WET GAS TESTING WITH THE V-CONE FLOWMETER

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SUMMARY

This paper discusses a series of tests conducted at the Southwest Research Institute for McCrometer Inc. Southwest Research in San Antonio, Texas has developed a wet gas testing loop using nitrogen gas and water. McCrometer contracted with Southwest Research to conduct a series of tests to evaluate the performance of the V-Cone flowmeter in wet gas applications. The geometry of the V-Cone provides a clean measurement of wet gas without liquid build up before or after the meter section.

Three V-Cone flowmeters were tested with a beta ratio range from 0.45 to 0.67. The test loop controlled the water loading from 0 to 5% by mass. Each meter was tested at six flowrates under two different pressures.

In addition to the performance testing, Southwest also installed a McCrometer supplied "clear" V-Cone made with acrylic pipe. This clear meter, under low pressure, allowed a visualization of the flow of wet gas through the meter. Still photography and video cameras were used to capture several combinations of gas flow and water loading.

Results show, as expected, that the V-Cone held no water either upstream or downstream of the cone section. Performance tests indicate a slight and consistent positive shift in flow coefficient under increasing water loadings. Smaller beta ratios showed less deviation from baseline conditions than larger beta ratios.

INTRODUCTION

For this paper, wet gas flow will be defined as the flow of a gas with the addition of liquid between 0 and 5% fraction by mass. Many field applications could fall into this category of flow, particularly in the oil and gas production industry. Wet, natural gas applications include flow after a separator or slug catcher or gas production without a separator.

Orifice plates have historically been used to measure the vast majority of natural gas flow in the world. The extended knowledge of the orifice plate is based on dry gas calibrations. With the introduction of liquid into a gas flow line, the calculations and parameters that the orifice calculations are based on become less accurate. Murdoch[1], Ting[2], and others have researched the effect of wet gas on orifice plate measurement. While the data for these research efforts have not always agreed, the conclusions point in the same direction…that wet gas can effect meter accuracy and more work should be done to quantify the effect.

An observed effect of wet gas on an orifice plate meter is the holding of liquid before or after the plate. As the velocity increases, the amount of liquid held before the plate is minimal. The low pressure, recirculating region after the plate, however, can hold a significant amount of liquid, as shown in figure 1.

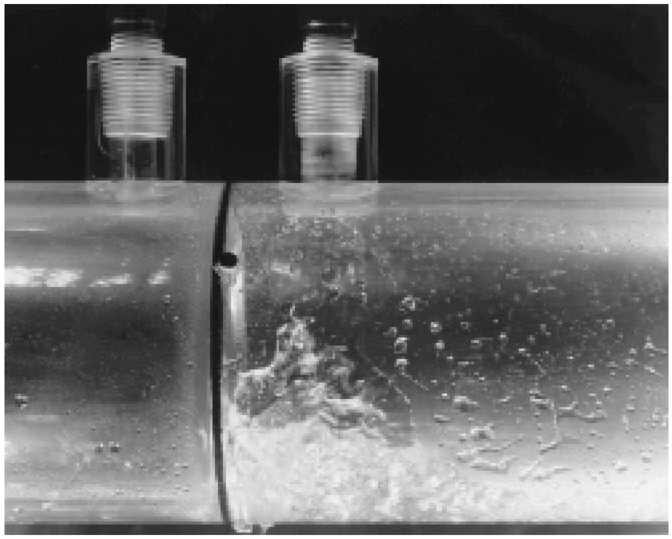

Figure 1. Photograph of an orifice plate in clear meter tube with wet gas. Flow is from left to right. Fluid is nitrogen with water injected upstream (Photograph courtesy of Southwest Research Institute)

The V-Cone differential pressure meter was introduced in 1986 as an alternative metering technology. Previous studies have shown the V-Cone insensitive to many installation conditions found in industrial field applications[3,4,5,6,7]. These papers considered the effects of flow disturbances upstream and downstream of the meter. The design of the V-Cone improves the performance of the meter in less than ideal conditions. The V-Cone is designed with a centrally located cone as a restriction. This is unlike other traditional differential pressure devices where the restriction comes from the pipe wall. The V-Cone leaves an annular opening around the cone. In wet gas, any free running liquid along the pipe wall would simply pass through, without touching the cone.

