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CORIOLIS FLOWMETERS FOR GAS MEASUREMENT

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GAS DENSITY MEASUREMENT

Since a Coriolis meter vibrates at a resonant frequency and the meter frequency changes when the fluid density changes, density can be measured as the meter frequency changes. Initial testing has indicated that with the current calibration method density accuracy is better than ±2 kg/m^3 over the entire tested flow range for each meter size. Micro Motion's current density calibration consists of correlating the density of ambient air to a tube frequency, and correlating the density of ambient water to a second tube frequency. The line resulting from these two points defines the relationship between frequency and density for all densities.

Micro Motion recently worked very closely with a customer to solve a difficult measurement problem in a process gas application. Density accuracy of ±0.5 kg/m^3 (0.03 lbm/ft^3, Micro Motion's current liquid density specification) on a gas of approximately 32 kg/m^3 (2.0 lbm/ft^3) was required. By calibrating the meter on densities very close to the actual operating condition and by restricting the fluid velocity through the sensor, the meter performed up to the customer's expectations. This effort indicated that Micro Motion has the capability to accurately measure gas density. Future work will be done in the area of calibration to improve this measurement.

CONCLUSIONS

Micro Motion Coriolis mass flowmeters are an accurate alternative for measuring the mass flow rate of gases. All tested accuracies are better than ±2.0% of rate, with much of the data better than ±0.5%. The meters are largely insensitive to gas temperature and pressure and provide a linear signal over a very wide flow range. Normal Micro Motion sizing guidelines should be followed when using a meter in its lower range; turndown considerations will affect the accuracy due to zero stability, although the Elite meters provide good zero stability and will therefore be useable at low flow rates. High velocity flow applications are to some extent self-limiting due to pressure drop considerations. In those applications where pressure drop may not be a problem, however, the gas velocity in the sensing element's tubes should be limited in accordance with Micro Motion recommendations.

The measurement of gas density is also possible. Fundamentally the meter can accurately measure density. Calibration improvements are key to making a better gas density measurement. Work is continuing to fully define the capability of Micro Motion meters on gas applications. The data presented herein is based on one meter of each size. Future tests will be conducted to test multiple meters in all sizes and employ a statistical analysis to develop performance capabilities and specifications.

REFERENCES

1. Presented by Peter van der Kam, Gasunie Research, Groningen, Netherlands, "Intercomparison Exercise of High Pressure Test Facilities within GERG", 3rd International Symposium on Fluid Flow Measurement, San Antonio, Texas, March 20-22, 1995.

