, so long as it is not so great as to stop the apparatus. —

At the close of a number of experiments, the valve regulating the supply of water was very slowly closed, to ascertain the amount of lift that the inspirator could hold at different pressures. —

My plan of work is as follows; I intend in the first place to make some experiments upon the relation of the amount of feed drawn, to the amount of steam. In the second place to make some experiments on the relation of the heat of supply water to the efficiency of the inspirator. Next to make some experiments with relation to the most economical way of running the inspirator, by ascertaining its efficiency under different conditions of pressure, and heat of supply, when the lift and boiler-pressure are constant.

I have once or twice made use of the term efficiency; by that, I mean the relation that exists between the amount of heat required to produce the steam used in raising the water and injecting it into the boiler, to the total work done in lifting and forcing the water against the boiler-pressure, and heating it a certain number of degrees.

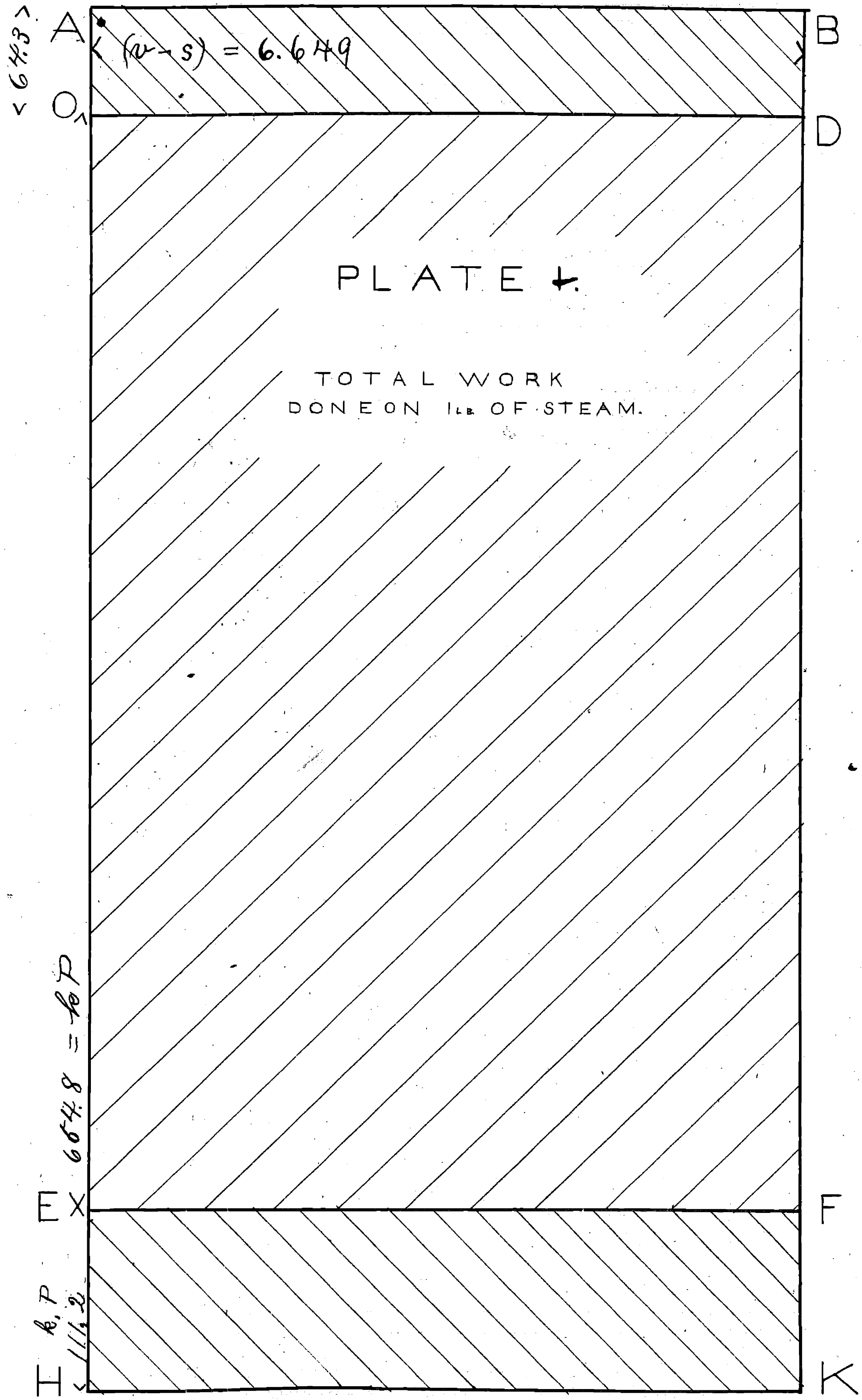
As an example of the method that I shall use to ascertain the efficiency of the inspirator, I will take experiment No. 31. of Mr. Schwamb, which may be found in his Thesis. The data are as follows. —

Diff. of Weight of Calorim.	Diff. of Weight of Barrel	Gauge			Temp.		Lift in Feet.
		1	2	3	1	2	
25 2	279.5	49.6	3.0	50.6	61.0	160.9	20

Duration of experiment 10 minutes.

First let us calculate the amount of heat, reduced to foot-pounds, given to one pound of steam in heating it from the temperature of the feed (160°.9) and evaporating it at the temperature corresponding to the initial pressure 49.6 lbs (64.3 lbs absolute), not taking into account the small losses which might occur from different causes. The temperature corresponding to this pressure is 297° on the ~~absolute~~ scale.

The graphical solution may



Scale .01" = 1 lb pressure.
1" = 1½ cu. ft. vol.

be followed on Plate I. —

From table III, page 316 in Cotterill's "Steam Engine considered as a Heat Engine" we find the value $(v-s)$ for steam at 64.3 lbs, pressure — 6.649 cu. ft. This we lay off on the line OD, and on the line of pressures, lay off OA = 64.3; now this area bounded by OABD, represents the external work done in evaporating the steam. Hence the external work is, —

