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Managing Irrigation for Environmentally Sustainable Agriculture in Pakistan

MANUAL FOR MEASURING PUMP DISCHARGES WITH A LOW-COST EASY-TO-USE PITOT TUBE

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NOMENCLATURE

$0.3d_w$	30 percent of the depth of water measured from the pipe invert.
$0.6d_w$	60 percent of the depth of water measured from the pipe invert.
$0.8d_w$	80 percent of the depth of water measured from the pipe invert.
$0.9d_w$	90 percent of the depth of water measured from the pipe invert.
A	Cross-sectional area of flow (L^2).
A_I	Inside cross-sectional area of the pipe (L^2).
A_w	Area of cross-section through which water is flowing (L^2).
C	Velocity coefficient equal to unity.
D_I	Inner diameter of the pipe (L).
D_o	Outer diameter of the pipe (L).
d_w	Depth of water in the pipe (L).
g	Acceleration due to gravity (L/T^2).
h	Rise of water above the free water surface i.e. velocity head (L).
h_1	Static pressure head (L).
h_{max}	Maximum rise of water in Pitot Tube (L).
$h_{max}+d_w$	Maximum velocity head gauge reading plus depth of water in the partially flowing pipe.
h_{mean}	Mean velocity head (L).
h_{min}	Minimum rise of water in Pitot Tube (L).
$h_{min}+d_w$	Minimum velocity head gauge reading plus depth of water in the partially flowing pipe.
K_w	Coefficient for partially filed pipe.
Q	Discharge rate (L^3/T).
Q_{60}	Discharge calculated when Pitot tube is placed at 60 percent of the depth of water in the delivery pipe (L^3/T).
Q_{80}	Discharge calculated when Pitot tube is placed at 80 percent of the depth of water in the delivery pipe (L^3/T).
Q_{90}	Discharge calculated when Pitot tube is placed at 90 percent of the depth of water in the delivery pipe (L^3/T).
R^2	Coefficient of determination.
t	Thickness of the pipe rim (L)
v	Velocity measured by Pitot Tube (L/T).
V	Mean Velocity (L /T).
v_{60}	Velocity measured at 60 percent of the depth of water from the pipe invert (L/T).
v_{80}	Velocity measured at 80 percent of the depth of water from the pipe invert (L/T).
v_{90}	Velocity measured at 90 percent of the depth of water from the pipe invert (L/T).
V_c	Velocity at the center of the pipe (L/T).

FOREWORD

There are at least 15-20 million pumps located in Asia for lifting irrigation water. Likely, there are 30 million, or more, irrigation pumps scattered around the world, with the vast majority (say 80 percent) having been installed during the past forty years.

In developed countries, many of these pumps (but not all) are fitted with flow measuring devices. In developing countries, the added cost for such devices is commonly avoided. Only occasionally are a few of the pumps measured for their discharge rate. This is most commonly done using the Trajectory Method, where the horizontal and vertical dimensions are measured on the upper nappe of the jet emanating from the pump discharge pipe into the atmosphere; however, the inaccuracy of the calculated discharge varies from roughly 5-15 percent, but is usually more than 10 percent.

Dr. M.S. Shafique began tackling this problem while Head of the Sudan Program for IIMI from June 1989 to June 1995. He was looking for an economical way to measure both small and large pump discharges in a manner that would not constrict the flow, which would reduce the pump discharge. He soon caught onto the concept of using a Pitot Tube, which measures velocity head that can be converted into a discharge rate by knowing the cross-sectional area of the water in the pipe. Then, Dr. Shafique began seeking ways to produce a low-cost Pitot Tube that would be easily affordable.

The initial field tests were conducted on small and large pumps for lifting irrigation water from the Whie Nile and Blue Nile rivers. Then, more detailed laboratory studies were undertaken with the Hydraulic Research Station located at Wad Madani in Sudan.

After transferring to the Pakistan National Program of IIMI in June 1995, Dr. Shafique undertook more extensive laboratory studies at the Centre of Excellence in Water Resources Engineering (CEWRE), University of Engineering and Technology, Lahore. He was soon joined by Mr. Nisar Hussain Bukhari, who had been deputed to IIMI by the On-Farm Water Management Directorate, Department of Agriculture, Government of Punjab. Later, Mr. M. Mohsin Hafeez undertook his M.Sc research at CEWRE as part of this team. They have made a significant contribution in developing an economical device for measuring pump discharge that is accurate within 2-3 percent.

This manual has been prepared for the benefit of those who would like to fabricate this low-cost Pitot Tube apparatus, then measure pump discharge rates with this easy-to-use device. The fabrication, use and discharge calculations are described in this manual.

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1. INTRODUCTION

There has been a proliferation of wells owned by individuals in South Asia and China (Yudelman, 1989). Beginning in the early 1960s, the number of pumps installed in the Indian Subcontinent to lift water from groundwater, rivers, canals or reservoirs now number in the millions. For example, in Pakistan, by 1986 there were 250,000 tubewells, with 80 percent in Punjab Province (Rehman et al, 1997); today, the total number of tubewells is estimated at 400,000 or more. The installation of private tubewells has been most significant in India where the number increased from 259,000 in 1968 to 3.3 million in 1984-85 (Yudelman, 1993). There are also many pumps in Bangladesh.

Yudelman (1993) also reported that there are more than five million small pumps in Thailand used primarily to lift water out of canals and rivers for use on rice paddies. Taking into account the millions of pumps used in China related to irrigation, there are well over ten million pumps used in developing countries for lifting water in order to irrigate croplands. In fact, a conservative estimate would be 15-20 million irrigation pumps installed in developing countries.

The explosion in employment of pump technology for irrigation has contributed significantly to increased production. But, at the same time, there is a growing concern about the conjunctive management of surface water and groundwater resources. There is a paucity of groundwater data, not only quantities, but also chemical characteristics. In addition, most groundwater reservoirs in developing countries are operated as "the commons" where any individual having sufficient financial resources can exploit this resource; there is a lack of institutional mechanisms for managing these commons. In fact, there is not even enough physical data available to arrive at appropriate management options. Certainly, one of the first steps will be to measure the discharges being pumped, which presently is rarely done.

The emphasis in irrigated agriculture is improved water management practices. As stated by Walker (1986), "whoever wrote water management had misspelled measurement." In other words, improved water management practices implies the necessity for water measurement. In addition, the statement can be made, "how can you improve the management of a resource when the quantity is not known, let alone the resource quality."

In developed countries, many of these pumps (but not all) are fitted with flow measuring devices. In developing countries, the added cost for such devices is commonly avoided. Only occasionally are a few of the pumps measured for their discharge rate. This is most commonly done using the Trajectory Method, where the horizontal and vertical dimensions are measured on the upper nappe of the jet emanating from the pump discharge pipe into the atmosphere; however, the inaccuracy of the calculated discharge varies from roughly 5-15 percent.

Dr. M.S. Shafique began tackling this problem while Head of the Sudan Program for IIMI from June 1989 to June 1995. He was looking for an economical way to measure both small and large pump discharges in a manner that would not constrict the flow, which would reduce the pump discharge.

He soon caught onto the concept of using a Pitot Tube, which measures velocity head that can be converted into a discharge rate by knowing the cross-sectional area of the water in the pipe. Then, Dr. Shafique began seeking ways to produce a low-cost Pitot Tube that would be easily affordable.

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2. HISTORICAL BACKGROUND

Henri Pitot (1695-1771) was a French engineer who conducted a series of experiments for measuring the flow of water in channels and pipes (Khurmi, 1982). He used a bent glass tube in 1730 to measure flow velocities in the River Seine (Daugherty et al., 1989). This tube was later named after the inventor. In its simplest and original form, the Pitot Tube has a right-angled bend to receive the impact of the stream as shown in Figure 1. In the case of open channel flow, when a Pitot Tube is impacted by the stream, water rises to a height 'h' above the free water surface (Figure 1) in the tube.

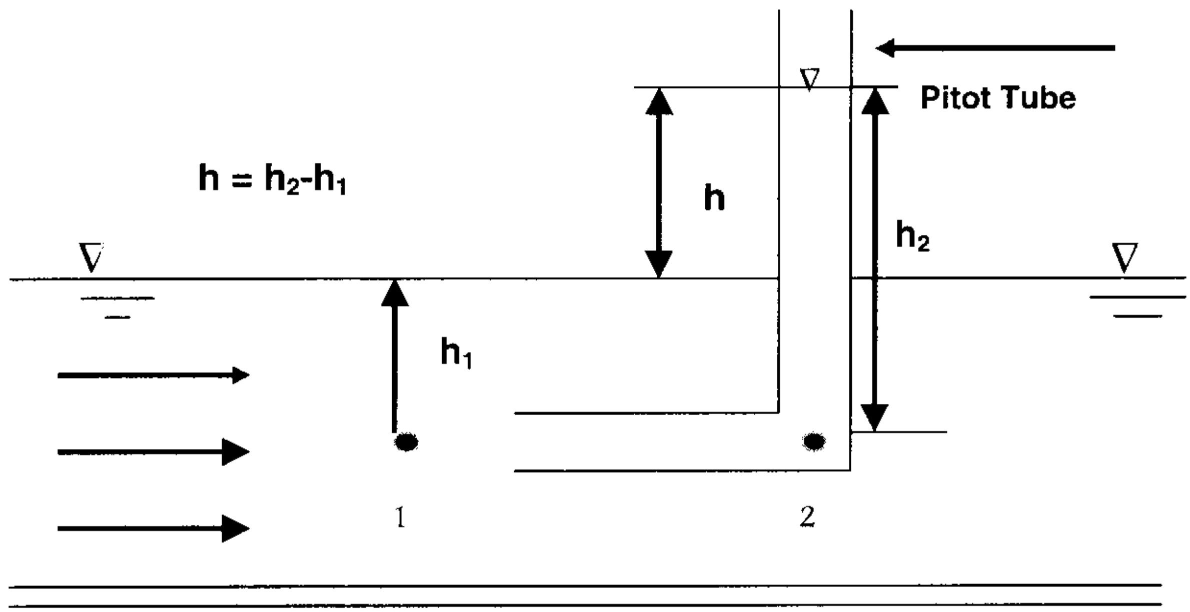


Figure 1. A simple Pitot Tube.

Since introduction of the tube, considerable advances have been made in the design and use of this simple flow-measuring instrument. Most of the efforts concentrated on studying and improving the impact surfaces of the Pitot Tubes and accurate procedures to determine the velocity head (Streeter and Wylie, 1985).

However, for a closed conduit under pressure, it is necessary to also measure the static pressure at Point 1 (Figure 1). The velocity head, h, in the latter case will be the difference between the total head (pressure head plus velocity head) measured by the Pitot Tube and the static pressure head measured by a piezometer as shown in Figure 2. The simple Pitot Tube measures the total head at Point 2, whereas the pressure head at Point 1 is determined by installing a piezometer.

Although it is possible to use the setup shown in Figure 2 for measuring the velocity head, it has been relatively convenient to combine the piezometer and the Pitot Tube into one apparatus which is generally labeled as a Pitot-static

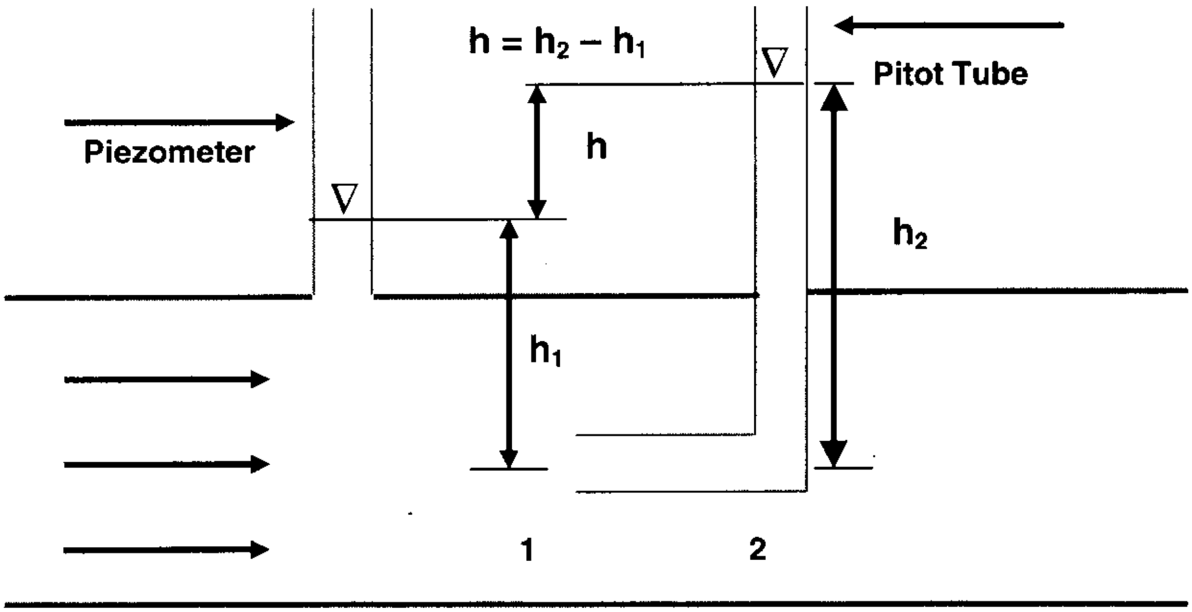


Figure 2. Pressurized closed conduit flow application of the Pitot Tube.