The V-Cone, therefore, should be well suited for wet gas applications. Prior to this testing, no research had been formally completed to analyze the effect of wet gas on the accuracy of a V-Cone meter.

TESTING

Facility

Southwest Research describes their flow loop with the following:

The experiments were conducted on a recirculating flow loop at Southwest Research Institute. The flow loop consists of a roots type compressor with a variable speed motor, compressor suction and discharge bottles to eliminate compressor pulsations, and a heat exchanger and chiller to control the gas temperature. The flow loop can flow at up to 550 ACFM at pressures up to 120 psia.

The wet gas flow meter performance tests were conducted using nitrogen as the gas phase and water as the liquid phase.

Figure 2 shows how the V-Cone meter was installed in the test facility and the location of the instrumentation. The V-Cone meter was installed in a 4-inch diameter horizontal pipe section that was located downstream of a sonic nozzle bank. The sonic nozzles were used as the reference gas flow meters for the tests. No flow conditioner was installed directly upstream of the V-Cone flow meter. A scrubber removed the liquid from the gas stream downstream of the V-Cone meter. A pump recirculated the liquid from the scrubber back to the liquid injection port.

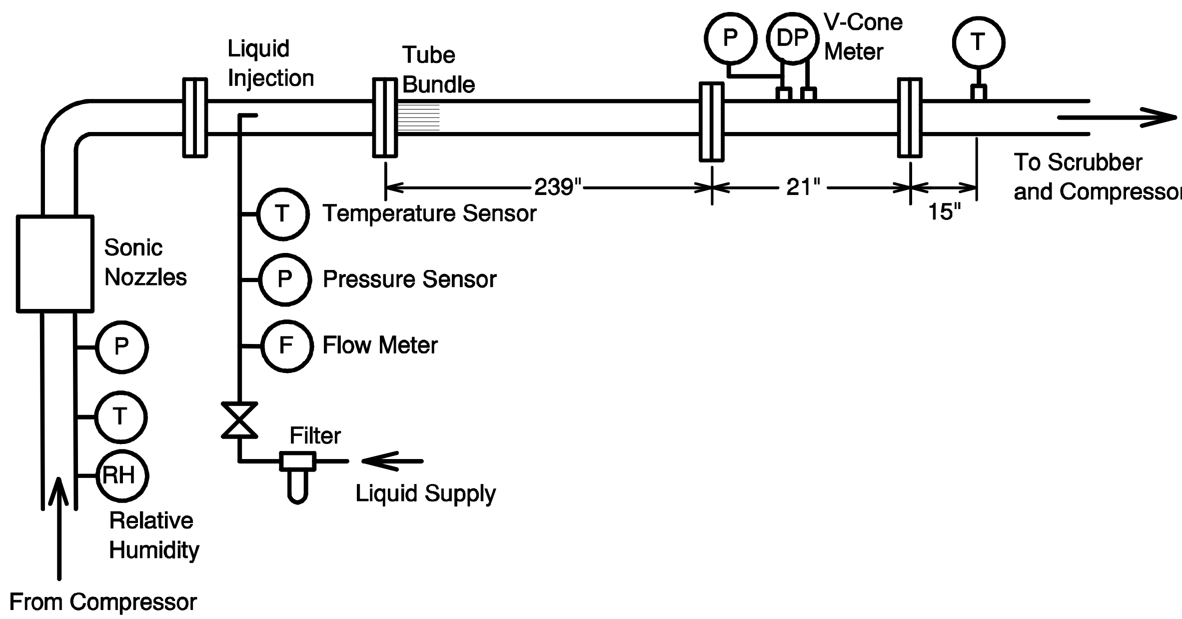

Figure 2. Schematic diagram of the V-Cone meter installation in the test facility. *The liquid was injected between the sonic nozzles and the V-Cone meter. This allowed the gas flow rate to be accurately metered, without the liquid present in the gas*.

Liquid was injected upstream of the V-Cone meter and allowed to mix with the gas for 59 pipe diameters before it entered the flow meter. This mixing length allowed the two-phase flow to be established in its natural flow regime, independent of the water injection method. The flow regimes for the tests were stratified-wavy and annular-mist.

Liquid was injected through a 3/8-inch outside diameter tube that was inserted straight into the pipe. The tube had seven 1/8-inch diameter holes drilled in the downstream side of the tube for water injection into the flow stream. Just downstream of the water injection tube, a 19-tube tube bundle was installed to eliminate any flow disturbance caused by the injection tube (this tube bundle was located 59 pipe diameters upstream of the flow meter).

