CORIOLIS FLOW METERS FOR CRITICAL PHASE ETHYLENE MEASUREMENT

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ABSTRACT

A consortium of major European petrochemical companies and an ethylene pipeline company initiated a feasibility study for Coriolis meters to measure critical-phase ethylene. The main drivers for evaluating a new technology are lower installed and maintenance costs. The traditional measurement method in this application is a high-precision turbine flow meter and vibrating vane density meter, which can cost as much as $65k. Coriolis mass flow meters offer a significant benefit, reducing the installed cost by as much as four times.

Although the evaluation was commenced because Coriolis meters offer significant cost benefits, a stipulation is that any alternate metering technology must provide equal or better accuracy than the current metering standard. This paper presents the third-party test results that demonstrate promising new capabilities to measure critical-phase fluids using Coriolis technology.

Results show that the 80mm (3”) Micro Motion Coriolis meter accurately measures critical-phase ethylene at all measurement points from 2 to 60 t/h.
Test conditions ranged from 20° to 40°C and 75 to 90 bar.
Density ranged from 150 to 350 kg/m^3.

Important conclusions are:

- Water calibration factor transfers directly to gas.
- The 80mm (3”) Micro Motion Coriolis meter measures critical-phase fluids accurately within ±0.5% at all tested measurement points, including changing temperature- and pressure conditions.
- The meter is highly immune to installation effects.
- The meter shows good long-term stability.

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1 INTRODUCTION

Ethylene was first synthesized by Dutch chemists in 1795, making it the oldest artificially produced hydrocarbon. It's two carbon atoms are joined by a double bond, which is characterized by high reactivity. This is one of the properties that has made ethylene the leading raw material in the chemical industry. It forms complex compounds with heavy metals. The chemical reactions of ethylene are greatly accelerated by catalysts.

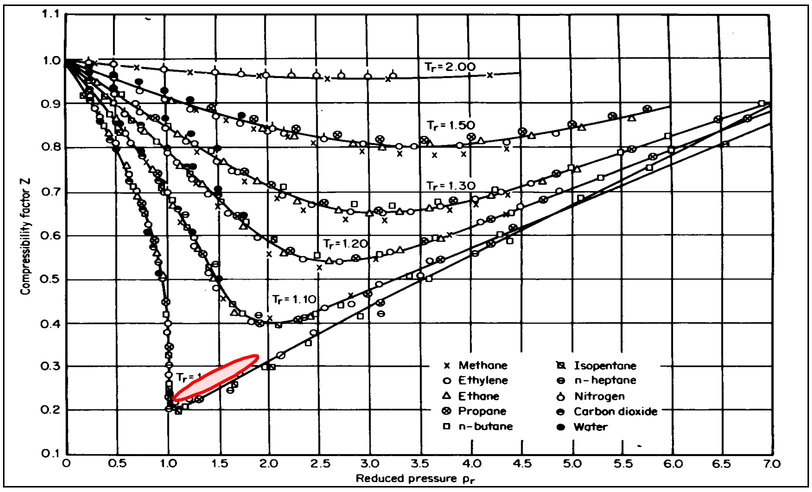

figure 1.1 Compressibility factor Z as a function of reduced temperature and -pressure

Critical-phase ethylene is considered a difficult gas to measure. Due to it's highly non-ideal behaviour (compressibility factor, $Z \neq 1$) fluid properties, like density, can change dramatically with relative small changes in temperature or pressure. The dotted area in the lower left corner of figure 1.1 represents the tested range of process conditions as discussed in this paper. In the tested range, ethylene density can change by 1 to 3 percent per degree Celcius, dependent on process conditions.

In 1968 the development of the ethylene market lead to the foundation of an ethylene pipeline partnership among several major ethylene producers and consumers. The partnership operates a 490 kilometre ethylene network among Belgium, The Netherlands, and Germany. It is an open transport system for companies with the mutual interest of ethylene transport. Most of these companies are major petrochemical companies, that can be either feeding ethylene to, or taking from the pipeline network. To manage the overall accounting, the organisation owns about 50 measurement points, controlled from a central dispatch in The Netherlands.

