# IN LINE FLOW-METER CALIBRATION
# ADVANCE METHODS AND SOLUTIONS

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**ABSTRACT:**

The demand for in-line Liquid Flow-meter and Flow-systems calibration has increased due to ISO 9000 requirements and environmental control demands. How can these tasks be accomplished? What are the sources of errors? How can these errors be minimized? A new concept for a PC based transfer standard for volumetric and mass flow calibration will be presented. This portable standard covers from very low flow to medium flow ranges. Measurement concepts for flow and density are analyzed. Error sources along with practical, economical solutions to minimize these errors are presented, along with actual data, using oil, gasoline and water calibration.

**1.0 INTRODUCTION:**

Liquid flow calibration is a complex process due to numerous variables that can affect accuracy. As ISO 9000 and ANSI/NCSL Z540-1 [1] requirements became wide spread standards, the calibration method used needs further examination. To comply with these standards, we need to examine the liquid flow calibration process from a "system" approach, in order to assure that the overall uncertainties present during the flow calibration and measurement process meet the 4 to 1 ratio of allowable measurement tolerance to system errors.

When flow-meters are used in test stands, engine test cells or process lines, the "traditional" methods of calibration are:

1.1 Remote Calibration: Removal of the flow-meter from its location and sending it to be calibrated against secondary or primary flow standards. Once calibrated, the new calibration factors are entered to the existing data acquisition system (such as PLC, flow-computers or PC). The remote calibration against primary standards seems to offer higher accuracy. However, from a "system" approach this assumption is not necessarily true. Moreover, this is an expensive and labor intensive practice.

1.2 Connecting a "reference flow meter", typically of the same type used, in line with the unit under test (uut). This approach gives the user a better understanding of the "system" performance, as the calibration is performed with the same liquid used, at similar flow conditions. This method usually degrades the accuracy of the flow measurements. As most flow sensors present their greatest error at the low end of the flow range, more than one reference meter may be required to cover the flow range, which makes this method cumbersome. Furthermore, improper compensation of the reference flow meter's original calibration to actual test conditions can add measurement errors which are unknown and not controlled. For example, using turbine meters which were calibrated at one viscosity, to certify flowmeters at different viscosities can result in significant measurement error.

1.3 Electrical signal calibration of the flow system. This approach is widely used in the process industry where the flow-meter output is disconnected from the data acquisition system, and electrical signals (frequency, current or voltage) are "injected" to calibrate the flow system based on the original calibration certificate provided by the meter manufacturer. This is only part of the sensor calibration process, which does not comply with the basic calibration concept to know the current and actual flow sensor performance, and therefore does not comply with ISO-9000 and ANSI/NCSL Z540-1 requirements.

The lack of current methods to fully comply with the new requirements, as well as the need to identify the performance of liquid flow meters as actually used, led us to develop the FLO-CAL (Figures 1 and 2). The FLO-CAL is a portable liquid flow transfer standard, which is designed to "map" a primary flow standard, and to compensate for known measurement uncertainties during actual use. The FLO-CAL can calibrate various liquids and various flow ranges with turn down ratio of 1000:1 or better using an automatic flow manifold with multiple standards.


**2.0 LIQUID FLOW MEASUREMENT, DEFINITION AND ANALYSIS:**

In order to understand the liquid calibration process, and its possible measurement errors, it is important to present the following equations and definitions:

** Liquid Measurement Type: Two types of flow measurements exist, Volumetric Flow and Mass Flow. The relation between these two flow types:

$$1) \quad \dot{m} = Q*Den = Q*Den|_{water} * S.G\ (T)$$

where:

$\dot{m} =$ Liquid mass flow rate, mass per time (kg/hr, lb/min, etc.).
$Q =$ Volume flow rate, volume per time (cc/min, gpm, etc.).
$Den =$ Liquid Density (lb/ in$^3$ , gr/cc).

Figure 1: Liquid Flow Calibration Cart- FLO CAL for high flow rates



Figure 2: FLO-CAL Cart for Low Flow with Density Standard and Hazardous Environment

*Den|water*= Water Density at 60 Deg. F (8.337176 lb/Gal or 0.999014 gr/cc [2] ).
*S.G (T)*= Liquid specific gravity, function of temperature (dimensionless).

From Equation 1, it is clear that density measurement is part of flow measurement, especially when the flow meters or standards are volumetric devices.

** The Continuity (mass conservation) equation: The continuity equation for non-compressible fluids (such as homogenous liquids at low pressure) states that the mass flow does not vary for a closed system. This concept stands behind any in-line flow calibration.

** Specific Gravity and Density: For liquid flow the density is temperature dependent, and type/batch of liquid. This relation can usually be described mathematically. Pressure affects on density exist due to liquid compressibility. However, when the calibration process takes place under 100 psig, the compressibility affect can be neglected and therefore is not discussed in this paper.

