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THE PROCESS CONTROLLER's GUIDE TO

FLOW MEASUREMENT

This is number 8 in the Process Controller Guide series of documents

Number 1	Pollution Control.
Number 2	Water Sources and Water Treatment**.**
Number 3	Wastewater Treatment
Number 4	Phosphorus Removal from Wastewater.
Number 5	Electricity and Electric Motors.
Number 6	Pumps, Blowers and their Operation.
Number 7	Mechanical Transmission of Power
Number 8	**Flow Measurement**

This guide is intended to give Process Controllers an overview of flow measurement the reasons therefore and how flow is measured.

It is intended that this document be a useful reference and training manual guide to all persons involved in the Water and Wastewater Industry.

These documents are dedicated to the thousands of men and women (both present and past) who are involved in the life critical profession of Water and Wastewater Treatment.

NOTE:

Credits: some information was obtained via Google. Where original authors/owners could be determined, this is indicated.

THE PROCESS CONTROLLER's GUIDE TO

FLOW MEASUREMENT

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FLOW MEASUREMENT.

PART 1.

WHY DO WE MEASURE FLOW?

1.1 INTRODUCTION.

In short, TO MEASURE IS TO KNOW and TO KNOW IS TO BE ABLE TO CONTROL A PROCESS.

The job of the Process Controller as the name suggests is to control the water and wastewater treatment processes to achieve the desired outcome. To be able to control the process optimally, the Process Controller needs to know many variables – the one that we will deal with in this guide, is that of flow of both water and air including chemical solutions such as coagulant dosing.

Flow measurement will include flows at different points in the water cycle. These are covered below for water and wastewater. To give the Process Controller a better understanding of the whole water cycle, both on the treatment works and off-site, are covered.

1.2 MEASUREMENT IN RESPECT OF WATER TREATMENT AND DISTRIBUTION.

1.2.1 The measurement of the flow of raw water into the water treatment works.

It is important to measure the daily flow and the peak flow rate:

1. to compare with the design daily and peak flow rates. As the flow rate increases towards the design flow, it become very important to monitor, amongst others, sedimentation tank quality as any deterioration here will have a significant impact on the sand filters;

2. by analysing historical data, one is able to predict future flows and thus begin to get an idea when the design loading is likely to be reached. Although the Process Controller may have only limited impact on the decision regarding any future need to enlarge or extend the treatment works, they should be in a position to bring these matters to their supervisor;

3. If water restrictions are introduced in the water distribution area, the Process Controller should be able to see the impact of these restrictions on the throughput of the water treatment works;

4. by measuring the flow rate and knowing the chemical consumption, the Process Controller will be able to compare the mean chemical dosage rate with historical data. This will determine if any optimization of the works has been effective.

1.2.2 The measurement of the flow rate of in-process water in the water treatment works.

It is important to measure certain of the in-process and final:

1. to determine loading rates on sand filters;

2. to determine sand filter backwash rate to ensure that the rate is sufficient to effectively clean the filter, but not too high as to cause the loss of sand;

3. to determine the quantity of water used for backwashing to minimize wastage or unnecessary return of water to the head of the treatment works;

4. to determine the quantity of water lost during the sludge handling and disposal operation;

5. to determine the final water production as a percentage of the raw water being received at the works and to perform a water volume balance where:

total flow in equals the total flow out plus any losses on the site

1.2.3 <u>The measurement of the water flow in the distribution system.</u>

While the responsibility for operation of the distribution system may not be part of the Process Controller's duties, it is useful that they know what happens to the water after it leaves the treatment works.

A typical simplified water treatment and distribution layout is given below in figure 1:

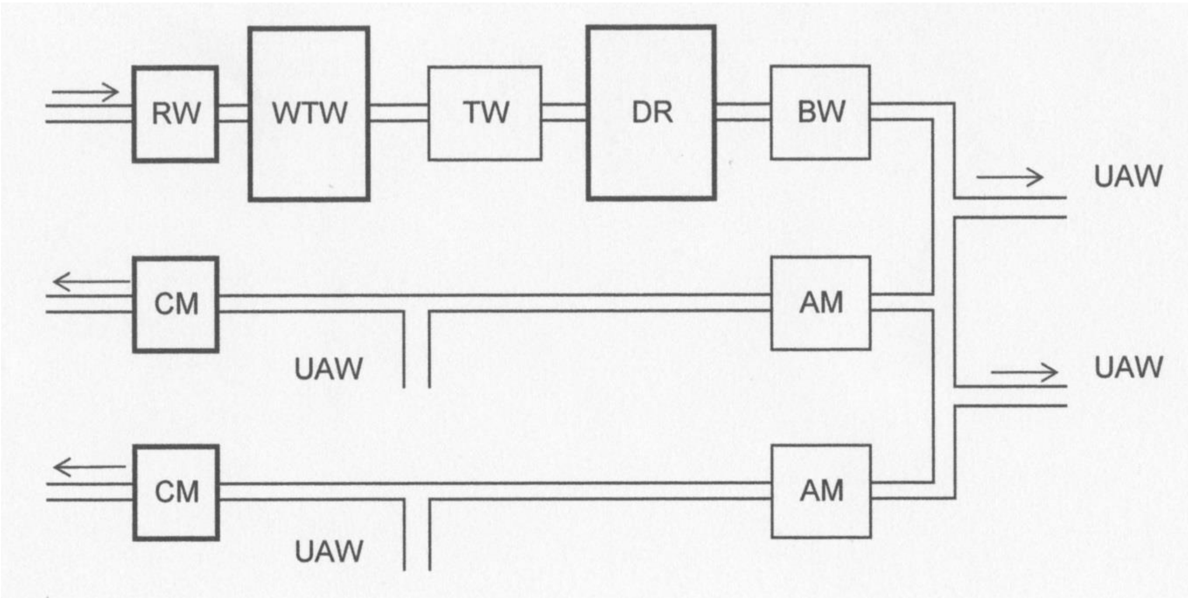

Figure 1 – A TYPICAL SIMPLIFED WATER TREATMENT AND DISTRIBUTION LAYOUT.

Meanings of codes in figure 1:

1. **RW** raw water flow meter;
2. **WTW** water treatment works;
3. **TW** treated water meter;
4. **DR** distribution reservoir;
5. **BW** bulk water meter for distribution;
6. **AM** area meter;
7. **CM** consumer's meter – included here are:

7.1 domestic, commercial and industrial consumers, both pre-paid and post-paid;

7.2 water supplied to informal settlements that is metered but not charged for;

7.3 metered standpipes used for temporary construction purposes.

8. **UAW** unaccounted for water.

8.1 water lost through leaks and pipe bursts;

8.2 illegal connections and theft of water.

Unfortunately in many cases, flow meters are not always installed at these various locations. The next section deals with why it is recommended that the above meters be installed.

1.2.4 <u>Determining the water balance across the whole water treatment and distribution system.</u>

1. **raw water meter** – this was covered above;

2. **the water treatment works** – here the various meters are required to process control – chemical dosing, feed rates onto sand filters, filter backwash rates and sludge handling;

3. **treated water meter** – it is important to know the total volume water produced. This is both as a percentage of inflow and as the input into the water balance across the distribution system;

4. **distribution reservoir outflow** – if there are no take off point between the water treatment works and the distribution reservoir, these two meters should record the same volume;

5. **area flow meter** – this assists in the water balance calculation;

6. **consumer's meter** – this will be used for charging for the water used or how much water is supplied to an informal settlement;

7. **unaccounted for water** – this is the difference between the volume of water produced and the amount of water calculated from adding all the **metered** usages.

Sometimes the volume of unaccounted for water is added to the volume of water for which <u>no</u> income is received and is together known as Non-Revenue Water (NRW). This would be applicable when the financial aspects of the water supply are being considered.

It would not be applicable when a **physical** water balance is being undertaken. The fact that the water being supplied to an informal settlement is being metered means that one <u>knows</u> where the water is going.

UAW = Total volume produced – Total recorded on all meters

1.3 MEASUREMENT IN RESPECT OF WASTEWATER CONVEYANCE AND TREATMENT.

1.3.1 The measurement of the wastewater flow in the collection and treatment system.

While the responsibility for operation of the wastewater collection system may not be part of the Process Controller's duties, it is important that they know what happens in the wastewater collection system before the flow arrives at the treatment works.

A typical simplified wastewater collection and treatment layout is given below in figure 2:

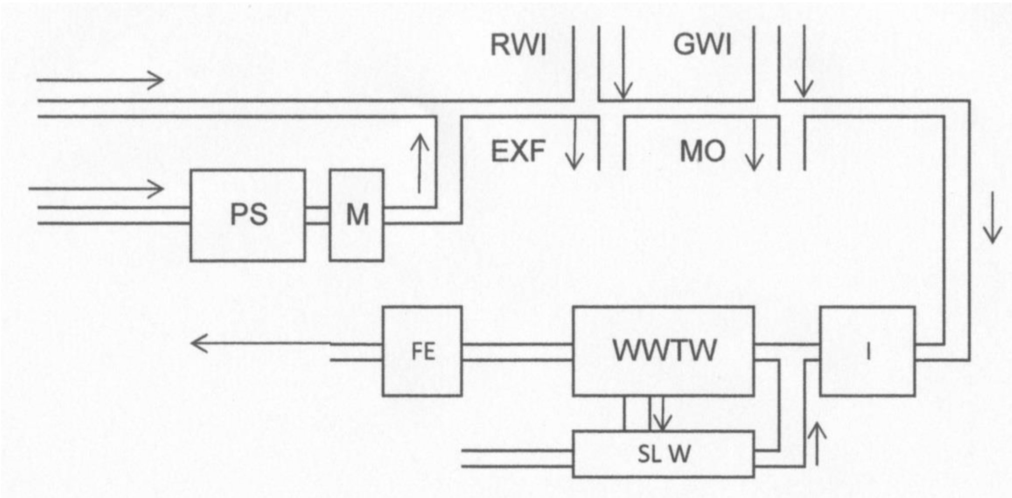

Figure 2 – A TYPICAL SIMPLIFED WASTEWATER COLLECTION AND TREATMENT LAYOUT.

Meanings of codes in figure 2:

1. **PS, M** **pump station**. Ideally there should be a flow meter at a larger pump station. It would not be necessary to have a flow meter at small pump stations. One could get an estimate of the flow from the running hour meter and the discharge rate from the pumps.

2. **RWI** **rain water ingress**. This is where rain water enters the sewer.

   2.1 this may be from incorrect or illegal connections from roofs, paved areas etc;

   2.2 missing manhole covers;

   2.3 persons deliberately lifting manhole covers to drain flooded areas;

   2.4 cross connections between sewers and the stormwater system. Some areas have these cross connections to limit the flow in the sewer by allowing excess water to overflow into the stormwater system or into rivers. This is a bad practice as this leads to pollution of rivers and can result in high flows in a river back flowing into the sewer system – This has happened!!!.

   Rain water ingress occurs during the rainfall, so the impact of the flow in the sewer is felt suddenly and immediately. It generally drops quite quickly after the rain has stopped.

3. **GWI** **groundwater infiltration.** This occurs when there are leaks in the sewers and manhole and the groundwater level is higher that the sewer.

Groundwater infiltration generally starts sometime after rainfall. The impact of the flow in the sewer is gradual and can continue for quite a long time afterwards. This may be weeks or even months.

4. **EXF** **exfiltration**. This is comparatively rare in gravity sewers. This will happen when there are leaks in the sewers and **the groundwater water level is lower than the invert (bottom) of the sewer**. There are two reasons why this impact, if present, would be small:

4.1 the water pressure on a leak in the sewer would only be the height of the flow in the sewer. For example in a 500mm sewer flowing half full, the depth of flow is 250mm and this is the pressure on the leak – very small;

4.2 wastewater contains suspended solids that would tend to block any small leak and so prevent the movement of wastewater from the sewer into the surrounding area.

In rising mains (pumped sewers), there is a different picture. Due to the higher pressures; the chances of a leak, particularly at pipe joints, is much higher. Leaks here would generally be easier to see due to the impact on the area such ponding and soil being washed away.

5. **MO** **manhole overflows.** These would be due to blockages in the sewer.

6. **I** **raw inflow meter** at the wastewater treatment works. This is the most important meter at the wastewater treatment works. Both the total daily flow and the variation of the flow during the 24 hour period are important pieces of information for the process controller.

7. **SL W** **sludge wasting meter**. This is also a very important meter at the works, especially for the activated sludge process. Knowing and maintaining the preferred sludge age is vital to the stable operation of the works. If the sludge is pumped to the sludge handling unit and the pumping rate is known, one can use the pump hour meter readings to calculate the volume of sludge pumped.

8. **FE** **final effluent meter**. It is preferable to have a final effluent meter. This is not always possible as the final effluent discharge point may be some distance away from the nearest electricity supply.

1.3.2 <u>The measurement of the flow into the wastewater treatment works.</u>

It is important to measure the daily flow and the peak flow rate:

1. to compare with the design daily and peak flow. As the flow rate increases towards the design flow, it become very important to monitor, amongst others, sedimentation tank quality as any deterioration here will have a significant impact on the effluent quality;

2. by analysing historical data, one is able to predict future flows and thus begin to get an idea when the design loading is likely to be reached. Although the Process Controller may have only limited impact on the decision regarding any future need to enlarge or extend the treatment works, they should be in a position to bring these matters to their supervisor;

3. to compare dry weather flow with wet weather flow to see if the increase in flow occurs very soon after rainfall or sometime later.

