THE EFFECTS OF OIL COATING ON THE MEASUREMENT OF GAS FLOW USING SHARP-EDGED ORIFICE FLOWMETERS

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ABSTRACT

Orifice plates are known to be sensitive to a variety of effects due to dimensional variations and flowing fluid conditions. A number of studies have been performed to determine the specific effects of water entrainment and two phase flow on orifices, but the results were not well documented and were limited in scope. This paper describes an investigation funded by the Gas Research Institute (GRI) to determine the effects of a coating of compressor oil on the flowmetering performance of orifice plates. A viscous oil is used to coat only the plate or both the plate and upstream piping. The effect of this coating on orifices having different diameter ratios (ß) in several different line sizes is evaluated by statistically comparing the discharge coefficient for the wetted orifice to the discharge coefficient when dry.

KEYWORDS

Orifice, Diameter Ratio, Discharge Coefficient, Oil Films, Compressible, Gas.

BACKGROUND

Orifice plates are the most commonly used flow measurement device in the natural gas industry today. The flow through an orifice based flowmeter station is found by using a discharge coefficient found during calibration of the orifice plate. The discharge coefficient of an orifice plate is specific to the conditions under which the calibration was performed and the assumption is then made that field conditions will not vary significantly from flow lab conditions. When removed for inspection orifice plates are often found to have liquid coating their surfaces. The liquid may be water, condensed natural gas, glycol, or compressor oil and is specific to the stage of production. The presence of oil on the orifice plate is an indication of oil in the process piping which may be present in large quantities but is typically found to be a thin coating. At this time, the effect of a thin coating of oil on the orifice plate discharge coefficient is unknown but may be of consequence when the magnitude of unaccounted for gas is considered.

OBJECTIVE

The objective of this project was to conduct a preliminary investigation of the effects of thin oil coatings on the performance of orifice plate flowmeters and attempt to identify the mechanisms the oil creates that affect flowmeter performance. It was desired to keep the experimental conditions similar to what is found in natural gas pipelines so the following guidelines were followed during the investigation:

10:1 range in differential pressures during any one test
ΔP/P less than 10%
Reynold's number range of 0.13 to 3.2 million for any one pipe size.

LITERATURE SURVEY

A sampling of the work done to date concerning liquid coating the internals of an orifice flowmeter station indicates that the presence of a liquid does alter flowmeter performance. Testing conducted by McConaghy et al. [1989] shows both negative and positive shifts in discharge coefficient. Their work was conducted utilizing oil or glycol injection with testing results showing the combined effects of oil films and puddles of oil upstream of the orifice. They determined that large quantities of oil moving through the orifice plate effectively reduced the size of the bore causing a negative shift in orifice plate discharge coefficient. Botros et al. [1992] also found shifts in discharge coefficient which varied in sign depending on the presence of puddles upstream of the orifice plate.

A large body of work exists on the effects of variations in orifice flowmeter geometry. Thin oil films do alter flowmeter geometry so a review of the existing work addressing flowmeter geometry may be useful. A uniform coating of oil increases the thickness of the orifice plate. Husain and Goodson [1986] and Husain and Teyssandier [1985] have investigated the effect of variations in orifice plate thickness and have found that an increase in plate thickness as small as 1/32 inch can cause an appreciable increase in orifice plate discharge coefficient. Streaks of oil on the upstream orifice plate face may make the plate appear to be rough or uneven to the approaching flow. Botros et al. [1992] found that increasing plate surface roughness caused a positive shift in discharge coefficient. Oil on the upstream face may effectively reduce edge sharpness. Benedict et al. [1974], Crockett and Upp [1972], Spencer [1986], and unpublished work done at CEESI all show positive shifts in discharge coefficient due to rounding of the orifice plate edge. Oil in the piping upstream of the orifice meter may form a thin uniform layer acting to smooth the pipe surface or it may form a thick layer and acquire a wavy surface increasing the roughness of the piping. Pipe roughness studies conducted by Sindt et al. [1987] and Brennan et al. [1989] show that discharge coefficient increases as pipe roughness increases.

