

servatives that were commercially used were injurious to health or not, and the value of Dr. Leffmann's researches was readily shown by the fact that, as a result of these, the State of Pennsylvania had prohibited the use of salicylic acid as a preservative, and had permitted the use of sodium benzoate.

Dr. Leffmann's researches were in accord with others that had been made, particularly in reference to the action of salicylic acid on the digestive processes.

There was little doubt to-day that the use of salicylic acid as a preservative should be condemned; for the reason given by Dr. Leffmann sodium benzoate would be more allowable.

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## COMMITTEE ON SCIENCE AND THE ARTS.

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### THE VENTURI METER.

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*Being the report of the Franklin Institute, through its Committee on Science and the Arts, on the inventions of Clemens Herschel, Frederick N. Connet and Walter W. Jackson.*

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HALL OF THE FRANKLIN INSTITUTE,  
[No. 1,868.] PHILADELPHIA, May 4, 1898.

The Franklin Institute of the State of Pennsylvania, for the Promotion of the Mechanic Arts, acting through its Committee on Science and the Arts, investigating the merits of the "Venturi Meter," reports as follows:

The Venturi Meter is designed for the measurement of the flow of liquids in pipes of dimensions so great that the use of meters of the ordinary types, with movable parts, is impracticable.

The complete device consists of two distinct and widely different instruments, viz.: (1) the "Venturi," or meter proper, or meter tube, and (2) the registering apparatus.

The first part, *i. e.*, the meter proper, patented by Clemens Herschel, of Holyoke, Mass., April 17, 1888, No. 381,373, consists essentially of a mere constriction in the area of

cross-section of the pipe, the flow in which is to be measured, with openings in the pipe opposite its normal and its constricted diameters, for measuring, by piezometers or pressure gauges, the pressures at those points; while the second part, *i. e.*, the register, patented by Messrs. Frederick N. Connet and Walter W. Jackson, of Providence, R. I., November 20, 1894, No. 529,365, consists of an elaborate mechanism, provided with clock-work and dials, by means of which the difference in pressure between the constricted and the normal sections of the Venturi tube is registered, at short intervals of time and in terms of the total discharge up to the termination of such intervals.

#### THEORY.

In the following statement of the theory of the Venturi meter, we shall, for convenience, assume that the water is a "perfect fluid," *i. e.*, a fluid free from viscosity and friction, although possessing mass (or inertia) and weight. (See Address to the Mechanical Section of the British Association, by William Froude, Esq., President, August 25, 1875.) This assumption will facilitate the exposition of the theory by eliminating from its discussion considerations not essential to its understanding; and the slight effects produced in the Venturi meter by such viscosity and friction as do exist in the water, will afterward be discussed in the proper place.

Let *Figs. 1 to 5* represent a Venturi meter tube, each with three piezometers in place, viz.: No. 1, over the tube up-stream from the constriction; No. 2, over the constriction itself; and No. 3, over the tube down-stream from the constriction. Let the unshaded area *W* in *Figs. 1 to 4*, represent the depths at which the water stands above any assumed horizontal datum plane *O-O*; and let the shaded area *A* represent the uniform pressure of the atmosphere, which, for convenience, we may suppose to be converted into some liquid of the specific gravity of water, but distinguishable, by its appearance, from the water.

The vertical distance, between the upper boundary of this latter area and any given point in the tube, represents the combined pressure of air and water at such point.

In *Fig. 1*, the water is at rest, and the tops of the water columns stand at one and the same level throughout, as do, also, the tops of the air columns; while, in *Figs. 2 to 5*, the water is in motion, as indicated by the arrows.

Now, if the tube were of uniform cross-section throughout, and if, as we assume, the water were a "perfect fluid" (*i. e.*, devoid of friction), the tops of the several columns, in *Figs. 2 to 5*, where the water is in motion, would still stand at the same level *with each other*, though at a lower

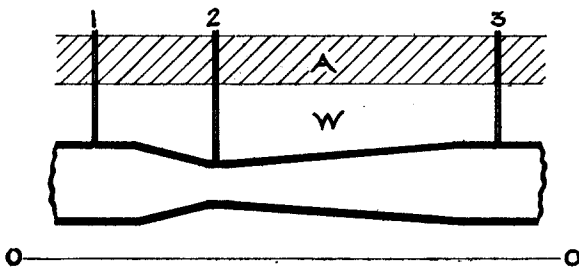


FIG. 1.

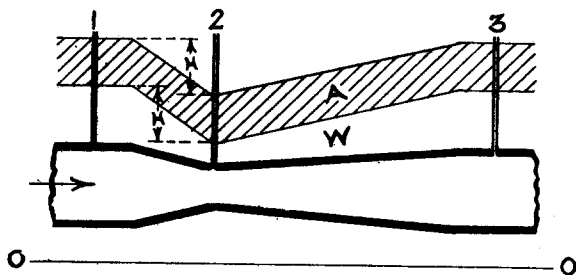


FIG. 2.

one than before, owing to the consumption of a portion of the head in generating the velocity.

But, owing to the differences in the areas of cross-section of the pipe at the several portions of its length, the velocities vary, being necessarily inversely as the areas; and, as the heads corresponding to the several velocities are proportional to the squares of those velocities, the remaining or pressure heads must vary also, the smallest or lowest

pressure head standing over the throat, where the velocity is greatest.

The increase of velocity, acquired by the fluid in passing from section 1 to section 2, is again given up in passing from section 2 to section 3; and in the case of a perfect fluid, the pressure lost between sections 1 and 2 would be perfectly restored in passing from section 2 to section 3. In practice, a small total loss occurs. This will be discussed in connection with the practical operation of the meters.

For a given head in piezometer No. 1 and given diameter of pipe at section 1, the expenditure of head in velocity between sections 1 and 2 increases as the area of the throat is diminished and as the throat velocity is thereby increased.

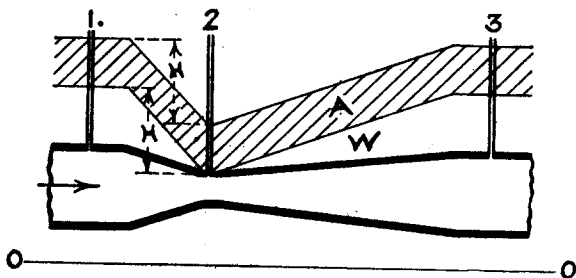


FIG. 3.

In *Fig. 3* is shown the case where all of the water head above the top of the throat is required to maintain the velocity through the throat.

In *Figs. 2* and *3* the head,  $H$ , expended in the increase of velocity between sections 1 and 2 is represented by the difference in level between the tops of the two water columns 1 and 2, or between the tops of the two corresponding air columns. In *Fig. 3* this difference is equal to the *total vertical height* of the water column at section 1 above the top of the throat at section 2.

If now (*Fig. 4*) the throat section be still further reduced (the other conditions remaining as before), the throat velocity will thereby be still further increased; for the *total pressure* available for increase of velocity between sections

1 and 2 consists not merely in the depth of *water* above the tube, but also in the *atmospheric pressure*, represented by the shaded area *A* above the water *W*.

In *Fig. 4* all the water has disappeared from piezometer 2, and even a portion of the liquid representing the air has also disappeared, leaving only a portion of the latter to represent such pressure as now remains in the throat. In other words, the pressure within the throat is now less than the atmospheric pressure. Hence, if an opening to the atmosphere were made in the throat, air would be drawn into the tube through such opening. The piezometer at section 2, however, excludes the atmosphere.

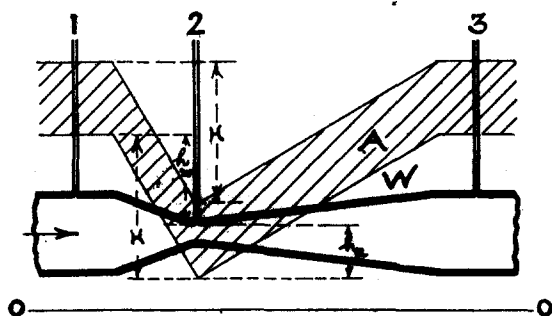


FIG. 4.

$$H = h_w + h_a$$

In *Fig. 4*, the loss of head, due to increase of velocity between sections 1 and 2, is  $H = h_w + h_a$  = the entire available head of water,  $h_w$ , plus a portion,  $h_a$ , of the atmospheric pressure. The latter portion,  $h_a$ , is frequently called "the vacuum."

The top of the water column having now disappeared below the top of the throat, it is no longer feasible to ascertain the loss of head by taking the difference between the levels of the water surfaces in piezometers 1 and 2. If the air were visible, and if it were practicable to use a piezometer extending above the upper surface of the atmosphere, or (as we have supposed) to replace the air by a heavier fluid, we could arrive at the loss of head by tak-

ing (as before) the difference between the levels of the air columns at sections 1 and 2. In practice, the degree of "vacuum" may be found, as shown in *Fig. 5*, by using, in place of the piezometers, a glass tube bent over and led *downward* into an open vessel containing water or mercury. The height to which the water (or the mercury converted into feet of water) rises in this tube, shows the extent of the vacuum, or the portion,  $h_w$ , of the air pressure which has been called into service in producing the high velocity through the throat. By adding this to  $h_w$ , we obtain, as above, the total loss of head  $H$  between sections 1 and 2.

