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DEVELOPMENT AND VALIDATION OF A NEW SINGLE STRAIGHT TUBE CORIOLIS METER

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Abstract: *The popularity of Coriolis meters continues to grow, largely as a result of the high performance and field robustness of dual, curved tube Coriolis meters. Such curved tube designs solved many of the problems that plagued early Coriolis meters, such as mount sensitivity and vibration effects.*

Although dual, curved tube Coriolis meters have gained acceptance, this design does not meet all application needs. In some applications, a single straight tube Coriolis meter is required due to process considerations, such as plugging problems, drainablity, and compactness.

Recently, a new single straight tube Coriolis meter having the high performance and field robustness of dual, curved tube Coriolis meters has been introduced. The development of this new flow meter employed advanced computer aided modeling techniques to accurately simulate and mitigate variations due to changing field conditions, including changes in meter installation practices, fluid density, and fluid temperature.

This paper will review and compare the technical challenges associated with designing curved tube and straight tube Coriolis meters, and will provide performance data to support the field robustness of the new straight tube design.

1 TECHNICAL CHALLENGES

Customer expectations and design requirements for single straight tube Coriolis meters are the same as for curved tube meters. In both cases, the meter must have no special installation requirements, such as rigid mounts or flow conditioners, and it must perform accurately over a wide range of process conditions, including changes in process fluid density, temperature, and pressure. On the other hand, the geometry and configuration for the single straight tube and the dual curved tube Coriolis meters are very different, and as a result the technical challenges that must be surmounted are also different. In this paper, we will describe the technical challenges and solutions for achieving field robustness for single straight tube Coriolis meters for several key, everyday process variations, specifically meter mounting and changes in fluid density and temperature. These attributes are chosen for discussion because they best illustrate the differences between single straight tube designs and more traditional dual, curved tube Coriolis meters.

Much of the field robustness of dual, curved tube Coriolis meters is inherent in the design. Consider first the requirement that the meter must have no special installation demands. Figure 1 shows a finite element computer model for a typical dual, curved tube Coriolis meter. Note the symmetry of the design, both from inlet-to-outlet and from tube-to-tube. Under normal operating conditions the tubes are driven in opposition to each other at resonance by a coil and magnet (not shown) located at the tubes' midpoints. This deflection is displayed in the figure, greatly exaggerated for clarity. In addition, coil and magnet velocity sensors (also not shown) are located equidistant upstream and downstream from the tube midpoints to measure relative velocity between the two tubes. The meter symmetry acts as a mechanical filter, rejecting motion that is common to both tubes, such as externally induced vibration. Furthermore, since the two tubes are essentially identical, change in fluid density does not affect either symmetry or mechanical filtering.

