interested in the subject, and to whom the ordinary water gauge fails to offer a means adequate to their requirements.

The Author illustrated the paper by actual instruments; one with a 12 inch, one with a 4 feet, and one with a 6 inch syphon. The latter instrument was designed to give continuous records by photography, the non-actinically coloured spirit intercepting the light in its course to a band of sensitive paper wound around a clock-driven drum enclosed in a dark chamber.

The methods of determining specific gravities and calibrating the instrument were demonstrated.

The use of the apparatus was shown in various ways. Amongst other methods a glass tube 18 inches long, open at both ends, was inverted over an open but unlit gas burner, then connected to the gauges. The ascensional pressure of the cold gas in the tube depressed the gauge about $\frac{1}{3}$ of one inch.

PITOT TUBES, AND THEIR USE IN MEASURING THE VELOCITIES OF WATER, GAS AND AIR.

By H. J. I. Bilton.
(Member of the Council).

Although the use of the Pitot tube is not unknown in Victoria, it has come to play such an important part in modern hydraulics, that it is advisable to preface this paper with a description of its history and purpose, after first giving a list of the abbreviations and terms used.

**NOMENCLATURE.**

- $A =$ Sectional area of pipe in square feet.
- B.W.I. = Black wrought iron (commercial pipe).
- C = Coefficient.
- C.F.M. = Cub. feet per minute.
- Comptd. $V =$ Velocity as computed by a formula applicable to the nature of the pipe.
- $D =$ Diameter of pipe in feet.
- $d =$ Diameter of pipe in inches.
- Dgm. = Diagram.
- $e$ or effec. = effective.
- eq. or equiv. = equivalent.
- $g =$ acceleration due to gravity = 32.2 ft. per sec.
- G.W.I. = Galvanised wrought iron (commercial pipe).
- $H =$ Head of water in feet (used in a general sense).
- $H_n =$ Loss of head at entry.
- $H_{100} =$ Loss of head per 100 ft. length.
- Hv. = Velocity head.
- Hvc. = Head giving the water its velocity at centre of pipe.
- $Hf =$ Friction head.
- $ht =$ Total head of water in inches.
hp. = Loss of head as indicated by Pitot pressure tube.
he. = Effective head of water in inches.
I.R. = India rubber.
L = Length of pipe in feet, used in a general sense.
l = Length of pipe in inches, used in a general sense.
le' = effective length of pipe in inches, after deducting mouthpiece.
lp = effective length of pipe in inches as measured from Pitot tube to outlet end. (See Fig. 11.)
P.T. = Pitot tube, consisting of an impact and a pressure tube.
R = Mean hydraulic radius or $\frac{A}{L}$.
r = radius of pipe in inches.
S = Sine of the slope or $\frac{m}{L}$.
T = Temperature of the water in Fahrenheit degrees.
V = Velocity in feet per second, used in a general sense.
Vm. = Mean velocity as obtained by tank calibration.
Vc = Velocity at centre of pipe as obtained by Pitot tubes.
$\frac{Vm}{Vc}$ = Ratio of mean to central velocity.
Pipe 0.9781 in, diam. = Termed, for brevity, a 1 in. pipe.
"Head Vessel."—An open water vessel or tank used as a reservoir, and kept gently overflowing, into which the pipes protruded 2½ internal diameters. (See Fig. 9.)
"Regulating Vessel."—An elevated open water vessel or tank used for maintaining the head and regulating the overflow of the Head Vessel by means of a plug cock.
"Measuring Vessels."—Cylindrical galvanized iron vessels or tanks, with conoidal tops and vertical mouthpieces, whose contents in cubic feet have been accurately determined by weighing; used for measuring the discharge and so obtaining the mean velocities.
"Critical Velocity" (of Prof. Reynolds).—That velocity, dependent on the diameter of the pipe, at which the nature of the flow begins to change, and at which the loss of head ceases to vary as approximately the square of the velocity, but begins to vary directly as the velocity. (See 1 in. pipe results, Log. Dgm. G.)
"Critical Diameter."—That diameter at which the ratio of the mean to the central velocity apparently reaches a maximum.
"Piezometer."—A hollow ring cast around a pipe, filled with water by means of several orifices in the pipe wall, and forming a chamber of still water, from which the pressure may be obtained, as shown by a glass gauge, apart from velocity effects (Fig. 6A).

PART I.

From Trautwines "Engineering Pocket Book" we find that 'Pitot's' tube was originally a simple glass tube (Fig. 1), open at
both ends, and bent in the shape of the letter L. One leg of the L was held horizontal under water, with its open end facing the current; and the velocity $V$ at the point $O$ where it was placed, was measured by the vertical height $H$ (theoretically $= \frac{V^2}{g}$), to which the water rose in the other leg above the surface of the stream.

"As developed by M. Darcy and Prof. W. S. Robinson,* and rudely indicated in Fig. 2, Pitot's tube consists essentially of two horizontal glass or metal tubes, $a$ and $b$, of very small bore, placed side by side in the current, and pointed upstream. Tube $a$ receives the current in its open upstream end, while $b$ is closed at its upstream end, and has small lateral openings only. The other end of each tube communicates, by means of small metal or rubber piping, with one leg of an inverted U-shaped glass gauge fixed in a boat or on shore."

"For convenience the two flexible pipes may be joined together into one double pipe. By sucking through a stopcock $T$ at the top, water is drawn up to any convenient height in the two legs of the gauge. When there is no current, the two columns of course stand at the same height; but in a current the difference $H$ in their heights is such that $V = \sqrt{2gH}$. The instrument is remarkably simple and accurate, and can be used in very narrow and shallow streams of water or of gas. It measures velocities as low as 4 inches per second."

A further description from the "Encyclopaedia Britannica" is as follows:

"A very old instrument for measuring velocities, invented or used by Pitot, consisted simply of a vertical glass tube with a right-angled bend, placed so that its mouth was normal to the direction of flow (Fig 3A). The impact of the stream on the mouth of the tube balances a column in the tube, the height of which is approximately $H = \frac{V^2}{g}$, where $V$ is the velocity at the depth $x$. Placed with its mouth parallel to the stream the water inside the tube is nearly at the same level as the surface of the

* See Van Nostrand's Magazine, March, 1878, and August, 1886.
stream, as at B. Turned with the mouth downstream, the fluid sinks a depth $H^t = \frac{v^2}{2g}$ nearly, as at C, though the tube in that case interferes with the free flow of the liquid and somewhat modifies the result. Pitot expanded the mouth of the tube so as to form a funnel or bell mouth. In that case he found by experiment $H = 1.5 \frac{v^2}{2g}$. The objection to this is that the motion of the stream is interfered with, and it is no longer certain that the velocity in front of the orifice is exactly the velocity of the unobstructed stream. Darcy preferred to make the mouth of the tube very small, partly to avoid interference with the stream, partly to check oscillations of the water column. In that case he found the difference of level of two tubes such as A and B, Fig. 3, to be almost exactly $H = \frac{v^2}{2g}$.

"One objection to the Pitot tube in its original form was the great difficulty and inconvenience of reading the height $H$ in the immediate neighbourhood of the stream surface. This is obviated in the Darcy gauge, which can be removed from the stream to be read."

"Fig. 4 shows a Darcy gauge. It consists of two Pitot tubes, having their mouths at right angles. In the instrument shown, the two tubes, formed of copper in the lower part, are united into one by means of a thin web, for strength, and the mouths of the tubes open vertically and horizontally."

"The upper part of the tubes is of glass, and they are provided with a brass scale and two verniers, b, b. The whole instrument is supported on a vertical rod, AA, the fixing at B permitting the instrument to be adjusted to any height on the rod, and at the same time allowing free rotation, so that it can be held parallel to the current. At C is a two-way cock, which can be opened or closed by cords. If this is shut, the instrument can be lifted out of the stream for reading. The glass tubes are connected at the top by a brass fixing, with a stopcock, a, and a flexible tube and mouthpiece m. The use of this is as follows. If the velocity is required at a point near the surface of the stream, one at least of the water columns would be below the level at which it could be read. It would be in the copper part of the instrument. Sup-
pose, then, a little air is sucked out by the tube \( m \), and the cock \( a \) closed, the two columns will be forced up an amount corresponding to the difference between atmospheric pressure and that in the tubes. But the difference in level will remain unaltered."

When used to measure the velocities in pipes under high pressures, air is pumped into the tube \( m \), till the water levels come within the reading limits of the gauge, with similar results.

"When the velocities to be measured are not very small, this instrument is an admirable one. It requires the observation only of a single linear quantity. The law connecting the velocity with the observed height is a rational one. If we take \( V = C \sqrt{2gH} \) it then appears from Darcy's experiments that for a well-formed instrument, \( C \) does not sensibly differ from unity. It gives the velocity at a definite point in the stream. The chief difficulty arises from the fact that at any given point in a stream, the velocity is not absolutely constant, but varies a little from moment to moment. Darcy in some of his experiments took several readings, and deduced the velocity from the mean of the highest and the lowest."
Fig. 5 shows a form of Pitot devised by Mr. R. Burnham* for measuring the velocities of air and gas in pipes, as described in the "Engineering News" of December 21st, 1905. The coefficient of the instrument was found to be 1.003 (owing no doubt to a slight suction effect), and in a gas main 2 feet in diameter the ratio of the mean to the central velocity was found to be 0.869, and the law \( V = \sqrt{2gH} \) to correctly apply up to velocities as high as 65 feet per second. The instrument consists of two brass tubes, one within the other, the inner or velocity tube being 3/16 inch outside diameter. The outer or pressure tube is of 3/32 inch tubing, provided with a slot 1 1/4 x 1/16 inch on the under side. Tips of various forms may be used, but it was demonstrated that the form of tip, within quite wide limits, makes no appreciable difference in the indications of the tubes. The pressures exerted were transmitted through rubber tubing attached to B and C to opposite sides of sensitive manometers, reading to thousandths of an inch. The readings were taken in inches of kerosene, reduced to inches of water by dividing by 1.038. (A very sensitive manometer can be made for reading small losses of head by using tetra-chloride of carbon diluted with gasoline or benzine to a specific gravity of say 1.1. Such an instrument will magnify the readings ten times).