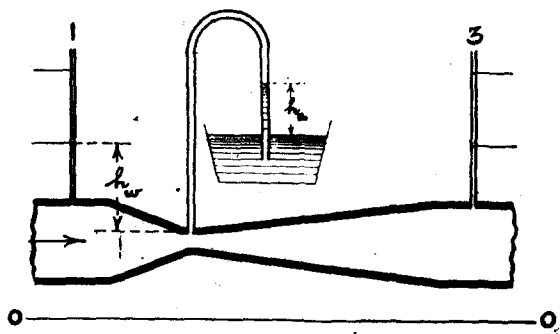


FIG. 5.

$$H = h_w + h_v$$

When the reduction of area at the throat has proceeded so far that the entire available pressure of water and air at section No. 1 is required, in order to maintain the corresponding velocity through the throat (*i. e.*, when the line representing the upper surface of the air falls to the level of the top of the throat), no further increase of throat velocity can be secured (with a given total head over section 1) by still further narrowing the throat. If the throat is further narrowed, the velocity through it will remain the same; and, the rate of discharge being thus diminished, the velocity through section 1 will be necessarily reduced. In other words, throttling begins.

Let  $v_1$  be the velocity in section 1, above the throat,  
VOL. CXLVII. No. 878.

and  $v_2$  the "throat velocity," or velocity in the throat or section 2.

Referring to *Fig. 6*, the velocity head at section 1 is

$$h_1 = \frac{v_1^2}{2g}$$

and the velocity head at section 2 is

$$h_2 = \frac{v_2^2}{2g}$$

Hence, the loss of head, between sections 1 and 2, or "the head on the Venturi," is

$$H = h_2 - h_1 = \frac{v_2^2}{2g} - \frac{v_1^2}{2g} = \frac{v_2^2 - v_1^2}{2g}$$

But, since the velocities are inversely as the areas of cross-section  $a_1$  and  $a_2$ ,

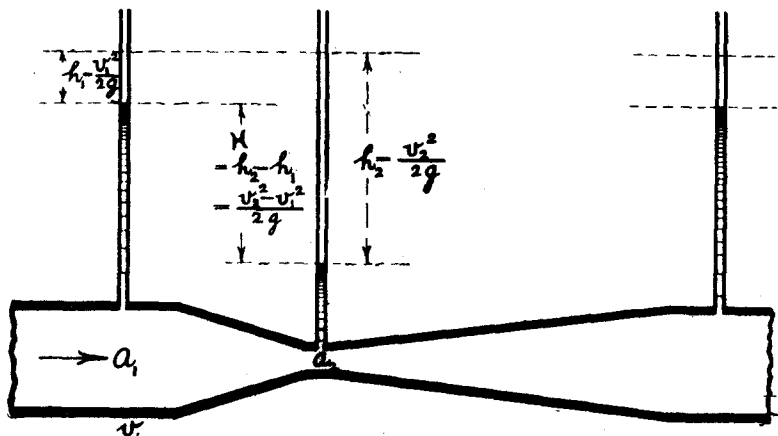


FIG. 6.

$$v_2 = \frac{a_1}{\sqrt{a_1^2 - a_2^2}} \sqrt{2gH}$$

$$v_1 = \frac{a_2}{a_1} v_2 \text{ and } v_1^2 = \frac{a_2^2}{a_1^2} v_2^2$$

Hence

$$H = \frac{v_2^2 - \frac{a_2^2}{a_1^2} v_2^2}{2g} = \frac{\left(1 - \frac{a_2^2}{a_1^2}\right) v_2^2}{2g} = \frac{\frac{a_1^2 - a_2^2}{a_1^2} v_2^2}{2g}$$

$$v_2^2 = \frac{2gh a_1^2}{a_1^2 - a_2^2}$$

and throat velocity =

$$v_2 = \frac{a_1}{\sqrt{a_1^2 - a_2^2}} \sqrt{2gH}$$

The ratio

$$\frac{a_2}{a_1}$$

between the area  $a_2$  of cross-section at the throat and that  $a_1$  at the upper end of the up-stream cone, is called the throat ratio. For a throat ratio of 1 : 9 we have

$$\frac{a_1}{\sqrt{a_1^2 - a_2^2}} = \frac{9}{\sqrt{9^2 - 1^2}} = \frac{9}{\sqrt{80}} = \sqrt{\frac{81}{80}} = 1.0062$$

or,

$$v_2 = 1.0062 \sqrt{2gH}$$

From the foregoing expression :

$$v_2^2 = \frac{2gH a_1^2}{a_1^2 - a_2^2} = 2gH \div \frac{a_1^2 - a_2^2}{a_1^2} = \frac{2gH}{1 - \frac{a_2^2}{a_1^2}}$$

we have

$$2gH = v_2^2 - \frac{a_2^2}{a_1^2} v_2^2$$

Hence,

$$v_2^2 = 2gH + \frac{a_2^2}{a_1^2} v_2^2$$

$$= 2gH + v_1^2$$

$$2g \left( H + \frac{v_1^2}{2g} \right)$$

and

$$v_2 = \sqrt{2g \left( H + \frac{v_1^2}{2g} \right)}$$

In other words, the velocity at the throat is that corresponding to the "head on the Venturi," plus the head corresponding to the velocity of approach in section 1.

#### THE VENTURI TUBE.

In practice, the Venturi tube, for pipes not over 60 inches in diameter, is formed of several short sections of cast iron



pipe, having the required taper, and furnished with flanges, by means of which the sections are bolted together to form

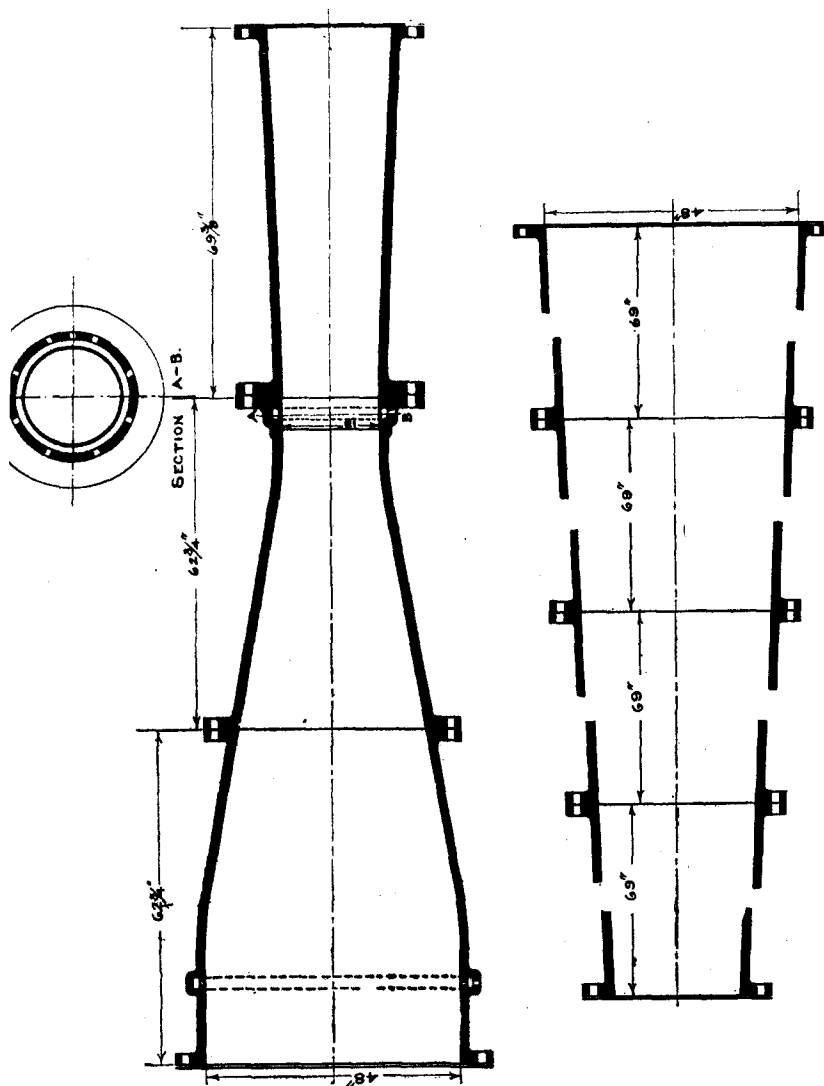


FIG. 7.—48-inch Venturi tube. Throat ratio, 1 : 7.

the two truncated cones required, as shown in *Figs. 7, 8* and *9*.

The throat section is generally made in a separate piece,

and is either made of bronze or lined with that metal. (See Fig. 7a.)

The ends of the Venturi tube are furnished with either bell, spigot or flanged ends, according to the character of the pipe in which the tube is to be used.

For still larger streams, such as those in masonry conduits or riveted flumes, the Venturi tube may be made of wooden staves, sheet steel, cement concrete, brick or other suitable material, metal being used for the throat piece and where required by the pressure.