Tube, or Prandtl Tube, as shown in Figure 3. For such complex forms of the Pitot Tube, the inner tube indicates the stagnation pressure or total head (i.e., the sum of the static pressure head plus dynamic velocity head) and the outer perforated tube displays the static pressure head only. Manometers are commonly used to measure these heads. By subtracting the static head from the total head, the velocity head is determined. The resulting head is then utilized to calculate the velocity at the point where the impact end of the tube lies.

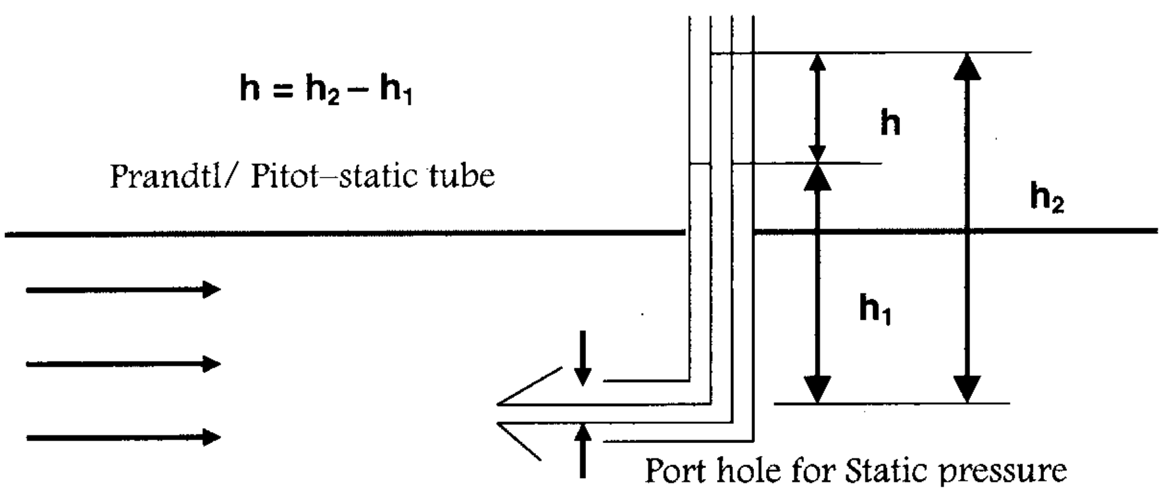


Figure 3. Combined piezometer and Pitot Tube.

The Pitot Tube is a simple and inexpensive device which measures the stagnation or total head accurately even if the device is as much as +/- 15º out of alignment with the direction of flow (Daugherty et al., 1989). With such accuracy, the use of this instrument attracted the attention of many scientists.

Although the initial testing of the device was for measuring velocities under open channel conditions, it is now mostly used in closed conduit pressurized flow applications (Kanen, 1986). In the latter case, the pressure conduits should be equipped with probing-ports to accommodate the Prandtl-type Tubes in order to monitor the velocity traverse at a cross section of the conduit so that the discharge rate can be calculated. Such complex devices also require differential manometers or pressure transducers, as well as the electronic recorders to facilitate the measurements. For a laboratory setting, these demands are not difficult to meet. However, for field applications, developing countries usually do not have such means available.

In the above stated context, exploratory studies wee initiated on a modified use of a simple Pitot Tube (as shown in Figure 4) for measuring the discharges from freely flowing irrigation water lift-pumps and tubewells. At the end of the pipe, where the water is discharged into the atmosphere, the jet of water has atmospheric pressure, so that the relative pressure is zero; thus, the Pitot Tube shown in Figure 4 is measuring the velocity head only.

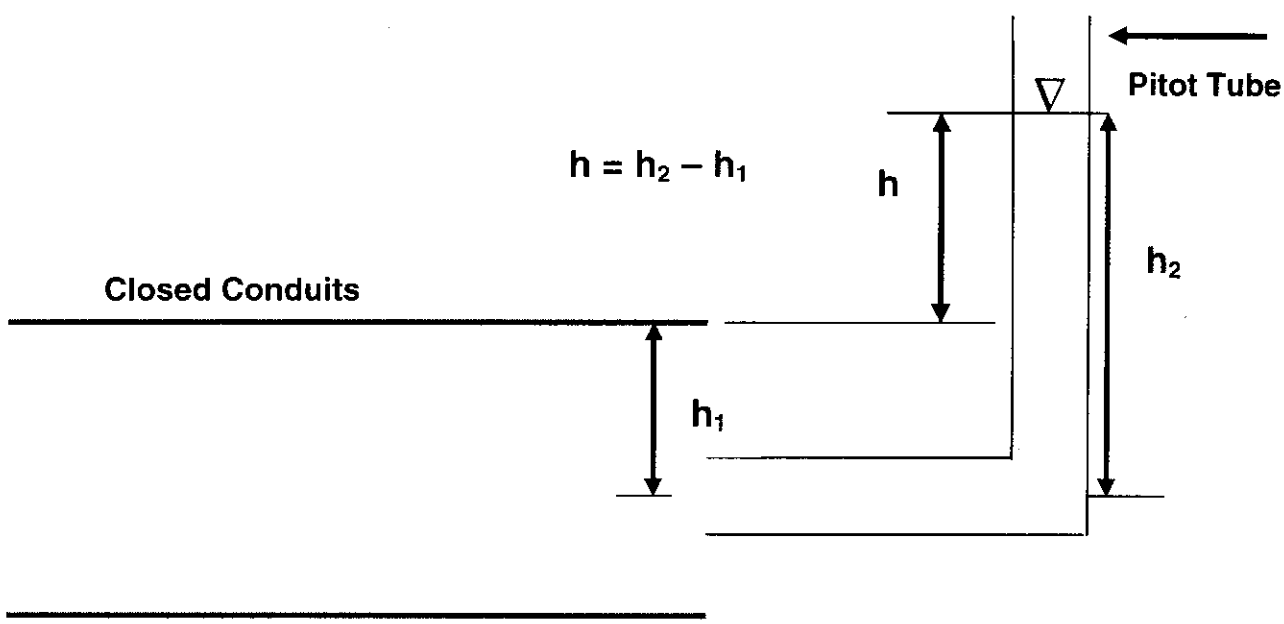


Figure 4. Proposed use of a simple Pitot Tube.

3. PITOT TUBE HYDRAULICS

3.1 FUNDAMENTAL RELATIONSHIPS

The Pitot Tube is one of the accurate techniques for measuring velocity head (Streeter and Wylie, 1985). Figures 1 and 2 show the use of the Pitot Tube for measuring the velocity of fluids (water in this case) flowing in open and closed conduits, respectively. The right-angle bend of the Pitot Tube is aligned opposite to the velocity vector to be measured. The streamlines lead through Point 1 to Point 2, where the fluid is halted. The velocity head in a Pitot Tube is derived from the Bernoulli Equation. The potential energy of water is converted into the kinetic energy when the water leaves the delivery pipe from a pump and the Bernoulli Equation will be reduced to:

$$\frac{v^2}{2g} \approx h \tag{1}$$

where

v = velocity at the tip of the Pitot Tube (L/T);
g = acceleration due to gravity (L/T^2); and
h = the measured velocity head (L).

Equation 1 can be written as follows:

$$v = C\sqrt{2gh} \tag{2}$$

where C = dimensionless proportionality coefficient.

For all practical purposes, it can be stated that a standard Pitot Tube will have this coefficient equal, or nearly equal, to 1.0 (USDI, 1984). Exploratory studies were initiated by Shafique et al., (1998) on a modified use of a simple Pitot Tube (as shown in Figure 4) for measuring the discharges from freely flowing irrigation water lift-pumps (tubewells). The experimental work included testing of pipes having 3, 4, 5, 6, and 8-inch internal diameters (Hafeez, 1998). The laboratory work has proven that there are negligible effects on flow measurements resulting from changing the diameters or the arm lengths of the Pitot Tube. Thus, using C equal to unity is a very reasonable assumption.

When reading the velocity head gauge during a Pitot Tube measurement, the water level fluctuates. Thus, both the maximum and minimum velocity heads must be recorded, then averaged, to arrive at the mean velocity head:

$$h_{mean} = \frac{h_{\min} + h_{\max}}{2} \tag{3}$$

where

h_{min} = minimum measured velocity head (L);
h_{max} = maximum measured velocity head (L); and
h_{mean} = mean velocity head (L).

Now, Equation 2 becomes:

$$v = \sqrt{2g\, h_{mean}} \tag{4}$$

or by substituting Equation 3 into Equation 4:

$$v = \sqrt{2\, g\, (h_{\min} + h_{\max}) / 2} \tag{5}$$

To calculate the discharge, the velocity of water coming out of the well delivery pipe has to be multiplied by the cross-sectional area of flow, which is the Continuity Equation:

$$Q = AV \tag{6}$$

where

A = cross-sectional area of the flow (L^2);
V = mean velocity in the flow cross-section (L/T); and
Q = discharge rate (L^3/T).

If the area of the pipe is expressed in terms of the diameter of the delivery pipe, the relationship becomes:

$$A_i = \frac{\pi}{4} D_i^2 \tag{7}$$

where

π = 3.14 (dimensionless)
D_i= inside diameter of the pipe (L); and
A_i= inside cross-sectional area of the pipe (L^2).

The remaining question is determining the mean velocity, V. This requires laboratory calibrations. The results reported by Shafique, Bukhari and Hafeez (1998) will be described below for: (1) full pipe flow; and (2) partial pipe flow.

3.2 DISCHARGE RATING FOR FULL PIPE FLOW

Consistently, Pitot Tube measurements in the center of the pipe gave more accurate results than measurements at quarter-diameter (D_i/4) or near the wall. Also, the calibration results were the same for all of the pipe diameters tested:

$$V = \frac{v_c}{1.116} \tag{8}$$

where

V_c = velocity at the center of the pipe (L/T). Note that v_c is the maximum velocity in the pipe cross-section, which has to be multiplied by the ratio 1/1.116 or divided by 1.116 as indicated by Equation 8, in order to arrive at the mean velocity, V.

The discharge rate can be calculated by substituting Equations 7 and 8 into Equation 6.

$$Q = AV = \frac{\pi}{4} D_i^2 \frac{v_c}{1.116} \qquad (9)$$

The velocity, v_c, is calculated using Equation 5, which can be substituted into Equation 9.

$$Q = \frac{\pi}{4} D_i^2 \frac{\sqrt{2g(h_{min} + h_{max})/2}}{1.116} \qquad (10)$$

Roughly, the mean discharge error for all pipe diameters tested in the laboratory was two percent. A review of the individual discharge measurements showed that 75 percent were accurate within three percent, while 89 percent of the discharge measurements were accurate within four percent.

3.3 DISCHARGE RATINGS FOR PARTIAL PIPE FLOW

The major requirement for using a Pitot Tube to determine the discharge rate in a pipe flowing partially full is that the velocity must exceed 1.5 meters per second (m/s), which is comparable to 5 feet per second (ft/sec). At lower velocities, the discharge errors rapidly increase to values exceeding 20 percent. Very good accuracy was achieved when the velocity exceeded 1.5 m/s, with the coefficient of determination (R^2) being 0.97 for all four depths tested in the laboratory.