TEST APPARATUS

The system configuration used in this investigation is shown in Fig. 1. A compressed air source supplied high pressure air to a critical flow venturi (CFV) used to accurately measure the flow passing through the orifice flowmeter. A silencer was placed between the sonic nozzle and the orifice flowmeter to attenuate noise generated by the sonic nozzle. A three piece meter tube section was used in all tests. An enlarged view of a typical meter tube assembly is shown in Fig. 2. The dimensions of the testing system were in compliance with AGA-3 [1990].

Some details of the meter tube assembly are not shown in Fig. 2. Static and differential pressures were measured with the flange taps located at the twelve o'clock or top position to minimize oil migrating into the pressure sensing lines. Flange pins were used to ensure that the orifice plate was positioned in the system correctly and consistently from test to test. A drain was installed on the bottom of the upstream orifice flange. Each component of the three piece meter tube assembly had o-ring grooves allowing the use of o-rings for flange-to-flange and flange-to-orifice seals.

Data was collected using a computer based data acquisition system. A Hewlett Packard Model 3497A Data Acquisition/Control Unit read the Mensor Digital Pressure Guages, T-type thermocouples, and the Honeywell differential pressure transducer used to monitor system parameters. A personal computer read data from the Data Acquisition/Control Unit and stored the values. Software was written to sample each parameter 20 times over a 15 second period, find the average of the 20 samples, and store all values.

TEST PLAN AND PROCEDURE

The following test matrix was set up for this investigation:

- Three pipe sizes to be used in testing: 2", 6", and 10" pipe
- Three diameter ratios or ßs per pipe size spaced from 0.2 to 0.75
- Three different oil conditions for each unique piping configuration:
  - An initial dry run to establish baseline data
  - An oily orifice plate run
  - An oily orifice plate and oily upstream piping run.

The test matrix consisted of a minimum of 27 test runs. Individual tests consisted of acquiring data at 5 flowrates covering a 10:1 differential pressure range. A constant pressure was maintained at the orifice flowmeter that was high enough to maintain a ratio of differential pressure to line pressure less than 10%. Tests with only the orifice plate surfaces coated with oil were conducted in an effort to identify separate mechanisms contributing to the shift in discharge coefficient.

Oily Orifice Plate

Before an oily orifice plate run was started the orifice plate was completely coated with oil and hung vertically by its handle for 5 minutes. The 5 minute hang time was to allow the film thickness to stabilize. After 5 minutes the orifice plate was installed in the piping system in a manner that ensured no oil was wiped from the plate surface. Once the orifice plate was installed, system leak checks were performed and instruments were zeroed. The elapsed time from dipping the orifice plate to the start of the run was held reasonably constant from run-to-run. Table 1 shows the times between significant actions in an oily orifice plate run.

Data were taken at 5 different flowrates, 5 data points were taken in order from the low to high flowrate and then taken again with repeats as the flowrate was decreased. This method of taking data generated 12 data points per test run. Just before each data point was taken the drain on the upstream side of the orifice plate was opened to remove any oil puddling in front of the orifice plate.

Oily Orifice Plate and Upstream Piping

Prior to an oily orifice plate and pipe run the section of pipe upstream of the orifice plate was removed to allow the inside surface of the pipe to be coated with oil. The pipe was held at a shallow angle and rolled while oil was poured through it to thoroughly coat the inside of the pipe. The 2" pipe section was placed vertically on its end and the 6" and 10" pipe sections were held at a 15 degree angle for 5 minutes to allow excess oil to drain from the pipe. Once the 5 minute drain time was complete the orifice plate was coated and hung for its 5 minute hanging period as the piping section was reinstalled in the piping system. When installing the 6" and 10" piping the orientation of the pipe was not changed as it was placed back in the system to keep the thicker layer formed during the draining process on the bottom of the pipe. Once the oiled piping was reinstalled in the system the test proceeded in a manner similar to an oily orifice plate run. Table 1 shows the times between significant actions in an oily orifice plate and pipe run.

Clear Acrylic Test Section

Several runs were conducted using the clear acrylic test section in an effort to identify the mechanisms causing the shift in discharge coefficient when oil films were present on the orifice and piping surfaces. Test runs were conducted with just the orifice plate coated and with the orifice plate and upstream piping coated with oil. Flow rates and static pressures were necessarily low as the test section was not built to withstand high pressures.

