Selection and Calibration of a Turbine Flow Meter

Turbine flow meters have been an effective flow measurement technology for many years. Advancements in other measuring technologies in recent years have provided many options when selecting a meter for a flow measurement application. This has the benefit of allowing the user to select the measuring technology that provides the optimum characteristics for the specific application. The downside of all these measurement options is the user must have a significant understanding of many technologies in order to make the best educated decision when selecting the meter.

The intent of this paper is to provide the reader with a basic understanding of the operational characteristics and calibration methods of turbine flow meters. The information provided is targeted at liquid meter applications. Turbine meters are also successfully used in gas applications. The operational characteristics of gas meters are basically the same as liquid meters, however the calibration methods and procedures are worthy of a paper specific to gas applications and will not be address at this time.

Turbine meter operation

A turbine flow meter is a volumetric flow metering device. The meter consists of a rotor and bearing assembly suspended on a shaft, which is mounted to a support device. This assembly is mounted inside a housing with a known internal diameter. (See figure 1) As fluid passes through the flow meter housing the rotor will spin at a rate proportional to the volume of liquid passing through the housing. A magnetic or modulated carrier pick-off sensor is used to detect the passage of each rotor blade and generate a frequency output. The frequency output can be read directly with the end users electronics or further processed to convert to an analog output, linearized or compensated for temperature variations.

There are several characteristics of turbine flow meters that make them an excellent choice for some applications. The flow sensing element is very compact and light weight compared to various other technologies. This can be advantageous in applications where space is a premium. Examples of these applications are; on board aircraft, marine vessels and motor vehicles; in subsea control pods and ROVs used in the oil and gas industry; and on R&D and production test equipment. The speed of response of a turbine is dependent on the size and mass of the rotor and the fluid being measured. Typically the response time is very fast, on the order of 5 ms. When correctly calibrated by a quality laboratory, turbines have a repeatability of +/-0.05% and can achieve an overall accuracy of +/-0.25% of reading over a wide turndown. A feature which is often not associated with turbines, is the ruggedness of the design. Turbines are unaffected by vibration. They are often used on aircraft, missiles, military weapons delivery systems and racing vehicles of various types. High shock designs for the turbine are also available making them very resistant to hydraulic fluid shock forces.

Calibration Systems

With any flow measurement instrument, the overall system accuracy achieved can be no greater than the equipment used to perform the calibration. There are several possible calibration techniques, positive displacement, time weigh, field prover, and the old stand by, bucket and stop watch. The technique that will be discussed here is the positive displacement calibrator. (See figure 2) A positive displacement calibrator utilizes a precision machined measurement chamber, or flow tube, that houses a piston. This piston acts as a moving barrier between the calibration fluid and the pressurizing media used to move the piston. Attached to the piston is a shaft that keeps the piston moving in a true path and provides the link between the piston and the translator. The translator converts the linear movement of the piston through the precision flow chamber into electrical pulses that are directly related to the displaced volume. Calibrators of this style can be directly traceable to the National Institute of Standards and Technology via water draw validation. Total accuracy of this type of calibrator is conservatively specified at 0.05%.

The calibration data that is recorded and normally presented in tabular format consists of: The frequency output of the meter at each data point, the corresponding fluid flow rate for each frequency and the K-Factor, or pulses per unit volume of fluid for each data point. Also presented for use when temperature compensation is required is the ratio of meter frequency divided by the kinematic viscosity of the calibration fluid. Typically ten data points are taken throughout the repeatable flow range of the meter however up to fifty data points can be taken if desired. The more data points taken, the better defined the meter calibration curve will be.

Typically a turbine meter will have a “normal 10:1” flow range where the K-Factor remains linear and the “extended” flow range where the meter maintains the specified repeatability, however the linearity of the K-Factor will be reduced. (See figure 3) With multiple calibration points to define the curve and processor based electronics to perform curve fitting calculations, outstanding accuracy can be maintained throughout the entire extended flow range. Care must be taken when using turbines with a single average K-Factor. When using only a single point from the calibration curve, the variation in linearity with flow rate is unknown. Accuracy of the reading will be reduced as the flow rate of the meter varies, and because the actual calibration curve is unknown, the amount of error will not be known.