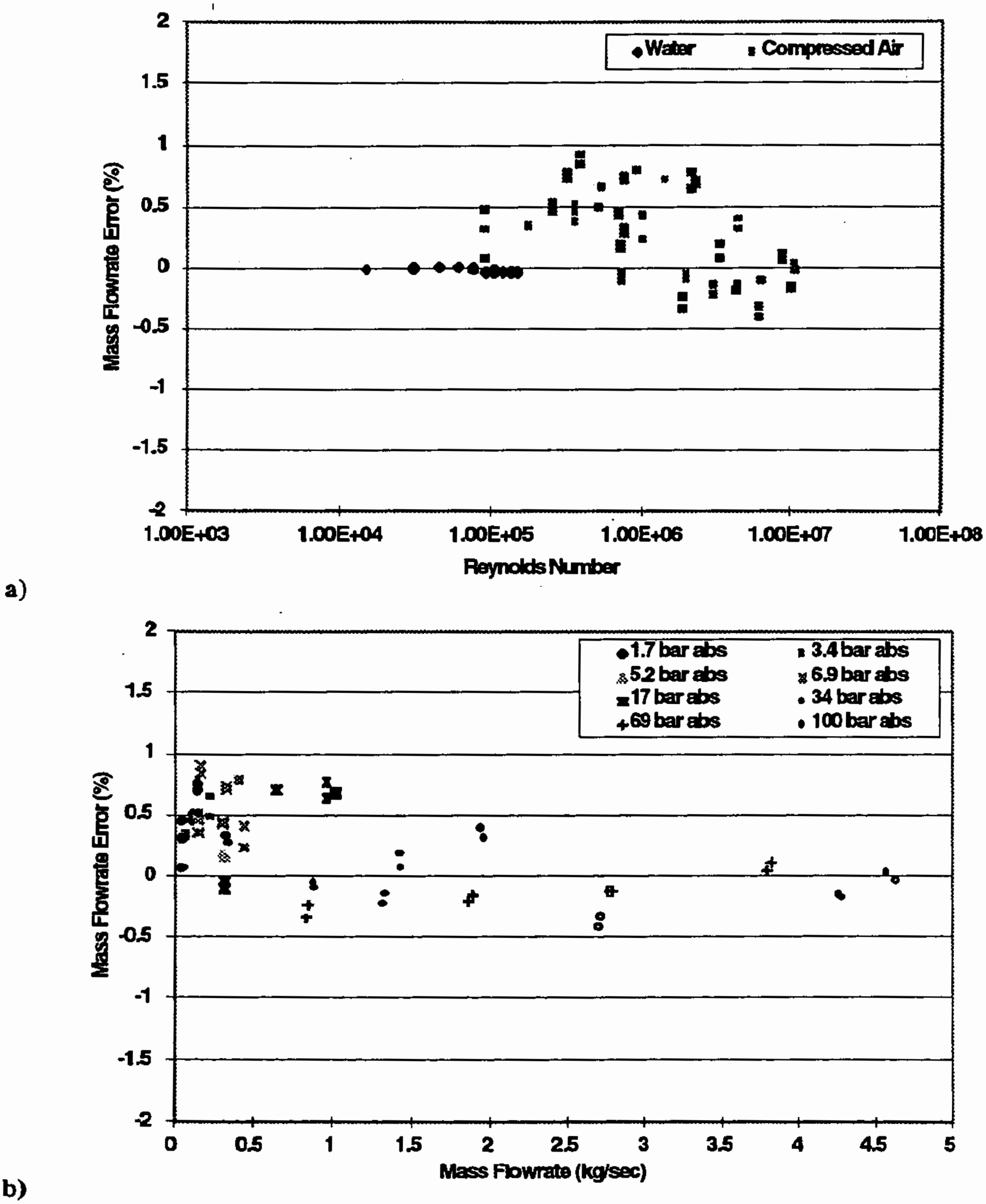

Figure 1- Micro Motion CMF100 Performance:
a) Mass Flowrate Error (%) vs. Re for water and air,
b) Mass Flowrate Error (%) vs. Mass Flowrate (kg/sec) for air