** Referred Specific Gravity: Specific gravity that is calculated based on temperature measurement and one of the following methods:

Specific Gravity for hydrocarbon liquids, NACA equation [3] :

$$3) \qquad SG\ (T)= SG\ (60)*(1+ CTE*(60-T))$$

where:
SG(T)= Specific gravity at Temperature.
SG(60)= Specific gravity at 60 Deg. F.  This variable represents the liquid properties.
T= Liquid Temperature (Deg. F).
CTE= Coefficient of Thermal Expansion:

$$4)\ CTE= 0.00440045-0.00903036*SG(60)+0.00612777*SG(60)^2 - 0.00113412*SG(60)^3$$

or, density for hydrocarbonate liquids, the API/ISO method [4] :

$$5)\ DEN\ (T)= DEN\ (15)*\ e^{-\alpha\cdot(T-15)\cdot(1+0.8\cdot\alpha\cdot(T-15))}$$

 where:
*DEN (T)*= Liquid density at Deg. C (kg/m$^3$ )
*DEN (15)*= Liquid Density at 15 Deg. C (kg/m$^3$ )
*T*=  Liquid Temperature (Deg. C)
$\alpha$ = Tangent Thermal Expansion Coefficient per Deg. C at 15 Deg. C, calculated as:

$$6) \qquad \alpha = \frac{k0 + k1* DEN(15)}{DEN(15)^2}$$

K0 & K1 are constants that vary for different density ranges [4] .
Figure 3 presents the referred specific gravity versus temperature difference (% of reading) of the two methods, for fuel oils. For hydrocarbonate liquids in the density range of 779-839 kg/m$^3$ , such as jet fuels, that difference is under 0.01%, and therefore,

considered negligible, however, for other hydrocarbon oils this difference is not negligible and the API/ISO method [4] should be used. Using the "referred density method" requires liquid temperature measurement, and the specific gravity at 60 deg. F or 15 deg. C, which can be obtained by sampling the batch of liquid used.
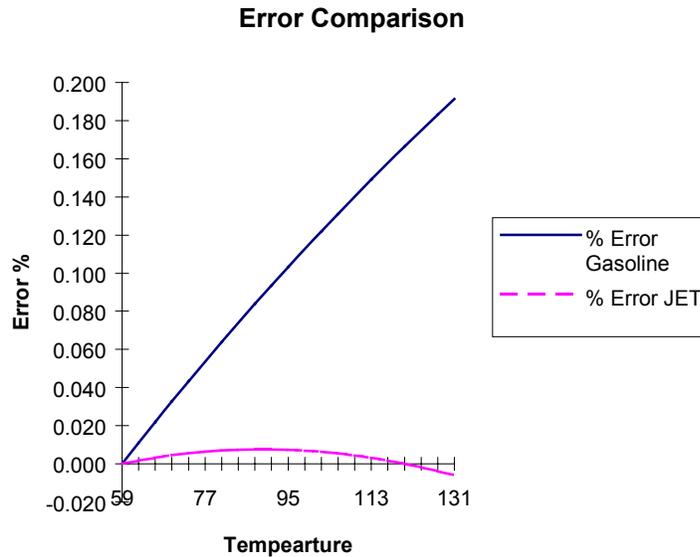
**Error Comparison**



Figure 3: SG error (% readings) vs. temperature comparison

For pure water density calculation can be based on existing water tables [2].

** Direct Density Measurement- Density measurement based on in-line density meters. These meters are typically based on vibrating tube and natural frequency concepts.

** Unit (flow-meter) Under Test Output:  Few types of electrical outputs exist, and can be identified into three main groups:
  - Frequency Output:  For this type of meter, a K factor is established during the calibration process.  Units are cycle/unit of volume or cycle/unit of mass.
  - Analog output meters:  Where the electrical signal is in mA or volts, analog signal vs. flow as well as slope and offset of the uut are the desired calibration results.
  - Flow-System or mechanical meters: Where comparison to known flow is the desired calibration result.

For frequency output meter, the flow is calculated as [6]:

7)
$$Q = \frac{f * TF}{K}$$

or

5

$$8) \qquad \dot{m} = \frac{f * TF}{K}$$

where:
Q= Volumetric flow (l/min, gpm, etc.)

$\dot{m}$ = Mass Flow  (kg/hr, etc.)
TF= Time Conversion factor (60 or 3600)
f= UUT frequency (Hz)
K= K factor of the flow (pulses/cc or pulses/kg etc)

For these flow meters, their nonlinearity error for a given flow point is defined as:

$$9) \qquad Linearity\_error(\%) = \frac{K - Kmean}{Kmean} * 100\%$$

## 3.0  COMMON SOURCES OF UNCERTAINTY DURING LIQUID FLOW CALIBRATION:

The uncertainty and errors during in-line flow meter calibration are of great importance as they are repeated during the actual usage of the flow meter.  Due to a large variety of liquid flow meters, we may not be able to cover all cases.
The sources of uncertainty are divided into two types [5] : 1) random and 2) systematic.

