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Real-time Alcohol Concentration and Net Flow Measurement System

Introduction

Measuring Alcohol Concentration is a science. Many companies, organizations and governments depend on precise measurements for process control (recipes) or taxation purposes.

This paper discusses the current methodologies used to measure alcohol concentration (quality) and net flow (quantity) and introduces a new method, which is more accurate and less costly. This method utilizes a Micro Motion® Coriolis flowmeter.

The standard for alcohol measurement has been rigidly defined in Europe as documented in the OIML tables. These tables are utilized for the calculations within the Micro Motion Series 3000 Transmitter.

The relationships of density, temperature and concentration are analyzed to determine expected performance and accuracy.

Current measurement methods

The method that is being used most often in the U.S. is periodic lab measurements and maintaining journals. Concentration measurement is typically done using a hydrometer and thermometer.

Currently in Europe a large gear-driven wheel device, the Weingeistzähler, is in use. This device counts the number of revolutions that the large internal wheel makes and utilizes an internal hydrometer and thermometer which relates this number back to the total volume of alcohol that goes through the device. It is an expensive device (approx. $100,000 US) and requires continuous maintenance. The temperature range of the Weingeistzähler is 0 to 30°C, and the factory calibration accuracy for it is 0.2%, and the field accuracy is 0.5%.

New	Current	
Micro Motion	U.S.	Europe
Advantages		
Low Cost	Accepted Practice	
Reliable		
Accurate		Accepted Practice
Zero Maintenance		
Real Time		
Net Flow, Conc, Temp		
3A Meters Available		
Wide Range Ability		
Disadvantages		
Emerging Technology in this Field	Lab Based	Expensive
Perceived as High Cost	Time Delay	No Longer Available
		High Maintenance

Figure 1. Micro Motion vs. current methods

Coriolis sensor

Micro Motion, Inc. is able to provide the real-time concentration results that institutions need through the combination of density, mass flow and temperature measurements. A Coriolis meter is the combination flow/density sensor device and a transmitter that outputs three process variables (density, mass flow, and temperature) by measuring the response that the flowing fluid has on the vibrating tubes.

Density is directly related to tube period or time that it takes the tube to complete one cycle. The twisting of the tubes, due to a Coriolis effect, is proportional to the fluid mass flow rate. Two pick-offs are utilized on each side of the tube to determine the phase shift of the tubes. Temperature is measured with a simple Platinum RTD (Resistance Thermometer Device) attached to the outside of one of the tubes.

Micro Motion also has a single, straight tube design. This provides a sensor with a clean, unobstructed flow path necessary for most food processing applications. The lack of gears or turbines minimizes cleaning and maintenance costs.

Alcohol (concentration standard)

The OIML (Organisation Internationale De Metrologie Legale - Tables Alcoométriques Internationales) tables are the European standard for measurable alcohol and were utilized as a baseline set of acceptable data. The tables include alcohol mass and volumetric concentration (-20°C to 40°C, 0 - 100%) as well as six other tables of concentration data.

These tables relate density, temperatures and concentrations for mass and volume measurements. Included in the OIML data tables were the coefficients and equations for generating some of the tabular data, including the alcohol