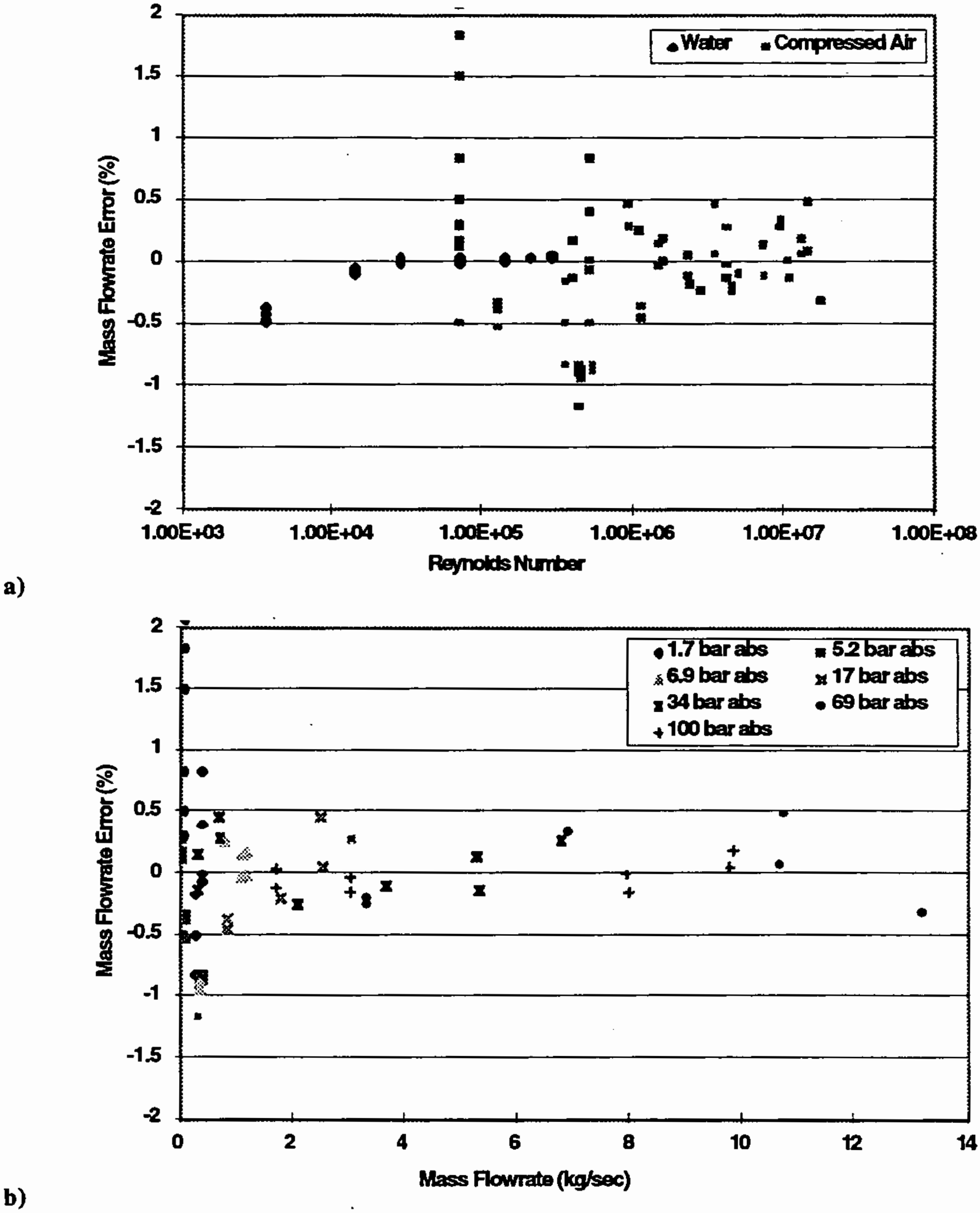

Figure 2- Micro Motion CMF200 Performance:
a) Mass Flowrate Error (%) vs. Re for water and air,
b) Mass Flowrate Error (%) vs. Mass Flowrate (kg/sec) for air