1) Random Sources of Uncertainty and Errors:

* Flow Stability.
* Non homogeneous fluid.

2) Systematic Sources of Uncertainty and Errors:

* Temperature variation along the flow path (affects liquid).

* Temperature affects on flow calibration/measuring devices.

* Liquid variations, which result in viscosity change from the calibration conditions.

* Pressure affects on liquid compressibility

**\* FLOW STABILITY:**

Most flow devices are "real time" devices that will follow the average flow rate. However, in "real life" flow varies, due to its natural turbulence, and mostly because of the flow source variations. Many times, the flow instability is greater than the measurement uncertainty of a flow meter, when calibrated against a primary standard. We will define the following terms, which will describe mathematically an actual flow stability:

$$10) \quad FLOaverage = \frac{\sum_{i=1}^{n} FLO(i)}{n}$$

where:
$n$= number of consecutive flow readings
*FLOaverage*= Average flow rate
*FLO (i)*=      Instantaneous flow readings

$$11) \quad TREND(\%) = \frac{FLOaverage - FLO(i)}{FLOaverage} *100\%$$

$$12) \quad VAR(\%) = \frac{FLO\_Std\_Dev}{FLOaverage} *100\%$$

where:
*TREND (%)*=  Flow Trend based on instantaneous reading compared to average flow readings.
*VAR (%)*= Flow variation, which is the continuous variation of the standard deviation of the flow, calculated based on n consecutive flow readings .
*FLO_Std_Dev = Flow* Standard Deviation based on n consecutive readings

$$13) \quad FLO\_Std\_Dev = \sqrt{\frac{\sum_{i=1}^{n}(FLO(i) - FLOaverage)^2}{n-1}}$$

If during continuous flow measurement, a "buffer" of n flow readings is set, and the buffer updates in FIFO method, then the calculated trend 11) and variation 12) represents the characteristics of the "real time" flow. The VAR enables us to define, using statistical tools, the fluctuations of the flow that results in flow measurement variance.

As different flow meters and flow standards have different time constants, it is important to control the flow to achieve an adequate level of flow variance, such that the level of statistical confidence in the calibration process will be satisfactory.

For example, if the flow standard combined uncertainty is 0.2% of reading, and the flow variance is only 0.2%, to achieve 95% confidence level (+/- 2 Std. Deviations), the combined flow calibration process uncertainty [5] is 0.45%.

It is obvious that flow stability is a major source of uncertainty during actual usage of the calibrated flow meter, which affects the overall measurement uncertainty. Therefore, only an in-line calibration process which uses the same flow source can identify this type of error. The user of the flow meter must add this measurement uncertainty to the overall flow measurement system uncertainty using common error analysis methods [5].
It is important to realize that flow VAR as defined in eq. 12) is a relative value and at low flow conditions, this value can be a large absolute number.

* NON HOMOGENEOUS LIQUID:

During calibration and actual flow measurement of liquids, the common assumption is that the fluid is homogeneous, and the flow is a single phase flow. The calibration set up should allow for means to assure homogeneous, single phase flow. For example, when using gasoline as a liquid, vapor or bubbles will change the flow characteristic. Therefore, vapor traps, or maintaining the liquid at low temperature, should be included in the set up. This error affects all flow meters, and can be detected by high flow variations or unstable liquid density.

* TEMPERATURE AFFECT ALONG THE FLOW PATH:

When dealing with the volumetric type of flow meters and standards (such as turbine meters, provers, positive displacement meters), variation in liquid temperature between the standard and the unit under test (uut) will result in liquid density changes. From equation 1,3 and 5 it can be shown that for some hydrocarbonate liquids, 1 Deg. F will result in approx. 0.05% variation in volumetric flow measurements between the standard and the uut. To minimize this error, where significant temperature difference exists, it is important to correct the volumetric flow based on UUT liquid temperature using the above mentioned equations.

* LIQUID VARIATIONS, WHICH RESULT IN VISCOSITY CHANGE FROM THE CALIBRATION RESULTS:

When using turbine meters as transfer standards, or when calibrating turbine meters, it is important to understand that the accuracy of this meter, relative to any calibration, is strongly dependent on its viscosity. Various tools were developed [6] to generate a "universal K factor" to enable the user to use a meter which was calibrated at different conditions, off line. Figure 4 presents K factor vs. Frequency of a turbine meter at various viscosities, when calibrated against a gravimetric primary standard. Figure 5 presents the same turbine meter K factor vs. f/v (the universal K factor chart).
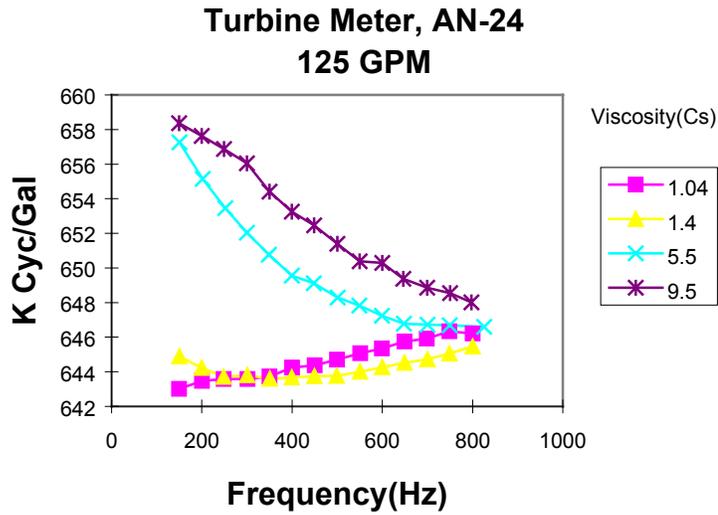
**Turbine Meter, AN-24**
**125 GPM**



Figure 4: K factor vs. Frequency for Various Viscosity Ranges
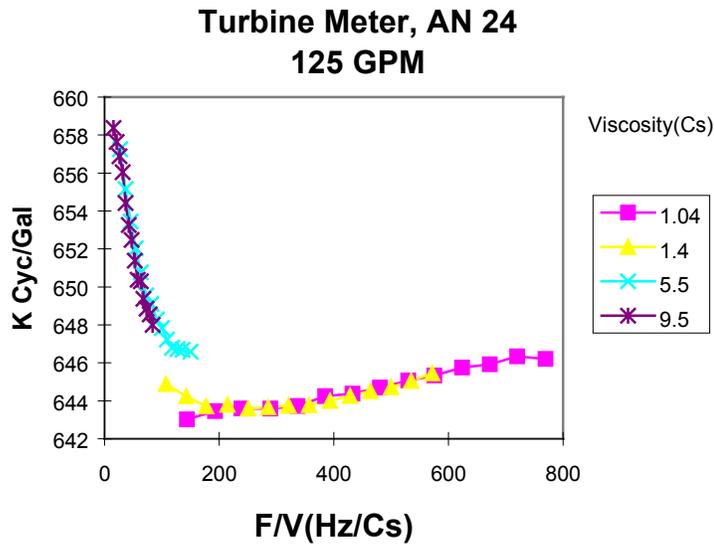
**Turbine Meter, AN 24**
**125 GPM**



Figure 5: K factor vs. F/V for Various Viscosity Ranges

Figure 6, shows K factor vs. frequency/viscosity of a smaller turbine meter. It is obvious that the universal K chart for turbine meters is applicable for a limited range of viscosity. Some manufacturers claim measurement accuracy of 1%, using this method. Comparing figure 5 and 6 indicates that different turbine meters (size and design) present different sensitivity to viscosity changes. The wider the range, the larger the measurement error (and it can be larger than 1%). Therefore, for best results, the calibration and usage of a turbine flow meter should be at the same viscosity range.
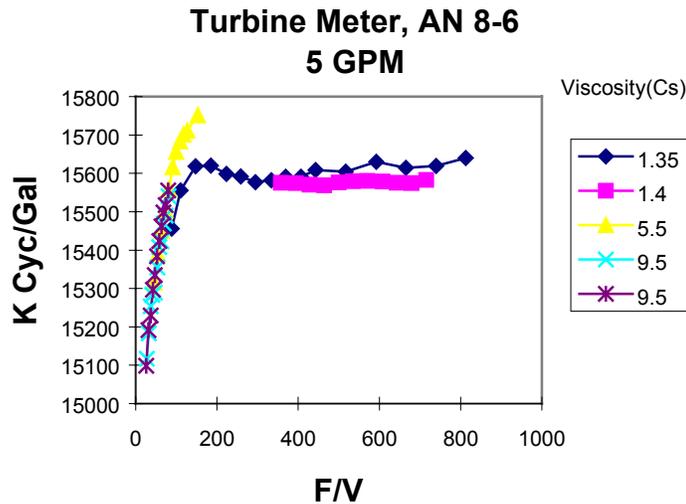
**Turbine Meter, AN 8-6**
**5 GPM**

Figure 6: K factor vs. F/V for Various Viscosity Ranges

\* PRESSURE AFFECT ON LIQUID COMPRESSIBILITY:

As mentioned above, during a calibration process that takes place under 100 psig, the affects of pressure on density are negligible (under 0.01% of reading). However, when in-line calibration is performed at higher pressure, density measurement or calculation, should be compensated for compressibility affect per common practices [7].