The throat piece is surrounded by an annular chamber

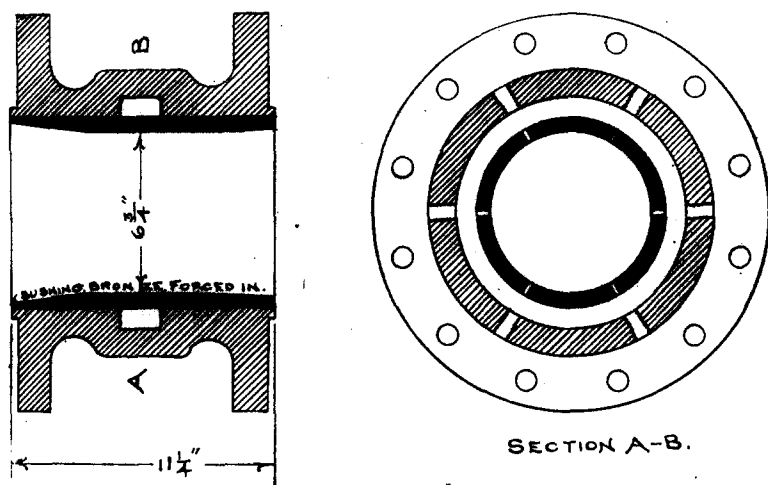


FIG. 7a.—Throat piece for 18-inch Venturi meter. Throat ratio, 1 : 7.

called the pressure chamber, which communicates with the interior of the throat by means of several holes drilled radially through the walls of the latter at equal or nearly equal distances around the circumference.

A similar pressure chamber is provided at the larger end of the short cone for observing the pressure in the normal section up-stream from the throat; and, if it is desired to ascertain the final loss of head due to the passage of the water through the Venturi, a similar chamber must be provided at the larger end of the longer or down-stream cone.

In designating the size of the meter, the diameter of the

pipe of which it forms a part is used, and not the throat diameter. Thus, a meter for use in a 6-inch pipe is called a 6-inch meter.

*Fig. 7* shows the construction of a 48-inch Venturi tube. Here the shorter cone, up-stream from the throat, is in two sections, and the longer one in five sections.

The cross-section shows a number of holes tapped radially through the outer wall of the pressure chamber. Of these, the one horizontally opposite the axis of the pipe is for tapping in the pressure tube connecting the throat with the register. The others are necessary for drilling holes connecting the pressure chamber with the throat.

In the smaller sizes, the shorter cone is generally in one section and the longer cone in two or more sections. (See

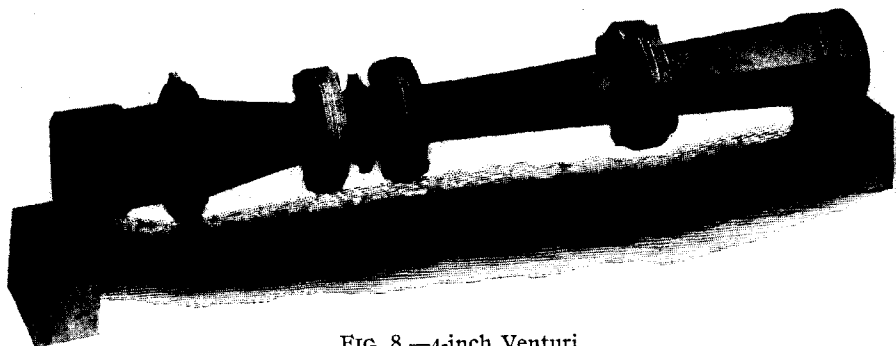


FIG. 8.—4-inch Venturi.

*Figs. 8 and 9*, showing photographic views of a 4-inch and a 60-inch meter, respectively.)

Mr. Herschel's original experiments were made at Holyoke, Mass., in June and October, 1887, with a 1-foot and a 9-foot Venturi meter. In both meters, the cones were formed of wooden staves, and the throat piece of cast iron, lined with brass.

#### THE REGISTER.

In the preceding discussion of the theory of the Venturi meter, we have, in order to facilitate the explanation, supposed the several pressures to be directly measured, as by piezometers or other suitable apparatus; and, indeed, this is sometimes done in practice, but such apparatus cannot

register the flow. Furthermore, the measurement of the head does not directly give the velocity or the discharge; and the reading of a mercury column, with its relatively small variations, is necessarily inaccurate, while the use of water piezometers would, in most cases, be impracticable, owing to their great length. Besides, the piezometers show only the pressures existing at the moment, and give no continuous or cumulative statement of the discharge.

The register devised by Messrs. Connet and Jackson, and about to be described, gives periodic registrations, in which the pressure existing at the instant of registry is recorded in terms of the total discharge in cubic feet since the last registry and as an increase in the total number of feet registered. In other words, it gives a cumulative registry of the discharge, like that of a gas meter.

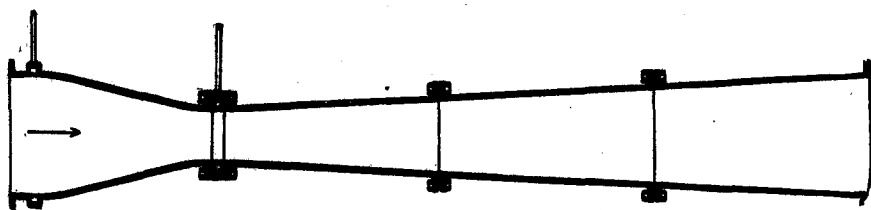


FIG. 8a.

*Fig. 10* represents the register, together with the connections between it and the meter tube. These connections consist of two brass, lead, lead-lined or tin-lined tubes, *U-U* and *T-T*, *U-U* leading from the wide upper section 1, and *T-T* from the throat or narrow section 2. *U-U* carries the higher pressure of the water from section 1 into a well, *W*, containing mercury. From this well rises an inner tube, or barrel, *B*, also containing mercury, and communicating, through a narrow passage at bottom, with the well. The lower pressure existing (during flow) at the throat, is carried by the tube, *T-T*, into the upper portion of the register, and acts upon the surface of the mercury in the tube, *B*, rising from the well.

Let  $m$  denote the inches in depth of mercury in the tube, *B*, above the surface of the mercury in the well, and  $w$  the

FIG. 9.—60-inch Venturi.

depth, in inches, of a mercury column equivalent, in pressure to a water column of depth  $m$ . Then  $m \cdot w = H$ , or the head on the Venturi, expressed in inches of mercury, and  $1.13 \cdot (m \cdot w) = H$  in feet of water.

We have now to describe the means by which this differ-

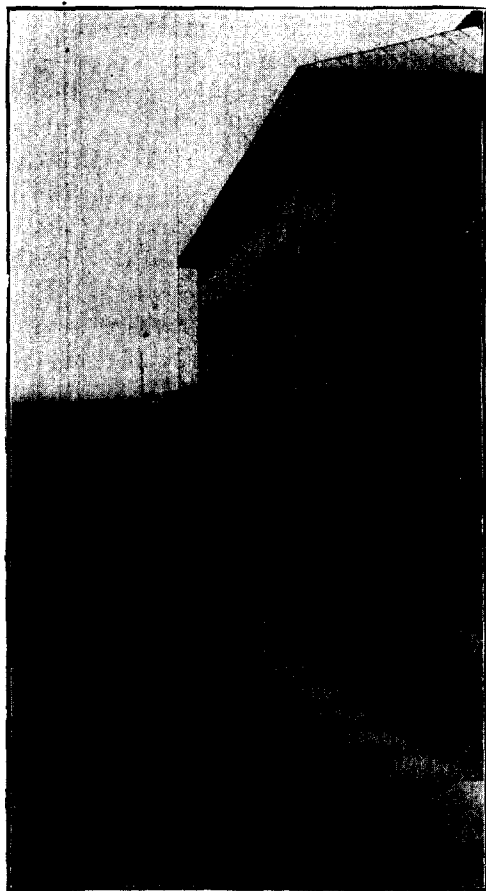


FIG. 9a.—60-inch tube at Ogden, Utah.

ence of pressure, which varies with the velocity, is made to record, periodically, the number of cubic feet which have passed through the Venturi tube.

Upon the surface of the mercury in the tube,  $B$ , rests a float,  $J$ , which carries, at its upper end,  $V$ , an idler wheel,

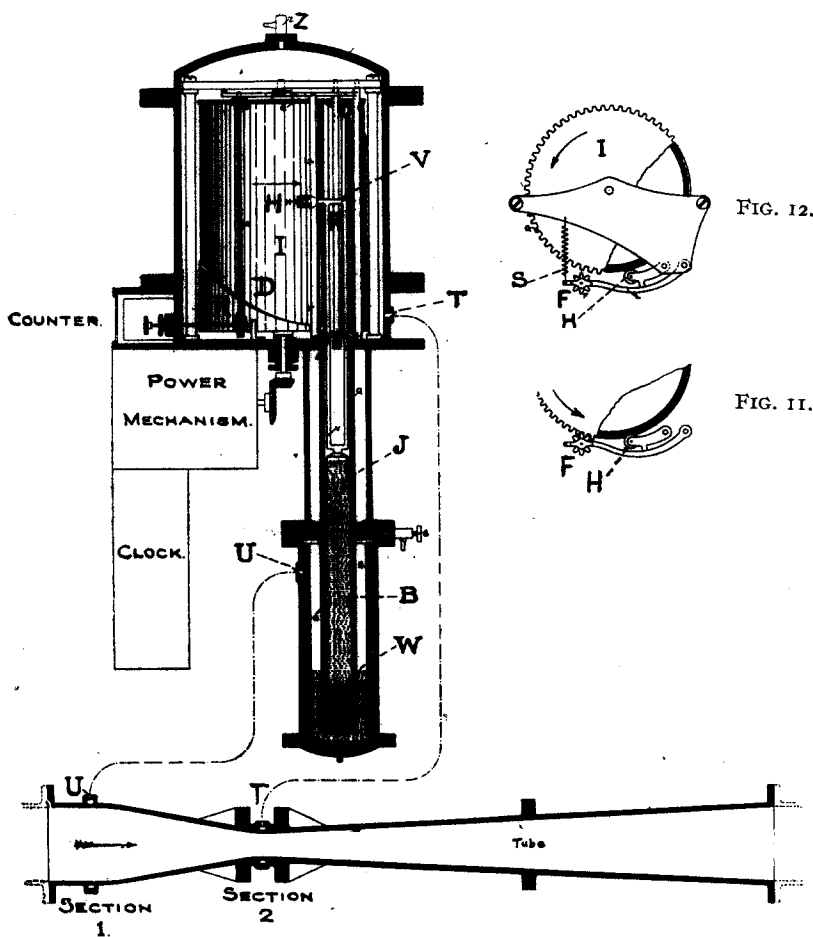
*H*, with vertical axle. From what has been said, it will be seen that this idler wheel rises as the velocity through the meter tube increases, and sinks as the velocity decreases. By means of the spring, *S* (*Fig. 12*), the idler wheel is held constantly in contact with the surface of the drum, *I*, which is periodically revolved about its vertical axis, by means of the power mechanism indicated in *Fig. 10*.

