Badger® Series 4000 Flow Sensor	Accuracy - Comparison with Competition	Technical Brief

The accompanying chart, compares the accuracy of six (6) different production specimens of Badger Meter's Model 400500 Flow Sensor (PVDF ½ inch diameter unit without low flow feature) with a single specimen of a competitive flow sensor designed for the same range of flow applications. The test spans the range of flow rates from 1 to 20 feet per second. Pipe size in this test was nominal ½ inch PVDF piping (16.2mm/0.638in. I.D.). Fluid measured was ordinary tap water.

The chart is constructed in a modified semi-logarithmic form. The vertical scaled *Error in Flow Rate* is constructed with a positive % error reading upward from the central horizontal graduation, covering the range from +0.01% to +1000% in the upper half of the plot. The lower half covers the range from -0.01% to -1000%, reading downward. The central horizontal graduation thus represents +0.01% and -0.01%. Secondary graduations are the appropriate lines for the intermediate 0.05, 0.5, 5.0, … 500%, as appropriate for the bounding major graduations.

The vertical scale is a bit non-conventional, but does provide a convenient means to illustrate the full spectrum of errors in the tests, and demonstrates graphically the relationship between % error of reading and % error based on a “full scale” specification. The scale also exaggerates the variability of low values of error, as in the Badger Meter Model 400500 values, and significantly compresses the variability above the 1% level. In the -10 to -20 region, the area bounding most of the error determined for the competitive sensor, the full ±1% error range plots into a band only ±15% of the distance between two adjacent major graduations.

The horizontal scale, for FLOW RATE in GPM, is graduated linearly, and should present no problems in interpretation.

Two pairs of envelope curves are shown on the plot. These curves related claimed % full scale accuracy to % accuracy at flow rate. The outer pair are based on ±1% full scale at 30 FPS, the claimed accuracy of the competitive sensor; the inner pair on Badger Meter’s ±1% full scale at 20 FPS. These accuracy claims relate to errors of ±0.302 GPM and ±0.201 GPM, respectively.

Throughout the plot, % error (e) is defined to be:

e = 100 (Read GPM - Actual GPM) / (Actual GPM)

Thus, a zero reading in the presence of actual flow will result in -100% error.
All tests were conducted in the Badger Meter flow laboratory. Real flow uncertainty in our lab is currently estimated to be ±0.18%.
Resolution of both the Badger Meter and the competitive sensors are in this set of tests, ±0.42% (0.1 gal. in 24). The combined uncertainties (added in quadrature) are ±0.46%.

DISCUSSION
The results speak for themselves. The Badger Meter 4000 operates within ±1% full scale @ 20 FPS accuracy over the entire range of the test. Indeed, all actual % errors inside the rated 1 to 20 FPS range are less than ±2.5%, with 93.9% falling within ±2% of actual.

In contrast, the competitive sensor operates outside the ±1% @ 30 FPS accuracy in the 4 GPM to 20 GPM range. Only at flow rates less than 3 GPM does it meet its producer’s claimed accuracy. This unit consistently reads with an actual error of 10 to 20% low over the entire test.

The apparently random fluctuation of the Badger Meter error curves is an indication that the calibration method used at Badger Meter is producing the anticipated (and desired) results. Linear regression techniques, both theoretical and practical must result in both positive and negative errors. Unbalanced errors, i.e. all positive or all negative, are an indication of bias or systematic error in calibration. The competitive sensor’s results show a strong negative bias across the range of GPM.

The Badger Meter 400500 does show a slight positive bias in the flow regime above about 2 GPM. This is the result of the strong negative error in the 0.2 to 0.5 GPM range. This results in a somewhat steeper calibration curve than that anticipated, if our calibration tests did not include these low flow rates.

The phenomena that produce the relatively high values of negative error at low flow rates for both sensors are related to the requirement for some finite threshold level of momentum in the flow stream. The flow needs to be great enough to dominate the retarding forces (inertial, frictional, and viscous shear) inherent in the impeller/shaft combination operating within the fluid chamber. In fact, at 0.5GPM the competitive sensor could not respond to flow; whereas the Badger Meter threshold is in the region of 0.05 to 0.15 GPM.

SUMMARY OF RESULTS
1) The Badger Meter Model 400500 Flow Sensor operates with an absolute error approximately 1/5 to 1/10 that of the popular and widely used competitive sensor.
2) The Badger Meter Model 400500 Flow Sensor operates with relatively little bias or systematic error.

3) The Badger Meter Model 400500 Flow Sensor operates within the specified 1% of full scale rated @ 20 FPS over the full range from 1 to 20 FPS.
4) The Badger Meter Model 400500 Flow Sensor operates within ±2.5% absolute error of its full rated range from 1 to 20 FPS, with better than 90% of readings within ±2%.