Long Duration Runs

Oily orifice plate and pipe runs of long duration were conducted to examine the time dependency of the shifts. Flowrates were held at one or two flowrates to see if the shift in discharge coefficient would reach some steady-state value or if the shift would drop to zero. Data points were taken every 2 minutes with puddled oil drained from the upstream side of the orifice plate just before each data point was taken.

RESULTS

Changes in orifice plate discharge coefficient are shown in Figures 3 through 16 as percent change from baseline data:

$$\text{Percent Change in } C_d = \frac{(C_D - C_{D,baseline})}{C_{D,baseline}} \times 100 \tag{1}$$

Figures 3 through 14 are plots of change in discharge coefficient versus flowrate and Figures 15 and 16 are plots of change in discharge coefficient versus time. The uncertainty associated with the values shown in all of the plots is estimated to be ±0.25%.

Figures 3, 4, and 5 show the oily orifice plate (dry inlet pipe) data from the low ß, 2" runs. Other oily orifice plate runs did not show shifts greater than 0.25%. Inspection of Figures 3, 4, and 5 reveals that oil was swept from the plate surface resulting in a diminishing shift in discharge coefficient as the test progressed. The shift in discharge coefficient during the oily orifice plate tests appears to be a function of how much plate surface area was exposed to the flow.

Figures 6 through 14 show the results from the oily orifice plate and pipe runs. Comparing the 2" oily orifice results with the 2" oily orifice and pipe results suggests that there is more than one mechanism contributing to the observed shifts in discharge coefficient. This idea is supported by the facts that oily orifice plate and pipe runs produced shifts that increased with increasing ß and that the magnitudes of the shifts produced during the oily orifice plate and pipe runs were far larger than the shifts observed during the oily orifice plate runs.

The oil in the pipe seemed to affect the discharge coefficient in different ways during the oily orifice and pipe tests. In Fig. 14 the shift in discharge coefficient increases during the initial stages of the test run. The increase may be due to the oil acquiring a wavy surface which became more pronounced as oil moved down the pipe and accumulated just upstream of the orifice plate. In Fig. 10 the shift in discharge coefficient is negligibly small during the entire run. The absence of a shift may be due to the oil acquiring a smooth surface. A smooth surface would promote a negative shift in discharge coefficient which would cancel out any mechanisms acting to create positive shifts in discharge coefficient. In Fig. 13 the shift in discharge coefficient increases during the final portion of a run. If oil was scoured from the pipe and orifice plate surfaces resulting in a movement of oil downstream of the orifice during a run it would seem that in the latter portions of a run the shift in discharge coefficient would decrease. An increase in shift suggests that oil may remain upstream of the orifice plate during a run and acquire different surface characteristics depending on the flow regime.

Figures 15 and 16 are plots of the results from the long duration runs. These plots show two of the different effects observed during the shorter oily orifice plate and pipe runs. Figure 15 shows how oil was thoroughly scoured from the pipe surface at high flowrates. The shift in discharge coefficient decreases to a negligibly small value over a time period of 18 minutes and does not change significantly when the flowrate is changed. Data plotted in Fig. 16 shows how oil can be held upstream of the orifice plate and acquire different surface characteristics at different flowrates.

Observations of the oil at the orifice plate and on the surface of the piping in the clear acrylic section revealed at least three ways in which the orifice plate discharge coefficient could be altered. First, during the initial part of the test run oil was drawn along the plate surface towards the bore. This oil movement changed the orifice plate thickness during the initial portion of the test run. Second, two recirculation zones were observed to hold oil for prolonged periods of time. These recirculation zones were on either side of the sharp upstream edge of the orifice bore. These oil-laden recirculation zones could cause the orifice plate edge to appear to be rounded to the approaching air flow. Finally, oil in the pipe acquired a smooth surface or a wavy surface depending on the relative velocity of the air. These changes in oil surface conditions could smooth or roughen the pipe surface.