The pipe invert was used as a zero reference level, which is indicated in Figure 5. The depth of water, d_w, in the pipe, as well as the velocity gauge readings, were measured from the invert of the pipe. Thus, d_w had to be subtracted from the maximum and minimum velocity gauge readings.

Pitot Tube measurements were taken at 30, 60, 80 and 90 percent of the depth of water, d_w, measured at the end of the pipe. Figure 5 schematically shows the measuring point for 60 percent of d_w measured from the pipe invert. The velocity equations for the 60, 80 and 90 percent water depths are quite comparable, which are listed below:

$$V = 0.806\, v_{60}^{1.22} = 0.798\, v_{80}^{1.22} = 0.795\, v_{90}^{1.22} \qquad (11\text{-a})$$

Where V is the average velocity measured in meters per second. For British System, the average velocity, V, is measured in foot per second and the corresponding equation is given as below:

$$V = 0.620\, v_{60}^{1.22} = 0.615\, v_{80}^{1.22} = 0.612\, v_{90}^{1.22} \qquad (11\text{-b})$$

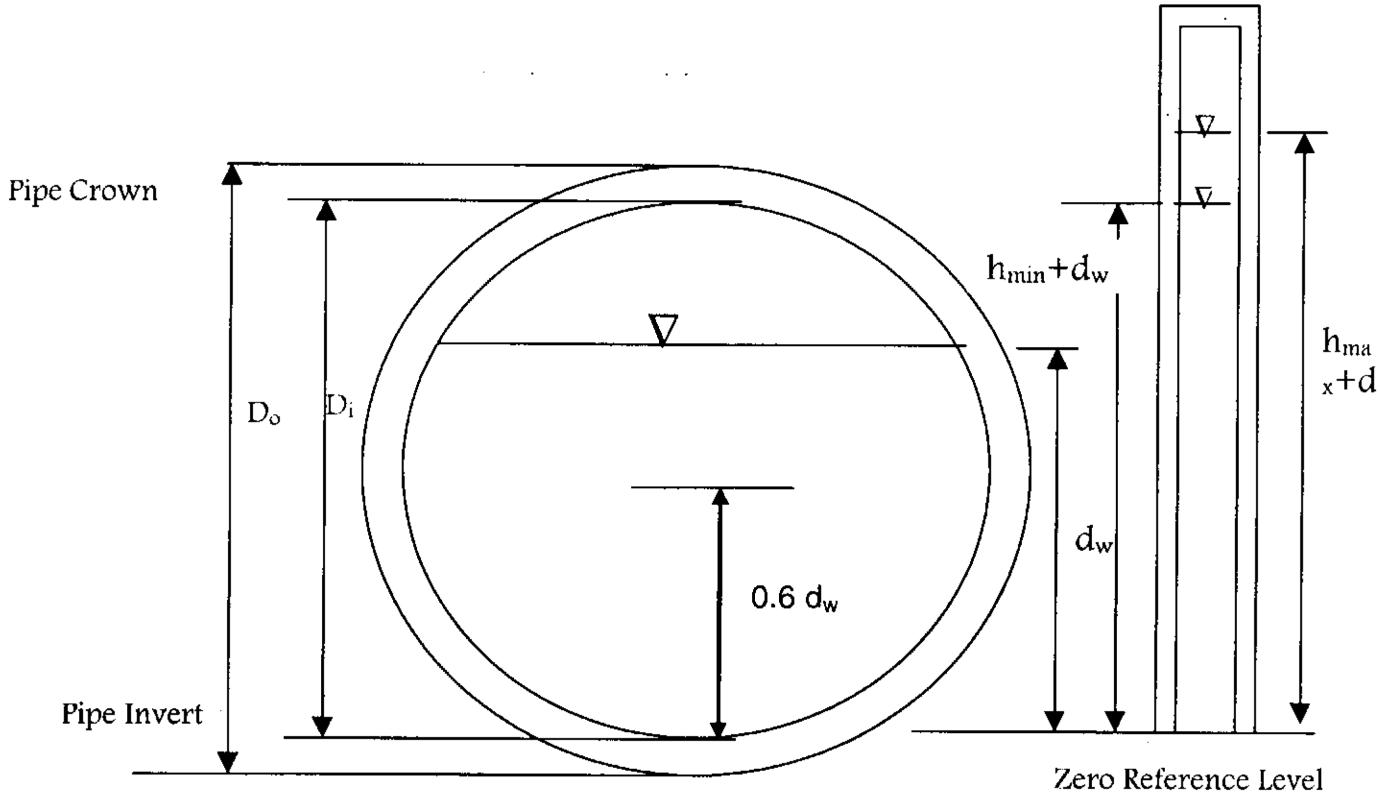


Figure 5. Definition sketch for partial pipe flow.

The discharge accuracy of these equations for partial pipe flow is nearly as good as described above for full pipe flow. With the coefficients in the denominators being very close to the same, this implies that the velocities measured at 0.6 d_w, 0.8 d_w and 0.9 d_w are nearly the same. Thus, if the placement of the Pitot Tube was in error by a large amount, the error in calculating the discharge would, at most, be one-half of one percent.

In order to calculate the discharge, the cross-sectional area of flow must be calculated for partial pipe flow, which will be designated as A_w. A coefficient, K_w, needs to be introduced, which will be defined as:

$$K_w = A_w/A_i \tag{12}$$

Or rearranging Equation 12,

$$A_w = K_w A_i \tag{13}$$

Also, this coefficient is a function of the ratio d_w/D_i shown in Figure 5.

$$K_w = f(d_w/D_i) \tag{14}$$

By calculating the ratio d_w/D_i, the coefficient K_w can be obtained from Table 1.

$$Q = 0.806 K_w A_i v_{60}^{1.22} \tag{15a}$$

Now, the discharge (Q) can be calculated in cubic meters per second by using any of the following equations, if velocity is in meters per second and cross sectional area of flow is in square meter:

In the same way, the discharge (Q) can be calculated in metric system by using v_{80}

$$Q = 0.798 K_w A_i v_{80}^{1.22} \tag{15b}$$

Also, the discharge (Q) can also be calculated in metric system by using v_{90}:

$$Q = 0.795 K_w A_i v_{90}^{1.22} \tag{15c}$$

where:

$$A_i = \frac{\pi}{4} D_i^2 \tag{7}$$

These velocities (v_{60}, v_{80} and v_{90}) would be calculated using Equation 5, but the velocity gauge readings have to be corrected by subtracting the depth of water, d_w as indicated in Figure 5.

In practice, only one of these three velocities would be measured using a Pitot Tube. Then, the discharge corresponding with the measured velocity head would be calculated from the respective Equation 15 (a, b & c). For example, if the Pitot Tube is placed at a depth of $0.6d_w$, the resulting Velocity Head Gauge readings (h_{min} and h_{max}) would be used in Equation 5 to calculate V_{60}. Next, V_{60} would be substituted in Equation 11 to calculate the actual velocity, V. Finally, Equation 15a would be used to calculate Q.

Similarly, the discharge (Q) can be calculated in cubic foot per second if cross sectional area of the water flowing in the pipe is in square foot and velocity is in foot per second by using the flowing equations:

$$Q = 0.620 K_w A_i v_{60}^{1.22} \tag{15d}$$

In the same way, the discharge (Q) can be calculated in British system by using v_{80}:

$$Q = 0.615 K_w A_i v_{80}^{1.22} \tag{15e}$$

Also, the discharge (Q) can be calculated in British system by using v_{90}:

$$Q = 0.612 K_w A_i v_{90}^{1.22} \tag{15f}$$

Table 1. Values of the Coefficient k_w for different ratios of d_w/D_i.

Ratio Coefficient		Ratio Coefficient		Ratio Coefficient	
d_w/D_i	K_w	d_w/D_i	K_w	d_w/D_i	K_w
0.11	0.060	0.41	0.386	0.71	0.759
0.12	0.068	0.42	0.399	0.72	0.771
0.13	0.076	0.43	0.411	0.73	0.782
0.14	0.085	0.44	0.424	0.74	0.793
0.15	0.094	0.45	0.436	0.75	0.804
0.16	0.103	0.46	0.449	0.76	0.815
0.17	0.113	0.47	0.462	0.77	0.826
0.18	0.122	0.48	0.475	0.78	0.837
0.19	0.132	0.49	0.487	0.79	0.847
0.20	0.142	0.50	0.500	0.80	0.858
0.21	0.153	0.51	0.513	0.81	0.868
0.22	0.163	0.52	0.525	0.82	0.878
0.23	0.174	0.53	0.538	0.83	0.887
0.24	0.185	0.54	0.551	0.84	0.897
0.25	0.196	0.55	0.564	0.85	0.906
0.26	0.207	0.56	0.576	0.86	0.915
0.27	0.218	0.57	0589	0.87	0.924
0.28	0.229	0.58	0.601	0.88	0.932
0.29	0.241	0.59	0.614	0.89	0.940
0.30	0.252	0.60	0.626	0.90	0.948
0.31	0.264	0.61	0.639	0.91	0.955
0.32	0.276	0.62	0.651	0.92	0.963
0.33	0.288	0.63	0.664	0.93	0.969
0.34	0.300	0.64	0.676	0.94	0.976
0.35	0.312	0.65	0.688	0.95	0.981
0.36	0.324	0.66	0.700	0.96	0.987
0.37	0.336	0.67	0.712	0.97	0.991
0.38	0..349	0.68	0.724	0.98	0.995
0.39	0.361	0.69	0.736	0.99	0.998
0.40	0.374	0.70	0.748	1.00	1.000

4. FABRICATION OF PITOT TUBE EQUIPMENT

4.1 PITOT TUBE

To fabricate a Pitot Tube, a simple copper tube, or any other metal tube, is used. This tube can be of any length, but for practical purposes, it is suggested that the length of the tube should be from 36 to 40 centimeters (cm). The inner diameter of the metal tube is recommended to be 4 mm, while the outer diameter of the tube is recommended to be 5.0 mm. Almost the same results can be obtained with Pitot Tubes of other diameters, but the problem of entrapped air is encountered with the Pitot Tubes having diameters less than 4.0 mm.

Fill the tube with sand and close the ends with wet clay, or with any other material that does not melt during heating. Apply heat very smoothly with a candle (Figure 6) at the point where the tube is to be bent, which should be a little more than 5 cm away from one of the two ends of the metal tube. Make a bend in the tube so that a right (90º) angle is made and the tube becomes a 'L' shape. Then, cut the short end of the tube to exactly the length of 5 centimeters (Figure 7).

Take a wooden block of 7-cm x 5-cm x 2.5-cm (length, width and height) cube. Now drill a hole at 5-cm away from one end of the cube as shown in Figure 8. The hole should have a diameter of 5.5-mm in the middle of the cube. A metal block is also equally good. The metal block can even be preferred sometimes because wooden blocks can swell and the sliding movement of the Pitot Tube may be somewhat difficult. The longer stem of the tube is inserted in this hole in the block. A screw can also be fixed in the cube so that the tube is held firmly. The way the tube is fixed in the cube is shown in Figure 9.

4.2 VELOCITY HEAD GAUGE

The rise of water in the Velocity Head Gauge is known as the velocity head. The Velocity Head Gauge is simply a graduated ruler, which measures the rise of water due to velocity at the end of the pump discharge pipe. To measure the rise of water coming from the Connecting Hose, a simple three to four foot long measuring rod can be used (Figure 10). The Velocity Head Gauge must be stiff enough so that it can be held in-hand firmly (Figure 11) without being turned on its own. The gauge may be marked in inches with markings every one-sixteenth of an inch, feet with markings every one-hundredth of a foot, or centimeters with markings every millimeter.

4.3 CONNECTING HOSE

The Connecting Hose is simply a transparent flexible plastic tube in which water rises due to dynamic velocity head at a height equivalent to the velocity head. This rise of water can be observed by the naked eye. The Connecting Hose is coupled with the Pitot Tube at one end (Figure 12), while the other end is open to the atmosphere but fastened onto the Velocity Head Gauge (Figure 13). The flexibility of the transparent Connecting Hose makes the apparatus very handy. The inner diameter of the Connecting Hose should be 5.0 mm so that the Pitot Tube can be easily inserted into this hose.

