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North Sea FLOW Measurement Workshop 1995

Paper 3:

IN-SITU CALIBRATION OF 500 MM DIAMETER ORIFICE METERS

1.3

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IN-SITU CALIBRATION OF 500 MM DIAMETER ORIFICE METERS

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Summary

Research conducted by Chevron in 1983 indicated that large diameter orifice meters may be subject to unforeseen installation effects. In order to determine if there were installation effects on three 500 mm diameter custody transfer orifice meters, a sonic nozzle in-situ proving system was installed to prove the meters. The custody transfer orifice meters are located at the outlet of the NOVA Gas Transmission Ltd. Kaybob South No. 3 meter station in northern Alberta, Canada. The in-situ proving facility was designed and conducted by NOVA at the request of Chevron Canada Resources. Chevron Petroleum Technology Company (CPTC) assisted with both the design and operation of the proving facility.

The three 500 mm diameter orifice meters each have a maximum capacity of 10,000 E3M3/D and were installed in 1989 according to specifications that exceed the current American Petroleum Institute (API) orifice metering standard. The sonic nozzle proving system was designed and installed in accordance with the American National Standards Institute (ANSI) MFC 7M. The nozzle system consisted of eight parallel 150 mm diameter nozzle runs and a 300 mm bypass turbine meter. Combinations of nozzles with diameters of 18 mm, 26 mm, 31 mm, and 38 mm are used to achieve flow rates throughout the range of the orifice meters. The nozzles were calibrated at Colorado Engineering Experiment Station Inc. (CEESI) using air. Samples from each size were tested at NOVA Gas Dynamics Test Facility (GDTF) using pipeline quality natural gas. The agreement between these two labs was within the stated uncertainties of the facilities.

Data acquisition and system control was accomplished by using high quality transducers connected to data loggers and a computerized data archiving and control system. Instrumentation was calibrated at the beginning of each day of operation and calculations were performed using a sonic nozzle mass flow program developed by NOVA for the in-situ meter prover project. The program, based on a PV=ZRT equation of state, uses the 1992 AGA-8 method for calculating compressibility factors and was verified against other independently developed programs using the 1985 AGA-8 and 1992 AGA-8 methods.

Results of the orifice meter calibrations indicated good agreement between the standard flow calculation and the proving system with low beta ratio plates. However, larger deviations occur as the beta ratio approaches 0.6. The cause of the high beta ratio deviation is under investigation. The current hypothesis, which will be tested as part of the on-going work at the facility, is that the bias is due to installation effects.

INTRODUCTION

Background

In-situ proving of orifice meters is a technology that is allowed for in current metering standards [1] but is one that is seldom practiced in field operations. The current state of the art in natural gas metering makes it possible to develop high quality and field rugged proving systems that can be used on any natural gas meter.

Chevron In-Situ Proving Prior Experience

Chevron Petroleum Technology Company (CPTC) began testing proving technology in natural gas operations in a number of locations and conditions beginning in 1981 [2, 3]. Orifice, turbines, vortex, pitotstatic, and other meters have all been installed in operating natural gas pipeline systems and proven using various sonic nozzle provers. Chevron's first commercial application of in-situ proving technology was at the Venice, Louisiana, sales meter station [4]. The Venice facility is still in operation and is currently using sonic nozzles to in-situ prove high pressure, high flow rate turbine meters. This turbine meter prover was installed in series with the existing orifice meter sales station and has performed very well in the hands of the field operating personnel since 1987.

Based on Chevron's field experience with orifice meters installation effect and its knowledge of the ease of accomplishing in-situ proving, the NOVA Kaybob South No. 3 metering station was considered, following its commissioning in 1990, by Chevron to be an obvious candidate for application of this technology.

NOVA's Metering Research

NOVA research has also been very active in evaluating the expected field performance of orifice meters. NOVA has conducted a number of installation effect experiments on orifice meters at their Gas Dynamics Test Facility at Didsbury, Alberta. The results of NOVA's research have been presented in a number of papers [5-8] and have validated measurement practices that included using meter tube lengths longer than those required by the standards, restricting the beta ratio range from 0.20 to 0.60 and minimizing the number of 50 mm orifice meters used.

NOVA's Metering Experience

Metering on NOVA's natural gas transportation system is primarily accomplished with orifice meters. There are approximately 1200 orifice meter runs in service in over 950 meter stations. The orifice meters range in size from 50 mm to 600 mm in size. NOVA's system gathers gas from gas producers and transports it to the borders of Alberta where it is passed on to connecting pipeline systems. Because of the gathering nature of the system, there is a predominance of smaller meters used to measure receipts; a small number of large orifice meters is used to measure the deliveries. In spite of the skewed distribution of meter sizes, NOVA metering balance is extremely low (typically within a few tenths of a percent) — a fact that NOVA considers to be strong evidence that no systematic bias exists between small and large diameter orifice meters.

Pretest Uncertainty Analysis of Provers and Orifice Meters

Prior to designing and constructing an in-situ meter prover for the Kaybob South No. 3 metering station, a general engineering study was conducted by Novacorp International Consulting Inc. The study included an investigation of the various proving meter options and their associated measurement uncertainty. The types of reference meters considered for the meter prover were sonic nozzles, turbine meters, and orifice meters. Novacorp recommended sonic nozzles for the in-situ meter prover because they had the lowest estimated measurement uncertainty at 0.50% for a single sonic nozzle and 0.42% for four nozzles operated in parallel (assuming a sonic nozzle coefficient of discharge uncertainty of 0.25%). Turbine meters and orifice meters, by comparison, were estimated to have an uncertainty of 0.66% and 0.76% respectively. The robust nature of sonic nozzles was also considered to be a benefit for an in-situ meter prover.