Test Procedure

The following procedure was outlined and followed:

- The gas flow rate was selected by opening the valves to the desired sonic nozzles.
- The compressor was turned on and the flow loop allowed to come to thermal equilibrium (~65°F). The liquid pump was also turned on to circulate liquid through the test section.
- The flow loop was briefly turned off and the "zero" reading taken on the differential pressure sensors. This was to check for any sensor drift.
- The compressor and liquid pump were turned back on and the desired gas flow rate established. The pressure drop across the sonic nozzles was set so that the flow was choked in the sonic nozzles.
- With a constant gas flow rate, seven different nominal liquid loadings were tested. The liquid rates were varied in the following order: 0%, 5%, 3%, 0.5%, 4%, 1%, 2%, 0% liquid mass fraction. For each liquid rate, three separate readings were recorded. Each separate data "reading" consisted of an average of 31 samplings of the sensors over a period of 2.5 minutes.

The tests were conducted to determine the effect of liquid on the V-Cone meter measurement accuracy. The sonic nozzles held the gas flow rate constant as the liquid flow rate was varied. Using this approach, the exact value of the gas flow rate was not important--the flow rate just had to be constant. The sonic nozzles provided the constant flow rate so that small changes in the V-Cone metering accuracy (caused by liquid loading) could be measured.

Three meters were tested with beta ratios of 0.45, 0.59, and 0.67. The beta ratio of the V-Cone equates to the same open area in the meter as an orifice of similar beta ratio. SwRI tested at two different pressures, with three flowrates at each pressure. The liquid loading was varied between 0 to 5% by mass in seven increments.

The V-Cone meter discharge coefficient, C_d, was computed for each test using the gas flow rate measured with the sonic nozzle ($\dot{m}_{nozzle}$), and the measurements of the V-Cone upstream static pressure, differential pressure (ΔP), and the downstream gas temperature. The gas density (ρ) was calculated using the AGA-8 equation of state. The following equation was used to calculate the V-Cone meter flow coefficient:

$$C_d = \frac{\dot{m}_{nozzle}\sqrt{1-\beta^4}}{A_o Y \sqrt{2\rho\Delta P}}$$

In the above equation, Y is the expansion factor and β is the beta ratio. For the V-Cone meter, the beta ratio equation is:

$$\beta = \sqrt{1-\frac{d^2}{D^2}}$$

where D is the pipe diameter, and d is the cone diameter.

TEST RESULTS

A visual recording of wet gas flow through a V-Cone was taken using both video and still photography. A clear section of 4" pipe held specially made V-Cone components. The stainless steel cone was a non-working model and used only for photography.

The V-Cone held no water along the pipe walls, as expected. A slight amount of water held to the downstream, low pressure face of the cone.

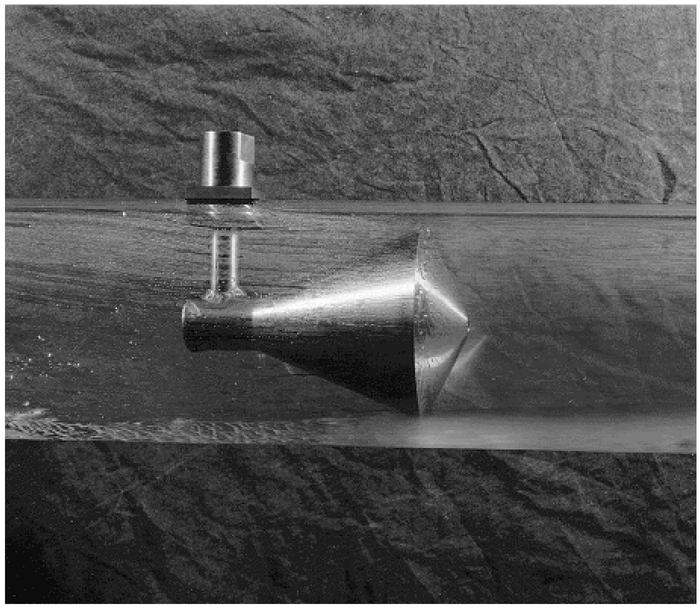

Figure 3. Photograph of V-Cone in clear meter tube with wet gas flow. Flow is from left to right. Fluid is nitrogen with water injected upstream

The following graphs display the test results as the error in gas reading vs. liquid mass fraction, both in percentages. The baseline point for each V-Cone was calculated as the average of all readings taken with no water flowing through the meter. The error in gas reading was calculated as:

$$Error(\%) = \frac{Q_{ind} - Q_{sn}}{Q_{sn}} \times 100$$

where Q_{ind} is the indicated flow from the V-Cone using an averaged baseline discharge coefficient, and Q_{sn} is the flow measured from the sonic nozzle bank.