Viscosity Effects

A factor that must be taken into account when applying a turbine flow meter is the operating kinematic viscosity of the fluid to be measured. Viscosity is the characteristic of a fluid which causes it to resist flow. The higher the viscosity, the greater resistance to flow the fluid will have. Turbines are designed to measure the velocity of the fluid passing through it, however the viscosity of the fluid also has an effect on the rotational speed of the rotor. Figure 3 was performed at 1 centistoke, or water. Water is a standard calibration media that many flow meter manufactures use. The media is low cost, easy to work with, none hazardous and easy to dispose of. Applying the turbine in an operating viscosity different from what the meter was calibrated at will create an offset in the calibration curve. Figure 4 demonstrates the effect of viscosity variations from 1 to 100 centistoke on a ½" meter. The amount of shift in the K-Factor curve can be significant depending on the viscosity variation. The amount of offset is also dependant on the flow rate of the meter. The lower the flow rate within the capable range of the meter, the greater the offset. In this example there is approximately 3% difference between the 1 centistoke and 100 centistoke curve at 5 GPM and 57% offset at 0.05 GPM. A common request is to provide a correction factor that can be applied to a calibration at one viscosity, to obtain corrected data at a different operating viscosity. As can be seen from the nonlinear nature of the offset to the curve, a single correction factor is not possible. In order to maintain the highest accuracy the flow meter should be calibrated at the same viscosity as the fluid it will be used to measure.

Real Time Correction for Viscosity and Density Variation

In many applications the viscosity of the fluid to be measured will change during the measurement period. In some situations the viscosity and density of the measurement fluid changes due to a physical change to the mixture of the fluid. In these situations the turbine meter will not be the best choice for a measurement instrument. However in most applications the density and viscosity is changing due to variations in the operating temperature of the fluid. In a Newtonian fluid as the operating temperature of the fluid increases, the kinematic viscosity and density decreases. In these situations the turbine can be an effective measurement instrument when properly calibrated. In order to correct for viscosity changes the relationship of temperature verses viscosity must be known for the fluid and the operating temperature range of the measurement must be known. With the operating kinematic viscosity range known, the turbine meter is calibrated at multiple viscosities covering the operating range. The meter will require a calibration for every factor of ten that the viscosity changes. For example a fluid with an operating range of 1 to 100 centistokes would require a multiple point calibration at 1, 10 and 100 centistokes. This data is then presented on a semi log plot called a Universal Viscosity Curve (UVC). The UVC is formed by plotting the meter K-Factor on the linear scale and frequency divided by kinematic viscosity on the logarithmic scale. (See figure 5) The result of this plot is one continuous curve covering the range of possible meter frequencies and viscosities.

Real time volumetric flow is obtained by measuring the operating temperature and addressing a temperature verses viscosity look up table to determine the operating kinematic viscosity. The frequency is measured directly from the flow meter and divided by the kinematic viscosity. This ratio of frequency and viscosity is used to determine the correct K-Factor for the specific operating temperature and viscosity. One additional factor that should be taken into account to obtain a temperature corrected flow rate, is the expansion or contraction of the meter housing due to the temperature variation from the calibrated condition. This correction is based on the thermal coefficient of expansion of the flow meter housing and can be accomplished through the use of two dimensionless numbers, Strouhal and Roshko. The Roshko correction is applied to the frequency/viscosity parameter and the Strouhal correction is applied to the K-Factor parameter. A full derivation of these parameters can be found in a paper "The Characterization of a Piston Displacement-Type Flowmeter Calibration Facility and the Calibration and Use of Pulse Output Type Flowmeters" by Dr. G.E. Mattingly with the National Institute of Standards and Technology.

In cases when a mass flow rate is desired over a volumetric measurement one additional table can be added to the electronics to determine the temperature verses density of the fluid. The corrected volumetric flow rate can then be multiplied by the fluid density at the operating temperature, achieving a real time corrected mass flow rate. Figure 6 is a block diagram indicating the temperature correction for viscosity, housing dimensional changes and density that would be performed by the manufacture supplied flow computer or within the end users data acquisition system.