The cost to install a sonic nozzle prover was determined to be comparable to that of a turbine or orifice meter prover. Further, the required additional compression necessary for sonic nozzle operation was available at Chevron's Kaybob plant. Based on NOVA Corp's study, Chevron's partners in the Kaybob Gas Plant agreed to fund the design and construction of the NOVA Kaybob South No. 3 in-situ meter prover.

LOCATION, SPECIFICATIONS, AND OPERATING CONDITIONS

Operating Conditions

Table 1, "High Pressure Prover Loop Operating Conditions", presents the general operating conditions and specifications for the proving system. The NOVA Kaybob South No. 3 meter station is located about 200 km northwest of Edmonton, Alberta, Canada (see Figure 9). Variable climate conditions made it a requirement to locate all metering equipment inside buildings. The design gas temperature of 35°C and pressure of 8450 kPa, shown in Table 1, were not obtained in actual operation. Actual operating pressure is closer to 5000 kPa and temperature is closer to 20°C.

TABLE 1
High Pressure Prover
Loop Operating Conditions

Elevation- Kaybob South No 3	1,065 m
Barometric Pressure - Kaybob South No. 3	89.22 kPa abs.
MAOP	8,450 kPa
Design Pressure	8450 kPa
Hydrotest pressure	
Maximum	12,500 kPa
Minimum	11,800 kPa
ANSI rating for equipment flanges and valves	600 ANSI
Natural gas temperature	35°C
Base measure/computation conditions	
Pressure	101.325 kPa
Temperature	15°C
Gas composition (typical)	
Nitrogen	1.62 (MOL %)
CO_2	0.01 (MOL %)
C_1	96.0 (MOL %)
C_2	2.21 (MOL %)
C_3	0.16 (MOL %)
Gas specific gravity	0.57
Minimum flow rate	13.61 kg/s
Maximum flow rate	90.28 kg/s

Specifications

Table 2, "Sonic Nozzle Specifications", presents the design parameters for the sonic nozzles installed in the prover. All nozzles and nozzle runs were manufactured and installed according to American Society of Mechanical Engineers (ASME) ASME 7M [9]. Nozzle discharge coefficients were determined experimentally as described later in this paper.

TABLE 2
Sonic Nozzle Specifications

Nozzle Serial No.	Throat Diameter [mm]	Operating Mass Flow Rate[1] [kg/s]
5031, 5032, 5033, 5034	18	2.35
5035, 5036	26	4.90
5037, 5038, 5039, 50310, 50311	31	6.96
50312, 50313, 50314	38	10.46

Table 3, "Orifice Meter Mechanical Specifications", presents the design guidelines for the NOVA metering station. NOVA's specification exceeds the current recommendations for

[1] Based on typical operating conditions of 5000 kPa, 20 °C and 0.58 specific gravity natural gas.

upstream lengths in API 2530 [1]. In addition to extra upstream lengths, NOVA restricts the orifice beta ratio to the range from 0.20 to 0.60.

TABLE 3
Orifice Meter Mechanical Specifications

Maximum beta ratio		0.6
Distance to vane		10 D
Distance to Flange		24 D
Run 1		
	Inside diameter	481.9 mm
Run 2		
	Inside diameter	482.2 mm
Run 3		
	Inside diameter	482.0 mm

Figure 1 presents a simplified flow schematic of the proving system. The general layout and operation of this type of proving system has been previously presented [2, 4]. However, a few important points about the design are worth noting: 1) in order to eliminate any chance of interference, the sonic nozzle bank is located downstream of the orifice meters, 2) a turbine meter bypass system was installed to account for the gas flow not being used by the prover, and 3) all important flow block valves are double block and bleed and the sealing of these valves was checked during operation.

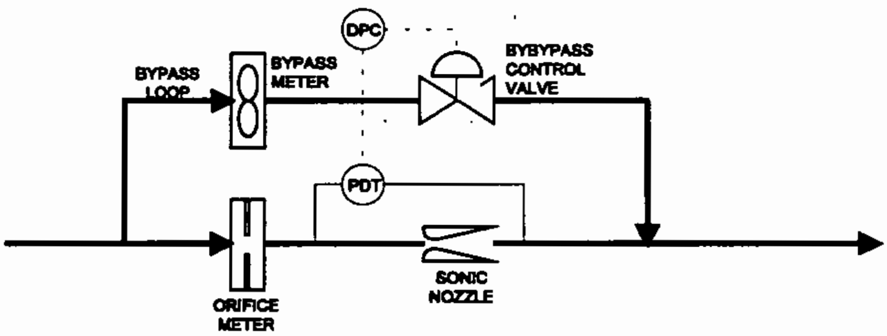

Figure 1: Simplified Flow Schematic

DATA COLLECTION AND ANALYSIS

Data collection and system control, Figure 2, was accomplished with high quality electronic transducers, modern computer equipment, and controllers. In order to ensure facility stability, and to obtain data with a low standard deviation of the sample mean, a long run time of 20 minutes or more was performed for each test point.