4. If water restrictions are introduced in the water distribution area, the Process Controller should be able to see the impact of these restrictions on the flow of wastewater to the treatment works;

1.3.3 The measurement of the flow rate of in-process water in the water treatment works.

It is important to measure certain of the in-process flows and final effluent:

1. to determine sludge wasting in order to maintain the desired sludge age;

2. to determine the final effluent volume in order to calculate the loading on the receiving water.

Unfortunately in many cases, flow meters are not always installed at these various locations.

1.4 THE MEASUREMENT OF AIR FLOW IN THE DIFFUSED AIR ACTIVATED SLUDGE PROCESS.

The aerated zones of the activated sludge process rely on a suitable rate of air flow to satisfy the oxygen demand of the process. The electricity requirement of the blowers to provide this air is the single largest cost of the treatment process. It makes sense to control the air flow as excess air will not speed up or improvement the treatment process except where described below. The main feature of the control of the activated sludge process is the measurement of the dissolved oxygen content. On larger wastewater treatment works, the rate of air production can often be varied automatically according the dissolved oxygen content of the reactor.

On a less sophisticated treatment works, it would be necessary to determine the dissolved oxygen content of the reactor and to manually adjust the rate of aeration accordingly. It is difficult to generalise as to exactly where in the reactor the dissolved oxygen measurement should be determined. This depends on many factors including:

1. diffuser layout – there should be more diffusers per square metre towards the inlet the aerated zone and fewer per square metre towards the effluent weir;

2. strength of the wastewater;

3. degree of loading on the works.

Where the measurement of the air flow becomes important is to note unexplained increases or decreases in air flow relative to the dissolved oxygen content.

If the air flow is much lower than normal while the dissolved oxygen remains within the desired range – then this indicates either a sudden reduction in flow/load (the reduction in flow should be detected through the inlet flow meter) **OR** the presence of some material in the inflow that is inhibiting the treatment process (some toxic material).

In the case of a toxic or inhibitory material entering the treatment works, it is usually the nitrifying bacteria that are affected first. When this happens, the **oxygen demand drops** and the **dissolved oxygen content rises.** The usual first reaction is to reduce the air input by slowing down blowers or turning off some blowers (or surface aerators). This is in reality, **THE EXACT OPPOSITE** to what the Process Controller must do. When the treatment organisms are under stress, the dissolved oxygen content must **be INCREASED.**

If the air flow is much higher than normal while the dissolved oxygen remains within the desired range – then this indicates either a sudden increase in flow (the increase in flow should be detected through the inlet flow meter) **OR** a sudden increase in organic load. This might be detected by a visual check on the colour etc. of the influent wastewater,

1.5 THE MEASUREMENT OF AIR FLOW IN THE AIR SCOUR OF A SAND FILTER.

Depending on the construction of a sand filter, the air scour during the backwash process will assist in the satisfactory cleaning of the sand filter. A reduction in air flow will suggest blinding of the diffusers at the bottom of the sand filter. This should be visible during the backwash process. The problem with a gradual reduction in air flow is often difficult to notice. This deterioration could be noticed only when it becomes apparent that the filter runs become much shorter – requiring more frequent back washing.

1.6 THE MEASUREMENT OF GAS PRODUCTION IN THE ANAEROBIC DIGESTION PROCESS.

The volume of digester gas produced is an important control parameter in the operation of an anaerobic digester. It is important to note the volume of gas produced as any reduction in daily gas production is an indication that an operational problem is ALREADY occurring. This could be due to a number of factors:

1. inhibition of the digestion process by some inhibitory material. The methane producers are the more sensitive group of organisms and any inhibition of the this step in the digestion process will lead to a reduction in gas production;

2. too much water entering the digester by poor desludging practice leading to cooling of the digester;

3. a sudden increase in the organic load on the digester leading to a higher production of volatile fatty acids before the methane producing bacteria can “catch up”. This will be detected by an increase in the Volatile Acids to Alkalinity ratio. This change will be detectable long before a drop in pH value is noted.

1.7 FLOW MEASUREMENT SCENARIO’s.

For the measurement of liquid flows, there are basically two scenario’s:

1. open channel flow measurement – covered in Part 2;

2. closed pipe flow measure – covered in Part 3.

For the measurement of air and gas flows, there is only one scenario namely closed pipe flow – covered in Part 4.

PART 2

OPEN CHANNEL FLOW MEASUREMENT.

2.1 INTRODUCTION.

By open channel, one is referring to a situation where the flow is by gravity from a high point to a low point. This definition includes the flow in pipes, even if the pipe is running full provided the only force moving the liquid is the force of gravity.

The open channel flow meters may be separated into two main types:

1. weirs – where the water flows OVER a specially made construction;

2. flumes – where the water flows THROUGH a specially made construction.

2.1.1 Types of Weirs.

These may be split into two main types:

1. sharp crested weir;

2. broad crested weir;

Each of these has advantages and disadvantages and will be covered below in more detail,

2.1.2 Types of Flumes.

These may be split into various types:

1. venturi flume;

2. Parshall flume;

3 Palmer –Bowlus flume;

4. H flume.

Each of these has advantages and disadvantages and will be covered below in more detail,

2.2 WEIRS IN GENERAL.

A **flow measuring weir** is simply a structure OVER which water flows in such a way that **volumetric flow rate** can be calculated.

All weirs suffer from the disadvantage that material may be deposited by settlement just upstream from the weir structure. A scour valve could be fitted near the bottom of the wall to allow sand etc to be washed through. Large stones and other debris cannot be removed by this method. The acculmulation of sediment upstream of a weir is shown, for a sharp crested weir, in figure 3 below:

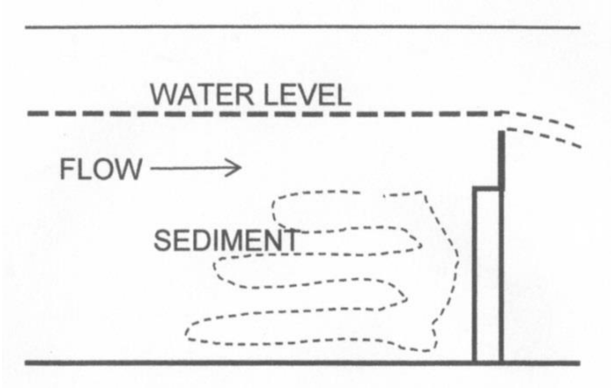

Figure 3 – SHOWING SEDIMENT ACCUMULATION UPSTRAM OF A WEIR.

Weirs can normally handle a very wide range of flows. However, at very low flows, the measurement of the head must be very accurate as an error of a few millimetres will make a big difference to the flow rate calculated

2.3 THE SHARP CRESTED RECTANGULAR WEIR.

There are two types of sharp crested rectangular weirs:

1. where the weir is the same width as the approach channel. This is sometimes known as a suppressed rectangular weir because the end contractions are suppressed. This actually means that there are no end contractions. This should rather be called a “full width” weir;

2. where the weir is narrower than the approach channel. This is sometimes known as a contracted rectangular weir.

These two types are shown in figure 4 below:

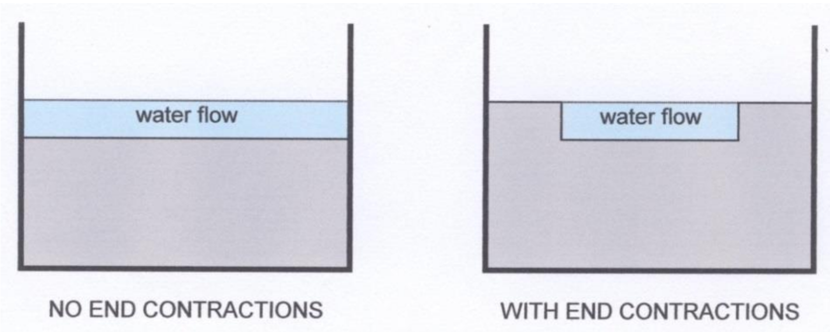

Figure 4 – SHOWING A RECTANGULAR WEIR WITHOUT AND WITH END CONTRACTIONS.

2.3.1 Requirements for Accurate Flow Measurement.

To ensure accurate flow measurement, there are certain dimensions and flow characteristics that are required, these include:

1. velocity of approach – the water flowing towards the weir must not have a significant velocity as this will have an influence on the calculation of flow rate. The channel feeding the weir should be flat or have only a very slight grade;

2. free fall of the water downstream of the weir - the **nappe** is a sheet or curtain of water that flows over a weir. There must be an air space between the water and the weir; otherwise this will affect the flow characteristic over the weir leading to an inaccurate result;

3. weir not flooded – there must be a free fall of the water into the downstream channel. If the downstream water level rises so that a free fall no longer exists, then the weir is said to be "flooded". This will cause an artificial raising of the water level above the weir and lead to an over-reading in the flow rate;

4. height of the weir – the height of the weir must be at least 3 times the height of the maximum flow at the flow measuring point;

5. height measuring point – the distance from the weir upstream to the measuring point should be at least 5 times the height of crest of the weir at maximum flow;

6. height of flow over weir – in order to obtain reasonable accuracy, the height of flow over the weir should be greater than about 5mm or greater than one third of the length of the weir;

7. thickness of weir – the consensus seems to be that the weir plate must not be thicker than 3 - 5 mm. This means that the whole weir plate must be made of one, usually, metal plate as shown in figure 5 below.

   In larger weirs this is not feasible. The alternative would be to bolt a metal plate to the UPSTREAM face of the weir supporting structure. There appear to be no guidelines as to the amount that the weir must protrude above the weir support structure. It suggested that a minimum protrusion of 50 mm is offered as a starting point. What is important is that the nappe falls clear of the weir support structure.

   An alternative for large weirs would be a broad crested weir - see later.

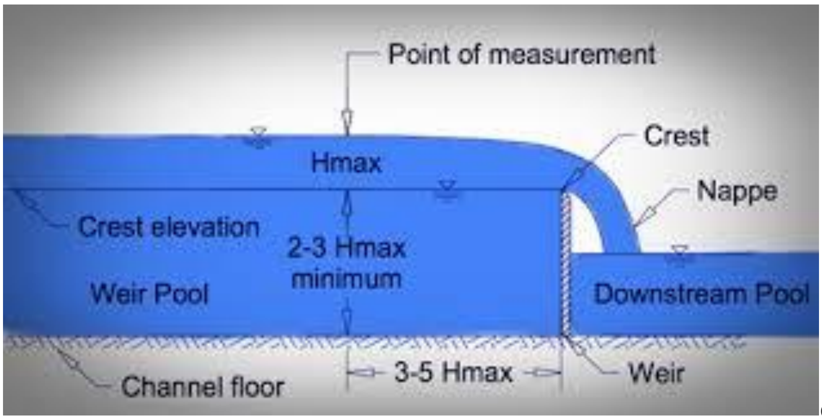

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Figure 5 – SHOWING REQUIREMENTS FOR ACCURATE FLOW MEASUREMENT

2.3.2 <u>Calculating the Flow Rate for a Full-Width Rectangular Weir.</u>

The most commonly used formula for calculating the flow rate is:

$$Q = 1.84\ L\ H^{1.5}$$

Where Q = m^3/s, L and H in m

EXAMPLE: The weir is 1 metre wide and the depth of flow as measured upstream is 100mm – need to calculate the flow in ML/day:

$$Q\ (m^3/s) = 1.84 \times 1.00\ (m) \times (0.1)^{1.5}\ (m)$$

$$= 1.84 \times 1.00 \times 0.0316$$

$$= 0.058\ m^3/s$$

There are 86 400 seconds in a day and 1 000 m^3 in a ML. Therefore the flow in ML/day

$$= \frac{0.058 \times 86\,400}{1\,000} \qquad \frac{\textit{seconds per day}}{m^3 \textit{ per ML}}$$

$$= 5.01\ \text{ML/day}$$

2.3.3 Calculating the Flow Rate for a Contracted Rectangular Weir.

Here the weir is narrower than the channel upstream – see right hand drawing in figure 4. As the water from the sides of the channel nears the notch, it accelerates and has to turn to pass through the opening. This turning cannot occur instantaneously, so a curved flow path or **side contraction** results in which the water springs free to form a jet narrower than the overflow opening width. For many experiments done over the years, it has been found that by reducing the physical width of the weir in the calculation by 0.2 times the height of the flow, gives a good approximation of the actual flow rate.

The effect on flow width of the two side contractions is shown in figure 6 below:

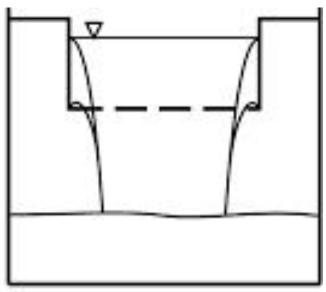


Figure 6 – SHOWING THE EFFECT ON FLOW WIDTH OF THE END CONTRACTIONS.

