MEASURING HIGH VISCOSITY LIQUIDS WITH FLOW METERS

Class # 2415.1

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INTRODUCTION

Measuring higher viscosity hydrocarbon liquids is much more interesting than measuring lower viscosity liquids for a number of very good reasons including those addressed in many published technical papers and articles. Although several different types of meters are typically discussed, quadrant-edged orifice meters are often not included in the mix. Compared to some of the more commonly used viscous flow meters, quadrant-edged orifice meters have no moving parts, are fairly inexpensive, reliable, and non-proprietary.[1]

As originally reported in Washington, DC in 1986 during the First International Symposium on Fluid Flow Measurement (ISFFM), a series of controlled tests performed in 1985 demonstrated the excellent characteristics of quadrant-edged orifice meters when used to measure viscous oil flowing at low Reynolds numbers and compared results to earlier work on the subject.

During the tests, new experimental data was presented for both quadrant-edge and sharp-edge orifice plates used in low Reynolds number applications. Twelve different orifice plates with diameter ratios (Beta ratios) from 0.25 to 0.54 were calibrated in 3" and 4" meter tubes using flange pressure taps. A white mineral oil with a kinematic viscosity of approximately five centistokes was used as the calibration fluid which resulted in a pipe Reynolds number range of from 290 to 45,000. Calibration data was presented for upstream meter tube lengths that met the requirements of AGA Report-3.

This paper addresses the results of some of those tests and calls for additional testing and technical work regarding quadrant-edged orifice meters in viscous flow applications.

DIFFERENTIAL PRESSURE METERS

Differential pressure meters all operate in generally the same way. As a flowing fluid (liquid or gas) passes through, around, or across a flow restriction, the fluid velocity must increase to maintain the same mass flow rate. Thanks to *conservation of energy,* one of the fundamental laws of physics, this increase in velocity results in a drop in pressure. This means the pressure downstream of the flow restriction is lower than the upstream pressure. This drop in pressure, called differential pressure, is commonly abbreviated DP, Dp, or ΔP. In a differential pressure meter, pressure sensing taps are located upstream and downstream of the flow restriction which allows differential pressure to be measured in order to calculate flow.

The combination of flow restriction, pressure sensing taps and adjacent upstream and downstream piping are commonly called the *primary device* in a differential pressure meter. The sensing elements (e.g., differential pressure transducer, temperature transducer, etc.) are commonly referred to as the *secondary devices*.

At a given mass flow rate, a smaller opening (larger restriction) causes a greater resistance to flow, thus resulting in a higher fluid velocity and higher differential pressure.

At the same mass flow rate, a larger opening (smaller restriction) causes a smaller resistance to flow, thus resulting in a lower fluid velocity and lower differential pressure for the same mass flow rate.

ORIFICE METERS

The term “orifice meter” as used in this paper refers only to the primary metering element that consists, fundamentally, of an orifice plate and meter tube. There are many different types of orifice plates including sharp-

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[1] The first published quadrant-edged orifice meter technical papers appeared in the 1930s.

edged and quadrant-edged. Sharp-edged orifice plates are addressed in the American Petroleum Institute (API), *Manual of Petroleum Measurement Standards* (MPMS*)*, Chapter 14 – Natural Gas Fluids Measurement, Section 3 – Concentric Square Edged Orifice Meters (parts 1 through 4).[2] Quadrant-edged orifice plates are not currently addressed in any known energy industry measurement standard.

VISCOSITY

Simply stated, viscosity is resistance to flow and can be thought of as "thickness" resulting from internal frication. For example, at typical room temperature water is much "less thick" than honey; and gasoline is "thinner" than lubricating oils and many crude oils. So, these thinner liquids are said to have a lower viscosity than the thicker ones.

How easily a fluid moves in a closed container such as a pipeline or through a meter can give some indication of viscosity. Through some more highly restrictive meters, lower viscosity liquids move more freely than higher viscosity liquids.

