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VALMORE L. STEWARD

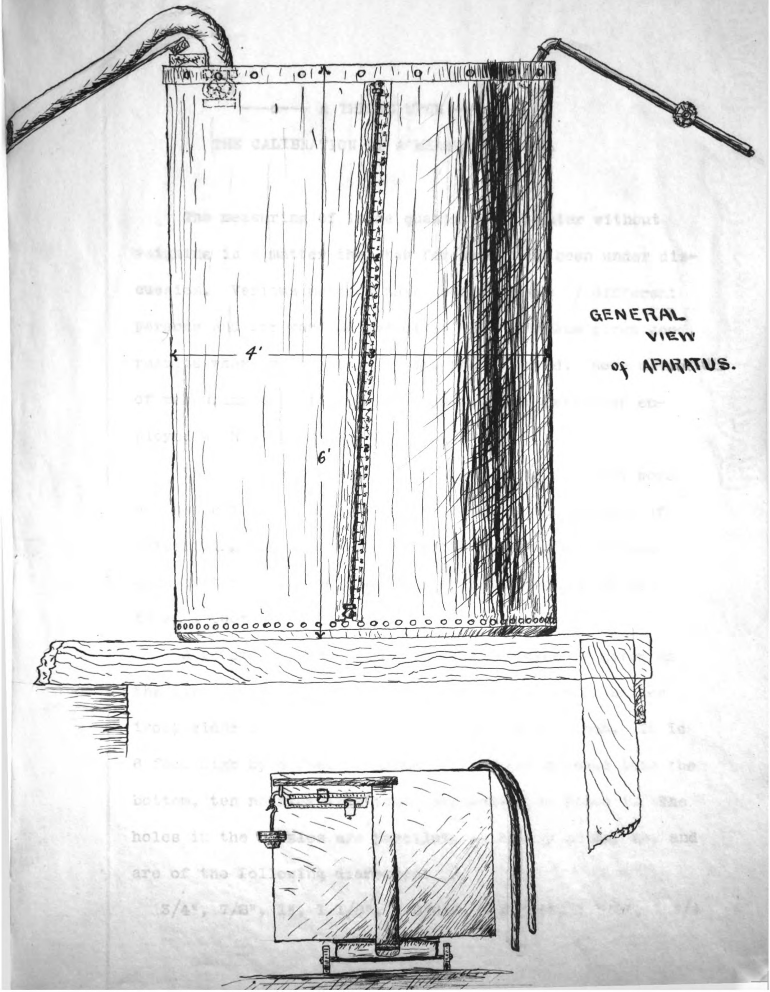
A THESIS

UPON

THE CALIBRATION OF A MEASURING TANK

BY

V. L. STEWARD. 1893



GENERAL VIEW of APARATUS.

---o--- A THESIS UPON ---o---

THE CALIBRATION OF A MEASURING TANK.

The measuring of large quantities of water without weighing is a matter that has for some time been under discussion. Various methods have been employed by different persons and for various purposes. The weir has given good results where great accuracy was not required. Some methods of measuring by discharge through orifices have been employed with varying success.

The experiments upon which this thesis is based were of the last type, and were carried on for the purpose of determining the amount of water that would flow through each of ten different sized orifices under any head between 1 foot and 5 1/2 feet.

A general view of the apparatus employed is given on the first page. The tank there represented is of boiler iron; sides 1/4 inch in thickness, bottom 3/8 inch. It is 6 feet high by 4 feet in diameter, and has screwed into the bottom, ten nozzles like that represented in Plate I. The holes in the nozzles are parallel, as nearly as may be, and are of the following diameters:

3/4", 7/8", 1", 1 1/8", 1 9/64", 1 31/64", 1 5/8", 1 3/4

and 1 7/8". On the side of the tank is a glass guage running the whole height of the tank by means of which the head of water in the tank may be read. The whole thing is elevated upon a platform sufficiently high to allow a pair of scales and a small tank to be placed underneath it. During the experimenting the holes in the bottom were stopped with wooden plugs which could be drawn out from beneath the platform. The water for conducting the experiment was conveyed to the tank from a fire hydrant through several lengths of fire hose. A valve was placed in the end of the hose by means of which the water flowing into the tank could be regulated to any desired amount up to the capacity of the hose (2 1/2 in.) under about 30 pounds pressure. An iron pipe 1 1/4 inches in diameter also brought water to the tank under the same pressure, but this was found sufficient only for experimenting with the smaller holes and at the lower heads. The method of conducting the experiments was somewhat as follows: Water was run into the tank until the glass guage showed some desired head. The plug was then drawn from the hole to be tested and the water allowed to flow off through a piece of tin pipe to a drain. The water flowing into the tank was then regulated so as to keep the required head constant; that is having arrived at the desired head the same amount of water was allowed to flow into as flowed out of the tank. When this had been regulated so that the level of the water was constant at the head desired the scales below were balanced up with this small tank upon them, and 600# of extra weight put upon the scale beam. A stop-watch in hand the stream of water from the large tank was turned into the small tank and at the same instant the watch set in motion. The watch was stopped just at the time when the water in the sm ll tank balanced the 600# of extra weight on the scale beam. The time registered by the watch would then be the time required for 600# of water to flow through the orifice at the head at which it was tested.

In this way each orifice was carefully tested at four different heads. The direct results of these experiments are given in Table I. - to get the results into more convenient form for comparison the amount of flow of water per second was computed and arranged to make Table II. - To further assist in comparisons and deductions the theoretical discharge was calculated from $V = \sqrt{2 GH}$ (in which V is the velocity of flow in feet per second, G is the acceleration of gravity in feet per second, and H is the head in feet,) and the ratio of the actual discharge to the theoretical discharge obtained. These results were compiled in Table III.

How to apply these results so as to find the amount of flow through a hole for any head between those for which it is tested, we employ a graphical method. We refer the four results obtained from each orifice to a system of coordinates in which the head of water is the ordinate, and the amount of water flowing through the orifice is the abcissa It is evident that the resulting curve will theoretically be a parobala from $V^2 = 2 G H$, since the amount of water flowing through the orifice is proportional to the velocity of the stream. The actual curve approaches somewhat closely to the parabola. The graphical representation of flow for all the holes are shown in Plate III. The only curve there represented that does not pass through the points found by actual experiments is the one for the 7/8 " hole. This curve is drawn in red ink and the points as found by experiments are marked by a small circle of red ink surrounding them.

Let us see what deductions may be made from an examination and comparison of the tables and plotted curves. In the first place we observe that except in one or two cases the results show a very fair degree of uniformity: which would seem to indicate a corresponding accuracy in the experimentation and in the results obtained. The orifice showing the most marked variations is the 7/8 inch one previously mentioned.

A little later we will notice some of the things that seem to enter in to effect the results obtained. Perhaps one of the first things we would notice from the study of the tables is the fact that most of the orifices give a nearly constant ratio for the theoretical and actual discharge. The same thing is seen in the near approach of the curve to the parabola. There may at first thought be some question about the curve being a parabola even with the ratio of actual discharge to theoretical discharge constant, unless the ratio be unity. Let us see, we may represent the theoretical flow by $V^2 = 2\ G\ H$, or $V = \sqrt{2\ G\ H}$. Suppose such conditions entering into that V', the actual flow $= K\ V$. Then $K\ V = \sqrt{2\ K^2\ G\ H}$ or $V' = \sqrt{2\ K^2\ G\ H}$ or $V'^2 = 2\ K^2\ G\ H$, which is still the equation of a parabola.In the most uniform results however this ratio is highest at the lowest head, and decreased slightly as the head increases, so that the actual curve is not actually a parabola, but approaches a direction parallel to the axis a little faster than the parabola would do.