$$64.3 \times 144 \times 6.649 = 61564.3 \text{ ft. lbs}$$

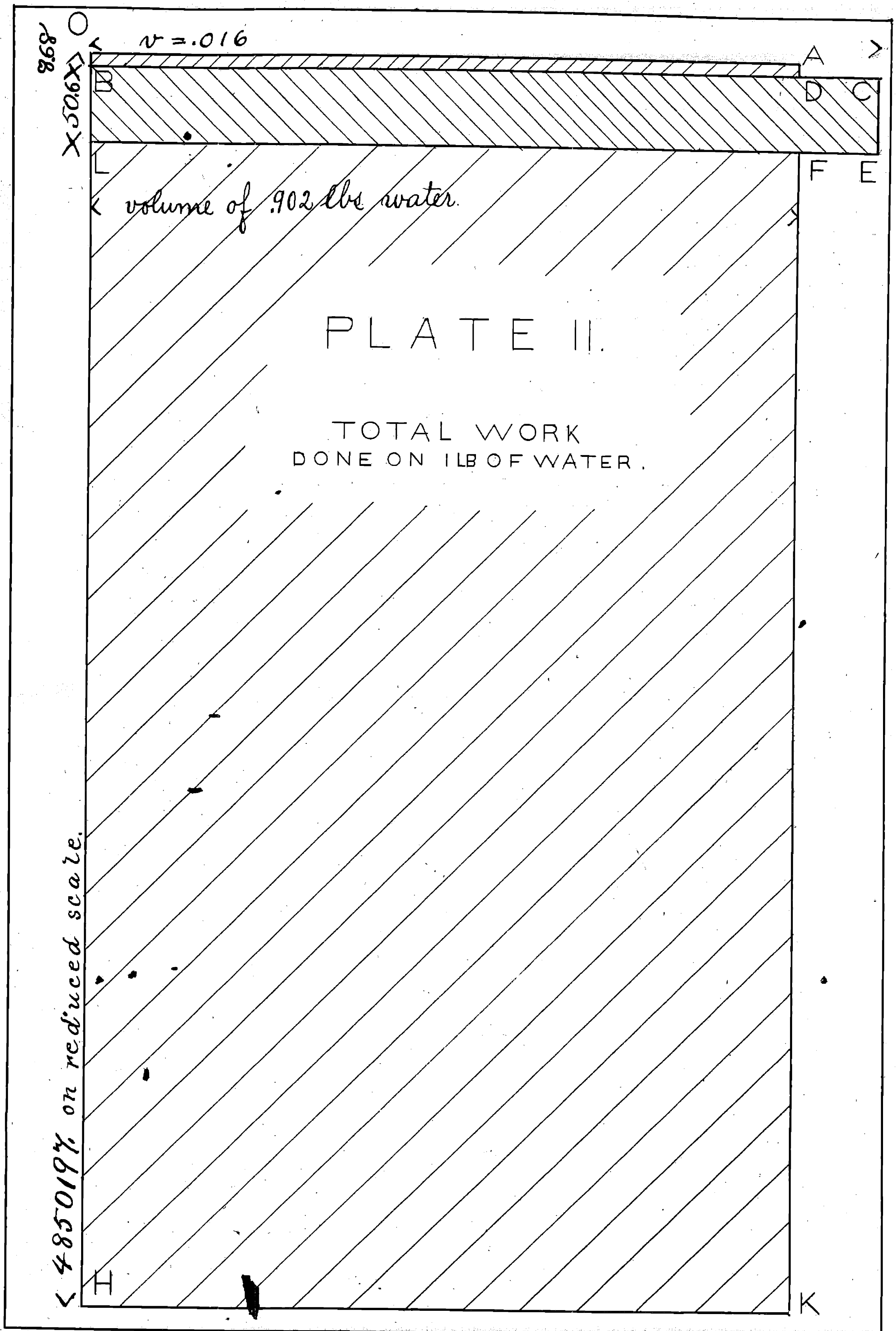
The internal work of evaporation is found by the formula $I = L - P(v-s)$, in which $\underline{L}$ is the latent heat of evaporation.

The latent heat of steam at 64.3 lbs pressure is 905.02 thermal units or 905.02 × 772 = 698675.4 ft. lbs. hence I = 698675.4 − 61564.3 = 637111.1 ft. lbs. This work is represented by the area ODEF, found as described on page 65 of Cotterill's work.

The remaining part of the internal work is that done in raising the water from the temperature of the feed (160°.9 F) to that of evaporation (297°). This amount is represented by $(h_1 - h_0)$, where h_1 = the number of thermal units necessary to raise the water from 32° to 297°, and where h_0 = the same from 32° to 160°.9, hence $(h_1 - h_0)$ =

267.5 - 129.3 = 138.2 thermal units or 106690.4 ft. lbs., which corresponds to the area EFHK in plate I. The sum of these three areas represents the total work done on one pound of steam, or 805365.4 ft. lbs.

Now having the amount of heat given to a pound of steam, let us ascertain how much work is expended for every pound of water put into the boiler. – In the first place we see that the weight of water and steam in the barrel was 279.5 lbs, while the water taken from the calorimeter is 252 lbs, so the difference or 27.5 lbs, is the



Scale. 1" = .006 cu. ft. vol.
.01" = 1 lb pressure.

amount of steam used. Hence we see that .098 of a pound of steam is used for every pound of water put into the barrel. We also see that for a pound of water put into the barrel, .098 lbs. is condensed steam and the remainder .902 lbs. is water from the calorimeter.

The work done in raising .902 lbs through 20 ft. is 18.04 ft. lbs. which is shown by the area OABD in Plate II, which is laid off with a volume OA = .0144 cu. ft., the volume of .902 lbs. of water; and with a pressure of 8.68 lbs. the equivalent of a 20 ft. lift. Next one pound of water is forced into the barrel, against

a pressure of 50.6 lbs. per sq. inch.
The work thus done is, —
$50.6 \times 144 \times .016 = 116.58$ ft. lbs., which
is shown by the area BCEL.
The water in going from the
calorimeter to the barrel is heated from 61° F to 160.9 F. To do
this a certain number of thermal units were given to it,
represented by $(h_0 - h_2)$, where h_0
is the number of thermal units
required to heat the water from
32° to 160.9 and h_2 is the same
from 32° to 61°. Substituting
for h_2 and h_0 their values we
have $129.3 - 29 = 100.3$ as the heat
given to a pound of water, but
as only .902 lbs. is heated, we
would have $.902 \times 100.3 = 90.47$

thermal units or 69842.84 ft. lbs.
This work would be represented by the area LFHK if LH were made equal to 4850197.
Now by adding together these three areas, we obtain the work that must be done on every pound of water coming to the barrel. This amount is 69977.46 ft. lbs.
But for every pound of water put into the barrel, as we have before seen .098 lbs. of steam was used. The heat contained in one pound of steam is as we have previously shown equivalent to 805365.4 ft. lbs.
Now the steam in passing through the injector goes through

a very small orifice by which its velocity is enormously increased and in consequence of which it obtains a very great vis viva; in passing through this orifice a certain amount of heat, due to friction is produced, but as the orifice is surrounded by the inflowing water, this heat is finally given up to the water, and hence all the energy stored up in the steam in the boiler is finally given up to the water either as heat or as motion. The amount of heat expended in producing .098 pounds of steam is equivalent to 78925.8 ft. lbs. So we may take the efficiency that is obtained, by the steam, in passing through the injector and forcing and heating the water, as the result obtained by dividing 69977.46 by 78925.8 which gives as a result .886 or an efficiency of about 89%.

The efficiency as obtained above may be expressed by the following formula for any case.

$$E = \frac{(1-x)l + .016P_1 + (h_0 - h_2)(1-x)}{x\left[P(v-s) + L - P(v-s) + h_1 - h_0\right]}$$

or reducing

$$E = \frac{(1-x)(l + h_0 - h_2) + .016P_1}{x\left[L + h_1 - h_0\right]}$$

$$= \frac{\text{Work expended on each lb. of water put into the boiler}}{\text{Heat required to evaporate } x \text{ lbs. of water from } t_0 \text{ at } t_1 \text{ in ft. lbs.}}$$

In the above formulae —

x = number of lbs. of steam used to put one pound of water into the boiler.

l = the lift in feet.