 \* TEMPERATURE AFFECT ON FLOW CALIBRATION/ MEASURING DEVICES:

The pressure and temperature, when significantly different from the original calibration condition will result in measurement error. This error can be compensated based on flow device pressure and temperature. For many flow sensors, temperature and pressure changes result in volume change of the measured volume. For example, for a cylindrical flow sensor, a temperature increase will increase the volume per the same amount of output cycles, therefore result in reduction of its K factor. For some meters, it can be shown that the variation of K factor, due to thermal expansion is in the magnitude of:

$$13) \qquad K(T) = K_{cal}/(1 + 3 * \alpha * (T - T_{cal}))$$

where:

$K(T)$= K Factor at temperature T.
$K_{cal}$= K Factor at sensor calibration temperature.
 $\alpha$  =  Linear thermal expansion coefficient (in/in/Deg. F)
$T - T_{cal}$= Temperature difference actual temperature from cal. temperature. (Deg. F)

The thermal expansion coefficient depends on the material of which the standard/sensor is constructed. For a stainless steel housing, a 10 degrees increase from the calibration

conditions results in 0.03% of reduction in the K factor. However, temperature increase will also increase the flow gap between the internal parts of some meters (as turbine or positive displacement flow-meters), and with reduction of viscosity will increase the leak flow (blow-by flow) around the moving elements.

To minimize this uncertainty, and for steady state conditions (equal liquid and meter temperature), measuring the temperature and compensation for variations from calibration temperature, will increase measurement accuracy.

The above mentioned random and systematic sources of uncertainties and errors, indicates that only a well designed, in-line calibration method will enable us to calibrate and define the overall performance of a flow system.

## 4.0 FLO-CAL, A LIQUID FLOW TRANSFER STANDARD, MEASUREMENT AND DESIGN CONCEPTS:

In order to accomplish an in-line flow calibration, the following measurement and design concepts were applied to the FLO-CAL, a flow transfer standard:

1) The FLO-CAL is a portable and compact unit.

2) The FLO-CAL, covers large flow turn down ratio (up to 1000:1) with multiple flow standards and an automatic flow control that is transparent to the operator.

3) The FLO-CAL "maps" a flow primary standard through the desired measurement range.

4) The FLO-CAL includes means to compensate for systematic uncertainties as measured during field calibration, and display or limit random errors. Measured parameters (flow, density, etc.) are displayed with their trend and variance.

5) The FLO-CAL can accurately measure frequency or analog signal from the unit under test.

6) The FLO-CAL is easy to use and train, minimizing the need for a dedicated flow-metrologist. It provides data protection from undesired changes.

7) The calibration process is rapid and efficient to minimize down time. Measurement analysis is performed on-site to enable the operator to take the proper corrective action.

8) Calibration reports comply with ISO 9000 and ANSI /NCSL Z540-1 requirements.

9) On-line analysis package enables the operator to make efficient judgments and corrections.

**5.0 FLO-CAL, A TOOL TO PERFORM IN LINE CALIBRATION, ANALYSIS AND REPORTING:**

The FLO-CAL is set as a portable cart (Fig. 1 & 2) with an industrial PC (ISA bus) and an advanced data acquisition system. Due to limitations in size, the current design is capable to support up to 130 GPM.

The flow measurement is performed via a flow manifold, with multiple flow standards, pressure and temperature transducers, and if necessary an in-line density standard. Typical schematic is presented in FIG. 7. The flow is automatically directed to the proper flow meter, using the proper valving sequence. Pressure and temperature of the liquid and density standards are measured.

The usage of an in-line density standard/meter is found to be affective when mass flow is required, and the properties of the liquid are not known or controlled. Otherwise, referred density measurement is sufficient.

The flow standards are typical piston type rotary provers for very low to medium flow range and turbine or positive displacement flow meters for the higher flow range. The rotary prover is a balanced four pistons in a precision bore design, which turn a crankshaft. Therefore, one complete revolution of a crankshaft is a fixed and precise volume. Therefore, the fixed volume combined with the precise time measurement to complete a revolution and displace this volume enables us to measure the volumetric flow. This unique mechanical and electrical standard represents a similar concept to a linear flow volume prover, (which is considered as a primary standard) but is significantly more compact, and faster. Standard's size is an important consideration for a portable flow calibration system.
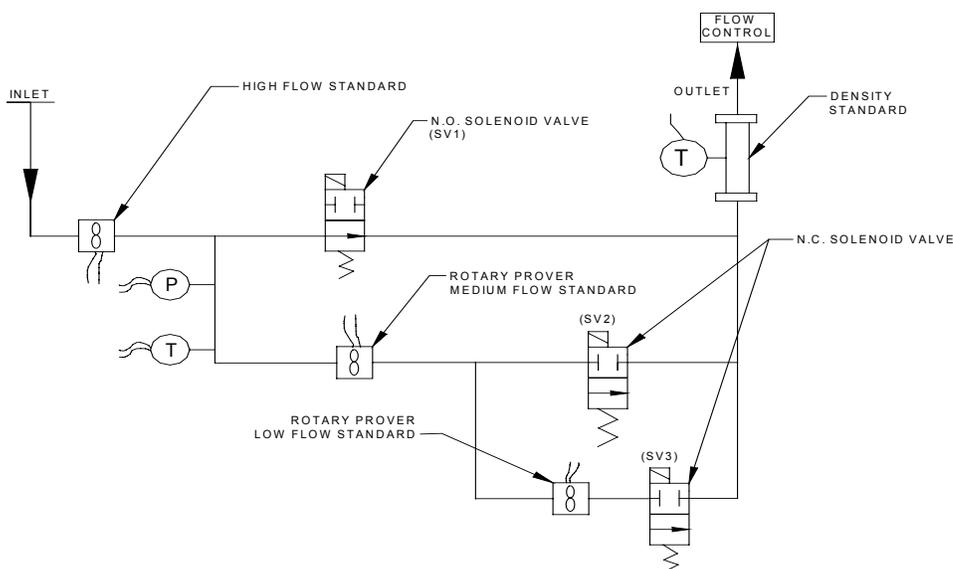