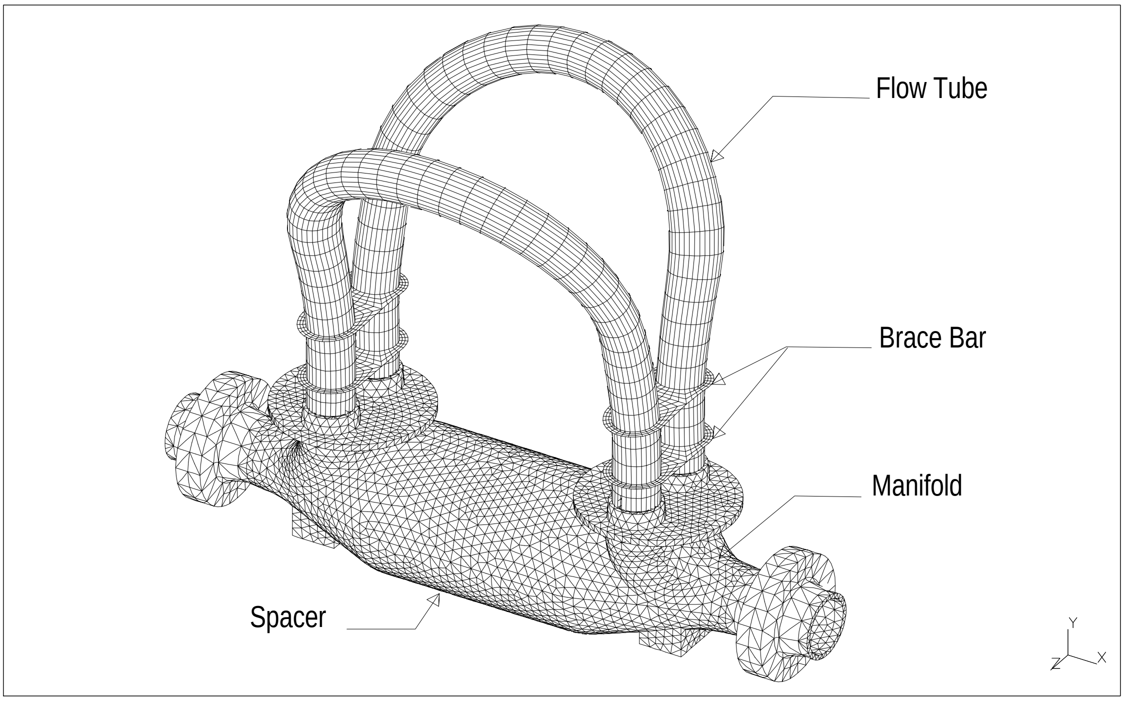

Figure 1

Also consider the case where a mechanical load, such as a force or a moment, is applied by the pipeline to the flanges of the sensor. These loads have relatively little influence on vibration of the tubes (and hence also little effect on the meter performance) due the high stiffness of the manifold which opposes the load, and due to the curved tube geometry which is insensitive to minor translation of the tube ends.

The fact that the tubes are curved has another advantage: the tubes are relatively free to expand with changes in fluid temperature. As a result, change in fluid temperature does not impart stress into the tubes and therefore has minimal effect on sensor performance (except for the change in material stiffness, which is easily compensated with a single flow tube temperature measurement).

Contrast the geometry of the dual, curved tube with that of a single straight tube, shown in Figure 2 again as a finite element model and in this case as an axial section through the case. (The vibration amplitude of this design has also been greatly exaggerated for clarity.) The straight tube design is symmetric from inlet-to-outlet, and about the plane of vibration. The vibration itself, however, is not symmetric. The flow tube and the concentric reference tube vibrate in opposition to each other as shown. This lack of symmetry in the plane of vibration means that the benefits of mechanical filtering will not be as readily achievable as for curved tubes. Design of the single, straight tube Coriolis meters must provide mechanical filtering despite the design's inherent lack of symmetry. Furthermore, the design in total must be robust enough to accommodate changes in fluid density, which only affects the dynamic characteristics of the flow tube, not of the reference tube.

Another important difference between straight tube and curved tube designs is that in the former case the measuring tube is coaxial with (i.e., directly in line with) the process pipeline. As a result, pipeline loads can be transferred directly into the measuring tube. To prevent this from affecting measurement performance, a rigid case is placed around the flow tube to carry pipeline load. The rigid case, however, can in turn introduce problems itself when fluid temperature changes. The case constrains the expansion and contraction of the tube due to temperature changes. This gives rise to thermal stresses in the flow tube, which can negatively influence both meter performance and reliability. The design of a single, straight tube Coriolis meter must effectively accommodate temperature changes in order to be acceptable for use under even relatively mild field conditions.