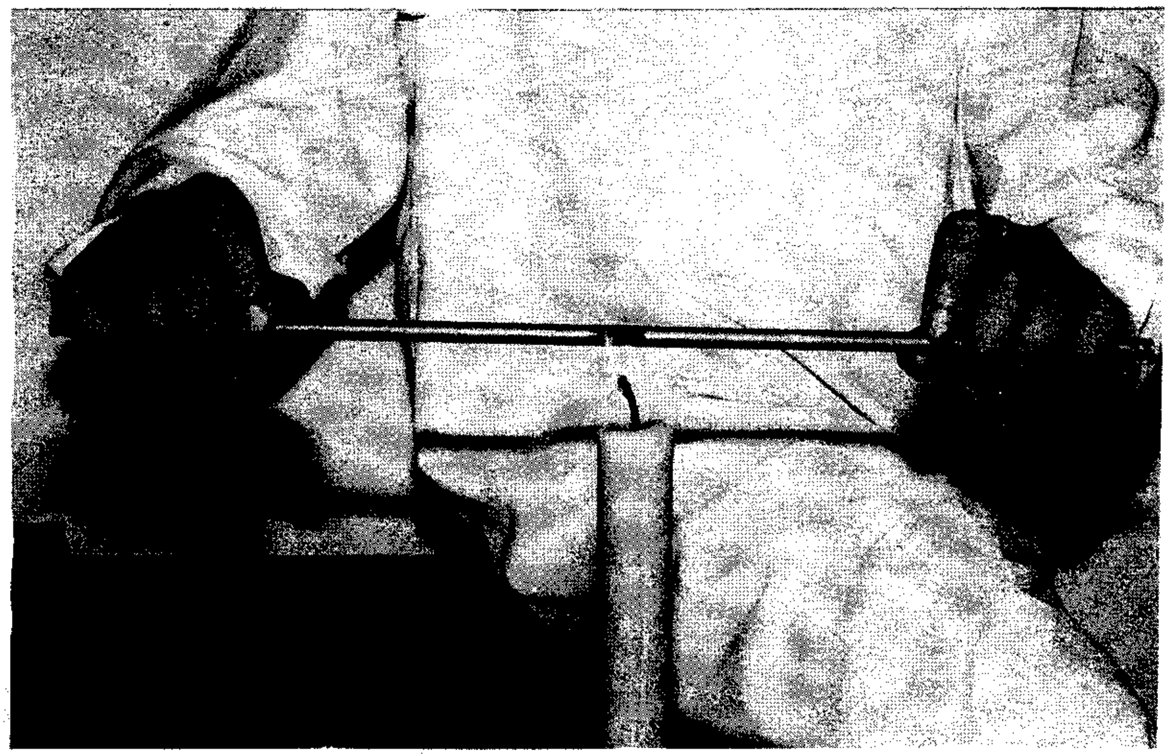


Figure 6. Heating the sand-filled metal tube with a candle in order to make a 90° bend.

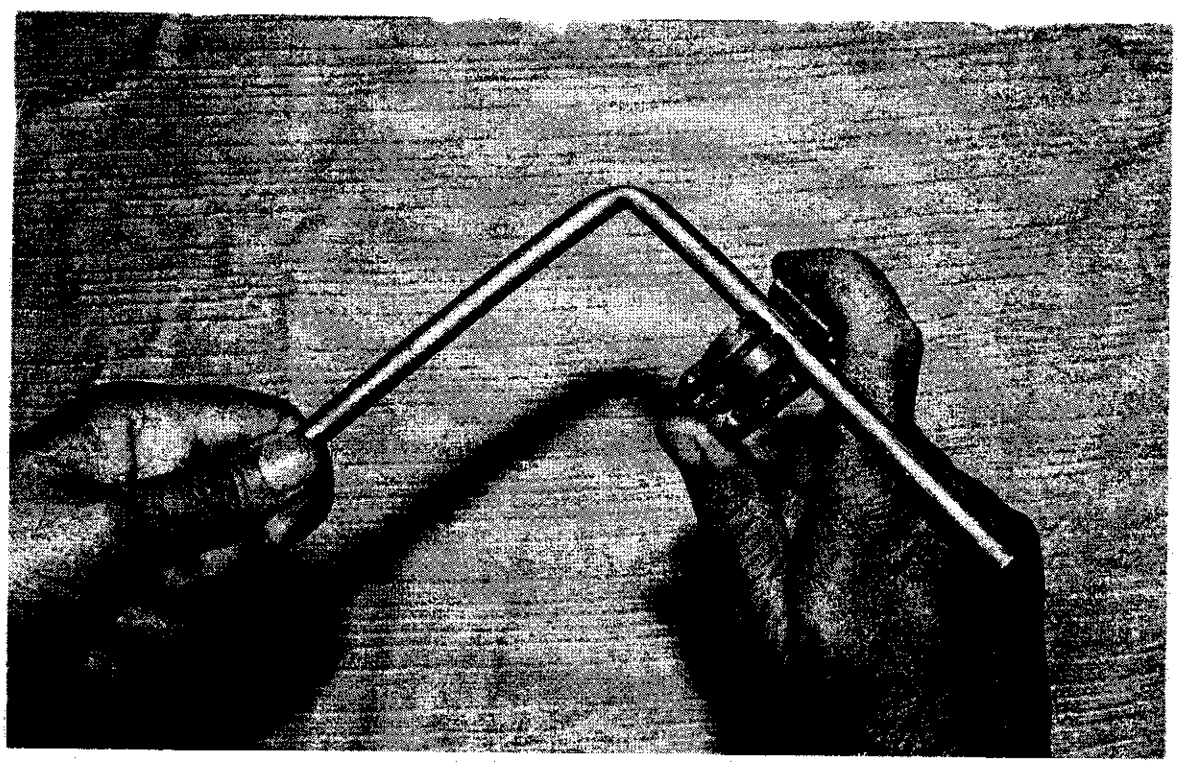


Figure 7. Cutting the end of the Pitot Tube to have a length of 5 cm.

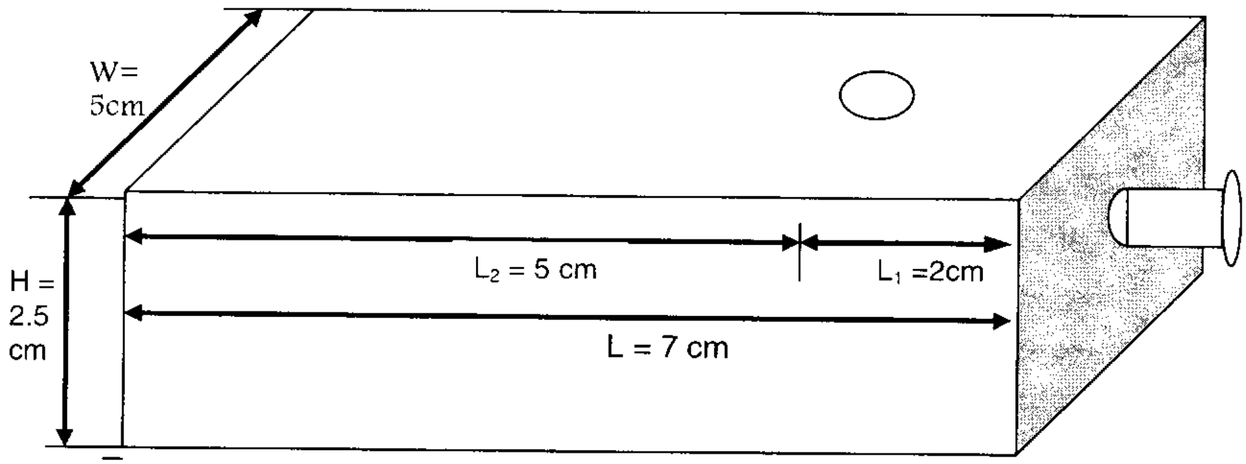


Figure 8. **Fabrication sketch for a wooden or metal block with screw attachment to lock the Pitot Tube position.**

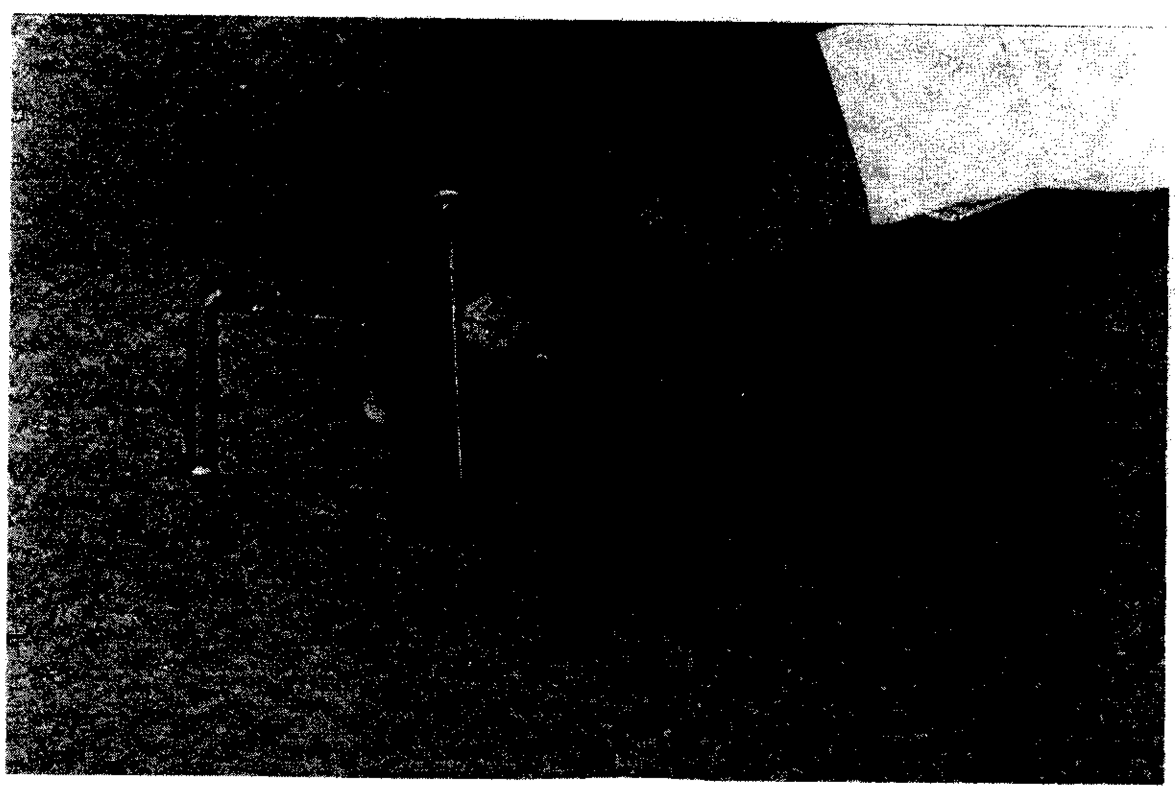


Figure 9. **Photograph of hand-held block with Pitot Tube locked in position.**

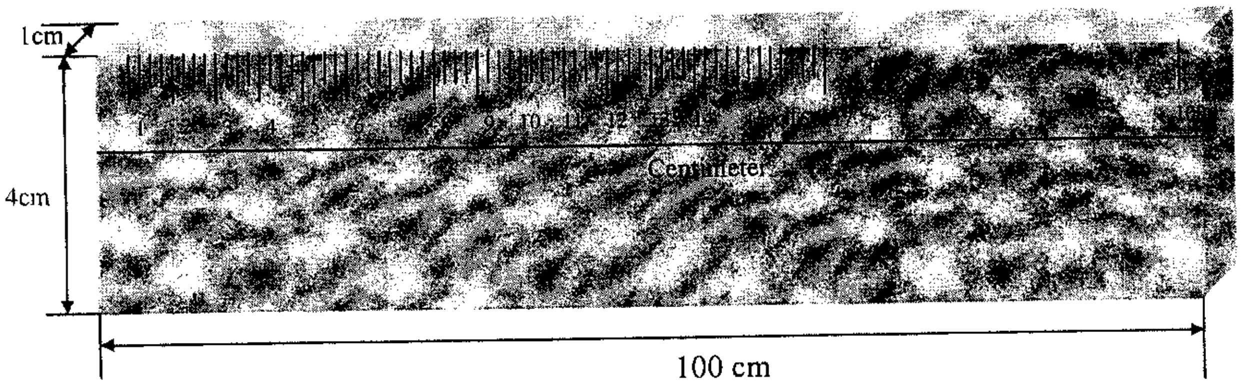


Figure 10. Fabrication details for a Velocity Head Gauge.

