Orifice Meter Tube Dimensional Tolerances

Class # 8132.1

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The orifice meter is one of the older devices that is utilized in the measurement and regulation of fluid flow. Romans regulated water flows to their homes by the use of orifice. Benoulli, Torricelli, and Venturi, discovered the original concept that the pressure of a flowing fluid varies as its velocity changes. When a flowing fluid is made to speed up by restricting the cross-sectional area of the flow stream, a portion of the pressure energy is converted into velocity energy and the pressure drops. Using this relationship with the fact that the quantity of the fluid flowing is equal to the product of the velocity times the cross-sectional area of the flow stream we can have flow measurement in the orifice meter. In order to correlate the theoretical flow with actual flow concepts there became a need for basic discharge-coefficient research to actually utilize these theories in custody transfer of products. In the early part of the last century the American Gas Association (AGA) established the Gas Measurement Committee to do just such.

First it must be understood what is considered the meter. The meter consists of a straight length of pipe, some type of fitting, differential pressure sensing taps, a possible flow conditioner and an orifice constructed within the tolerances specified by the standards. This is the Primary Element and is where the measurement occurs. The "**meter**" is not the Secondary Element which entails an Electronic or Mechanical device that records the information being disseminated by the flow of fluid through the Meter Tube or Primary Element. The Secondary Element is utilized to record the data, calculate the flow and determine the volume being passed through the Primary Element. The calculated flow data is directly related to the accuracy of the data being determined in the meter itself. The old saying "Garbage in, Garbage out" is a cornerstone to Fluid Measurement. The data utilized to convert to Custody Transfer quality flow volumes is only as accurate as what is seen and measured within the confines of the meter tube. Strict tolerances have been developed by the Industry and are reported in various publications, including AGA 3 and API 14.3.2 to insure all industry operates on a level playing field. Millions of dollars and thousands of hours have been and are being dedicated to the development of these Standards. There is continual research to enhance the work began by the early pioneers of the Industry.

Orifice Plate

The orifice plate is the heart of flow measurement. This seemingly simple and insignificant device is quite the opposite. It is defined in AGA Report #3 as a thin square-edged plate with a machined circular bore, concentric with the meter tube ID, when installed. Strict adherence to the published tolerances is the only way to ensure there is not a distortion being caused by the inaccuracies found when these tolerances are not met. The manufacturing process defined in the Standards allows one the confidence that a consistent measurement can be determined. Tolerances are established for a specific purpose. Not only have tests been devised and ran to ensure repeatability but they also insure that when tolerances are adhered to the pressure drops across the face of the orifice will be consistent within the parameters defined in the Standard. If these devices are manufactured to meet certain tolerances then they can be replicated between manufacturers with a sense of certainty. One must understand that tolerances and exact are not one in the same. An example would be when manufacturing an orifice plate it is often said it must be flat, when in all actuality it has a tolerance which can be quite visual when a straight edge is laid across it. Thus not only when an orifice is manufactured but when installed and later inspected after use checks must be made to insure the “flatness” of the plate is within published standards. Pressure forces within the Meter Tube can often cause the orifice to no longer be within the prescribed tolerances. Below is a chart for determining allowable departure from flatness.

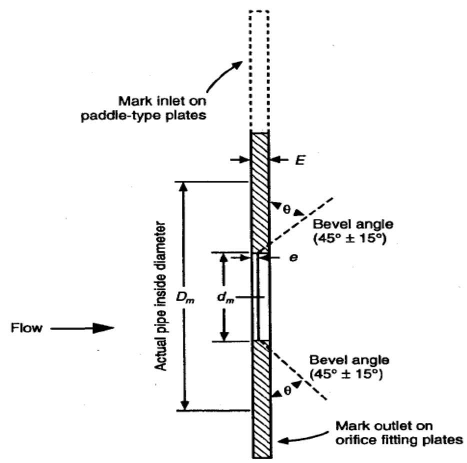
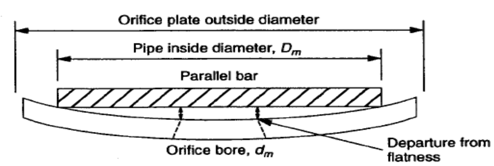