Highly accurate measurement is critical since each measurement point is a custody transfer point, either buying or selling to the pipeline. In addition, close accounting is necessary to quickly identify leak points (magnitude and location along the pipeline) in the unfortunate event that the pipeline is damaged. The only effective way to achieve the required measurement accuracy is on a mass-basis. The 'lively' behaviour of critical phase ethylene makes highly accurate mass measurement using *PTZ*-corrections difficult. Therefore, a mass measurement system was developed in the mid-80's, consisting of a volumetric flow measurement device in combination with a density meter. As a consequence, process conditions need to be identical in both measurement devices to ensure accurate mass measurement.

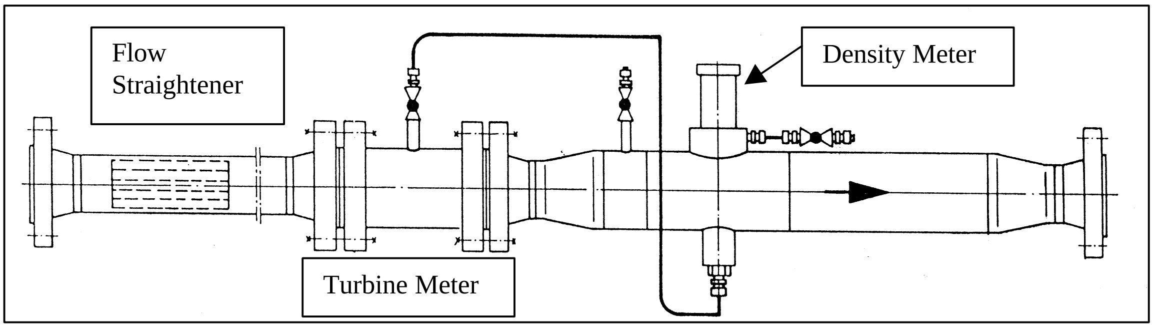

figure 1.2 *Mass measurement system: flow straightener, turbine, density meter*

The developed mass measurement system is shown in figure 1.2. The density meter is positioned in a closed chamber, filled with ethylene, in a 6" pipeline directly downstream of a 4" turbine meter. A direct tubing connection between turbine- and density meter ensures equal pressure in both devices. Temperature in the closed density chamber will follow the fluid flow temperature via heat transfer. Any temperature difference between turbine- and density meter will result in an additional mass measurement error. More concrete, a temperature difference of only 0.1°C will result in a 0.1-0.3% percent mass measurement error, dependent on the actual process conditions.

Twenty years of experience with this measurement system has proven it to be very accurate. However, high maintenance and frequent calibration cost of the '*traditional*' mass measurement system forced the partnership to search for alternative measurement technologies with lower *cost-of-ownership.*

Coriolis technology is a very attractive alternative to the 'traditional' measurement system for several reasons:

- Installed cost is low because Coriolis measures mass directly; there is no need for separate flow and density meters
- No flow conditioning or filtering is required, minimising the "foot-print" of the meter installation
- Calibration and proving costs can be minimised once proven that the water calibration transfers to ethylene
- Calibration and proving costs are minimised since only one devise needs proving (opposed to the turbine and density meters)
- Long-term reliability is high since there are no moving parts