.016 = volume in cu. ft of 1 lb. of water.

P = pressure per sq. ft. of steam as it enters the inspirator.

P_1 = pressure per sq. ft. in the boiler against which the water is forced.

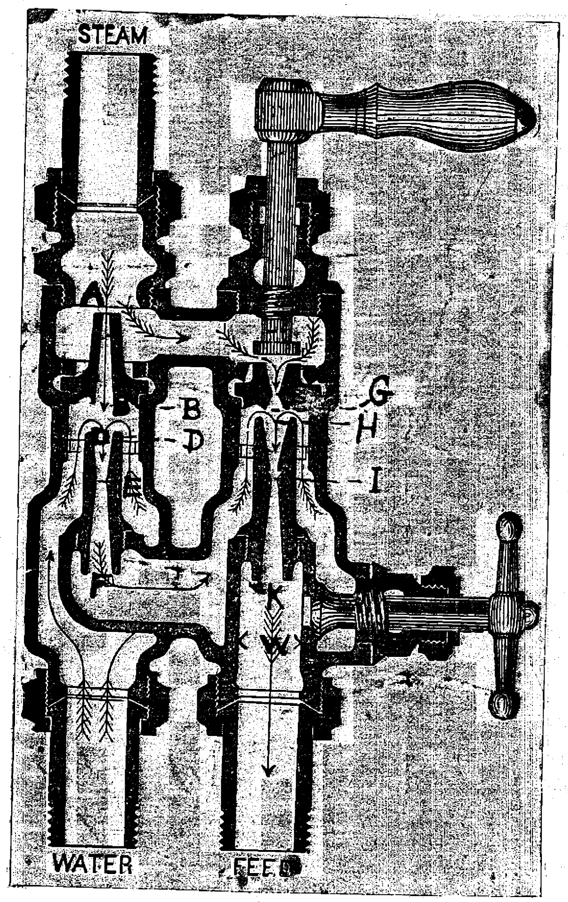
h_0 = equivalent in ft. lbs. of the number of thermal units required to raise 1 lb. of water from 32° F. to the temperature of the feed water.

h_1 = the same from 32° to the temperature of the steam used.

h_2 = the same from 32° to the temperature of the supply water.
v = volume of 1 lb of steam at the pressure P.
L = the latent heat of steam expressed in ft. lbs., at the pressure P.
s = volume of one pound of water in cu. ft.

Another mode of calculating the efficiency, would be to neglect the heating of the water and to only consider the action as a pump. In this case the formula would be; —

$$E = \frac{(1-x)\ l + .016\ P_1}{x\ [L + h_1 - h_0]}$$



Section.

Let us next discuss the whole action of the inspirator, from a theoretical standpoint.

We will deal with a certain amount of steam – x – which is necessary to force one pound of water into the boiler, and we will suppose that $\frac{1}{y}$ of this steam enters at A (shown in the section).

The amount $\frac{x}{y}$ of steam, as it passes from B, to the space BD, has we will say a velocity – v – and hence its vis viva is equivalent to $\frac{x\,v^2}{2gy}$, besides this there is in the steam a certain amount of internal work, which is expressed by –

$$(h_{P_{11}} + I)\frac{x}{y}$$

where $h_{P_{11}}$ is the value of h, as before defined, correspond-ing to the value P_{11} of the pressure of the jet as it issues from B; and

$$I = [L_{11} - P_{11}(v_{11} - s)] \text{ in ft. lbs.}$$

where L_{11} and v_{11} are the la-tent heat and volume of steam at the pressure P_{11}.

The total heat equivalent in ft. lbs. in the steam of the jet B is –

$$\frac{x\,v^2}{2gy} + [h_{P_{11}} + L_{11} - P_{11}(v_{11} - s)]\frac{x}{y} \quad (1.)$$

The steam in issuing from B meets with water which con-tains h_2 ft. lbs. equivalent of heat, but at the same time the steam condenses, and in so doing the amount of heat $P_{\prime\prime}(\bar{v}_{\prime\prime}-S)$ corresponding to the work of condensation, is added to the internal heat of the steam, so that the stream of condensed steam and water as it passes into D has a work equivalent of —

$$\frac{x\,v^2}{2gy} + \left[h_{P_{\prime\prime}} + L_{\prime\prime}\right]\frac{x}{y} + (1-x)\,h_2, \quad (2.)$$

now the water is forced through the tube DEF. Let V represent its velocity as it makes its exit from F, then its vis viva is

$$\left(1 - x + \frac{x}{y}\right)\frac{V^2}{2g}.$$

Its internal heat we will call h_t or the number of thermal units reduced to ft. lbs, necessary to heat water from 32° F to $t_1°$ the temperature of the mixture; hence the work equivalent at F

is $\left(1 - x + \frac{x}{y}\right)\left[\frac{V^2}{2g} + h_t\right]$ (3.)

After reaching F the mixture passes to the space GH, where it meets $\left(x - \frac{x}{y}\right)$ lbs. of steam which has a vis viva as it issues from G equal to

$\left(x - \frac{x}{y}\right)\frac{v_1^2}{2g}$ where v_1 = the velocity of the jet from G. The internal heat of the steam is $\left[h_{P_{III}} + L_{III} - P_{III}(\bar{v}_{III} - s)\right]\left(x - \frac{x}{y}\right)$ where L_{III}, $\bar{v}_{III}$ and $h_{P_{III}}$ correspond to the pressure P_{III} in the space GH. So this steam has a work equivalent of

$$\left(x - \frac{x}{y}\right)\frac{v_1^2}{2g} + \left[h_{P_{III}} + L_{III} - P_{III}(\bar{v}_{III} - s)\right]\left(x - \frac{x}{y}\right) \quad (4.)$$

This steam mixes with the water and condenses as before and the resulting mixture contains the equivalent of

$$\left(1-x+\frac{x}{y}\right)\left[\frac{V^2}{2g}+h_t\right]+\left(x-\frac{x}{y}\right)\frac{v_1^2}{2g}+\left(h_{p_{III}}+L_{III}\right)\left(x-\frac{x}{y}\right) \quad (5.)$$

or as equation (3) = equation (2) when we assume no losses by radiation, (5.) becomes, —

$$\frac{x\,v^2}{2g\,y}+\left[h_{p_{II}}+L_{II}\right]\frac{x}{y}+h_2(1-x)+\left(x-\frac{x}{y}\right)\frac{v_1^2}{2g}+\left[h_{p_{III}}+L_{III}\right]\left(x-\frac{x}{y}\right) \quad (5_1)$$

This mixture is now forced through H I K. When the water passes through I, call its velocity V_1, then its vis viva is $\frac{V_1^2}{2g}$, as there is now just 1 lb. of the mixture. If we let h_i represent the internal heat in ft. lbs, the mixture at I has a work equivalent of

$$\frac{V_1^2}{2g}+h_i \quad (6)$$

The water passes along the tube I K which gradually enlarges and finally empties into W, hence calling its velocity at W equal to V_{ii}, its vis viva must be $\frac{V_{ii}^2}{2g}$ which will force the water against a corresponding boiler pressure, but as the internal heat is, say h_w the water as it leaves the inspirator, should, if there were no losses have an energy whose work equivalent is—

$$\frac{V_{ii}^2}{2g} + h_w \qquad (7)$$

In the action of the machine it is evident that the energy of the mixture at D and F as shown by expressions (2) and (3) are equal and also the energy at H, K and W as shown by (5), (6) and (7).