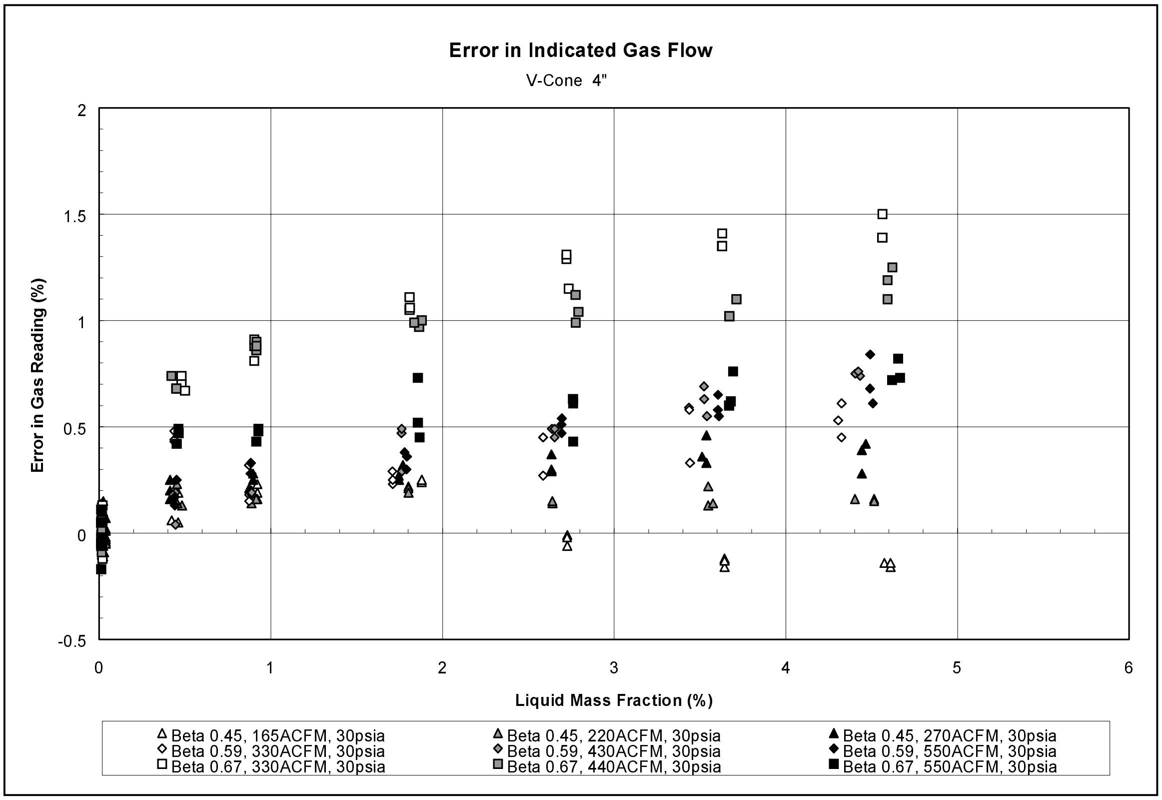

Figure 4. Test results for all beta ratios V-Cone for all flowrates at low pressure.

