TeST "Watchdog" Inter-Laboratory Comparison Test

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ABSTRACT

The measurement agreement between the participating gas flow meter calibration laboratories has been evaluated as part of a voluntary quality assessment effort between the collaborating test facilities. Terasen Measurement (TM), Southwest Research Institute® (SwRI) and TransCanada Pipeline (TCPL) have initiated the "TeST" program as a quality effort between the facilities. The TeST "watchdog" artifact used for the inter-lab comparison was a tandem meter package consisting of two 8-inch diameter Instromet SMRI turbine meters, and associated piping with CPA 50E flow conditioners. The first round of an ongoing, periodic inter-lab test comparison has been completed. The test results are reported herein. The test results show close agreement between the participating laboratories, and confirm the stated measurement uncertainty estimates for the individual facilities.

INTRODUCTION

Each of the participating calibration facilities provides gas flow meter calibration services to the natural gas industry. Accurate gas meter calibrations help ensure fair transactions at custody transfer locations. Meter station operators trust that the meter calibration facilities provide accurate meter calibrations. One way that calibration laboratories can demonstrate their performance is through test comparison with other calibration labs. Furthermore, those calibration labs that have implemented International Standards Organization (ISO) 17025 quality assurance programs are required to participate in inter-lab comparisons on a regular basis.

As a first step towards enhanced process control for laboratories within North America and, locally, within Canada, Terasen Measurement (i.e., Triple Point), TransCanada Pipeline (i.e., TransCanada Calibrations), and Southwest Research Institute (i.e., Metering Research Facility) have voluntarily developed the "watchdog" package for ongoing inter-comparison testing between these organizations. This quality initiative is referred to as "TeST."

The concept of a traveling volumetric flow measurement package is not new and has been utilized for some time in Europe between various parties, such as The Netherlands Measurement Institute (NMi), Physikalisch-Technische Bundesanstalt (PTB), and Laboratoire National d'Essais (LNE).

This paper describes the participants' objectives, the current TeST artifact, and results from the first round of inter-laboratory comparison testing involving these organizations. The principal objective of the first-round inter-lab comparison was to quantify how closely the laboratories agree over an overlapping range of operating conditions.

GOALS AND OBJECTIVES

Prior to commencing this project, the participants defined their goals and objectives. The following points were considered:

1. How closely do the working measurement standards of the respective test facilities agree?
2. What is the long-term stability of these individual working standards? (Are the values used in the uncertainty statement for each facility supported by test data?)

3. Can the watchdog artifact provide additional process control value for the individual facilities, thus, giving clients more confidence in these test facilities?
4. Can the operators of the facilities that do not possess a primary measurement standard utilize an unrelated primary measurement standard to enhance the confidence in their own working standards? Note that the primary measurement traceability standards for TransCanada Calibrations (TCC) and Terasen Measurement (TM) reside at NMi in Europe, while SwRI possesses its own, mass-based primary measurement standard. So, can TCC and TM management utilize comparison test data from SwRI for the purpose of confirming reference integrity within their own measurement systems?
5. Can a client utilizing the services of any of these independent flow meter calibration facilities do so without fear of introducing a significant measurement bias due to differences in the reference measurement values of these three labs? That is, could one calibrate a low- or high-pressure flow meter at TM or SwRI and still expect agreement with a high-pressure/higher-volume meter calibration at TCC?

DESCRIPTION OF TEST FACILITIES

Table 1 (on the following page) summarizes the facilities participating in this continuing comparison.

Both Triple Point (TP) and the Metering Research Facility (MRF) are closed-loop gas flow facilities with the ability to regulate and control the process pressure and temperature. TCC is a mainline bypass flow facility, utilizing pipeline flows for the purpose of flow meter calibration. At TCC, the normal line pressure is approximately 900 psia and the normal gas temperature is approximately 75°F. Calibrations of ANSI 300 rated flow meters 20 inches in diameter or larger are also available at a line pressure of 700 psia under special arrangements.

The "watchdog" artifact was installed and calibrated in each flow facility using the standard operating procedures normally used for commercial flow meter calibrations. All three facilities have the ability to simultaneously collect calibration data for flow, pressure, and temperature from each meter in a dual meter package.

TeST ARTIFACT DESCRIPTION

The TeST artifact was comprised of two 8-inch diameter Instromet SM-RI-X-L G1000 turbine flow meters plumbed in series, as shown in Figure 1. The maximum flow rate for the artifact was 56,500 ACFH (1,600 m^3/hr).