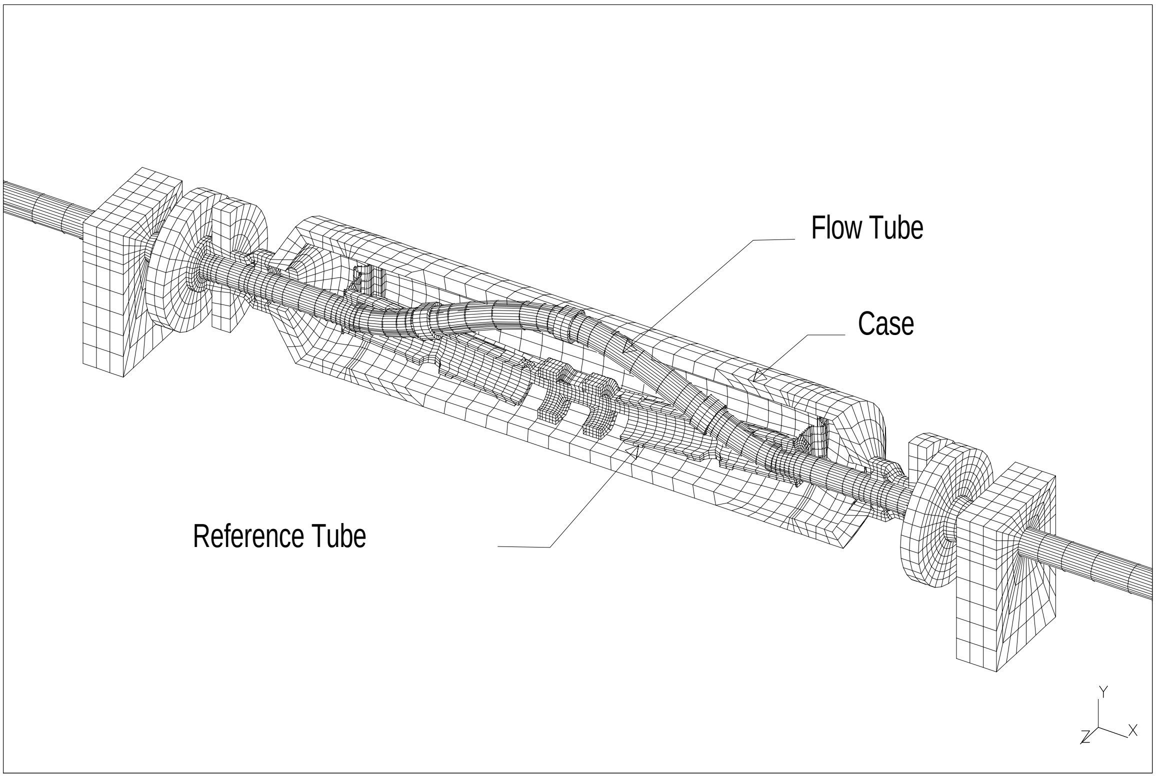

Figure 2

SEQARABICIn today's world, the kind of structural design issues described in the previous paragraphs can be accurately and comprehensively modeled on computers. Most of the major characteristics of Coriolis meters can be analyzed, predicted, and optimized before units are ever built, and such a modeling approach is the one Micro Motion pursued in the development of a single, straight tube Coriolis meter. This work specifically addressed both the necessary matter of achieving good reference performance (i.e., performance under ideal laboratory conditions), and the equally important and more difficult problem of developing a design that would be robust when exposed to real-world field conditions.

In the following sections, we review the results obtained for several of the most important of these real-world conditions, namely, meter mounting, fluid density, and temperature changes.

METER MOUNTING

One of the most difficult challenges for single tube Coriolis meters is mounting. As explained above, pipeline forces, which can be in the form of axial loads, transverse loads, torques, or moments (or combinations), will in general be more readily transmitted to the measurement tube for straight tube designs than for curved tubes. This means that the straight tube design must be sufficiently robust so that it can tolerate variations in mounting conditions (and consequently also in pipeline forces) without deleteriously affecting measurement performance. This is achieved through the use of computer models and mechanical designs which minimize the transfer of pipeline forces between the process connections of the flow meter and the measuring section of the flow tube.

In our tests to demonstrate mounting robustness, the meter was mounted to a steel beam with standard pipe clamps, and this entire test bed with meter in place could be rotated such that flow direction could be horizontal or vertical. The distance from the mounting clamps to the meter flanges was varied, as were the number of clamps per end, the flow tube vibration direction (horizontal or vertical), and the fluid flow direction (horizontal or vertical). For each condition the meter was tested on water against a master meter (Micro Motion Elite meter). Flow rate was varied from 10% to 100%

of the rated flow capability of the meter, and five separate one-minute batches were run at each flow rate.