The arrangement of the tubes in the stuffing box, as shown, permits a longitudinal movement, and also some lateral adjustment, in the event of the hole in the pipe not being tapped exactly perpendicular to the axis. The position of the tube with reference to the centre of the pipe is indicated on a graduated scale, by the pointer T.

The mean velocity radius was found to be 8.97 in. or 70.4 per cent. of the pipe radius and it was concluded that a Pitot tube

*Professor of Experimental Engineering, Armour Institute of Technology, Chicago, Ill.
of this form is a perfectly reliable instrument for measuring the velocity of gases. An exactly similar instrument was used by Mr. D. W. Taylor, naval constructor, U.S.N. Navy Yard, Washington, in testing the efficiency of the ventilating fans on U.S.S. "Missouri," described in "Engineering News," November 3rd, 1904. He states that there seems no doubt that a properly-shaped Pitot tube is a very accurate appliance for measuring the velocity and pressure of moving air, and that the principle of the Venturi meter, so well known for measuring the flow of water, is essentially the same as that of the Pitot tube.

In the "Engineering News," of March 31, 1904, p. 318, a number of experiments by Messrs. Boyd* and Judd† on various forms of Pitot tubes are described, and the conclusion is arrived at that the co-efficient for an impact or velocity tube is practically unity, but that some of the discrepancies in the use of Pitot meters may be due to failure to get the true static pressure in the pressure tube (as has been pointed out by other observers), rather than in any error of the Pitot itself.

The author's experience, as presently described, is that it is just as easy to get a velocity or impact tube with a co-efficient of unity, as it is difficult to get a pressure tube which will indicate the true pressure apart from velocity effects. Especially is this so when the two tubes are combined in one, as the eddies caused by the rush of water past one will affect the other, usually causing an aspiration or suction action. The result is that the gauges will show too great a difference in the levels of the water columns, and will consequently indicate a greater velocity than is actually the case. The reverse of this is particularly noticeable in very small pipes, when the head or nib of the pressure tube is near the wall of the pipe, where it is subject to further eddies of a disturbing nature, which cause an impact effect. The velocity tube is not subject to these influences when near the pipe wall, because it receives the impact before they can take effect, but is particularly subject to irregularities due to deviations of the maximum velocity from the centre of the pipe. Hence it is usually the custom to average the height of the water column of the impact tube by taking readings at intervals of about 15 or 20 seconds. The result is not altogether satisfactory, and the method necessitates a special observer. These objections have to a great extent been overcome by the author by means of a glass vessel, 1 1/2 ins. diameter, 6 ins. high, connected to the impact tube by a rubber hose. This he has found to automatically register the average height of the water column. It requires 3 to 5 minutes to adjust itself, but as the duration of the Author's tests was seldom less than 3 minutes, the delay was of no consequence, and the reading was taken at the end of each test, provided the water showed no indications of further movement. Under low velocities, however,
where no oscillations occurred, the gauge glass was used in preference.

The whole subject of Pitot tubes for gauging the discharge and stream line velocities in pipes has been very thoroughly investigated by Messrs. Williams, Hubbell and Fenkell in a paper published in the "Transactions of the American Society of Civil Engineers," volume xlvii, April, 1902. This paper principally deals with the effects of curvature on the flow of water in large mains, and from the results obtained it can be at once recognised that if Pitot tubes are to be made practical use of in gauging the discharge of pipes by means of the ratio of the mean to the central velocity, straight pipes only must be selected, of such length as not to allow of the normal flow being disturbed by any obstructions or bends. The effect of abnormal conditions is a matter of which very little is apparently known. It has been claimed, for instance, that the disturbance caused by contraction will die away in a length of 35 diameters, by a partially opened stop valve in 100 or as much as 200 diameters, and in very large mains the irregular-velocity stream lines have been attributed to gate valves at a much greater distance away, and to slight curvature or bad alignment. It seems probable that the distance required for the normal flow to adjust itself may vary with the nature and eccentricity of the obstruction, the diameter and the velocity, and there is still large scope for investigation of a subject, only the fringe of which has apparently been touched.

Incidental to the main object of Messrs. Williams, Hubbell and Fenkell's investigations was the question of the ratio of the mean to the central velocity and the shape of the curves or distribution of stream line velocities as obtained by traverses of the pipes with Pitot tubes. Their ratio results for straight pipes are given in Table I. Three results at below critical velocities are shown at the end. These experiments were made on 12, 16, 30 and 42 inch cast iron pipes, through which the water was pumped at various rates as required. The mean velocities were obtained by dividing the cross section of the pipe into concentric rings of equal area, corresponding to the points of the traverse.

A number of experiments were made on Pitot tubes of various shapes, the impact and pressure tubes being combined. The same difficulty seems to have been met with as the author has experienced, viz., to get a combination tube having a co-efficient of unity. The co-efficients of the various tubes tried by Messrs Williams, Hubbell and Fenkell appear to have ranged from 0.8351 to 0.9658. The P.T. which appears to have been most successful is shown in Fig. 6, in which, however, there seems to have been a slight impact effect on the pressure tube, necessitating corrections.

The general average result of the ratios \( \frac{u_m}{u_c} \) is taken as 0.84, which is, apparently, assumed to apply to all diameters at all

* Prof. Gardner S. Williams, Cornell University.
PITOT TUBES.

velocities, and the curve of stream line velocities is found to be approximately elliptical instead of parabolic as hitherto generally supposed. In the discussion on the paper, Mr. H. Tutton computed that if the curve were parabolic the radius of the circle of mean velocity would be 0.737 of the radius of the pipe, and if elliptical 0.74535 (or at a position 0.127D inwards from the pipe wall).

TABLE I.

Experiments by Messrs. Williams, Hubbell & Fenkell.

<table>
<thead>
<tr>
<th>Diam.</th>
<th>Vc</th>
<th>Vm/Vc</th>
<th>Diam. 30°</th>
<th>Vc</th>
<th>Vm/Vc</th>
<th>Diam. 30°</th>
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</thead>
<tbody>
<tr>
<td>42&quot;</td>
<td>3.884</td>
<td>0.813</td>
<td>3.72</td>
<td>0.858</td>
<td></td>
<td>3.972</td>
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<td></td>
<td>3.914</td>
<td>0.848</td>
<td>4.65</td>
<td>0.854</td>
<td></td>
<td>4.380</td>
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<tr>
<td>16&quot;</td>
<td>4.485</td>
<td>0.840</td>
<td>3.29</td>
<td>0.853</td>
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<td>4.578</td>
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<tr>
<td></td>
<td>2.900</td>
<td>0.818</td>
<td>3.38</td>
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<td>4.428</td>
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<td>3.970</td>
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<td></td>
<td>5.590</td>
<td>0.842</td>
<td>0.940</td>
<td>0.914</td>
<td></td>
<td>3.460</td>
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<tr>
<td></td>
<td>6.830</td>
<td>0.846</td>
<td>2.405</td>
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<td>2.210</td>
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<tr>
<td></td>
<td>7.700</td>
<td>0.863</td>
<td>3.292</td>
<td>0.840</td>
<td></td>
<td>2.820</td>
</tr>
<tr>
<td>12&quot;</td>
<td>Vm</td>
<td>Vm</td>
<td>Vm</td>
<td>Vm/Vc</td>
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<td>4.240</td>
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<td>3.733</td>
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<td>6.273</td>
<td>0.908</td>
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<td>0.779</td>
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<td>1.509</td>
<td>0.841</td>
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<td>2.585</td>
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<tr>
<td></td>
<td>3.473</td>
<td>0.820</td>
<td></td>
<td></td>
<td></td>
<td>1.630</td>
</tr>
</tbody>
</table>

Messrs. Adams and Wilson submitted the result of a number of experiments on a brass pipe 2.006in. in diameter, in which they found that if the P.T. readings were taken near to a contraction in the pipe, the ratio $\frac{V_m}{V_c}$ was considerably increased; but if taken at any point 35 diameters or more from the point of disturbance, the average ratio for these normal conditions of flow was 0.798 for centre velocities ranging from 1.46 to 5.92 ft. per second. When the P.T. was inserted only 2.4 diameters from the
contraction the disturbance caused the ratio to be as high as 0.938. The following table is given by them as illustrating the results of tests on pipes of various diameters.