The artifact was shipped between laboratories in two sections:

Section #1: A 5-diameter (D) long, 8-inch diameter pipe spool; a CPA 50E flow conditioner; another 5D spool; and Meter S/N 10510034

Section #2: A 5D long, 8-inch diameter pipe spool; a CPA 50E flow conditioner; another 5D spool; Meter S/N 10510035; and a 3D spool

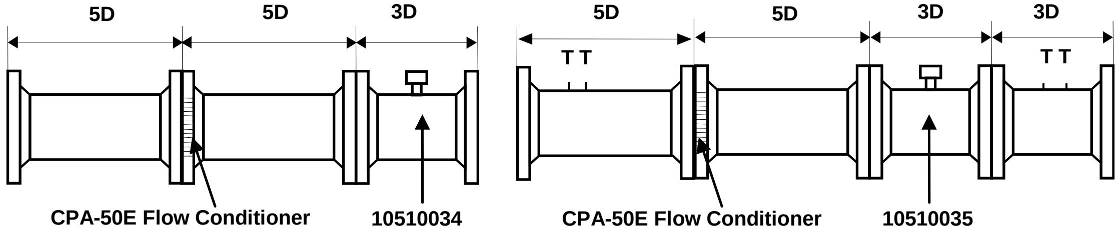

Figure 1. TeST Watchdog Artifact Layout

Table 1. Flow Lab Performance and Operational Characteristics

Operating Parameter	TM (Triple Point)	SwRI (Metering Research Facility)	TCPL (TransCanada Calibrations)
Line Pressure Range (psia)	Atmospheric to 240	165 to 1,100	850 to 1,000 (700 via special arrangement)
Operating Fluid	Carbon Dioxide or Air	Nitrogen or Natural Gas	Natural Gas
Minimum Flow Capacity (ACFH)	300	3,600 (720 extended)	1,420
Maximum Flow Capacity (ACFH)	230,000 $Reynolds_{max}$=9,200,000	83,000	1,950,000
Nominal Meter Diameter Range (inches)	2 – 12	2 – 20	4 – 36
ANSI Pipe Flange Rating(s)	150, 300, 600	150, 300, 600, & 900	300 (20" and larger); 600; 900; 1,500; & 2500
Working Flow References	Turbine Meters	Critical Flow Venturis	Turbine Meters
Volumetric Flow Rate Uncertainty (2σ values)	0.27% of Reading	0.20 - 0.25% of Reading	0.19 - 0.30% of Reading
Long-Term Reproducibility (2σ values)	0.10% of Reading	0.10% of Reading	0.10% of Reading
Primary Process Control Method	Transfer Master Turbine Meters	Primary Mass/Time Standard	Real-time, Dedicated Check Ultrasonic Meters
Secondary Process Control Method	Cross-reference Checks	Turbine Meters	Dual Master Meter Packages (Turbine Meters)

Connections for pressure measurement were provided on the meters via the process tap labeled “Pr” for each device. Connections for temperature measurement were provided via ¾” diameter thread-o-lets installed in the spool immediately downstream of each turbine meter.

Each laboratory was responsible for supplying pressure and temperature measurement devices, as in a normal commercial calibration. The piping upstream of the artifact was supplied and configured at the discretion of each calibration laboratory and was consistent with the piping customarily used for a commercial flow meter calibration.

TEST RESULTS

Flow tests performed at the MRF and TCC used high-pressure, dry natural gas as the test medium. At the Triple Point facility, carbon dioxide was used as the test gas. The artifact was tested over a comparable range of Reynolds numbers at each of the three facilities. Test pressure was varied over the range of about 140 to 1,000 psia.

The plots that follow show the percent error in meter output, based on the turbine meter manufacturer’s stated meter factor, as compared to each facility’s flow reference. Data were plotted as a function of the pipe Reynolds number.

TERASEN MEASUREMENT (Triple Point)

The test results for Triple Point are shown in Figures 2a and 2b. The artifact was tested at line pressures of 140 psia and 240 psia. These test pressures are in the range of typical test pressures for the Triple Point facility. The plots show three repeat samples for each test point. Each sample was acquired over a 100-second period.

Figure 2a shows the results for turbine meter no. 10510034, while Figure 2b shows the results for turbine meter no. 10510035. The results from each meter indicate close agreement between the tests conducted at two different pressures.