Summary

Turbine flow meters are a tried and proven technology that offer the benefits of minimal size and weight, high accuracy and fast speed of response, rugged construction and a favorable cost compared to other measurement technologies. When specifying a flow measurement technology for an application the user needs to be aware of the benefits and limitations of the various technologies in order to make the best decision. The intent of this paper was to show that when properly calibrated, turbine meters can provide an accurate option for applications of various viscosities and in situations with viscosity and density changes due to temperature variation.

Figures

Figure 1

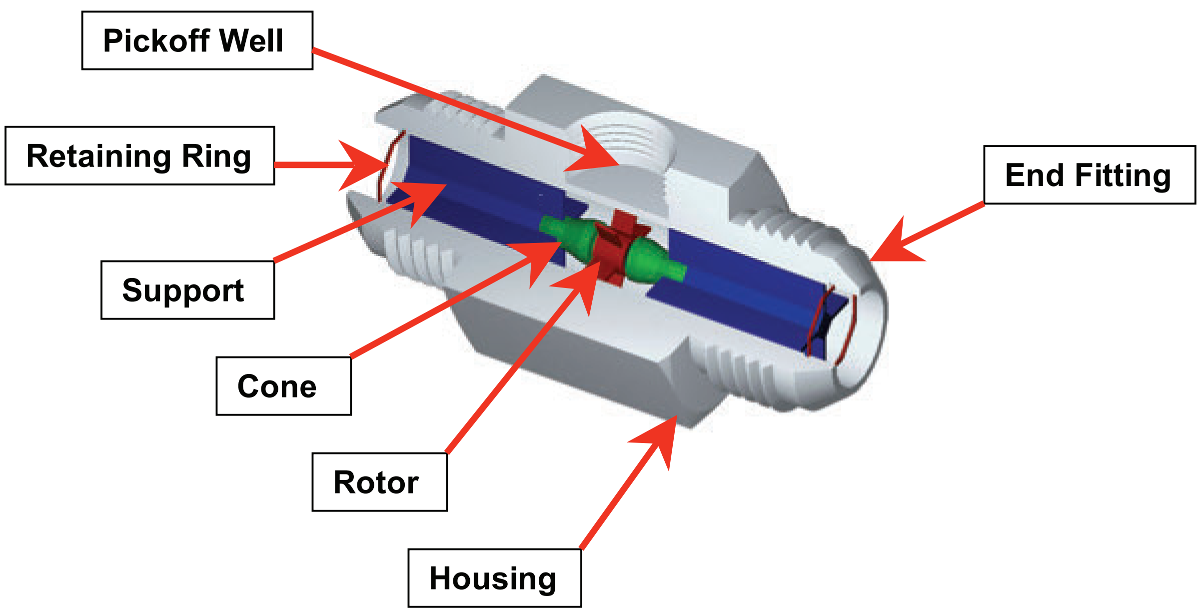