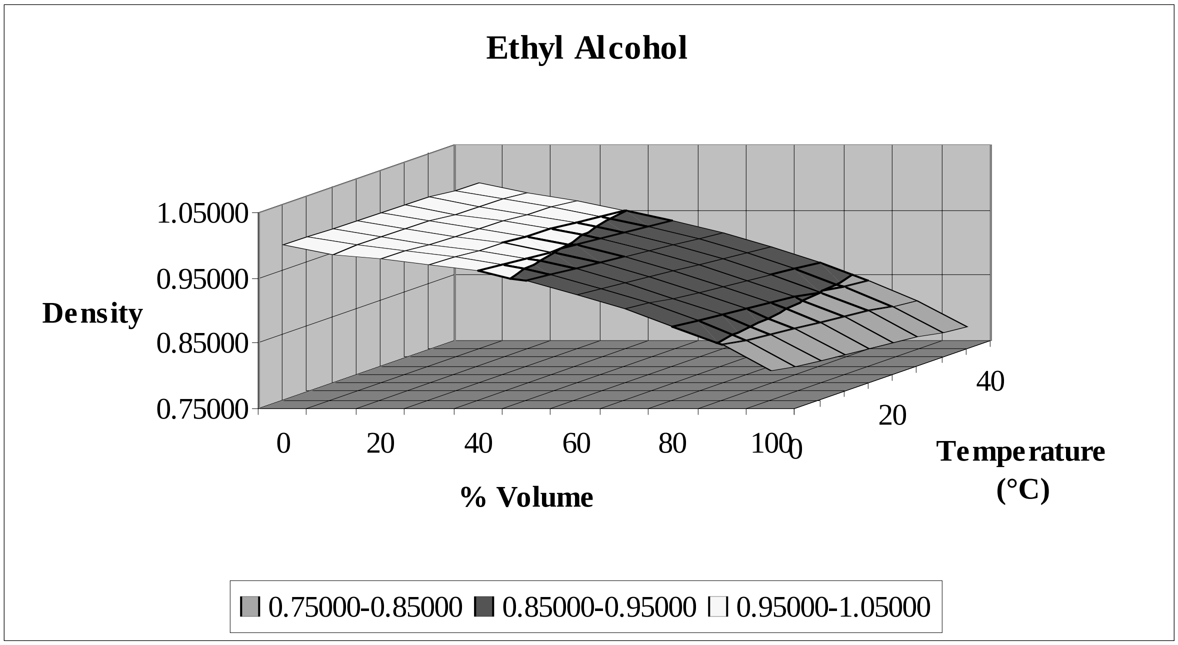

Figure 2. Surface plot of alcohol concentration; 0 - 100%, 0 - 40°C

and water mixture densities at various temperatures and concentrations. These equations were implemented as Visual Basic macros in a Microsoft Excel spreadsheet. The remaining tables were derived by interpolation of the calculated tables using Excel's spreadsheet solver functionality. After generating all of the tables in Excel, a verification was performed to ensure that the data matched the source OIML tables exactly.

Implementing the entire OIML specification in Excel macros allows quick analysis and validation of alcohol applications.

When measuring alcohol using %Mass, there is a conservation factor that is involved that is not present using volume. Mass is always conserved in combining any two fluids. However, volumetric combinations of fluids are not conserved. For instance, mix 50g of alcohol with 53g of water; the resulting combination is 103g of solution. Mix 50cc of alcohol with 53cc of water and the result is a total of 100cc of solution. Unfortunately, industry utilizes the volumetric concentration (%Volume or proof) as the standard, which makes the calculations a little more complex.

Dealing with this non-linearity in addition to the non-linear coefficient of expansion of water produces a complex curve/surface, for the relationship of density, temperature and concentration.

Concentration measurement implementation methodology

Given a range of density, concentration and temperature points, a fourth order linear regression is performed in two directions over the surface data to calculate coefficients that are utilized in the real-time computer to calculate a density at reference temperature curve (see Figure 2.) Another fourth order linear regression is performed over the 'density at reference temperature' curve and the concentrations; this produces the coefficients to calculate the concentration from 'density at reference.' The real-time computer uses the derived coefficients in a series of polynomial equations.

Verification is performed by using the data created from the reduced set of coefficients and comparing against the OIML equations to calculate the mathematical residuals. Entering the data into the sensor's computer allows a final verification; the coefficients are recalculated to a single precision floating point (seven digits), and the concentration calculation is performed in the sensor's computer. After verification the unit is ready for use measuring the %Volume of alcohol in a given application with known accuracy.

It takes significant processing time to calculate the entire range of alcohol concentration in the OIML tables on a desktop PC using Excel. A smaller user-defined range is calculated with a much simpler algorithm inside of the Micro Motion Series 3000 transmitter.

Sensor performance

The performance of the sensor is determined by 2-sigma sensor accuracy. This is determined by the combination of density measurement, temperature measurement and mathematical residual errors. For the most part, these three measurements are independent and the errors are considered stochastic (random and unrelated errors). Temperature has little effect on accuracy at low concentrations; however, at concentrations around 50%, temperature has a greater effect on the accuracy.

As the concentration continues to increase above 50%, the effect that temperature error has on the measurement begins to decrease.

The temperature of the fluid is determined by the change in resistance that is measured in the wires leading to and from the RTD. The RTD is made up of three wires attached to a piece of platinum on the base of a tube and then relayed to the transmitter. Micro Motion has employed a number of methods to improve the temperature measurements. In addition, other means, such as a thermal blanket, can be utilized. This is essentially an insulated jacket on the sensor to protect from outside changes in temperature. Also available is a RTD that is in a protective coating that can be immersed into the fluid as it flows through the sensor to eliminate outside influences. Both methods correct most environmental influences that may bias the temperature accuracy.

Density errors are relatively small. The accuracy of ±0.0005 g/cc relates to 'out of the box' performance in concentration measurement. A density repeatability of ±0.0002 g/cc can be used for accuracy if a field adjustment to the concentration is made.

The density measurement error is a function of the temperature error and then adding the factory-determined performance for the sensor. The temperature measurement error is determined by multiplying the concentration/temperature slope by the temperature error. Using the methods mentioned above, we are able to calculate the estimated performance very reasonably (see Figure 3.)