Figure 2-1—Symbols for Orifice Plate Dimensions



Maximum allowable departure from flatness = 0.005 $(D_m - d_m)$

Figure 2-2a—Orifice Plate Departure from Flatness
(Measured at Edge of Orifice Bore and Within Inside Pipe Diameter)

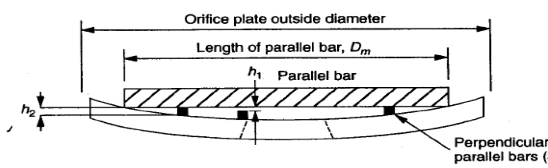
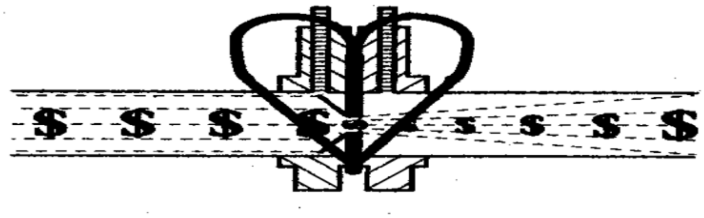


Figure 2-2b—Alternative Method for Determination of Orifice Plate Departure from Flatness
(Departure from Flatness = $h_2 - h_1$)

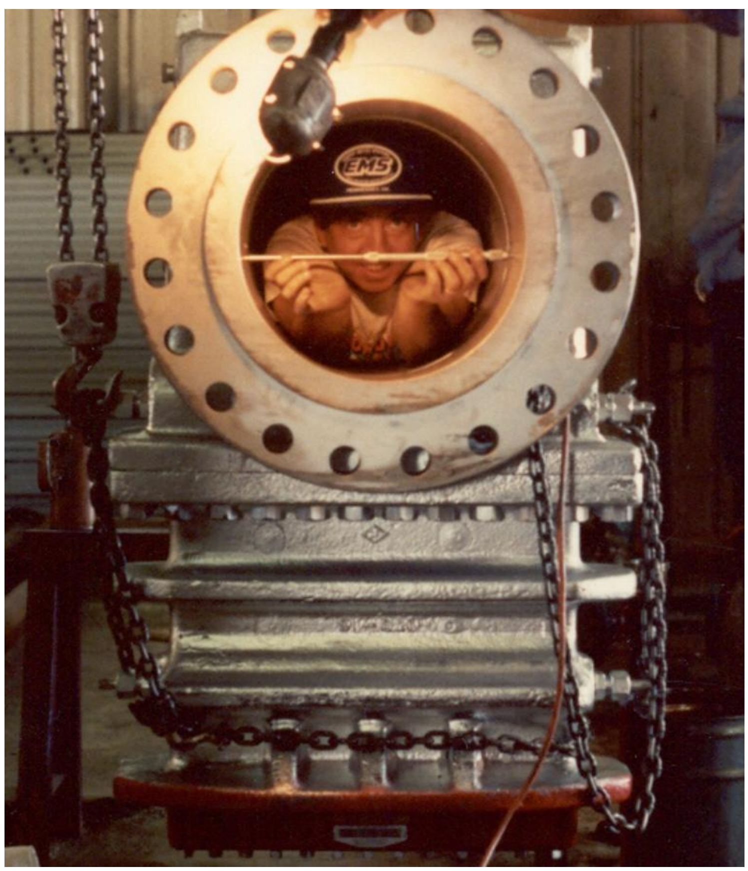
This is only one section of the tolerances involved in determining the suitability of the orifice plate. The orifice bore, the orifice plate thickness, the orifice bore diameter, the orifice bore bevel and the surface roughness are additional areas of potential error in the determination of the acceptance of an orifice plate. There are available tools which need to be utilized to assure the tolerances are being met in the determination of orifice plate acceptability. These tolerances are tight and have been developed to insure the repeatability of the process; therefore, it is inherent of the responsible party to adhere to the methods put forth within the Standard if one expects to have quality measurement. Again the orifice plate is the "Heart of the Measurement" and if it is not beating properly all else is for naught.