Figure 7: Typical Flow Manifold with Three Flow and One Density Standards

Figure 8 presents typical K factor for different viscosity ranges of a PD, piston type of flow standard. At lower viscosity, the leakage around the pistons is higher, however, this design is significantly less sensitive to viscosity in comparison to a turbine meter.

As mentioned above, viscosity and temperature affects the flow standards' performance, a unique "mapping" method was developed using the FLO-CAL program. Figure 5,6 and 8 suggest that best performance will be achieved if each flow meter/standard is calibrated at a defined and limited viscosity range.  Large turbine meters, when used with the universal K factor (fig. 5) over limited viscosity range (i.e. from 0.8 to 1.5 Cst or 5.5 to 9.5 Cst) will present K factor variation within the measurement accuracy of the primary standard (0.15% or reading). PD flow meter/standard will demonstrate less sensitivity to viscosity over a much larger viscosity range.
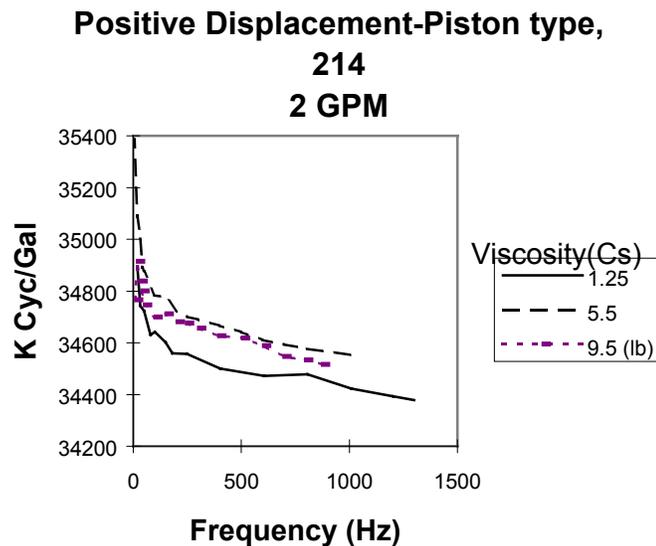


Fig. 8: K vs. Frequency for various viscosity ranges-PD meter

The mapping method is done automatically by the program, and is demonstrated in Fig 9. During the FLO-CAL calibration process, each flow meter is calibrated against a gravimetric, dynamic weight type, of a primary flow standard at the viscosity and temperature ranges used during the field application.  The number of ranges is practically unlimited. The various viscosity ranges are accomplished by using different liquids and different temperature ranges. Each calibration process results in a different file associated with a specific viscosity range, which is stored on a disk with security features.

The user defines the liquids used, along with their properties. This one time effort results in a liquid record, one for each type of record or file. Each liquid is associated with one flow standard calibration file, which covers the viscosity range of that liquid for all the flow standards.

When the user configures a specific UUT, he defines the liquid used, which automatically brings the proper flow standard calibration file.
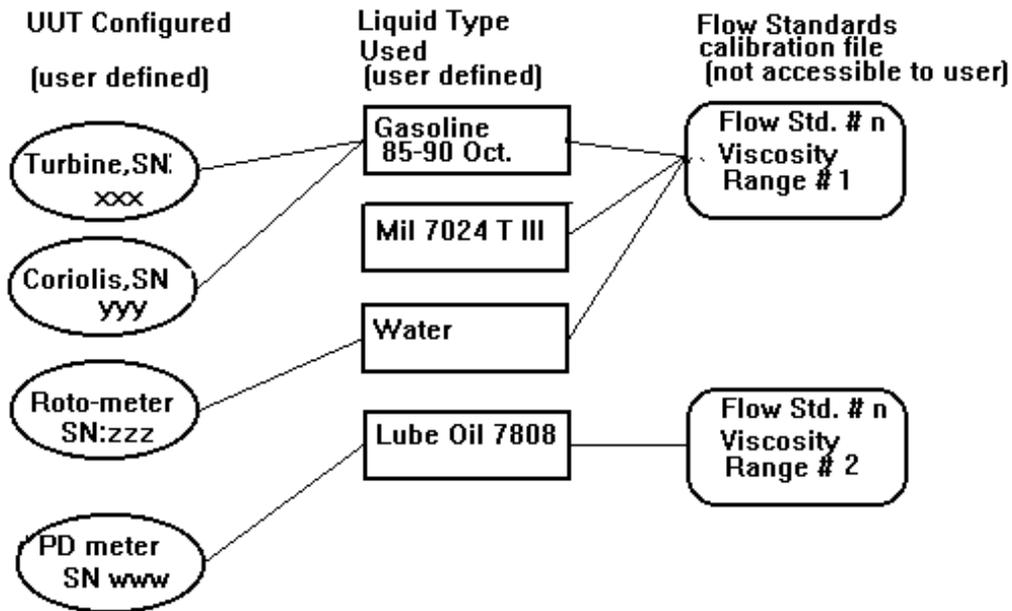