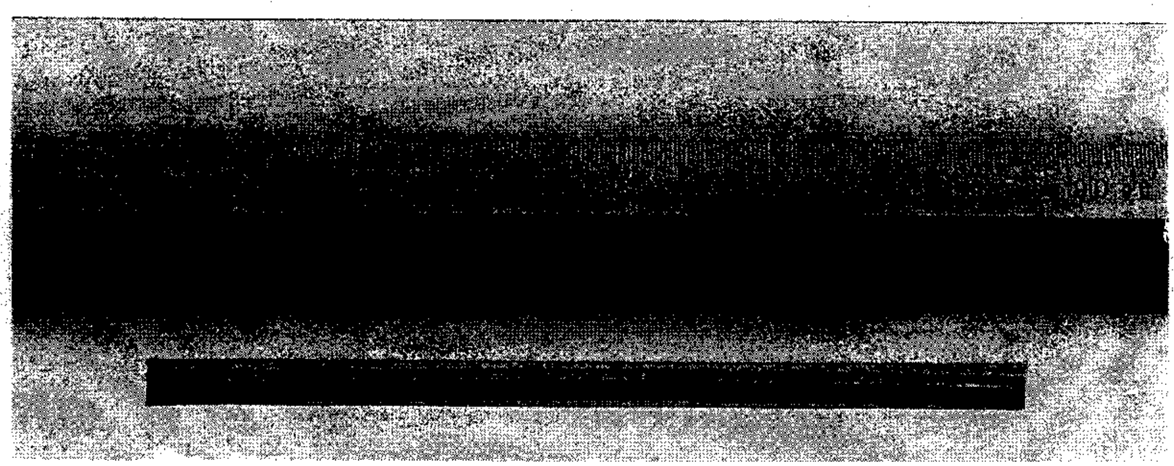


Figure 11. Photograph of a Velocity Head Gauge.

Figure 12. Photograph of attaching the Connecting Hose to the long stem of the Pitot Tube.

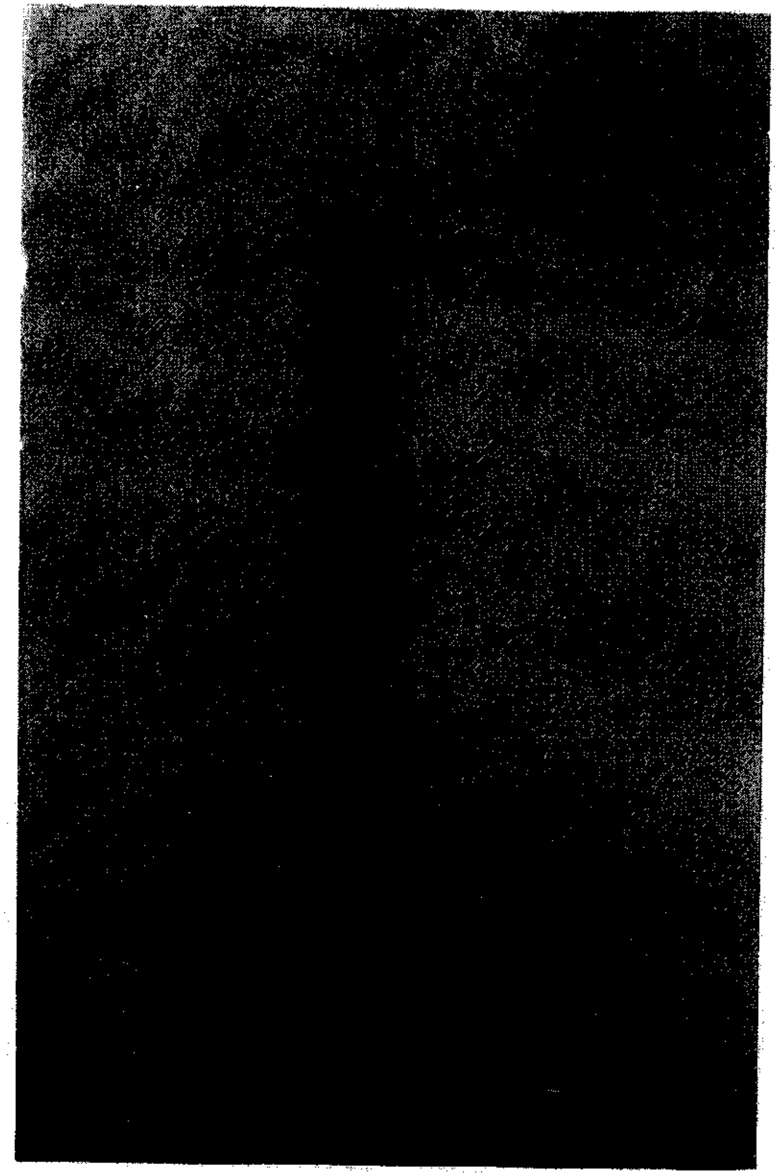


Figure 13. Photograph of Connecting Hose fastened onto the Velocity Head Gauge.

Next >>

The assembled apparatus is shown in Figure 14. The Pitot Tube is located to the left in the photograph, while the Velocity Head Gauge is to the right, with the Connecting Hose attached to the Pitot Tube and fastened onto the Velocity Head Gauge.

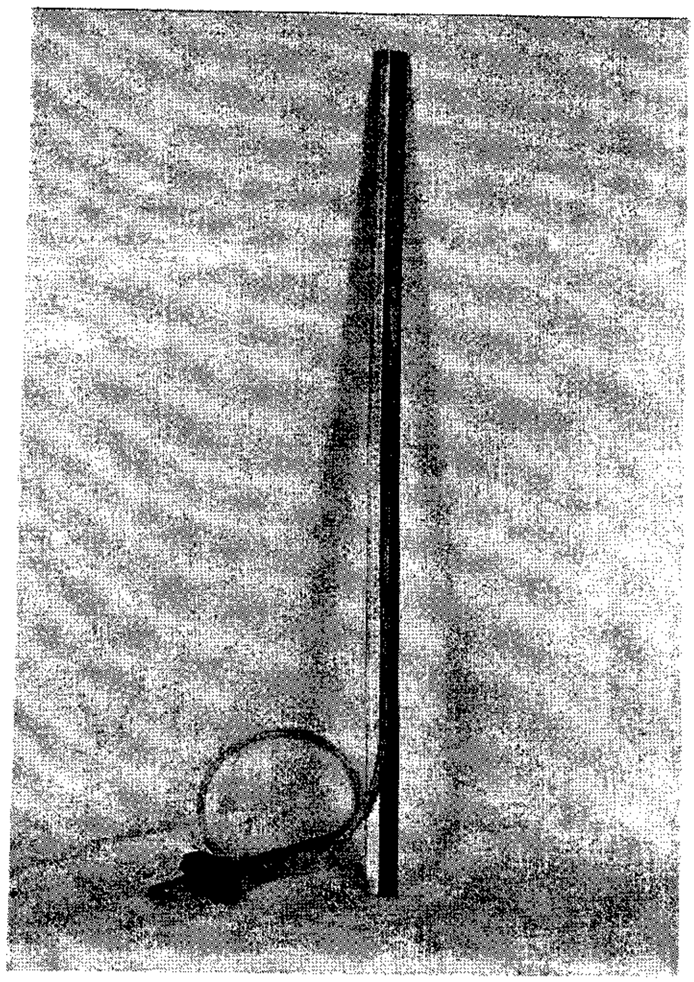


Figure 14. Photograph of apparatus for measuring pump discharges with: (1) Pitot Tube on the left; (2) Velocity Head Gauge on the right; and (3) Connecting Hose attached to Pitot Tube and fastened onto the Velocity Head Gauge.

USE OF PITOT TUBE EQUIPMENT

5.1 FULL PIPE FLOW

5.1.1 Placement of Pitot Tube

For discharge measurements from fully flowing pipes, the Pitot Tube should be placed in a way that the stem (smaller arm) of the Pitot Tube is parallel to the streamlines of the water coming out of the delivery pipe. Moreover, the end of the Pitot Tube facing towards the tubewell delivery pipe should be in the center of the delivery pipe. In addition, the end of the Pitot Tube should be in line with the outer rim of the delivery pipe as shown in Figure 15. Placing of the Pitot Tube away from the center up to one-half the radius of the delivery pipe results in a negligible difference in readings -- a difference of 2 percent. However, proper placement of the Pitot Tube results in accurate measurements.

Placing of the stem at the right place can be made possible with the help of a wooden or metal cube having a hole in the center at a distance of five centimeters from one of the rims of the cube as described in Section 4.1 and shown in Figures 8 and 9. The longer end of the Pitot Tube should be placed in the hole of the cube and fixed in the hole with the help of a screw so that the Pitot Tube is held firmly. There are two purposes of fixing the Pitot Tube in the cube or block. Firstly, to hold the Pitot Tube firmly in the cube so that the impact of flowing water (Figure 16) may not turn the Pitot Tube sideways. Secondly, to hold the tube at a distance equal to the length of the smaller stem of the metal tube. Holding the Pitot Tube in this cube or block ensures that the end of the Pitot Tube is held just at the tip of the tubewell delivery pipe.

5.1.2 Placement of Velocity Head Gauge

The Velocity Head Gauge is placed differently for measuring fully flowing delivery pipes and partially flowing pipes. In the fully flowing pipes, the Velocity Head Gauge may be placed so that its lower end is placed on the top of the delivery pipe (Figure 17). The essence of the Velocity Head Gauge reading is that its zero point must coincide with the upper streamline of water coming out of the tubewell delivery pipe, which is the crown of the pipe as shown in Figure 5. The Velocity Head Gauge must be held vertically parallel to the connecting hose so that rise of water in the connecting hose can be noted accurately. To ensure the rise of water correctly, the thickness of the delivery pipe must be added to the vertical rise of water in the connecting hose, as illustrated in Figure 18. Therefore, care must be exercised while noting the readings.

Figure 15. Photograph showing proper placement of the Pitot Tube at the tip of the pump discharge pipe in the center of the pipe

Figure 16. Holding the Pitot Tube while making a measurement with full pipe flow.

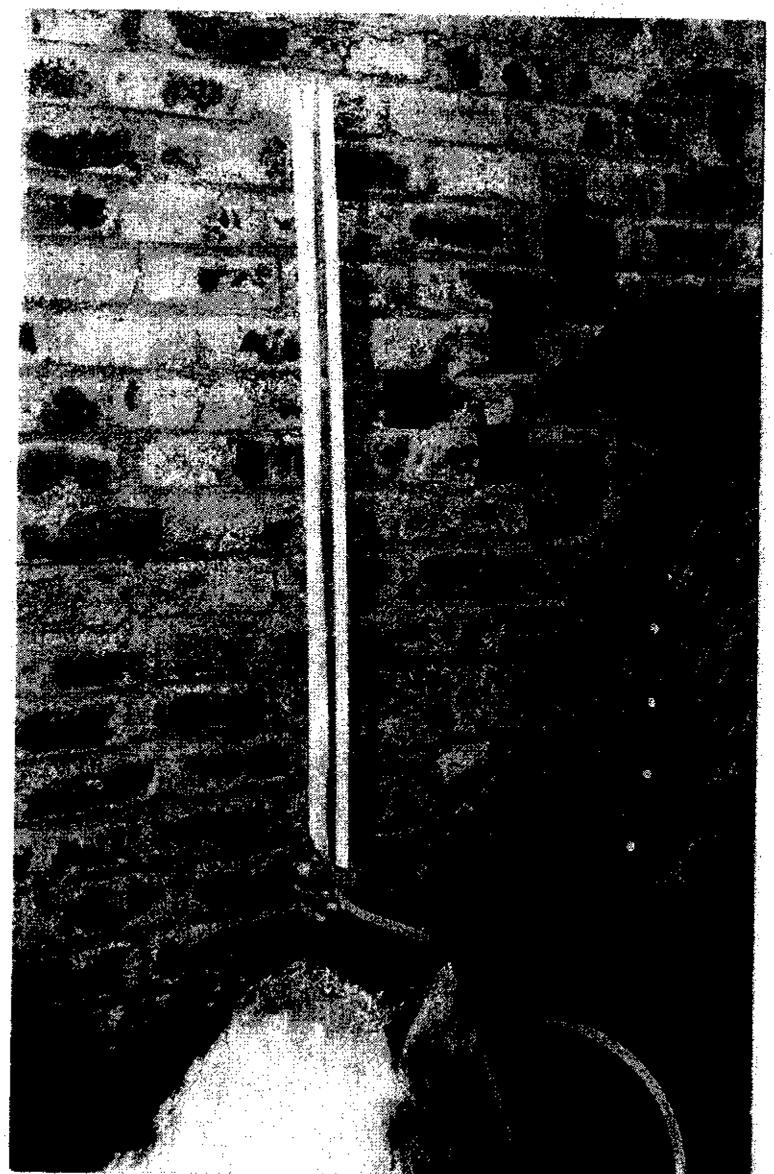


Figure 17. Photograph of Velocity Head Gauge placed on top of pipe.

