What are Stem Conduction Errors and How Can They Create Errors in Calibration?

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Stem conduction is heat conduction along the length of a thermometer. When the heat source temperature and the handle, or cable end, of the thermometer are at different temperatures, stem conduction happens. This difference produces a sensor reading that is different from the actual heat source temperature. Two thermometers side by side in the same heat source with stems made of different materials may read two different temperatures. The following chart illustrates the stem conduction effect. Five different, but high quality thermometers were tested in a liquid bath at 80°C.

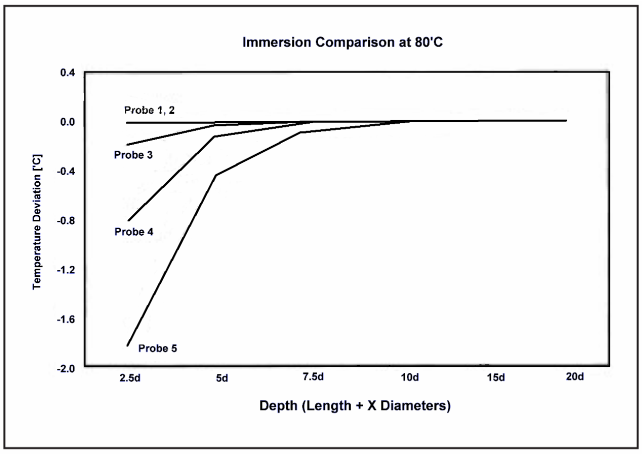
The test was performed by immersing each of the thermometers to a specific depth. Since each thermometer or probe had design differences including the length of sensor and the diameter, the immersion was adjusted for those variables.

Immersion Depth = Sensor Length + X Diameters

Temperatures were normalized at *SL + 20 Diameters.*

Temperature Error at 80°C Due To Stem Conduction, Degrees C

Depth	Probe 1 SPRT, Inconel Sheath, 5.5 mm Dia 50 mm SL	Probe 2 SPRT, Quartz Sheath, 7 mm Dia 29 mm SL	Probe 3 SPRT, Inconel Sheath, 6.3 mm Dia. 29 mm SL	Probe 4 Secondary, Inconel Sheath, 6.3 mm Dia. 41mm SL	Probe 5 Secondary, Inconel Sheath, 6.3 mm Dia. 38 mm SL
SL+20D	0	0	0	0	0
SL+17.5D	0	0	–0.001	–0.002	–0.002
SL+15D	0	0	–0.005	–0.003	–0.003
SL+12.5D	–0.002	–0.002	–0.010	–0.005	–0.005
SL+10D	–0.002	–0.001	–0.015	–0.010	–0.050
SL+7.5D	–0.004	–0.003	–0.020	–0.050	–0.100
SL+5D	–0.007	–0.005	–0.050	–0.130	–0.430



The results show that thermometers 1 and 2 read nearly the same temperature values for each depth, while thermometers 3, 4, and 5 read very different temperatures with less immersion depth. This illustrates stem conduction effects. This simple test has many implications for the work you do. How much immersion depth do you need for your sensors?

Factors That Impact Stem Conduction Error

Remember the heat conduction formula:

Q = (K x A x Delta T)/d

Q = heat, *K* = thermal conductance factor, *A* = cross sectional area, *Delta T* is the temperature difference between the sensor and ambient, and *d* is the immersion depth. Knowing that an increase of *Q* will increase the error of the measurement, consider each of the components of this equation.

Thermal Conductance Factor

A high thermal resistance (hence low conductance value) helps to isolate the temperature sensor against the conduction of heat to the ambient air (or vice-versa). The material type and diameter of lead wires, the sheath thickness and materials of construction all factor into this. The copper lead of a type T thermocouple is clearly a high thermal conductor for a given diameter of wire and may need to be compensated for in some way.

Probe 5 in our test had a heavy walled sheath. The effect of the heat conducted along this sheath contributed to the errors. A related factor for quartz sheaths is light piping.

Cross Sectional Area

Whatever the heat conduction coefficient of the stem material, the bigger the cross-sectional area of the stem, the more heat conduction and the greater the error. Using the diameter to determine immersion depth helps compensate for this. However, a calibration comparison of two thermometers of vastly different stem diameters may actually require the smaller one to be placed at the same depth as the larger one so both sensors are at the same temperature.

Labs calibrating short, large diameter sensors find it very difficult to obtain a high accuracy calibration because of the dominating effect of stem conduction.

Delta T

Delta T refers to the temperature difference between the heat source and the ambient temperature. Calibrations are usually made over wide temperature ranges. Stem conduction errors increase directly with this temperature difference as our equation suggests.

Depth

Many factors influence the errors related to stem conduction but few are as easy to control as depth. The equation shows that the other effects can be reduced by increasing the value of immersion depth. Immerse the thermometer as far as possible while still keeping all the test and reference sensors as close together as practical. Remember not to cook the connection or handle end of the thermometer. In our example, we used a liquid bath for our heat source. If you are using a dry well or furnace, stem conduction errors are greater and more difficult to manage.

Conclusion

The formula given in this brief, simple discussion of stem conduction error can be used as a general rule-of-thumb for figuring the required immersion depth of both devices under test and reference probe. You should do some similar experiments with your own sensors to establish their stem conduction errors and required immersion depths.

In addition when using dry well or metrology well devices the use of a reference probe can have a profound effect on the accuracy of the calibration of short sensors. Common types of short sensors found in industrial applications are dial indicator types, thermostatic switches and sanitary sensors. All of these types present their own unique challenges but immersion depth and stem effects have the biggest influence on the results.

Use of a reference probe with a 90' bend allows the block temperature to be established with a better uncertainty and although in these cases, the reference probe will exhibit different stem effects than the device under test the overall system uncertainty can be improved significantly.

Advances in the design of some dry well type calibrators, often referred to as Metrology Wells rather than Dry Wells due to the improvement in performance, now incorporate dual zone control of the block temperature resulting in much improved temperature homogeneity, which in turn leads to improved calibration performance.¦

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