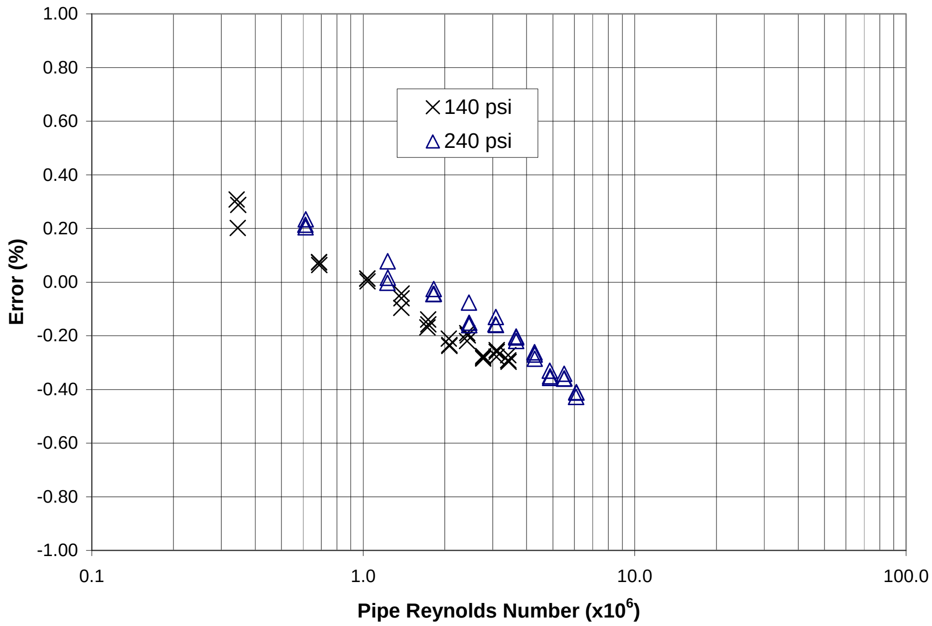

Figure 2a. TM Triple Point Results for Meter No. 10510034

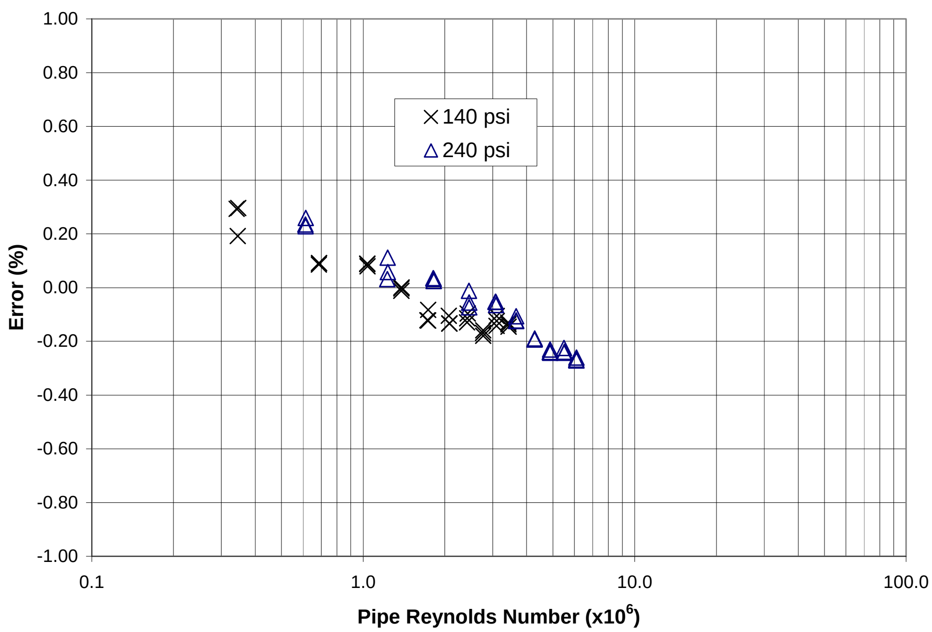

Figure 2b. TM Triple Point Results for Meter No. 10510035

SOUTHWEST RESEARCH INSTITUTE (Metering Research Facility)

The test results for the Metering Research Facility are shown in Figures 3a and 3b. The artifact was tested at line pressures of 300 psia and 900 psia. These test pressures were chosen to produce the best overlap in Reynolds number with the other test facilities. The data plots show the six repeat samples for each test point. Each sample was acquired over a 90-second period.

Figure 3a shows the results for turbine meter no. 10510034, while Figure 3b shows the results for turbine meter no. 10510035. The data set for each meter indicates results from the two test pressures are in close agreement.