The above formula may be used with the corrected weir width. The formula then becomes:

$$Q = 1.84\ (L - 0.2H)\ H^{1.5}$$

Where $Q = m^3/s$, L and H in m

EXAMPLE: The weir is 1 metre wide and the depth of flow as measured upstream is 100mm – need to calculate the flow in ML/day:

$$Q\ (m^3/s) = 1.84 \times [1.00 - (0.2 \times 0.1)]\ (m) \times (0.1)^{1.5}\ (m)$$

$$= 1.84 \times 0.98 \times 0.0316$$

$$= 0.0570\ m^3/s$$

There are 86 400 seconds in a day and 1 000 m^3 in a ML. Therefore the flow in ML/day

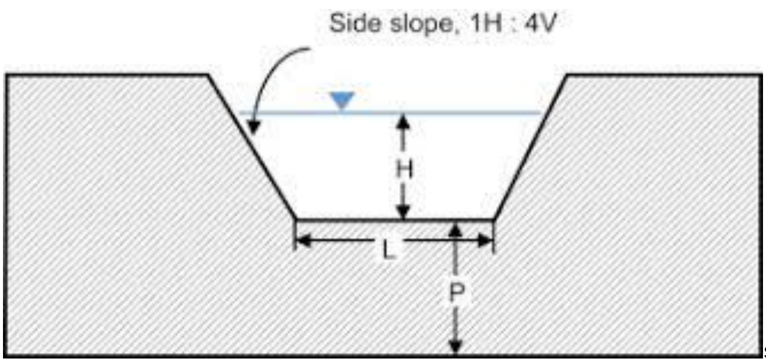
$$= \frac{0.0570 \times 86\,400}{1\,000} \qquad \frac{\textit{seconds per day}}{m^3 \textit{ per ML}}$$

= 4.92 ML/day

2.4 THE TRAPEZOIDAL (CIPOLLETTI) WEIR.

It may be seen that in the case of a contracted weir, the EFFECTIVE width of the weir is reduced by a significant amount. For example – if the weir is 1.00 metre wide and the depth of flow of the water is 0.2 metres, then the EFFECTIVE width of the weir is (1.00 – (0.2 x 0.2) = 0.96 metres

The trapezoidal (also known as Cipolletti) weir overcomes the problem by being wider at the top than at the bottom. The side slope must be in the ratio of 1 unit horizontal : 4 units vertical. This is shown in figure 7 below:



sciencedirect.com

Figure 7 – SHOWING A TRAPEZOIDAL WEIR

2.4.1 Calculating the Flow Rate for a Trapezoidal weir

The most commonly used formula for calculating the flow rate is:

$$Q = 1.86\ L\ H^{1.5}$$

Where Q = m^3/s, L and H in m

EXAMPLE: The weir **AT THE BOTTOM** is 1 metre wide and the depth of flow as measured upstream is 100 mm – need to calculate the flow in ML/day:

$$Q\ (m^3/s) = 1.86 \times 1.00\ (m) \times (0.1)^{1.5}\ (m)$$

$$= 1.86 \times 1.00 \times 0.0316$$

$$= 0.059\ m^3/s$$

There are 86 400 seconds in a day and 1 000 m^3 in a ML. Therefore the flow in ML/day

$$= \frac{0.059 \times 86\,400}{1\,000} \qquad \frac{\textit{seconds per day}}{m^3 \textit{ per ML}}$$

= 5.08 ML/day

It may be seen that although the weir **IS** narrower than the approach channel; the flow rate for a given weir width and flow height is almost the same as if the weir **WAS** the same width as the approach channel.

2.5 THE TRIANGULAR OR V-NOTCH WEIR.

It was seen earlier that there must be an air gap between the wall below the weir plate and the nappe (the water stream). At very low flows, this may not be possible as the water will tend to "stick" to the wall – this will lead to inaccurate flow calculation. Even with the required air gap, the accuracy of the measurement of the height of the water becomes very important. If the flow over the weir is, say, 10mm and the inaccuracy in reading the height of the water is, say, 1mm – this means that the error in the flow calculation is at least 10%!!.

Where low flows need to be measured, then the V-notch weir is suitable. The V-notch may be any angle but 90 degree and 60 degree are the most common.

The most commonly used formula is:

$$Q = 1.4 \tan\left[\frac{\Theta}{2}\right] H^{2.5}$$

Where Q = m^3/s, Θ is angle of the V, H in m

EXAMPLE: The depth of flow as measured upstream is 50mm of a 90 degree V-notch weir – need to calculate the flow in L/second.

Θ = 90 degrees so Θ/2 = 45 degrees. Tan 45 degrees = 1.0

50 mm = 0.05 m

Formula then becomes 1.4 x $H^{2.5}$

Q (m3/s) = 1.4 x $(0.05)^{2.5}$

=1.4 x 0.0179

= 0.00078 m^3/s

To covert to L/s, multiply by 1 000

= 0.78 L/s

Even at a water flow depth of 300 mm (0.3 m); the flow rate is only 69 L/s (5.8 ML/day).

Some references suggest that the maximum height of flow through a V-notch should not exceed 380 mm.

2.6 COMBINATION OF V-NOTCH AND RECTANGULAR WEIR.

Where low flow accuracy is required as well as the ability to accurately measure high flows then a combination of a V-notch and a rectangular weir may be used. An example would be in measuring the flow in a river.

An example of a combination V-Notch and rectangular weir is shown in figure 8 below:

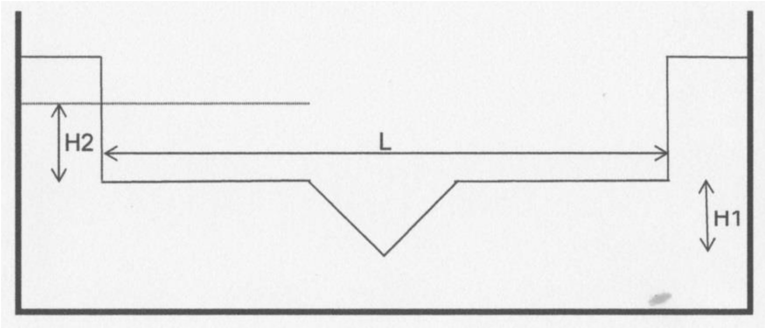


Figure 8 – SHOWING A COMBINATION V-NOTCH and RECTANGULAR WEIR.

2.6.1 Calculating the Flow over a Combination Weir.

If the flow is through the V-notch only then the height of the flow is measured as H1 and the flow rate calculated as shown in section 2.5.

If the flow is over the rectangular part as well, then there are three parts to the calculation:

1. the measurement H1 would be equal to the height of the V-notch and this part of the flow would also be calculated as shown in section 2.5;

2. the measurement H2 would be the height of the flow ABOVE the flat section of the weir. It is most likely that there would be two end contractions, so the flow would be calculated as shown in section 2.3.3;

.

3. add the two flows together to get the total flow.

2.7 THE BROAD CRESTED WEIR.

Most large rectangular weirs will be of the broad crested type. This is because of the strength of the wall that is required. The most common construction would be reinforced concrete. In some instances plastered brick may be used.

It is most important that the crest (width) of the weir be broad enough in the direction of flow for the surface of the water to be parallel to the weir as it passes over the weir. THIS IS VERY IMPORTANT otherwise the standard formula does not apply.

As with other weirs, the height of the flow relative to the top surface of the weir must be measured at a point upstream of the weir. To ensure an accurate reading, this point must be least 3 (and preferably 5) times the height of the maximum flow of the weir measured at the weir; upstream of the weir. The flow pattern over a broad crested weir is shown in figure 9 below:

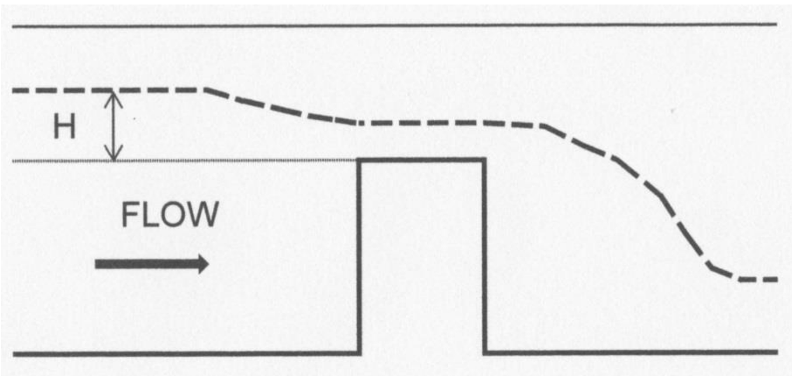


Figure 9: SHOWING THE FLOW PATTERN OVER A BROAD CRESTED WEIR

2.7.1 Calculating the Flow Rate for a Combination Weir.

The most commonly used formula for calculating the flow rate is:

$$Q = 1.705\ L\ H^{1.5}$$

Where Q = m^3/s, L and H in m

It may be seen that the formulae for the different types of weirs (except the V-notch) are similar; it is just the constant that varies.

EXAMPLE: The weir is 1 metre wide and the depth of flow as measured upstream is 100mm – need to calculate the flow in ML/day:

$$Q\ (m^3/s) = 1.704 \times [1.00 - (0.2 \times 0.1)]\ (m) \times (0.1)^{1.5}\ (m)$$

$$= 1.704 \times 0.98 \times 0.0316$$

$$= 0.0528\ m^3/s$$

There are 86 400 seconds in a day and 1 000 m^3 in a ML. Therefore the flow in ML/day

$$= \frac{0.0528 \times 86\,400}{1\,000} \qquad \frac{\textit{seconds per day}}{m^3 \textit{ per ML}}$$

$$= 4.056\ ML/day$$

2.8 FLUMES IN GENERAL.

A **flow measuring flume** is simply a structure THROUGH which water flows in such a way that volumetric flow rate can be calculated

Flumes generally do not suffer from the disadvantage that material may be deposited by settlement just upstream from the flume structure as most of the bottom of the flume is flat.

2.9 THE VENTURI FLUME.

The Venturi flume has a flat bottom section so that grit etc. will not settle out if the velocity remains above about 0.3 m/s. This type of flume may be used for raw wastewater. It consists of three sections: converging section; throat section and diverging section.

Some designs use a curved converging section while others use a straight converging section. In both cases, the measuring point is upstream of the converging section. The same calculation of flow rate formula applies to each layout. The two layouts are shown in figures 10 and 11 below:

The approach channel must be straight and almost flat for a distance of at least 20 times the throat width. The 10x given in figure 10, is considered to be a bit short, from practical experience.

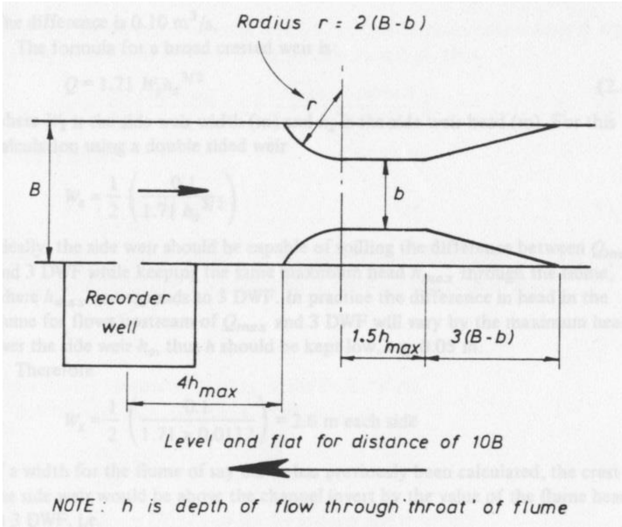


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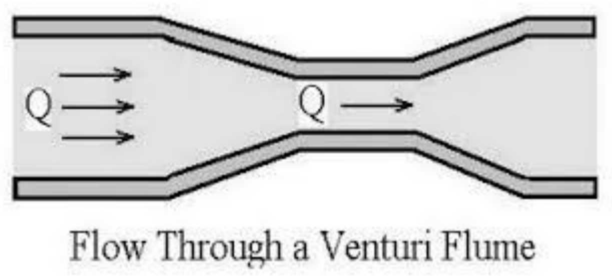
Figure 10 - SHOWING A VENTURI FLUME WITH A CURVED CONVERGING SECTION.



test-and-measurement-world.com

Figure 11 – SHOWING A VENTURI FLUME WITH A STRAIGHT CONVERGING SECTION.

2.9.1 <u>Calculating the Flow Rate for a Venturi Flume.</u>

The most commonly used formula for calculating the flow rate is:

$$Q = 1.705\ L\ H^{1.5}$$

Where Q = m^3/s, L and H in m

<u>EXAMPLE:</u> The flume is 0.25 metre wide and the depth of flow as measured upstream is 300 mm – need to calculate the flow in ML/day:

$$Q\ (m^3/s) = 1.705 \times 0.25\ (m) \times (0.3)^{1.5}\ (m)$$

$$= 1.705 \times 0.25 \times 0.164$$

$$= 0.070\ m^3/s$$

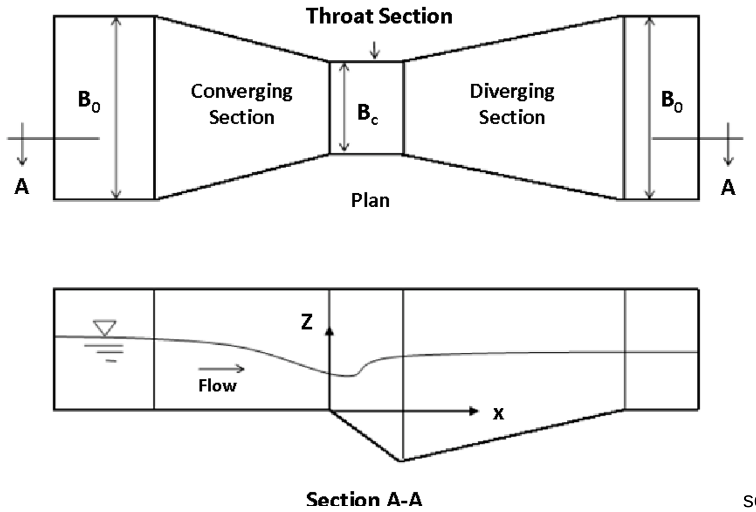
There are 86 400 seconds in a day and 1 000 m^3 in a ML. Therefore the flow in ML/day

$$= \frac{0.070 \times 86\,400}{1\,000} \qquad \frac{\textit{seconds per day}}{m^3 \textit{ per ML}}$$

= 6.05 ML/day

2.10 THE PARSHALL FLUME.

The Parshall flume is an improvement on the Venturi flume in that the overall head loss through the flume is reduced. This is achieved by having a dip in the throat section and then a rise in the diverging section before discharge into the downstream channel, sump etc. This may be seen in figure 12 below:



semanticscholar.com

Figure 12 – SHOWING A PARSHALL FLUME IN PLAN AND SECTION.