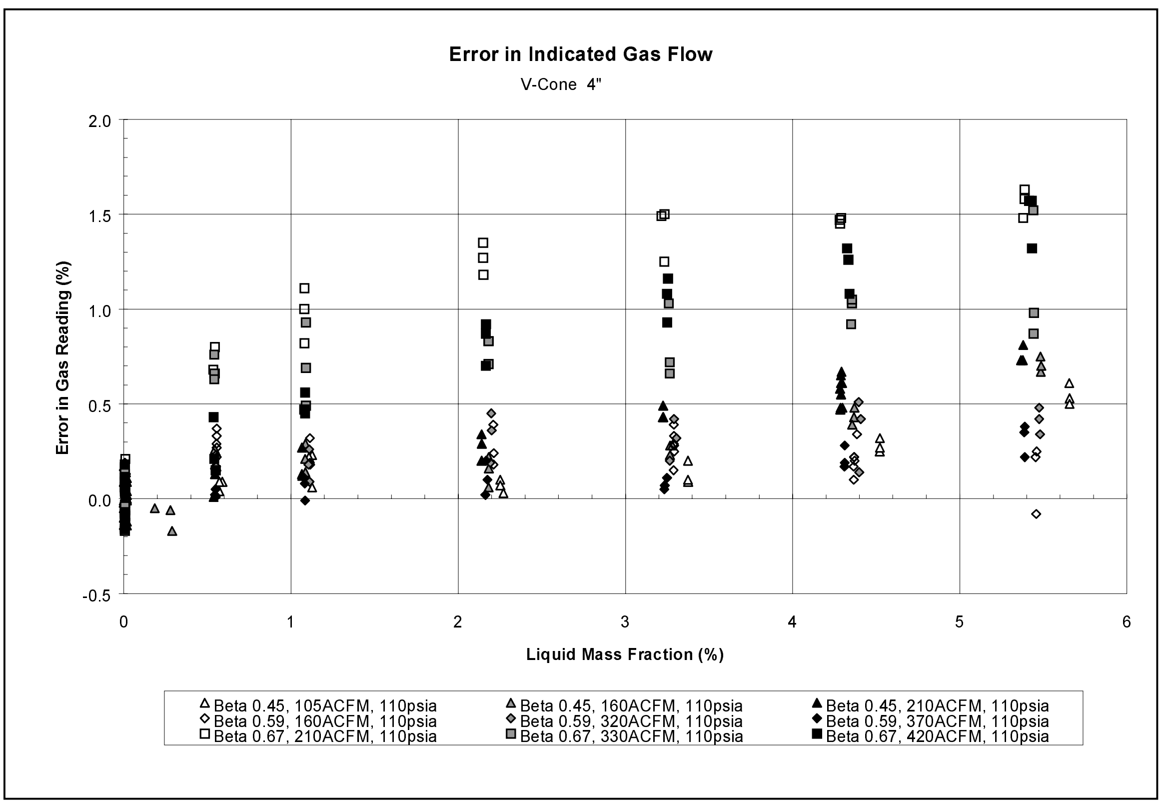

Figure 5. Test results for all beta ratios V-Cone for all flowrates at high pressure.