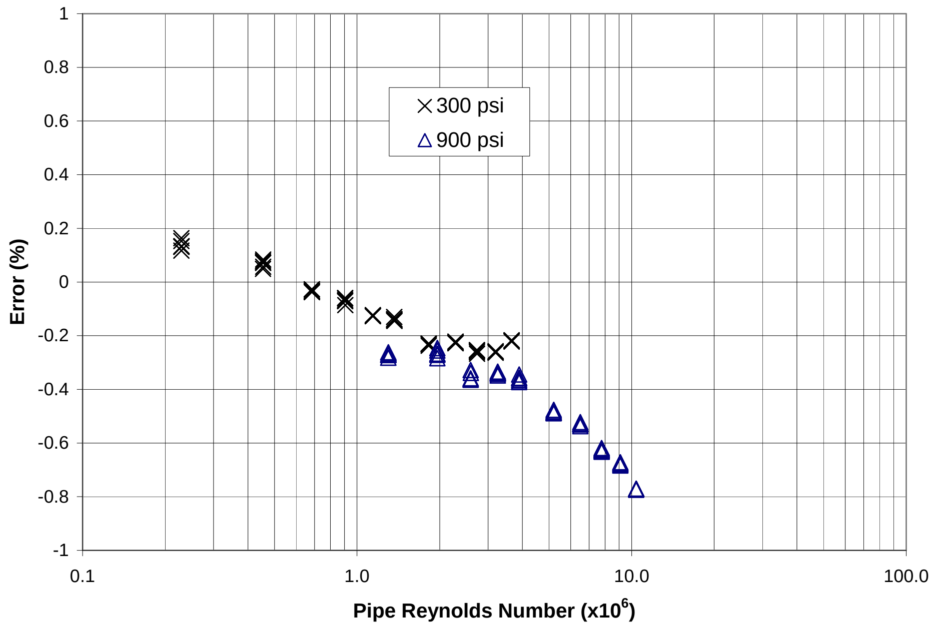

Figure 3a. SwRI Metering Research Facility Results for Meter No. 10510034

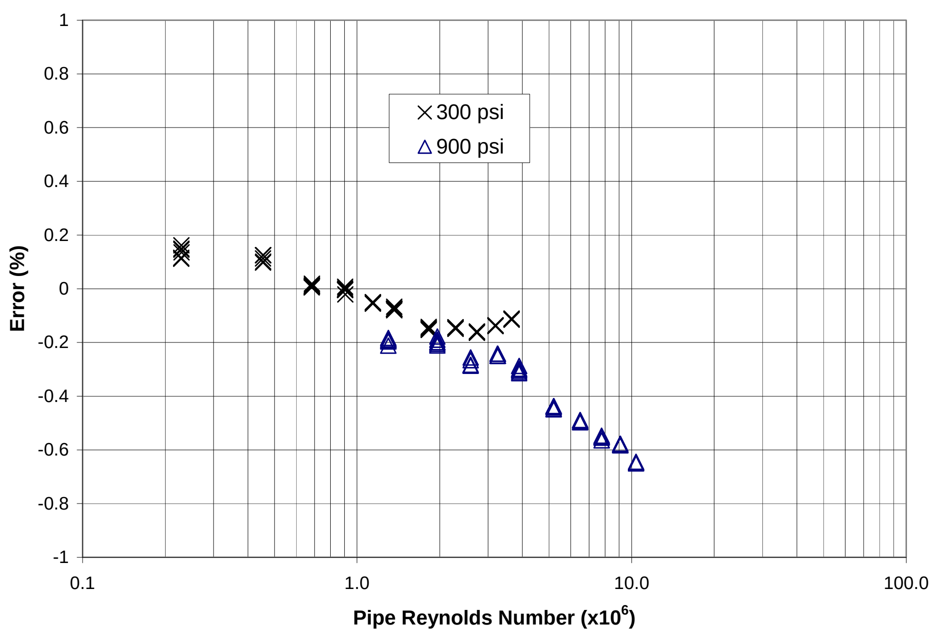

Figure 3b. SwRI Metering Research Facility Results for Meter No. 10510035

TRANSCANADA CALIBRATIONS

The results from TransCanada Calibrations are shown in Figures 4a and 4b. The artifact was tested at a line pressure of 880 psia. The plots show three repeat samples for each test point. Each sample was taken over a 300-second period.