The cylindrical surface of this drum consists, in fact, of portions of *two* cylinders, an inner or depressed surface, *D*, and an outer or raised one, *R*, the raised surface, *R*, being about  $\frac{1}{8}$  inch farther from the axis than the depressed one, *D*. When the idler wheel rests against the *depressed* surface, *D*, as in *Fig. 11*, the drum is in gear with the pinion, *F*, by which its motion is transmitted to the counter shown in *Fig. 10*; but when the idler wheel rests against the *raised* cylindrical surface, *R*, as in *Fig. 12*, the drum and pinion are thrown out of gear, and the revolution of the drum is not recorded upon the counter.

The boundary between the two cylindrical surfaces, *R* and *D*, forming the drum (*Fig. 10*), is a spiral curve whose origin of co-ordinates is the position occupied by the idler wheel, *H*, when the drum is at rest and there is no flow in the meter tube, and when, consequently, the surfaces of the mercury in the tube, *B*, and in the well, *W*, are at the same level. The abscissas of the curve are the velocities of the water in the throat, and its ordinates are the corresponding heights to which the idler wheel rises above the origin or zero line. Inasmuch as the surface area of the mercury in the well, *W*, is double that in the tube, *B*, the ordinates are  $\frac{2}{3}$  of the corresponding heads, *H*, in inches of mercury. The values of these ordinates are calculated from the results of careful experiments with a 48-inch Venturi'meter.

Suppose the drum to be at rest, with the idler wheel, *H*, in the position shown in *Fig. 10*. As the idler wheel is resting against the depressed surface, *D*, of the drum, the drum and pinion are in gear. Now let the drum begin to revolve in the direction indicated by the arrow. The revolution of the drum will be recorded at the counter until the raised cylindrical surface, *R*, comes around to the idler

wheel, which then rides up upon it, throwing drum and pinion out of gear, and terminating the registration for that revolution. Plainly, the greater the velocity through the throat of the Venturi meter tube, and the higher the posi-



tion of the idler wheel, the longer time the drum and pinion will remain in gear during the revolution, and the greater will be the registration of discharge for that revolution.



For difference in size of the meter tube, a difference is made in the gearing between the integrating drum and the counter, the drum remaining the same for all sizes. Strictly speaking, therefore, the drum speaks to the gearing in terms of the head on the Venturi, or of the corresponding velocity, while the gearing (constructed according to the

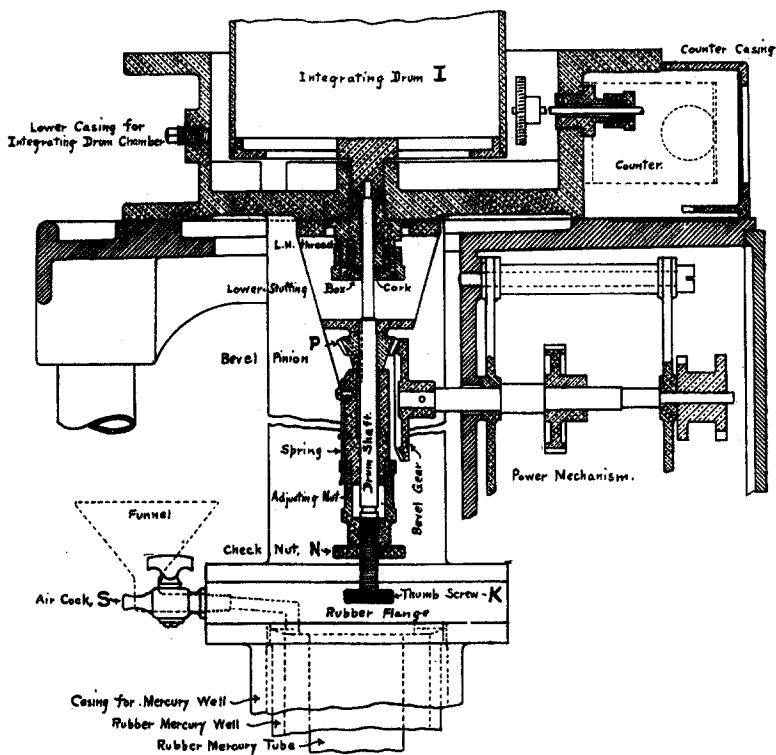


FIG. 13.—Section through lower portion of register.

dimensions of the Venturi tube) translates this message into cubic feet delivered during ten minutes.

The entire circumference of the drum represents a throat velocity of 38 feet per second. Hence, this is the highest velocity which can be registered.

At the boundary between the two cylindrical surfaces, *R* and *D*, a beveled surface is provided, to facilitate the passage of the idler wheel, *H*, from one to the other.

The mercury required in the tube, *B*, and well, *W* (*Fig. 10*), weighs 16½ pounds; but it will usually happen that a little more or a little less than this is actually introduced. Hence, the volume of mercury is variable, and the height of the float, for a given velocity or for no velocity, is variable also. To compensate for this variation, the integrating drum, *I*, is made adjustable by means of a thumb-screw, *K*, placed under the foot of the drum shaft, as shown in *Fig. 13*.

*Figs. 14* and *15* are photographic views of the registering apparatus. *Fig. 15* is a front view, showing the entire length of the apparatus; while *Fig. 14* is a rear view of the principal portion, on a larger scale.

To introduce the mercury, the top of the dome is removed, and a cast iron funnel is screwed into its place, proper arrangement of the other valves and cocks being made for the exclusion of water and the escape of air.

When the instrument is in use, it must be entirely full of water, to the top of the dome, and free from air.

From time to time it becomes necessary to open slightly the air-cocks to permit the escape of air, especially when much air is contained in the water. This may be done while the apparatus is in use, but not while the drum is revolving.

The large weights shown in *Figs. 14* and *15* drive the power mechanism, which, once in ten minutes, turns the integrating drum through one revolution. This motion occupies a few seconds and is transmitted to the counter so long as the idler wheel rests upon the depressed surface, *D*, of the drum. This depends, as already explained, upon the height of the idler wheel, and this, in turn, upon the throat velocity. Upon this latter depends, again, the quantity of water passed through the Venturi during the ten-minute period. Thus the quantity registered is made to correspond with the quantity actually discharged.

The release or tripping of the power mechanism, once in ten minutes, is effected by an eight-day clock, provided with a separate weight.

The tripping may be done by hand, at shorter intervals, whenever this is desired, but it must then be remembered

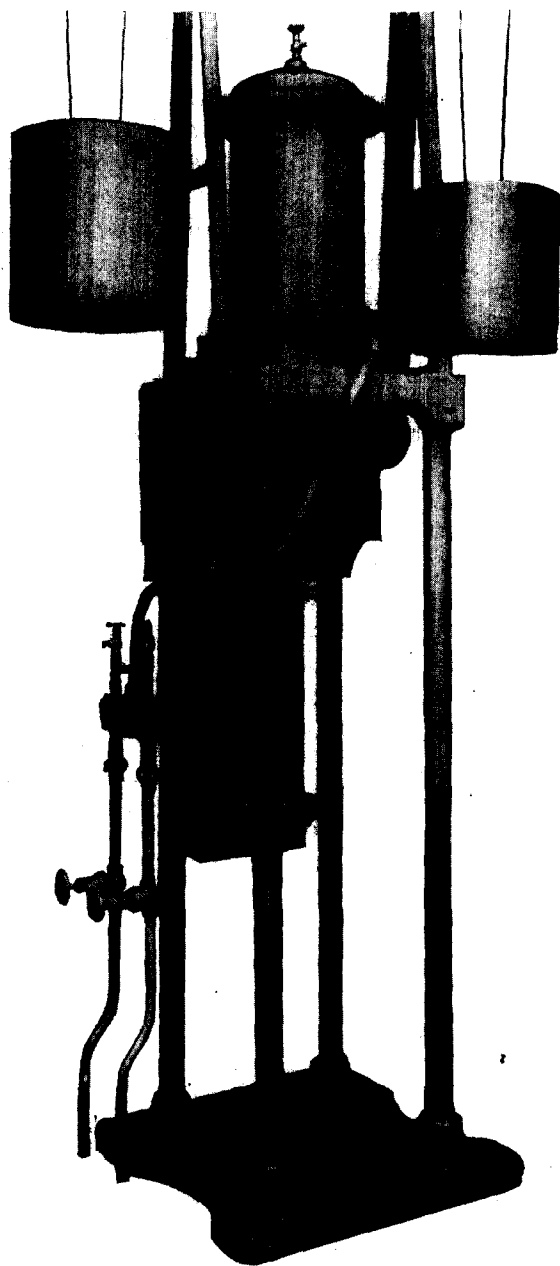


FIG. 14.—Register. Rear view of lower portion.

that the registration, at each tripping, shows the quantity discharged *in ten minutes*, regardless of the time which has actually been allowed to elapse since the last tripping, and a corresponding correction must be made. If, for instance, the mechanism is tripped at intervals of two minutes, each increment in the registration must be divided by five.