<u>Orifice Fittings</u>

The orifice fittings are the device utilized to hold the orifice plate in place. These fittings are designed and manufactured to tight tolerances which limit uncertainty in the measurement of flowing fluids. These tolerances include but are not limited to flange taps, orifice concentricity, tap-hole dimension, and pressure tap edges, flange tap relative to the faces of the orifice plate, internal surface roughness, and internal diameter of the fitting. All dimensional tolerances are addressed in the body of the AGA3/API14 standards. The heart of fluid flow measurement is obtained when upstream and downstream tubing is properly combined with the orifice fitting in conjunction with the orifice plate.

<u>Meter Tube Specifications</u>



"Getting into his work"

AGA 3.2.5.1 defines the meter tube as follows: “The meter tube is defined as the straight upstream pipe of the same diameter length UL of the installation Tables 2-7 and 2-8, (see Figure 2-6), including the flow straightener/conditioner, if used; the orifice plate holder; and the similar downstream pipe (length DL of the installation Tables 2-7 and 2-8, see Figure 2-6) beyond the orifice plate. The upstream section of the meter tube is defined as the length of straight pipe extending from the upstream face of the orifice plate to the nearest upstream change in cross-sectional area (not including flanged fittings allowed in the standard) or change in the axis of the pipe center line.”

It is imperative when building, inspecting, designing or cleaning a meter tube that one has available the tolerances the tube is to be designed to. One of the major problems is the installation of tubes in situations that do not meet the correct design tolerances. The meter tube has a variety of acceptable lengths and configurations which can and do meet the correct design qualifications; however, without knowing the requirements for meeting these scenarios it is quite possible to put in place tubes that will not “measure up” or meet the proper tolerances. Most tubes are built to a .75 beta ratio (Ratio between the maximum orifice diameter allowed and the internal diameter of the meter tube). Even though one might be led to believe all is well with the .75 Beta ratio designs this is not always the case. The inlet configuration the gas is being subjected to, determines the amount of upstream length necessary to meet the correct tolerances. Meter tube tolerances vary from as short as 13 Upstream pipe diameters for a Concentric reducer to the catch all category of 145 Upstream pipe diameters. Common mistakes occur when one assumes that the meter tube was constructed to the most common 44 pipe diameters and that this will be an acceptable field installation. Unfortunately companies sometimes leave installation to untrained personnel that are just “doing their job” and getting the measurement station installed the easiest way possible. This leads to configurations that can throw the upstream lengths to distances of 95 or even 145 pipe diameters to meet the code. Experience and testing prove that in the case where the meter tube design does not meet tolerance, significant error can be put into place. AGA 3 Figure 2-7 is a necessary guide to “Orifice Meter Installation Requirements “**Without**” a Flow Conditioner”. Understanding the guidelines in advance will prevent unnecessary errors and reconfigurations in the future. With that being said it is a necessary evil that in order to understand and utilize the proper dimensions when building or inspecting meter tubes, one must have access to the design tables to insure proper tolerances are met.

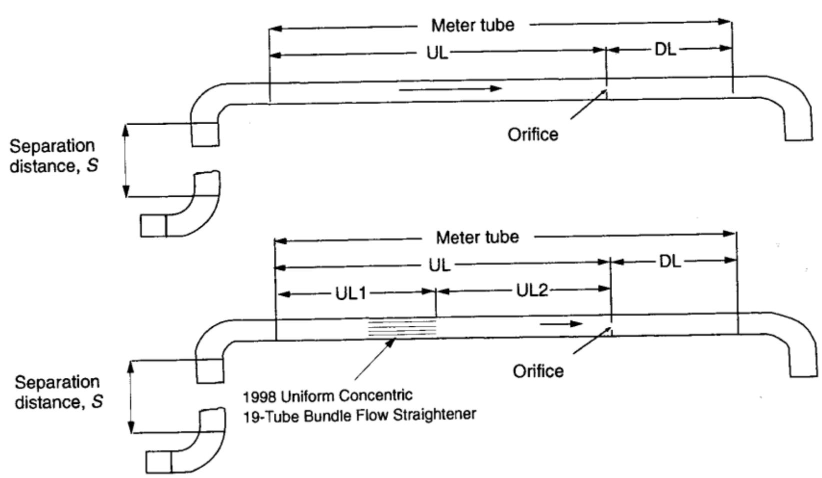


Figure 2-6—Orifice Meter Tube Layout for Flanged or Welded Inlet

Flow Conditioners

Flow conditioners can be classified into two categories: straighteners or isolating flow conditioners.