The mixture as it leaves the inspirator will have a vis viva equal to the sum of the vis viva at B, and of that at G, of the steam, or

$$\frac{x v^2}{2gy} + \left(x - \frac{x}{y}\right)\frac{v_1^2}{2g} \qquad (8.)$$

In consequence of this vis viva the water will overcome a certain corresponding pressure in the boiler.

The velocity at any point which may be required may be found easily when the size of the orifice is known by dividing the quantity of liquid passing through in a second, by the section of the orifice.

The quantity passing through is easily found when we know x, y, and the total number of pounds of water and steam used in a given time.

We can find the velocity of the stream at any point, in still another manner.

Let u be that velocity i.e. the velocity of the water and steam mixed.

Let M = mass of water.

let m = mass of steam.

let v = velocity of steam.

then $\frac{u}{v} = \frac{m}{m+M}$, or $u = \frac{mv}{m+M}$

now substituting the values for m_1 and M_1 namely $\frac{x}{y}$ and $(1-x)$ we obtain —

$$u = \frac{\frac{x}{y}}{1-x+\frac{x}{y}} v. \text{ hence}$$

taking the case at B and D as the mixture enters D its velocity is as just shown and its vis viva is expressed by.

$$\frac{W u^2}{2g} = \frac{\left(1-x+\frac{x}{y}\right)\left(\frac{x}{y}\right)^2 v^2}{\left(1-x+\frac{x}{y}\right)^2 2g} = \frac{\left(\frac{x}{y}\right)^2 v^2}{\left(1-x+\frac{x}{y}\right)2g} \quad (9.)$$

which is also its vis viva till it meets the other jet of steam. This jet imparts an additional vis viva which may be obtained easily as the mass of the steam is $(x - \frac{x}{y})$ and its velocity is v_1, hence the vis viva of this steam is

$$\frac{W v_1^2}{2g} = \frac{\left(x - \frac{x}{y}\right) v_1^2}{2g} \quad (10.)$$

The total vis viva imparted to the water is the sum of (9.) and (10) or

$$\frac{v^2\left(\frac{x}{y}\right)^2}{2g\left(1-x+\frac{x}{y}\right)} + \frac{v_1^2\left(x-\frac{x}{y}\right)}{2g} \qquad (11.)$$

as it is just one pound of water, which has this vis viva, the expression (11.) must be the exact equivalent of the pressure which the water can overcome. This value may be substituted for $\frac{V_{11}^2}{2g}$ in (7.)

The heat that should be in the water may be found by subtracting (11) from (5) or

$$h_w = \frac{x\,v^2}{2gy} + \left(h_{P_{11}} + L_{11}\right)\frac{x}{y} + h_2(1-x) + \left(x-\frac{x}{y}\right)\frac{v_1^2}{2g}$$

$$+ \left(h_{P_{111}} + L_{111}\right)\left(x-\frac{x}{y}\right) - \frac{v^2\left(\frac{x}{y}\right)^2}{2g\left(1-x+\frac{x}{y}\right)} - \frac{v_1^2\left(x-\frac{x}{y}\right)}{2g} \qquad (12.)$$

we may substitute (11) and (12)

Equation 12 may be further reduced, viz -

$$h_w = \frac{x v^2}{2gy} + \left(h_{P_{II}} + L_{II}\right)\frac{x}{y} + h_2(1-x) + \left(x - \frac{x}{y}\right)\frac{v_1^2}{2g}$$

$$+ \left(h_{P_{III}} + L_{III}\right)\left(x - \frac{x}{y}\right) - \frac{v^2\left(\frac{x}{y}\right)^2}{2g\left(1-x+\frac{x}{y}\right)} - \frac{v_1^2\left(x-\frac{x}{y}\right)}{2g}$$

$$= \left[\frac{v^2}{2g} - \frac{v^2\left(\frac{x}{y}\right)}{2g\left(1-x+\frac{x}{y}\right)} + h_{P_{II}} + L_{II}\right]\frac{x}{y} + \left(x - \frac{x}{y}\right)\left(h_{P_{III}} + L_{III}\right) + h_2(1-x)$$

$$= \left[\frac{v^2}{2g}\left(\frac{(1-x)\,y}{y - xy + x}\right) + h_{P_{II}} + L_{II}\right]\frac{x}{y} + \left(x - \frac{x}{y}\right)\left(h_{P_{III}} + L_{III}\right) + h_2(1-x)$$

in (7) and we will have a resulting expression which will give the exact state of the water on leaving the inspirator both as to velocity or vis viva and as to heat contained, when the apparatus is perfect. By a similar discussion the necessary values for V and $V_{\prime}$ in (3) and (6) can be obtained.

The only unknown terms in (11.) and (12.) are $v_{\prime\prime}$, v, $v_{\prime}$, y, $P_{\prime\prime}$ and $P_{\prime\prime\prime}$. These can be found from laws deduced from experiments on the flow of steam and by experiments with the inspirator. So we may state if necessary the precise condition of the fluid at any point of

the inspirator.
From the point of view of this discussion, if in some way radiation were prevented there might be 100% efficiency realized; as the loss by radiation appears to be the only cause for a lower efficiency. This point might be made the subject of a series of quite interesting experiments.

Experiments.

Apparatus.

The apparatus used in the experiments is the same or very similar to that used by Mr. Schwamb. The differences are as follows; — There is no gauge connected with the pipe joining the lifter and forcer in the place of gauge No 2 of Mr. S's. A vacuum gauge to be tested by the mercury column is used instead of the small mercury column used by Mr. S. to show the lift. All the gauges are smaller than those used by Mr. S. and they are only graduated

to denote pressures divisible by five.
The water after passing through the injector goes through a 3/4" pipe and then a 1/2" pipe into a barrel placed on platform scales. This barrel has a short piece of 3/4" pipe screwed into it at about two inches from the bottom; the pipe has a valve on one end which opens just over a wooden spout connected with the sink, in this way the barrel can be emptied at the close of an experiment.
Before commencing the experiments all the thermometers and gauges with the exception of the vacuum gauge

were tested. The results and the curves of error may be found at the end of this paper.

Mode of conducting the experiments.