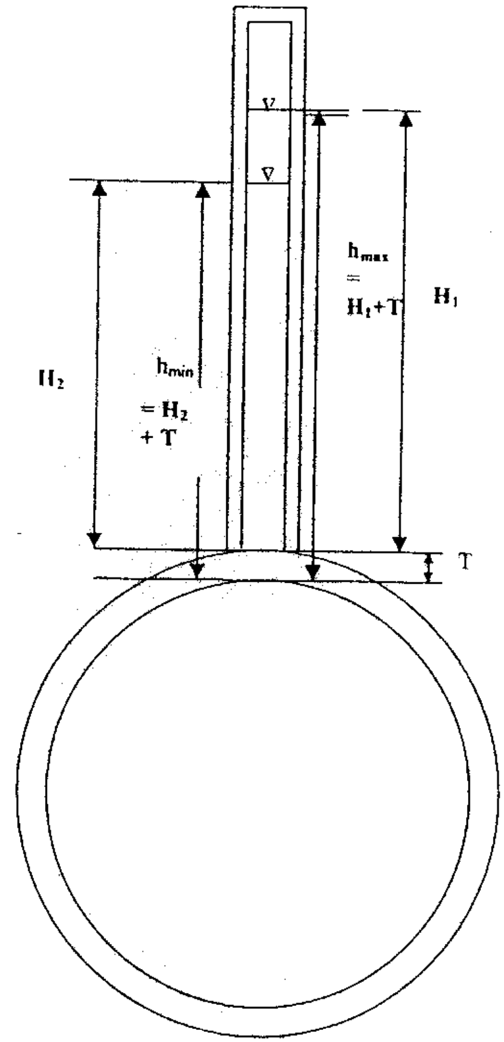


Figure 18. Schematic illustrating the pipe thickness correction for Velocity Head Gauge readings.

5.2 PARTIAL PIPE FLOW

The flow from the delivery pipe of a tubewell is said to be discharging partial pipe flow if the upper water surface of the discharging water at the tip of the pipe is not touching the upper inner side (crown) of the pipe. The hydraulics of the fully flowing pipe and that of partially flowing pipe are quite different. In case of partially flowing tubewells, the flow under this regime may be considered as open channel flow (or semi-circular open channel flow).

5.2.1 Placement of Pitot Tube

Like fully flowing delivery pipes, in case of tubewells discharging partially, the Pitot Tube may be placed in a way that the stem (smaller arm) of the Pitot tube is parallel to the streamlines of the water coming out of the delivery pipe. Care should, however, be taken that the end of the Pitot Tube facing towards the tubewell delivery pipe should be placed at either 0.6, 0.8 or 0.9 of the depth of water in the delivery pipe (Figure 19). The end of the Pitot Tube should be in line with the outer rim (tip) of the delivery pipe as shown in Figure 15. Placing of the stem at the right place can be made possible with the help of a cube having a hole with a distance of five centimeters from one end of the cube (in the same way as is done in the case of fully discharging delivery pipes). The longer end of the Pitot Tube should be placed in the hole of the cube and fixed in the hole with the help of a screw so that the tube is held firmly. The end of the Pitot Tube must be in the same plane as that of the rim (tip) of the delivery pipe.

5.2.2 Placement of Velocity Head Gauge

Contrary to the fully flowing tubewell delivery pipes, the essence of the Velocity Head Gauge placement is that its zero point is top of the water surface in the delivery pipe. In order to avoid shaking, the Velocity head Gauge must be placed firmly against some fixed object. The Velocity Head Gauge must be held vertically and parallel to the Connecting Hose so that the rise of water in the Connecting Hose can be noted accurately. To note the rise of water correctly, the depth of water above the invert of the pipe must be subtracted from the total vertical rise of water in the Connecting Hose as illustrated in Figure 20.

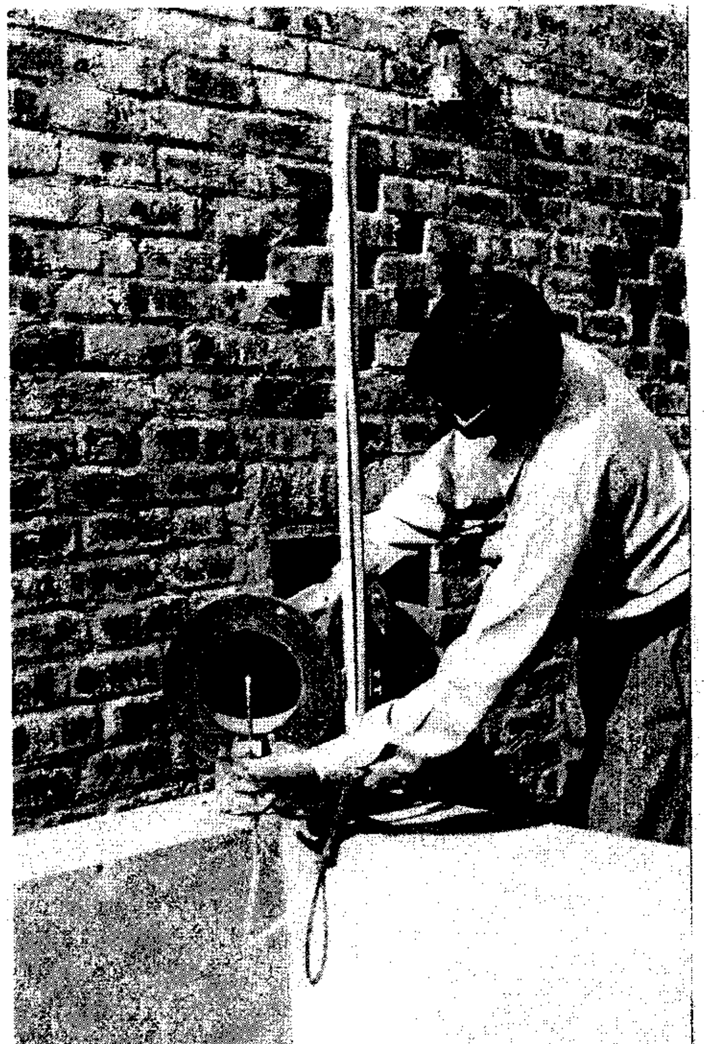


Figure 19. Holding the Pitot Tube while making a measurement with partial pipe flow

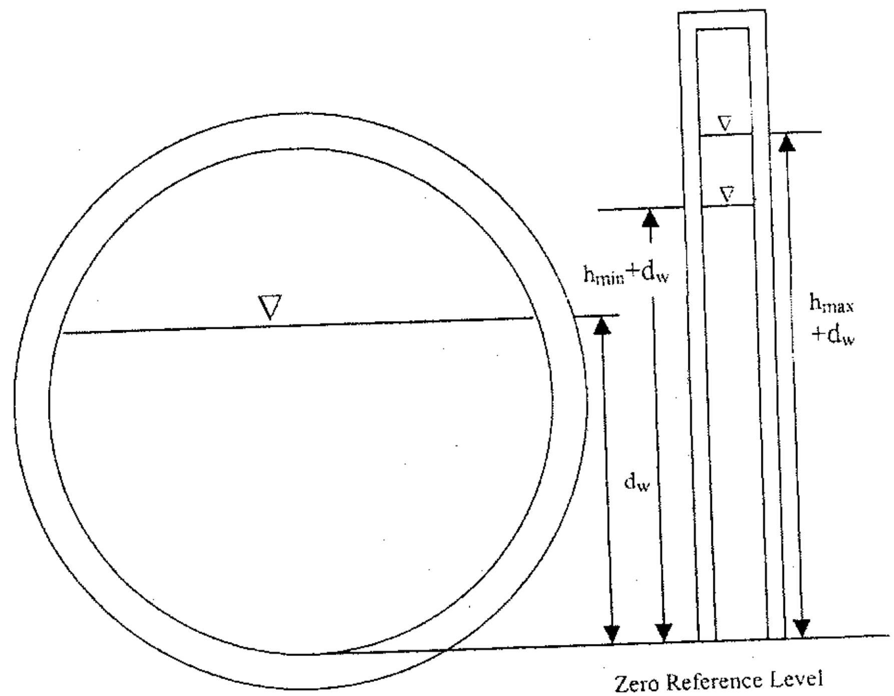
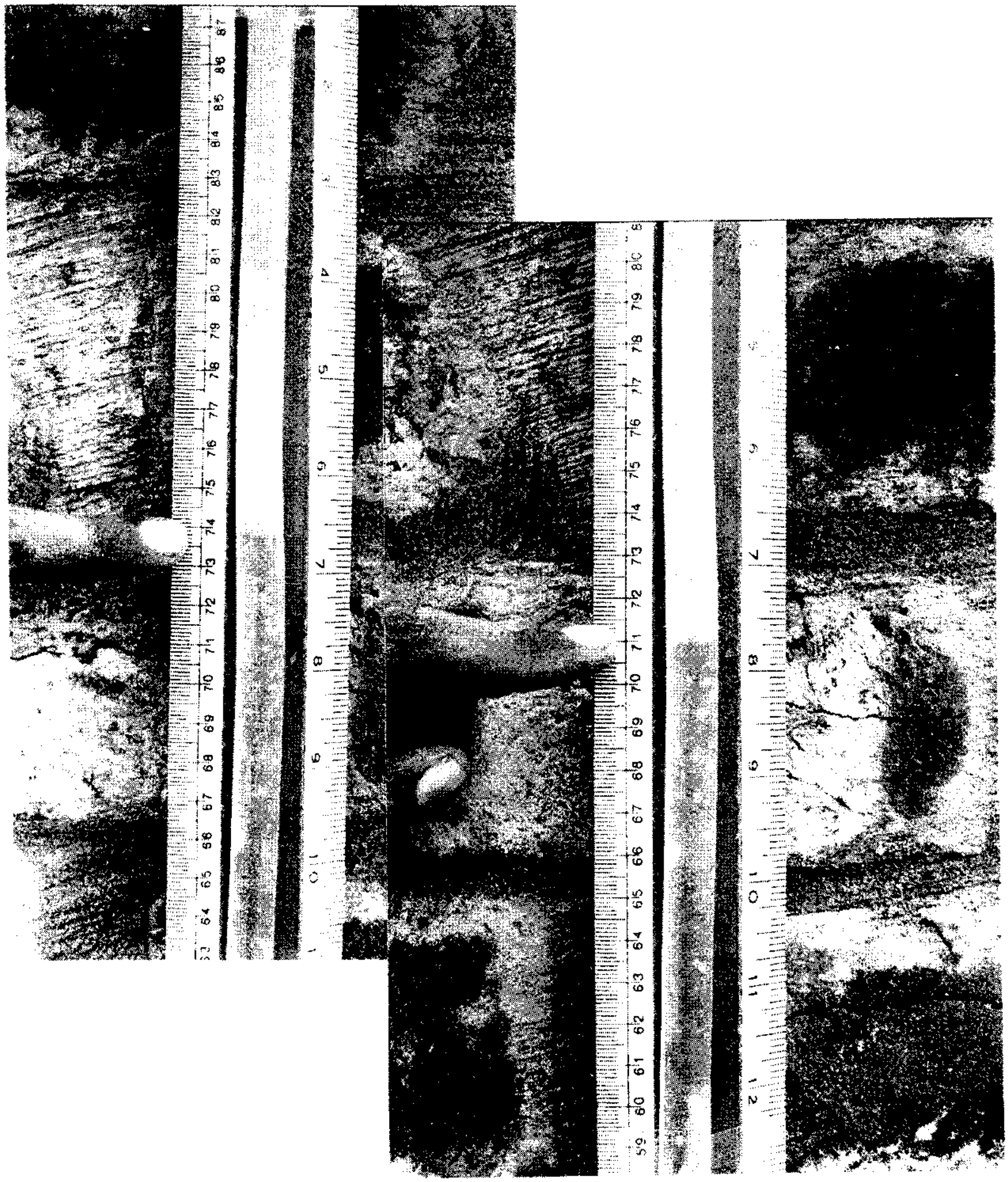


Figure 20 Schematic illustrating the referencing of the Velocity Head Gauge readings to the water surface at the pipe tip for partial pipe flow.