Flow straighteners are devices that effectively remove or reduce the swirl component of a flowing stream, but may have limited ability to produce the flow conditions necessary to accurately replicate the orifice plate coefficient of discharge database values. AGA3 2.5.5

Isolating flow conditioners are devices that effectively remove the swirl component from the flowing stream while redistributing the stream to produce the flow conditions that accurately replicate the orifice plate coefficient of discharge database values. AGA3 2.5.5

The 19-Tube Bundle Straightener has been around for a number of years and has tolerances which should be adhered to when utilized. These tolerances and design criteria must be followed to assure the coefficient of discharge remains within the designated uncertainty band. As stated above the straightening vane will reduce the swirl component but will not necessarily replicate the flow profile to the point there is not a possibility of error. On the other hand the Isolating flow conditioner removes swirl and subsequently re-profiles the flow to replicate the orifice plate coefficient of discharge database values. Understanding the fact that without a proper flow profile there is potential for error within the measurement of the meter tube, it is becoming much more commonplace to utilize the isolating flow conditioner in lieu of the 19-Tube bundle straightener.

Not only are flow conditioners useful in insuring flow profiles remain consistent, they also substantially reduce the upstream length of tubing required to fabricate a meter tube that will allow flow measurement within the guidelines set forth by the printed industry standards. The 19-Tube bundle has published lengths which need to be adhered to in order to stay within the defined tolerances; however, the isolating flow conditioners are to be installed according to the manufacturer’s recommendations. These manufacturers have spent both dollars and research time in determining the proper placement of their product upstream of the orifice plate.

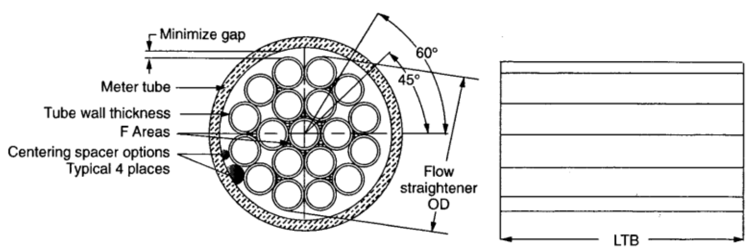


Figure 2-4—1998 Uniform Concentric 19-Tube Bundle Flow Straightener

Ongoing Inspection

Various designs are found within the confines of the published Standards and some of these designs have been highlighted here. Once the proper design and tolerances have been determined, the meter tube has been built, tested and installed; the measurement of fluid is just beginning. All the engineering in the world will not make for good measurement without proper maintenance. These design tolerances are only as good as the attention paid to them. Once installed ongoing inspection and maintenance must be adhered to. Over time the meter tube measurements can be distorted due to fluids that contain contaminants, rust, ice, salt, improper operation and neglect. The meter tube is no different than a cash register and if not properly maintained will give forth errant measurements, which in turn leads to loss revenues for someone. Orifice plate distortion is not an uncommon occurrence and also leads to errant measurement. Ongoing attention to the detail of good measurement will pay abundant dividends in the future.

Rust Pitts and Gunk are not your Friend!!!

Conclusion

Studies for accuracy, repeatability and reproducibility are ongoing and the Standards followed today, quite possibly, will be obsolete tomorrow. Thus, it is imperative one keeps abreast of the changes within the Industry. Design tolerances and specifications allow everyone the means of building equipment that is capable of measuring fluid with the confidence, when built to these specifications, accurate and definite answers can be obtained. Measurement is more than Pig Iron and Steel and measurement personnel when properly armed and trained can meet the measurement world with confidence that they are measuring their fluid with the most accurate designs available.