![Fig. 6 - Pitot Tube](image)

![Fig. 6a - Piezometer](image)

**TABLE II.**

<table>
<thead>
<tr>
<th>Diameter of Pipe in inches</th>
<th>Name of Experimenter</th>
<th>Ratio $\frac{V_m}{V_c}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>Adams &amp; Wilson</td>
<td>0.798</td>
</tr>
<tr>
<td>5</td>
<td></td>
<td>0.800</td>
</tr>
<tr>
<td>12</td>
<td>Williams, Hubbell and Fenkell</td>
<td>0.843</td>
</tr>
<tr>
<td>16</td>
<td>Cole</td>
<td>0.843</td>
</tr>
<tr>
<td>16</td>
<td>Williams, Hubbell and Fenkell</td>
<td>0.841</td>
</tr>
<tr>
<td>30</td>
<td></td>
<td>0.842</td>
</tr>
<tr>
<td>31.5</td>
<td>Bazin</td>
<td>0.856</td>
</tr>
<tr>
<td>42</td>
<td>Williams, Hubbell and Fenkell</td>
<td>0.831</td>
</tr>
</tbody>
</table>
Messrs. Adams and Wilson claim that the ratio 0.84 does not apply to small pipes; and that it probably increases as some function of the diameter.

_Pitot Meters:_ "The Pitot tube is made use of as a meter for measuring the discharge of pipes, as for instance the Ferris-Pitot Meter, the invention of Mr. Walter Ferris, of Philadelphia. Its register, like that of the Venturi meter, records the velocity existing at the instant of registration in terms of the total discharge since the last registry, and as an increase in the total number of cubic feet registered. The registry thus involves the assumption that the average velocity during the period between registrations, is equal to the velocity at the end of that period. In the Ferris meter the registration is made every two minutes. The instrument measures the velocity at only one point in the cross section of the pipe. Though such velocity may or may not represent the mean velocity of the entire cross section, it is claimed that the Ferris-Pitot meter will ordinarily register within 3 per cent. of the true discharge."

Pitot tube readings have also been successfully recorded by means of photography. Mr. E. S. Cole stated that he had spent considerable time in perfecting a recording device for this purpose. It was found that photography was the only practicable means of registering continuously the tube indications. The instrument, which is called a photopitometer, combines upon a photographic diagram on a revolving cylinder a record of the impact and pressure tube indications, and it is said to have shown itself capable of producing a good continuous record upon ordinary velox paper, which is convenient for the purpose.

It is claimed by those who are well conversant with the subject that the weir, the circular orifice, the Venturi, or other meter, and the nozzle are the only devices to be compared with the P.T., and that the results obtained by them are rarely if ever better than those of well-constructed and properly calibrated Pitot instruments. Some of them, moreover, are not always directly applicable to the flow of water in pipes. To the author its use in determining the velocity and loss of head, in indicating obstructions and the effects of incrustation and so determining whether cleaning is warranted, and if so, the effect of such cleaning, would have been alone sufficient inducement to warrant a study of the subject.

From the foregoing pages it will be readily understood that the correct ratio $\frac{v_m}{v_w}$ is an all-important factor in the use of Pitot tubes, and to a study of this question, particularly as regards small pipes, the author's efforts have been principally directed.

PART II.

The author has been experimenting for some years, as time and opportunity have permitted, on the effects of temperature on the flow of water through pipes. The use of long pipes was precluded because of the fluctuations and drops in temperature of the warm water passing through them. Consequently the tests had to be carried out with comparatively short pipes. The actual loss of head at entry then became of the utmost importance in determining the slopes. The co-efficients of discharge for re-entrant pipe mouthpieces, $2\frac{1}{2}$ diameters in length, had been previously determined by experiment, and were found to be as under:

**TABLE III.**

Coefficients of discharge for sharp-edged, square-cut re-entrant pipe mouthpieces, $2\frac{1}{2}$ diams. in length, with free discharge to the atmosphere.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>$\frac{3}{8}$&quot;</td>
<td>.91</td>
<td>$\frac{7}{8}$&quot;</td>
<td>.87</td>
<td>$\frac{1}{2}$&quot;</td>
<td>.83</td>
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<tr>
<td>$\frac{1}{4}$&quot;</td>
<td>.95</td>
<td>$\frac{5}{8}$&quot;</td>
<td>.81</td>
<td>$\frac{3}{4}$&quot;</td>
<td>.79</td>
</tr>
<tr>
<td>$\frac{1}{2}$&quot;</td>
<td>.77</td>
<td>1&quot;</td>
<td>.76</td>
<td>1 1/2&quot;</td>
<td>.75</td>
</tr>
</tbody>
</table>

It was, however, found that the formula, $Hn = \frac{V^2}{2g \times C_a}$, using the above co-efficients for such mouthpieces, did not apply with sufficient accuracy when the mouthpiece formed the end of a pipe, except in diameters of one inch and under. Pitot tubes inserted in the pipes near the head vessel showed such disturbances as to warrant the conclusion that the water had not adjusted itself to its normal flow in the larger pipes at a distance of only 2 diameters from the inlet end. Errors in the slopes naturally resulted, and many experimental results had to be abandoned. As a consequence it became necessary to make a special study of Pitot tubes, with the object of obtaining the correct loss of head at any point along the pipe where the flow might be considered normal, and so obtaining the correct slope, without which the value of the experimental results would have been much discounted.

A number of experiments were accordingly made with small brass tubes, $\frac{1}{16}$in. internal, and $\frac{1}{10}$in. external diameter, of various shapes. There was not much originality in the shapes tried, except perhaps in the sharp-pointed pressure tubes, and much of the work consisted of going over old ground. The difficulty was soon experienced of obtaining a combined P.T. having a co-efficient of unity, and as it was intended to make tests on pipes as small as $\frac{3}{8}$ inch in diameter, the attempt was abandoned,
and it was determined to use the impact and pressure tubes separately, so as not to interfere more than was necessary with the pipe waterway.

It was found to be invariably the case that when a straight tube was projected just through the wall or any distance into the pipe, the flow of the water past it caused an aspiration or suction effect, which increased with the velocity. (See Fig. 3, B.) The result was that a greater velocity was indicated than the actual. The author fails to see how a number of small piezometer openings can overcome this difficulty, as although suction effects may be almost negligible, any such effects must be communicated to the dead water inside the piezometer. (See Fig. 6A.) No trouble was experienced in obtaining an impact tube with a coefficient of unity, provided the nib was pointed exactly up stream. It was much more difficult to obtain a pressure tube showing neither impact nor suction effect.

The following sketches show the two forms which were found most satisfactory. Fig. 8 is the impact tube with the nib slightly tapered to a feather edge. Fig. 7 is the pressure tube, tapered to a needle point, and with two holes, one at the top, the other at the bottom of the nib. It was found that if these holes were too close in to the bend, the results were affected by the eddies formed by the body of the tube, as was also the case when a third hole was made on the inside of the nib. A fourth hole on the outside made no perceptible difference. Finally two vertical holes in the position shown were adopted, placed on the incline of the nib, so that impact and suction effects would neutralise each other.

**Calibration of Tubes**: The impact tube was calibrated by placing the nib in the *vena contracta* of the jet from a standard circular orifice. Several of such orifice plates were placed at various levels in the side of a water tank for the purpose. It is known (particularly from the experiments of Messrs. Judd and King on circular orifices from $\frac{3}{4}$ inch to $2\frac{1}{4}$ inch diameter, described in the "Engineering News," of September, 1906) that the coefficient of velocity for such jets is unity within a negligible fraction of 1 per cent.; and it was found that the water delivered by the impact

![Fig. 7](image1.jpg)  ![Fig. 8](image2.jpg)
The tube rose to exactly the levels of the water determining the velocities of the jets. It was consequently assumed that the co-efficient of the impact tube was for all practical purposes unity.

The pressure tube was calibrated as follows. A one inch pipe 23 feet long was set perfectly level between the head vessel and the gauge staff as shown in Fig. 9. The pipe protruded 2½ diameters into the head vessel. A piece of I.R. insertion, with putty on the inside, formed a flexible water-tight joint. Three slots, ⅛ inch x ⅛ inch, were cut in the side of the pipe, at a, b, and c, for the insertion of the tubes. The velocity of discharge under a total head H, was 3.16 feet per second by tank calibration. This gave a loss of head at entry (Hn.) of exactly 3 inches, computed by means of the previously-determined co-efficient of discharge (Table III.) for a 1 inch pipe mouthpiece 2½ diams. in length. A line was then stretched taut from this level to the centre of the pipe outlet, which represented the hydraulic gradient. Pencil marks corresponding to this line were drawn on the vertical timber battens shown. The pressure tube (Fig. 7) was then placed in each slot in turn, being lashed to the pipe, the insertion forming a tight joint. It was found that the water rose in the glass tube in all three cases exactly to the line of the hydraulic gradient, thus proving the correctness of the pressure tube.

The impact tube was then tried, and the difference in water level between the two tubes was found to be the same at the three points, thus proving that the differences in the two tube readings gave correct results as regards velocity head (Hvc). In the case of the impact tube, the rubber hose and glass vessel D, Fig. 10, were used, on account of the difficulty in reading the mean position of the oscillations of the water level in an ordinary glass tube.

The Author has found that whenever the nib of the pressure tube has a blunt end facing the stream, as in Figs. 2 and 5, the
water will splay off the edges and cause a suction effect or negative pressure, which prevents the Hf water column from rising to its proper level. The difference (Hve) of the two columns is then greater than it should be, and the computed

*Differential Gauge and Instrument.*
velocities consequently too high, the ratios \( \frac{v_m}{v_e} \) being correspondingly low. The success of the tube shown in Fig. 6 is probably due to the obtuse angle which the nib offers to the stream. The Author thinks the sharp-pointed pressure tube is probably the most perfect form obtainable, though it of course necessitates the use of separate and distinct tubes.