The usual measuring point for a Parshall flume is 1/3 of the way **MEASURED ALONG THE WALL** into the converging section. Some references indicate that the measuring point nay be upstream of the converging section – however the consensus is this is NOT a suitable measuring point.

2.10.1 Calculating the Flow Rate for a Parshall Flume – Measuring Point in Convergent Section.

The most commonly used formula for calculating the flow rate is:

$$Q = 2.207\ L\ H^{1.5}$$

Where Q = m^3/s, L and H in m

EXAMPLE: The flume is 0.25 metre wide and the depth of flow as measured 1/3 into converging section is 250 mm – need to calculate the flow in ML/day:

$$Q\ (m^3/s) = 2.207 \times 0.25\ (m) \times (0.25)^{1.5}\ (m)$$

$$= 2.207 \times 0.25 \times 0.125$$

$$= 0.0689\ m^3/s$$

There are 86 400 seconds in a day and 1 000 m^3 in a ML. Therefore the flow in ML/day

$$= \frac{0.0689 \times 86\,400}{1\,000} \qquad \frac{\textit{seconds per day}}{m^3 \textit{ per ML}}$$

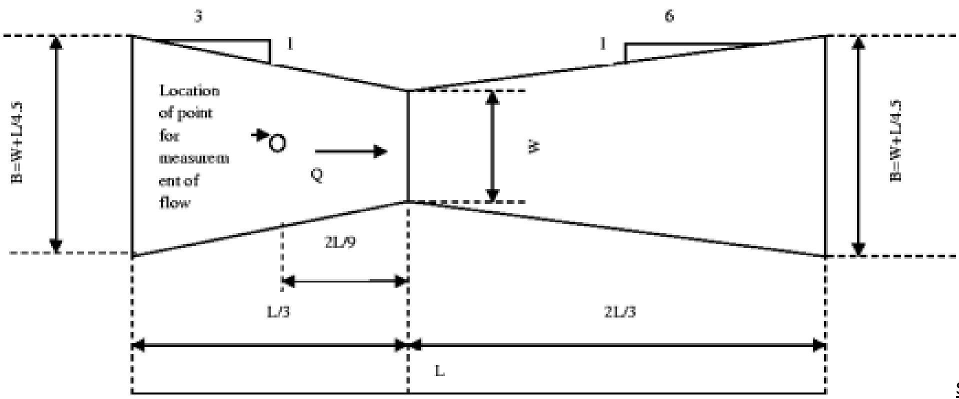
$$= 5.96\ \text{ML/day}$$

2.11 THE CUTTHROAT FLUME.

This is a flat bottomed flume without the extended throat of other types of flumes. The converging and diverging sections have prescribed ratios of width to length. The converging section is 1/3 of the overall length and the diverging section is 2/3 of the overall length. The water level is measured at a point 2/9 of the overall length upstream of the throat.

As it has a flat floor it can be used for measuring wastewater flows. It is however, not recommended for a throat width of less than 100mm.

The head loss across a cutthroat flume is about the same as across a Venturi flume but more than across a Parshall Flume. A typical Cutthroat flume is shown in figure 13 below:



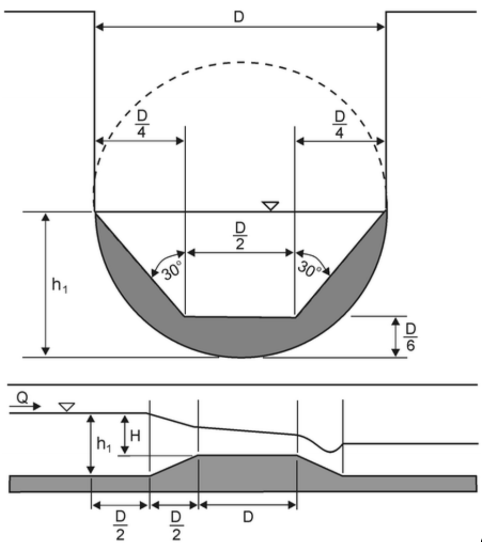
springerLink

Figure 13 – SHOWING A TYPICAL CUTTROAT FLUME.

The calculation of the flow rate throat a Cutthroat flume is very complicated and depends on many factors. For this reason, only standard sizes are used and the flow rate is determined from Look-Up tables.

2.12 THE PALMER-BOWLUS FLUME.

The above flumes are fitted or constructed in open channels. The Palmer-Bowlus flume may be fitted into a pipe. It is seen in figure 14 below that the flume is narrower than the pipe in which it is fitted in both the horizontal direction and the vertical direction.



ASCE library

Figure 14 – SHOWING A PALMER-BOWLUS FLUME

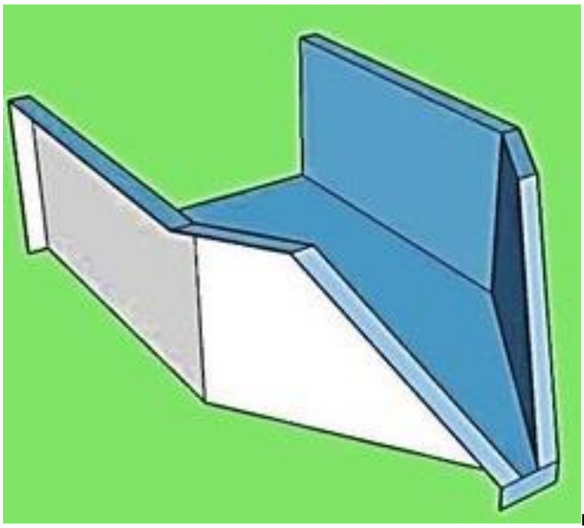
Provided a self-cleansing velocity is maintained in the pipe, this flume may be used in sewers. A major disadvantage of the Palmer-Bowlus flume is that it becomes inaccurate at very low flows.

As with the Cutthroat Flume there is no standard formula for calculating the flow rate from the depth of flow measurement. One reason is that there is no standard construction for these flumes. Each manufacturer has their own design and therefor Look-Up tables are required to determine the flow rate.

2.13 THE H FLUME.

All the above flumes are less accurate at low flows due to the shallow depth of flow. The H flume was developed to overcome this problem. The letter "H" is used as it was the 8^{th} one in a series of designs.

The H series of flumes are more modified weirs than they are true flumes – with a V shaped throat and no diverging / discharge section. The H flume design allows a wider range of flows than any other flume type – providing low flow sensitivity as well as the ability to measure high flow rates. Applications with a wide range of flows are ideal candidates for H flumes. The flat floor of the H flumes means that it passes sediments and smaller debris fairly easily. However, smaller HS / H flumes are generally not recommended for use in wastewater treatment as solids or larger debris can lodge in the narrow discharge of the flume. A typical H flume is shown in figure 15 below:



research gate

Figure 15 – SHOWING A TYPICAL H FLUME.

The equation for calculating the flow rate is quite complicated and there are 3 flow regimes as the flow rate increase: low; transitional and main. For typical applications, the need to transition from one equation to another as the level in the flume rises complicates the calculation. The equation below gives a good best-fit.

$$\text{Log } Q = A + B \log H + C(\log H)^2$$

Q = flow rate in m^3/s
H = head in metres
A, B, C are constants dependent on the flume size.

There are difference types of H flume depending on the range to be measured. HS is for low flows, H is for in between flows and HL for large flows, these are shown in figure 16 below:

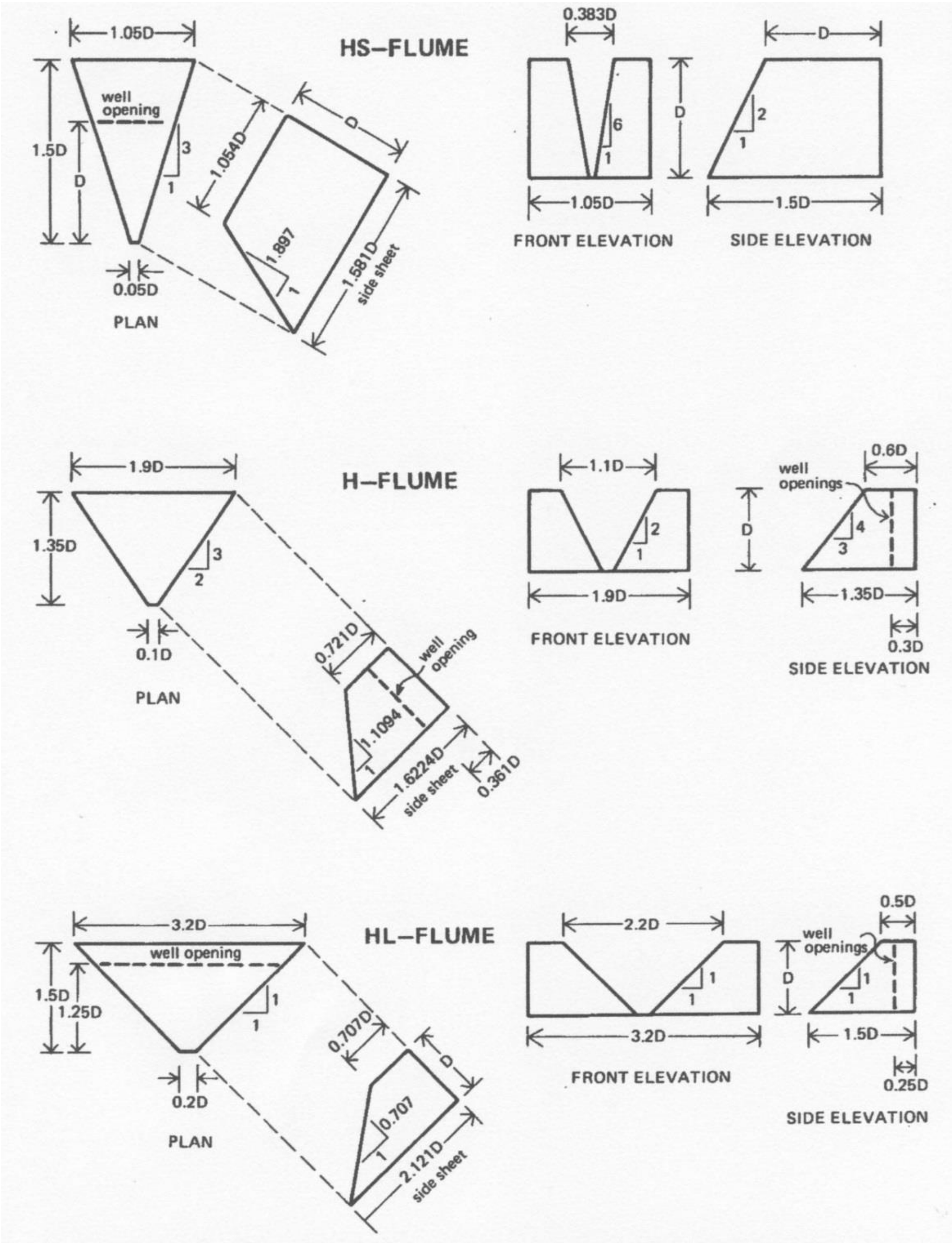


Figure 16 – SHOWING THE RANGE OF H FLUMES.

FLOW MEASUREMENT

PART 3.

FULL PIPE FLOW MEASUREMENT.

3.1 INTRODUCTION.

It was seen in part 2 that in open channel flow, the flow of the liquid is caused by the force of gravity.

When at pipe is flowing full, there are two possible scenario's:

1. there is pressure applied at one end of the pipe, usually by a pump that forces the water along the pipe to the discharge end;

2. the pipe, usually a sewer, is surcharged by the head in the upstream portion is higher than that in the downstream portion, and the liquid is made to flow by the force of gravity. This is caused by flows higher than the design capacity of the pipe. This is usually caused by rainwater entering the sewer system.

Scenario no. 1 was covered in *Process Controller Guide 6 on Pumps, Blowers and their Operation.*

Scenario no. 2 is a non-standard operating mode and will hopefully be only a temporary situation. It would not be possible to measure the flow in this case. This scenario is illustrated in figure 17 below:

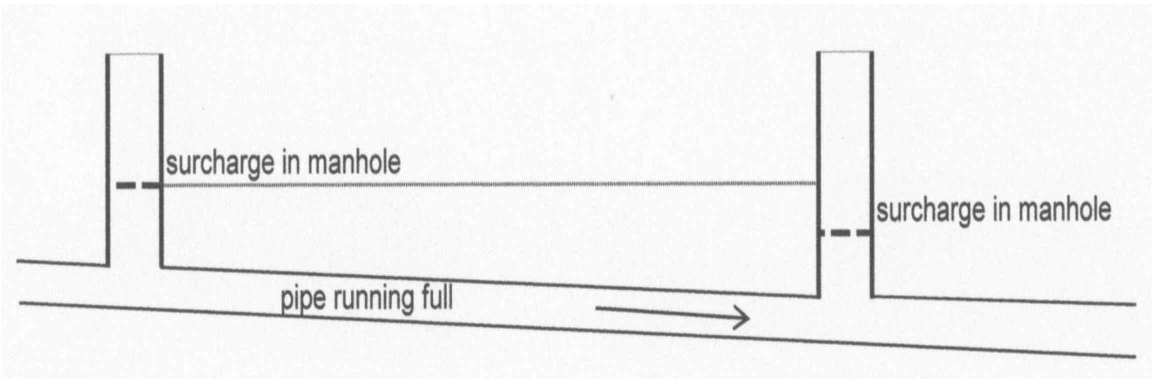


Figure 17 – SHOWING A SEWER RUNNING FULL BECAUSE OF SURCHARGING.