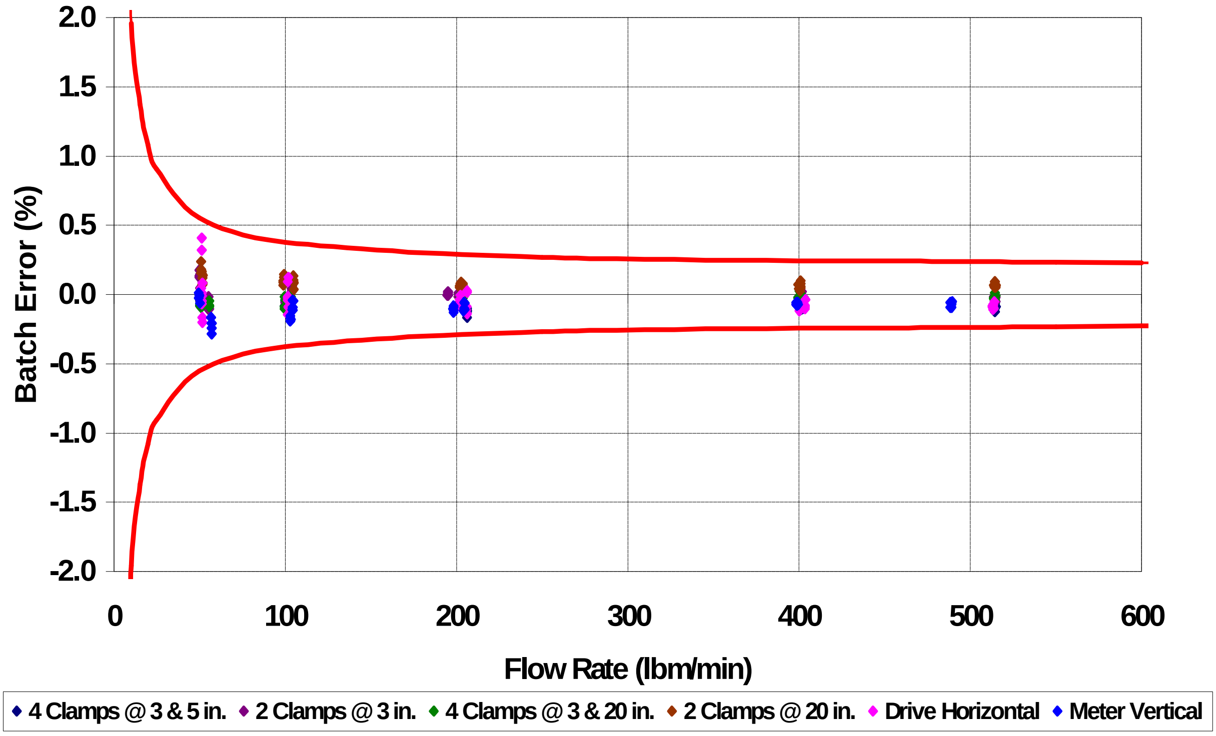

Figure 3

The results of the mounting test are shown in Figure 3. Each color represents a different mounting condition per the legend on the figure. As can be seen, performance meets specification under all conditions.

3 FLUID DENSITY

Changes in fluid density shift the dynamic characteristics of the flow tube, because the total mass of the vibrating element will be greater or smaller depending on whether the fluid density increases or decreases. For dual tube meters, this effect is well balanced, and can be largely neglected for flow measurement, by virtue of the fact that both tubes carry fluid and therefore show equivalent changes in dynamics. For single tube designs, however, only the flow tube experiences this change in fluid density, resulting in a change in relative dynamics between it and the reference tube. This situation inherently leads to a more complex fluid density sensitivity for single straight tube meters than for dual curved tube designs. Again, the computer modeling tools enable this effect to be taken into account and compensated for.

Testing for the effect of changes in fluid density on flow calibration factor was also done using a transfer standard meter. The meter under test was calibrated on water, and then tested on two other fluid densities, Multitherm 503, a heat transfer fluid with density of about 0.8, and a calcium chloride-water mixture having a density of about 1.2. Figure 4 compares the predictions from the computer model to the actual test results. There is good agreement, which permits accurate, real time compensations to be incorporated into the product.