The small tubes, Figs. 7 and 8, were only used in pipes of less than 1 inch diameter. For the larger pipes the instrument shown in Fig. 11 was designed, in which the tubes could be advanced separately without any resetting of the instrument, rubber hose connecting them with the differential gauge shown in Fig. 10. An adjustable scale and pointer allowed traverses to be taken with accuracy as regards position. The nib of the pressure tube was advanced to a position about \( \frac{3}{4} \)D from the pipe wall in taking the pressures, \( H_f \).

Figures 10, 11 and 12 are marked with letters,signifying as follows:

**Fig. 10.—Differential gauge.**

- A. Cedar frame.
- B. Gauge glass connected with pressure tube.
- C. Gauge glass connected with impact tube, used at low velocities only.
- D. Open glass vessel connected with impact tube, used at the higher velocities.
- E, E. Brass set squares, bevelled to a knife edge, supported by a steel rod \( F \), and capable of being fixed at right angles to the vertical plane by the pinching screws \( G G \).
- H. Adjustable box scale in \( \frac{1}{10} \)in. divisions.
- J, J. Rubber stoppers, into which are screwed brass screw-tapered couplings \( K, K \), connected with the hose from Pitot tubes.
- T, T. Rubber Rings supporting glass tubes.

**Fig. 11.—Pitot tube instrument.**

- b, b. Twine lashing.
- c. Rubber insertion forming watertight joint.
- d. Screw for adjusting the instrument by means of the spirit level \( e \).
- f. Adjustable brass scale in \( \frac{1}{10} \)in. divisions.
- g. Adjustable pointer fixed to impact tube.
- h. Pressure tube.
- j. Impact tube.
- k. Centre line scribed on tubes, corresponding to line 1 scribed on brass boss, to ensure nibs of tubes pointing exactly upstream.
- m, m. Pinching screws to hold tubes in position when adjusted.
- n. Adjustable clip to hold tubes in place.
PITOT TUBES.

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o. Needle valve to release air.
lp. Point from which length of pipe was measured.
s. Slot in pipe ⅛in. x ⅜in. for insertion of tubes.

Fig. 12.—High pressure glass vessel, to be used with an instrument similar to that shown in Fig. 4:

A. Glass tube 2in. diam.
B. ⅛in. G.W.I. pipe, with holes at intervals.
CC. Gunmetal caps.
DD. Adjusting clips.
EE. Rubber joint rings.
FF. Brass nuts.
GG. Brass couplings, screwed into plugs at ends of G.W.I. pipe.
HH. ⅛in. 3-ply insertion hose.

One tube in the differential gauge was used solely for indicating the pressure or friction head, Hf, the other was sometimes used to indicate the total head, Hf + Hv, but as already mentioned was not a success, except at low velocities, owing to the fluctuations in the level of the meniscus. The glass vessel attached to the side of the frame was much more satisfactory, and automatically registered the mean head.

The boxwood scale was fixed as shown, so that its zero coincided with the level of head vessel overflow. The upper brass set square was fixed in this position as a precaution in case the scale shifted. The lower set square was used to measure by the scale the loss of head below the overflow level as indicated by the pressure and impact tubes. Table IV. is an example of some of the readings taken, together with the computed velocities, and the ratios \( \frac{v_m}{v_c} \) for a 1 inch B.W.I. pipe.

Pipe Diameters: The diameters of the small pipes were obtained by measuring the number of cubic centimetres of water required to fill the dry pipe. The larger pipes were weighed, first empty and dry, then full of water, by means of standard weights on a sensitive balance, or on reliable finely adjusted scales. The difference in weight, allowing for the length and the temperature of the water, gave the mean diameter. The woodstave pipe was soaked for several days before weighing. The following in round figures are the diameters of the pipes tested for the ratio \( \frac{v_m}{v_c} \) by the author:—⅛ inch and 1 ⅛ inch brass, ⅜ inch and ⅝ inch G.W.I., ⅜ inch I.R., ⅜ inch B.W.I. encrusted and cleaned, 1 inch, 1 ⅛ inch, 2 inch, and 2 ⅛ inch B.W.I., and 2 inch woodstave.

It will, of course, be understood that the slightest error in the diameter would affect the mean velocities, and consequently the ratios, \( \frac{v_m}{v_c} \).

Measuring Vessels: These vessels (see Fig. 9) were of various sizes, made of galvanised iron, with conoidal tops and vertical mouthpieces. Their capacities were obtained by the weight of their water contents at known temperatures, and at 60 degrees F.
**TABLE IV.**

Showing some experimental results on a B.W.I. Pipe 0.9871 inch diameter, 211.6 inches long, with computed velocities and ratios $\frac{V_m}{V_c}$

<table>
<thead>
<tr>
<th>ht</th>
<th>hp</th>
<th>he</th>
<th>Slope 1 in.</th>
<th>$H_{100}$</th>
<th>Length of run in Sec's.</th>
<th>Cu. ft. disch'gd</th>
<th>$V_m$ by tank Calibr'n</th>
<th>Comptd $V^*$</th>
<th>Loss of Head</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>Pressure Tube.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>ht</th>
<th>hp</th>
<th>he</th>
<th>Slope 1 in.</th>
<th>$H_{100}$</th>
<th>Length of run in Sec's.</th>
<th>Cu. ft. disch'gd</th>
<th>$V_m$ by tank Calibr'n</th>
<th>Comptd $V^*$</th>
<th>Loss of Head</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Pressure Tube.</td>
</tr>
</tbody>
</table>

* Computed by the Author's formula for new commercial iron pipes of average roughness

$V = 70 S^{0.5} D^{0.3}$, or $\frac{H}{100} = \frac{44 V^{0.82}}{D^{1.45}}$
were as follows: 0.36546, 0.7758, 1.4540, 1.0992, 8.85793, and 31.8651 cubic feet. Taking the coefficient of linear expansion for iron at .000005, it was computed that their capacities were increased or diminished 0.02 per cent. for every 10 deg. F. above or below that temperature, and they were taken accordingly. The normal temperature during the tests varied from 50 degrees to 60 degrees F. A few tests were made at 100 degrees F.

Regulating and Head Vessels: The capacities of the regulating vessels (Fig. 9) varied from 5 gallons to 800 gallons, and of the head vessels from 5 to 100 gallons, depending on the diameter of the pipe on which the experiments were being made.

Timing: The lengths of runs were taken by means of a reliable stop-watch regulated to within a negligible amount of error per hour by means of a galvanometer actuated by a standard timepiece at the Melbourne Observatory. It was frequently tested during the periods of experiment.

Levels of Pipes: In order to get the correct slopes by the gauge staff, the pipes were first set level by fixing them perfectly straight and filling the head vessel with water up to half bore of the pipe inlet. A glass plate was then placed over the outlet end, and the level of the pipe adjusted by wedging up the head vessel till the water rose behind the glass to exactly the same level as at the inlet. This was found to be a more reliable method than that of the ordinary carpenter's level or the surveyor's instrument. As a further precaution and check a plug was inserted in the end of the pipe, to which a rubber tube was attached, communicating with a vertical gauge glass. The pipe was then filled, all air expelled, and the water allowed to rise in the glass tube to the overflow level, which was scribed on the gauge staff. The height of the bottom of the meniscus above the centre of the pipe outlet, gave the total head, H, which could be measured to one-fortieth inch. The chief trouble in regulating the slope was found to lie in maintaining the exact rate of overflow in the head vessel. In all the experiments the head may at times have varied ± 1/16 inch owing to this difficulty. The pipes were kept fairly straight by means of trestles. Care was taken that all points were well below the hydraulic gradient, and that the head of water in the head vessel was always sufficient to amply meet the demands of entry head.

Gauge Staff: This consisted of two 4 x 2 inch timber uprights fixed 6 inches apart and supported on a well-bedded sill (Fig. 9). Holes 3 inch diameter were bored at 3 inch centres through the two uprights. An iron bar, 3 inch diameter, was put through any two of the holes as required to give the necessary fall to the pipe.

Calculations: Considerable saving in the time of computing results was effected by means of diagrams, which were made use of wherever possible. Some slight numerical discrepancies or inaccuracies may here and there appear in the tables owing to their use, but insufficient to sensibly affect the general results.

Positions of Pitot Tubes: The inlet ends of the iron pipes were
slightly bell-mouthed, so as to give the water a good lead, and reduce the positions of normal flow to as short a distance from the head vessel as possible. In nearly all the pipes the Pitot tubes were inserted about 35 diameters from the inlet end, but in the very small pipes the distance was sometimes as little as 20 diameters. It is thought that at all these positions the flow had become for all practical purposes normal.