Figure 2

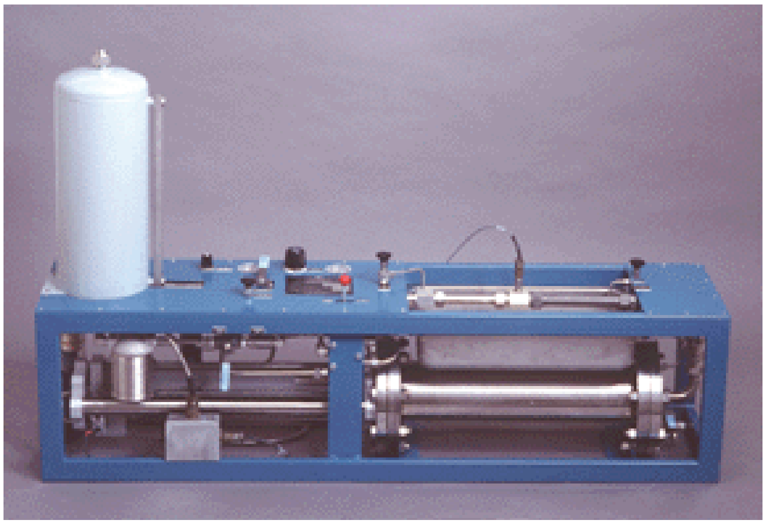


Figure 3

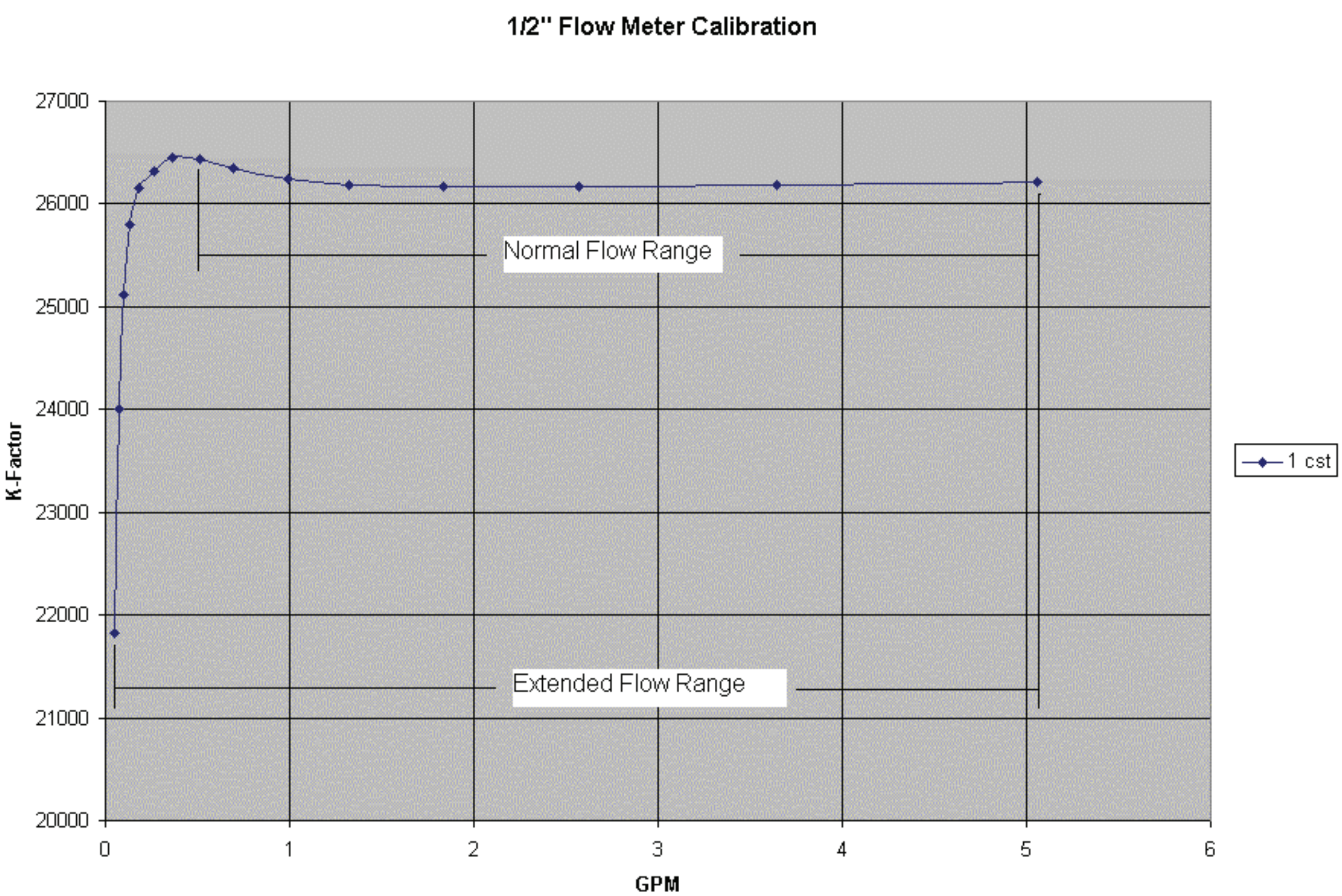


Figure 4

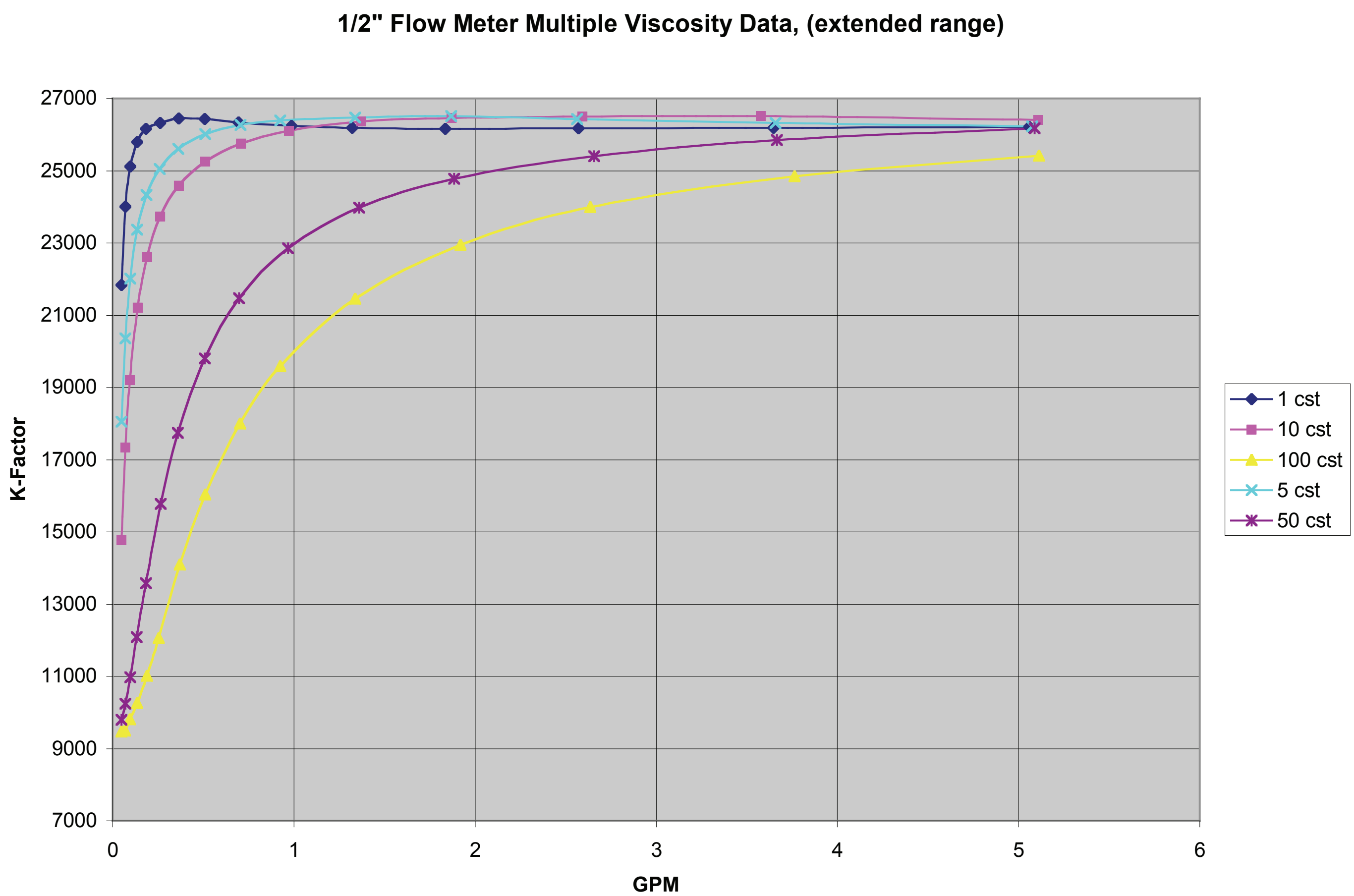
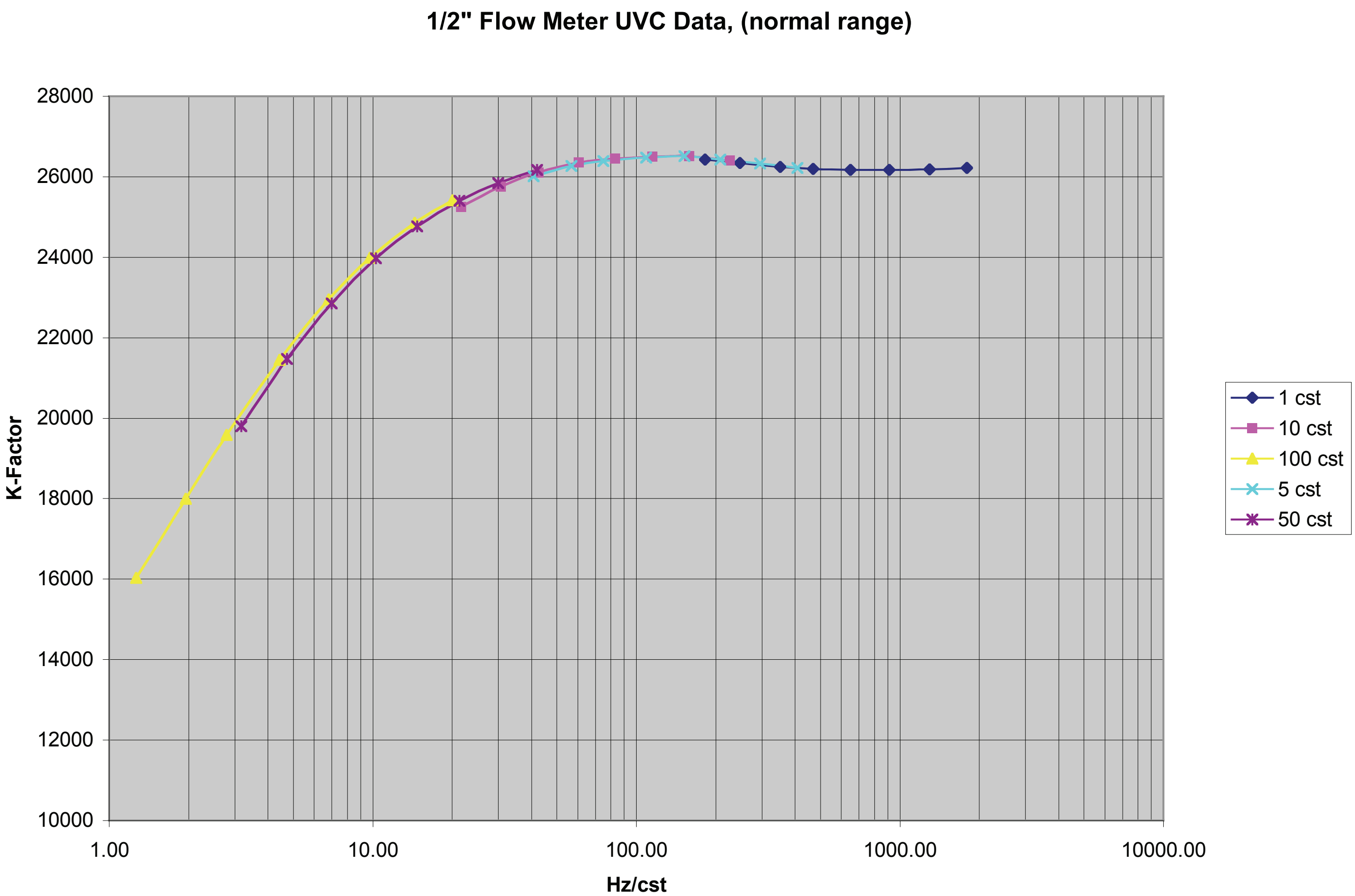
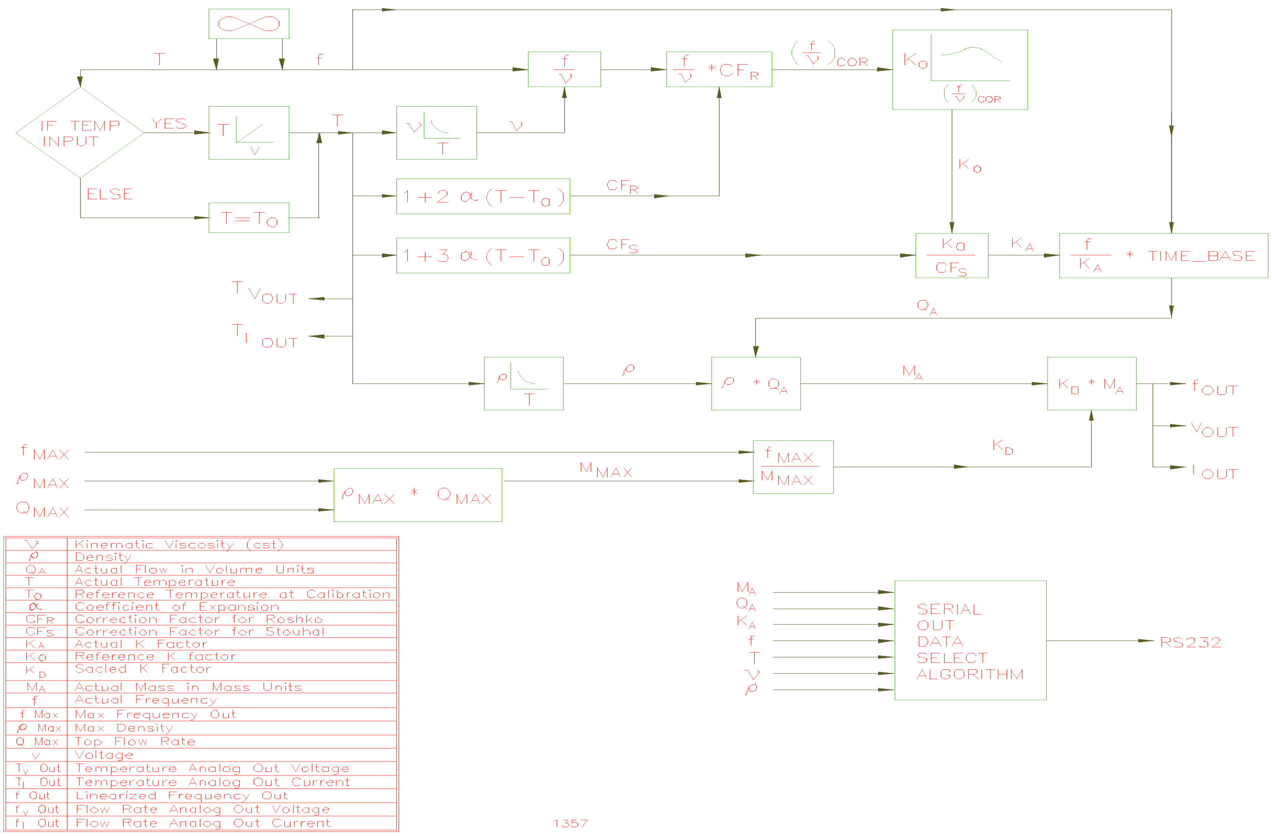