3.1.1 Types of Full Pipe Flow Meters.

There are two main types of full pipe flow meters:

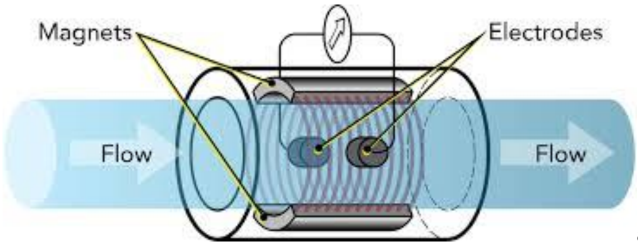
1. Non-obstructive – where the flow measuring device is the same diameter as the pipe both upstream and downstream and there are no parts of the metering device within the path of the flow and hence no obstruction to the flow of the liquid;

2. Obstructive - where the flow measuring device does have components protruding into the path of the flow of the liquid.

3.2 NON-OBSTRUCTIVE FULL PIPE FLOW METERS.

3.2.1 Magnetic Flow Meter.

In Process Controller's Guide 5 on Electricity and Electric motors in section 2.6, it was seen that moving a conductor in a magnetic field induced a voltage (produced electricity). This is the principle of operation of the magnetic flow meter. The conductor is moving water, wastewater or sludge within the pipe. The induced voltage is directly proportional to the velocity of the liquid in the pipe. The components of a typical magnetic flow meter are shown in figure 18 below:



assuredautomation.com

Figure 18 - SHOWING THE COMPONENTS OF A TYPICAL MAGNETIC FLOW METER.

One major advantage of this type of flow meter is that it can measure the flow in either direction. This would be useful where there were two incoming feeds that could be fed into two different treatment units. This can apply to water or wastewater treatment. An example of where this system is used; is at Wesfleur Wastewater Treatment Works in Cape Town. As may be seen in figure 19 below there are separate sewers from the industrial area (plus the original 654 houses) and from the rest of the residential area. Under normal operating conditions, the two flows are kept separate but the facility exists to pass some of the raw flow from the one stream to the other. There are two flow recorders one recording the flow in direction "A" and the other recording flow in direction "B".

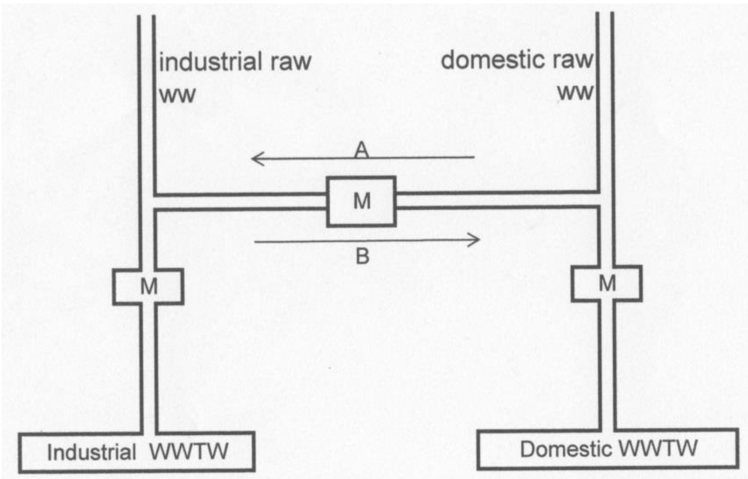


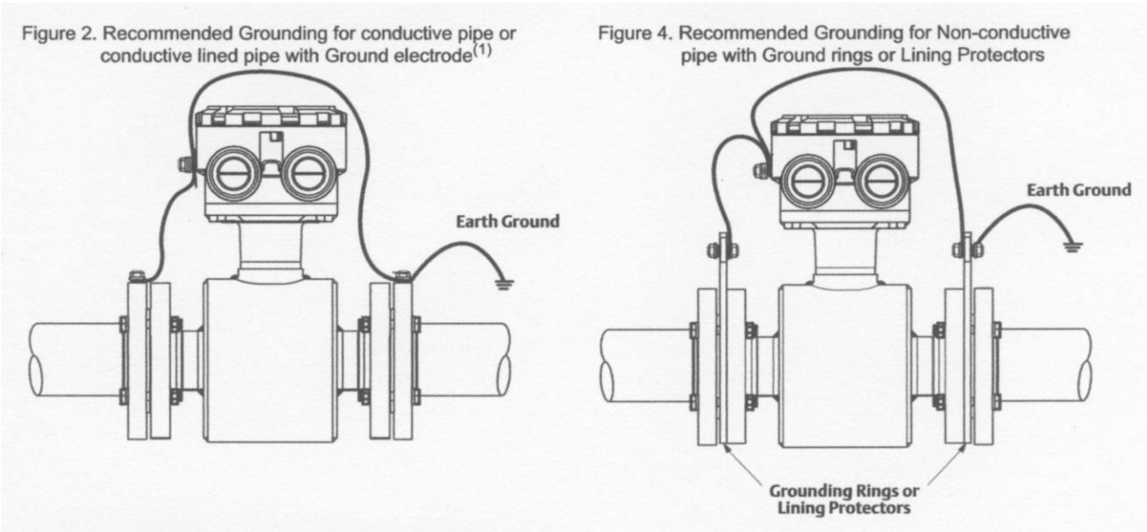
Figure 19 - SHOWING THE USE OF A BI-DIRECTIONAL FLOW MEASUREMENT SYSTEM.

The magnetic flow meter is a pre-constructed unit and usually installed in a pipeline with flanges. As the magnetic flow meter depends on small electrical current produced by the liquid moving through the magnetic field, any stray electrical current from elsewhere will adversely affect the accuracy of the reading. It is, therefore, necessary that the casing of the meter be grounded to earth. There are basically two types of pipes used to carry water and wastewater. These are:

1. Conductive – iron and steel pipes;

2. Non-Conductive – PVC, HDPE, fibreglass etc.

The methods for grounding these two types of pipes are shown in figure 20 below



rosemount magnetic flow meters

Figure 20 – SHOWING RECOMMENDED GROUNDING FOR MAGNETIC FLOW METERS.

A typical accuracy is ±0.5 % over a flow range of 0.1 to 10 m/s.

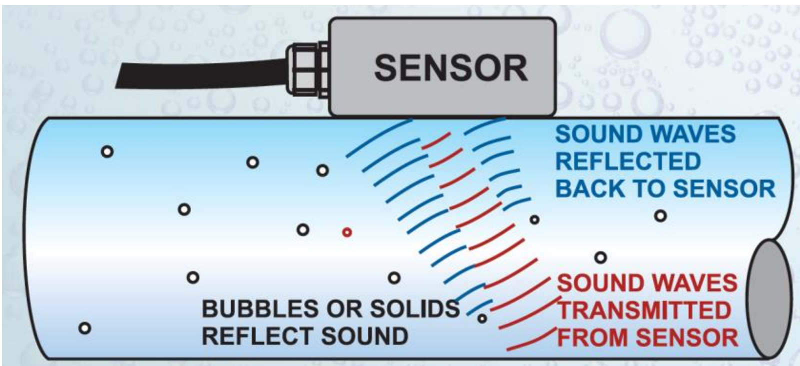
Suitable and unsuitable flow meter layouts are covered later in section 3.8.

3.2.2 Doppler Flow Meter.

The Doppler Effect is that, when the source of a sound is moving towards you, the frequency (pitch) of the sound is INCREASED. When the source of the sound is moving away from you, the frequency (pitch) is DECREASED. In both case, the change in frequency is proportional to the speed at which the sound generator is moving.

Doppler flow meters use the Doppler principal described above. For this effect to work, the liquid must contain **some** gas bubbles or solids for the Doppler measurement to work. This means that this type of flow meter would NOT work with very high quality water.

How the Doppler flow\meter works is shown in figure 21 below:



N&Z Instrumentation

Figure 21 – SHOWING THE PRINCIPLE OF A DOPPLER FLOW METER

This type of flow meter can have the sensor fitted onto an existing pipe irrespective of the material of construction of the pipe. Unsuitable locations are covered in section 3.8.

This type of flow meter should be capable of determining the flow in either direction. This would depend on the software program being able to accept negative values. Typical accuracy is ±1 %.

3.2.3 <u>Time of Flight Flow Meter (Transit Time Flow Meter).</u>

Time of Flight or Transit Time flow meter utilizes two units which function as both ultrasonic transmitters and receivers. These units are known by a number of names: Transducers, transceivers or simply "sensor":

The flow meters operate by alternately transmitting and receiving a burst of sound energy between the two transducers. The burst is first transmitted in the direction of fluid flow and then against the fluid flow. Since sound energy in a moving liquid is carried faster when it travels in the direction of fluid flow, i.e. (downstream) than it does when it travels against fluid flow i.e. (upstream); (these are called the Time-of-Flight). There will be a slight difference in time taken between these two signals.

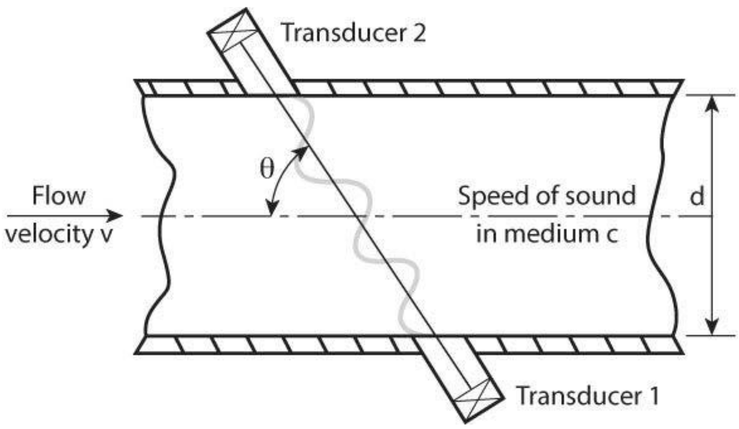
The liquid velocity (V) inside the pipe can be related to the difference in time of flight (dt) through the following equation: V = K * D * dt, where K is a constant and D is the distance between the transducers.

There are two possible layouts:

1. where the transducers are on either side of the pipe;

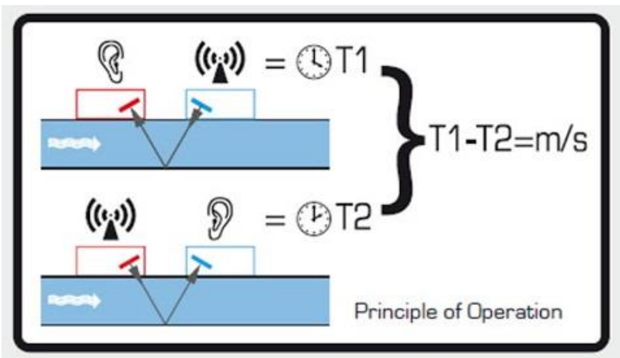
2. where the both transducers are on the same side of the pipe.

In either case, the transducers may be fitted into a special length of pipe as shown in figure 22, or clamped onto the outside of the pipe as shown in figure 23.



JLCInternational.com

Figure 22 – SHOWING INTERNAL AND SAME SIDE MOUNTING



EPG500.com

Figure 23 – SHOWING EXTERNAL (CLAMP ON) AND OPPOSITE SIDE MOUNTING.

In either layout, the flow meter should be capable of measuring flow in either direction. This would depend on the software program being able to accept negative values.

Typical accuracy is ±1 %.

3.3 OBSTRUCTIVE FULL PIPE FLOW METERS.

In contrast to the above types of flow meters, the obstructive type of flow meter has a change in shape inside the pipe. This means that they can only be used for clean water or wastewater effluent with a very low suspended solids content. Except for the rotameter (see section 3.4); these flow meters measure the pressure at two points near the obstruction in the pipe. This will become clearer in the sections below.

3.3.1 Introduction.

In this section, one is considering water (or wastewater) which is an incompressible fluid. In figure 24 below where the pipeline has a constant diameter (and cross sectional area); the velocity at point A is the same as the velocity at point B. As one is considering a very short length of pipe (less than 1 metre); the friction loss between point C and point D may be ignored. As the pipe is horizontal, the pressure head at point C is the same as at point D.

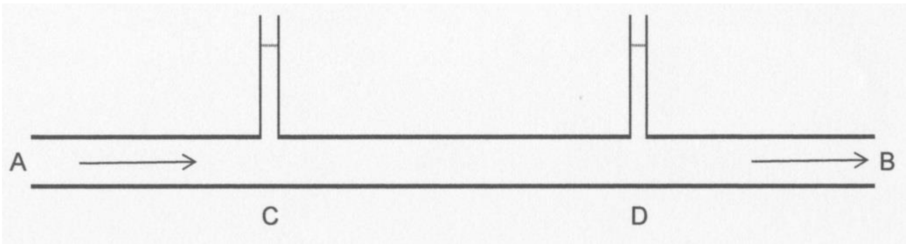


Figure 24 – SHOWING A CONSTANT DIAMETER PIPELINE.

The total head at a point is equal to the sum of:

1. the elevation head – the height above some reference point (often sea level);

2. the pressure head – the pressure inside the pipeline relative to the atmosphere outside;

3. the velocity head – due to the speed of flow in the pipe.

When one is considering a length of pipeline that is horizontal, then the elevation head may be ignored. Using Bernoulli’s Principle one can then say the following;

[Pressure head + Velocity head] at point C = [Pressure head + Velocity head] at point D.