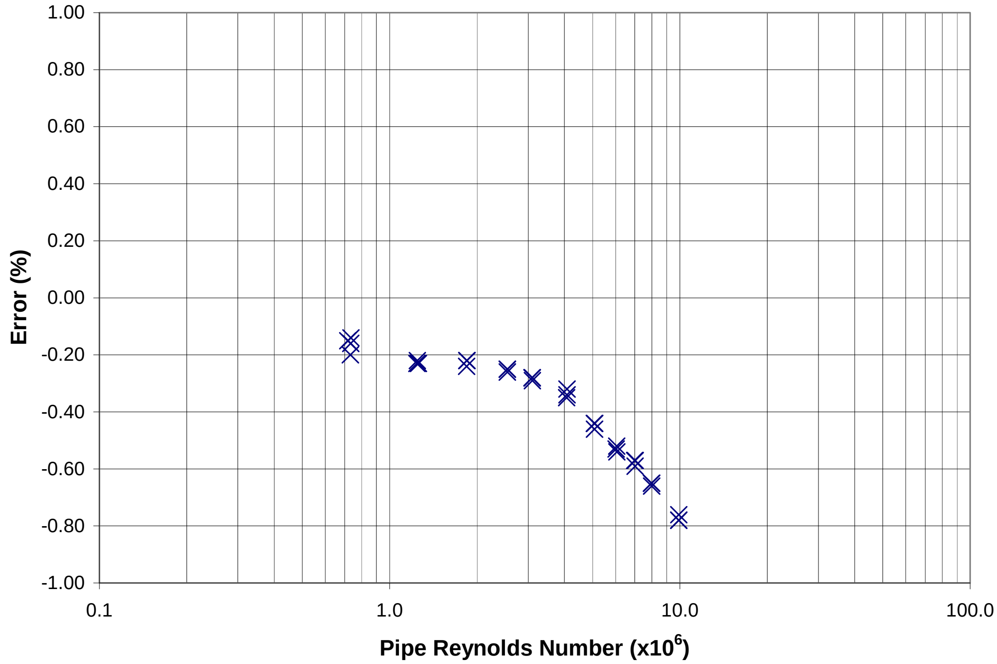

Figure 4a. TCPL TransCanada Calibrations Results for Meter No. 10510034

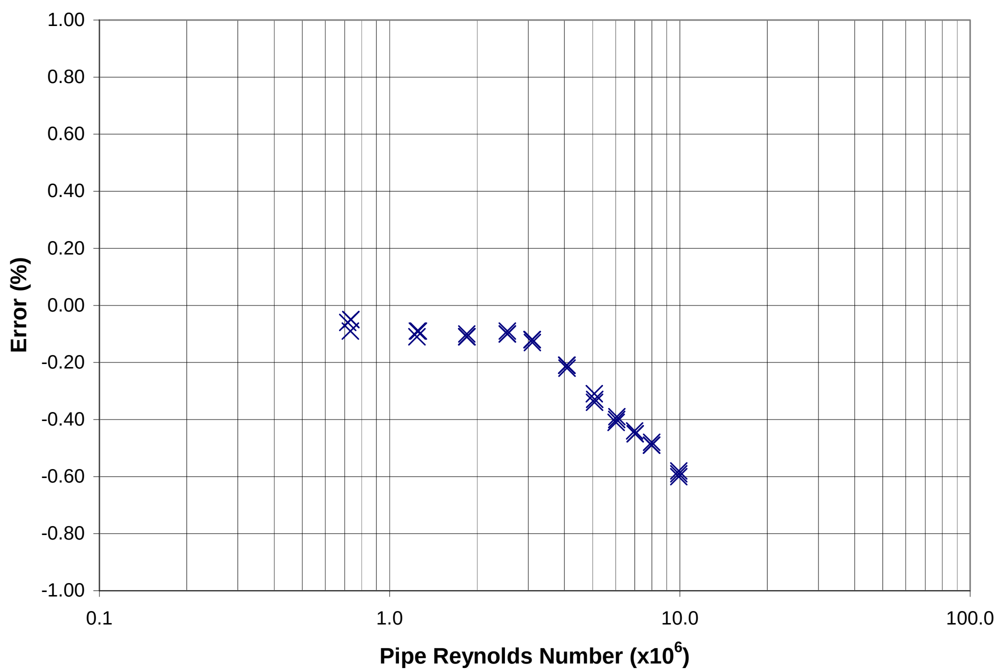

Figure 4b. TCPL TransCanada Calibrations Results for Meter No. 10510035

COMPARISON OF DATA SETS

Figure 5a and Figure 5b show the comparison of the data sets from each laboratory. For clarity, the average error value is plotted versus Reynolds number at a given pressure for each laboratory.