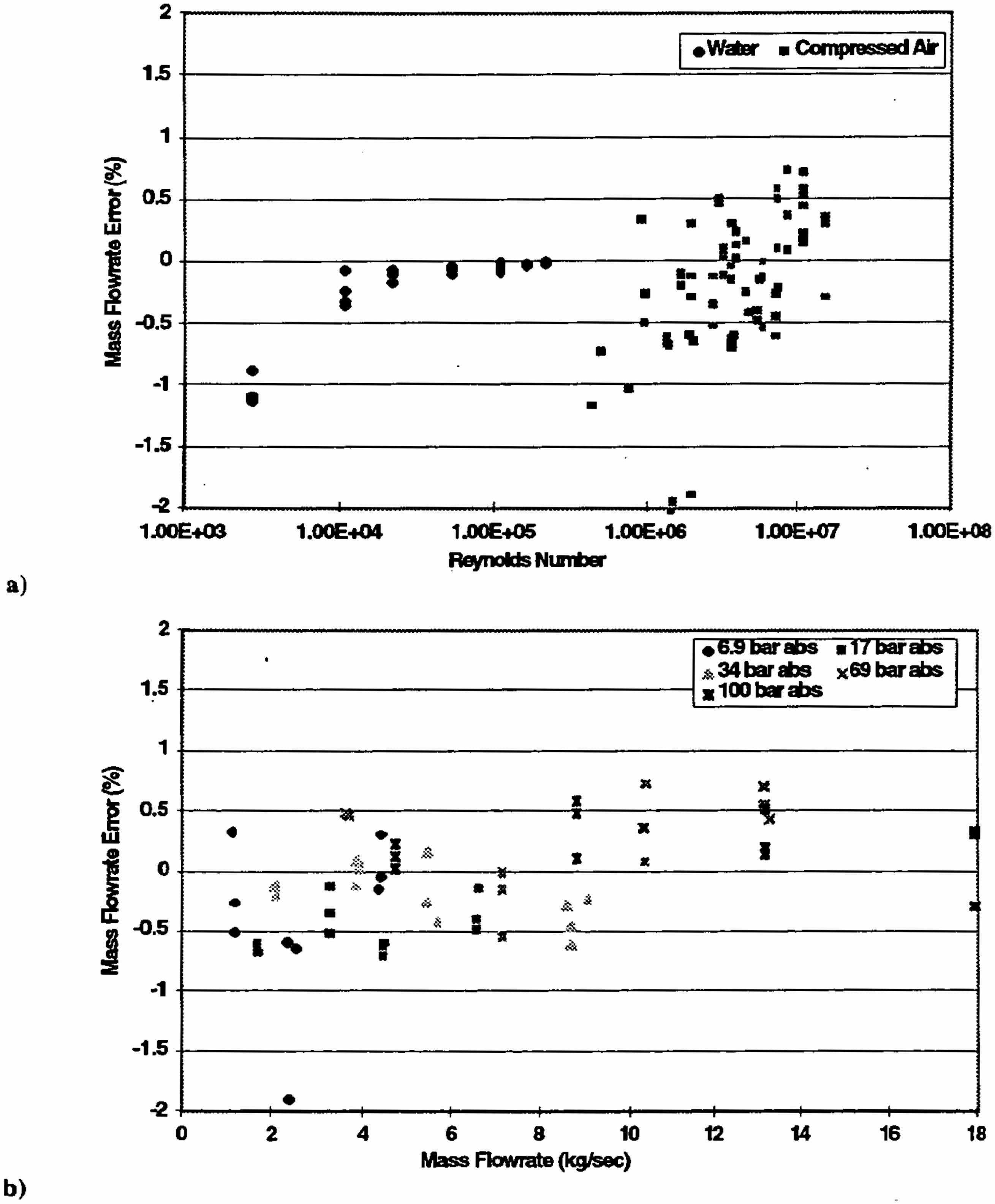

Figure 3- Micro Motion CMF300 Performance:
a) Mass Flowrate Error (%) vs. Re for water and air,
b) Mass Flowrate Error (%) vs. Mass Flowrate (kg/sec) for air