Referring again to figure 24, as the pipe has a constant diameter (and cross sectional area), the velocity (v) is the same at each point. As water is compressible, the volume per unit time passing point C is the same as passing point D. Therefore the kinetic energy of the water is the same at point C as at point D. From the conservation of energy law, one can state that the potential energy or pressure is the same at point C as at point D.

If the diameter of the pipe at point D is smaller from that at point C, then the velocity at point D will be higher than at point C. As the sum of the pressure head and the velocity head must stay the same; any INCREASE in velocity head MUST equal the DECREASE in pressure head. It is upon this principle that the following flow meters work.

The calculation of flow rates for the following types of meters is quite complex when compared with the open channel flumes. One would need to use look-up tables, PLC’s (Programmable Logic Controllers) or a computer to process the readings.

3.3.1 The Venturi Meter.

This type of flow meter has a narrowed section in the middle of the pipe. As seen above, this will cause the velocity of the flow to increase and the pressure to drop. The difference between the upstream pressure and the pressure at the narrowed point is used to calculate the flow rate.

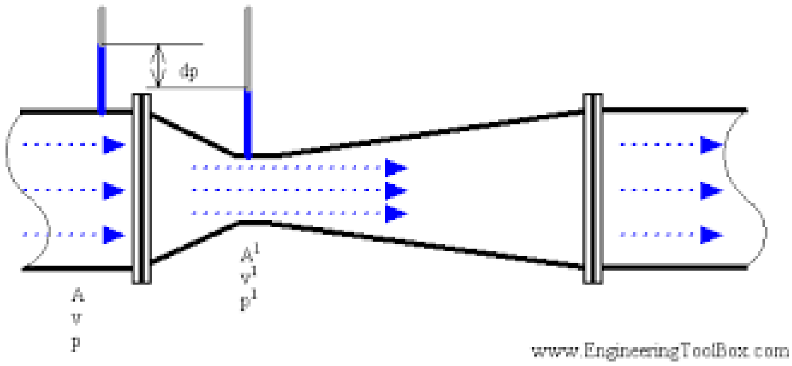
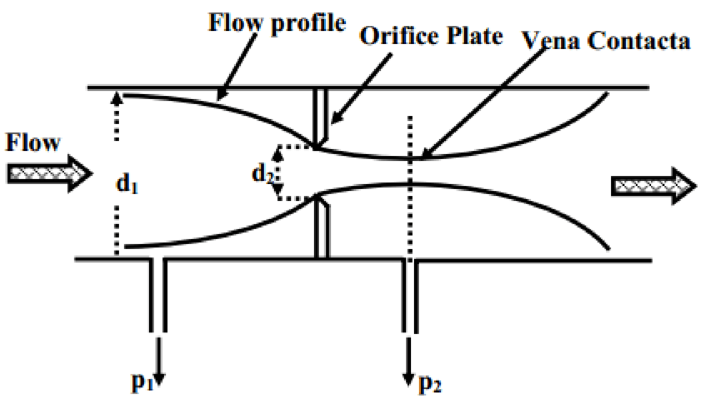


Figure 25 – SHOWING A VENTURI FLOW METER.

These flow meters can only measure flow in the one direction. Accuracy is normally of the order of ± 2%. The head loss through the unit depends on the ratio of the narrow part to the upstream pipe and is generally about 10% of the differential pressure. Venturi meters are relatively expensive due to their construction.

3.3.2 The Orifice Plate.

This is a much simpler construction than a Venturi meter and is installed between two flanges of a pipe. There are various patterns of orifice plates with the concentric type (hole in the middle being the most common). As with the Venturi meter, the pressure is measured at two points and the flow rate calculated from the difference in pressure. An example showing the flow profile is given in figure 26 below:



the processpiping .com

Figure 26 – SHOWING AN ORIFICE PLATE WITH THE TYPICAL FLOW PROFILE.

As with the Venturi flow meter, the pressure loss is dependent on the ratio of the cross section area of the narrowed part to the upstream pipe diameter. For example for an area ratio of 0.5, the head loss is about 75% of the differential pressure. They are claimed to have an accuracy of ±3%. As with the Venturi flow meter, the calculation of the flow rate is quite complicated.

The orifice plate flow meter may be used with a liquid containing fine particles of suspended solids.

3.3.3 The Flow Nozzle.

This is a compromise between the Venturi and the orifice plate. The gradual narrowing of the flow passage helps to smoothen the flow. This results in a pressure drop that is lower than an orifice plate but still higher than a Venturi flow meter. It can handle some suspended solids. A typical layout is shown in figure 27 below:

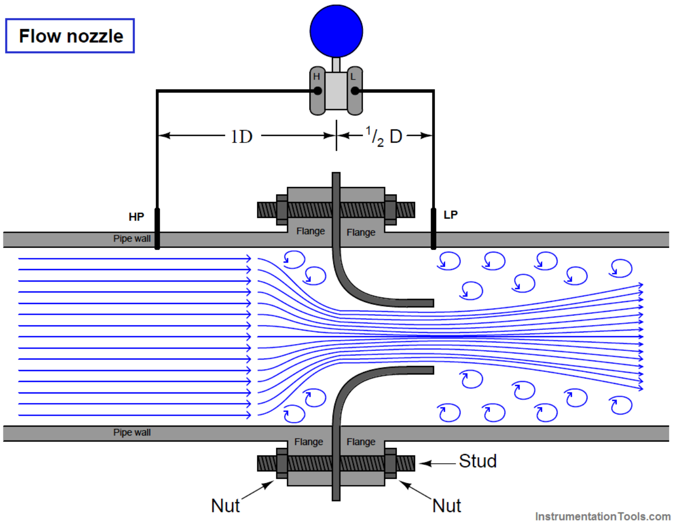


Figure 27 – SHOWING A TYPICAL FLOW NOZZLE FLOW METER.

They are claimed to have an accuracy of ±3%. As with the Venturi and orifice flow meters, the calculation of the flow rate is quite complicated.

3.3.4 The Pitot Tube.

Although this may be used for measuring flow of water, it is usually used to measure air flow and will be covered in part 4.

3.3.5 The Rotameter.

The flow meters covered above all work on the principal of a constant flow area and a variable pressure differential. The Rotameter has a constant pressure drop and a variable flow area. This is best illustrated in figure 28 below:

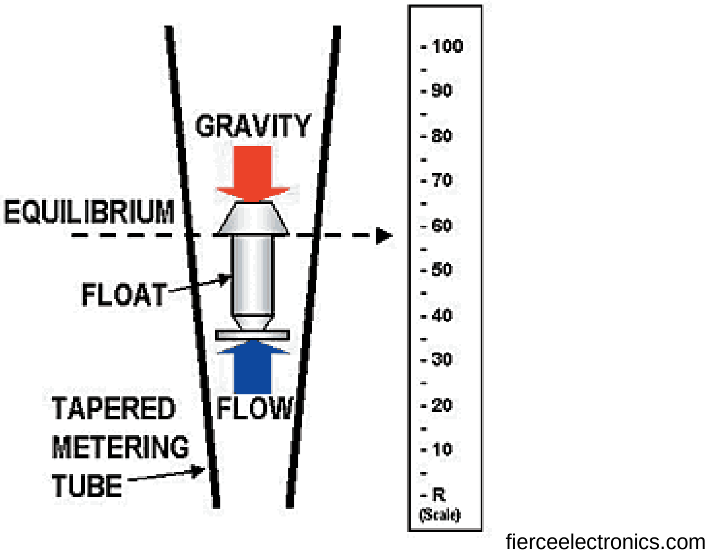


Figure 28 – SHOWING A TYPICAL ROTAMETER.

The kinetic energy of the liquid flowing upwards will at some point balance the force of gravity trying to make the float settle. The flow rate can then be read on the scale situated next to, or behind the measuring tube.

Among the advantages of the rotameter are:

1. the flow rate may be measured directly off the scale after the latter has been calibrated;

2. the unit is cheap and easy to install;

3. it does not require electricity to operate.

4. if the float is magnetic, then it may be possible to obtain a reading for transmission to a remote site, eg a control room;

Disadvantages include the following:

1. the liquid must be free of suspended solids;

2. scale could form on the float that would affect the accuracy;

3. algae could grow on the transparent tube making it difficult to read;

4. dark coloured fluids such as Ferric Chloride solution will make it difficult to see the float;

5. it must be installed in an upright position with an upward flow.

Their accuracy is typically ±2 %.

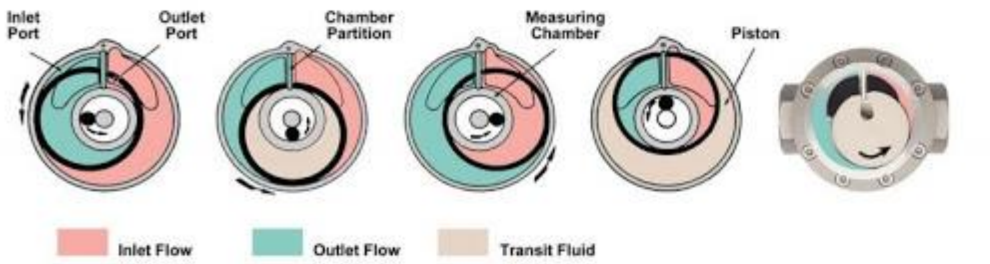
3.4 POSITIVE DISPLACEMENT METERS.

The above meters (except the Rotameter) determine the velocity of the flow and using the cross sectional area of the meter to convert this into a flow rate. Positive displacement meters in contrast directly measure the volume of the water passing along a pipe. This is done by passing a specific volume of water with each movement of the meter. This makes them very accurate and is not affected by temperature, velocity of the water in the pipe etc.

These meters are commonly used for metering water supplies to houses, industries etc.

3.4.1 Piston Flow Meters.

They operate by having a piston rotate in a chamber with a known volume. Every rotation the piston makes passes a volume of water equivalent to the chambers known volume down the pipe. Knowing the number of rotations and the volume of the chamber allows the flow rate to be calculated. An example of a rotating piston flow meter is shown in figure 29 below:



swordtek.com

Figure 29 – SHOWING A ROTATING PISTON FLOW METER.

3.4.2 Gear Flow Meters.

Gear flow meters consist of two gears that are mounted in overlapping compartments. When a fluid flows through the inlet it gets trapped in the teeth of the gears and is transported to the outlet.

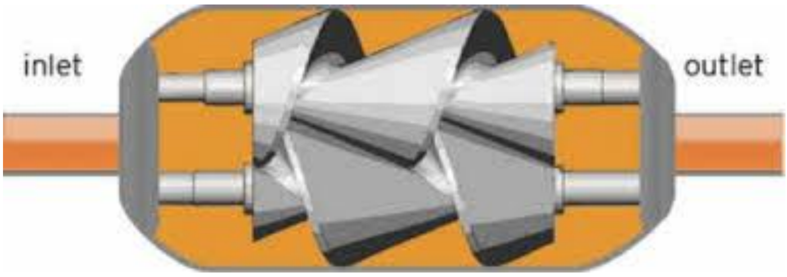
Knowing the volume of the voids between the teeth and the wall and the number of rotation, the flow rate can be calculated. An example is shown in figure 30 below:

macnaughtusa.com

Figure 30 – SHOWING A GEAR FLOW METER

3.4.3 Helical Flow Meters.

These are similar to a gear flow meter in that both have two rotating parts that turn together and pass a fixed volume of fluid with each rotation. An example is shown in figure 31 below:

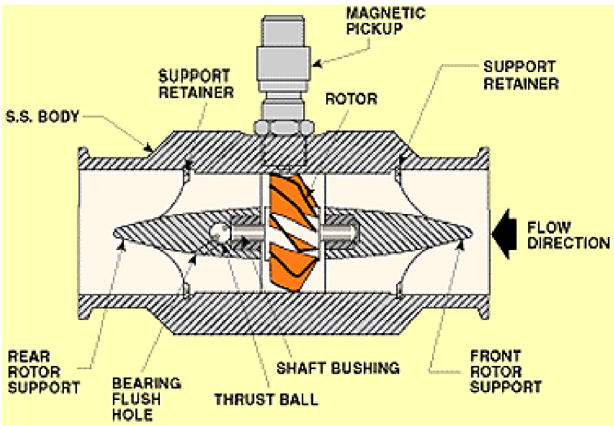


instrumentation and control engineering

Figure 31 – SHOWING A HELICAL FLOW METER.

3.4.4 Turbine Flow Meter.

This is a volumetric measuring turbine type. The flowing fluid engages the rotor causing it to rotate at an angular velocity proportional to the fluid flow rate. The angular velocity of the rotor results in the generation of an electrical signal (AC sine wave type) in the pickup. The summation of the pulsing electrical signal is related directly to total flow. The frequency of the signal relates directly to flow rate. The vaned rotor is the only moving part of the flow meter. An example is shown in figure 32 below:



enggcyclopedia.com

Figure 32 – SHOWING A TYPICAL TURBINE METER.

They have a claimed accuracy of ±0.5%.

3.4.5 Converting Flow into a Reading.

Some positive drive flow meters do not require electricity to give a reading as the rotating part is directly connected through a number of gears to the readout. The latter may of two types:

1. consisting of numbers only. The black on white numbers indicate the kilolitres. The white on red numbers represent the decimal fraction of a kilolitre. An example is shown in figure 33 below:

2. consisting of numbers and dials. The numbers indicate the kilolitres. The dials in a clockwise direction indicate 0.1 kL (100 L); 0.01 kL (10 L); 0.001 kL (1 L) and 0.0001 kL (0.1L). An example is shown in figure 34 below:

elstermetering.com

Figure 33 – SHOWING A NUMBERS ONLY METER.

asmeter.com

Figure 34 – SHOWING A NUMBERS AND DIALS METER.