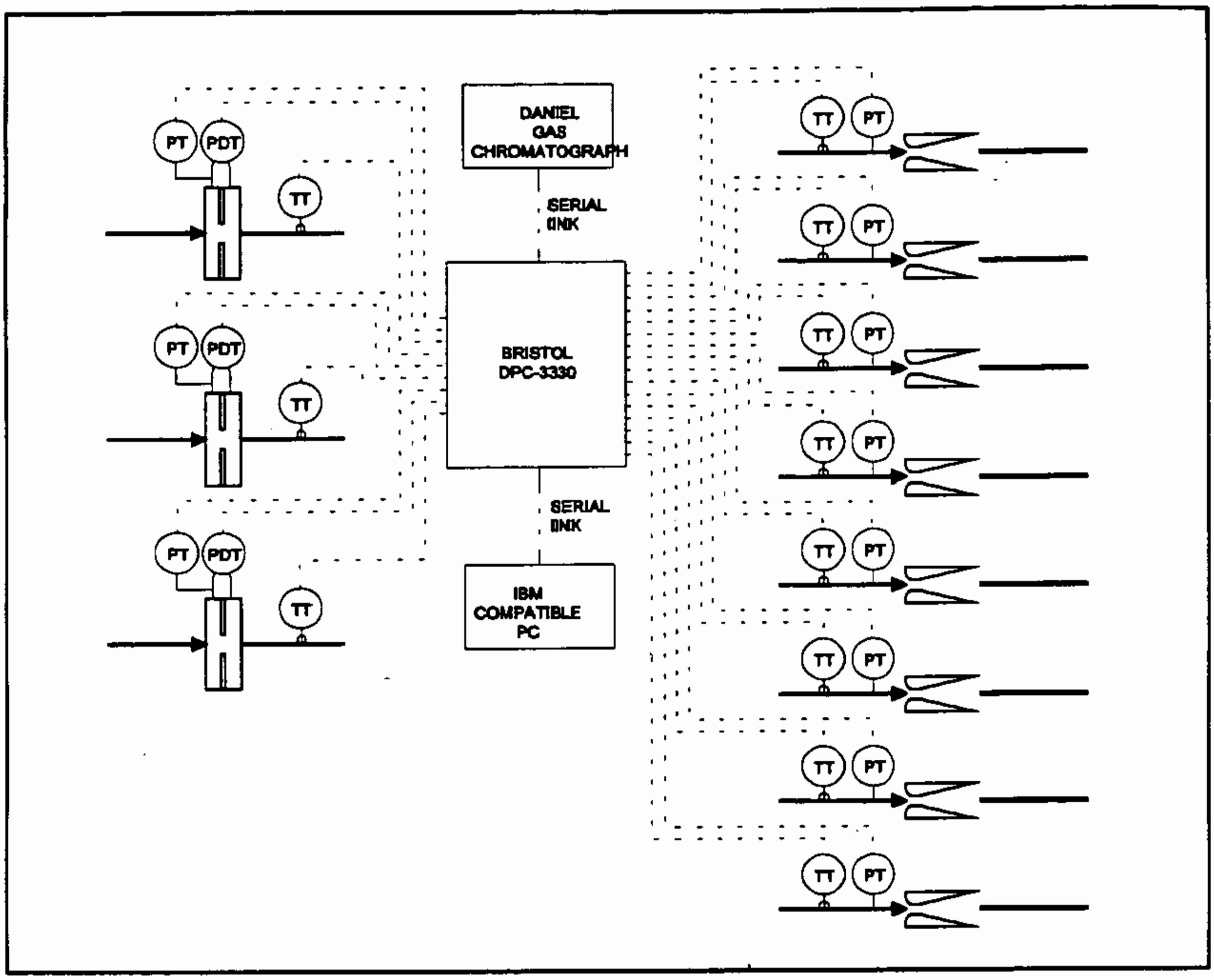

Figure 2: Data Acquisition System Schematic

During the 20 minute test period, data was collected at 10 second intervals producing 120 points. Data for each of these tests was processed by applying the transducer calibrations that were performed at the beginning of each day. The adjusted transducer readings were then combined with the gas analysis obtained from the on line gas chromatograph and a flow computed for each point.

SONIC NOZZLE OPERATION

Thermodynamics of Sonic Nozzle Operation

The calculation of flow rate through sonic nozzles requires that one know the speed of sound and the density of the gas at the throat of the nozzle. Measuring the plenum pressure and temperature, and computing throat conditions along an isentropic path is the accepted method of determining this velocity and density. Several older methods [10, 11] are publicly available to accomplish this calculation. However, as part of the project, the accuracy and traceability of the proving system was insured by NOVA developing a program to compute the sonic nozzle mass flow based on the latest natural gas equation of state. The program is based on a PV=ZRT equation of state and uses the 1992 AGA-8 [12] method to calculate compressibility factors.

Critical flow coefficients, or C*, also calculated by this program were compared to programs based on the 1985 AGA-8 [11], and to the beta versions of the Gas Research Institute's (GRI) critical flow program which uses the 1992 AGA-8 [12]. The comparison indicated that all methods based on AGA-8 agreed to within 0.1% at typical operating conditions (plenum pressure, temperature, and gas composition). Additionally, the NOVA program agreed with the GRI critical flow program beta version to within a few hundredths of a percent.

Calibration of the Sonic Nozzles

Discharge coefficients for the sonic nozzles used in the prover were obtained by calibrating the nozzles in air at CEESI using a combined calibration method which employs both CEESI's primary and secondary facilities. CEESI's primary facility has an uncertainty of 0.1% and the secondary facility 0.5%. The uncertainty of a combined calibration was estimated by CEESI to be 0.25%.

As a quality control check, one nozzle of each size was tested in natural gas at GDTF. The estimated uncertainty of the nozzle discharge coefficients determined at the GDTF was 0.35%. Due to operating and scheduling difficulties usable data was collected for only three of the four nozzles tested at GDTF.

Table 4, "Comparison of Nozzle Discharge Coefficients", presents the discharge coefficients determined by CEESI and NOVA and compares them to the International Standards Organization (ISO) [13] standard values. As can be seen, the CEESI values vary about the standard value with a maximum deviation of 0.18%. NOVA's calibration shows a bias with respect to the standard and a maximum deviation of -0.5%. However, when the two labs are compared to each other, the agreement is within 0.31%. Considering the uncertainty statements of the GDTF and CEESI calibrations, the difference is not statistically significant.