Another fact that the tables seem to indicate is that the small holes give a greater ratio of actual to theoretical discharge than the larger holes do. This is just contrary to what might be expected. It would seem as though the smaller orifice would present more friction in proportion to the area of cross-section, and would thus cut down the actual flow in greater proportion. But this idea is not carried out by the results from experiments, and I am convinced that at least for these particular orifices and with the condition under which the tests were made the results obtained are practically correct.

With reference to the conditions that might enter into and alter the results obtained the two following seem to me to be the most potent. First the amount by which the axis of the orifice inclines from the vertical, and second the amount by which the axis of the orifice inclines from a prependicular to the bottom of the tank. The most uniform results will be obtained with the axis of the orifice verticle and also perpendicular to the bottom of the tank.

When in actual use the tank is to set in some permanent position where the water which flows through it can run directly into a drain. The holes are to be stopped by plugs like that represented in Plate II. to each plug will be attached a chain and ring which can be reached from the top of the tank. If we desire to measure the rate of flow of water from any source we may convey the water to the tank, draw out one of the plugs and let the water run until it maintains a constant head. Note this head and by the use of the curve plotted for the orifice the amount of water flowing through the tank per second may be determined.

Again, suppose we have a large quantity of water to measure. Let it be conducted to the tank in some way so that the rate at which it flows into the tank can be regulated by a valve or some other means. Fill the tank to any desired head from some other source. Now draw one of the plugs and at the same time open and regulate the valve allowing the water which it is desired to measure to flow into the tank sufficiently fast to maintain the head constant. Take the time required to run all of the water into the tank, multiply this time expressed in seconds by the rate of flow of the orifice employed at the head used and the result gives the amount of water.

Of course this last method is more or less inaccurate in starting and stopping, and should only be employed for large quantities of water, and where great accuracy is not required. By using considerable care, however, very good results may be obtained, and for the purpose of getting rates of flow I believe it will give even more accurate results than are ordinarly obtained by weighing, and with much less trouble and inconvenience.

-: TABLE I. :-

DIAMETER OF HOLE	HEAD.	TIME REQUIRED TO RUN 600#	
		Minutes.	Seconds.
I Inch.	1.4 feet	4	37
I "	2.8 "	3	25
I "	4.2 "	2	50
I "	5.4 "	2	29 1/2
I 3/4 "	1.4 "	I	33 3/4
I 3/4 "	2.7 "	I	09 1/2
I 3/4 "	4.3 "	0	55
I 3/4 "	5.3 "	0	49 1/2
3/4 "	I.4 "	6	16 1/2
3/4 "	2.8 "	4	29 3/4
3/4 "	4.2 "	3	43 1/2
3/4 "	5.4 "	3	17
I 9/64"	1.4 "	3	38 1/4
I 9/64"	2.8 "	2	34 3/4
I 9/64"	4.2 "	2	06 1/4
I 9/64"	5.4 "	I	51 1/2
I 7/8 "	1.4 "	I	27 3/4
I 7/8 "	2.8 "	0	60
I 7/8 "	4.2 "	0	48 1/4

-: TABLE I. :-

DIAMETER OF HOLE	HEAD.	TIME REQUIRED TO RUN 600#	
		Minites.	Seconds.
1 7/8 Inch	5.4 feet.	0	42 3/4
I 31/64 "	I.4 "	2	12 1/4
1 31/64 "	2.8 "	I	33 1/4
I 31/64 "	4.2 "	I	15 1/4
I 31/64 "	5.4 "	I	07 1/4
I I/8 "	I.4 "	3	48 1/2
I 1/8 "	2.8 "	2	43 I/4
I I/8 "	4.2 "	2	14 1/2
I I/8 "	5.0 "	2	02 3/4
7/8 "	1.4 "	6	00 1/4
7/8 "	2.8 "	3	18 1/2
7/8 "	4.2 "	3	32 1/2
7/8 "	5.0 "	2	31
I 5/8 "	1.4 "	I	50 1/4
I 5/8 "	2.8 "	I	19
1 5/8 "	4.2 "	I	05 1/4
1 5/8 "	5.0 "	0	60