In making an experiment the apparatus was first started and allowed to run directly into the barrel, the valve at the bottom being open, thus allowing the water to pass into the sink, after starting, the conditions were brought the same that they were wished in the experiment, and the inspirator was allowed to run under these conditions for

five minutes.
Now knowing the weight of the barrel and what little water was in it the scales were set about ten pounds higher and the valve at the bottom of the barrel closed. When the water just balanced the reading of the scales, the time was taken to within two seconds and at the same time the weight of the calorimeter was taken and also the reading of the gauges and thermometers; the gauge readings were kept as nearly constant as possible; when the barrel was nearly full the valve from the calorimeter

which was open only part of a turn, was closed, and also the steam supply valve, the time being carefully noted. The weights of the barrel and calorimeter were then taken and then all the data were known. I should have mentioned that the gauge and thermometer readings were taken twice during every five minutes.

In the experiments made, the lift has been varied, the two pressures being kept as nearly at 30 lbs as possible.

Results.

In the results of the experiments as seen at the end of the paper, the values of $(v-s)$, $h_2, h,$ and h_0 and L, are taken from Cotterill's "Steam Engine considered as a Heat Engine."

The reading given by gauge #1 gives the lift in inches of mercury. Owing to lack of time this gauge was not accurately tested and so some of the calculations intended were not made.

Gauge #2 gives the pressure of the steam used, and gauge #3 the pressure against which the water is forced.

The numbers in red are the corrected average results.

The objection has been raised against using a vacuum gauge or mercury column to show the lift, that on account of the velocity of the water passing through the pipe the gauge or column would not show the true lift and hence it does not give the inspirator a fair test. That the reading of the gauge does not show the true lift is very probably true but if the circumstances are examined it will be seen that the effect of the velocity of the water is to make a vacuum gauge read more and hence credit the inspirator

with a greater lift than it really has.
Thus it is evident that the test, favors the instrument rather than opposes it.

In commencing this paper I had planned a number of sets of experiments, without entering upon the theoretical discussion. But as the theoretical part required so long a study of the action of the inspirator, I am obliged to leave what I have begun, in an unfinished state, at least, unfinished when compared with what I had planned.

Test of Gauges No's. 157 and 158 — No. 1.

No. of Obs.	Reading of M. Col. (Inches)	Temp.	Reading of M. Col. (Pounds)	Gauge No 157	Error of No. 157	Gauge No. 158	Error of No. 158	Remarks
								March. 18. 1879
1	0	71°	0	0	0.	0	0	
2	7.3		3.57	5	1.4	3.5	-.1	
3	19.3		9.45	10	0.5	9.5	.0	
4	29.3		14.34	15	0.7	14.5	.2	
5	38.9		18.99	20	1.0	19.5	.5	
6	49.4		24.16	24.5	0.3	24.5	.3	
7	61.1		29.88	30	0.1	29.8	-.1	
8	71.4		34.87	35	0.1	34.8	-.1	
9	81.9		40.08	40	-.1	39.8	-.3	
10	92.3		45.17	45	-.2	44.8	-.4	
11	101.5		49.67	50	0.3	49.8	.1	
12	112.5		54.06	55	0.9	54.8	.7	
13	122.4		59.88	60	0.1	59.5	-.4	
14	132.7		64.92	65	0.1	64.	-.9	Not plotted on the curve.
15	143.0	80.3 top	69.96	70	0.0	69.	-1.0	
16	153.2	71 bot.	74.95	75	0.0	74.	-1.0	
17	163.2		79.82	80	0.2	79.	-.8	

Test of Gauges No's 157 and 158. No. 2.

No. of Obs.	Reading of M. Col. (Inches)	Temp.	Reading of M. Col. (Pounds)	Gauge No. 157	Error of No. 157	Gauge No. 158	Error of No. 158	Remarks
1	164.	81.5 top 71.0 bot.	80.21	80.	-.2	79.75	-.4	March 18, 1879
2	153.9	80.5 71.0	75.25	75.	-.3	74.5	-.8	Not plotted on the curve
3	143.3		70.07	70.	-.1	69.8	-.3	
4				65.		64.5		no readings
5	122.2		59.75	60.	.2	59.8	.0	
6	112.2	80.5 71.5	54.87	55.	.1	54.5	-.4	
7	101.4	80.0 72.0	49.59	50.	.4	49.25	-.3	
8	92.+		44.99	45	.0	44.8	-.2	doubtful.
9	80.9		39.57	40.	.4	39.8	.2	
10	71.3		34.87	35	.1	34.8	-.1	
11	61.9	72.3	30.28	30	-.3	29.8	-.5	
12	51.0	72.5	24.94	25	.1	25.0	.1	
13	40.0		19.58	20	.4	19.75	.2	
14	30.8		15.07	15	-.1	14.75	-.3	
15	19.9	72.5	9.74	10	.3	9.75	.0	
16	8.0	72.7	3.92	5	1.1	3.5	-.4	
17	3.1	73.0	1.52	2	.5	0.0	-1.5	
18	0.1		.05	0	-.1	0.0	-.1	

Test of Gauges No's 157 and 158 — No. 1.

No. of Obs.	Reading of M. Col. (Inches)	Temp.	Reading of M. Col. (Pounds)	Gauge No. 157	Error of No. 157	Gauge No. 158	Error of No. 158	Remarks
1	0.	71.5	0.	0	0	0	0	March 20. 1879
2	7.1	72.0	3.48	5	1.5	3.50	0	
3	19.3		9.45	10	.5	9.50	0	
4	29.4		14.39	15	.6	14.50	.1	
5	39.5		19.33	20	.7	19.75	.4	
6	51.3		25.09	25	-.1	25.00	-.1	
7	61.2		29.93	30	.1	29.75	-.2	
8	71.7		35.07	35	-.1	35.00	-.1	
9	81.2	72.0	39.71	40	.3	40.00	.3	
10	91.9	80. top 73. bot	44.94	45	.1	44.75	-.2	
11	101.4		49.59	50	.4	49.25	-.3	
12	112.5		55.01	55	.0	54.50	-.5	
13	122.6	81.0 73.0	59.95	60	.0	59.50	-5	

Test of Gauges No's 157 and 158 — No. 2.

