SURVEY ON FLOW CONDITIONS

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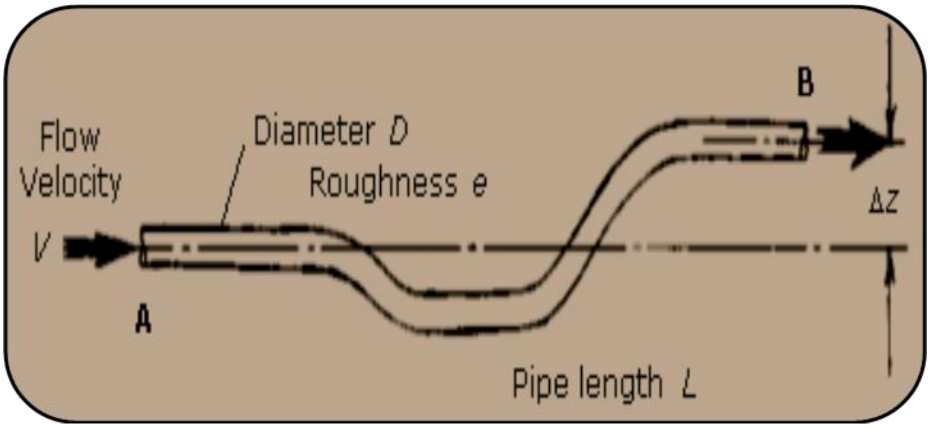
ABSTRACT

Flow conditioning makes a huge effect on the accuracy of liquid turbine meter which results into flow disturbances. These effects are mainly caused by debris on strainer screens, for various upstream piping geometries and different types of flow conditioners. To calculate the pressure drop and flow rates in a section of uniform pipe running from Point A to Point B, enter the parameters below.

Keywords : cause , point , smooth , rate .

Introduction :

The pipe is assumed to be relatively straight (no sharp bends), such that changes in pressure are due mostly to elevation changes and wall friction. (The default calculation is for a smooth horizontal pipe carrying water, with answers rounded to 3 significant figures.) Note that a positive Dz means that B is higher than A, whereas a negative Dz means that B is lower than A.



Equations used in the Calculation

Changes to inviscid, incompressible flow moving from Point A to Point B along a pipe are described byBernoulli's equation,

$$h = z(x) + \frac{p(x)}{\rho g} + \frac{V(x)^2}{2g}$$

where *p* is the pressure, *V* is the average fluid velocity, r is the fluid density, *z* is the pipe elevation above some datum, and *g* is the gravity acceleration constant.

Bernoulli's equation states that the total head *h* along a streamline (parameterized by x) remains constant. This means that velocity head can be converted into gravity head and/or pressure head (or vice-versa), such that the total head *h* stays constant. No energy is lost in such a flow.

For real viscous fluids, mechanical energy is converted into heat (in the viscous boundary layer along the pipe walls) and is lost from the flow. Therefore one cannot use Bernoulli's principle of conserved head (or energy) to calculate flow parameters. Still, one can keep track of this lost head by introducing another term (called *viscous head*) into Bernoulli's equation to get,

$$h = z + \frac{p}{\rho g} + \frac{V^2}{2g} + \int_{x_0}^{x} \frac{f}{D} \frac{V(\tilde{x})^2}{2g} d\tilde{x}$$

where *D* is the pipe diameter. As the flow moves down the pipe, viscous head slowly accumulates taking available head away from the pressure, gravity, and velocity heads. Still, the total head *h* (or energy) remains constant.

For pipe flow, we assume that the pipe diameter *D* stays constant. By continuity, we then know that the fluid velocity *V* stays constant along the pipe. With *D* and *V* constant we can integrate the viscous head equation and solve for the **pressure at Point B**,

$$p_B = p_A - \rho g \left(\Delta z + f \frac{L}{D} \frac{V^2}{2g} \right)$$

where *L* is the pipe length between points A and B, and Dz is the **change in pipe elevation** (z_B - z_A). Note that Dz will be negative if the pipe at B is lower than at A.

The viscous head term is scaled by the pipe **friction factor *f***. In general, *f* depends on the Reynolds Number *R* of the pipe flow, and the relative roughness *e*/*D* of the pipe wall,

$$f = f\left(R, \frac{e}{D} \right)$$

The roughness measure *e* is the average size of the bumps on the pipe wall. The relative roughness *e*/*D* is therefore the size of the bumps compared to the diameter of the pipe. For commercial pipes this is usually a very small number. Note that perfectly smooth pipes would have a roughness of zero.