Of course, viscosity is more complex than simply "thickness" and "thinness," but the above concepts help us to begin understanding some of the problems associated with measuring viscous fluids in the oil and gas industry.

In the study of fluid dynamics, and in the scientific community, we find much more complex and exacting definitions and explanations. For this brief article, however, the above explanation will suffice.

DISCHARGE COEFFICIENT

A discharge coefficient, sometimes called *coefficient of discharge* (Cd), is a performance-based value used to characterize differential pressure meters. Coefficient of discharge is the ratio of the true flow to the theoretical flow, and is applied to the theoretical flow equation to obtain the correct flow rate.

One explanation of Cd given in the ASME publication Fluid Meters - Their Theory and Application (1971) is as follows.

"*The actual rate of flow through a differential pressure meter is very seldom, if ever, exactly equal to the theoretical rate of flow indicated by the particular theoretical equation used. In general, the actual rate of flow is less than the indicated theoretical rate. Hence, to obtain the actual flow from the theoretical equation, and additional factor, called "discharge coefficient" must be introduced. This coefficient is represented by C and defined by the simple equation:*

$$C = \frac{\text{Actual Flow Rate}}{\text{Theoretical Flow Rate}}$$

The rate of flow may be in terms of mass (or weight) or volume per unit of time."

Discharge coefficient is commonly correlated with pipe Reynolds number, a dimensionless value based on meter tube inside diameter, fluid density, fluid velocity, and fluid viscosity.

REYNOLDS NUMBER

Reynolds number is a dimensionless value which can be defined by the following equation.

$$ReD = 4 \times Qm / (\pi \times D \times Vis \times 0.00005998)$$

Where:

ReD = pipe Reynolds number
Qm = Mass flow rate (lbm/sec.)
π = pi (3.141592654)
D = Meter tube diameter (in.)
Vis = Viscosity of liquid (centipoise)

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[2] This standard is also available through the American Gas Association (AGA), titled AGA Report No. 3 (AGA-3).

In a given measurement application, Reynolds number and flow rate are directly related; as flow rate increases so does Reynolds number.

QUADRANT-EDGED ORIFICE PLATES

Quadrant-edged orifice plates (sometimes also called "quarter circle," "quarter-round" or simply "quad plates") are so named because their inlet edge is rounded to a full ninety-degree (quarter circle) radius rather than having a sharp inlet edge, or other shape. Figure 1 shows the basic design and provides an equation used to calculate the inlet edge radius based on the orifice plate bore and meter tube diameter.