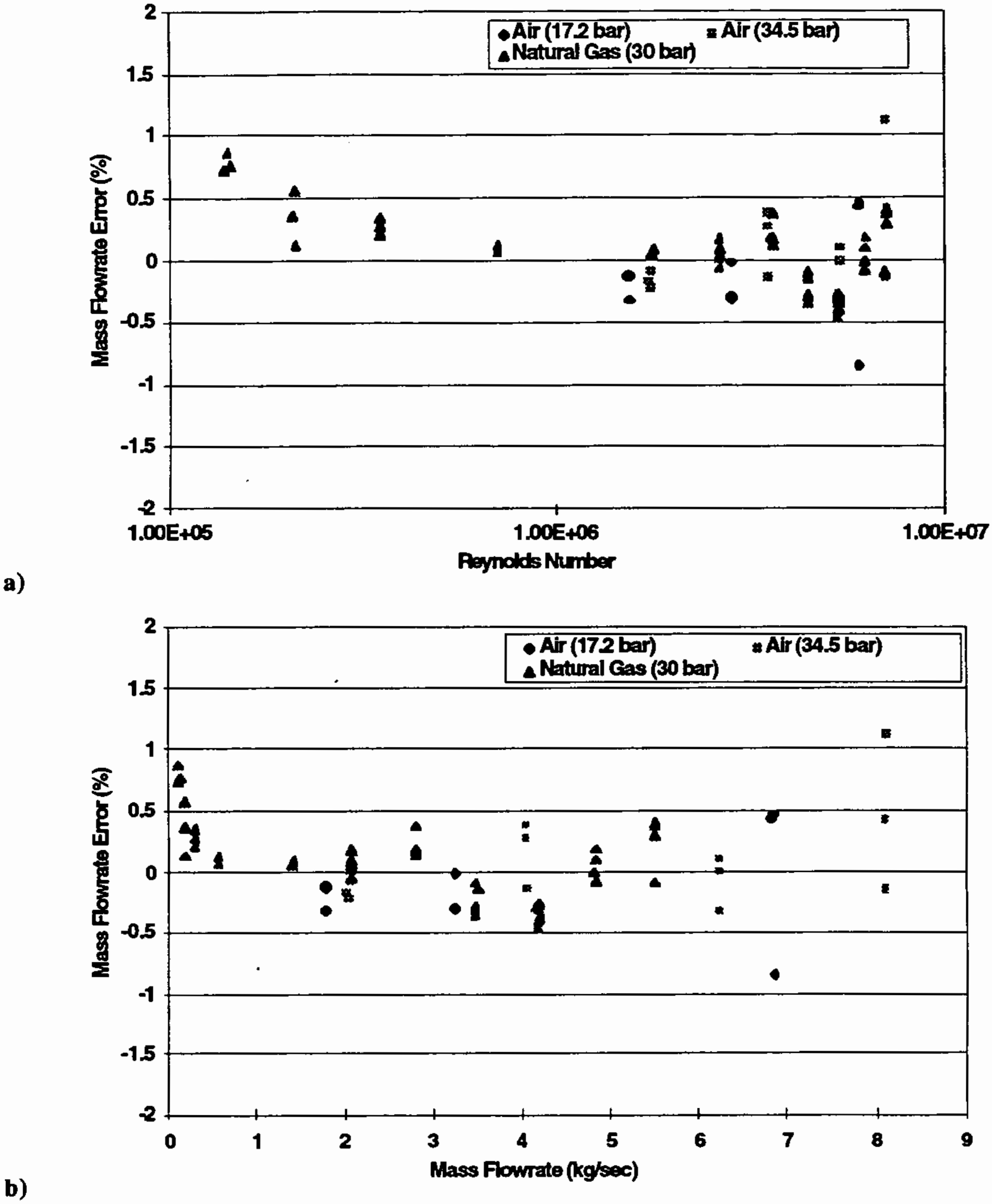

Figure 4- Micro Motion CMF300 Performance:
a) Mass Flowrate Error (%) vs. Re for air and natural gas,
b) Mass Flowrate Error (%) vs. Mass Flowrate (kg/sec) for air and natural gas

Coriolis Flowmeters for Gas Measurement

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ABSTRACT

This paper demonstrates Coriolis mass flowmeters (CMF) can provide a solution for measuring the mass flowrate of gases directly, i.e. no knowledge of the gas properties is required. The test results for compressed air and natural gas presented here were obtained using a standard factory water calibration. This demonstrates properly designed CMF are linear devices and can provide accurate results independent of gas composition over wide pressure and mass flowrate ranges.

INTRODUCTION

Coriolis flowmetering has become increasingly popular over the past 10 years, especially for liquid applications. The primary advantage lies in the fact that mass flow rate is measured directly; small temperature and pressure compensations are required to adjust for changing stainless steel properties of the sensor itself, but these corrections are very small and independent of fluid properties. A direct mass flow rate measurement of gas is especially appealing because of the issues surrounding gas compressibility. A Coriolis mass flowmeter is a good measurement alternative because, as with liquids, it measures mass flow rate directly and addresses the complexities of density changes intrinsically.