Fig. 9: Mapping Concept, from flow standards to UUT

This method not only enables us to use each flow standard at its proper calibration range, during the field application, but also minimizes systematic uncertainty when using the same flow standards to calibrate multiple flow-meters (uut) used at different viscosity ranges.

For best performance of the FLO-CAL, each flow standard is typically used in a "conservative" turn down ration of 10:1. Therefore, during field application the flow manifold is switched to assure that each flow range is measured with the optimum flow standard.

The FLO-CAL is equipped with the capability to measure the liquid temperature at the flow standards, using a precision RTD to compensate for liquid density and viscosity changes, as well as thermal expansion of the flow-standards. When significant temperature difference exists between the UUT and the flow-standards, a remote temperature can be automatically measured, or entered by the operator, which results in density corrections per equations 3 through 5. This correction is extremely important if the UUT is calibrated for volumetric flow.

A strain-gage type of pressure sensor enables the program to compensate for liquid compressibility and pressure affects when the FLO-CAL is used for high-pressure applications.

As flow stability is an important consideration during flow measurement and calibration, the real time Trend and Variation (eq. 10 through 12) are displayed. The operator has the ability to adjust the flow stability to the level required, in order to obtain overall system measurement uncertainty.

To achieve the design requirements, the FLO-CAL program was expanded to perform all other operator interface and reporting. To minimize operator training, the program operates under MS Windows and uses the standard Windows conventions.  As a metrology program, data, which includes calibration information, is write protected and can only be viewed.

Each UUT, once configured, is saved so data can be recalled for multiple calibrations. Figure 10 is the UUT configuration screen.
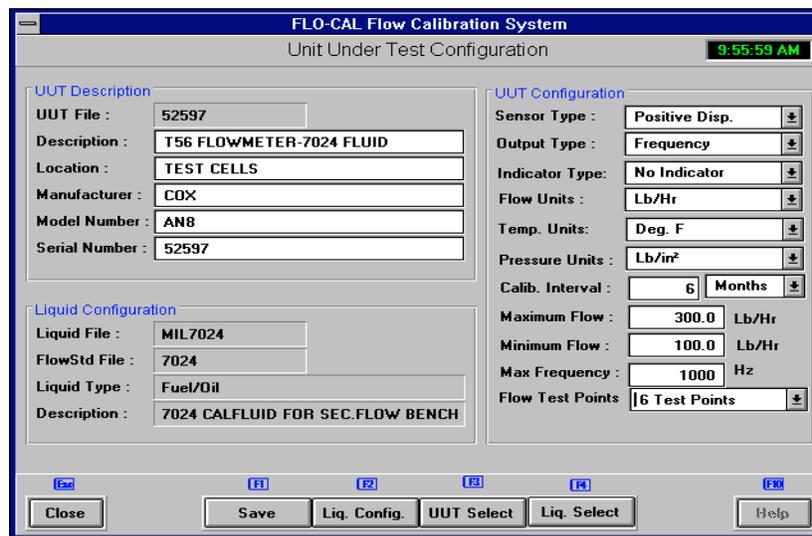


Figure 10: Unit Under Test (UUT) Configuration Screen

The program allows the user to select between volumetric and mass flow by the flow units definition. To protect the UUT, if an overflow conditions occur, the flow manifold will block the flow. The Flow Test Points table enables the user to have a "built in" calibration procedure, so all calibration points will be taken in the desired flow range.

During calibration, the Unit Under Test Calibration Data Collection screen is displayed. Each measurement is displayed with its trend and variance.  Data is manually captured, once flow stability reaches the desired level. The configured flow test points are displayed for the operator to manually adjust the flow.

Once calibration is completed, the operator can generate reports on screen and paper (Calibration reports). The report functions consist of two sections. The data section (fig. 11) and multiple

analysis functions section, (example, fig. 12). The analysis screens enable the operator, while in the field to view the flow system performance, such as linearity error (calculated per equation 8) and measurement errors. On-line analysis package increases the calibration process efficiency, as operator can make judgments and necessary corrections on-site.