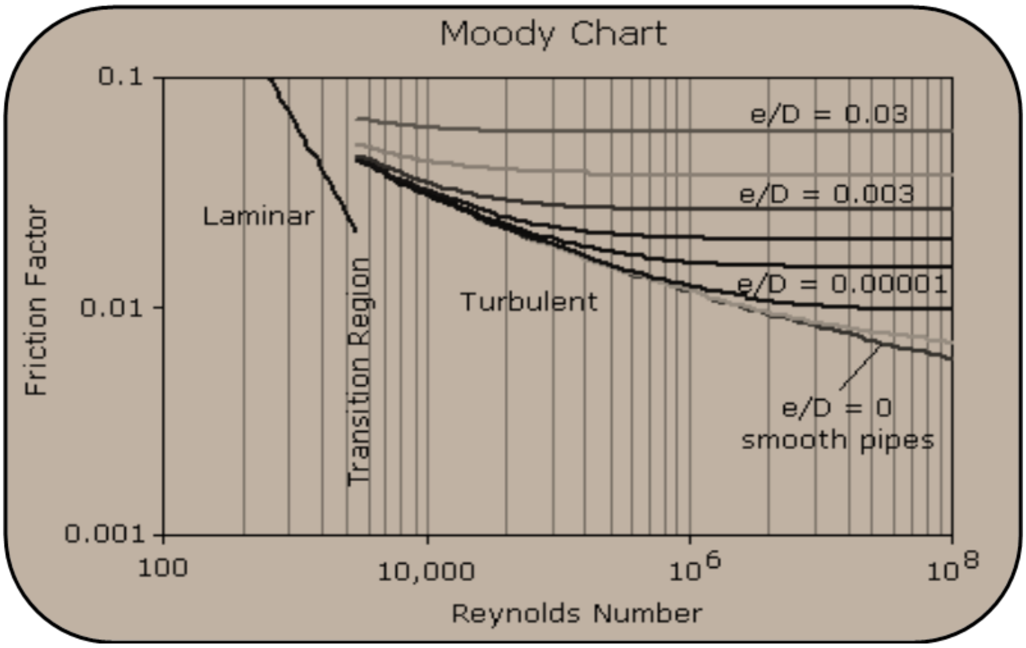
For laminar flow ($R < 2000$ in pipes), *f* can be deduced analytically. The answer is,

$$f = \frac{64}{R}$$

For turbulent flow ($R > 3000$ in pipes), *f* is determined from experimental curve fits. One such fit is provided by Colebrook,

$$\frac{1}{\sqrt{f}} = -2 \cdot \log\left(\frac{e/D}{3.7} + \frac{2.51}{R\sqrt{f}} \right)$$

The solutions to this equation plotted versus *R* make up the popular Moody Chart for pipe flow,



The calculator above first computes the Reynolds Number for the flow. It then computes the friction factor *f* by direct substitution (if laminar; the calculator uses the condition that $R < 3000$ for this determination) or by iteration using Newton-Raphson (if turbulent). The pressure drop is then calculated using the viscous head equation above. Note that the uncertainties behind the experimental curve fits place at least a 10% uncertainty on the deduced pressure drops. The engineer should be aware of this when making calculations.

Effects on flow measurement devices:

The condition of a flow can affect the performance and accuracy of devices that measure the flow.

Effects of flow conditioning on Orifice meter:

The basic orifice mass flow equation provided by API 14.3 and ISO 5167 is given as,

$$q_m = (C_d)(E_v)(Y)\left[\frac{\pi}{4}\right](d)^2\sqrt{2\rho\Delta P} \quad ----(4)$$

Where, q_m = Mass flow
C_d = Coefficient of discharge
E_v = Velocity of approach factor
Y = Expansion factor
d = orifice diameter
ρ = density of the fluid
ΔP = differential pressure

Now to use the eq.(4), the flow field entering the orifice plate must be free of swirl and exhibit a fully developed flow profile. API 14.3 (1990) and ISO standards determined the Coefficient of Discharge by completing numerous calibration tests where the indicated mass flow was compared to the actual mass flow to determine coefficient of discharge. In all testing the common requirement was a fully developed flow profile entering the orifice plate.[9] Accurate standard compliant meter designs must therefore ensure that a swirl free, fully developed flow profile is impinging on the orifice plate. There are numerous methods available to accomplish this. These methods are commonly known as "flow conditioning". The first installation option is to revert to no flow conditioning, but adequate pipe lengths must be provided by the eq.(2) mentioned above. This generally makes the manufacturing costs for a flow measurement facility unrealistic due to excessively long meter tubes; Imagine meter tubes 75 diameters long.