When reading this type of meter, record the LOWER of the two numbers between which the needle is pointing.

A disadvantage of this type of meter is that it cannot give an output that can be recorded or relayed to a central data collection point.

As an experiment many years ago, a water meter with a rotating needle, such as seen in figure 35; was fitted with a small magnet and a pulse counter fitted to the outside of the meter body. This in turn was linked to a data logger and was successful in recording flows.


wikipedia

Figure 35 – SHOWING A METER WITH A ROTATING NEEDLE.

Meters such as the turbine meter would be fitted with a small magnet and the revolutions would be counted by a sensor as seen in figure 32 above. With the increase in automation and the need for remote collection of data, it is becoming more common for meters to be fitted with a 4 - 20 milli-amp output for data transmission.

3.5 BRIEF COMPARISON OF VARIOUS NON-OBSTRUCTIVE FLOW METERS.

Table 1 gives a brief comparison a various non-obstructive flow meters.

TABLE 1 – COMPARISON OF VARIOUS NON-OBSCTRUCTIVE FLOW METERS.

Type	Turn down ratio	Accuracy	Advantages	Disadvantages
Magnetic	10 to 1	± 0.5 %	Can handle solids very well	Special section of pipeline required
Doppler	Up to 50 to 1	± 1 %	Can be retro-fitted to existing pipeline	Water must contain some bubbles or fine solids
Time of Flight	Up to 50 to 1	± 1 %	Can be retro-fitted to existing pipeline	Water to be fairly clean

3.6 BRIEF COMPARISON OF VARIOUS OBSTRUCTIVE FLOW METERS.

Table 2 gives a brief comparison a various obstructive flow meters.

TABLE 2 – COMPARISON OF VARIOUS OBSTRUCTIVE FLOW METERS

Type	Turn down ratio	Accuracy	Advantages	Disadvantages
Orifice Plate	4 to 1	± 3 %	Low cost	High pressure loss
Venturi	Up to 10 to 1	± 2 %	Low pressure drop	High cost; <150mm size
Flow Nozzle	3.5 to 1	± 3 %	Medium pressure loss; Can handle some solids	Higher cost than orifice plate
Turbine	20 to 1	± 0.5%	Very accurate: Good turndown ratio	High cost; Cannot handle any solids
Positive Displacement	>10 to 1	± 0.5%	Very accurate; Good turndown ration	High pressure drop; Cannot handle any solids

Notes: Turn down ratio is the ratio of full span to smallest flow that can be measured with sufficient accuracy.

3.7 LAMINAR AND TURBULENT FLOW.

There are two main flow profiles when a liquid flows in an open channel or in a pipe – these are Laminar flow and Turbulent flow. There is also a transition type between these. This is also called Critical flow.

Into which group a particular flow falls depends on a number of factors. These include:

1. velocity of flow;
2. dynamic viscosity of the liquid;
3. density of the liquid;
4. diameter of the pipe.

Into which group a particular flow would fall is determined by calculating the Reynolds number R_e.

$$R_e = \frac{\rho V d}{\mu}$$

where ρ = density of the liquid;

V = velocity of flow;

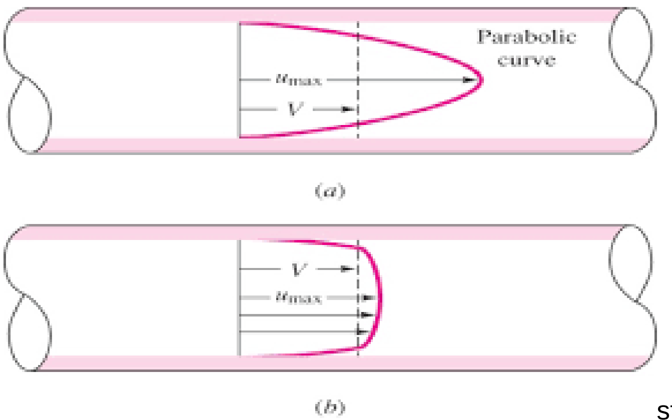
D = diameter of the pipe;

μ = dynamic viscosity of the liquid.

For Laminar flow, the Reynolds number will be less than 2 300.
For Turbulent flow. The Reynolds number will be more than 4 000.
For Reynolds numbers in between, the flow will be in the transition stage – part laminar and part turbulent.

The question is – **why does this matter**?

The answer may be seen in figure 36 below. Here the upper diagram illustrating laminar flow; shows that there is a very big difference between the flow velocity in the centre of the pipe and that near the pipe wall. In contrast, when there is turbulent flow; there is much less variation in flow rate.

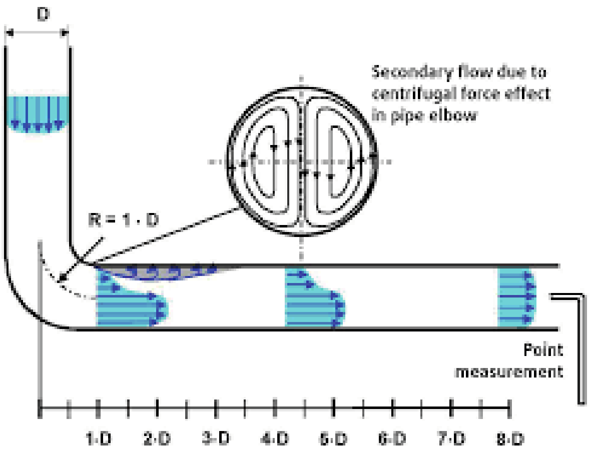


sfa.ca

Figure 36 – SHOWING FLOW PROFILES FOR LAMINAR AND TURBULENT FLOW.

While the positive displacement flowmeters can accurately measure laminar flow; the other types of flow meter require turbulent flow to measure flow rate accurately.

Fittings in a pipeline, such as bends and valves will alter the flow profile of both laminar and turbulent flow. An example is given in figure 37 below:



systemair.com

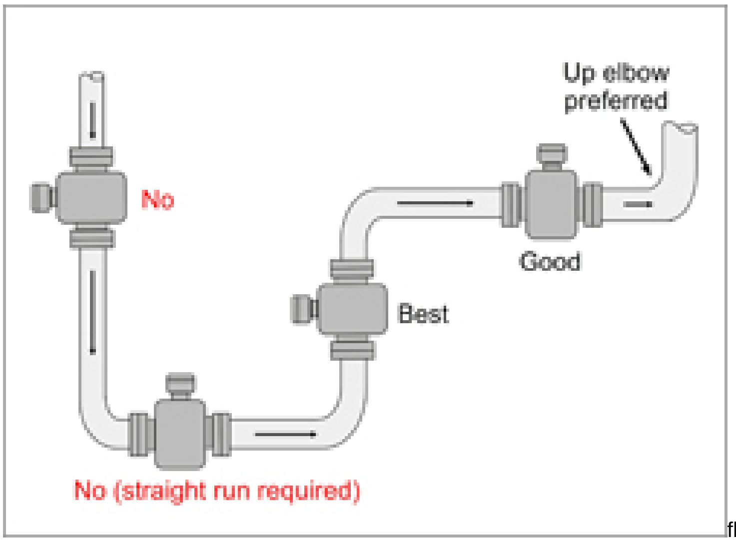
Figure 37 – SHOWING THE IMPACT OF A BEND ON THE FLOW PROFILE IN A PIPE.

The impact of valves would vary from a gate valve (lower impact) to a globe valve (higher impact) on flow profile

3.8 SUITABLE AND UNSUITABLE LOCATION OF FLOW METERS.

In order to minimize the impact of bends, elbows and valves excetera on flow measurement; it is necessary to have a specified distance between any upstream fitting and the flow meter; and between the flow meter and any downstream fitting. These requirements are usually specified by the flow meter supplier and expressed as number of pipe diameters. For example, the supplier might specify 10 diameters upstream and 5 diameters downstream as minimum requirements. It is always better to use higher values than the minimum specified to ensure best accuracy.

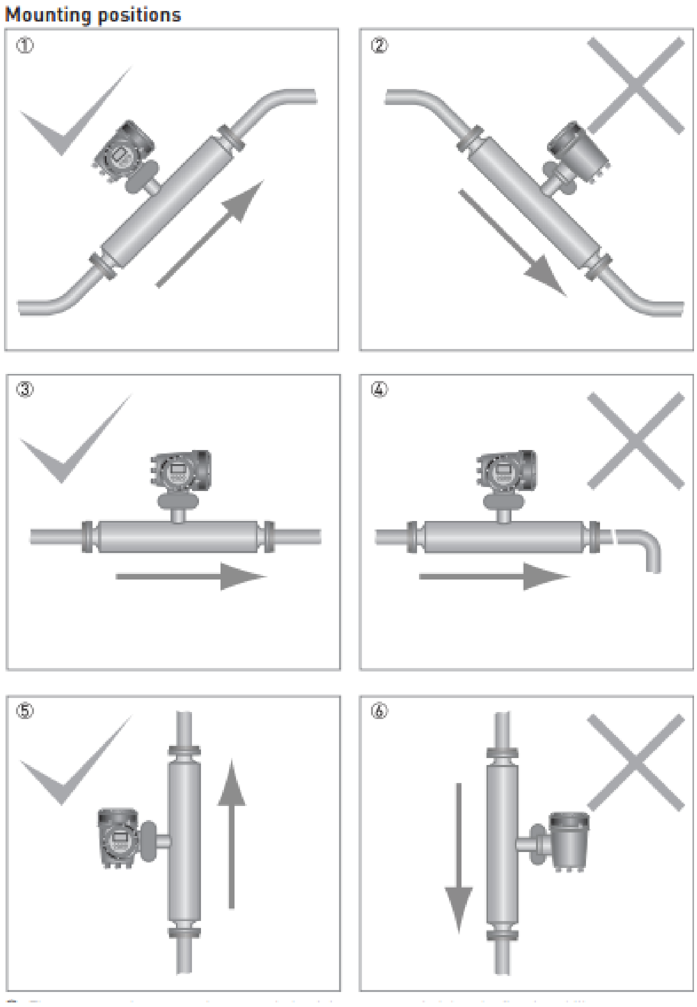
An example of suitable and unsuitable meter positions is shown in figures 38 and 39 below:



flowcontrolnetwork.com

Figure 38 – SHOW SUITABLE AND UNSUITABLE POSITIONS FOR FLOW METERS.

It is important that flow meters remain full of liquid even under no flow conditions. This is because air present in the pipe will cause incorrect readings.



RMS engineering

Figure 39 – SHOWING SUITABLE AND UNSUITABLE METER POSITIONS.

The suitable positions are where any air in the pipe is able to escape upwards to minimize impact on the flow meter.

FLOW MEASUREMENT

PART 4.

AIR AND GAS FLOW MEASUREMENT.

4.1 INTRODUCTION.

In contrast to water, both air and gases such as digester gas (Bio-gas) are compressible. This means that the volume of a given mas of gas will vary with the temperature and the pressure and in the case of digester gas – with the composition as well. These factors significantly complicate the flow measurement of gases.

These three factors will be covered in the following sections.

4.2 THE EFFECT OF PRESSURE ON GAS VOLUME (AT CONSTANT TEMPERATURE).

Here Boyle's Law enables one to determine the effect of pressure on the volume of a certain mass of a gas. The law states:

$$P_1V_1 = P_2V_2$$

This means that if the pressure is doubled, then the gas volume is halved.

4.3 THE EFFECT OF TEMPERATURE ON GAS VOLUME (AT CONSTANT PRESSURE).

Here Charles's Law enables one to determine the effect of temperature on the volume of a certain mass of gas. The law states:

$$\frac{V_2}{V_1} = \frac{T_2}{T_1}$$

$$\text{Or rearranging } V2 = V1 * \frac{T2}{T1}$$

The temperature that is used in this formula is based on the Kelvin scale, where 0K is absolute zero. This is the theoretical lowest possible temperature when all motion of atoms stops. It is equal to minus 273.15 degree Celsius.

Note that one uses the term Kelvin **NOT** degrees Kelvin.

To convert from degrees Celsius (our usual temperature measuring scale), to Kelvin; add 273.15. So 20 degrees Celsius = 293.15 Kelvin.

As an example if one heats 1 000 litres **(V_1)** of air from 20 degrees Celsius to 30 degrees Celsius, the volume will increase as calculated below **if the pressure is kept constant**:

$$V2 = 1\,000 * \frac{(30 + 273.15)}{(20 + 273.15)}$$

$$= 1\,000 * \frac{303.15}{293.15}$$

$$= 1\,000 * 1.034$$

$$= 1\,034 \text{ litres}$$

4.4 THE EFFECT OF TEMPERATURE ON GAS PRESSURE (AT CONSTANT VOLUME).

Here Guy-Lussac's Law enables one to determine the effect of temperature on the pressure of a certain volume of gas. The law states:

$$\frac{P_2}{P_1} = \frac{T_2}{T_1}$$

$$\text{Or rearranging } P2 = P1 * \frac{T2}{T1}$$

Again the Kelvin scale is used in the calculation.

As an example if one heats a fixed volume of air at 101.3 kPa from 20 degrees Celsius to 30 degrees Celsius, the pressure will increase as calculated below **if the volume is kept constant**:

$$P_2 = 101.3 * \frac{(30 + 273.15)}{(20 + 273.15)}$$

$$= 101.3 * \frac{303.15}{293.15}$$

$$= 101.3 * 1.034$$

$$= 104.74 \text{ kPa}$$

THE IMPACT OF TEMPERATURE OF GAS PRESSURE AT CONSTANT VOLUME IS A VERY IMPORTANT FACTOR IN REFERENCE TO THE STORAGE OF LIQUIFIED CHLORINE IN CYLINDERS. THIS IS THE REASON WHY CHLORINE CYLINDERS MUST NOT BE ALLOWED TO BECOME HOT.