References

The following publications have been referenced:

1. American Gas Association (AGA) Report #3, Part 2, latest edition
2. American Petroleum Institute (API) Chapter 14, Natural Gas Fluids Measurement, Section 3 Part 2, latest edition
3. Rod Dent "Orifice Meter Tube Dimensional Tolerances" ISHM

AGA - Meter Tube Design Criteria

Table 2-7—Orifice Meter Installation Requirements Without a Flow Conditioner

Diameter ratio β	Minimum Straight Unobstructed Meter Tube Length from the Upstream Side of the Orifice Plate (in multiples of published internal pipe diameter, D_i)										Downstream meter tube length
	a. Single 90° elbow. b. Two 90° elbows in the same plane with $S > 30D_i$. c. Two 90° elbows in perpendicular planes with $S > 15D_i$.	Two 90° elbows in the same plane "S" configuration spacer $S \leq 10D_i$	Two 90° elbows in the same plane, "S" configuration $10D_i < S \leq 30D_i$	Two 90° elbows in perpendicular planes, $S < 5D_i$*	Two 90° elbows in perpendicular planes, $5D_i \leq S \leq 15D_i$	Single 90° Tee used as an elbow but not as a header element	a. Single 45° elbow. b. Two 45° elbows in the same plane "S" configuration $S \geq 22D_i$	Gate valve at least 50% open	Concentric reducer	Any other configuration (catch all category)*	
	UL	UL	UL	UL	UL	UL	UL	UL	UL	UL	DL
≤0.20	6	10	10	50	19	9	30	17	6	70	2.8
0.30	11	10	12	50	32	9	30	19	6	108	3.0
0.40	16	10	13	50	44	9	30	21	6	145	3.2
0.50	30	30	18	95	44	19	30	25	7	145	3.5
0.60	44	44	30	95	44	29	30	30	9	145	3.9
0.67	44	44	44	95	44	36	44	35	11	145	4.2
0.75	44	44	44	95	44	44	44	44	13	145	4.5
Recommended length for maximum range β ≤ 0.75	44	44	44	95	44	44	44	44	13	145	4.5

UL = Minimum meter tube length upstream of the orifice plate in internal pipe diameter (D_i)(see Figure 2-6). Straight length shall be measured from the downstream end of the curved portion of the nearest (or only) elbow or of the tee or the downstream end of the conical portion of reducer or expander.
DL = Minimum downstream meter tube length in internal pipe diameters (D_i)(see Figure 2-6).
S = Separation distance between piping elements in internal pipe diameter (D_i) measured from the downstream end of the curved portion of the upstream elbow to the upstream end of the curved portion of the downstream elbow.
* These installations exhibit the strong effect of Reynolds number and pipe roughness on the recommended length due to the rate of swirl decay. The present recommendations have been developed for high Reynolds numbers and smooth pipes to capture the worst case.

Note: The tolerance on specified lengths for UL and DL is ± $0.25D_i$.

Table 2-8a—Orifice Meter Installation Requirements With 1998 Uniform Concentric 19-Tube Bundle Flow Straightener for Meter Tube Upstream Length of $17D_i \leq UL < 29D_i$.

	Single 90° elbow $R/D_i = 1.5$	Two 90° elbows out of plane S ≤ 2Di $R/D_i = 1.5$	Single 90° tee used as an elbow but not as a header element	Partially closed valves (at least 50% open)	High swirl combined with single 90° Tee	Any fitting (catch-all category)	Downstream meter tube length
Diameter Ratio, β	UL2	UL2	UL2	UL2	UL2	UL2	DL
0.10	5 – 14.5	5 – 14.5	5 – 14.5	5 – 11	5 – 13	5 – 11.5	2.8
0.20	5 – 14.5	5 – 14.5	5 – 14.5	5 – 11	5 – 13	5 – 11.5	2.8
0.30	5 – 14.5	5 – 14.5	5 – 14.5	5 – 11	5 – 13	5 – 11.5	3.0
0.40	5 – 14.5	5 – 14.5	5 – 14.5	5 – 11	5 – 13	5 – 11.5	3.2
0.50	11.5 – 14.5	9.5 – 14.5	11 – 13	[b]	11 – 13	[c]	3.5
0.60	12 – 13	13.5 – 14.5	[a]	*Not allowed*	[a]	*Not allowed*	3.9
0.67	13	13 – 14.5	*Not allowed*	*Not allowed*	*Not allowed*	*Not allowed*	4.2
0.75	14	*Not allowed*	*Not allowed*	*Not allowed*	*Not allowed*	*Not allowed*	4.5
Recommended tube bundle location for maximum range of β	13 β ≤ 0.67	13.5 – 14.5 β ≤ 0.67	13 β ≤ 0.54	9.5 β ≤ 0.47	13 β ≤ 0.54	9.5 β ≤ 0.46	4.5