A Coriolis meter requires two components: an in-line sensing element and a transmitter which interprets the signals from the sensor and converts the signals into useable outputs, usually pulse, analog (4-20 mA), and digital outputs. The sensing element usually consists of a manifold which splits the flow into two parallel paths. Two parallel tubes are vibrated at a resonant frequency of the system, similar to a tuning fork. As the flow passes through the tubes the fluid momentum coupled with the oscillatory motion created by the vibration induces a Coriolis force along the length of the tubes. This force translates into a phase shift (or Δt) along the length of the tube. The Δt is directly proportional to mass flow rate. Two electromagnetic sensors ("pickoffs") are located on opposite legs of the flow tubes. The vibration of the tubes generates sinusoidal signals on the pickoffs, which are shifted in phase due to the Coriolis force. The Δt between the two sinusoidal signals is then measured by the transmitter and mass flow rate is calculated.

When the stainless steel flow tubes change temperature, the material properties change slightly. At elevated temperature Young's modulus decreases which decreases the stiffness of the tube. This stiffness change affects the mass flow rate signal linearly by about 5% per 100 °C for a 316SS sensor. An RTD is mounted to the tube so that a correction can be made for the changing steel properties due to the temperature change.

To a much smaller degree, pressure influences the mass flow measurement. At elevated pressures the flow tube stiffens slightly due to the radial stress imparted by the fluid pressure. Typical values range from essentially unmeasurable for small sensors to approximately 0.08% per 6.9 bar (100 psi) for larger sensors. In lower pressure applications pressure compensation is not required since the effect is small. In high pressure applications, if the pressure is stable, the calibration constant can be biased appropriately to adjust for the influence of pressure and no compensation is required.

Due to the high quality tubing and tightly controlled manufacturing processes, the temperature and pressure constants are very consistent from one sensor to the next. Adjustments to the mass flow signal are therefore easy and repeatable from sensor to sensor.

Prior to operating the meter in any application, the transmitter must be zeroed. Zero flow must be established at conditions as close to the meter operating conditions as possible. The zero algorithm of the meter is activated by simply pushing a button on the transmitter. Zeroing relates the internal meter signals that arise due to residual installation effects to an actual zero flow condition.

In the following sections, test results are presented for Coriolis mass flowmeters (CMF) measuring compressed air and natural gas. Mass flowrate accuracy is determined as a function of gas pressure and mass flowrate using a factory water calibration. Results indicate properly designed CMF can provide accuracies up to ±0.5% over a wide range of pressures and mass flowrates.

COMPRESSED AIR TEST RESULTS

In 1992, gas measurement testing on Micro Motion's new Elite (CMF series) Coriolis was begun at the Colorado Engineering and Experimental Station, Inc. (CEESI) in Nunn, Colorado, USA. Based on the performance of the Elite meters on liquids, ±0.10% ± zero stability, it was anticipated that the new meters would also be capable of accurately measuring gas over a very wide mass flow range. The two primary advantages of the Elite meters over previous models (i.e. model D meters) are the superior zero stability making the meters accurate at low mass flow rates, and improved noise immunity which improves the signal stability (i.e. repeatability) during noisy, high velocity flows.

The results of testing performed at CEESI on the CMF100, CMF200, and CMF300 meters (25, 50, and 75 mm, respectively) are shown in Figures 1, 2 and 3. The figures contain post-processed data which includes the known pressure effect for each sensor size. The pressure effect is due to the slight stiffening of the sensing element tubes and was characterized on high pressure water.

Figures 1a), 2a), and 3a) show the mass flowrate error versus Reynolds number (Re) for the water calibration and compressed air test results. These results are shown solely to demonstrate that the water calibration for a properly designed CMF can be used for gas measurements. (Note: $Re = \rho VD/\mu$, where ρ= fluid density, V= flow tube fluid velocity, D= flow tube diameter, and μ= fluid viscosity.)

To understand the gas measurement performance of a CMF, plots of mass flowrate error versus mass flowrate need to be examined. Figures 1b), 2b), and 3b) contain this data for the compressed air test results as a function of air pressure (from 1.7 to 100.0 bar). The turndowns for the air data in these figures are 100:1 (CMF100), 280:1 (CMF200), and 50:1 (CMF300), respectively. Figure 2b) clearly shows the zero effect present in the CMF200 which is typical of a CMF with a large turndown.