4.5 THE COMBINED GAS LAW.

The three laws covered above may be combined into one law that for convenience is called the Combined Gas Law:

$$\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T^2}$$

The question is now: What do we do with this information?

As water is basically incompressible, the impact of pressure and temperature is very small in the temperature range that we deal with in water and wastewater treatment – say 10 to 25 degrees Celsius. With air, it is a different matter. If one considers the air produced by a blower and used in the Activated Sludge process, the air after leaving the blower would be at about 50 – 60 kPa pressure and 30 to 45 degrees Celsius. If wants to compare the amount of air used between different units or between different treatment works, one needs to convert the measured volume of air to some standard for easy comparison. The commonly used standard conditions are 1.0 bar (101.3 kPa) and 20 degrees Celsius.

One can also use the combined gas law to compare the output of different blowers if the information available has not been converted to the standard conditions.

4.6 ABSOLUTE PRESSURE AND GAUGE PRESSURE.

The technical definition of the two is as follows:

The simplest way to explain the difference between the two is that **absolute pressure** uses **absolute** zero as its zero point, while **gauge pressure** uses atmospheric **pressure** as its zero point. Due to varying atmospheric pressure, **gauge pressure** measurement is not precise, while **absolute pressure** is always definite.

It is easier to think of the absolute pressure as the air pressure around one while the gauge pressure is that measured in the pipe RELATIVE to the atmosphere. In other words, if the pressure gauge reads 100kPa then the pressure in the pipe is 100kPa ABOVE the surrounding atmosphere.

The FIRST question is: can the gauge pressure be NEGATIVE? – the answer is YES. What this means is that pressure in the pipe is LESS than the atmospheric pressure outside the pipe – we call this being under vacuum.

The SECOND question is: why do we want to talk about absolute pressure? When we used the temperature in the above gas laws, we worked on a temperature scale that had absolute zero as equal to 0 Kelvin. The same method applies when dealing with pressure - we start from a point that has zero pressure. To convert from degree Celsius to Kelvin, we added 273.15 to get the reading on the Kelvin scale. When dealing with pressure, we add the atmospheric pressure AT THE POINT WHERE WE ARE WORKING to the pressure on the pressure gauge to get the absolute pressure AT THAT POINT.

In temperature conversion, one always adds 273.15 to the Celsius temperature to get the reading on the Kelvin scale. When dealing the pressure matters, the outside pressure changes – it decreases with altitude. This is covered in the next section.

4.7 VARIATION OF AIR PRESSURE WITH ELEVATION ABOVE SEA LEVEL.

The higher one is above sea level, the lesser the height of air is above one and hence the lower the air pressure. This is shown in a chart such as figure 40 below:

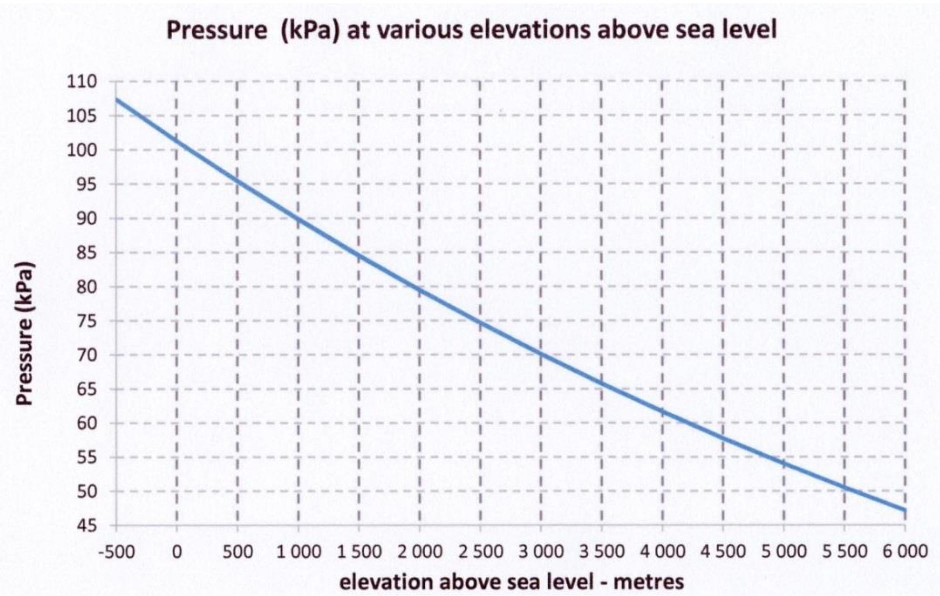


Figure 40: SHOWING VARIATION OF AIR PRESSURE WITH ELEVATION ABOVE SEA LEVEL.

4.8 CORRECTING THE AIR FLOW TO STANDARD CONDITIONS.

This is best shown via a calculation.

Conditions at test site:

a. Elevation above sea level – 1 000 metres;

b. Temperature of air at point of measurement – 45 deg Celsius;

c. Gauge Pressure at point of measurement - 50 kPa;

d. Air flow under these conditions – 10 000 m^3 per hour.

1 Determine the atmospheric pressure on site - use a barometer or use above figure. At 1 000m, the atmospheric pressure is 90 kPa;

2. Convert temperature from Celsius to Kelvin (add 273.15); temperature on Kelvin scale = 45 + 273.2 = 318.2 K [$\mathbf{T_1}$];

3. Determine Absolute pressure (equals gauge pressure plus atmospheric pressure) = 50 + 90 = 140 kPa [$\mathbf{P_1}$];

4. Measured air flow = 10 000 m³/h [**V1**];

5 Standard Condition is 101.3 kPa [$\mathbf{P_2}$] and 20º Celsius {= 293K} [$\mathbf{T_2}$];

6. Combined Gas Law: $\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T^2}$

7. Rearrange: $V_2 = \frac{P_1 * V_1 * T_2}{P_2 * T_1}$

$$= \frac{140 * 10\ 000 * 293}{101.3 * 318.2}$$

$$= 12\ 725 \text{ m}^3/\text{h}.$$

8. Therefore under standard conditions, the air flow is 12 725 m³/h. It makes sense that this value is higher as the air has been compressed under a pressure of 50 kPa. The impact of the pressure in compressing the air is greater than the impact of the temperature increase that would increase the volume of the air at a constant pressure.

4.9 AIR FLOW MEASUREMENT.

The types of air flow measurement covered here are:

1. Orifice Plate;

2. Pitot Tube.

4.9.1 The Orifice Plate.

This works on the same principle as used for water flow measurement and was covered in section 3.3.2 above. A typical Orifice Plate diagram is shown in figure 41 below:

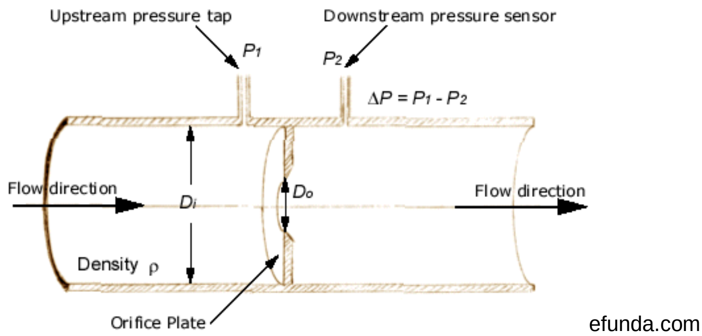


Figure 41 – SHOWING A TYPICAL ORIFICE PLATE LAYOUT.

The orifice plate MUST face the correct direction. This is why the orifice plate has a piece that sticks out from the joint and indicates the UPSTREAM face. This is shown in figure 42 below:

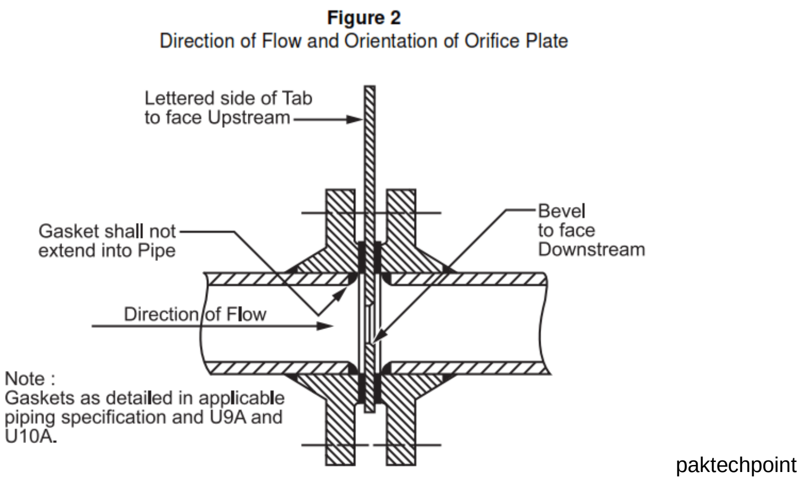


Figure 42 – SHOWING CORRECT INSTALLATION OF AN ORIFICE PLATE.

4.9.2 The Pitot Tube.

This also uses the difference in pressure to calculate the air flow. The major difference is that the kinetic energy of the air flow is converted into potential energy that provides the higher pressure. This is seen in figure 43 below:

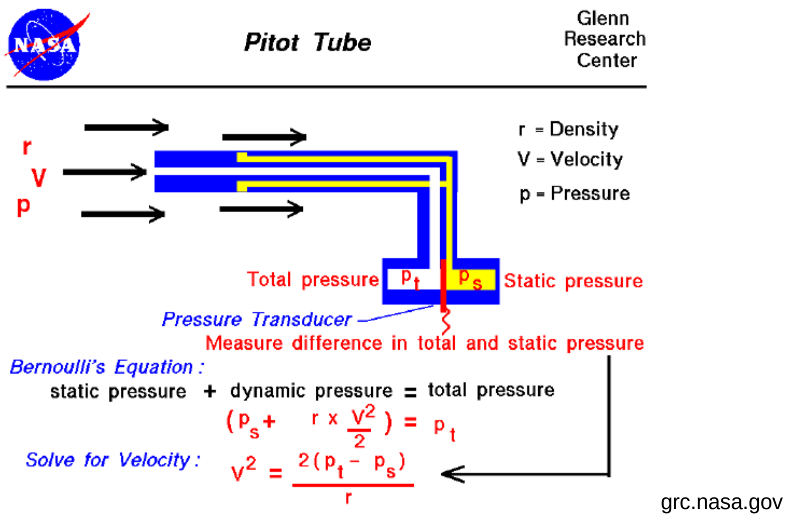


Figure 43 – SHOWING LAYOUT OF A PITOT TUBE AND CALCULATION.

The Pitot tube is commonly used on aircraft to measure air speed.

4.9.3 Other types of flow meters.

The meters described above are used to determine volumetric flow rate eg m³/h. They may be used to convert the volumetric flow rate into a mass flow rate eg kg/h. This is done by multiplying the volumetric flow rate by the density of the air being measured.

The mass flow meter does not measure the volume per unit time (e.g., cubic meters per second) passing through the device; it measures the mass per unit time (e.g., kilograms per second) flowing through the device. Volumetric flow rate is the mass flow rate divided by the fluid density. If the density is constant, then the relationship is simple. If the fluid has varying density, then the relationship is not simple. The density of the fluid may change with temperature, pressure, or composition, for example. [Wikipedia].

The mass flow meter is used in some industrial applications and in motor car engines with fuel injection to maximise fuel efficiency and in flow meters for anaerobic digesters – see 4.10.

4.10 GAS FLOW METERS.

The gas from an anaerobic digester has the following properties that would impact on the choice of flow metering equipment:

1. high moisture content;

2. variable composition;

3. at low pressure;

4. flammable;

5. contains contaminants such as hydrogen sulphide;

6. can contain particulate matter;

7. as the gas cools from the digester operating .temperate (about 35º), condensation may occur.

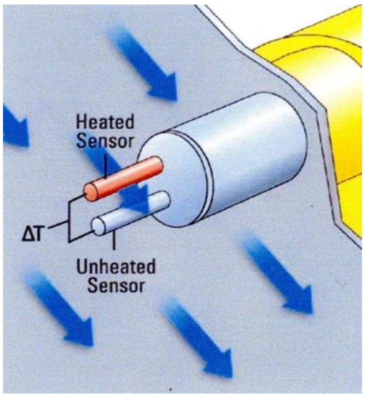
For the above reasons, the orifice plate, Pitot tube and other similar types of flow meters cannot be used for the measurement of anaerobic digester gas flow measurement.

The only really suitable type of flow measurement device for anaerobic digester gas is the thermal mass meter.

Thermal mass meters deliver an accuracy of around one percent with a turndown ratio of around 150:1. This means they are far more accurate than most flow measurement techniques for the very low flows often found in biogas applications. Thermal mass meters also provide a direct measurement of the mass flow so their use is much more straightforward and cost effective than techniques that derive the mass flow information indirectly, using additional instrumentation and flow calculation equipment or software.

In addition, because thermal mass flowmeters take measurements using two small probes on the end of an insert they form only a minor obstruction in the surrounding flow. This means that correctly sized thermal mass flowmeters offer an extremely small pressure drop of between one and two millibars, which is important in this application where the gas pressure can drop to very low levels.

An example of a thermal dispersion mass flow sensor is shown below in figure 44:



.fluidcomponents.com.

THE END