-: TABLE I. :-

DIAMETER OF HOLE.	HEAD.	TIME REQUIRED TO RUN 600 #	
		Minutes.	Seconds.
1 23/64 Inch	1.4 feet.	2	35 1/2
I 23/64 "	2.8 "	I	5I
I 23/64 "	4.2 "	I	31 3/4
I 23/64 "	5.0 "	I	24 1/2

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-: TABLE II. :-

DIAMETER OF HOLE.	HEAD.	POUNDS RUN PER SECOND.
I Inch.	1.4 FEET.	2.116
I "	2.8 "	2.927
I "	4.2 "	3.529
I "	5.4 "	4.019
I 3/4 "	1.4 "	6.400
I 3/4 "	2.7 "	8.633
I 3/4 "	4.3 "	10.909
I 3/4 "	5.3 "	12.121
3/4 "	1.4 "	I.594
3/4 "	2.8 "	2.224
3/4 "	4.2 "	2.684
3/4 "	5.4 "	3.046
1 9/64"	1.4 "	2.749
I 9/64"	2.8 "	3.877
I 9/64"	4.2 "	4.752
I 9/64"	5.4 "	5.381
1 7/8 "	1.4 "	6.838
I 7/8 "	2.8 "	10.000
I 7/8 "	4.2 "	12.435

-: TABLE II. :-

DIAMETER OF HOLE.	HEAD.	POUNDS RUN PER SECOND.
I 7/8 Inch.	5.4 feet.	13.956
I 31/64 "	1.4 "	4.536
I 31/64 "	2.8 "	6.434
I 31/64 "	4.2 "	7.973
I 31/64 "	5.4 "	8.922
I 1/8 "	1.4 "	2.626
I 1/8 "	2.8 "	3.676
1 1/8 "	4.2 "	4.461
I I/8 "	5.0 "	4.888
7/8 "	1.4 "	I.665
7/8 "	2.8 "	2 ~~1~~.022
7/8 "	4.2 "	2.823
7/8 "	5.0 "	3.974
I 5/8 "	I.4 "	5.442
I 5/8 "	2.8 "	7.595
I 5/8 "	4.2 "	9.195
I 5/8 "	5.0 "	10.000
I 23/64 "	1.4 "	3.858
I 23/64 "	2.8 "	5.405
1 23/64 "	4.2 "	6.540
I 23/64 "	5.0 "	7.100

-: TABLE III. :-

DIAMETER.OF HOLE.		Head.		RATIO OF ACTUAL DISCHARGE TO THEORETICAL DISCHARGE.
I	Inch.	1.4	feet.	2.17 ÷ 3.19 = .68
I	"	2.8	"	2.93 ÷ 4.5I " .65
I	"	4.2	"	3.53 ÷ 5.96 " .592
I	"	5.4	"	4.02 ÷ 6.32 " .636
I 3/4	"	1.4	"	6.4 ÷ 9.87 " .648
I 3/4	"	2.7	"	8.63 ÷13.7 " .63
I 3/4	"	4.3	"	10.91 ÷17.29 " .632
I 3/4	"	5.3	"	12.12 ÷19.2 " .631
3/4	"	1.4	"	1.59 ÷ 1.81 " .878
3/4	"	2.8	"	2.22 ÷ 2.56 " .867
3/4	"	4.2	"	2.68 ÷ 3.13 " .856
3/4	"	5.4	"	3.05 ÷ 3.55 " .858
I 9/64	"	1.4	"	2.75 ÷ 4.19 " .656
I 9/65	"	2.8	"	3.88÷ 5.92 " .655
I 9/64	"	4.2	"	4.75 ÷ 7.26 " .654
1 9/64	"	5.4	"	5.38 ÷ 8.23 " .654
I 7/8	"	1.4	"	6.84 ÷11.33 " .604
1 7/8	"	2.8	"	1o.00 ÷16.02 " .624
I 7/8	"	4.2	"	12.44 ÷19.62 " .634
I 7/8	"	5.4	"	13.96 ÷22.25 " .627