As with many instruments, there is a small uncertainty associated with the zero of a Coriolis meter. As the mass flow rate decreases, the zero becomes a larger portion of the error as a percentage of rate. The performance of Coriolis meters at low flow is especially important for low density gases at low pressure (less than 6.9 bar) or low molecular weight (e.g. hydrogen gas). Velocity and pressure drop considerations in low gas density applications force the size of the sensing element to increase. This, however, forces the mass flow rate into the lower range of the selected sensor (i.e. high turndown) where the mass flow rate signal is small. The zero uncertainty, or zero stability, of the meter becomes critical in these applications if acceptable accuracy is to be maintained.

Three important points should be noted regarding the results from all three meter sizes:

1) **The flow calibration constant used for all testing was established on water at Micro Motion and was never changed.** To better than 2% the factory calibration constant is accurate over a very wide density range - 1000 kg/m^3 (water) to 2 kg/m^3 (air at 1.7 bar). In general, the errors are less than 0.5%. The calibrations should also be viewed in the context of the ±0.5% lab accuracy at CEESI.

2) **Typical accuracies for all three meter sizes are better than ±0.5%, with all data better than ±2% over a wide mass flowrate and pressure range.**

3) **The meters were zeroed only prior to the testing, indicating that the meter zero was stable for each sensor over the entire pressure range tested.** This is especially important for low flow rates where the zero plays a large role in the expected accuracy.

As indicated by the unchanging flow calibration factor over the entire pressure range, the mass flow measurement is independent of density. The air results from CEESI and the natural gas data presented below suggest that the mass flow rate measurement is independent of fluid properties. As previously discussed, temperature and pressure measurements are made to correct for changing properties of the sensing element itself, but the corrections afforded by these measurements are small and independent of the fluid properties.

NATURAL GAS TEST RESULTS

To examine the effect of gas composition on meter performance a CMF300 (75 mm meter) was tested on compressed air at CEESI and then on natural gas at the Ruhrgas/PIGSAR facility in Dorsten, Germany. The PIGSAR volumetric measurement uncertainty is 0.25% and the density measurement uncertainty is 0.15%. Thus the worst case mass flowrate measurement uncertainty of the PIGSAR facility is 0.40%. The CEESI facility mass flowrate uncertainty is stated as 0.50%. The air and natural gas data has also been pressure compensated as discussed earlier.

Initial comparison of the test results from the two facilities revealed an average mass weighted bias of 0.48% in the PIGSAR natural gas data while the CEESI air data had a negligible bias. The PIGSAR natural gas data calibration error shown in Figure 4 has been adjusted by -0.48% for comparison purposes. Future efforts will be directed towards understanding the apparent lab bias (see Reference [1] for example) exhibited in the test results.

Figure 4a illustrates the mass flowrate error versus Re for the air (17.2 and 34.5 bar) and natural gas (30 bar) test results. The same data is replotted in Figure 4b to show the mass flowrate error versus mass flowrate. Several results are apparent in the plots.

Typical accuracies are again ±0.5% for the two gases over a wide range of Re and/or mass flowrate ranges. Figure 4b again shows the zero effect present at large turndowns in the natural gas data. The natural gas data meets the current Micro Motion gas specifications, ±0.5% ±Z.S., over a 50:1 turndown (7 to 333 kg/sec at 30 bar).

The repeatability of the air data decreases while the repeatability of the natural gas changes little at high Re/mass flowrates. This may be due to the inherent testing differences between the two standards used at the two facilities, i.e. turbine meters/sonic nozzles at PIGSAR/CEESI, respectively.

References

[1] Paper presented at the North Sea Flow Measurement Workshop, a workshop arranged by NFOGM & TUV-NEL

Note that this reference was not part of the original paper, but has been added subsequently to make the paper searchable in Google Scholar.