TABLE 4
Comparison of Nozzle Discharge Coefficients

Serial Number	Cd CEESI	Percent Diff From Standard	Cd NOVA	Percent Diff From Standard	Cd Standard	Percent Diff CEESI-NOVA
5031	0.9944	0.13%	0.9918	-0.13%	0.9931	0.27%
5035	0.9914	-0.18%	0.9883	-0.49%	0.9932	0.31%
50311	0.9914	-0.18%	0.9883	-0.50%	0.9932	0.31%
50314	0.9941	0.08%	0.9900	-0.33%	0.9933	0.41%

Note: The Cd calculated from the standard are based on nominal diameters.

Choking Pressure Differential

The correct operation of a sonic nozzle requires an adequate pressure drop across the nozzle. This pressure drop, required to insure that the nozzles have sonic flow at the throat, is commonly called the back pressure ratio. Standards on critical flow venturi nozzles [9, 13] specify where the pressures are to be measured and the amount of pressure drop required, for nozzle throat Reynolds number greater than 2×10^5, as a function of the area ratio of the divergent cone of the nozzle. A common rule of thumb is that for toroidal throat nozzles, this pressure ratio, the downstream pressure divided by the upstream pressure, should be 0.9 or a 10% pressure drop.

Previous experiments carried out by Jones [14] have shown that the pressure drop required for sonic flow at the throat of the nozzle design used in this in-situ proving could be as low as approximately 5%. Reduction in the pressure drop across the nozzle allows for a reduction in the required compression horsepower and lowers the potential of processing plant and field facilities problems.

Tests were conducted at the Kaybob South #3 Meter Prover to confirm that an adequate back pressure ratio was being used during the calibration runs. Sonic operation was determined by using the meter factor as the indicator. Calibration runs were made with back pressure ratios ranging from 4% to 13%. The results, contained in Figure 8, show that the meter factors stayed constant down to a back pressure ratio of 0.94 and confirmed that the typical back pressure ratio of 10% used in the calibration runs was ample to ensure that the flow through the nozzles was choked.

RESULTS

Discussion

The data collection procedures and computerized operation of the equipment provided large amounts of data on which to base in-situ proving results. As can be seen from Figure 3, the typical data set for a calibration point consisted of over 120 data points. Data sets similar to those shown on Figure 3 were averaged to obtain a single calibration point shown on Figures 4 through 7.

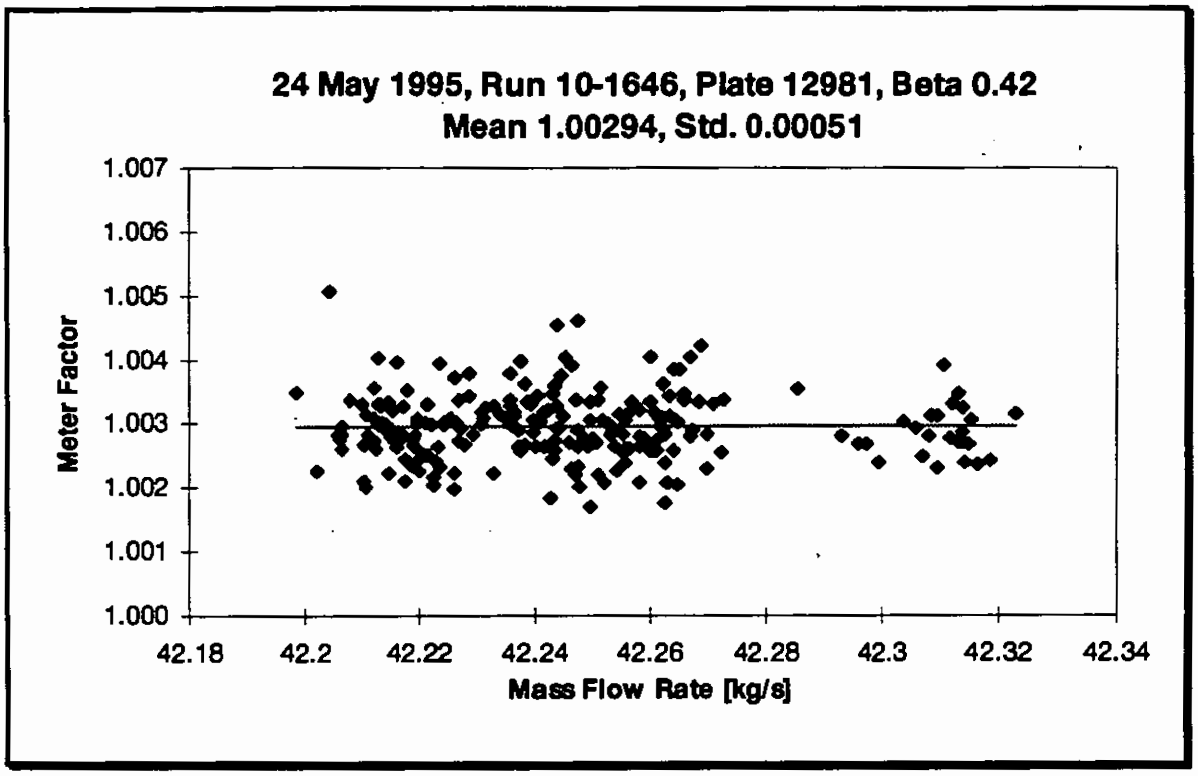

Figure 3: Calibration Point Data

The spread of the data on Figure 3 provides one with a measure of the stability of the proving and control systems. Figure 3 shows that the standard deviation of this data set is 0.051%. Visually, one can identify a few possible outlier data points; however, no attempt was made to remove these points or any others unless an operational problem could be identified that could account for the deviation.

Figure 4 shows the 0.42 beta ratio calibration points obtained for all three 500 mm runs. The data was obtained over numerous days and should contain a representative amount of scatter due to short and mid-term repeatability effects. Of note is the apparent trend in the data and the spread between the meter factors for the various meter runs and plate combinations.