[a] $13D_i$ allowed for up to β = 0.54.
[b] $9.5D_i$ allowed for up to β = 0.47.
[c] $9.5D_i$ allowed for up to β = 0.46.
S = Separation distance between elbows, measured as defined in Table 2-7.
UL1 = UL – UL 2 (see Figure 2-6).
Note 1: Lengths shown under the UL2 column are the dimensions shown in Figure 2-6, expressed as the number of published internal pipe diameters (D_i) between the downstream end of the 1998 Uniform Concentric 19-Tube Bundle Flow Straightener and the upstream surface of the orifice plate.
Note 2: The tolerance on specified lengths for UL, UL2, and DL is ± $0.25D_i$.
Note 3: *Not allowed* means that it is not possible to find an acceptable location for the 1998 Uniform Concentric 19-Tube Bundle Flow Straightener downstream of the particular fitting for all values of UL.

Table 2-8b—Orifice Meter Installation Requirements With 1998 Uniform Concentric 19-Tube Bundle Flow Straightener for Meter Tube Upstream Length of $UL \geq 29D_i$.

	Single 90° elbow $R/D_i = 1.5$	Two 90° elbows out of plane $S \leq 2D_i$ $R/D_i = 1.5$	Single 90° Tee used as an elbow but not as a header element	Partially closed valves (at least 50% open)	High swirl combined with single 90° Tee	Any fitting (catch-all category)	Downstream meter tube length
Diameter Ratio, β	UL2	UL2	UL2	UL2	UL2	UL2	DL
0.10	5 – 25	5 – 25	5 – 25	5 – 13	5 – 23	5 – 13	2.8
0.20	5 – 25	5 – 25	5 – 25	5 – 13	5 – 23	5 – 13	2.8
0.30	5 – 25	5 – 25	5 – 25	5 – 13	5 – 23	5 – 13	3.0
0.40	5 – 25	5 – 25	5 – 25	5 – 13	5 – 23	5 – 13	3.2
0.50	11.5 – 25	9 – 25	9 – 23	7.5 – 15	9 – 19.5	11.5 – 14.5	3.5
0.60	12 – 25	9 – 25	11 – 16	10 – 17	11 – 16	12 – 16	3.9
0.67	13 – 16.5	10 – 16	11 – 13	10 – 13	11 – 13	13	4.2
0.75	14 – 16.5	12 – 12.5	12 – 14	11 – 12.5	14	*Not allowed*	4.5
Recommended tube bundle location for maximum range of β	13 β ≤ 0.75	12 – 12.5 β ≤ 0.75	12 – 13 β ≤ 0.75	11 – 12.5 β ≤ 0.75	13 β ≤ 0.75	13 β ≤ 0.67	4.5

S = Separation distance between elbows, measured as defined in Table 2-7.
UL1 = UL – UL2 (see Figure 2-6).

Note 1: Lengths shown under the UL2 column are the dimensions shown in Figure 2.6 and as defined in Table 2-8a.
Note 2: The tolerance on specified lengths for UL, UL2, and DL is ± $0.25D_i$.
Note 3: *Not allowed* means that it is not possible to find an acceptable location for the 1998 Uniform Concentric 19-Tube Bundle Flow Straightener downstream of the particular fitting for all values of UL.