CONCLUSIONS

Orifice plate discharge coefficients are shifted significantly as a result of thin oil films on the orifice plate and upstream piping surfaces. This preliminary investigation revealed evidence of different mechanisms that can produce shifts in discharge coefficient. These mechanisms can work together to produce large positive shifts in discharge coefficient or work against each other to produce negligible shifts in discharge coefficient. Additionally, evidence was found of oil coating the pipe surface changing its effect on orifice plate discharge coefficient as a result of changes made in flowrate through the pipe. More work is planned to gain a better understanding of the effects of thin oil films on orifice flowmeter performance.

ACKNOWLEDGMENTS

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Table 1. Timing and Sequence of Test Events

Oily Orifice Plate	Oily Orifice Plate and Pipe	
Time (minutes)	Time (minutes)	Action
0		coat pipe with oil
5	0	install pipe in system and coat orifice plate with oil
10	5	install orifice plate in system
15	10	system leak check and zero D/P transducer
21	16	begin test

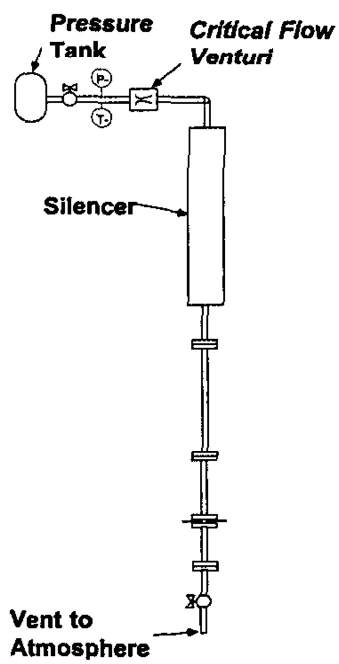

FIGURE 1. Test system

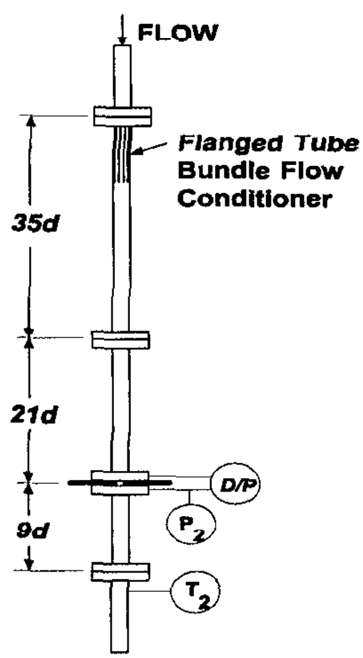

FIGURE 2. Expanded view of meter tube assembly

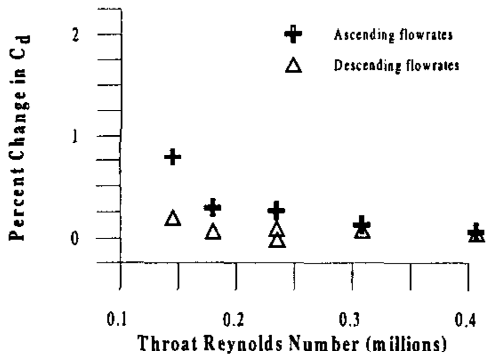

FIGURE 3. 2" Pipe, ß = 0.25, Oily Orifice

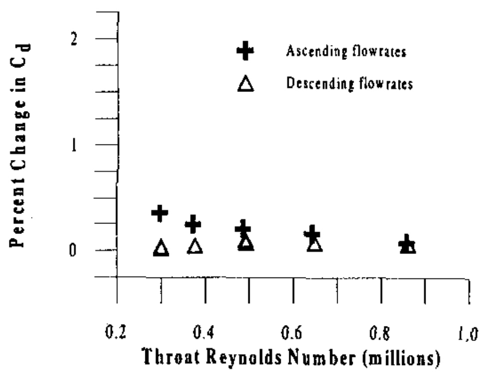

FIGURE 4. 2" Pipe, ß = 0.50, Oily Orifice

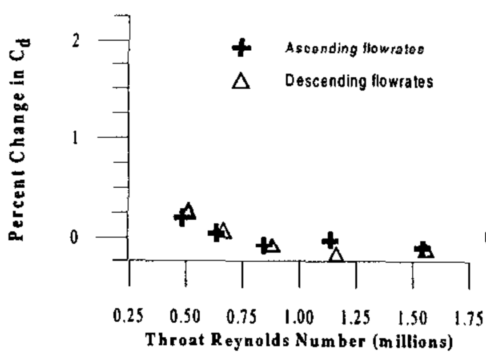

FIGURE 5. 2" Pipe, ß = 0.75, Oily Orifice

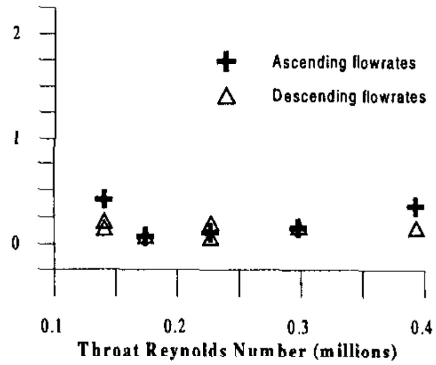

FIGURE 6. 2" Pipe, ß = 0.25, Oily Orifice and Pipe

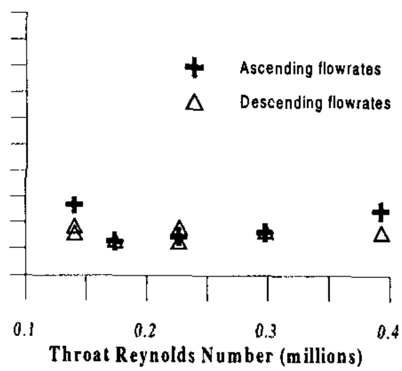

FIGURE 7. 2" Pipe, ß = 0.50, Oily Orifice and Pipe

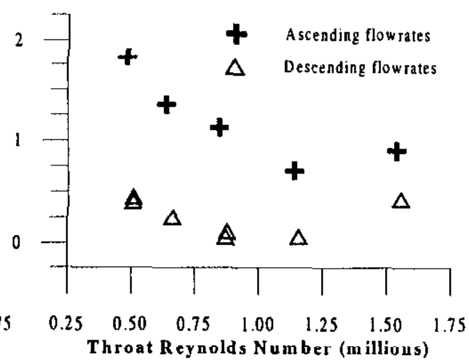

