Technical Bulletin: 73

Data Industrial
A BadgerMeter, Inc. Company

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Data Industrial BTU Meter Accuracy

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2300 ✓
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The purpose of this Technical Note is to explain the basis of the statement of accuracy for the Data Industrial Corporation Series 2300 and 1550 Btu meters. On the basis of tests and theoretical analysis, these meters are stated to be accurate within ± 0.48%. The balance of this note justifies the claim, and provides information on the effects of the accuracy of the sensors used for input to the meters.

A method of specification of Btu meter accuracy has not as yet been determined by any recognized body, and such specification is currently reported by the various manufacturers of this type of instrument as their best estimate of the performance of the various proprietary designs they offer. The final accuracy of the meter is affected by the installation of the individual input sensor components and by the parameters under which they operate, and indeed may be dependent on the configuration of ancillary systems to which they are connected. Any instrument accuracy claim by any supplier of Btu measuring systems should be carefully studied by the potential user, to reach a clear understanding of the basis of the such claims.

The energy content in any fluid system is a function of the pressure and temperature of the fluid being monitored. The rate of energy pumped into a heated volume or out of a refrigerated volume, is a function of the difference in pressure and temperature between the inlet conditions and the outlet conditions, and of the fluid velocity. The function of a Btu meter is to transform these measurable phenomena, into a rate of energy transfer, e.g. Btu/minute.

Most commercially available Btu meters function by combining either volumetric or mass flow rate transducer output with outputs from two temperature transducers, one located at the entrance to the metered volume and one at the exit. The effect of pressure on variation in isothermal energy content is under ± ¼% in the temperature region from 50° to 150°F at pressures below saturation pressure at the given temperature. Thus for operation in this range, the energy content with variations in pressure is usually neglected. Errors caused by not compensating for the effect of pressure on specific enthalpy increase rapidly as operating temperature approaches 32°F.

This basic data input, from the flow rate and temperature transducers, is manipulated mathematically to provide a rate of energy transfer within the monitored volume. While the effect of pressure on energy content is not monitored, an average value of Btu per pound mass is used in the calculations as a means of compensation of the pressure effect. This simplification results in some loss in accuracy in the instrument reading as discussed above. The actual error will vary depending on the method used by the instrument manufacturer to compensate for this unavoidable simplification required by using temperature transducers only.

Many Btu meters using volumetric flow rate sensors take an even more simplistic approach, assuming that 1 Btu is the heat required to raise the temperature of one pound (mass) of water exactly 1°F, without regard to the variation in mass density of water with temperature. Thus, a 1°F temperature rise for 1 gallon of water is, in these terms, 8.337 Btu. This assumption can result in large errors over relatively low temperature differentials when the water is at high input temperatures. For example, in a 50 psia (35.3 psig) system operating at 220 °F inlet and 210°F outlet, this assumption has a built-in error of 3.3%, before any consideration is given to calculation errors in the meter software, in A to D conversion of the temperature sensor signal, and in basic sensor calibration errors.

Error Sources:

Errors in any non-pressure compensated Btu meter installation are the result of:

1. Built in systematic errors in the basic meter. These include:
   a. Method of compensation for changes in density of the metered fluid that are temperature and pressure dependent.
   b. Conversion errors in relating temperature sensor output to Temperature. (The effect of this error in the Btu calculation in a condition of low temperature difference (ΔT) between the inlet and outlet temperature sensors can be an error source, but such errors are normally far smaller than errors resulting from the basic errors in sensor calibration.)
   c. Conversion errors in relating flow signal input to a calculated Flow Rate.

2. Basic errors in transducer calibration and installation. These include:
   a. Flowmeter calibration error
   b. Temperature sensor calibration error
   c. Installation wiring for temperature sensors

Error analysis has been performed on each of the above sources with the following results.

1. Systematic errors in the Btu meter:

1.a. Compensation for density changes:
Both the 1550 and 2300 Series Data Industrial Btu meters convert the volumetric flow rate entering the metered area to an enthalpy flow rate by converting the volumetric rate at operating temperature, to a mass flow rate based on the specific density of the fluid at the incoming temperature. The resulting mass flow rate is then converted to an incoming Btu (enthalpic) rate by using an adjusted average specific enthalpy of water over the temperature range from 32°F to 250°F and the pressure range of 15 to 50 psia. The fitting constants are derived from *ASME Steam Tables, Ed IV*, published by the American Society of Mechanical Engineers (1983). Applied to a metered area operating within the range of 32 - 250°F, with a 5 psia ΔP and a 10°F ΔT between the inlet and outlet, the algorithm as implemented has an inherent error of ± 0.43% maximum over the entire range. Standard error of the algorithm results based on actual Steam Table values is 0.237%.

1.b. A/D Conversion errors, temperature sensors:
By actual test in the Data Industrial laboratories, using a precision resistor decade box to simulate temperature sensor resistance, the following % error data over the input range of 32°F to 250°F data was developed:

Sensor Type	Accuracy	Standard Deviation
100Ω Pt RTD, DIN 43760	±0.18%	0.06%
1000Ω Ni RTD	±0.10%	0.05%
10000Ω Thermistor	±0.21%	0.06%

1.c. A/D Conversion errors, Flow Rate calculation:
Flow Rate is measured by the internal system clock which is accurate within ±3 microseconds. The usual frequency range for DI sensors is from 3 Hz to 200 Hz, with concomitant periods of 250 milli-seconds to 5 milliseconds. The greatest % error thus occurs at the 200 Hz level or ±0.06%. Calculations are carried out to 7 decimal digits for a maximum error of 10^{-5} % (0.00001%).