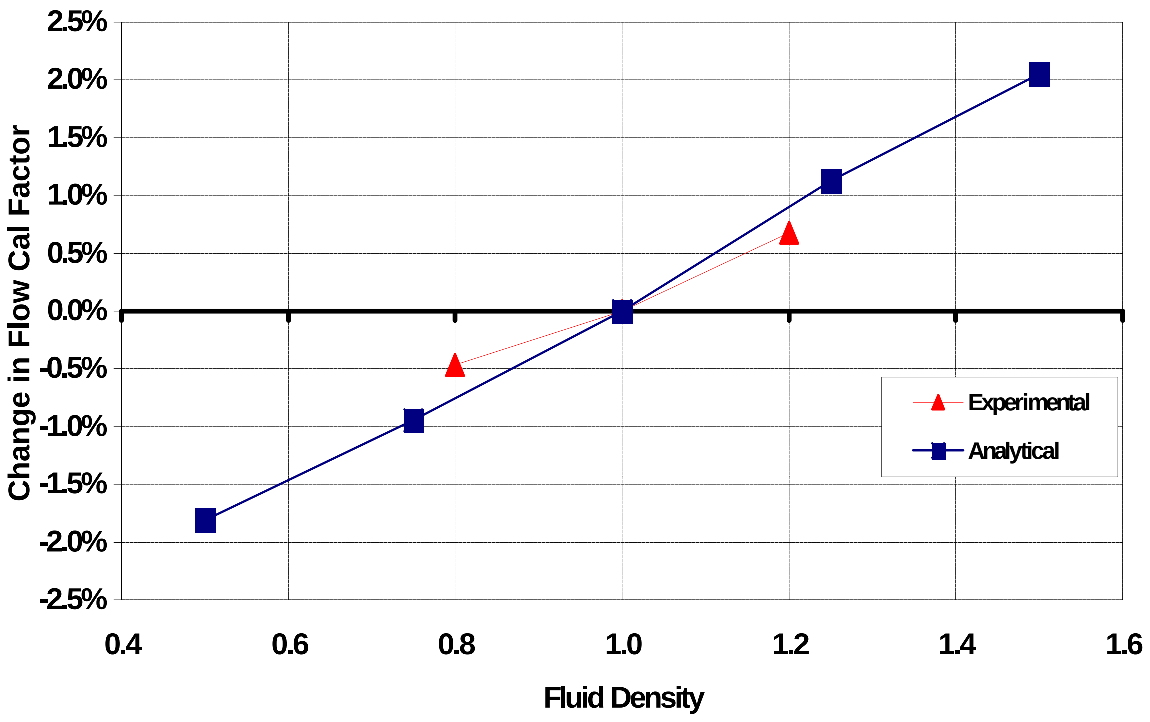

Figure 4

4 TEMPERATURE

Perhaps the most difficult field-effect issue to deal with for straight tube Coriolis meters is temperature. Meters can run hot or cold fluids, they can be (and often are) exposed to daily and seasonal ambient temperature changes, and they are sometimes subjected to thermal shock associated with, for example, steam cleaning. The effects on flow measurement performance of such temperature excursions, alone or in combination, can be large. Furthermore, referring again to figure 2, the three concentric structural components of the straight tube meter – the flow tube, the reference tube, and the case – can each be exposed to different temperature regimes. If not handled properly, stress levels associated with thermal conditions can exceed the yield points for the materials of which the meter is constructed. Clearly in this complex situation, computer-modeling tools are crucial to achieving satisfactory results.

Two different test methods were used in order to fully assess the effects of temperature on meter performance. In one of these, fluid temperature and ambient temperature external to the meter were changed over a 40^{o} C temperature range. In the second test, fluid temperature changed by 40^{o} C and the ambient temperature was held constant. These tests represent significantly different thermal conditions, from a uniform high temperature to a high thermal gradient.

Results are shown in Figures 5 and 6. In both cases, the uncompensated flow measurements show substantial errors – as much as 1% or more -- as fluid temperature changes, but performance is stable and accurate after compensation is performed. The compensation is performed real time, based on several temperature measurements made at carefully selected locations inside the flow meter.