The apparent trend of the meter factor with respect to the orifice bore Reynolds number could be a result of any of the following:

1. The static pressure effect on the orifice meter differential pressure transmitters.
2. An increasing bias in Cd with increasing nozzle size.
3. Gas leaking past the flow block valves on the closed orifice meter runs.
4. A bias in the orifice meter discharge coefficients predicted by the 1985 AGA-3.

The first two reasons are considered to be the most likely and will be the subject of future testing.

The spread between the various meter runs and plate combinations is the result of the specific characteristics of the individual meter runs and orifice plates. Testing was performed in an attempt to determine how much of the spread can be attributed to differences in the meter runs and how much is a result of differences in the orifice plates.

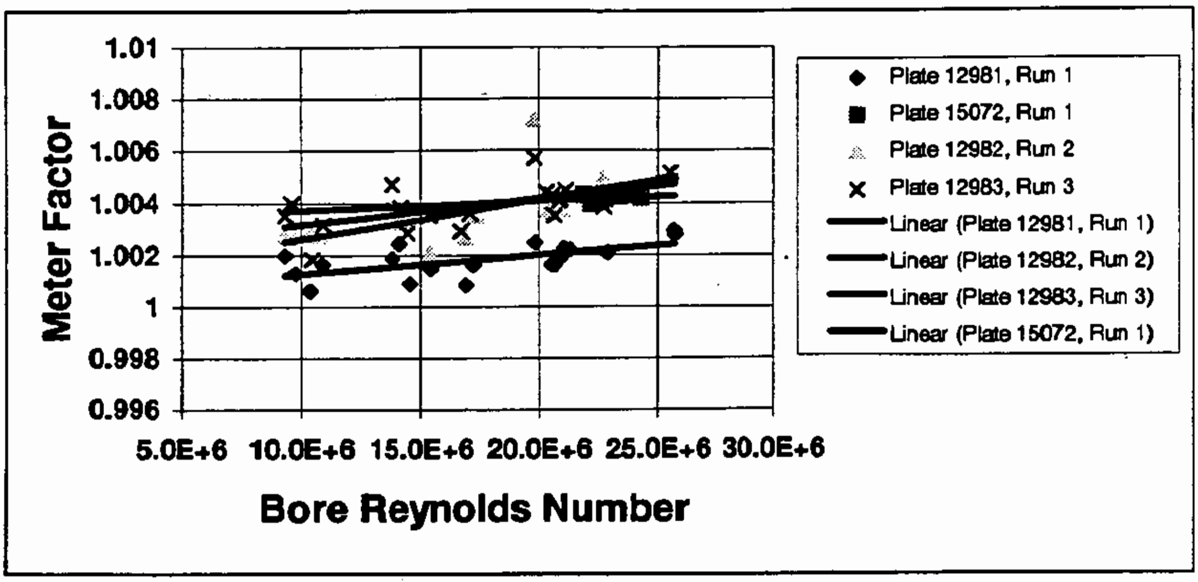

Figure 4: Beta Ratio 0.42 Calibration Points

Figure 5 shows all the 0.42 beta ratio calibration points obtained to date. The trends in the data indicate that about 0.1% of the spread in the meter factors, for the various meter run and orifice plate combinations, can be attributed to differences between the meter runs and about 0.2% can be attributed to differences in the orifice plates. Plate #12,981 has a noticeably different meter factor than the other 200 mm plates. Careful measurement of the 200 mm plates have ruled out variations in the bore diameter and eccentricity as possible causes of this difference. Future measurement and testing will hopefully reveal the cause of these observed variations.