The second and most well known option is the 19-tube tube-bundle flow conditioner. The majority of flow installations in North America contain the tube bundle. With the help of hot wire, pitot tube and laser-based computerized measurement systems which allow detailed measurement of velocity profile and turbulence intensity; we know that the tube bundle does not provide fully developed flow.[10] Therefore, this device is causing biased orifice flow measurement. As a result of these recent findings, few tube bundles are specified for flow measurement and reduce the use of such device. Numerous references are available providing performance results indicating less than acceptable meter performance when using the conventional 19-tube test bundle.[11] The individual results should be reviewed to ascertain details such as beta ratio, meter tube lengths, Re and test conditions.

Figure (3) showing Conventional tube bundle performance

The general indications are that the conventional tube bundle will cause the orifice installation to over register flow values up to 1.5% when the tube bundle is 1 pipe diameter to approximately 11 pipe diameters from the orifice plate. This is caused by a flat velocity profile that creates higher differential pressures than with a fully developed profile. There is a crossover region from approximately 10 to 15 pipe diameters where the error band is approximately zero. Then a slight under-registration of flows occurs for distances between approximately 15 to 25 pipe diameters. This is due to a peaked velocity profile that creates lower differential pressures than a fully developed profile. At distances greater than 25 pipe diameters the error asymptotes to zero. Fig.(3) showing the Conventional Tube Bundle Performance explaining typical characteristic behavior of the popular 19 tube, tube-bundle. An additional drawback of the conventional 19 tube, tube bundle is variation in sizing.

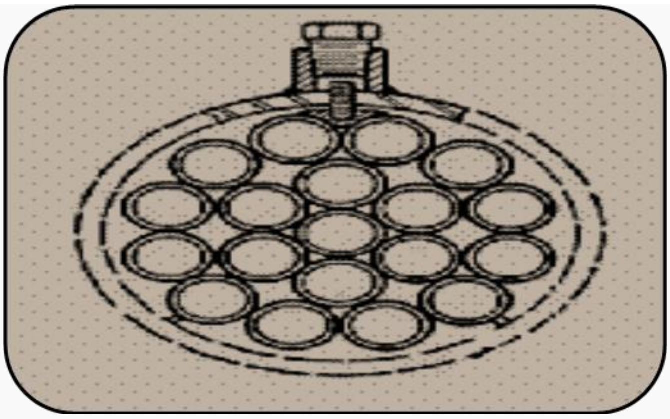


Figure (4) showing the 19-tube bundle

The conventional tube bundle provides errors very much dependent on installation details, that is, the elbows on and out of plane, tees, valves and distances from the last pipe installation to the conditioner and conditioner to the orifice plate. These errors have a great significance. Therefore the latest findings regarding conventional tube bundle performance should be reviewed prior to meter station design and installation. The final installation option for orifice metering is perforated plate flow conditioners. There is a variety of perforated plates have entered the market. These devices generally are designed to rectify the drawbacks of the conventional tube bundle (accuracy andrepeatability insufficiency). The reader is cautioned to review the performance of the chosen perforated plate carefully prior to installation. A flow conditioner performance test guideline should be utilized to determine performance.[12] The key elements of a flow conditioner test are -

1. Perform a baseline calibration test with an upstream length of 70 to 100 pipe diameters of straight meter tube. The baseline Coefficient of Discharge values should be within the 95% confidence interval for the RG orifice equation (i.e. the coefficient of discharge equation as provided by AGA-3).
2. Select values of upstream meter tube length, and flow conditioner location, to be used for the performance evaluation. Install the flow conditioner at the desired location. First, perform a test for either the two 90° elbows out-of-plane installation, or the high swirl installation for β = 0.40 and for β = 0.67. This test will show whether the flow conditioner removes swirl from the disturbed flow. If the ΔCd is within the acceptable region for both values of β i.e. 0.40 and 0.67, and if the Cd results vary as $(\beta)^{3.5}$, then the conditioner is successful in removing swirl. The tests for the other three installations namely, good flow conditions, partly closed valve and highly disturbed flow) may be performed for β = 0.67, and the results for other (i ratios predicted from the $\Delta Cd-(\beta)^{3.5}$ correlation. Otherwise, the tests should be performed for a range of p ratios between 0.20 and 0.75.