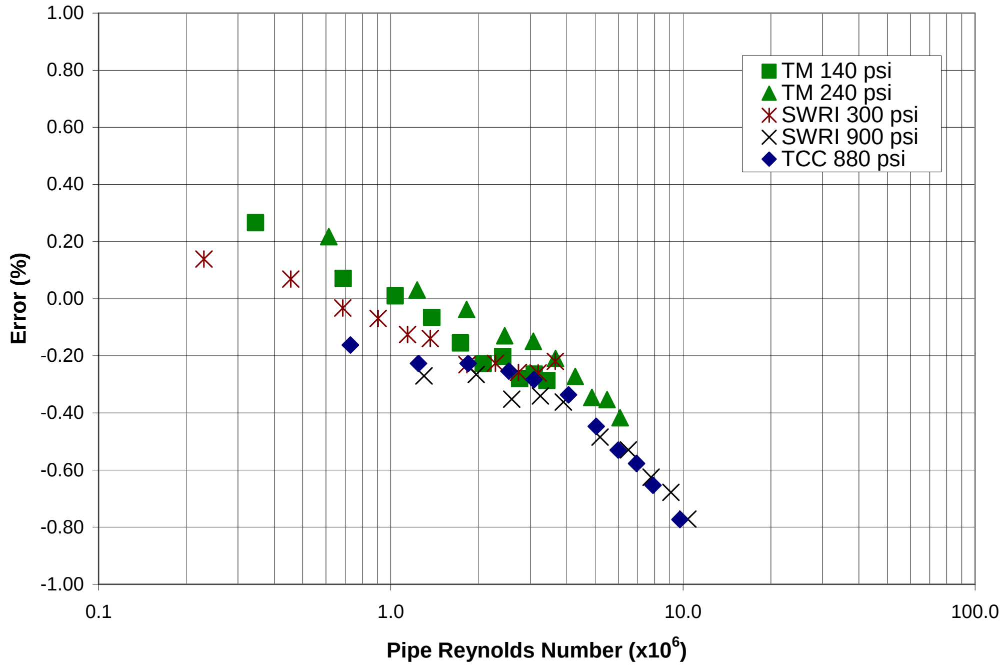

Figure 5a. Comparison of Test Results for Meter No. 10510034

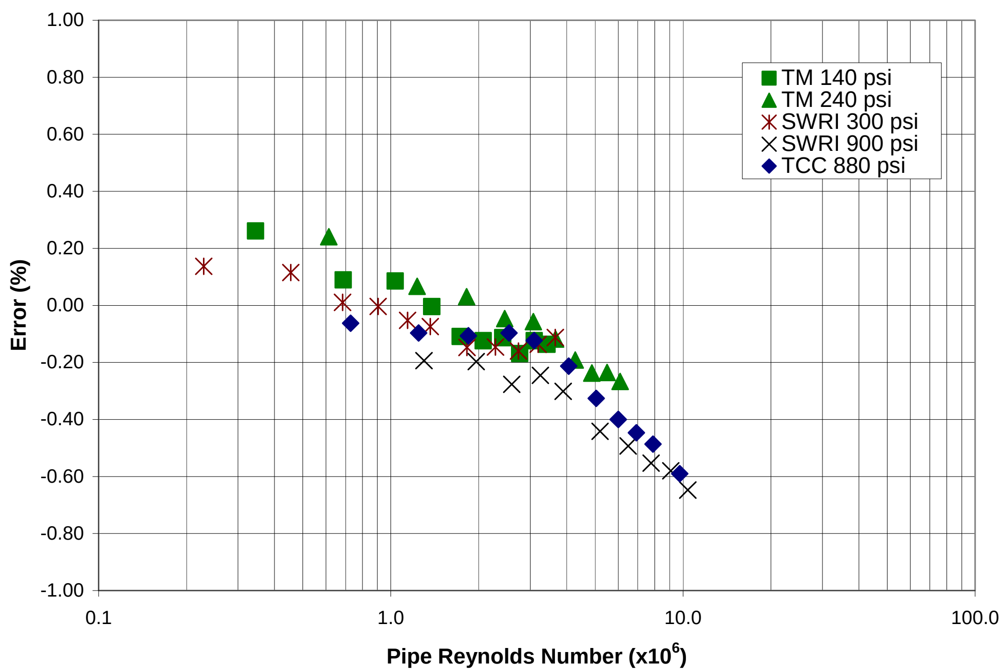

Figure 5b. Comparison of Test Results for Meter No. 10510035

The agreement of the individual data sets is very good for meter no. 10510034, especially at Reynolds numbers greater than one million. The data set for meter no. 10510035 shows a little more spread over the Reynolds number range of one million to four million when evaluated at the individual pressure, but on average, is still very good. Further evaluation in future comparisons may help determine if it is a function of this specific turbine meter or an installation effect within one or more of the laboratories. It may be helpful to reverse the order of the turbine meters in the future to provide further evaluation.

ANALYSIS OF THE TEST ARTIFACT

Figure 6 shows the difference between the indicated meter deviations for the two TeST meter as a function of Reynolds number. The difference in the meter deviations has been calculated for each facility's data set over the entire range of test Reynolds numbers. This plot shows the correlation between the two turbine meters and can be used as an indicator of the stability of the metering package.

From the plot, it is apparent that the correlation between the meters for each facility data set over the full range of Reynolds numbers tested was within a 0.1% of each other and often within 0.07%, which is a clear indicator of the stability of the package.