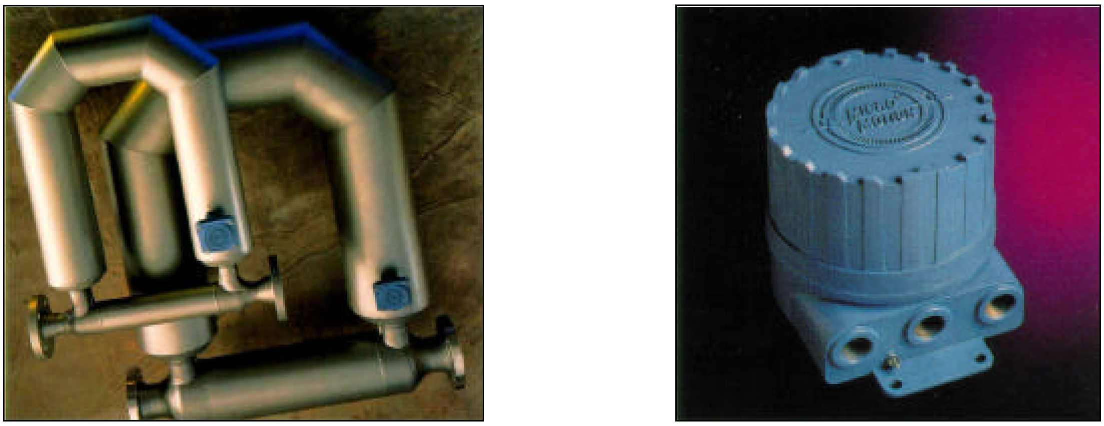

figure 1.4 *Coriolis direct mass flow meter – sensor and transmitter*

With an understanding of these important features of Coriolis meters, the critical goal of the investigation was to prove the accuracy of Coriolis to be identical to, or better than, the *'traditional'* mass measurement system. The uncertainty of the *'traditional'* mass measurement system is between ±0.21% and ±0.42%, depending on flow rate and process conditions. (Van Laak, June 1999, [1])

Along with the major European petrochemical companies, several Coriolis manufacturers were approached by the ethylene pipeline company to join the consortium.
Only one decided to participate.

The consortium chose to install two meters at two sites on the pipeline. Each meter was to be fully tested in several laboratories to gain as much knowledge and information about performance as possible. The test program consisted of three major parts:

1. Initial verification on water – water calibration laboratory in Geleen, The Netherlands
2. Initial verification on critical phase ethylene – ethylene test facility in Antwerp, Belgium
3. Field verification on critical phase ethylene – on site in Belgium and one in Germany.

Test flow rates on critical-phase ethylene range from 2 to 60 t/h. Test process conditions range from 20°C to 40°C, 75 to 90 bar and 150 to 350 kg/m^3. It should be noticed that the minimum test flow rate is at a turndown of more than 100:1 from meter maximum flow rate (272 ton/h).

The initial set of meter calibration parameters, as determined on water at the Micro Motion factory in the US, is to be used at all points of time during the test program.

Test Artifact

figure 1.5 Test artifact with 80 mm (3") Coriolis Mass Flowmeter

Since testing was to occur at three different sites in Europe and one in the US (initial calibration and characterisation), a test artifact was developed that ensured that any potential installation effects were negated. Figure 1.5 shows the artifact, which includes the Micro Motion CMF300 and mounting skid. The complete test artifact (including the skid) was evaluated in each test facility, ensuring that the sensor installation was constant and stable from one facility to the next. Changing only the fluid, from water to ethylene, and not the installation at the same time.

Once meter performance on critical phase ethylene was proven with the skid attached, it was removed to quantify any effect it had on performance.

Water test results from the calibration laboratory in Geleen, provided the consortium with enough confidence to proceed, and forward the meters to the more expensive ethylene testing. With an estimated cost of $100K, the project team clearly had a high interest in testing on ethylene only if there was a high confidence in the water performance. A more thorough discussion of the water tests is outside the scope of this paper. For more detailed results is referred to Van Laak, June 1999 [2].

2 INITIAL VERIFICATION ON CRITICAL PHASE ETHYLENE


figure 2.1 Ethylene test facility - Antwerp, Belgium

2.1 Ethylene Test Facility - Antwerp, Belgium

The ethylene test facility is located in Antwerp, Belgium. The site is an active distribution point on the ethylene pipeline. Additionally, a built-in calibration and proving system at this site provides calibration services for the meters distributed along the pipeline. Periodically, each turbine meter along the pipeline is removed and brought to the Antwerp site for calibration. The density meters are sent to an ethylene density calibration facility in The Netherlands for periodic re-calibration.

The calibration reference at Antwerp consists of a turbine meter in combination with a vibrating vane density meter, identical to each existing measurement point on the pipeline. Traceability is maintained by periodically proving the reference meter with an on-site piston-prover. Netherlands Measurement Institute (NMi) certifies the prover and calibration method for the ethylene pipeline.