3. Perform test and determine the flow conditioner performance for the flow conditioner installed in good flow conditions, downstream of a half closed valve, and for either the double 90° elbow out-of-plane or the high swirl installation.

Effects of flow conditioning on turbine meter:

The turbine meter is available in various manufacturer's configurations of a common theme; turbine blades and rotor configured devices. These devices are designed such that when a gas stream passes through them they will spin proportionally to the amount of gas passing over the blades in a repeatable fashion. Accuracy is then ensured by completion of a calibration, indicating the relationship between rotational speed and volume, at various Reynolds Numbers. The fundamental difference between the orifice meter and the turbine meter is the flow equation derivation. The orifice meter flow calculation is based on fluid flow fundamentals (a 1st Law of Thermodynamics derivation utilizing the pipe diameter and vena contracta diameters for the continuity equation). Deviations from theoretical expectation can be assumed under the Coefficient of Discharge. Thus, one can manufacture an orifice meter of known uncertainty with only the measurement standard in hand and access to a machine shop. The need for flow conditioning, and hence, a fully developed velocity flow profile is driven from the original determination of Cd which utilized fully developed or 'reference profiles' as explained above.

Conversely, the turbine meter operation is not rooted deeply in fundamentals of thermodynamics. This is not to say that the turbine meter is in any way an inferior device. There are sound engineering principles providing theoretical background. It is essentially an extremely repeatable device that is then assured accuracy via calibration. The calibration provides the accuracy. It is carried out in good flow conditions (flow conditions free of swirl and a uniform velocity flow profile) this is carried out for every meter manufactured. Deviations from the as-calibrated conditions would be considered installation effects, and the sensitivity of the turbine meter to these installation effects is of interest. The need for flow conditioning is driven from the sensitivity of the meter to deviations from as calibrated conditions of swirl and velocity profile. Generally, recent research indicates that turbine meters are sensitive to swirl but not to the shape of the velocity profile. A uniform velocity profile is recommended, but no strict requirements for fully developed flow profiles are indicated. Also, no significant errors are evident when installing single or dual rotor turbine meters downstream of two elbows out-of-plane without flow conditioning devices

Effects of flow condition on ultrasonic meter:

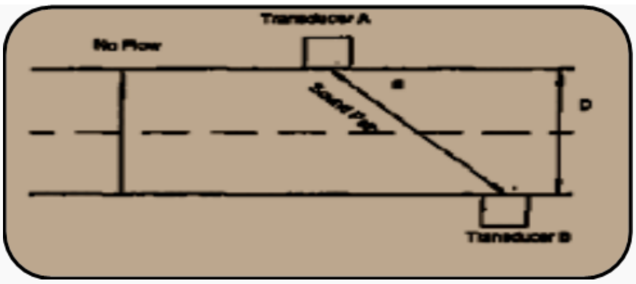


Figure (5) showing ultrasonic meter sound path - no flow

Due to the relative age of the technology, it may be beneficial to discuss the operation of the multipath ultrasonic meter to illustrate the effects of flow profile distortion and swirl. There are various types of flow measurements utilizing high frequency sound. The custody transfer measurement devices available today utilize the time of travel concept. The difference in time of flight with the flow is compared to the time of flight against the flow. This difference is used to infer average flow velocity on the sound path.[15] Fig.(5) showing the Ultrasonic Meter sound path no flow which illustrates this concept.

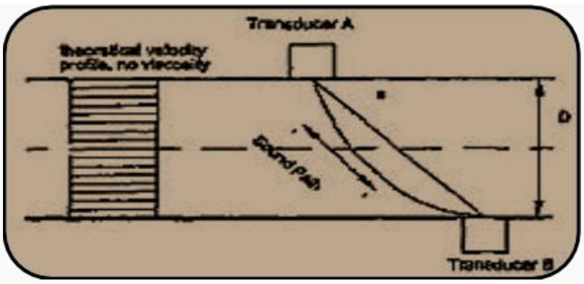


Figure (6) showing Ultrasonic meter sound path - uniform velocity profile

The resulting flow equation for the mean velocity experienced by the sound path is given by,

$$\bar{V}_{flow} = \left[\frac{1}{T_{ab}} - \frac{1}{T_{ba}}\right]\left[\frac{Dist_{Soundpath}}{2\cos\phi}\right] \quad \text{----(5)}$$

The case of no flow gives the actual path of the sound when there is zero flow (by equating eq.(5) to zero). In case of theoretical flow profile, say a uniform velocity flow profile where the no-slip condition on the pipe walls is not applied, Fig.(6) shows Ultrasonic Meter sound path - uniform velocity profile which illustrates the resultant sound path.