The correlation calculation showed a slightly larger spread in results between the laboratories for Reynolds numbers between five million and seven million. However, the differences remained less than 0.1% and the order in which tests were conducted (first at TM, then at TCC and finally at SwRI) may have influenced this behavior. A "close-out" test of the artifact at TM, and additional testing in the future, will help determine if this was a characteristic of the metering artifact or indicated a facility effect in one or more of the laboratories. In the future, the TeST group may consider reversing the order of the two turbine meters to help explain the performance of the metering package.

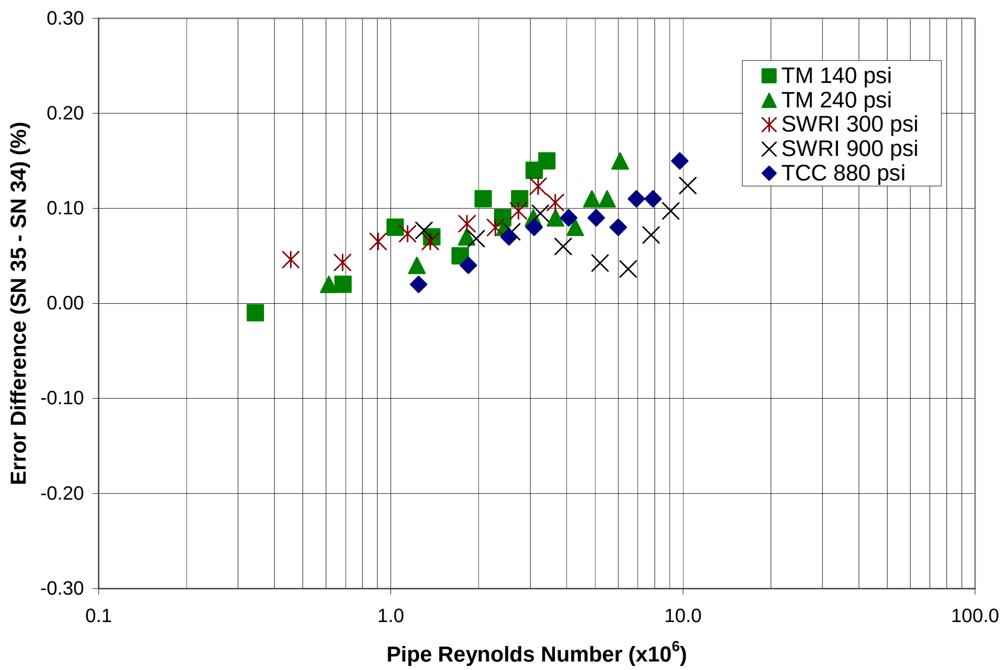

Figure 6. Difference in Meter Error Comparison

YOUDEN ANALYSIS OF THE DATA

Figure 7 presents the results in the form of a Youden plot where the error for test meter no. 10510034 is plotted against the error for meter no. 10510035. For the purpose of equal comparison, data sets in the overlapping Reynolds number region were used from each laboratory. The overlapping Reynolds number region was between 0.6 million and 6 million. For this region, a mean value for each flow meter was determined. To provide equal weighting for all laboratories testing (since some laboratories tested at multiple pressures over this range of Reynolds number), an average number for each lab was first determined for eight data points within the indicated Reynolds number range. A mean value was then determined for all three laboratories and used in the Youden analysis. The eight data points for each laboratory, and each laboratory's mean value, were plotted in Figure 7.