A gain or loss, by the clock, of fourteen minutes in twenty-four hours, causes an error of about 1 per cent. in the reading.

The register may be placed at a considerable distance (not exceeding, say, 500 feet) from the Venturi tube. It must be placed at such a depth below the hydraulic grade line that the pressures existing in the Venturi tube shall at all times be transmitted to the two mercury surfaces.

The pipe lines must be covered, and a shelter from weather and frost must be provided for the register. If suitable accommodation for the latter is not available in some existing building, a frost-proof vault or register-house, not less than 6 feet square and 6 feet high, must be constructed.

The counter may be either straight-reading, like that of a revolution indicator, or provided with dials and pointers, as in a gas meter.

The registration may be automatically transmitted, by electricity, through any desired distance, to a secondary or office dial, shown in *Fig. 16*.

#### BEHAVIOR.

As already stated, the complete device forming the Venturi meter consists of two distinct instruments, manufactured under different patents issued to different patentees, viz.: (1) the Venturi tube, and (2) the registering apparatus. The character of the results obtained depends, therefore, jointly upon the behavior of each of these parts.

As to the Venturi tube itself, it is a demonstrable fact that, as already stated, with a perfect (*i. e.*, frictionless) fluid, the indications of the piezometers would form an infallible and exact index to the velocity, and that the pressure lost during the contraction of the stream would be perfectly

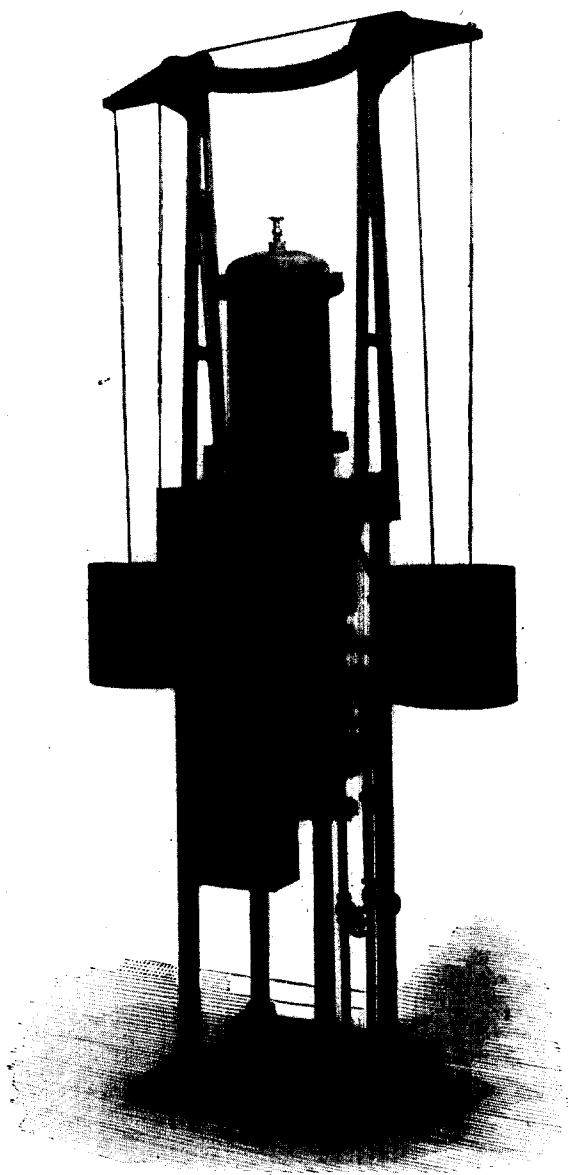


FIG. 15.—Register.

restored during its subsequent expansion, so that there would be no resulting loss of head.

It has long been known that, with a certain form of mouthpiece, approaching the shape of the "vena contracta," these conditions could be almost perfectly obtained in practice; and experiments with the Venturi tube have shown quite clearly that in it a very satisfactory approximation to these conditions is obtained.

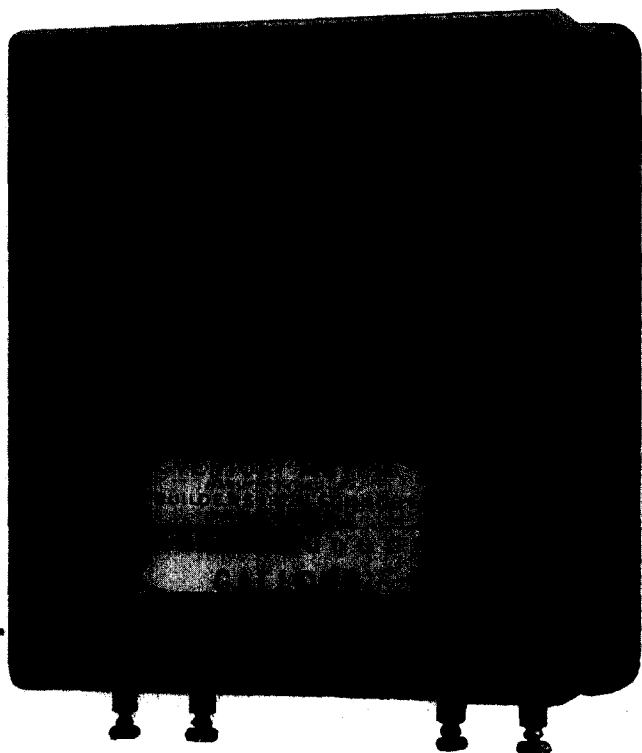


FIG. 16.—Office register.

Furthermore, in the present state of the mechanic arts there is no difficulty in forming the throatpiece so perfectly that the discharge can be very closely inferred from the throat velocity.

The construction of the tube is so simple, so strong and so little subject to wear or disarrangement, that, apart from

these purely hydraulic questions, there is but little to investigate so long as the conditions are normal. Certain matters, respecting its behavior in practical use under trying conditions, will, however, be mentioned further on.

The registering apparatus, on the contrary, is an elaborate piece of machinery, composed of many delicate moving parts. It is therefore important, in studying it, to ascertain, not merely whether it is so designed and constructed as to register faithfully the indications of the piezometers,

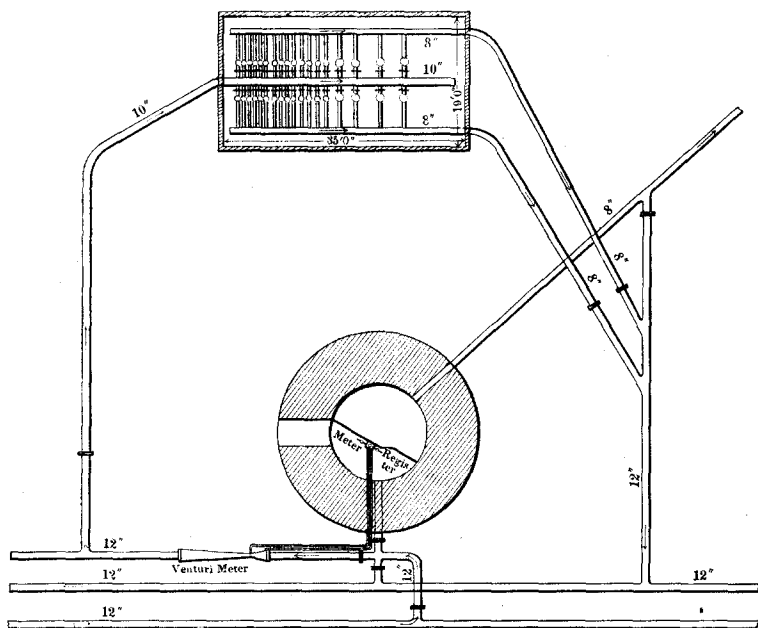


FIG. 17.—Chestnut Hill, Philadelphia.

but also whether, after long-continued use, it remains a practicable and serviceable tool, or whether its delicacy and its consequent liability to derangement, are such as to militate against its usefulness, and so interfere with the availability of the entire device.

It is for this reason that your sub-committee would hardly have been justified in making a much earlier final report, even if its members had had the necessary time at their disposal.

As already stated, the first recorded experiments with the Venturi meter were those of its inventor, Mr. Clemens Herschel, described by him in *Transactions* of the American Society of Civil Engineers, November, 1887, Vol. XVII, p. 228.