A theoretical derivation of the Mean velocity equation for this sound path becomes much more complicated. In case of a perfect fully developed real velocity profile of Ultrasonic meter which is shown in Fig.(7) indicating a possible sound path as a result of an installation in a real flow.

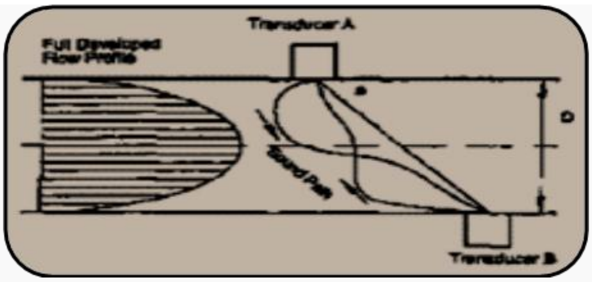


Figure (7) showing Ultrasonic meter sound path - fully developed flow

Here a mathematical derivation for this Ultrasonic meter is also becomes very complicated. Developing a robust flow algorithm to calculate the mean flow velocity for the sound path can be quite complicated. Now add to this; sound path reflection from the pipe wall, multi paths to add degrees of freedom, swirl and departure from axisymmetric fully developed flow profile and the problem of integrating the actual velocity flow profile to yield volume flow rate can be an accomplishment. Hence the real performance of ultrasonic meters downstream of perturbations, and the need for calibrations is required.[10]

Effects of flow condition on Coriolis meter:

Coriolis meter shown in fig.(8) is very accurate in single-phase conditions but inaccurate to measure two-phase flows. It poses a complex fluid structure interaction problem in case of two-phase operation. There is a scarcity of theoretical models available to predict the errors reported by Coriolis meter in aforementioned conditions.

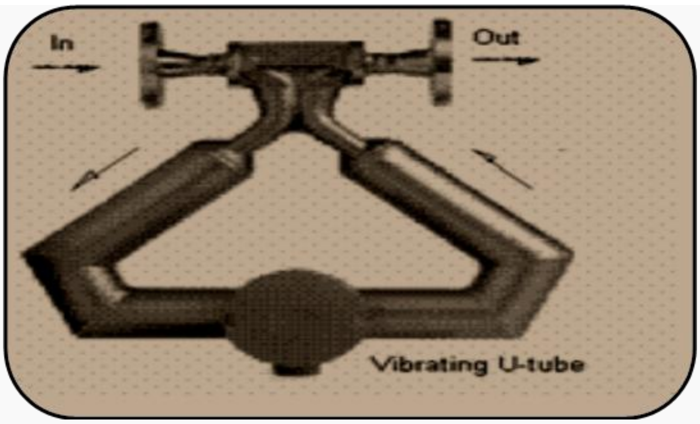


Figure (8) showing Coriolis meter

Flow conditioners make no effect on meter accuracy while using wet gas due to the annular flow regime, which is not highly affected by flow conditioners. In single-phase conditions, Coriolis meter gives accurate measurement even in presence of severe flow disturbances. There is no need for flow conditioning before the meter to obtain accurate readings from it, which would be the case in other metering technologies like orifice and turbine. On the other hand in two-phase flows, the meter consistently gives negative errors. The use of flow conditioners clearly affects the reading of the meter in aerated liquids. This phenomenon can be used to get fairly accurate estimate of flow rate in low gas volume fraction liquid flows.[12]

Liquid flow measurement:

Flow conditioning makes a huge effect on the accuracy of liquid turbine meter which results into flow disturbances. These effects are mainly caused by debris on strainer screens, for various upstream piping geometries and different types of flow conditioners. The effectiveness of a flow conditioner can be indicated by the following two key measurements:

- Percentage variation of an average meter factor over the defined range of flow disturbances for a given flow rate and inlet piping geometry. The lesser the value of percentage variation of an average meter factor over the range of flow disturbances, the better will be the performance of flow conditioner.
- Percentage meter factor repeatability for each flow disturbance, at a given flow rate and inlet piping geometry. The lesser the value of percentage meter factor repeatability at a given set of installation/operating conditions, the better will be the performance of flow conditioner.

Note : All these information are taken from reference in this review.

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