(a) Maximum Velocity Head (b) Minimum Velocity Head

Figure 21. Reading the maximum and minimum velocity heads from a Velocity Head Gauge.

6. FIELD DISCHARGE MEASUREMENTS

6.1 FULL PIPE FLOW

6.1.1 Reading the Velocity Head

The Velocity Head Gauge measures the rise of water in the Connecting Hose. Unfortunately many of the people involved in fabrication of pumps in developing countries are not necessarily technically sound. Bad workmanship by tubewell makers is another problem that adds toward fluctuations in tubewell discharge measurements. Power variation also contributes towards deviations from accurate discharge measurements. Due to these imperfections in pump manufacturing, a lot of fluctuations in the discharge are noticed that ultimately result in fluctuating rise of water in the Connecting Hose.

There should not be entrapped air in the Connecting Hose while recording the rise of water. The entrapped air does not allow the proper rising of water in the Connecting Hose and erroneous results are obtained. Care should also be exercised while noting the rise of water in the Connecting Hose. The rise of water should be noted in the Connecting Hose up to the lower meniscus in the transparent flexible tube. The rise of water is shown in Figure 21 for both the minimum and maximum levels of the meniscus that correspond with the minimum and maximum values of velocity head being measured by the Pitot Tube.

While noting the rise of water in the Pitot Tube, the precautions listed below must be considered.

- The Pitot Tube stem must be placed at the center of the delivery pipe. It is easy to place the Pitot Tube in the center of the pipe by visual examination. Small deviations from the center do not cause much difference. A difference up to 2 percent may result due to placing the Pitot Tube at one-fourth of the diameter away from center. For example, the diameter of the delivery pipe is six inches, the Pitot Tube may be held in such a way that the center of the Pitot Tube is at three inches from the inner edge for accurate measurements. Even placing the Pitot Tube in the middle visually can produce fairly accurate results.
- While noting the rise of water in the Pitot Tube, the stem must be horizontal or parallel to the streamlines of the water in the delivery pipe. To place the Pitot Tube in such a way that its stem is horizontal can also be ensured by the naked eye.
- Both ends of the Pitot Tube should not be dented.
- The transparent Connecting Hose should be clear, so that the water meniscus can be easily seen.
- The measuring rod fixed with the transparent Connecting Hose must be held vertically. This can also be ensured by the naked eye.
- There should be no bubbles inside the transparent Connecting Hose.

Luckily, the average of the minimum and maximum readings of the water rise in the Connecting Hose can still produce good results. The average rise of water in the Connecting Hose is calculated by taking the average of the maximum and minimum readings, which is given as:

$$h_{mean} = \frac{(h_{\min} + h_{\max})}{2} \qquad (3)$$

6.1.2 Calculating the Discharge Rate

The discharge rate for full pipe flow can be calculated using Equation 10:

$$Q = \frac{\pi}{4} D_i^2 \frac{\sqrt{2g(h_{\min} + h_{\max})/2}}{1.116} \qquad (10)$$

Only three measurements are required: (1) the inside diameter of the pipe, D_i; (2) the minimum velocity head, h_{min}; and (3) the maximum velocity head, h_{max}.

The square root term in Equation 10 is the velocity at the center of the pipe, v_c, measured by the Pitot Tube:

$$v_c = \sqrt{2g(h_{\min} + h_{\max})/2)} \qquad (5)$$

or

$$v_c = \sqrt{2g\,\mathrm{h}_{\mathrm{mean}}} \qquad (4)$$

These equations are valid for any Pitot Tube measurement at any location. Note the more general form of Equations 4 and 5 when they were first listed, where v was used to represent the velocity resulting from a Pitot Tube measurement.

Tables 2 and 3 have been prepared in metric and English units, respectively, for determining the velocity, v, for any value of mean velocity head, h_{mean}. If Tables 2 or 3 are to be used, then Equation 9 is preferable for calculating the discharge rate.

$$Q = \frac{\pi}{4} D_i^2 \frac{v_c}{1.116} \qquad (9)$$

Table 2. Value of velocity corresponding with the mean velocity head from a Pitot Tube measurement in metric units.

Velocity Head	Velocity	Velocity Head	Velocity	Velocity Head	Velocity	Velocity Head	Velocity
Cm	m/sec	cm	m/sec	cm	m/sec	cm	m/sec
1	0.443	26	2.259	51	3.163	76	3.862
2	0.626	27	2.302	52	3.194	77	3.887
3	0.767	28	2.344	53	3.225	78	3.912
4	0.886	29	2.385	54	3.255	79	3.937
5	0.990	30	2.426	55	3.285	80	3.962
6	1.085	31	2.466	56	3.315	81	3.987
7	1.172	32	2.506	57	3.344	82	4.011
8	1.253	33	2.545	58	3.373	83	4.035
9	1.329	34	2.583	59	3.402	84	4.060
10	1.401	35	2.620	60	3.431	85	4.084
11	1.469	36	2.658	61	3.460	86	4.108
12	1.534	37	2.694	62	3.488	87	4.132
13	1.597	38	2.730	63	3.516	88	4.155
14	1.557	39	2.766	64	3.544	89	4.179
15	1.716	40	2.801	65	3.571	90	4.202
16	1.772	41	2.836	66	3.598	91	4.225
17	1.826	42	2.871	67	3.626	92	4.249
18	1.879	43	2.905	68	3.653	93	4.272
19	1.931	44	2.938	69	3.679	94	4.295
20	1.981	45	2.971	70	3.706	95	4.317
21	2.030	46	3.004	71	3.732	96	4.340
22	2.078	47	3.037	72	3.759	97	4.362
23	2.124	48	3.069	73	3.785	98	4.385
24	2.170	49	3.101	74	3.810	99	4.407
25	2.215	50	3.132	75	3.836	100	4.429

Table 3. Value of velocity corresponding with the mean velocity head from a Pitot Tube measurement in English units.

Velocity Head	Velocity	Velocity Head	Velocity	Velocity Head	Velocity	Velocity Head	Velocity
Inches	ft/sec	Inches	ft/sec	Inches	ft/sec	Inches	ft/sec
1.0	2.317	6.0	5.675	11.0	7.683	16.0	9.266
1.2	2.538	6.2	5.768	11.2	7.753	16.2	9.324
1.4	2.741	6.4	5.861	11.4	7.822	16.4	9.382
1.6	2.930	6.6	5.951	11.6	7.890	16.6	9.439
1.8	3.108	6.8	6.041	11.8	7.958	16.8	9.495
2.0	3.276	7.0	6.129	12.0	8.025	17.0	9.552
2.2	3.436	7.2	6.216	12.2	8.092	17.2	9.608
2.4	3.589	7.4	6.302	12.4	8.190	17.4	9.663
2.6	3.735	7.6	6.386	12.6	8.223	17.6	9.719
2.8	3.876	7.8	6.470	12.8	8.288	17.8	9.774
3.0	4.012	8.0	6.552	13.0	8.353	18.0	9.829
3.2	4.144	8.2	6.634	13.2	8.417	18.2	9.883
3.4	4.272	8.4	6.714	13.4	8.480	18.4	9.937
3.6	4.395	8.6	6.794	13.6	8.543	18.6	9.991
3.8	4.516	8.8	6.872	13.8	8.606	18.8	10.045
4.0	4.633	9.0	6.950	14.0	8.668	19.0	10.098
4.2	4.748	9.2	7.027	14.2	8.730	19.2	10.151
4.4	4.859	9.4	7.103	14.4	8.791	19.4	10.204
4.6	4.969	9.6	7.178	14.6	8.852	19.6	10.256
4.8	5.075	9.8	7.252	14.8	8.912	19.8	10.308
5.0	5.180	10	7.326	15.0	8.972	20.0	10.360
5.2	5.283	10.2	7.399	15.2	9.032	20.2	10.412
5.4	5.383	10.4	7.471	15.4	9.091	20.4	10.463
5.6	5.482	10.6	7.542	15.6	9.150	20.6	10.514
5.8	5.879	10.8	7.613	15.8	9.201	20.8	10.565

6.2 PARTIAL PIPE FLOW

6.2.1 Reading the Velocity Head

All of the precautions cited above (Subsection 6.1.1) for full pipe flow would also be applicable to partial pipe flow. The major difference between the two pipe flow conditions (full or partial) is the reference level for measuring the velocity head.

For fully flowing pipes, the reference point for measuring the rise of water in the Connecting Hose is the upper water surface of the water stream coming out of the delivery pipe, which is the pipe crown as shown in Figure 5. For the partially flowing pipes, the reference point for measuring the rise of water in the Pitot Tube is the free water surface in the delivery pipe. If the Velocity Head Gauge is placed just parallel to the lower invert of the delivery pipe, the depth of water, d_w, may be subtracted from the rise of the water in the Pitot Tube; thus:

$$h_{max} = \text{(maximum Velocity Head Gauge reading)} - d_w$$
$$h_{min} = \text{(minimum Velocity Head Gauge reading)} - d_w$$

Then, the mean velocity head, h_{mean}, would be the average of h_{max} and h_{min} as shown in Equation 3.

6.2.2 Calculating the Discharge Rate

The discharge rate for partial pipe flow can be calculated using Equation 16-a for metric units and Equation 16-b for English units:

$$Q = A_w V = 0.806 K_w A_i v_{60}^{1.22} = 0.798 K_w A_i v_{80}^{1.22} = 0.795 K_w A_i v_{90}^{1.22} \qquad (16a)$$

$$Q = A_w V = 0.620 K_w A_i v_{60}^{1.22} = 0.615 K_w A_i v_{80}^{1.22} = 0.612 K_w A_i v_{90}^{1.22} \qquad (16\text{-}b)$$

where

$$A_i = \frac{\pi}{4} D_i^2 \qquad (17)$$

First of all, the velocity resulting from the Pitot Tube measurement can be obtained from either Table 2 (metric units) or Table 3(English units) by entering the mean velocity head, h_{mean}. Secondly, the value of K_w can be obtained from Table 1 by entering with the ratio, d_w/D_i. Then, the appropriate discharge equation must be used in Equation 16 depending on whether the Pitot Tube was placed at 60, 80 or 90 percent of the depth of water, d_w in the partially full pipe.

7. EXAMPLES

7.1. FULL PIPE FLOW

Example 1

What is the discharge of a well when it is discharging water with full delivery pipe if water rises from 20 to 22 centimeters in a Pitot tube? Diameter of the pipe is 15 centimeters.

Solution:

Diameter of the pipe is 15 centimeters = 0.15 meters
h_{min} = 30 centimeters
h_{max} = 32 centimeters

h_{mean} = (30+32)/2 = 31 centimeters =31/100= 0.31meters

The velocity at center can be calculated with the formula $v_c = \sqrt{2gh_{mean}}$
g is the acceleration due to gravity and is equal to 9.81 meter per second per second.
Substituting these values in equation 4 will result $\sqrt{2*9.81*0.31}$ = 2.466 meter per second (this value can be seen directly from Table 2)

Equation 9 will lead to $Q = \frac{\pi}{4} D_i^2 \frac{v_c}{1.116}$

or $Q = \frac{3.146}{4} (0.15)^2 \frac{2.466}{1.116}$
= 0.0391 cubic meter per second
= 39.1 liter per second

Example 2

What is the discharge of a well when it is discharging water with full delivery pipe if water rises from 22 to 23 inches in a Pitot tube? Diameter of the pipe is six inches.