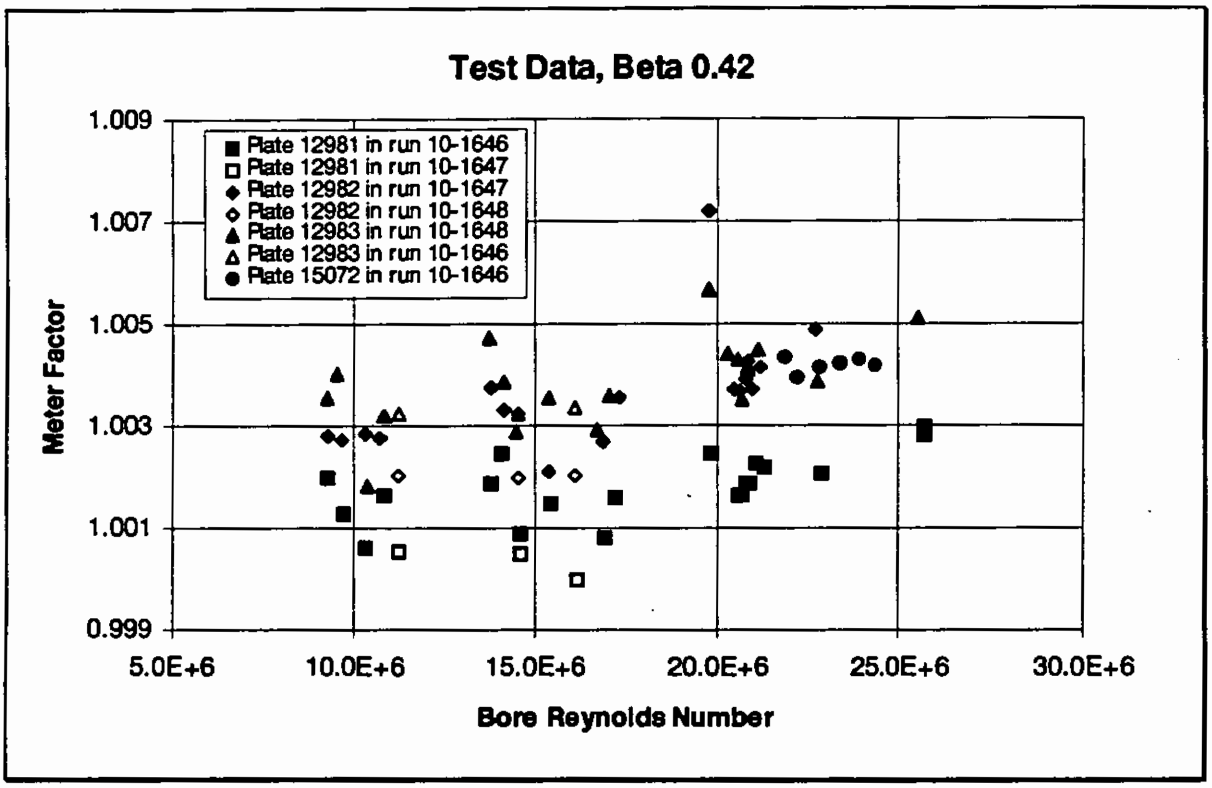

Figure 5: Beta 0.42 Calibration Points

Figure 6 is a summary of the calibration points obtained on 20 June 1995. This test was conducted specifically to measure beta ratio effect. In order to accomplish this, nozzle variation was removed by using the same nozzle configuration for the entire test. The number of orifice meter runs in parallel was varied to match the flow through the fixed nozzle bank: 3 runs with 0.32 beta ratio plates (150 mm); 2 runs with 0.42 beta ratio plates (200 mm); and, 1 run with 0.58 beta ratio plates (280 mm). This averaging procedure was justified by prior testing that has shown that a meter factor obtained from multiple flow runs operating in parallel with the same beta ratios was equivalent to the average of the meter factors for the individual runs.