No. of Obs.	Reading of M. Col. Inches	Temp.	Reading of M. Col. (Pounds)	Gauge No. 157	Error of No. 157	Gauge No. 158	Error of No. 158	Remarks
1	122.8	81. top 73 bot.	60.04	60	0	59.50	-.5	March 20. 1879
2	112.5		55.01	55	0	54.75	-.2	
3	101.3		49.54	50	.5	49.50	0	
4	92.2	82.0 73.0	45.09	45	-.1	44.75	-.3	
5	81.9		40.05	40	-.1	39.25	-.8	
6	71.3		34.87	35	.1	34.75	-.1	
7	61.5		30.08	30	-.1	30.00	-.1	
8	51.5		25.19	25	-.2	25.00	-.2	
9	40.5		19.82	20	.2	20.00	.2	
10	30.5	73.0	14.93	15	.1	15.00	.1	
11	19.7	74.0	9.64	10	.4	9.75	.1	
12	8.3		4.06	5	.9	4.00	-.1	
13	3.6		1.76	2.5	.7	0	-1.8	
14	0.1	74.0	.05	0	-.1	0	-.1	

Expt. No. 1

Obs.	Time	Wt. Cal'r	Wt. Bbl.	Gauges 1	Gauges 2	Gauges 3	Temp. 1	Temp. 2	Remarks
	h m s						74	75	
1	4-20-0	7358	65	-2	49.5	53	72	143	
2	4-22-30			-2	51.0	50	72	144	
3	4-25-0			-2	51.0	50	72	144	
4	4-28-0			-2	51.0	50	72	144	
5	4-29-0	7035	416	-2	51.0	50	72	144	
	Diff 9m	diff 323	diff 351	-2	50.7	50.6	72	143.8	Average
	9m	323	351		50.4	50.8	70.8	141.9	Corrected

Expt. No. 2

Obs.	Time	Wt. Cal'r	Wt. Bbl.	Gauges 1	Gauges 2	Gauges 3	Temp. 1	Temp. 2	Remarks
	m s								
1	47-45	7368.5	115	-4	30.	30.	71	134	
2	50-0			-4	30.5	30.5	71	134	
3	52-30			-4	30.	30.	71	134	
4	55-0			-4	30.	30.	70.5	134	
5	57-20	7096.0	410.5	-4	30.	30	70.5	134	
	Diff 9-35	diff 272.5	diff 295.5	-4	30.1	30.1	70.8	134	Average
	9-35	272.5	295.5		30.1	30.25	69.6	132.	Corrected

Expt. No. 3.

Obs.	Time	Wt. Calr.	Wt. Bbl.	Gauges 1	Gauges 2	Gauges 3	Temp. 1	Temp. 2	Remarks.
	m s								
1	15-13	6820	110	-6	30	30	71	134	
2	17-30			-6	30	30	71	133.5	
3	20-0			-6	30	30	71	133.5	
4	22-30			-6	30	30	71	133.5	
5	25-0			-6	30	30	71	133.5	
6	25-55	6545	406	-6	30	30	71	133.5	
	diff 10-42	diff 275	diff 296	-6	30	30	71	133.6	Average
	10-42	275	296		30	30.15	69.8	131.6	Corrected

Expt. No. 4.

Obs.	Time	Wt. Calr.	Wt. Bbl.	Gauges 1	Gauges 2	Gauges 3	Temp. 1	Temp. 2	Remarks.
	m s								
1	33-5	7450	110.	-8	30	30	70	133.5	
2	35-0			-8	30	30	70	133.	
3	37-30			-8	30	30	70	133.	
4	40-0			-8	30	30	70	133.	
5	47-47	7176	411.5	-8	30	30	70	133.	
	diff. 14-42	diff 274	diff 301.5	-8	30	30	70	133.1	Average
	14=42	274	301.5		30	30.15	68.8	131.1	Corrected

Expt. No. 7/5

No.	Time	Wt. Calr.	Wt. Bbl.	Gauges 1	2	3	Temp. 1	2	Remarks.
	m s								
1	1 - 38	6884	110	-10	30	30	70	133	
2	2 - 30			-10	30	30	70	133	
3	5 - 0			-10	30	30	70	133	
4	7 - 30			-10	30	30	70	133	
5	10 - 0			-10	30	30	70	133	
6	10 - 23	6601.8	412	-10	30	30	70	133	
	diff. 8 - 45	diff. 282.2	diff. 302	-10	30	30	70	133	Average
	8 - 45	282.2	302		30	30.15	68.8	131	Corrected

Expt. No. 6.

No.	Time	Wt. Calr.	Wt. Bbl.	Gauges 1	2	3	Temp. 1	2	Remarks.
1	24 - 18	6401.8	110	-12	30	30	70	133	
2	27 - 30			-12	30	30	70	133	
3	30 - 0			-12	30	30	70	133	Barrel ran over a little; allowed 1 lb.
4	32 - 30			-12	30	30	70	133.25	
5	34 - 25	6113.5	417	-12	30	30	70	133	
	diff 10 - 7	diff. 288.3	diff. 307	-12	30	30	70	133	Average
	10 - 7	288.3	308		30	30.15	68.8	131	Corrected

Expt. No. 7.

Nos.	Time	Wt. Calr.	Wt. Bbl.	Gauges 1	Gauges 2	Gauges 3	Temp. 1	Temp. 2	Remarks
	h 10 m 52 - s 50	5841.5	110	-14	30	30	70	133.5	
	55 - 0			-14	30	30	70	133.5	
	57 - 30			-14	30	30	70	133.5	
	60 - 0			-14	30	30	70	133.5	
	11 1 - 25	5567.5	405	-14	30	30	70	133.5	
	diff. 8 - 35	diff. 274.0	diff. 295	-14	30	30	70	133.5	Average
	8 - 35	274.	295		30	30.15	68.8	131.5	Corrected

Expt. No. 8.

Nos.	Time	Wt. Calr.	Wt. Bbl.	Gauges 1	Gauges 2	Gauges 3	Temp. 1	Temp. 2	Remarks
1	2 52 - 35	7672.5	110	-16	30	30	68	132.5	
2	55 - 0			-16	30	30	66	132.	
3	57 - 30			-16	30	30	66	131.5	
4	60 - 0			-16	30	30	66	131.	Barrel ran over a little about a pound and a half.
5	3. 2 - 30			-16	30	30	66	130.5	
6	3 - 45	7387.	416.5	-16	30	30	66	130.5	
	diff. 11 - 10	diff. 285.5	diff. 316.5	-16	30	30	66.3	131.3	Average
	11 - 10	285.5	316.5		30	30.15	65.1	129.3	Corrected