These experiments were made at Holyoke, Mass., in June and October, 1887, with two Venturi tubes made of wooden staves with cast iron throatpieces lined with brass. One of

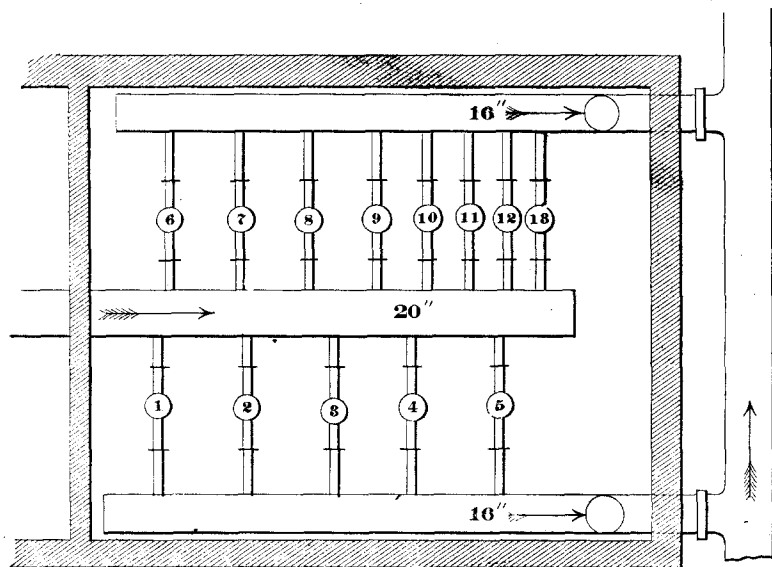


FIG. 17a.—Chestnut Hill, Philadelphia.

these was about 1 foot in greatest diameter; the other, nine times as large, was placed in a flume of nearly circular cross-section, about 9 feet in diameter. In each, the throat ratio, or ratio of area of cross-section in throat of Venturi to that in the up-stream end of the tube, was 1:9, the diameters being as 1 to 3. The pressures within the Venturi tubes were measured by piezometric columns, that leading from the throat being immersed in an open vessel containing water, as indicated in *Fig. 5* herewith. The discharge through the smaller Venturi tube was measured in a tank, the dimensions of which were accurately ascertained, while that through the larger tube was measured over a weir. The



smaller Venturi tube formed nearly the entire length of the pipe used in that case, receiving its water from a forebay and discharging it into a wooden box only 22 feet distant; but the flume in which the larger tube was placed was 224 feet long, and the conditions in that case, therefore, more nearly corresponded with those obtaining in lines of water pipe.

For throat velocities varying from 9 to 50 feet per second (corresponding to pipe velocities from 1 to 5.5 feet per second) in the smaller Venturi, and from 4 to 35 feet per sec-

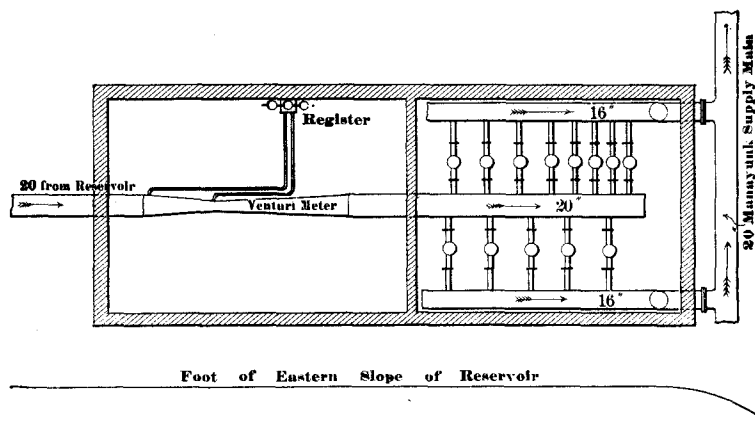


FIG. 18.—Roxborough, Philadelphia.

ond (pipe velocities, say 0.5 to 4 feet per second) in the larger one, Mr. Herschel obtained for the formula,

$$v_2 = C \frac{a_1}{\sqrt{a_1^2 - a_2^2}} \sqrt{2gH} = C \sqrt{2g \left( H + \frac{v_1^2}{2g} \right)}$$

coefficients,  $C$ , varying only from about 0.95 to 1.00. In other words, within the range of velocities named, the Venturi showed, in general, a discharge less than the measured discharge by from 0. to 5 per cent.

Similar results were obtained by Mr. Herschel with a 48-inch Venturi meter on a main of the East Jersey Water Company, at Macopin, N. J., in November, 1891. (See *Journal of the New England Water Works Association*, Vol. VIII; No. 1, September, 1893.)

The following series of experiments with Venturi meters have been made by Mr. A. J. Fuller, Assistant in Charge of Distribution of the Bureau of Water, Philadelphia, under the supervision of your sub-committee:

(1) Belmont Pumping Station, November–December, 1895, 6-inch Venturi, throat ratio, 1 : 9. Discharge measured in tank 17 feet in diameter, 6 feet deep.

(2) Chestnut Hill Pumping Station, 1896–98. 12-inch Venturi, throat ratio, 1 : 9. Discharge passed through a nest of small meters. *Figs. 17 and 17a.*

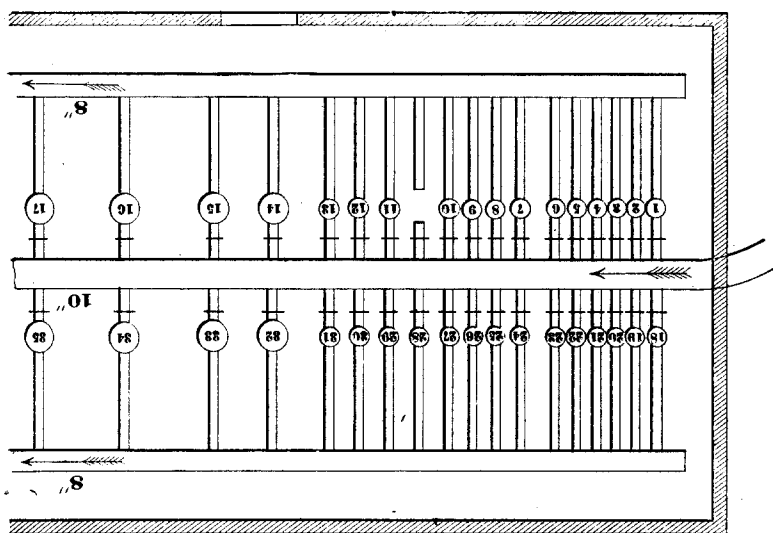


FIG. 18a.—Roxborough, Philadelphia.

(3) Old High-service Pumping Station, Roxborough, 1896–98. 20-inch Venturi, throat ratio, 1 : 7. Discharge passed through a nest of small meters. *Figs. 18 and 18a.*

(4) Wentz Farm Reservoir, 1896–98. On pumping main. 48-inch Venturi, throat ratio, 1 : 7. Discharge measured over a weir.

(5) Frankford Pumping Station, 1897–98. 48-inch Venturi, throat ratio, 1 : 7. On same pumping main with No. 4. Discharge measured over same weir.

As these experiments were inaugurated chiefly in order

to ascertain the suitability of the entire device to the needs of the Bureau of Water, and only secondarily as a source of information to your sub-committee, and as the correctness of the Venturi principle had already been pretty well established, no great refinement was attempted in making or recording the experiments. In general, however, the results obtained confirmed those mentioned above as given by Mr. Herschel, the discrepancy between the Venturi readings and the accepted standard (tank or weir measurement, as the case may be) being usually within 3 per cent. This included the operation of the registering apparatus, which was generally found to tally closely with the results obtained from readings of mercury piezometers.

At Belmont (Series No. 1) considerable trouble was experienced, particularly in connection with the electrically driven register there used, in getting fairly under way. On December 23, 1895, the following results were obtained (discharge measured in tank):

Test No.	Throat Velocity. Feet per Second.	Percentage of Error.
1 . . . . .	22'90	— 0'92
2 . . . . .	6'80	+ 5'25
3 . . . . .	6'80 1st adjustment	— 1'77
4 . . . . .	6'80 2d       "	— 2'64
5 . . . . .	6'75 3d       "	— 1'87
6 . . . . .	6'75 4th       "	— 0'28
7 . . . . .	22'00	— 0'76
8 . . . . .	33'5	+ 0'17
9 . . . . .	10'1	+ 0'75

The adjustments here noted consisted in raising or lowering the integrating drum by means of the thumb-screw, *K* (*Fig. 13*), to make the height of the idler wheel, under static conditions, coincide with the level of the origin of co-ordinates of the curve inscribed on the drum.

At Chestnut Hill and at Roxborough (Series 2 and 3) the water, after passing through the Venturi, was passed through nests of small mechanical meters, all of which had been carefully tested.\* Comparisons were made, also, be-

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\* The discharges here given for the mechanical meters are those obtained after making correction in accordance with the tests of those meters.

tween the readings of the Venturi register and those of mercury piezometers.

The following results are recorded:

COMPARISONS BETWEEN VENTURI REGISTER AND MECHANICAL METERS.

CHESTNUT HILL, JUNE 3 TO DECEMBER 31, 1896.

	Cubic Feet.	Per Cent.
Mechanical meters,* 4-inch and 6-inch . . . . .	1,897,084	
Venturi meter, 12-inch (register) . . . . .	1,910,480	
Venturi in excess . . . . .	13,396	= + 0.706
Mechanical meters,* ½-inch to 4-inch . . . . .	6,341,479	
Venturi meter, 12-inch (register) . . . . .	6,361,570	
Venturi in excess . . . . .	20,091	= + 0.317

ROXBOROUGH, OCTOBER 22 TO DECEMBER 31, 1896.