2.2 System Uncertainty

The mass uncertainty of the ethylene reference meter is a combination of the turbine flow meter and vibrating density meter. The volumetric uncertainty of the reference turbine is ±0.10% for flow rates larger than 20 m3/h**,** and ±0.20% for flow rates smaller than or equal to 20 m3/h. The reference uncertainty of the density meter is ±0.10%. The combination of thermodynamic behaviour in the mass measurement system and the sensitivity of ethylene density to temperature results in a complex determination of the mass reference uncertainty. The following effects and thermodynamic phenomena need to be taken into account:

- Time delay of heat transfer from fluid to closed density chamber.
  Time-constant is in the order of magnitude 10-15 minutes.
- Adiabatic expansion of the fluid over the expander and stagnation conditions at the density meter ‘bluff body’ cause temperature in the density chamber to be different than at the turbine meter.
- Thermal leakage between density chamber and ambient.
- Influence of temperature control in the test facility on the fluid temperature at the density meter.

In depth studies by Van Laak [1], [3] show a systematic temperature difference between turbine- and density meter, which will be corrected for. Furthermore, a fluid temperature stability of ±0.1°C is required to guarantee the stated mass reference uncertainties. As a consequence, operating conditions in the test facility need to be extremely stable. Assuming fluid temperature to be stable within ±0.1°C, the mass reference uncertainty is between ±0.21% and ±0.42%, depending on flow rate and process conditions. (Van Laak, 1999, [1])

2.3 Results

Five primary aspects of performance were of interest:

- Viability of using the factory water calibration on critical-phase ethylene
- Effect of ethylene temperature variations
- Effect of ethylene pressure variations
- Effect of changing mounting conditions
- Long term meter stability

The results of the tests are summarised in the following sections:

2.3.1 Water Calibration Factor Transfers to Gas

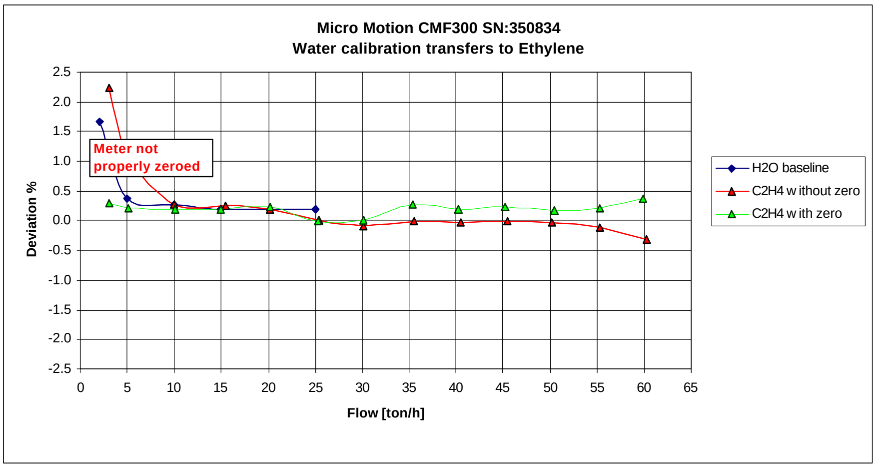

figure 2.3.1 Water calibration factor transfers to Ethylene

The “baseline” water calibration result is established at the water calibration laboratory in The Netherlands. The bias in meter zero is likely due to air entrainment at time of zero-calibration in the water calibration laboratory. The test artifact was transported as a complete unit to the Antwerp ethylene test facility and tested as-is. Especially important was that, at first stage, the meter was not re-zeroed on ethylene. The “baseline” water calibration factor directly transfers to ethylene. A slight change in meter zero is observed due to the density change from water to ethylene. Excellent performance was obtained after zeroing was completed on ethylene.

The important conclusions are:

- meter water calibration factor transfers to critical-phase ethylene.
- meter zero calibration ensures optimal performance.