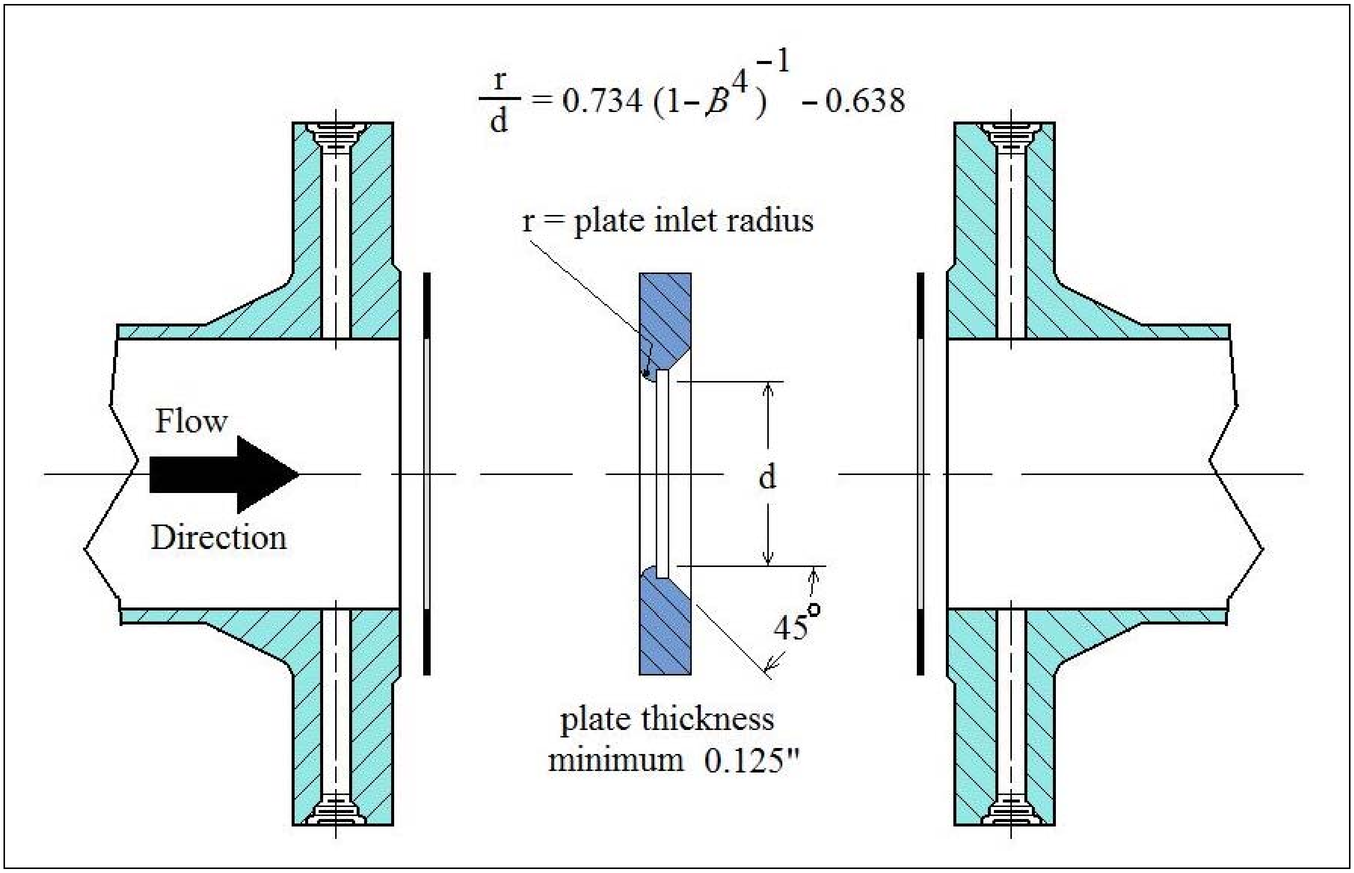

Fig. 1 – Quadrant-edge orifice meter basic geometry.

The rounded inlet edge of a quadrant-edged orifice plate results in a lower differential pressure and higher discharge coefficient than with a traditional sharp-edged orifice plate of the same diameter and operating under the same flowing conditions. A quadrant-edged orifice produces an average discharge coefficient of around 0.8 as compared to roughly 0.6 for sharp-edged orifices operating at higher Reynolds numbers.

Sharp-edged orifice meters are intended to operate at higher Reynolds numbers where their performance is well documented. However, sharp-edged orifice meters do not perform well in viscous flow and lower Reynolds numbers. Figure 2 is an indication of flow testing of a four-inch orifice meter in viscous flow, and demonstrates the difference in performance as compared to a sharp-edged orifice plate.

The data in the graph represents flow testing performed at the CEESI viscous oil flow measurement laboratory in 1985; the same laboratory where the special low Reynolds number testing was performed during development of the orifice measurement standard in use today.

In viscous flow applications, the main advantage of a quadrant-edged orifice plate over a sharp-edged orifice plate is that the discharge coefficient changes very little over the low Reynolds number ranges often encountered in the measurement of higher viscosity hydrocarbon oils and similar fluids.