**Critical Velocity:** As some of the experiments were made at very low velocities, it is necessary to make a few remarks on the subject of "critical velocity." Under ordinary conditions of flow, the loss of head varies as approximately the square of the velocity, but under extremely low velocities, depending on the diameter of the pipe and temperature of the water, it has been found that a change in the conditions of flow takes place. Prof. Osborne Reynolds* has shown that when water flows through pipes of small diameter, up to \( \frac{1}{4} \) inch at least, at such low velocities, the loss of head varies as the first power of the velocity. Then the flow takes place clear and unperturbed; but at certain critical velocities this condition changes, and the loss of head thereafter varies as a higher power of the velocity than the first (See Log. Dgm. G.) According to Messrs Saph and Schoder† (arrived at after many experiments on smooth brass pipes at the Cornell University) the laws for impending critical velocity for such pipes appear to be approximately

\[
V = \frac{6}{D^{0.57}}, \text{ with water at } 70 \text{ deg. F., and } V = \frac{0.16}{D^{0.76}}, \text{ with water at } 40 \text{ deg. F.}
\]

For pipes up to 2 inch diameter their conclusions may be expressed in tabular form as under:

<table>
<thead>
<tr>
<th>Diameter</th>
<th>At 40°</th>
<th>At 55°</th>
<th>At 70°</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \frac{1}{4}'' )</td>
<td>2.74</td>
<td>2.28</td>
<td>1.82</td>
</tr>
<tr>
<td>( \frac{1}{2}'' )</td>
<td>1.63</td>
<td>1.35</td>
<td>1.08</td>
</tr>
<tr>
<td>( \frac{3}{4}'' )</td>
<td>1.30</td>
<td>1.00</td>
<td>0.80</td>
</tr>
<tr>
<td>1''</td>
<td>0.97</td>
<td>0.80</td>
<td>0.64</td>
</tr>
<tr>
<td>( 1\frac{1}{2}'' )</td>
<td>0.71</td>
<td>0.59</td>
<td>0.47</td>
</tr>
<tr>
<td>2''</td>
<td>0.57</td>
<td>0.47</td>
<td>0.38</td>
</tr>
</tbody>
</table>

Decided evidences of critical velocity were found by the author, as shown on Log. Diagram G, and it would certainly seem that the irregular ratio \( \frac{V_m}{V_c} \) at low velocities, as presently illustrated, is in some way connected with this phenomenon.

* Proceedings of Royal Society, Vol., xxxv, 1883.
In the discussion on Messrs. Williams, Hubbell and Henkell’s paper upon the flow of water in pipes,* in which the authors found that the ratio of the mean velocity to the maximum velocity at the centre of the pipe averaged 0.84 in 12in., 16in. and 30in. pipes, Mr. E. C. Thrupp remarked that the 12in. pipe experiments show the critical velocity at which the ratio begins to diminish to be about 0.14 foot per second, the 16 inch at about 0.30, and the 30 inch at about 0.70 feet per second; and that the phenomenon in the case of rivers is illustrated clearly in the experiments of the Mississippi River Commission, at Carrollton, in 1882. He states that he has found “that when the hydraulic radii of pipes or open channels exceed 2 inches, the critical velocities increase with the hydraulic radius, whereas from experiments in pipes less than one inch in diameter, it is well known that the critical velocity bears an inverse relation to the hydraulic radius.”

If we assume these two critical velocities to be analogous, and take a mean temperature of 55 degrees, and plot the results obtained by Messrs. Saph and Schoder’s formula, together with the results referred to in Messrs. Williams, Hubbell and Henkell’s paper, the reversal of the curve is clearly indicated on the following diagram.

Diagram F.

Approximate Critical Velocities at 55° F. for pipes of various diameters.

Mr. Thrupp further stated that he had found “that the velocity required to disturb fine silt in channels of various depths is apparently identical with the critical velocity, and the whole question of the scouring power and silt carrying capacity of rivers is intimately bound up with the critical velocity laws, which are the main factors determining the ‘degree of turbulence’ of the motion and the consequent power of the water to disturb and transmit solid matter.”

Logarithmic Diagram G: On this diagram are shown the mean velocities, as obtained by tank calibration for all the pipes

Logarithmic Diagram G.
tested by the author, except those whose plotting's would by overlapping have led to confusion. The experimental results, for instance, of the 2.02 inch woodstave pipe and the 2.089 inch B.W.I. pipe almost exactly overlap those of the 1.74 inch brass tube shown.

On the diagram are also plotted such of the author's collated experiments on larger pipes, as run down into low velocities within the scope of the diagram—two groups by Darcy, one by Iben, and one by Hamilton Smith, jr. From these results it would appear that at the critical velocity the exponents of S and V do not change abruptly, but by easy transition, commencing at somewhat higher velocities than Saph and Schoder's formula would indicate, with a reversal of the critical velocity curve, if such reversal exist, at a much smaller diameter than that shown on diagram F. The computed exponents of S and V are marked in each case on this diagram. The following is an example of the method of computation in the case of the 1 inch B.W.I. pipe.

To find the exponent of S corresponding to the straight line intersecting the experimental results shown in Diagram G.

Given \( H = \frac{1.75}{100} \) or \( S = 0.0175 \), and \( V = 1.56 \times 10^2 \)

Given \( H = \frac{74.6}{100} \) or \( S = 0.746 \), and \( V = 13.05 \times 10^2 \)

Ratio of Velocities = \( \frac{1}{8.365} \)

Let \( x \) equal the required exponent.

Then \( \frac{74.6^x}{0.175^x} = 8.365 \)

or \( 42.63^x = 8.365 \)

\( x \) \( \log \) 42.63 = \( \log \) 8.365

\( x \) \( \log \) 8.365 = \( \log \) 42.630

\( x \) = \( \log \) 42.630

\( x \) = 0.922466

\( \therefore \) the exponent of S = 0.566

In Chezy's fundamental formula \( V = C \sqrt{S} \), the exponent of S is seen to be 0.5, but it is now generally recognised that this figure is too low, and that it is nearer 0.55 or 0.57. It would seem, however, that this conclusion may only apply to comparatively small pipes. Darcy's results indicate that already at 5 in. diameter, \( \sqrt{S} \) is correct, and that the loss of head then varies as the square of the velocity. Evidence is moreover not wanting that in pipes of 6 feet diameter \( \sqrt{S} \) correctly applies at above the critical velocity region, the exponent increasing at velocities below the critical, thus indicating a falling off in the discharge. From the indications on Diagram G these critical velocities might be ex-
pected to fall into a curve or straight line in the approximate direction A—B. Such a line would evidently be somewhat at variance with the curve shown in Diagram F.

Diagram H.—This diagram shows in a fairly representative form the results as generally obtained by the Author with the P.T. instrument. The two lines indicating the loss of head by the impact and pressure tubes are plotted on the scale on the left, the curves of the velocities to the scale on the right of the diagram.

Diagram J.—On this are shown a number of traverses of the 1 inch pipe. No. 1 traverse indicated a straight line as the distribution of velocities, the water apparently advancing as a square ended column, perhaps rounded a little at the pipe walls, where, owing to the finite dimensions of the Pitot impact tube the velocity could not be ascertained. No difference whatever could be detected in the level of the water columns in traversing the pipe with water flowing at this low velocity. In No. 2 traverse the straight portion extends over half the diameter only. No. 3 is almost the segment of a circle. Nos. 5, 6, 7 and 8 show a well defined apex. In No. 9 the apex has changed to a curve. No. 10 clearly indicates that some temporary obstruction or abnormal condition (probably at the pipe inlet) has caused a deflection of the maximum velocity away from the centre of the pipe, continuing throughout the period of time occupied in making the traverse.

Diagram H.
0.9871" B.W.I. Pipe.
Diagram J.
Horizontal Traverses of B.W.I. Pipe 0.9871" Diameter showing distribution of Velocities of various rates of discharge as obtained by Pitot Tubes.

Diagram K.
B.W.I. Pipe 0.9871 inch diameter.

No. 11 indicates a return of the maximum velocity to the centre, the obstruction no doubt having been removed by the disturbance of setting the pipe to the steeper slope after completing the former traverse. This curve shows a peculiar flattening of the head, and were it not for the long trailers, might be taken as showing a tendency to revert to the original straight line. Its ratio, however, computes to exactly 0.84, which is apparently the maximum for this particular pipe, in which the velocity at the pipe wall appears to be about two-thirds of the central velocity.

The following table shows in detail the readings and computations of traverse No. 11:

### TABLE VI.
Computations for traverse No. 11, Diagram J.
(Loss of head by pressure tube = 71°40")

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>0°5d</td>
<td>39°50</td>
<td>31°90</td>
<td>13°08</td>
</tr>
<tr>
<td>1</td>
<td>36°00</td>
<td>35°40</td>
<td>13°78</td>
</tr>
<tr>
<td>1'5</td>
<td>31°75</td>
<td>39°65</td>
<td>14°39</td>
</tr>
<tr>
<td>2</td>
<td>28°40</td>
<td>43°00</td>
<td>15°19</td>
</tr>
<tr>
<td>2'4</td>
<td>26°80</td>
<td>44°60</td>
<td>15°47</td>
</tr>
<tr>
<td>2°45</td>
<td>26°50</td>
<td>44°90</td>
<td>15°57</td>
</tr>
<tr>
<td>3°15</td>
<td>26°00</td>
<td>45°40</td>
<td>15°61</td>
</tr>
<tr>
<td>3</td>
<td>26°50</td>
<td>44°90</td>
<td>15°52</td>
</tr>
<tr>
<td>3'55</td>
<td>26°75</td>
<td>44°65</td>
<td>15°48</td>
</tr>
<tr>
<td>4</td>
<td>27°00</td>
<td>44°40</td>
<td>15°44</td>
</tr>
<tr>
<td>4'7</td>
<td>26°75</td>
<td>44°65</td>
<td>15°48</td>
</tr>
<tr>
<td>5</td>
<td>27°30</td>
<td>44°10</td>
<td>15°38</td>
</tr>
<tr>
<td>5'85</td>
<td>32°00</td>
<td>39°40</td>
<td>14°54</td>
</tr>
<tr>
<td>6</td>
<td>36°00</td>
<td>35°40</td>
<td>13°78</td>
</tr>
<tr>
<td>6'95</td>
<td>39°50</td>
<td>31°90</td>
<td>13°08</td>
</tr>
</tbody>
</table>

\[ V_m = 13°05 \]
\[ V_c = 15°52 \]
\[ = 0°84 \]
Ratio Diagrams $\frac{V_m}{V_c}$

1. No. 1: 0.315" Brass
   Ip = 52.12

2. No. 2: 0.325" GI
   Ip = 52.40

3. No. 3: 0.495" IR
   Ip = 41.40

4. No. 4: 0.604" GI
   Ip = 50.60

5. No. 5: 1.74" Brass
   Ip = 317.8

6. No. 6: 2.089" GI
   Ip = 217.4

7. No. 7: 12° C.I.
   Williams, Hubbell & Fenkell

8. No. 8: 16° C.I.

9. No. 9: 30° C.I.
   Williams, Hubbell & Fenkell

Velocity at Centre of Pipe, Ft per Sec
Diagram K.—This shows experimental results at two temperatures. It is evident that the ratio increases slightly with the temperature of the water in small pipes.