-: TABLE III. :-

DIAMETER OF HOLE.	HEAD.	RATIO OF ACTUAL DISCHARGE TO THEORETICAL DISCHARGE.
I 31/64 Inch	1.4 FEET.	4.54 ÷ 7.1 = .639
I 31/64 "	2.8 "	6.43 ÷ 10.04 " .64
I 31/64 "	4.2 "	7.97 ÷ 12.3 " .645
I 31/64 "	5.4 "	8.92 ÷ 13.94 " .64
I 1/8 "	1.4 "	2.63 ÷ 4.07 " .646
I 1/8 "	2.8 "	3,68 ÷ 5.76 " .639
I 1/8 "	4.2 "	4.46 ÷ 7.05 " .633
I 1/8 "	5.0 "	4.89 ÷ 7.69 " .636
7/8 "	1.4 "	1.67 ÷ 2.46 " .679
7/8 "	2.8 "	3.02 ÷ 3.48 " .868
7/8 "	4.2 "	2.82 ÷ 4.26 " .662
7/8 "	5.0 "	3.97 ÷ 4.65 " .854
I 5/8 "	1.4 "	5.44 ÷ 8.5 " .64
I 5/8 "	2.8 "	7.6 ÷ 12.02 " .632
I 5/8 "	4.2 "	9.2 ÷ 14.72 " .625
I 5/8 "	5.0 "	10.00 ÷ 16.06 " .623
I 23/64 "	1.4 "	3.86 ÷ 5.95 " .649
L 23/64 "	2.8 "	5.4I ÷ 8.41 " .643
I 23/64 "	4.2 "	6.54 ÷ 10.3I " .634
I 23/64 "	5.0 "	7.1 ÷ 11.25 " .63I

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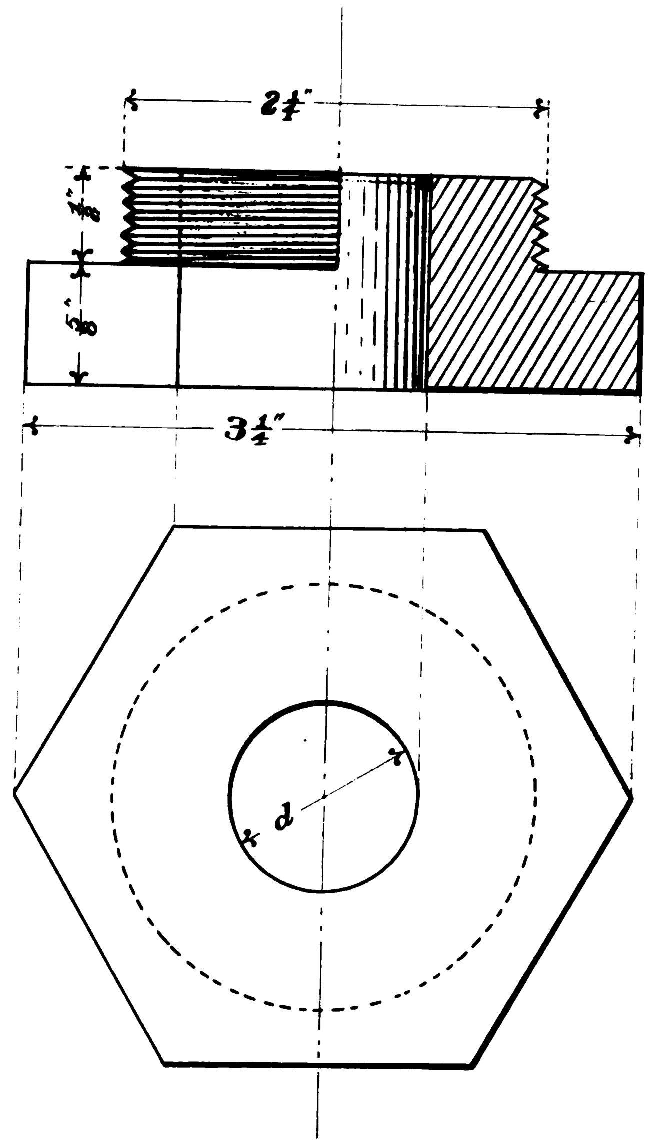
PLATE I.