Solution:

Diameter of the pipe is 6 inches = 0.5 foot
h_{min} = 22 inches
h_{max} = 24 inches

h_{mean} = (22+24)/2 = 23 inches =23/12=1.917 foot

The velocity at center can be calculated with the formula $v_c = \sqrt{2gh_{mean}}$
g is the acceleration due to gravity and is equal to 32.2 foot per second per second.
Substituting these values in equation 4 will result $\sqrt{2*32.2*1.917}$ = 11.111 foot per second (this value can be found directly from Table 3 for specific diameters)

Equation 9 calculates the values of discharge $Q = \frac{\pi}{4} D_i^2 \frac{v_c}{1.116}$

or $Q = \frac{3.146}{4} (0.5)^2 \frac{11.111}{1.116}$
= 1.955 cubic foot per second

7.2. PARTIAL PIPE FLOW

Example 3

What is the discharge of a well when it is discharging water with partially flowing delivery pipe if water rises from 22.0 to 22.30 centimeters in a Pitot tube when placed at 60% of the water depth? Diameter of the pipe is 15.24 centimeters. Depth of water in the delivery pipe of the tube well is 8.63 centimeters.

Solution:

Diameter of the pipe = 15.24 centimeters
h_{min} = 22.0 centimeters
h_{max} = 22.3 centimeters

h_{mean} = (22.0+22.3)/2 = 22.15 centimeters = 22.15/100= 0.2215meters

The velocity at 60 calculated with the formula $v_{60} = \sqrt{2gh_{mean}}$
g is the acceleration due to gravity and is equal to 9.81 meter per second per second
Substituting these values in equation 4 will result $\sqrt{2*9.81*0.2215}$ = 2.085 meter per second (this value can be seen directly from Table 2)

Average velocity can be calculated by the following formula
V = $0.806 v_{60}^{1.22}$ = $0.806*2.085^{1.22}$ =1.975 meters per second
Depth of water in the tubewell delivery pipe 8.63 centimeters
Ratio of water depth to the area of pipe ≈ 0.57
K_w factor from Table 1 = 0.589
Cross sectional area of tubewell delivery pipe = $A_i = \frac{3.1416}{4} 0.1524^2$
= 0.01824 m^2
Cross Sectional Area of water flowing in pipe = A_w = 0.01824*0.589
= 0.01074 m^2

Discharge of the tubewell = 0.01074 * 1.975 * 1000 = 21.22 liters per second.

Example 4

What is the discharge of a well when it is discharging water with partially flowing delivery pipe if water rises from 6.52 inches 6.80 inches in a Pitot tube when placed at 60% of the water depth? Diameter of the pipe is 8 inches. Depth of water in the delivery pipe of the tube well is 3 inches.

Solution:

Diameter of the pipe = 8 inches
h_{min} = 6.52 inches
h_{max} = 6.80 inches
h_{mean} = (6.52+6.80)/2 = 6.66 inches = 6.66/12 = 0.555 ft

The velocity at 60 calculated with the formula $v_{60} = \sqrt{2gh_{mean}}$
g is the acceleration due to gravity and is equal to 32.2 foot per second per second.
Substituting these values in equation 4 will result $\sqrt{2*32.2*0.555}$ = 5.98 foot second (this value can be seen directly from Table 3).

Average velocity can be calculated by the following formula

V = $0.620v_{60}^{1.22}$ = 0.620*5.98$^{1.22}$ = 5.495 foot per second
Depth of water in the tubewell delivery pipe = 3 inches
Ratio of water depth to the depth of pipe =3/8=0.375
K_w factor from Table 1 = 0.342
Cross sectional area of tubewell delivery pipe = $A_i = \frac{3.1416}{4} 0.667^2$ = 0.349 ft^2
Cross Sectional Area of water flowing in pipe = A_w = 0.342*0.349 = 0.1195 ft^2
Discharge of the tubewell = 0.1195 * 5.495 = 0.6567 cubic foot per second.

8. DEVELOPMENT OF SPECIAL ROD FOR DIRECT DISHCARGE MEASUREMENTS

Special rods can be fabricated for directly reading the discharge. Direct rod readings in quantitative terms can be marked on the rod. The formula for developing such a rod for full pipe flow is as follows:

$$h = \frac{9.96Q^2}{\pi^2 D^4 g} \tag{17}$$

For every additional unit of discharge in the CGS metric system, the rod reading is given in Table 4. The table also represents discharges for partially flowing delivery pipes. The formula used for the relationship is (Bos, 1989):

$$h = \frac{1}{2g}\left[\frac{(1.24Q)^{0.95}}{A}\right]^2 \tag{18}$$

where

$$A = \frac{1}{8} D^2 (\theta - Sin\theta) \tag{19}$$

and

$$\theta = 2 Cos^{-1}(1 - 2\frac{d_w}{D}) \tag{20}$$

where

A_w = Area of cross-section through which water is flowing (cm^2);

d_w = Depth of water in the pipe (cm); and

θ = Angle unit in radians associated with the pipe cross-sectional area without water.

Table 4 has been developed based upon Equations 18 and 19 for marking measuring rods for reading direct by the discharge rate.

In case of tubewells with a delivery pipe having a diameter of 15.24-cm, the rise of water indicated in Table 4 is 12.8-cm against a discharge of 8.0 liters/second. The first reading will therefore start from 12.8 centimeters from the lower end of the rod indicating 8 liters/second. The reason for starting at a value of 8.0 liters/second, instead of 0.0 liters/second, is that the Pitot Tube is a useful device for measuring velocities greater than 1.5 m/sec. Velocities lower than this limit cannot be measured accurately by using a Pitot Tube. The next sign will be made for 9.0 liters/second, which is at a distance of 16.9 cm from the same end of the rod, and so on. Similarly, rods for measuring discharges for other pipe sizes can be made.

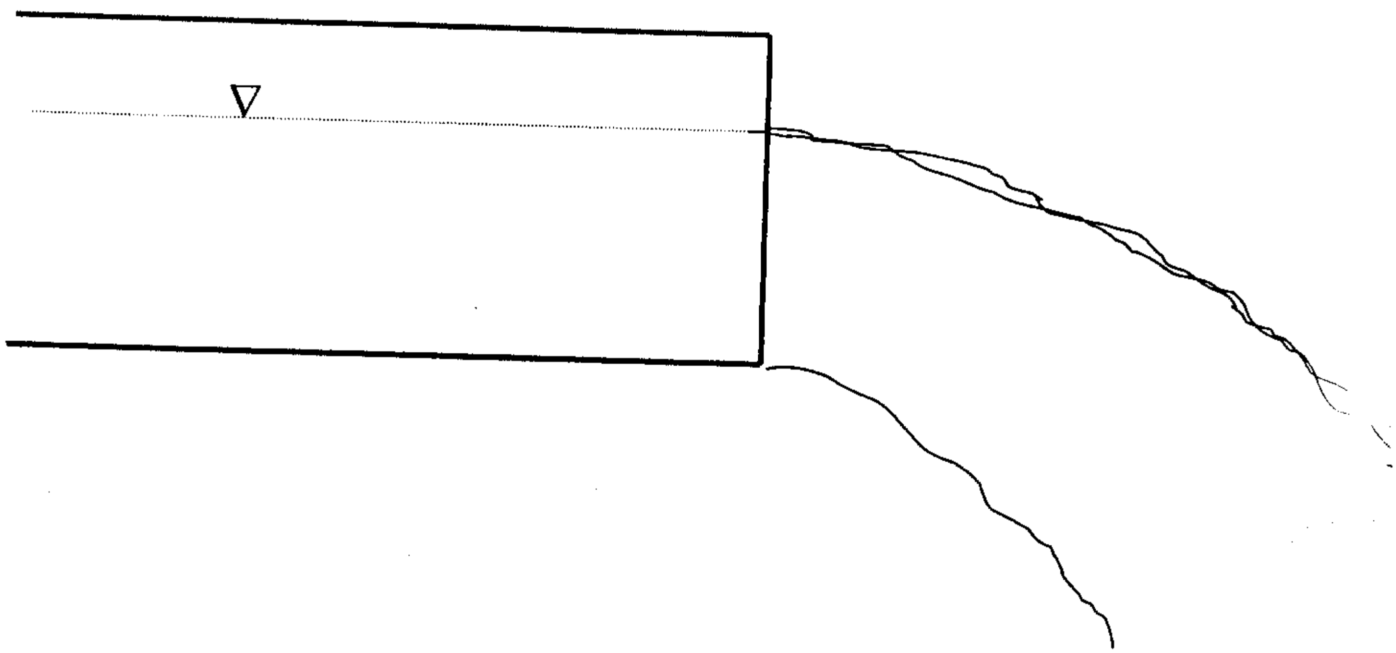


Figure 22. Schematic diagram of partial pipe flow.

Table 4. Discharge of water from delivery pipes of tube wells.

Sr. No.	Discharge (lps)	Diameter (cm)				
		7.62	10.16	12.7	15.24	20.32
		Rise of Water in Pitot Tube (cm)				
1	4	11.75	11.00			
2	5	13.50	12.50			
3	6	14.75	14.00			
4	7	14.96	15.25			
5	8	19.53	16.20			
6	9	24.72	17.05			
7	10	30.52	17.80			
8	11	36.93				
9	12	43.95	PARTIAL PIPE FLOW			
10	13	51.58				
11	14	59.83	18.93			14.00
12	15	68.68	21.73		8.00	15.80
13	16	78.14	24.72	10.00	9.50	16.30
14	17	88.21	27.91	10.80	10.40	16.80
15	18	98.90	31.29	11.25	11.30	17.25
16	19		34.86	11.80	12.30	17.60
17	20		38.63	12.50	13.40	18.15
18	21		42.59	14.60	15.00	18.50
19	22		46.74	20.40	17.50	19.00
20	23		51.09		22.50	19.40
21	24		55.63	22.79		19.80
22	25		60.36	24.72		20.30
23	26		65.29	26.74		20.60
24	27		70.40	28.84		21.10
25	28		75.72	31.01		21.40
26	29		81.22	33.27		21.85
27	30		86.92	35.60		22.20
28	31		92.81	38.02		22.50
29	32		98.90	40.51		22.90
30	33			43.08		23.30
31	34			45.73		23.65
32	35	FULL PIPE FLOW		48.46		23.97
33	36			51.27	24.72	24.30
34	37			54.15	26.12	24.60
35	38			57.12	27.55	24.95
36	39			60.17	29.02	25.20
37	40			63.29	30.52	25.60
38	41			66.50	32.07	25.90
39	42			69.78	33.65	26.20
40	43			73.14	35.27	26.35
41	44			76.58	36.93	26.60

Table 4 (Continued)

Sr. No.	Discharge (lps)	Diameter (cm)				
		7.62	10.16	12.7	15.24	20.32
		Rise of Water in Pitot Tube (cm)				
42	45			80.11	38.63	26.75
43	46			83.70	40.37	
44	47			87.38	42.14	
45	48			91.14	43.95	
46	49			94.98	45.80	
47	50			98.90	47.69	
48	51			102.89	49.62	
49	52				51.58	
50	53				53.59	
51	54				55.63	
52	55				57.71	
53	56				59.83	
54	57				61.98	
55	58				64.17	
56	59				66.41	
57	60				68.68	
58	61				70.99	
59	62				73.33	
60	63				75.72	
61	64				78.14	
62	65				80.60	
63	66				83.10	
64	67				85.64	27.10
65	68				88.21	27.91
66	69				90.83	28.74
67	70				93.48	29.58
68	71				96.17	30.43
69	72				98.90	31.29
70	73				101.66	32.17
71	74					33.05
72	75					33.95
73	76					34.86
74	77					35.79
75	78					36.72
76	79					37.67
77	80					38.63
78	81					39.60
79	82					40.59
80	83					41.58
81	84					42.59
82	85					43.61
83	86					44.64

Table 4 (Completed)

Sr. No.	Discharge (lps)	Diameter (cm)				
		7.62	10.16	12.7	15.24	20.32
		Rise of Water in Pitot Tube (cm)				
84	87					45.69
85	88					46.74
86	89					47.81
87	90					48.89
88	91					49.98
89	92					51.09
90	93					52.21
91	94					53.33
92	95					54.48
93	96					55.63
94	100					60.36
95	101					61.57
96	102					62.80
97	103					64.04
98	104					65.29
99	105					66.55
100	106					67.82
101	107					69.11
102	108					70.40
103	109					71.71
104	110					73.04
105	111					74.37
106	112					75.72
107	113					77.07
108	114					78.44
109	115					79.83
110	116					81.22
111	117					82.63
112	118					84.05
113	119					85.48
114	120					86.92
115	121					88.37
116	122					89.84
117	123					91.32
118	123					91.32
119	124					92.81
120	125					94.31
121	126					95.83
122	127					97.36
123	128					98.90
124	129					100.45
125	129					100.45

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