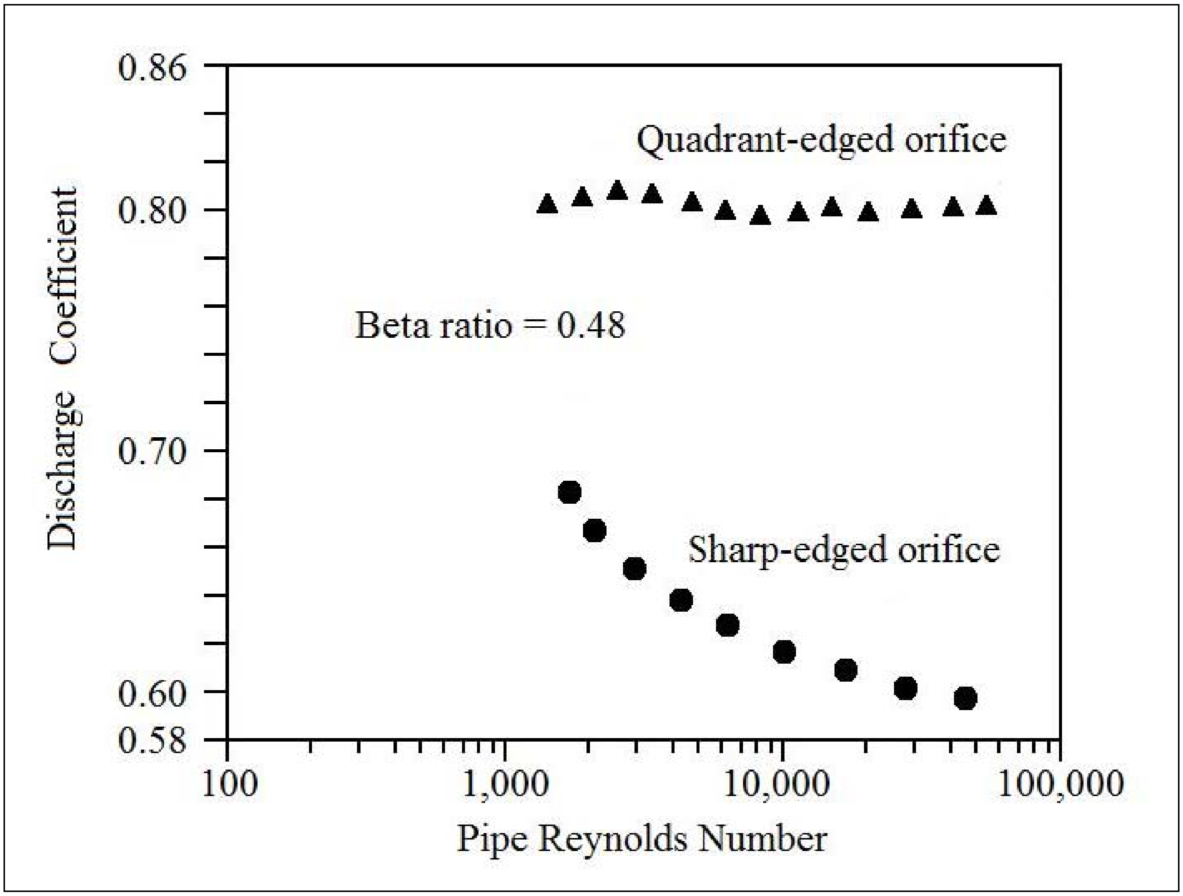

Fig. 2 – Sketch showing performance differences between sharp-edged orifice plate and quadrant-edged orifice plate under similar flowing conditions in viscous flow at low Reynolds numbers.

The results of the other tests performed in 1985 can be found in reference number five, listed below.

CONCLUSION

Many different types of flow meters aree used to measure viscous flow in different applications and under varying circumstances. Quadrant-edged orifice meters offer an excellent option to the more traditional flow meters available today.

More work is needed in the area of viscous flow measurement using myriad meter types including quadrant-edged orifice meters.

REFERENCES

The following references are among those used in the preparation of this paper. Please contact the author through his Web site at ***www.StarkAssoc.com*** for additional technical clarification or to comment on the contents of this paper.

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