The performance for the user's given ranges of process temperature and concentration is determined. This is calculated by taking the root, sum, squares of the density error, temperature measurement error, and the residuals for the curve fit error. The smaller the ranges defined by the user, the more accurate the performance.

Field tests

Alcohol applications are currently being used at the following locations, and Micro Motion has received government approval in Eastern Europe.

In Jim Beam Brands (JBB), Invergordon Grain Distillery, a sensor was installed on a by-pass stream on the outlet of the kettle still. The operating temperature was in excess of 80°C and this temperature is outside the limits of the OIML tables, which only provides densities for temperatures up to 40°C. However, Micro Motion obtained a set of curves based on physical testing up to the required temperature. This allowed Micro Motion to configure the Series 3000 Transmitter to give reference density at 20°C for the measured concentration. The unit was installed on a trial basis, proved successful and was purchased. Since this unit is for process control only, government approval was not required.

Another U.S. company is using the Micro Motion meter to control proof from 100 to 160 (50% - 80%) in a distilling process. They purchased additional sensors for additional plants.

In Hungary, Micro Motion's meters replaced the Weingeistzähler (old wheel device). After one month of government testing in field conditions, the accuracy was demonstrated to be 0.02% at high concentrations.

Customer benefits

- Process control - consistent production, cost controls
- Quality control of received product
- Production/utilization of alcohol products

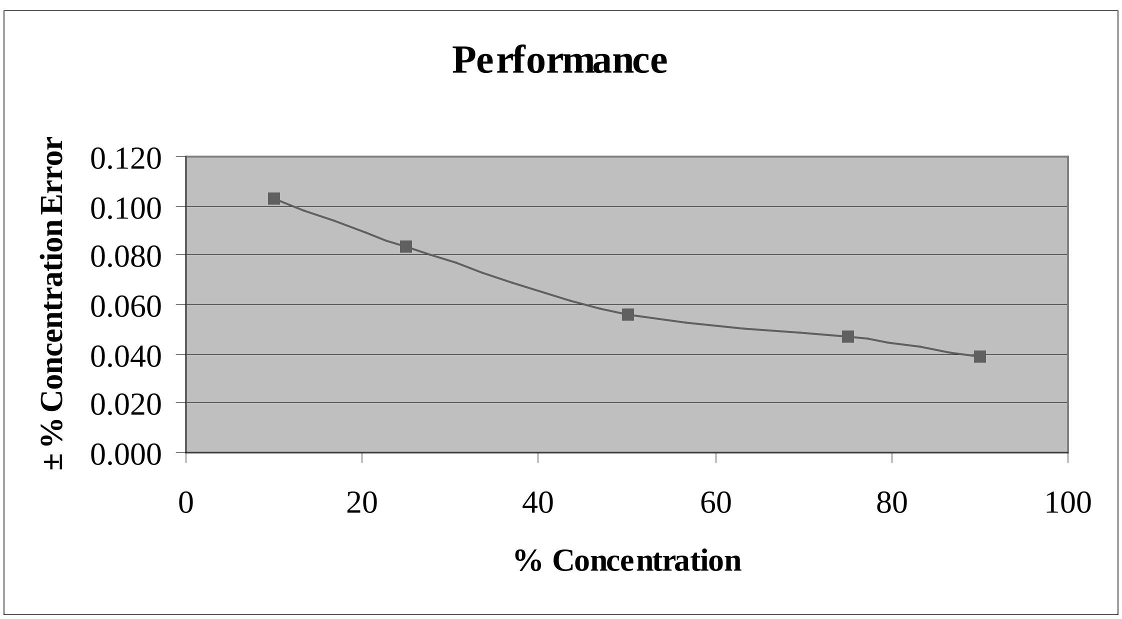

Figure 3. Performance @ 20°C -- Data Range Entered 0° - 40°C; 10% - 90%

- Minimal/no maintenance

This technology applies to other areas for concentration measurements such as:

- Similar use for sugars; Micro Motion developed and validated Excel macros to create the concentration/density/temperature tables for fructose, dextrose, and sucrose blends
- Starches, cooked and uncooked

Conclusion

The Micro Motion Coriolis sensor is a more reliable, accurate, and time-efficient way of measuring alcohol.

Micro Motion is able to fit the curves to the data that is specific to each application and Micro Motion can aid in finding data, if a customer does not have any. With a Micro Motion Coriolis meter, the calculations are all done internally and the customer sees only the desired display. The Series 3000 Transmitter can display concentration (proof), temperature, as well as gross and net flow, and can control the process (batching).

References

(1) "Tables Alcoométriques Internationales" Organisation Internaionale De Metrologie Légale

Presented at the 2000 IFT Annual Meeting & IFT Food Expo in Dallas, Texas - June 12, 2000

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WP-00595