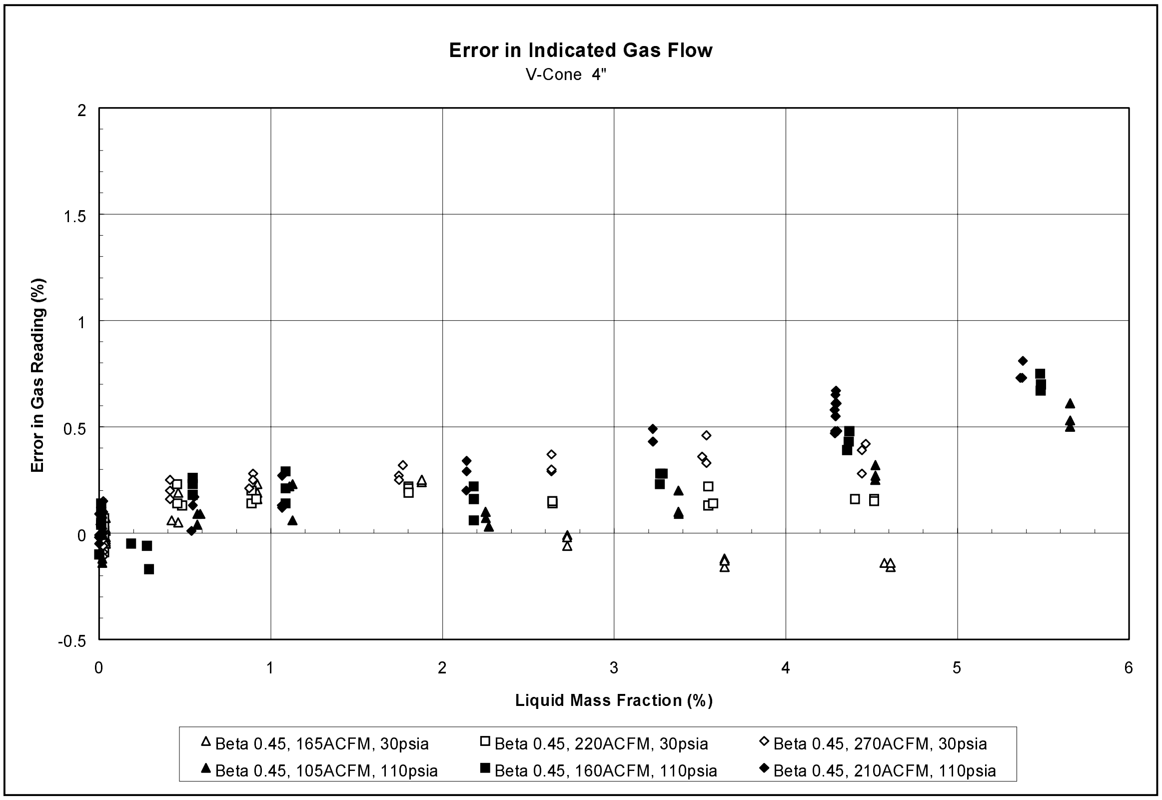

Figure 6. Test results for beta 0.45 V-Cone for all flowrates and pressures.

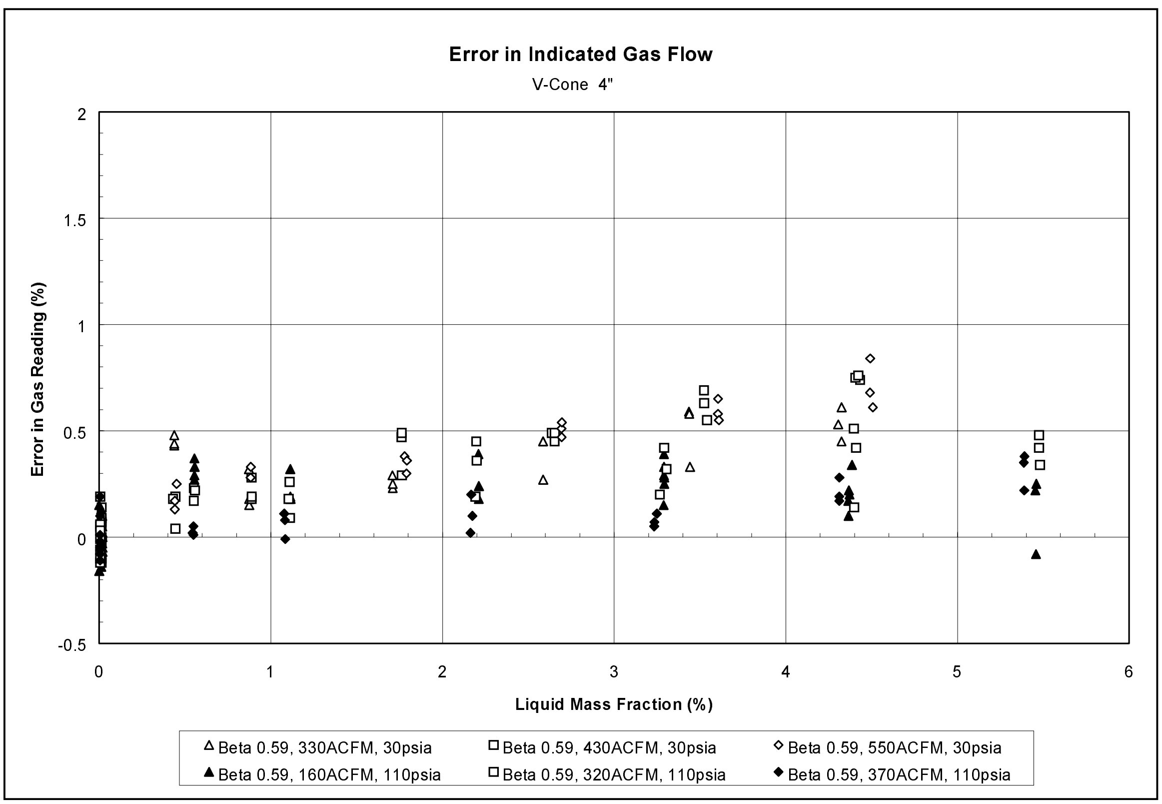

Figure 7. Test results for beta 0.59 V-Cone for all flowrates and pressures.