2.3.2 Temperature- and Pressure Variations

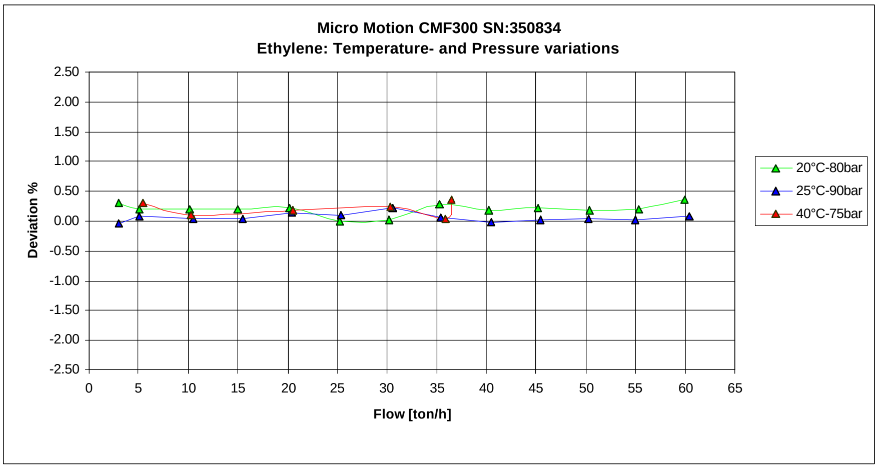

figure 2.3.2 Ethylene: Temperature- and Pressure Variations

Meter performance was validated over a wide range of possible operating conditions. Pipeline pressures are typically between 70-90 bar. Fluid temperatures vary between 10-40 °C. Results are shown in figure 2.3.2.

The important conclusion is:

- the meter can measure critical-phase ethylene at changing temperature- and pressure conditions without significant impact on meter performance.

2.3.3 Installation Effects

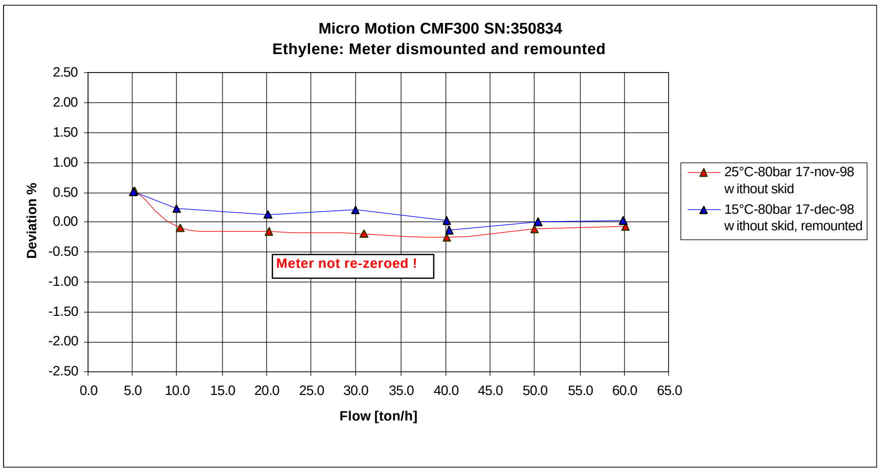

figure 2.3.3 Ethylene: Meter without skid - dismounted and remounted

Once meter performance on critical phase ethylene was proven with the skid attached, the skid was removed to quantify any effect it had on performance. No significant effect was observed, as can be seen in figure 2.3.3. Ultimately the meter was dismounted from the installation and tested again after remounting the device. It should be noted that the meter was **not re-zeroed** after remount. Figure 2.3.3 shows test results after removing the meter from the pipeline and remounted one month later. No significant effect was observed.

Important conclusions are:

- mounting skid does not have a significant impact on meter performance.
- dismounting and remounting does not have a significant impact on meter performance.
- the Coriolis meter shows good long term-stability over five months of ethylene testing.