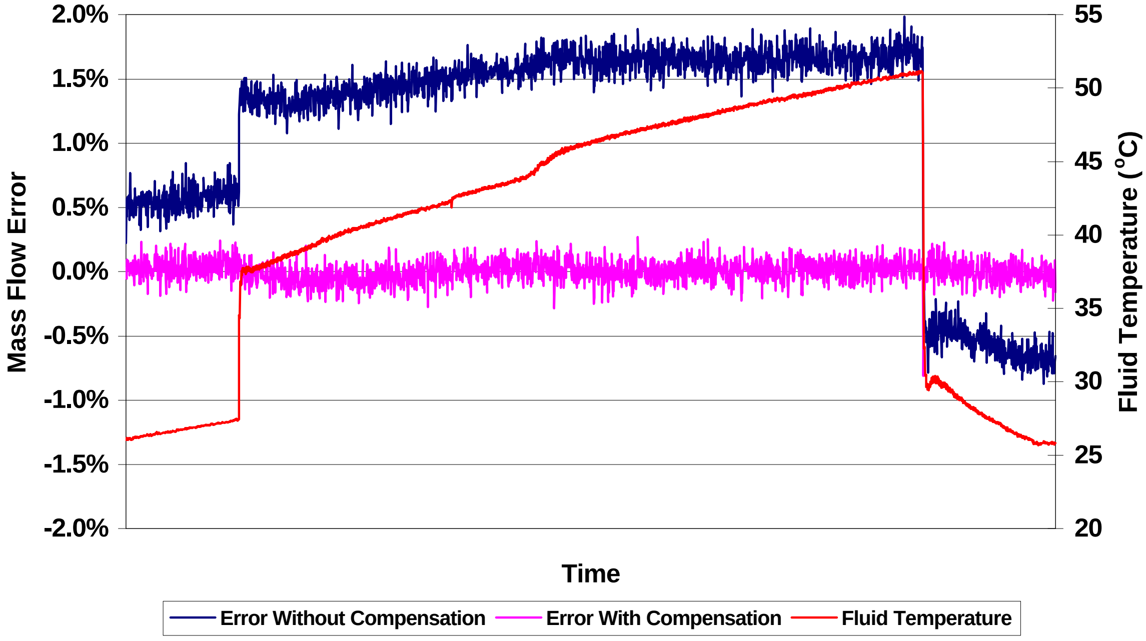

Figure 5

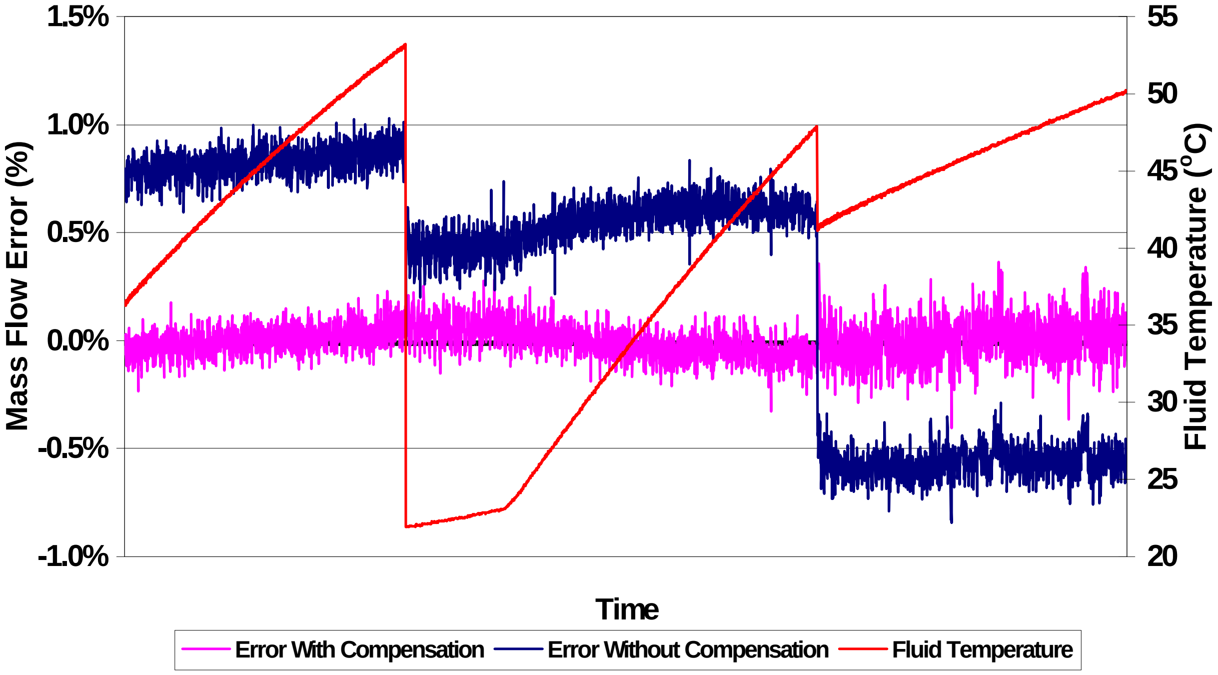

Figure 6

4 CONCLUSION

This paper discussed the design challenges in developing a single straight tube Coriolis meter. These challenges were overcome through the use of sophisticated finite element software, which accurately simulates performance under changing conditions, such as varying installation, fluid density, and temperature. Also discussed were the results of testing which validates meter performance under varying conditions. Other effects that must also be taken into account in the design of single straight tube products, but were outside the scope of this paper, are immunity to pipeline vibration in multiple axes, density measurement performance, and demonstration of acceptable performance in the presence of pipeline elbows, and without straight runs or flow conditioners. Successfully dealing with all these performance attributes – both those discussed in this paper and the others which were not reviewed here – is essential for a flowmeter to perform acceptably under real world, field conditions.