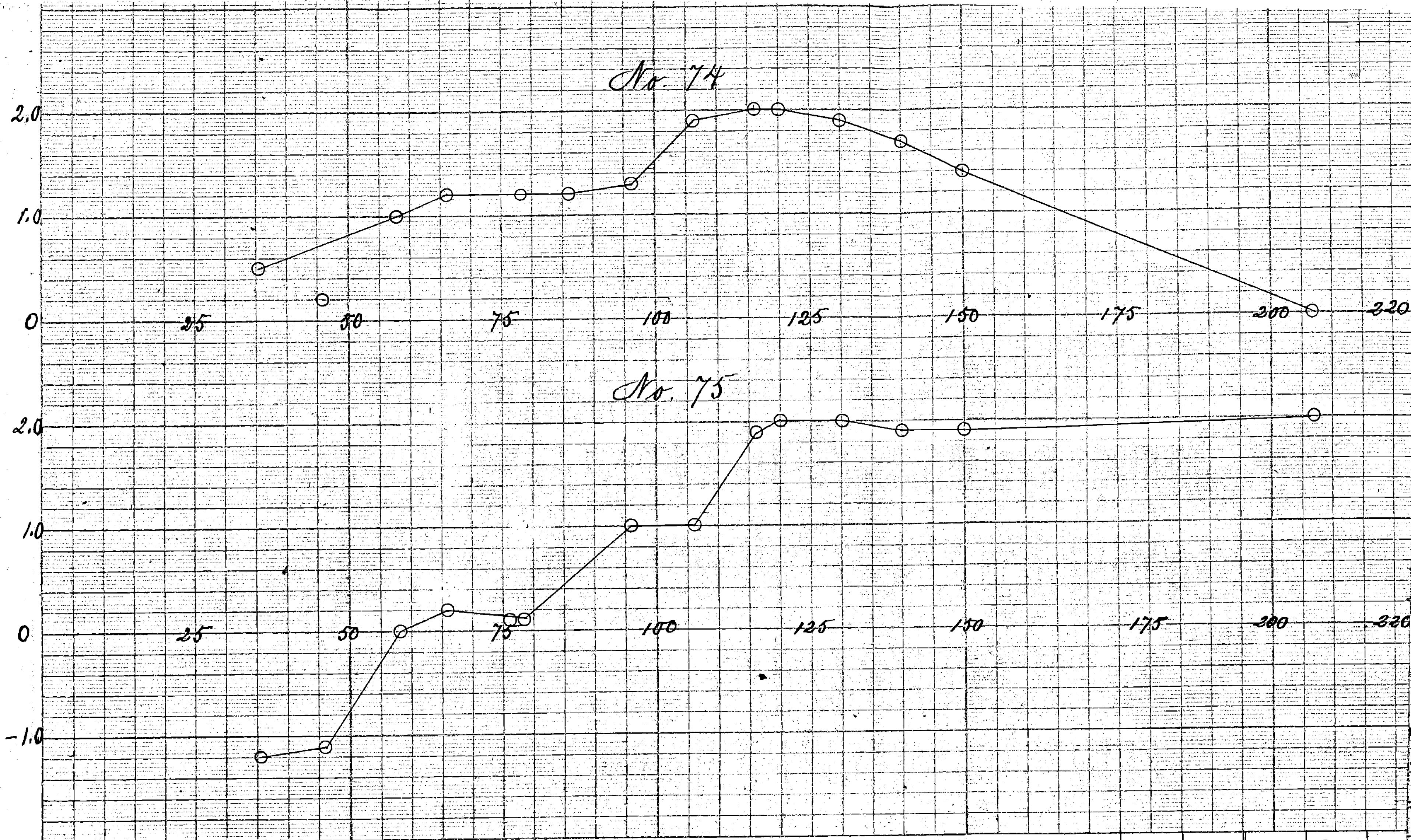
Expt. No. 9

No.	Time	Wt. Calr.	Wt. Bbl.	Gauges 1	Gauges 2	Gauges 3	Temp. 1	Temp. 2	Remarks
	3. m. s.								
1	47-56	7127	110	-20	30	30	63	147	
2	50-0			-20	30	30	63.5	148	
3	52-30			-20	30	30	64	149.5	
4	55-0			-20	30	30	64	148	
5	57-30			-20	30	30	64	148	
6	60-0			-20	30	30	64.5	148.5	
7	4 1-25	6867.8	402.5	-20	30	30	64.5	148.5	
	diff. 13-29	diff 259.2	diff. 292.5	-20	30	30	63.9	148.2	Average.
	13-29	259.2	292.5		30	30.15	62.8	146.3	Corrected

Expt. No. 10.

No.	Time	Wt. Calr.	Wt. Bbl.	Gauges 1	Gauges 2	Gauges 3	Temp. 1	Temp. 2	Remarks
1	15-55	6589.3	110	-16	30	30	65.5	130	
2	17-30			-16	30	30	65.5	129	
3	20-0			-16	30	30	65.5	129	
4	22-30			-16	30	30	65.5	129	
5	25-0			-16	30	30	65.5	129	
6	25-25	6318	404	-16	30	30	65.5	129	
	diff. 9-30	diff. 271.3	diff. 294	-16	30	30	65.5	129.1	Average
	9-30	271.3	294		30	30.15	64.3	127.1	Corrected

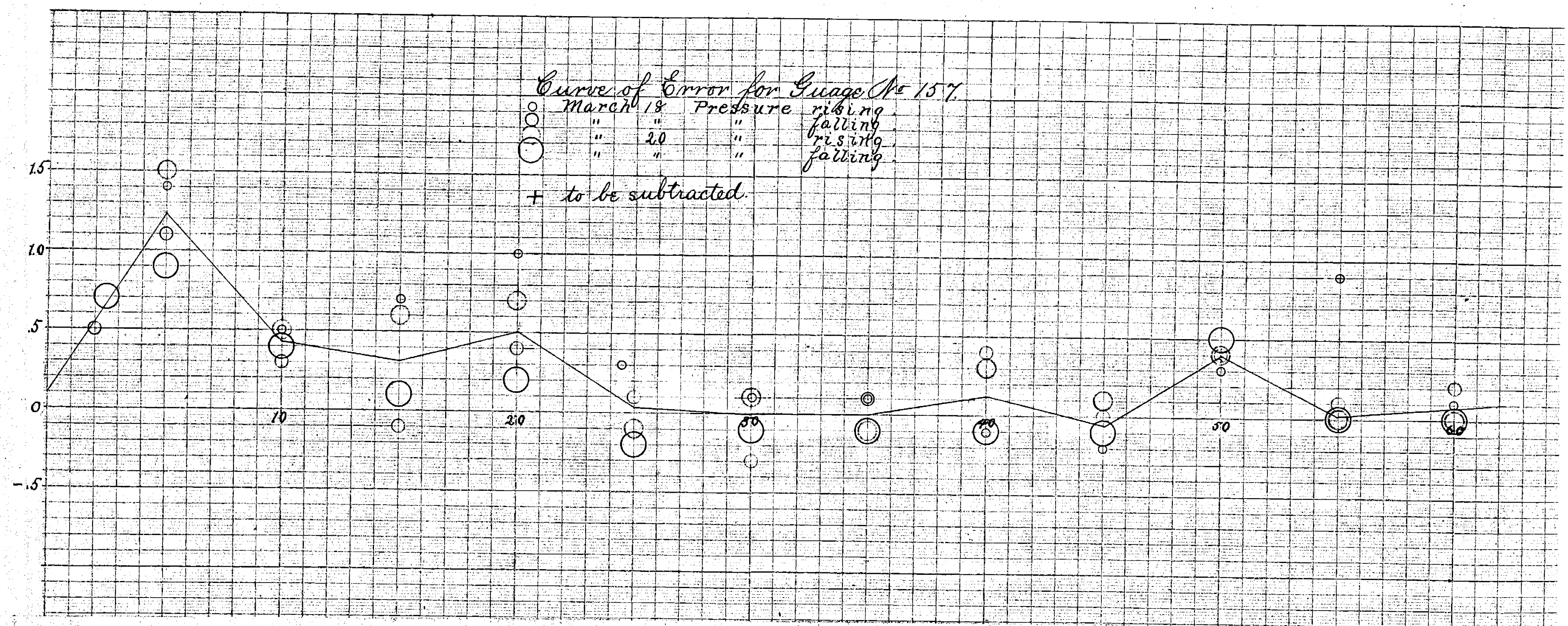
Expt.	Duration in minutes and Seconds (m s)	Dif. of Wts Cal'r.	Dif. of Wts. Bbl.	Steam used.	Steam used per lb. of water put in Bbl = x.	Gauges: Lift (inches mercury) 1	Gauges: $\frac{P}{144}$ 2	Gauges: $\frac{P}{144}$ 3	Lift in feet.	(v − s) for pressure P.	Temp. 1	Temp. 2	Difference	h_2	h_1	h_0	$h_1 - h_0$	$h_0 - h_2$	Latent heat of steam at pressure P.	Efficiency by formula Page 15.	Efficiency as a pump only by formula Page 17.
1	9-0	323.0	351.0	28.0	.079	2	50.4	50.8	2.26	7.817	70.8	141.9	71.1	38.33	251.17	110.16	141.01	71.83	918.0		
2	9-35	272.5	295.5	23.0	.077	4	30.1	30.25	4.52	13.44	69.6	132.0	62.4	37.62	219.5	100.00	119.5	62.38	938.3	.709	
3	10-42	275.0	296.0	21.0	.070	6	30.0	30.15	6.78	13.47	69.8	131.6	61.8	37.82	219.5	99.8	119.7	61.88	938.3		
4	14-42	274.0	301.5	27.5	.091	8	30.0	30.15	9.04	13.47	68.8	131.1	62.3	36.82	219.5	99.3	120.2	62.48	938.3		
5	8-45	282.2	302.0	19.8	.065	10	30.0	30.15	11.30	13.47	68.8	131.0	62.2	36.82	219.5	99.2	120.3	62.38	938.3	.847	
6	10-7	288.3	308.0	19.7	.064	12	30.0	30.15	13.56	13.47	68.8	131.0	62.2	36.82	219.5	99.2	120.3	62.38	938.3	.862	
7	8-35	274.0	295.0	21.0	.071	14	30.0	30.15	15.82	13.47	68.8	131.5	62.7	36.82	219.5	99.7	119.8	62.88	938.3		
8	11-10	285.5	316.5	31.0	.098	16	30.0	30.15	18.08	13.47	65.1	129.3	64.2	33.12	219.5	99.0	120.5	57.38	938.3		
9	13-29	259.2	292.5	33.3	.114	20	30.0	30.15	22.60	13.47	62.8	146.3	83.5	30.81	219.5	114.2	105.3	83.39	938.3	.622	
10	9-30	271.3	294.0	22.7	.077	16	30.0	30.15	18.08	13.47	64.3	127.1	62.8	32.32	219.5	95.3	124.2	62.98	938.3		