NOTES ON TEMPERATURES AND PRESSURE

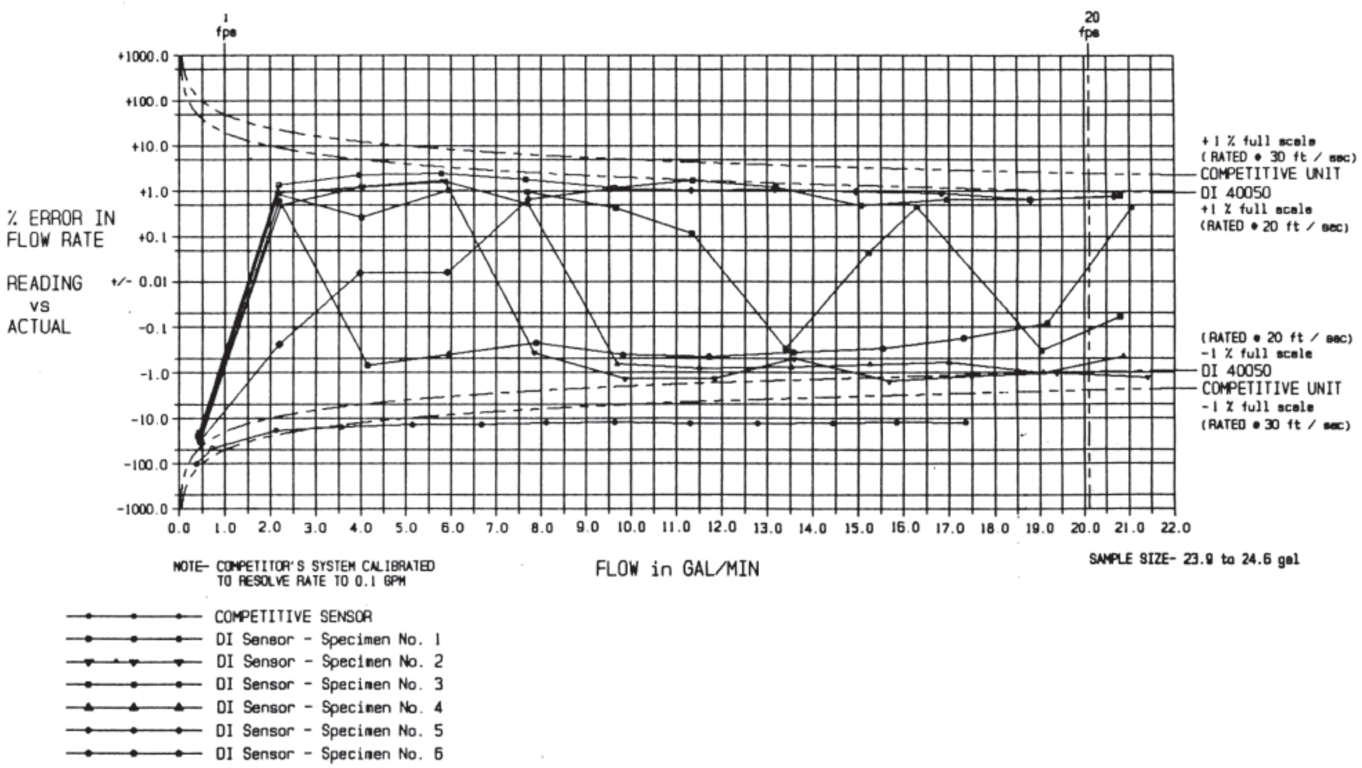
This test was run without precise control or pressure to simulate worse case effect in a real sensor installation. Temperature varied within runs up to 30°F, and between runs up to 10°F in the mean. Pressure varied ±10% around a nominal 20psi.

1) Temperature is a strong source of variation in both density and viscosity. Thus, there is considerably broader variation in Reynolds Number than the range of flow rate alone would indicate.
2) Similarly, the variation in Euler Number is broader than indicated by velocity variation.
3) Basic dimensional analysis indicates a functional relationship between output frequency at a given flow rate and kinematic viscosity. This relationship is currently under investigation at Badger Meter to help better define the anticipated accuracy of our flow sensors with the variation in temperature. This will be reported upon conclusion of this further study.

It should be noted that these phenomena are not unique to impeller flow sensors, but to a greater or lesser degree influence the operational accuracy of all flow velocity sensors.

SETUP FOR THE COMPETITIVE FLOW SENSOR

The competitive flow sensor was initially set up using the appropriate mounting fitting and flow display supplied by its manufacturer, and using the calibration constant recommended by the manufacturer. As installed, the flow display was incapable of resolving total flow to a minimum precision of less than 1 gallon. Since the test runs used sample sizes of only 24 gallons, the uncertainty in flow rate resulting was ±4.2%. The output error in flow rate ranged from -14% to -22.5%. To reduce the uncertainty, the calibration factor was reprogrammed to be 0.1 times the pulse per gallon calibration factor supplied by the manufacturer, effectively "fooling" the meter to read 10 times the actual flow. This reduced the uncertainty to ±0.42%, with a concomitant reduction in reported error to the rangeof -12 to -19%.



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