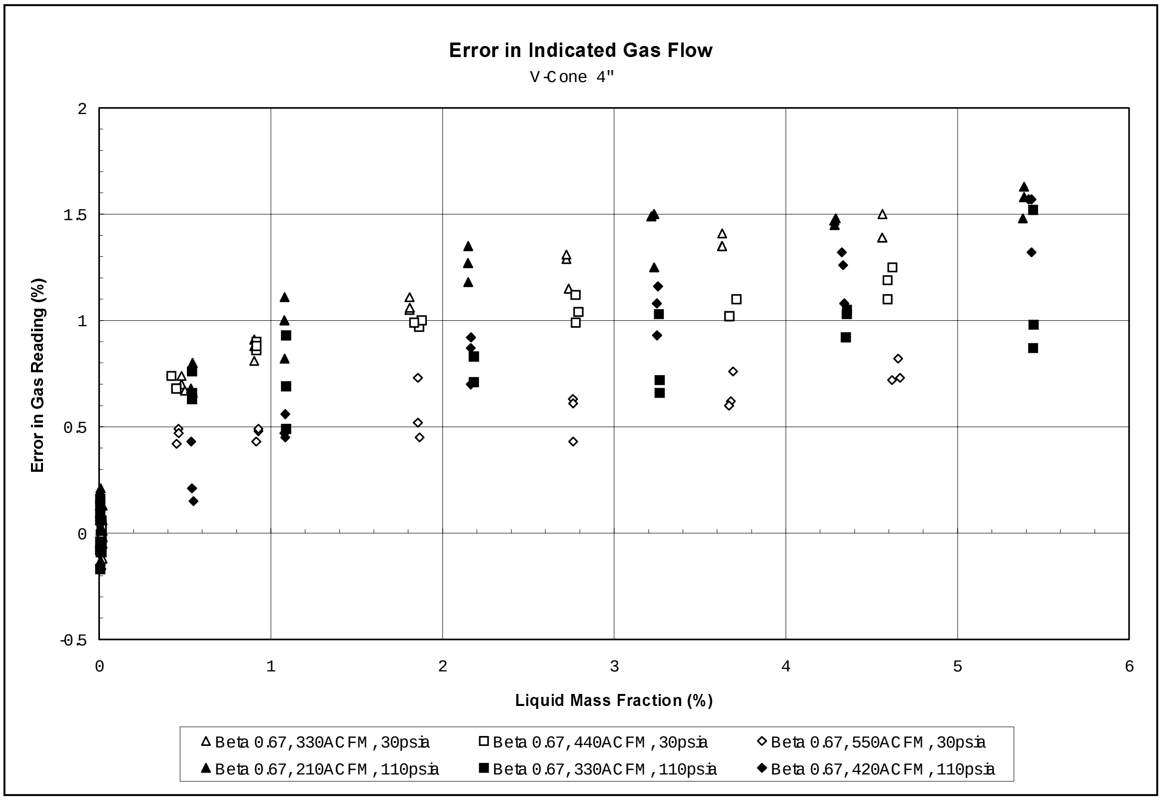

Figure 8. Test results for beta 0.67 V-Cone for all flowrates and pressures.

CONCLUSIONS

Visual recording of the V-Cone meter in low pressure wet gas flow reveals that very little liquid is held before or after the meter section.

Performance tests show the V-Cone discharge coefficient will decrease with increased water loadings. The amount of this decrease depends on the beta ratio of the meter and the line pressure. The decrease in discharge coefficient will cause a positive error in the gas reading calculation. Thus the meter will overpredict the gas flow in the pipe.

The errors in indicated gas flow were nearly always positive. For the two smaller beta ratios, the errors reached a maximum of 1.0%. At the lower pressure, the beta 0.45 error stayed within –0.25% to 0.5%. For the higher pressure, the beta 0.59 performed best with errors between 0 and 0.5%. The largest errors of 1.5% were measured with the beta 0.67 meter at both pressures.

The V-Cone appears capable of measuring wet gas flow to a system accuracy of better than ±1.0% of rate. Beta ratios smaller than 0.59 would be recommended. The consistent positive errors are conducive to easy correction factors in the presence of wet gas.

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