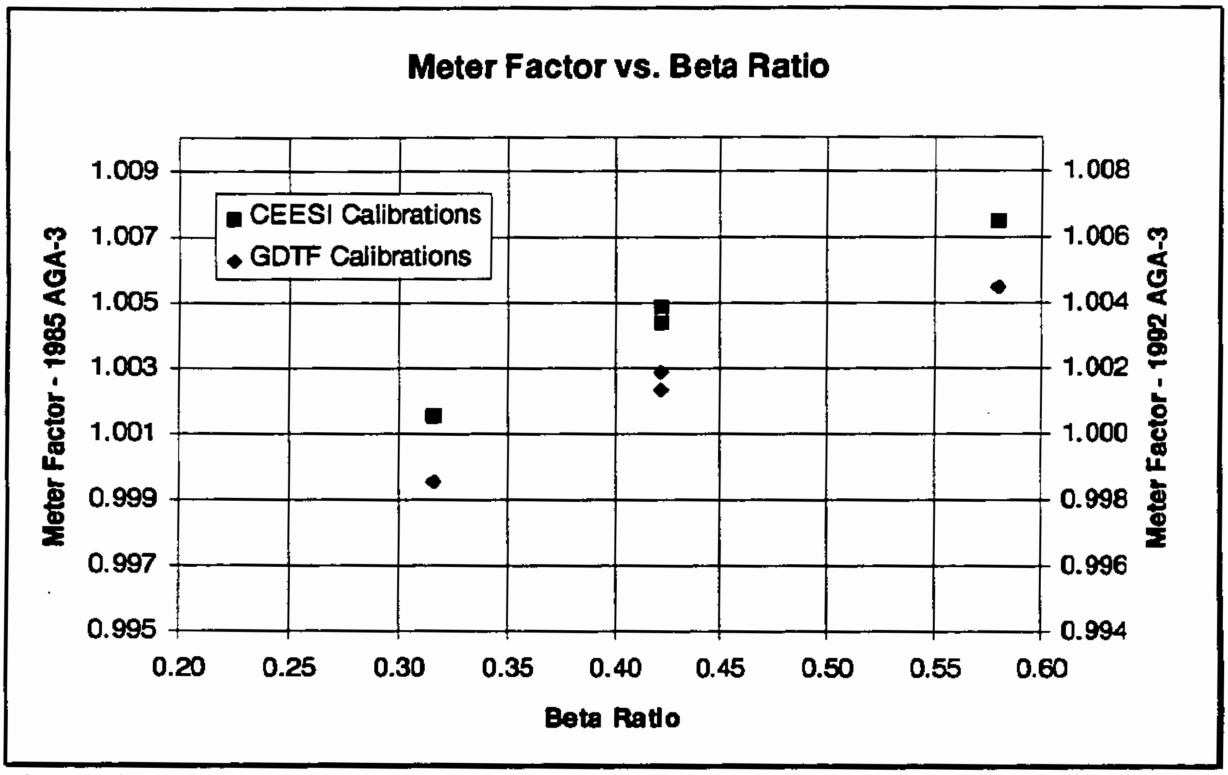

Figure 6: Results of Beta Ratio Test

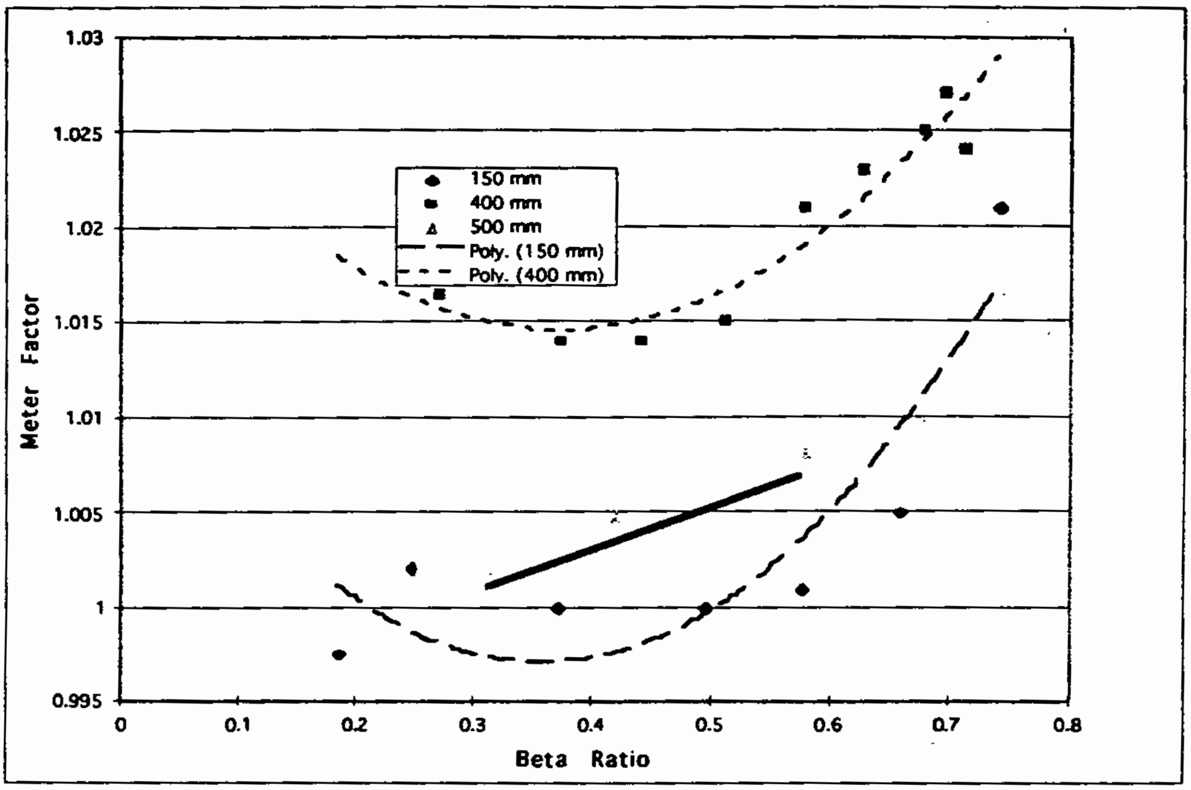

Figure 7: Kaybob Data Compared to Other Field Calibrations

Figure 7 presents data collected on all the meter runs and beta ratios tested. The meter factor is shown as a function of beta ratio. For reference, data collected by CPTC on 150 mm and 400 mm orifice meters in previous in-situ proving projects is presented along with the 500 mm data collected with the Kaybob prover. Apparent is the similarity of the general slope of the beta ratio curve for the field meter tests. However, the value of the meter factor varies with each test case.

For the Kaybob meters, the maximum factor is approximately 0.8% for a beta ratio of 0.58. The Venice 400 mm orifice meter had a factor of approximately 1.7% for the same beta ratio while the field-tested 150 mm runs had factors of approximately 0.2%. All of these different size runs were in-situ proven using similarly designed proving systems. However, the installation and operation of each orifice meter was different.

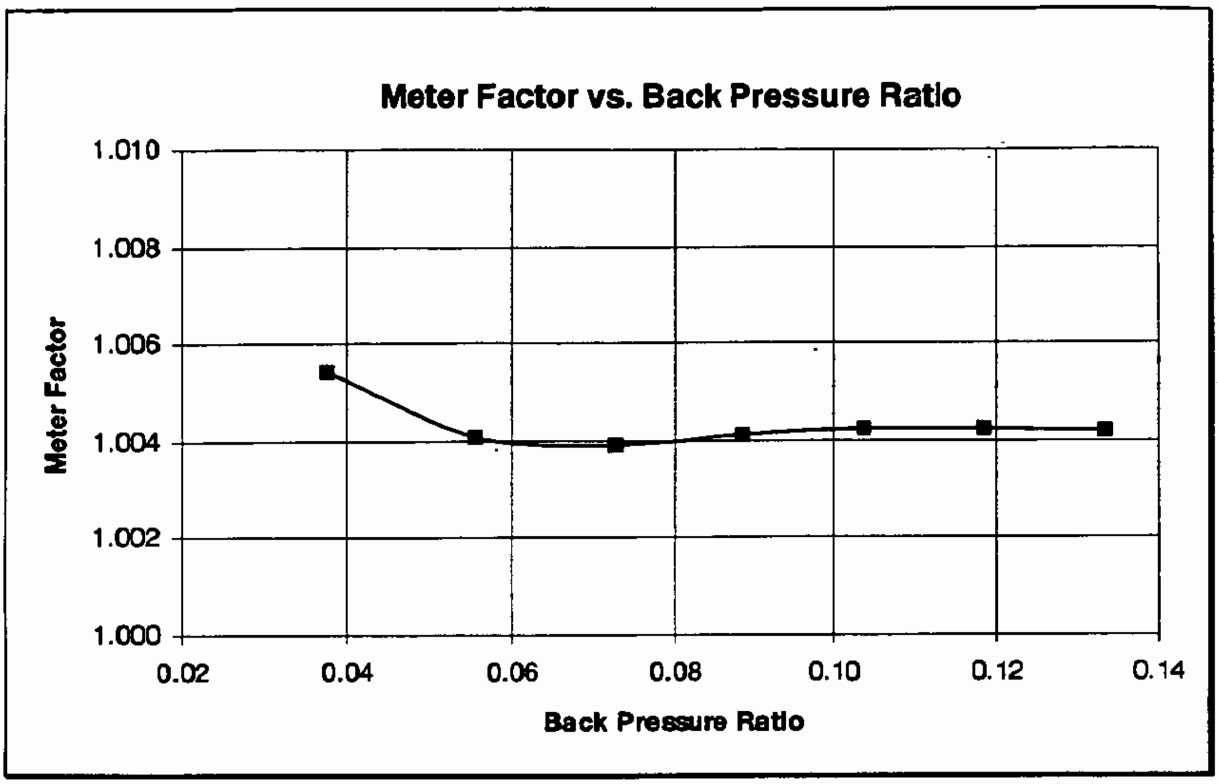

Figure 8: Results of Back Pressure Ratio Test

Figure 8 shows the data collected for the choking pressure differentials for the sonic nozzles. The test demonstrated that nozzles of the design used at the Kaybob facility may be operated with only a 6% pressure drop.