After making tests up to a velocity of 8 feet per second at 60 degrees it was desired to find in what direction the ratio curve would advance under the higher velocities. If, for instance, the ratio continued to increase indefinitely as along A B, a velocity would eventually be reached at which the ratio would be unity, and the distribution of velocities would again form a straight line. This is possible, but hardly probable; whilst if the ratio increased to anything above unity it would signify that the mean velocity was greater than the maximum, which is absurd. Consequently, it seems a reasonable proposition that a certain maximum ratio must obtain, and this is assumed to be 0.84 for this particular tin. pipe (as shown by the horizontal line on the diagram). This is apparently reached at a central velocity of about 8 feet per second.

The high velocities in this pipe were obtained by substituting a vertical 10in. tube 8ft. 6in. high for the head vessel shown in Fig. 9, and shortening the pipe from 211.6 to 100 inches.

Ratio Diagrams.—On this sheet are shown in diagrams 1 to 6 a number of the Author's experiments regarding the ratio \( \frac{V_{in}}{V_{c}} \) for different kinds of pipe. They are typical of the results generally obtained. The tendency of the ratio to increase with the velocity at central velocities of from 2 to 7 1/2 feet per second is clearly observable, also the tendency in the small pipes for the ratio to increase towards unity under the low velocities, as found in the case of the tin. pipe.

Mr. Hiram F. Mills,* in experiments on a straight 12in. diameter smooth tar-coated cast iron pipe also found the ratio to increase with the velocity up to a \( V_c \) of about 7ft. per second, thereafter remaining fairly constant at an average of 0.855, as shown in the following table:

<table>
<thead>
<tr>
<th>( V_{in} )</th>
<th>( V_{max} )</th>
<th>Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>1'0001</td>
<td>1'206</td>
<td>0'8293</td>
</tr>
<tr>
<td>2'090</td>
<td>2'500</td>
<td>0'8360</td>
</tr>
<tr>
<td>3'233</td>
<td>3'811</td>
<td>0'8483</td>
</tr>
<tr>
<td>4'244</td>
<td>4'990</td>
<td>0'8505</td>
</tr>
<tr>
<td>5'164</td>
<td>6'053</td>
<td>0'8531</td>
</tr>
<tr>
<td>6 to 11'5</td>
<td>6'9 to 13'4</td>
<td>0'855 average</td>
</tr>
</tbody>
</table>

In No. 6 an attempt was made to locate the curve in the case of a 2in. B.W.I. pipe, but the results are seen to be very erratic. It is evident that even at 2in. diameter, central velocities of less than 2½ feet per second are insufficient to ensure the maximum velocity remaining in the centre of the pipe.

Diagrams 7, 8 and 9 show the experimental results of Messrs. Williams, Hubbell, and Fenkell, tabulated in Table I. Diagram 9 indicates much uncertainty in the case of the 30in. pipe, but there can be no doubt as to the indications of Nos. 7 and 8.

At central velocities below 2 feet per second, the evidence regarding the ratio \( \frac{V_m}{V_c} \) is very contradictory. Whereas, in his special experiments on a 1in. pipe, the Author found the ratio to increase towards unity with diminishing velocities, Messrs. Williams, Hubbell and Fenkell found in four cases in the 30in. pipe the following marked decreases from their average ratio of 0.84:

<table>
<thead>
<tr>
<th>( V_c )</th>
<th>( \frac{V_m}{V_c} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.986</td>
<td>0.575</td>
</tr>
<tr>
<td>1.070</td>
<td>0.569</td>
</tr>
<tr>
<td>1.630</td>
<td>0.723</td>
</tr>
<tr>
<td>0.779</td>
<td>0.751</td>
</tr>
</tbody>
</table>

They, however, found in two cases very marked increases, as under:

<table>
<thead>
<tr>
<th>( V_c )</th>
<th>( \frac{V_m}{V_c} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.940</td>
<td>0.914</td>
</tr>
<tr>
<td>1.322</td>
<td>0.994</td>
</tr>
</tbody>
</table>

It is evident, then, that there is much uncertainty regarding the ratio at central velocities below 2 or 2½ feet per second in large pipes, and the reason is apparently not difficult to understand.

Assume, for instance, the case of a large main with a stop valve on it, only slightly opened, so that the velocity of the water in the main is very low. It is evident that the bulk of the water space on each side of the valve, in proximity to it, will be filled with practically still water, the main stream being along the bottom of the pipe. The tendency of the water to advance along the line of least resistance should, however, cause the stream of maximum velocity to gradually approach the centre of the pipe—not directly, as after passing a bend where the whole body of
the water is affected, but probably by an irregular wave-like or sinuous motion. The distance of the position of normal flow from the valve may be very considerable on account of the scope for amplitude of such wave motion in large diameters. The ratio $\frac{v_m}{v_c}$ may, therefore, be high or low according to the position of the Pitot tube with respect to this sinuous motion of the maximum velocity. The larger the pipe, the greater the scope for fluctuations in its position, and consequently the more erratic would the ratios probably be, while curvature and bad alignment would no doubt accentuate the sinuosity, with a consequent loss of energy and a reduced discharge.

In order to overcome this difficulty, a number of impact tubes combined in one have been tried and readings of the traverse taken simultaneously. With what degree of success the Author is unaware. The practical engineer, however, seldom deals with such low velocities, and there would be no demand for such an instrument, even if successful, which is doubtful, considering that once the maximum velocity departs from the centre it may occupy almost any position in the pipe.

In small pipes, on the other hand, there is little scope for these fluctuations, and at extremely low velocities, friction being almost negligible, the water may advance as a square-ended column, with the distribution of velocities as practically a straight line, and consequently a ratio approaching unity, as in the case of the tin pipe.

Consideration then leads to the conclusion that in large pipes the ratio may either fall below or rise above the normal, depending on circumstances impossible to foresee, and that the ratios for large pipes under low velocities are, therefore, not definitely ascertainable. In fact, it would almost appear with regard to the larger pipes that the critical velocity is that mean velocity, not at which the ratio $\frac{v_m}{v_c}$ begins to diminish, but at which the maximum velocity ceases to maintain its normal position in the centre of the pipe, and at which any formula suited to the higher velocities ceases to apply. Further, it would seem that at above critical velocities the stream flow under normal conditions is in straight lines, while at below critical velocities, the reverse is the case. There are strong indications that in large pipes the critical velocity may reach as high as 3 feet or more per second. The subject, however, is only incidental to this paper, and space does not permit more than passing reference pending further investigation.

The method adopted by the Author has been to neglect these low velocities and to read from the curves on the Ratio Diagrams the ratios $\frac{v_m}{v_c}$ at velocities from 2 to 8 feet per second for the various pipes. These have been plotted on Diagram L, and curves drawn through the results, as shown. These curves have been reproduced on Diagram M, which may be said to represent a diagrammatic mean of means.
TABLE VIII.

Ratios $V_m / V_c$.

(As read from Diagram M).

<table>
<thead>
<tr>
<th>Diameter of Pipe in inches.</th>
<th>Central Velocities feet per second.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2</td>
</tr>
<tr>
<td>1/4</td>
<td>-750</td>
</tr>
<tr>
<td>1/2</td>
<td>-780</td>
</tr>
<tr>
<td>1</td>
<td>-798</td>
</tr>
<tr>
<td>1 1/2</td>
<td>-807</td>
</tr>
<tr>
<td>2</td>
<td>-812</td>
</tr>
<tr>
<td>2 1/2</td>
<td>,,</td>
</tr>
<tr>
<td>3</td>
<td>,,</td>
</tr>
<tr>
<td>4&quot; &amp; ov.</td>
<td>,,</td>
</tr>
</tbody>
</table>

The ratios submitted in Table VIII have been read from Diagram M. It should be remembered that these ratios...
PITOT TUBES. 191

may vary slightly with the nature of the pipe and the temperature of the water, but it is thought they should give results within ± 3 per cent. of the truth, under such ordinary conditions as are usually met with in practice.

Pressure Distribution.—As already mentioned, horizontal traverses of the small pipes below 1 in. diameter with the pressure tube showed a slight rise of the water level in the gauge glass when the nib of the tube was in proximity to the wall of the pipe. This is attributed to the comparatively large portion of the area of the pipe occupied by the tube and to impact effects caused by eddies in the circumscribed space so occupied. In pipes over 1 in. diameter no difference whatever in the level of the water column could be detected in any of the horizontal traverses. Hence it is concluded that the pressure $H_f$ in a pipe discharging water is the same at all points on a horizontal traverse.