FIGURE 8. 2" Pipe, ß = 0.75, Oily Orifice and Pipe

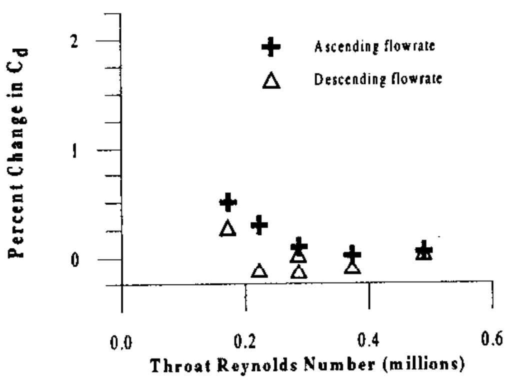

FIGURE 9. 6" Pipe, ß = 0.21, Oily Plate and Pipe

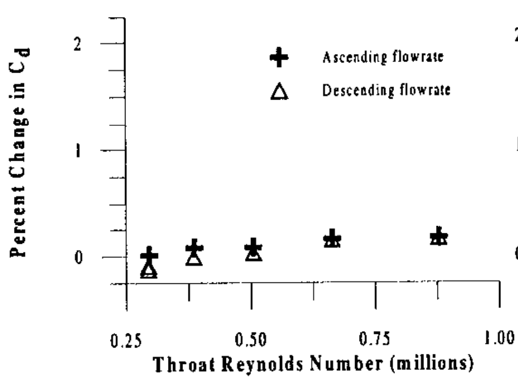

FIGURE 10. 6" Pipe, ß = 0.38, Oily Plate and Pipe

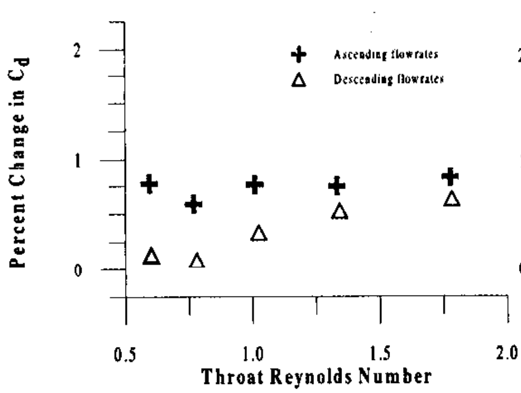

FIGURE 11. 6" Pipe, ß = 0.67, Oily Plate and Pipe

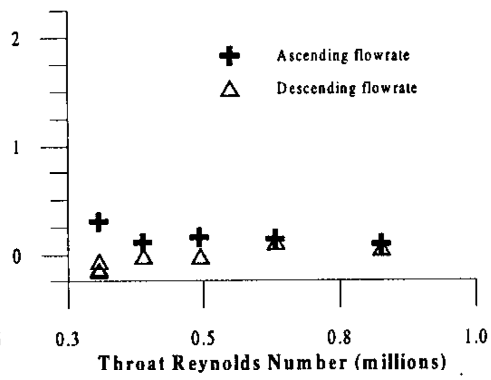

FIGURE 12. 10" Pipe, ß = 0.20 Oily Plate and Pipe

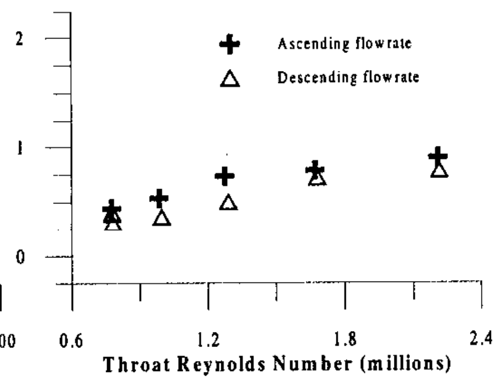

FIGURE 13. 10" Pipe, ß = 0.50, Oily Plate and Pipe

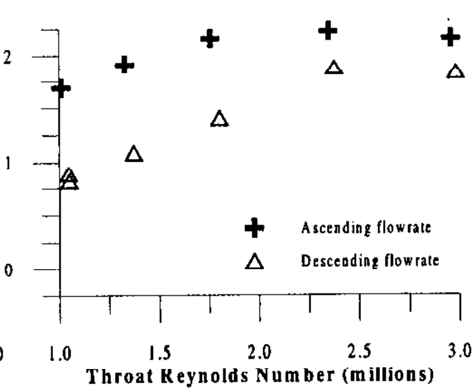

FIGURE 14. 10" Pipe, ß = 0.66, Oily Plate and Pipe

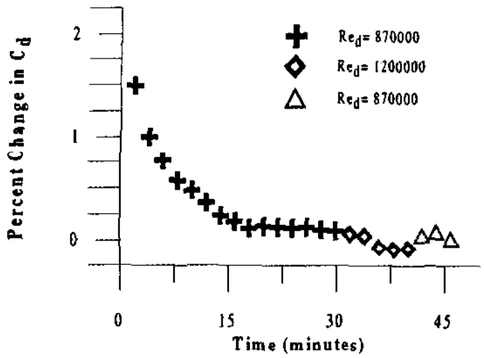

FIGURE 15. 2" Pipe, $\beta = 0.75$, Time Run Oily Plate and Pipe

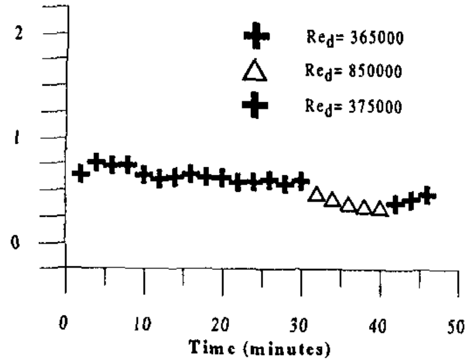

FIGURE 16. 2" Pipe, $\beta = 0.50$, Time Run Oily Plate and Pipe

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