CONCLUSION

1. In-situ proving of large diameter orifice meter runs is achievable with today's technology. The application of in-situ proving is allowed for in orifice meter standards and can be applied to insure that the meters are functioning correctly.

2. Properly conducted, proving results in reduced orifice measurement uncertainty by removing unknown installation effects. The application of in-situ proving at the Kaybob facility has lowered the orifice measurement uncertainty to 0.42% from the pretest estimate of 0.76%.

3. The Kaybob meters displayed the same beta ratio effect as displayed by the recent installation effects work and previous in-situ proving projects.

4. Sonic nozzle provers of the design used may require less pressure drop than currently specified in standards. Testing has shown that a 6% pressure drop from

the nozzle plenum pressure is sufficient to obtain sonic flow at the throat of the nozzle.

FUTURE WORK

The authors can offer no definitive proof for the cause of the meter factor variation with beta ratio at the Kaybob meters, but hypothesize that it is the effect of either the upstream installation effect and flow conditioning device or the surface finish of the orifice meters. Tests are planned, which should be conducted by year end, that will either confirm or deny this hypothesis.

Additional tests using higher beta ratio plates will also be conducted to determine if the meter factor continues to increase with increasing beta ratio.

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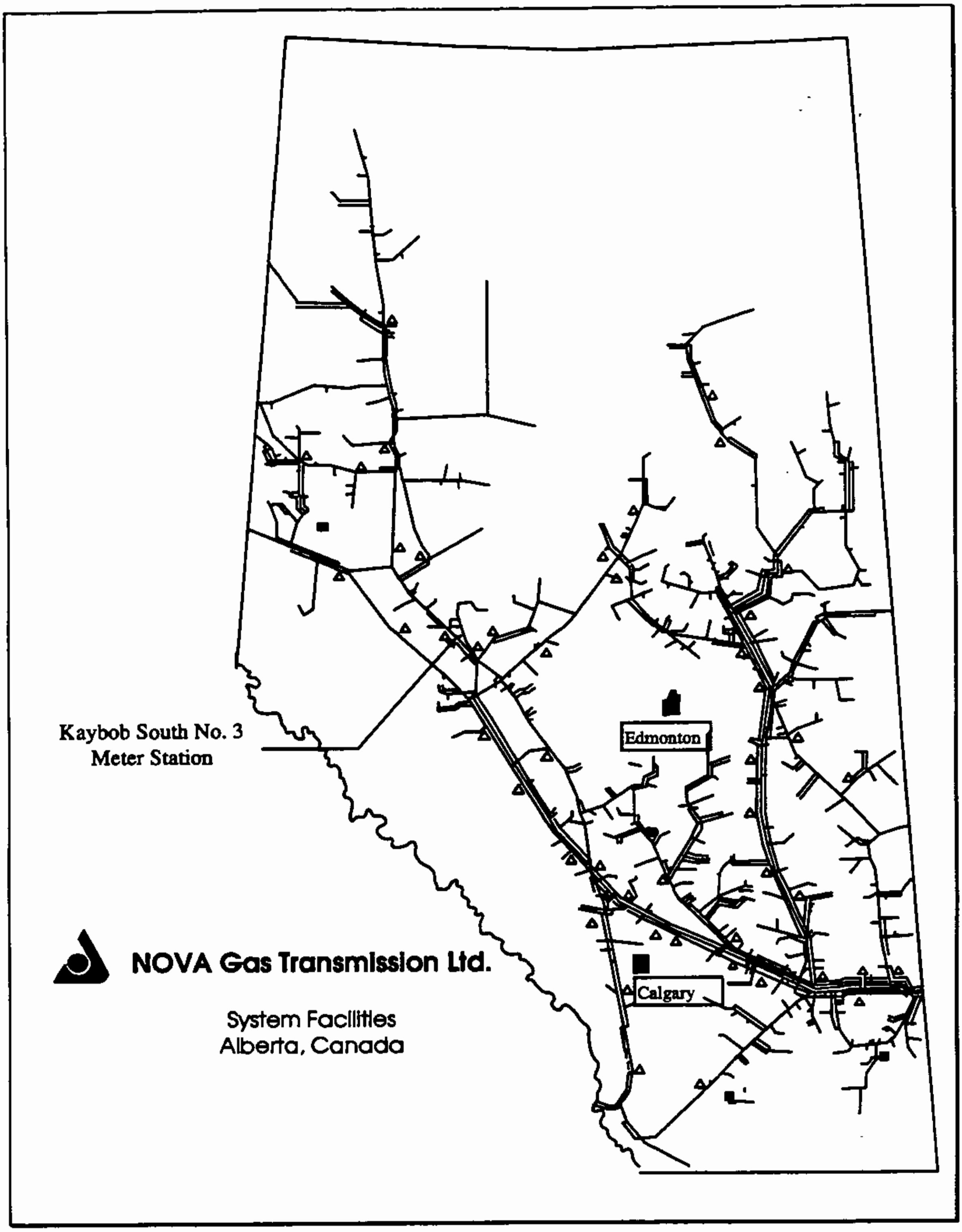

Figure 9: Location of the Kaybob South #3 Meter Prover