1/2" Flow Meter Multiple Viscosity Data, (extended range)
K-Factor
27000
25000
23000
21000
19000
17000
15000
13000
11000
9000
7000
0
1
2
3
4
5
6
GPM
1 cst
10 cst
100 cst
5 cst
50 cst

Figure 5


1/2" Flow Meter UVC Data, (normal range)
K-Factor
28000
26000
24000
22000
20000
18000
16000
14000
12000
10000
1.00
10.00
100.00
1000.00
10000.00
Hz/cst
1 cst
10 cst
100 cst
5 cst
50 cst

FLOW TECHNOLOGY

Figure 6



ν	Kinematic Viscosity (cst)
ρ	Density
Q_A	Actual Flow in Volume Units
T	Actual Temperature
T_O	Reference Temperature at Calibration
α	Coefficient of Expansion
CF_R	Correction Factor for Roshko
CF_S	Correction Factor for Stouhal
K_A	Actual K Factor
K_O	Reference K factor
K_D	Sacled K Factor
M_A	Actual Mass in Mass Units
f	Actual Frequency
f Max	Max Frequency Out
ρ Max	Max Density
Q Max	Top Flow Rate
v	Voltage
T_V Out	Temperature Analog Out Voltage
T_I Out	Temperature Analog Out Current
f Out	Linearized Frequency Out
f_V Out	Flow Rate Analog Out Voltage
f_I Out	Flow Rate Analog Out Current

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