3 FIELD VERIFICATION ON CRITICAL PHASE ETHYLENE

figure 3.1 Ethylene: Field Verification – Installation

A field verification was performed at a major refiner in Antwerp, Belgium. The Coriolis meter[1] was installed downstream of a '*traditional*' mass measurement system. Daily totals were compared with each other over close to a month's period. At an average mass flow rate of 30 ton/h, process pressure was around 52 bar, fluid temperature varied between 13-38°C and ambient temperature varied between 3-21°C. It should be noticed that these operating conditions are even more challenging than those from the initial ethylene verification in the test facility. Especially process pressure is very close to ethylene critical pressure of around 50.8 bar.

3.1 System Uncertainty

The '*traditional*' mass measurement system is fully insulated and has a mass reference uncertainty of ±0.3% at stationary process conditions.

[1] Field verification on Micro Motion CMF300 with sn:350834 was delayed due to external influences. To date, there are no results available. The field verification results as presented, are observed on a 2nd Micro Motion CMF300 meter. Important to mention is that again the water calibration factor is used for the tests on critical phase ethylene.

3.2 Results

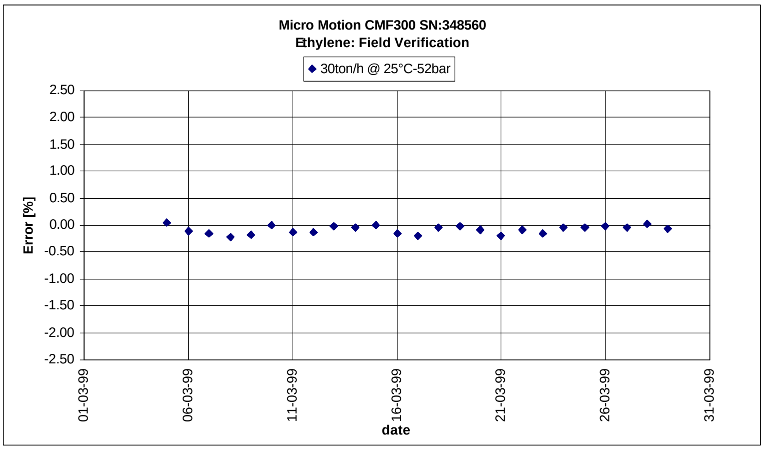

figure 3.2 *Ethylene: Field Verification – Test Results*

Totals of both measurement devices are compared on a daily basis and shown in figure 3.2. Monthly totals of both systems only differ by 0.08%. Day tot day variation around this value is only ±0.15% (*2s*).

Important conclusion are:

- the Micro Motion Coriolis meter shows good long-term stability.
- under 'real-life' operating conditions, the tested Coriolis meter accuracy is identical to the *'traditional'* mass measurement system.

Therefore the expectation is that Micro Motion Coriolis meters will be considered as an alternative technology to the 'traditional' mass measurement system.

4 CONCLUSIONS

An extensive test plan was initiated to evaluate the potential of Coriolis meters to perform within the accuracy requirements of a consortium of major petrochemical companies. Initial results are very promising; pending complete results of the field trials, the expectation is that Micro Motion Coriolis meters will be considered as an alternative technology to the 'traditional' mass measurement system[2].

Important conclusions are:

- Water calibration factor transfers directly to gas.
- The 80mm (3") Micro Motion Coriolis meter measures critical-phase fluids accurately within ±0.5% at all tested measurement points, including changing temperature- and pressure conditions.
- The meter is highly immune to installation effects.
- The meter shows good long-term stability.

REFERENCES

[1] Uncertainty of ethylene mass calibration facility in Antwerp (in concept), DSM, F.A.L. van Laak, June 1999

[2] Performance evaluation of Coriolis mass flow meters (in concept), DSM, F.A.L. van Laak, June 1999

[3] Uncertainty of mass measurement in super critical ethylene, using the ARG measurement concept (original in Dutch), R 88 7183 DSM , F.A.L. van Laak, 13 June 1988

[2] Testing is currently underway at three field sites to prove the 3" Coriolis meter accuracy versus the 'traditional' mass measurement system. A final report is expected by December, 1999, detailing the entire test plan and meter performance results.