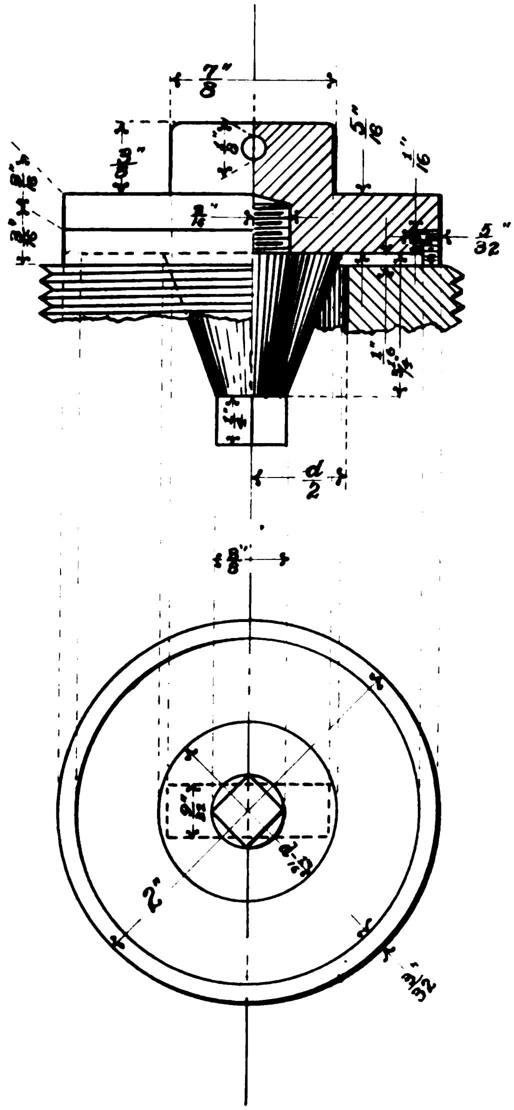


NOZZLE for ORIFICES.

d Varies for the Different Nozzles According to the Orifice Desired.

Full Scale.

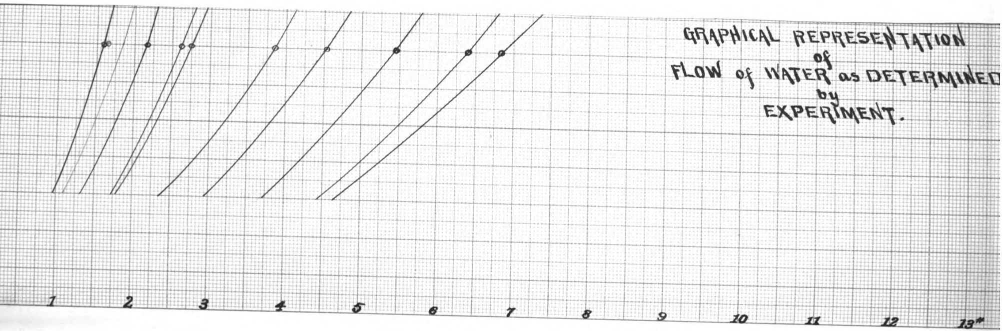
PLATE III.



PLUG for NOZZLES.

d Varies as in Plate I.

Full Scale.


GRAPHICAL REPRESENTATION
of
FLOW of WATER as DETERMINED
by
EXPERIMENT.
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2
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13"