## FloCal Calibration Report

| Company Info: | | UUT Desc: | **Turbine Flow Meter** | UUT File: | **KOR.001** | **03/12/2002** |
|---|---|---|---|---|---|---|
| | | Model Number: | **AN 10** | Liquid File | **7024RR.00I** | **02/28/2002** |
| | | Serial Number: | **82996** | Flow File | **7024CAL.002** | **03/11/2002** |
| | | Location: | **Teststand2** | System File | **SYSCAL.01 0** | **0211312002** |
| RECAL Date: | **08-2001** | Manufacturer: | **Cox** | Sensor Type: | **Turbine** | |
| ID.: | **PTOI-1** | Cal. Liquid: | **7024 FLUID@ROLLS-ROYCE CORP.** | Output Type: | **Freq: Hz** | |
| Uncertainty: | **+1.0.2%** | | | Minimum Flow: | **1.00000 gal/mm** | |
| | | | | Maximum Flow: | **11.0000 gal/mm** | |

### UUT Calibration Data Table:

Calibration Record Type: **Temporary**

| | Temp. Deg.C | lb/in$^2$ | FS Freq Hz | Visc. cSt | SG — | FS No. | FS gal/min | — | UUT Freq Hz | — | — | UUT F/V Hz/cSt | UUT K cyc/gal | — | — | Cfg Flow gal/min |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 19.93 | 1.336 | 350.642 | 1.315 | 0.77149 | 1 | 10.072 | | 930.159 | | | 707.08 | 5541.1 | | | 10.000 |
| 2 | 19.74 | 14.65 | 1005.95 | 1.318 | 0.77164 | 2 | 8.0058 | | 741.682 | | | 562.58 | 5558.6 | | | 8.0000 |
| 3 | 19.78 | 10.26 | 759.072 | 1.318 | 0.77161 | 2 | 6.0353 | | 559.636 | | | 424.68 | 5563.6 | | | 6.0000 |
| 4 | 19.79 | 6.967 | 504.971 | 1.318 | 0.77161 | 2 | 4.0084 | | 373.405 | | | 283.39 | 5589.3 | | | 4.0000 |
| 5 | 19.80 | 4.750 | 263.351 | 1.317 | 0.77160 | 2 | 2.0848 | | 195.507 | | | 148.39 | 5626.6 | | | 2.0000 |

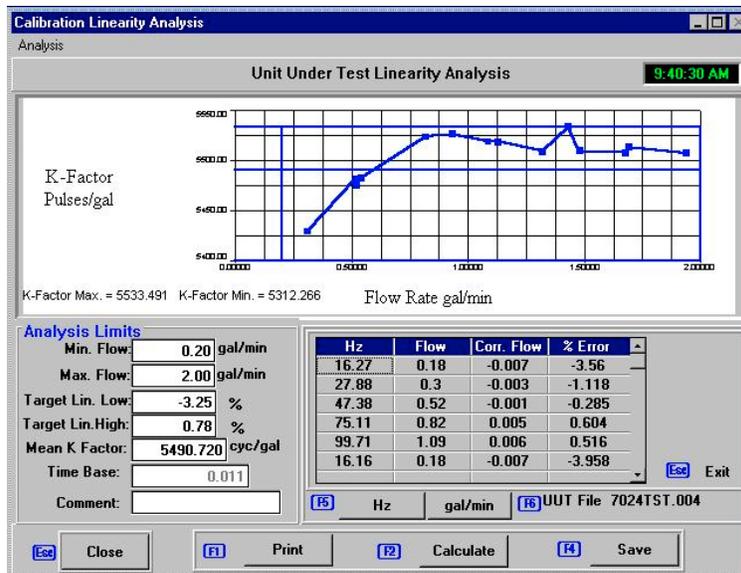| | | | | | | |
|---|---|---|---|---|---|---|
| Average Calib. Temperature: | 19.8 Deg. C | | Calibration Record Date: | **Mar 12, 2002** | Test Comment: | as-found |
| Average Calib. Specific Gravity: | 0.77159 | | Calibration Next Date: | **Mar 12, 2003** | | |
| Average Calib. Viscosity: | 1.31735 | cSt | Calib. Interval: | **1 Year** | Calibrated By: | |
| | | | | | | Wishcha |

Figure 11: Calibration report- Example



Figure 12:  UUT Analysis Screen

## 6.0  CONCLUSIONS:

The increasing requirements for higher accuracy, less operator skill requirements, economical calibration process are successfully accomplished using the FLO-CAL method. This in-line calibration method enables us to bring the "primary standard" to the field, compensate for measurement uncertainties, present and correct the true flow system measurement errors as required by ISO 9000 and ANSI/NCSL Z540-1.

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