The total basic error of the instrument is found by adding, in quadrature, the individual errors listed above, or ±0.48% for the model described in 1.a above

2. Basic errors in transducer calibration and installation:

2.a. Flowmeter calibration error:

For the purpose of this note, flowmeter calibration error is the variation from true flow rate and that resulting from the use of the calibration constants supplied by the manufacturer. This error affects the reported values of Btu/minute directly, and is independent of the instrument itself. All other things being equal, the % error in flowmeter calibration produces the same % error in Btu output.

2.b. Temperature sensor calibration errors:

Temperature sensor calibration error affects the accuracy of the reported energy flow, with *increasing error* as the operating ΔT *decreases*. For example, in a system operating at a 5°F ΔT using two sensors each with an error of ± 1°F will produce an error of ± 40%. The practice of trimming the paired temperature sensors so that their temperature output is identical at one measurement point can reduce the effect of calibration error, provided that this is done at the mean operating temperature. This zeroing practice could actually increase the error in the readout if performed at temperatures outside the operating range.

Thermistors:

10,000Ω @ 25°C (77°F) thermistor temperature transducers are commercially available as ±0.8°F interchangeable devices. Analysis of resistance/temperature data indicates that the error band actually achieved is a smooth non-linear function decreasing from ± 1.01% @ 32°F to ±0.57% @ 212°F and then increasing to ±1.17% @ 250°F.

Platinum RTDs:

0.00385Ω/Ω/°C, 100Ω @ 0°C, RTD transducers are commercially available as conforming to IEC 751. Analysis of resistance/temperature data indicates that the error band actually achieved is a smooth non-linear function monotonically increasing from ± 0.45°F (1.41 %) @ 32°F to ±0.70°F (0.58%) @ 120°F and then increasing to ± 1.0°F (0.40%) @ 250°F.

Nickel RTDs:

A multitude of Nickel RTDs are available, frequently to proprietary designs, although DIN 43760 may govern the basic specifications. There is little available information on the temperature/resistance tolerances achieved with this sensor, and thus little can be said here. The rule of thumb should be to use as precise a sensor as is economical for the installation. (Of course, the same recommendation applies for thermistors and platinum RTDs, as well.) Note that use of nickel RTDs should be referred to the instrument manufacturer, with temperature/resistance data, so that the proper conversion algorithm can be supplied with the delivered instrument.

2.c. Installation wiring for temperature sensors:

Wiring of the temperature sensors and the flow rate transducer should follow the instrument suppliers wiring specifications. Generally, for the flow rate transducer, shielded twisted pairs of appropriate size should be used with careful attention to any special grounding instructions.

The temperature sensor wiring deserves special attention. Wire sizes appropriate to the basic sensor resistance should be used. Splices in either or both leads from each sensor must be avoided, and termination connections should be carefully used. 100Ω RTDs should be wired to apply at least a 3-wire bridge connection. Thermistors and 1000Ω or higher nickel RTDs are less sensitive to lead resistance. Thermistors are usually wired using a two wire twisted shielded pair. 1000Ω and higher RTDs are usually used to avoid the 3- or 4-wire bridge type of wiring configuration.

Technical Bulletin: 73a

Data Industrial®
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Addendum **September 2002**

Model 340 Programmable Energy Transmitter Accuracy

PRODUCTS
200
4000
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2100
2200
2300 ✓
HTT
WSS

Analysis of the Model 340 Programmable Energy Transmitter measurement accuracy may be divided into two areas:

1. Systematic errors in the 340
2. Transducer measurement errors

1. Systematic errors in the 340

An overall description of general Btu meter accuracy with a detailed look at Data Industrial Btu meter systematic error is provided above in Data Industrial Technical Bulletin 73, "Data Industrial BTU Meter Accuracy". The preceding pages examine errors introduced by ignoring pressure differences, improvements from incorporating thermal density changes, errors introduced by Analog/Digital converter truncation error and system clock induced error. This analysis of systematic meter error applies precisely to the Model 340 as well, and will not be repeated here.

Using the analysis techniques above, the instrument error of the Model 340 Programmable Energy Transmitter may also be shown to be ±0.48%.

2. Transducer measurement errors

2.a Temperature sensor error:

Data Industrial 10,000(thermistors exhibit an absolute error of ±1.01% in expected resistance at 32° Fahrenheit, decreasing to ±0.78% at 122° Fahrenheit. Data Industrial's calibration technique, however, yields a very small error in measured temperature difference even with slightly mismatched thermistor temperature sensors. The Model 340 will provide a temperature difference accuracy of ±0.02° Fahrenheit. Error in BTU measurement will be determined by the ΔT error and the magnitude of ΔT (temperature difference between input and output). With a larger ΔT a smaller BTU measurement error may be expected. For instance, a ΔT measurement of 20° Fahrenheit will be subject to an error of ±0.02/20 or ±0.1%. This would result in an error of ±0.1% in the reported values of BTU/minute.

2.b. Flow sensor error:

Data Industrial flow sensors are delivered with an expected flow measurement error of ±1% in the flow range of interest.

As the instrument and sensor errors will be uncorrelated, the total error is found by adding individual errors in quadrature. The total error for the Model 340 and sensors with a heat exchange medium temperature drop or rise of 20° Fahrenheit will be ±1.1% or an accuracy of 98.9%.