In order to find the effects in a vertical traverse, the 2.6874 in. B.W.I. pipe was turned round 90 degrees, so as to bring the Pitot instrument vertical. Under hydrostatic conditions the water of course rose to the level of the tank overflow. When the pipe was discharging water, the column naturally rose to the same level as that found in the horizontal traverse, when the tube was in the centre of the pipe. When the tube was drawn up to the top of the pipe, the water, however, rose about 1-10 in. in the gauge glass above the normal ($V_m$, being 2.9), and when the nib was traversed to the bottom of the pipe, it dropped a corresponding amount below. These differences are attributed to changes in the hydraulic gradient when measured from $H_n$ (see Fig. 9) to the top or bottom of the pipe outlet, instead of to the centre. In long pipes they would probably be so small as to be negligible, so that the indications $H_f$ on the Pitot pressure tube gauge should then be the same, no matter what position the nib may occupy in the pipe, i.e., the water should rise to the hydraulic gradient.

Incrustation.—Some experiments were made with a pipe incrusted with a hard and very rough lime deposit, whose mean incrusted diameter was 0.8 inch. The mean ratio of eleven experiments at central velocities ranging from 2 to 8 feet per second was found to be 0.723 or 70 per cent. below the normal. The effect of roughness, however, may be expected to diminish with an increase in diameter. The same pipe thoroughly cleaned gave a mean ratio of 0.812 with water at 50 degrees, and 0.803 at 100 deg. F.

Conclusions.

The following are the conclusions arrived at by the Author:—

(1) That the discharge of any pipe of known diameter in which the conditions of flow are normal, should ordinarily be obtainable within ± 3 per cent. of error by means of properly calibrated Pitot tubes when the mean velocity is not less than about 1½ ft. per second.
(2) That in a rín. black wrought iron pipe the ratio of the mean to the central velocity \( \frac{V_m}{V_c} \) is approximately unity under a very low velocity, decreasing as the velocity increases till a minimum ratio is reached at a central velocity of about 2½ ft. per second, thereafter increasing till a maximum ratio is attained at a central velocity of about 8 ft. per second, and then remaining constant.

(3) That in large pipes the ratio \( \frac{V_m}{V_c} \) at low velocities may rise above or fall below the normal, according to circumstances, and is not definitely ascertainable.

(4) That in all pipes the ratio \( \frac{V_m}{V_c} \) increases with the velocity from about 2 ft. per second, till a maximum ratio is attained at a central velocity of 7 to 8 feet per second, thereafter apparently remaining constant.

(5) That the ratios \( \frac{V_m}{V_c} \) vary from 0.750 in the case of a \( \frac{1}{2} \) in. pipe with \( V_c = 2 \) ft. per second, to 0.890 in pipes 4 in. diameter and over with \( V_c = 8 \) ft. per second.

(6) That the mean ratios \( \frac{V_m}{V_c} \) for central velocities of 4 feet per second at 60 deg. F. are approximately as follows: For \( \frac{3}{4} \) in., 0.764; for \( \frac{3}{8} \) in., 0.793; for 1 in., 0.810; for \( \frac{5}{8} \) in., 0.830; 2 in., 0.839; 2 \( \frac{3}{8} \) in., 0.842; 3 in. and over, 0.843.

(7) That the ratio varies slightly with the nature of the pipe, particularly in the small diameters, diminishing as the degree of roughness increases.

(8) That in small pipes the ratio increases slightly with an increase in temperature of the water.

(9) That the critical diameter at which the ratio reaches a maximum appears to vary from about 2 \( \frac{1}{4} \) in. to 4 in., according to the velocity.

(10) That the critical velocity of Professor Reynolds, at which any formula suited to the higher velocities in any particular pipe ceases to apply, apparently extends throughout all diameters, and may reach as high as 3 ft. per second in the large sizes.

(11) That in pipes of over 1 in. diameter, the loss of head at entry is somewhat more than that computed by using the coefficient for a pipe mouthpiece discharging free to the atmosphere, and that the flow does not become normal till a position is reached some distance from the inlet of the pipe—depending on the shape of the mouthpiece.

(12) That in short pipes over 1 in. diameter, the correct loss of head and effective slope can only be obtained with sufficient accuracy for experimental work by means of a piezometer, or, preferably, a properly calibrated Pitot pressure tube.

Finally, that as a water measuring instrument (except in cases where the mean velocity is below 1.5 ft. per second) the Pitot tube
should have about the same efficiency as a well adjusted turbine inferential meter—that its lightness, portability, low cost and ease of application, should render it highly valuable for occasional observations in the hands of a practised operator, who knows his instrument and its limitations.

The tables, diagrams, and sketches in the above paper, together with some of the results of Messrs. Williams, Hubbell, and Fenkell’s, and of Messrs. Saph and Schoder’s experiments (in Diagrams marked A to E) were illustrated by means of lantern slides. A number of experimental Pitot tubes and other appliances were also exhibited by the Author.
might be some minor advantage in placing it elsewhere; but in practice the method adopted had been found satisfactory.

The President exhibited lantern view illustrations of the steel irrigation channels referred to by him at the preceding meeting.

Slides prepared by Mr. A. S. Kenyon in illustration of Victorian irrigation practice were exhibited on the screen, and were explained (in the absence of Mr. Kenyon) by Mr. Dethridge.

LIST OF LANTERN VIEWS ILLUSTRATING VICTORIAN IRRIGATION PRACTICE

2. Off-take from Casey's Weir.
4. Goulburn Weir, Western Channel.
5. Goulburn Weir, Western Channel Regulator.
7. Coliban Scheme, Gauging Weir near Malsbury.
8. Coliban Scheme, Inlet No.1, Tunnel under Railway between Malsbury and Taradale.
9. Coliban Scheme, Outlet Tunnel, Branch Channel to Expedition Pass Reservoir, Castlemaine.
10. Coliban Channel, Ferguson's Flume on Bendigo Branch.
12. Head-works, Cudgel Creek on Murrumbidgee River to supply Yanko, Narrandera, etc.
15. Mildura—Nicholl's Point.
17. Mildura—70ft. Channel, lined.
18. Wyuna Farm—Irrigating.
19. Wyuna Farm—Irrigating Fruit Trees.
21. Scooping at Birchip-Sea Lake Channel.
22. Preparing Land for Irrigation, by Buck Scraper.
23. Using the Buck Scraper.

Discussion closed.

PITOT TUBES, AND THEIR USE IN MEASURING THE VELOCITIES OF WATER, GAS AND AIR.

The President said a discussion on Mr. Bilton's paper would be no light undertaking. The communication would, however, have considerable value for reference purposes. In the title, Mr. Bilton had referred to "Gas and Air." He could not find that that application had been specifically dealt with in the body of the paper. Naturally, as an hydraulic expert, Mr. Bilton had given prominence to the question of water flow. Of course the principle was the same for all classes of fluid flow, and there was no great difference in the application if the air velocities were relatively high, such as the discharge from a pressure fan.

He had, however, found that there were very considerable difficulties in dealing with air, or gas, velocities of from ten feet down to a few inches per second. He had been brought into contact with such problems and had found the Pitot tube
effective, but the velocity heads were so small that ordinary fluid gauges were quite useless in this connection. That was one of the reasons which had induced him to seek a simple form of sensitive gauge.

Bearing in mind the fundamental fact that the velocity of free efflux was the same for a given vertical head of fluid, whatever (in this connection) the nature of the fluid, the difficulty was obvious. The pressure when dealing, for instance, with water, would be some sixteen hundred times greater than that to be determined when dealing with, say, illuminating gas.

For example: a velocity of 2 feet per second implied a head—whatever the fluid—of about \( \frac{3}{4} \) of an inch. Now, a simple water gauge could be conveniently read to \( \frac{1}{16} \) inch; that would in the case of the water flow mean an accuracy of 2 per cent. But dealing with the gas it would be necessary, to attain the same percentage accuracy, to read to \( \frac{1}{16} \) of \( \frac{3}{4} \) inch—a quite impossible condition. With a two-fluid differential gauge about twenty times as sensitive as the ordinary water gauge they could, in practice, hardly hope for a difficulty attainable accuracy within 20 per cent of the truth, when dealing with an air flow of about 2 feet per s., or within 40 per cent. in the case of the gas. The scale value of one per cent. accuracy on a given gauge varied, however, as the square of the velocity. Therefore at a velocity of about 100 ft. per s., one per cent. accuracy could be comfortably secured in the case of air.

Mr. C. P. Fairie Wright said Mr. Bilton had dealt so fully with the subject that he felt some diffidence in attempting to discuss it.

In the first place, in connection with the form of pressure tube adopted, there seemed to have been a difficulty in getting a satisfactory one. The type which Mr. Bilton had adopted was very similar to one adopted in the National Physical Laboratory, and used by Dr. Stanton.* That type had a torpedo-shaped point. The tube was about \( \frac{1}{10} \) inch in diameter, the distance from the point of the nib to the bend in the tube being about 2 inches. The holes were \( \frac{1}{10} \) inch from the point, and there were 4 holes \( \frac{3}{50} \) inch diameter. That was used for measuring air pressure, and gave very satisfactory results.

Also for gas measurement there was a form of pressure tube which had been used by Messrs. Heenan and Gilbert,† and by Mr. R. Threlfall.‡ This was simply a straight tube with a flange at the end, and projecting into the inside of the pipe. On inserting the tube into the flow, the stream lines were deflected, and they got a low pressure area on the down stream side of the tube, causing suction. The flange was said to protect the mouth of the tube from this influence, and gave very satisfactory results.