Mechanical meters,* 2-, 3-, 4- and 6-inch . . . . .	14,434,004	
Venturi meter, 20-inch (register) . . . . .	13,917,835	
Venturi in deficiency . . . . .	516,169	= - 3.576†

COMPARISONS BETWEEN VENTURI REGISTER AND VENTURI MERCURY  
PIEZOMETER, CHESTNUT HILL.

June 3, 1896.	Register 0.1 per cent. less than mercury piezometers.
June 5, 1896.	Register 0.2 per cent. less than mercury piezometers.
Oct. 29, 1896.	Register 1.2 per cent. less than mercury piezometers.

ROXBOROUGH.

Oct 28, 1896.	Register 0.50 per cent. more than mercury piezometers.
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The meters at Wentz Farm, No. 4, and at Frankford Pumping Station, No. 5, were placed upon the pumping main from the Frankford Station to the Wentz Farm Reservoir, a 48-inch main, four miles long. No. 4 was first placed upon this main, near the reservoir.

In a test of this meter by Prof. H. W. Spangler, of the University of Pennsylvania, November 19-23, 1896, the Venturi gave results from 0.5 per cent. to 5.2 per cent. less than those obtained from the weir, with an average deficiency of 2.1 per cent.; but, as very fitly remarked by

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† Near the close of these experiments it was discovered that at times the draught upon the system had been so great as to draw water from the dome containing the integrating drum of the register. This is regarded as having increased the discrepancy in this case.

Mr. Herschel, a comparison of results between a weir and a Venturi meter is a test rather of the skill of the person manipulating the weir than of the correctness of the Venturi. In this case, the weir was placed at the end of an open box, 4 feet deep, 13 feet wide and 70 feet long, the pumping main discharging vertically upward into the box near its other end. Hook gauge readings were taken in a rectangular chamber adjoining and communicating with the weir box. The agitation of the water was reduced, as far as possible, by placing floats in the weir box. These reduced the maximum oscillation in the hook gauge box to about 0.04-inch and the usual allowance was made for velocity of approach; but the arrangements connected with the weir were still far from ideal.

In connection with these experiments, it was found that the register could be so adjusted as to read in practical identity with the weir.

Another series of tests, made by the Bureau of Water, November 23-24, 1896, gave the following results, as compared with those of the weir above mentioned:

Date 1896.	Throat Velocity deduced from weir. Feet per second.	Percentage of error.	
		Mercury column.	Venturi register.
November 23.	17.1	+2.60	-4.41
" "	21.4	+1.79	-1.91
" "	24.3	+2.16	-0.88
" "	28.0	+2.69	+0.02
" "	31.7	+2.68	+0.03
" 24.	17.4	+0.91	-1.27
" "	20.6	+2.76	+0.68
" "	24.6	+3.37	+1.07
" "	27.6	+9.98	+7.44
" "	32.1	+3.10	+0.50

On June 10, 1897, this meter was removed to the Frankford Pumping Station, where it was placed upon the same pumping main as before, and was used, June 16-19, in measuring the delivery of the engine recently completed there by the Southwark Foundry and Machine Company, of Philadelphia.

The water was measured, also, over the weir at the Wentz Farm reservoir.

During the high-speed test of the pump, the Venturi recorded 4·6 per cent., and during the low-speed test 10·7 per cent. more water than the weir; but it is altogether probable that a considerable portion of this was diverted, through partly open stops or leaky pipe joints, between the Venturi and the weir at the reservoir.

Later an additional 48-inch Venturi meter was placed upon the same main near the reservoir, at the location formerly occupied by the one already mentioned. The two meters, 4·24 miles apart, were thus placed in tandem, so that their registrations could be compared, for the purpose of estimating the amount of leakage from the intervening main.

The first test under these conditions was made October 26, 1897, when the lower meter showed 4·16 per cent. greater flow than the upper one. Investigation showed that a part of the water which passed through the lower meter, was diverted, through a leaky stop, from the 48-inch main, on which the two Venturis were placed, into the 30 inch pumping main, and a pump was started on this latter main, in order to equalize the pressures in the two mains and thus reduce the leakage from one to the other. The 30-inch main discharged beneath the water level in the reservoir. The pressures in it were, therefore, necessarily at all times less than those in the 48-inch main which discharged through the weir placed about 16 feet above the water level in the reservoir.

Under these conditions the mercury columns of the two meters were read, and the lower one averaged 0·63 per cent. more than the upper one.

A comparison between the Venturi register and the mercury column, on June 10, 1897, showed the register 0·8 to 3·9 per cent. in deficiency.

The investigations of the Philadelphia Bureau of Water, although perhaps of limited scientific value, have sufficed to satisfy the Bureau thoroughly as to the value of the Venturi meter as a means for determining the discharge of water pipes and as to the desirability of extending its use in the service of the Bureau.

An 18-inch Venturi meter, throat ratio 1 : 7, was installed at Spring Creek Temporary Driven Well Station of the Brooklyn Waterworks, December 16, 1896, and shortly afterward tested in comparison with a weir. We are indebted to Mr. I. M. de Varona, Engineer of Water Supply, for a report of this test, according to which the Venturi gave a discharge about 5 per cent. greater than the weir by Francis' formula, and about 1.5 per cent. greater than by Hamilton Smith, Jr.'s formula.

At Lawrence, Mass., a Venturi meter in a 30-inch main was tested, on the 20th of April last, in comparison with a weir, at a nearly uniform velocity. The mean discrepancy between meter and weir, for a series of eighteen observations, was 0.6 per cent., with the meter in excess, and the greatest discrepancy in any of the tests was 4.93 per cent., with the meter in excess. In connection with the figure last named, it should be borne in mind that the smallest division of the register corresponded to a flow of 1,000 cubic feet, so that it was necessary to estimate the hundreds, and, as the total flow at each observation was only about 4,400 cubic feet, this would account for a considerable discrepancy. Mr. R. A. Hale, of the Essex Company, has kindly furnished these data.

Your sub-committee obtained, from the builders of the Venturi meter and register, the Builders Iron Foundry, of Providence, R. I., a list of all persons and corporations using the device, and addressed inquiries to all of them, soliciting information as to their experience with it. The results of this correspondence are embodied in the following:

The first registers made were provided with weight-driven mechanism; but, in order to obviate the necessity of frequently winding these, an electrically driven mechanism was substituted. This, however, owing to the uncertainty of the action of the batteries used, proved almost universally unsatisfactory. The Builders Foundry recognizing this, has abandoned the manufacture of electrically-driven registers and is replacing with weight-driven registers those furnished. Except for the necessity of winding

them twice each week, these give general satisfaction. The foregoing has been the experience of the Philadelphia Water Bureau, as well as of nearly all our correspondents.

A letter received from the Water Commissioner of Clinton, Mass., stated that a 16-inch meter had failed to record parts of two days' results, owing to corrosion of a wheel in the register. During the summer of 1897 the electrically driven register was replaced by one driven by weights, and this has since run without a break.

Mr. George Kent, of London, who represents the Venturi meter in England, sends a drawing, showing an application of the Venturi meter to the purpose of showing the condition of a filter bed.

Mr. F. L. Cushing, Water Registrar, Medford, Mass., reports that in January, 1897, the 12-inch meter in use there gave unsatisfactory results, owing to a chip, which had lodged in the throat. The throat ratio of this meter is not given, but, if it was as great as 1 : 9, the throat diameter was 4 inches, so that it must have required a chip of respectable dimensions to lodge in the throat. Nevertheless, manholes have been provided, above and below the meter, to facilitate the removal of such obstructions.

One of the principal advantages of the Venturi meter is, that, owing to its unobstructed channel, free from moving parts, it is far less liable to clogging than the forms of meter in common use. Most of the solid bodies which would inevitably clog and stop any form of mechanical meter, would pass freely through the unobstructed throat of the Venturi.

On July 23, 1897, the Medford meter, which, in the meantime, had been furnished with a weight-driven register, was tested, in comparison with a square gate-house, of accurately known dimensions, which was used as a measuring tank. Eight tests were made, and the average flow, by the Venturi register, was 1.37 per cent. less than the flow as measured by the tank. The Venturi readings ranged from 3.65 per cent. less to 0.77 per cent. greater, than the measured flow. The rate of flow remained uniform during the test.



Mr. Dexter Brackett, Engineer of Distribution Department, Massachusetts Metropolitan Water Board, writes that since February, 1896, the Board has had a 36-inch Venturi in a pumping main, supplied by two Gaskill engines, near the Chestnut Hill Pumping Station. The discharge has ranged from 8,000,000 to 20,000,000 gallons per day. Indications, obtained by comparing the plunger displacement of the engines with the meter record, show that the latter is probably within 2 per cent. of the truth. One of the engines shows a slip of between 7 and 8 per cent., and the other about 3 per cent., as compared with the meter record. The weight-driven register has thus far worked very satisfactorily.

The De Kalb Electric Company, of De Kalb, Ill., which has a 12-inch meter, has had an electrically driven register in use about two years, and considers it a very satisfactory arrangement.

E. and T. Fairbanks & Co., of St. Johnsbury, Vt., have a 10-inch meter, with an office counter at the factory, two miles distant. At one time, the counter registering abnormally large volumes of water, an investigation was made, and it was found that a break in a distributing pipe was carrying large quantities of water directly into the sewer.