Figure 7 shows that the mean value for turbine meter no. 10510034 was -0.26% and for turbine meter no. 10510035 was -0.16%. The mean values for each laboratory, the differences from the mean (per meter) and the average differences are shown in the table.

Clearly, the agreement between the laboratories, when evaluated on average, is very good and within ±0.08%. This result is consistent with the measurement uncertainty claims stated in Table 1 for the respective labs.

For the range of Reynolds numbers for these tests, the correlation between the two turbine meters is very good. All test data shown in Figure 7 fall very close (within 0.1%) to the line of slope equal to one, indicating good repeatability of the test artifact. The spread of the individual data points along the unity slope line is attributed to the meter behavior shown in Figures 5a and 5b.

Shifting of the average value for any laboratory to the upper-right or lower-left quadrants of Figure 7 typically indicate a systematic effect (i.e., a consistent difference in the reference value) within the individual laboratory. As Figure 7 shows, the average value for each laboratory falls very closely on the slope line equal to one, identifying the differences are a function of the reference value for each lab.

Shifts to the upper-left or lower-right quadrants of Figure 7 are likely due to installation effects. The data plotted on Figure 7 suggest little to no significant installation effect was present during the tests.

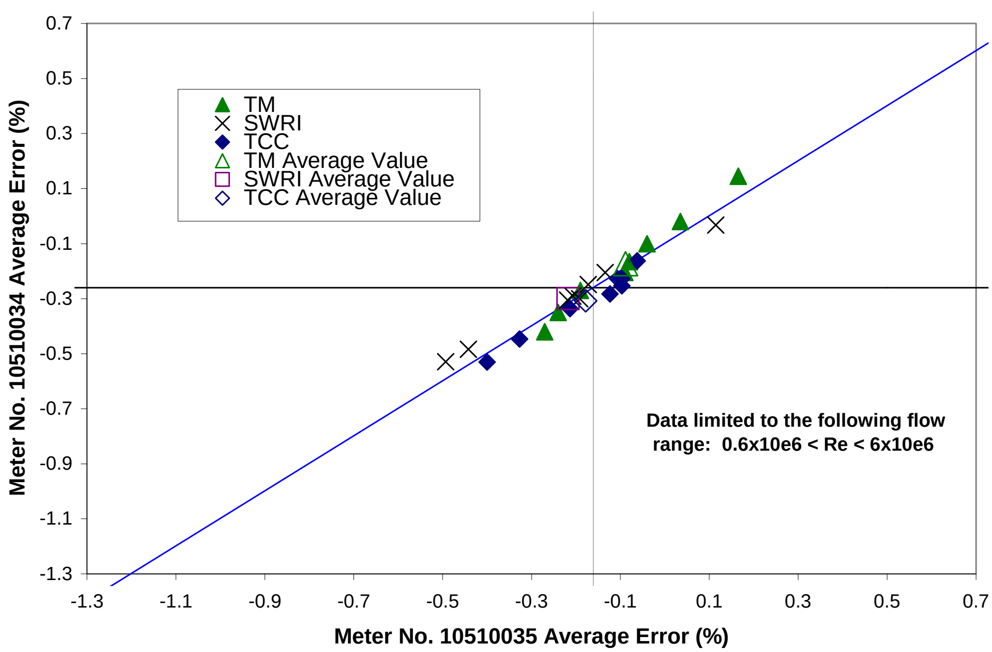

Figure 7. Youden Plot Comparison of Test Results

Table 2. Comparison of Test Results

Laboratory	Meter No. 10510034		Meter No. 10510035		Average Difference
	Mean Value	Difference From Mean	Mean Value	Difference From Mean	
TM	-0.17%	+0.09%	-0.09%	+0.07%	+0.08%
SwRI	-0.30%	-0.04%	-0.22%	-0.06%	-0.05%
TCC	-0.31%	-0.05%	-0.18%	-0.02%	-0.04%

CONCLUSIONS

The TeST "watchdog" artifact has provided very valuable information, which will continue to assist the participating laboratories and the industry in evaluating the equivalence of their reference measurement values. Results show an agreement between the labs within ±0.08% of reading over the range of conditions tested. This result is very similar to historical values of past inter-lab comparisons. Future testing of the artifact will help clarify findings from this first round of testing.

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