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The President asked what would be the effect were the disc at a considerable distance from the wall of the channel.

Mr. Wright said he could not say, but he thought the effect would be the same—to protect the mouth from the low pressure on the down stream side.

Mr. Threlfall, working with gas, had found that the distribution of the velocity in a pipe was not a function of the velocity, as far as his experiments went. The experiments had been conducted with velocities of from 10 feet up to 60 feet per second, and the distribution did not vary with the velocity. In these experiments (on gas pipes from 6 inches to 36 inches in diameter), the mean velocity radius was found to be 77.5 per cent. of the pipe radius, and the ratio of the mean to the maximum velocity to be very constant, and equal to 0.873.

Mr. Threlfall had recommended the use of the Pitot tube for meter purposes, and considered that where calibration of the pipe was not resorted to, it was preferable to place the Pitot tube at the radius of mean velocity, rather than to place it at the centre of pipe and rely on the ratio of mean to maximum velocity.

The meter described by Mr. Threlfall was of a different type to those mentioned in the paper. In this meter, the difference of pressure, due to the velocity of flow, was brought to bear on a bell held in position with springs, and partly immersed in oil, like a gasholder. The pressure tended to depress the bell. This action was resisted by a series of electro-magnetic coils, the apparatus being so arranged that the forces exactly balanced. If the bell were depressed, it increased the current flowing through the coils, and thus the bell was practically held in a constant position. Now the pressure, tending to displace the bell, would vary as the square of the velocity, and the attraction of the magnetic coils, resisting the displacement, varied as the square of the current flowing through the coils. Hence the current was proportional to the velocity of flow, and if the current were passed through an ampere-hour meter, it was possible, once the constants were determined, to deduce the flow of gas from the readings of the meter. Mr. Threlfall stated that this meter had been tested for 18 months, and had given very satisfactory results.

Another thing he might mention was the case of measuring air pressure where eddies were experienced, as in measuring the resistance of railway carriages. What was found very serviceable by Mr. Wingfield* was a wire gauze sandwich, held in position between iron plates, and placed over the mouth of the pressure tube. It gave very good results. Mr. Threlfall had also tried a plug of cotton wool in the mouth of the pressure tube.

In connection with Mr. Bilton's remarks on critical velocity, it was interesting to notice that up to a certain diameter of pipe, the critical velocity varied inversely with the diameter.

decreasing as the diameter increased, whilst above that the critical velocity apparently varied directly with the diameter, increasing as the diameter increased. As bearing on this point, he might refer to some experiments made by Messrs. Barnes and Coker, * of the McGill University. They were interesting because of a novel way of checking the critical velocity, depending on the fact that when water was flowing through a pipe in steady or stream line flow, i.e., below the critical velocity, the transmission of heat from the centre of pipe to the sides, or vice versa, was exceedingly slow. As soon, however, as the critical velocity was reached, and the eddy flow set in, heat was rapidly transmitted. Messrs. Barnes and Coker surrounded a brass pipe with a water jacket, and placed a thermometer in a glass pipe connected to the outlet of the brass pipe. A large supply tank was used, in which the water could be brought to a perfectly still condition. At the end of the glass pipe they had a two-way cock by which they could turn the flow into a measuring vessel or allow it to waste. The water was allowed to flow through at an increasing velocity, and the thermometer watched. At a certain point, corresponding to the critical velocity, the thermometer rose with a sudden jump. At that the water was turned into the measuring vessel, and the flow measured. Working in that way, they had from some of the bigger sizes of pipes got a critical velocity much greater than that calculated from the formula of Professor Osborne Reynolds. In one case the pipe experimented on was about 2 inches diameter. The calculated critical velocity was about \( \frac{1}{3} \) meter per sec., and the observed critical velocity about 1 meter per sec. Messrs. Barnes and Coker pointed out that in small pipes the influence of the walls or sides was proportionately greater, and that in larger pipes the conditions of flow might gradually approximate to those in the jet from an orifice, where there were no walls, and where they had obtained stream line flow at velocities of 20-30 feet per sec. Thus they considered that the inverse diameter law might hold up to a diameter of about \( \frac{1}{4} \) inch, but that above that diameter, the critical velocity might increase with the diameter of pipe. He thought that was interesting, because it bore out the fact shown by Mr. Bilton in his paper, that for the larger sized pipes the critical velocity increased with the diameter.

As regarded the distribution of velocity across the diameter of a water pipe, Mr. J. Morrow* had investigated this at velocities below, and slightly above, the critical velocity; using a pipe about 2 inches diameter. Below the critical velocity he found practically a parabolic distribution, and the velocity at the wall of the pipe was practically nil. In all his experiments there appeared to be no slip at the sides of the pipe. As Mr. Bilton had pointed out, it was impossible, owing to the finite dimensions of a Pitot tube, to measure the velocity right at the walls of

*Proc. Roy. Soc., Vol. 74, p. 34.
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a pipe, so that what took place there was somewhat a matter of conjecture. Thus Professor Hele-Shaw considered that his experiments showed a layer or film of water adjoining the solid surface, moving in steady flow, even where the body of the water was in sinuous motion. Professor Osborne Reynolds had, however, differed from the conclusions arrived at by Professor Hele-Shaw.

The President said that a description of stream-line methods would be found in the "Proceedings" for 1902.†

He thought attempts to determine critical velocity by measurement of the thermal condition of the flow left matters in a very indeterminate condition. He had found it so in researches into condensation. The heating was progressive and the viscosity conditions therefore varied at every point. The matter was complicated by the non-knowledge of the exact mean condition on the outside of the tube, i.e., in the heating jacket.

The novelty of Messrs. Barnes and Coker's thermal method had been referred to by Mr. Wright. If Vol. VI. of the "Proceedings," pp. 194-7, were referred to it would be found that he also had dealt with that phase then. The diagrams relative to comparatively small tubes, then plotted, showed a quick change, but no indication of abruptness or "critical point."

The President called upon Mr. Bilton to reply.

Mr. H. J. I. Bilton, in reply, said, with reference to the President's remark as to the title of the paper, he had not made any tests either with gas or air, for which he had no time or opportunity. He would have been very pleased to have been able to do so, especially if he had had one of the sensitive instruments submitted by Mr. Smith. He had to do the best he could in a limited time, with the ordinary water column. That had been found fairly reliable down to water velocities of about 4 inches per second. They would see plotted on diagram J a traverse at this velocity. He could find no difference whatever in the levels of the water columns in this traverse. Possibly if he had possessed an instrument as sensitive as that exhibited by the President, some changes might have shown themselves. His conclusions were entirely dependent on the gauge he used. It was possible that between the points of traverse there might have been variations, but they were so slight that for all practical purposes it might be said that the water advanced as a square ended column in that particular case. The reason he gave the title to the paper was that it largely dealt with the shapes of Pitot tubes, and he thought it would be interesting to members to see what had been done in that direction, when applied to gas and air measurement as well as water. He found Mr. Wright's remarks very interesting. The shape of the pressure tube with the flange was not unknown to him, but he was not aware

* The speaker described the Hele-shaw stream line methods.
whether the results would be affected by its position, in relation to the wall of the pipe. He should imagine they would be to some extent, though he could not speak from personal knowledge, as he had not noted it. His experiments were made first with a blunt ended tube, and the water could be distinctly seen splaying off the edges. He soon realised that that shape of pressure tube was not the best, and finally found that a pointed nib, not less than six external diameters in length, gave the best results, as far as could be seen, when the nib was placed in the jet from a circular orifice. There was no trouble with air bubbles in a pressure tube of that shape. He had found two holes most suitable. If one hole only were placed on the inside of the nib, this would cause oscillation of the water column.

In his paper he had been careful to remark as to the possibility of the sharp-pointed pressure tube being original, but from Mr. Wright’s remarks it appeared that it was not so. It was truly difficult to find anything new under the sun.

He was very much interested in Mr. Wright’s description of the means of measuring by photopitometer.

The subject of critical velocity was to him one of the most important points suggested in the paper. But he had had so little time to study the available data that he could not make a particular point of it. He might say that much of the data he had collected tended to show that the discharge of pipes often fell off considerably, even at high velocities. It was particularly noticeable in large steel rivetted mains. It was very seldom that the velocity in such large mains exceeded 5 or 6 feet per second, and it practically meant that the critical velocity factor might account for the abnormal diminution in the discharge, and the barren results of attempts often made to fit such velocities to any formula. If they would look at diagram G, page 29, they would see that the curves extended down to the 12 inch pipe, at a velocity of 3 feet per second. A line in the direction, A-B, across the diagram would indicate an approximate critical velocity curve. If the critical velocity was as high as 2 feet per second in a 12 inch pipe, what might it not reach in the larger mains, such as 6 feet diameter? It seemed to him that the larger the diameter of the pipe, the more scope there was for sinuous motion and eddy flow of the water. Was it not possible that the low velocities that were frequently found might be largely due to this phenomenon? It was a subject in which there was scope for a great deal of further investigation.

In conclusion he thanked members for the interest they had taken, and the attentive hearing they had given to a somewhat long and technical paper.

The President, in closing the discussion, said there was reason to hope that Mr. Bilton would contribute a further paper next year upon the effect of temperature upon flow. Members would look forward to having further matter on that phase so placed before them.
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Pitot tubes, and their use in measuring the velocities of water, gas and air (Paper & Discussion)

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