Prof. Dwight Porter, of the Massachusetts Institute of Technology, Boston, has a 3-inch meter, throat ratio 1 : 9, without register. Comparing the actual discharge with that theoretically due to the head on the Venturi, one set of experiments gave a coefficient varying from 0.98 for throat velocity of 27 feet per second, to 0.995 for a throat velocity of 72 feet per second. A later series of 45 tests, by other experimenters, gave a coefficient varying from about 0.95 to about 0.985 (with three exceptions) for throat velocities from about 7 to about 40 feet per second, no regular law of variation appearing.

From unsatisfactory results given by another test, with a 12-inch meter on a pumping main, Professor Porter is inclined to question the adaptability of the device to such service; but the satisfactory results obtained with the 36-inch meter in Boston, and with the two 48-inch meters in Philadelphia,

all on pumping mains, would indicate that his misgivings are unfounded.

The Solvay Process Company, of Syracuse, N. Y., has a 12-inch and an 8-inch Venturi meter, measuring brine, under a pressure of about 40 pounds, and two 5-inch Venturis measuring very hot boiler-feed water at a pressure of about 145 pounds. Weight-driven registers are used, except on one of the brine meters, and are less liable to get out of order, and require less watching, than the electrical register, which, however, is reported as very satisfactory.

The brine meters work very satisfactorily indeed. As tested very accurately, by a chemical test, they are found to vary not more than from 1 to  $1\frac{1}{2}$  per cent.

The discharge from the hot-water meters is measured in a tank, and the error of the meters, when in good condition, is found to be within the errors of tank measurement, although the tank is measured with exceptional care and checked by means of a recording gauge. It is found that the meter record is at least as trustworthy as the tank measurement, if not more so. Owing, however, to the presence of carbonate of lime in the feed water, even after treatment with soda, some scale forms in the Venturi throat, causing the apparatus to give readings in excess of the truth. This necessitates frequent cleaning of the Venturi.

"The mechanically driven registering apparatus gives no more trouble than any good clock."

The North Packing and Provision Company, of Somerville, Mass., has had a 4-inch meter in use since December 20, 1897, registering daily over 91,000 gallons of water at an average temperature of 210° Fahr. It gives entire satisfaction.

Many other replies have been received, but the foregoing embodies the substance of the correspondence.

Mr. Herschel's experiments with a 48-inch Venturi, at Macopin, N. J., already quoted, gave a total loss of head, due to the passage of the water through the two cones and throat, forming the meter, of about 0.106 foot for each foot of head on the Venturi.

Professors Marx, Wing and Hoskins, experimenting with

two 54-inch Venturi meters at the power-house of the Pioneer Electric Power Company, at Ogden, Utah (Proceedings, American Society of Civil Engineers, Vol. XXIV, No. 5, May, 1898), found a loss of head of 0.149 foot, per foot of head on Venturi. This would make the added force required by the Venturi, in pumping 20,000,000 gallons daily through a 48-inch Venturi meter, with throat ratio 1:9, about 1.12 feet. It was found that dirt collected on the surface of the column of mercury in the third or last piezometer, causing uncertainty, amounting probably to not more than 0.004 foot, in the readings for total loss of head. This trouble was not experienced with the throat and up-stream piezometers.

The Ogden meters received their water from a riveted steel main 6 feet in diameter, over 4,000 feet in length, with a head of nearly 400 feet above the meters. The steel main, in turn, received it from a wooden flume, 6 feet in diameter, about 3,000 feet long, with a head of about 50 feet, making a total length of about 7,000 feet of 6-foot pipe, with a total head of 462 feet. It was found that, after changes in the rate of flow, it required about fifteen minutes for the flow and pressures in the pipe to become steady. The Venturi meters, on the contrary, become steady in not more than two or three minutes.

Venturi tubes are made with throat ratios ranging from 1:4½ (or 2:9) to 1:16. The former are adapted to high, and the latter to low velocities; for, where the velocity in the pipe is low, it is necessary to accelerate it greatly in the throat in order to obtain sufficient loss of pressure and rise of float to secure reliable indications from the integrating drum. These cannot be obtained where the throat velocity is less than about 3 feet per second. With a throat ratio of 1:16, this would give a pipe velocity of  $\frac{3}{16}$  foot per second. On the other hand, a meter with a high throat ratio, adapted to low velocities, would, with high velocities, exceed the upper limit of the integrating drum, which, as already mentioned, is arranged for a maximum throat velocity of 38 feet per second.

The manufacturers do not make a practice of selling Venturi meters less than 6-inch. Below that limit the cost

of the register, which is a constant quantity, becomes relatively so great as to prevent successful competition with the ordinary mechanical meters.

The facility provided for the adjustment of the height of the integrating drum, while a very necessary provision, lays the device open to the manipulation of interested parties. It is desirable that this difficulty should be obviated.

It is also greatly to be desired that a continuously-recording register should be devised.

#### CONCLUSIONS.

Although the invention of Mr. Herschel and that of Messrs. Connet and Jackson have now been very prominently before the engineering profession for several years, your sub-committee is not aware that their claims of priority have been disputed. This, together with the granting of the patents in both cases, justifies us in regarding both inventions as new.

Differing radically in principle from all existing forms of meters, the Venturi is not a mere improvement upon them, but is a distinct innovation. It has also the very important advantage of being without any moving parts.

It is true that the ancient Romans used the Venturi mouthpiece as a means for defrauding the commonwealth, by taking, from the public pipes of distribution, more water than they were entitled to take, and that Venturi himself, a hundred years ago, used it as an *ajutage* in experiments for the purpose of obtaining a high coefficient of discharge through orifices; but Mr. Herschel appears to be entitled to the honor of being the first to propose its use as a means of measuring the flow of water through pipes, by the use of piezometers, as herein explained.

Prior to its invention, there were no means for such measurement, except the weir and the measuring tank; and in the great majority of cases it was out of the question to apply these means. The Pitot meter gives promise of usefulness in this connection, but it has not yet been so developed as to offer serious competition.

The Venturi meter, unlike the weir or the measuring

tank, calls for no disturbance in the existing conditions, and it may be placed in the pipe at any convenient point. Its extreme simplicity and the entire absence of moving parts are scarcely less important advantages than the remarkable accuracy of its registration.

While the registering apparatus owes its existence to the Venturi tube, and is dependent upon it for its value, the tube, on the other hand, has a distinct and highly important value of its own, independently of the register, for, by the use of suitable pressure and vacuum gauges, the actual rate of discharge at any moment may be obtained with great accuracy.

For these reasons, we regard the Venturi meter tube as one of the most important of recent inventions, and we unhesitatingly recommend the award, to its inventor, Mr. Clemens Herschel, of the highest honor within the gift of the Institute—the Elliot-Cresson Gold Medal.

The highly ingenious and meritorious registering apparatus, invented by Messrs. Connet and Jackson, is entitled to the very important honor of having made the Venturi meter available for a host of purposes, for which, otherwise, it could not have been satisfactorily used. As now furnished with weight-driven mechanism, it gives excellent satisfaction, and, as one of our correspondents, already quoted, remarks: it gives no more trouble than any ordinary clock. The results obtained by its use appear to be as reliable as those obtained by extremely careful readings of mercury columns under favorable circumstances; with the additional and important advantage that it gives a cumulative record of the quantity discharged.

The device, however, like all others, has its limitations, some of which we have pointed out. It is as complex and delicate as the Venturi is simple and rugged. Whereas the tube, by its stoutness, seems almost to invite maltreatment, the register requires care to avoid damage, and skill to obtain the best results. Its cost is such as to prohibit the use of the combined device in the smaller sizes. Its record is not continuous. Its registration depends upon the assumption that the velocity has remained practically constant dur-

ing the ten minutes elapsing between the times of tripping, or at least that the mean velocity during that period has been the same as at the moment of tripping.

Nevertheless, its invention, design and perfection are the fruits of great ingenuity and of much knowledge and painstaking labor, and they have been of vast benefit to the community by making, of the Venturi meter, a practical working tool.

Its inventors, Messrs. Frederick N. Connet and Walter W. Jackson, of Providence, R. I., are therefore entitled to distinguished honor at the hands of the Franklin Institute, and we take pleasure in recommending the award, to them, of the John Scott Legacy Premium and medal for their Registering apparatus.

Adopted at the special meeting of the Committee on Science and the Arts, held Wednesday, June 22, 1898.

JOHN BIRKINBINE, *President.*

WM. H. WAHL, *Secretary.*

Countersigned by

JAMES CHRISTIE,

*Chairman Committee on Science and the Arts.*

[The sub-committee which conducted this investigation was composed of Messrs. J. C. Trautwine, Jr., chairman, John E. Codman and Rudolph Hering.]

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## THE HYATT ROLLER BEARING.

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[*Being the report of the Franklin Institute, through its Committee on Science and the Arts, on the invention of J. W. Hyatt, of Harrison, N. J.*]

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[No. 1880.] HALL OF THE FRANKLIN INSTITUTE,

PHILADELPHIA, June 22, 1898.

The Franklin Institute of the State of Pennsylvania, for the Promotion of the Mechanic Arts, acting through its Committee on Science and the Arts, investigating the merits of Hyatt's Roller Bearings, reports as follows:

The utility of anti-friction rollers is well known among mechanics, and they have been very extensively employed