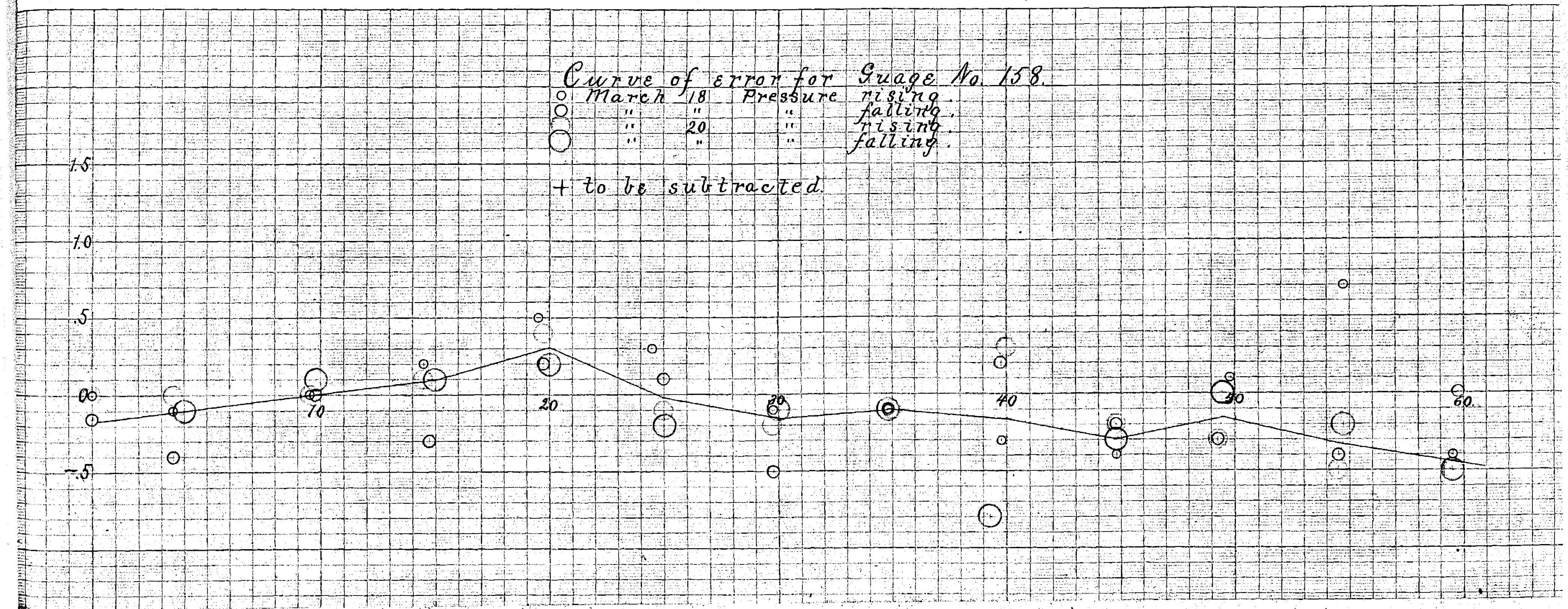
Temp.	Error No. 73	Temp.	Error No. 73
35.6	+ .5	120.0	+2.0
46.0	.2	130.0	1.9
58.0	1.0	140.0	1.7
66.0	1.2	150.0	1.4
78.0	1.2	212.0	0
86.0	1.2		
96.0	1.3		
106.0	1.9		
116.0	2.0		

Curve of error of Thermometers
Nos 74 & 75

Temp.	Error No. 74	Temp.	Error No. 74
35.6	-1.2	120.0	+2.0
46.0	-1.1	130.0	2.0
58.0	.0	140.0	1.9
66.0	+ .2	150.0	1.9
78.0	.1	212.0	2.0
86.0	.2		
96.0	1.0		
106.0	1.0		
116.0	1.9		



Curve of Error for Guage No 157.
March 18 Pressure rising.
" " " falling.
" 20 " rising.
" " " falling.
+ to be subtracted.
1.5
1.0
.5
0
-.5
10
20
30
40
50
60


Curve of error for Guage No. 158.
March 18 Pressure rising.
" " " falling.
" 20 " rising.
" " " falling.
+ to be subtracted.
1.5
1.0
.5
0.0
-.5
10
20
30
40
50
60.