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(713) 242-1190

VISCOSITY COMPENSATION OF HELICAL TURBINE METERS
Class # 2480.1

Christopher Johnson
Product Marketing Manager, Turbine Meters
FMC Technologies Measurement Solutions
1602 Wagner Avenue
Erie, PA USA

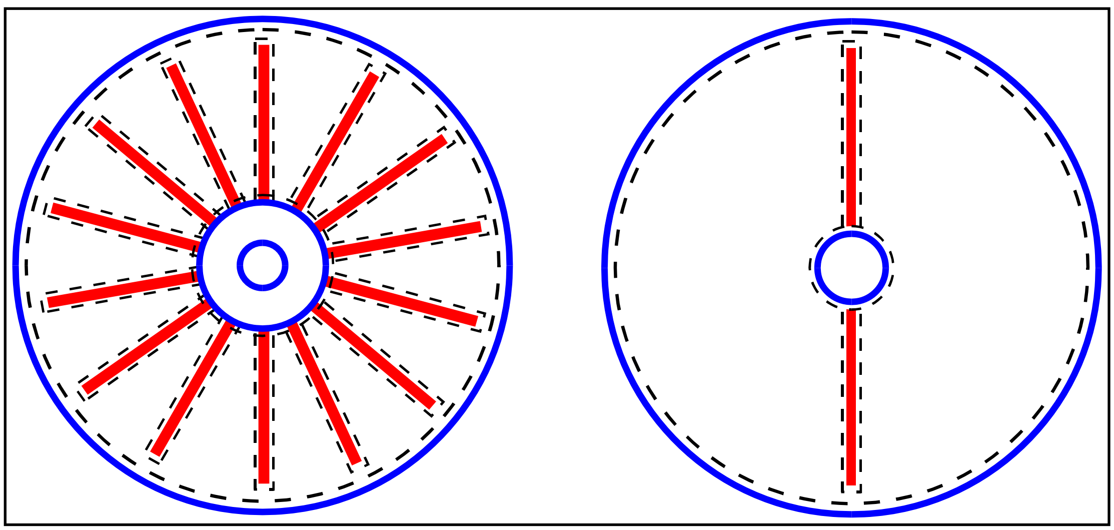
Introduction

Helical rotor turbine meters can provide significant performance advantages over conventional rotor turbine meters for crude oil service. The use of viscosity compensation (also referred to as “Universal Performance Curve Compensation” or “Viscosity Indexing”) and the concept of Dynamic Similitude allows the application range of helical turbine meters to be extended even further.

Effect of Viscosity on Turbine Meters

Turbine meters infer volumetric flow by measuring the rotational speed of the rotor. Hence, turbine meters are classified as “inference” meters. Turbine meter accuracy relies on the relationship between the axial velocity of the fluid and the rotational speed of the rotor. In other words, the rotor rotates at a speed that is proportional to the speed of the fluid flowing through the meter. When applied to a narrow viscosity range, this relationship is relatively constant. However, when a turbine meter is applied to a wider viscosity range as a result of multiple products, this relationship will change as viscosity changes. This is a result of changes in the boundary layer thickness.

The boundary layer is a thin layer of fluid that builds up on the wetted surfaces of the meter. It is a layer of fluid that is “stuck” on the surfaces. The thickness of the boundary changes as the viscosity of the fluid changes. Higher viscosity products result in a thicker boundary layer and hence increase the apparent thickness of the wetted surfaces in the meter. This results in a decrease in the open flow area through the meter as shown in figure 1. The dashed lines represent the boundary layer that is present on the wetted surfaces of the meter.



Conventional Rotor Helical Rotor

Figure 1 – Illustration of effect of boundary layer

Assuming that the volumetric flow rate is held constant, a decrease in the open area through the meter will result in a corresponding increase in the axial speed of the fluid according to the following relationship:

$$Q = V \; x \; A$$

Where:

Q = Volumetric flow rate
V = Fluid velocity
A = Open area

As the fluid velocity increases, the rotational speed of the rotor must also increase, thus changing the inferred volumetric flow rate when the actual volumetric flow rate has remained constant.

Since helical turbine meters only have 2 blades, a smaller diameter hub and no outer rim, they are less sensitive to this boundary layer thickness and therefore have a wider inherent viscosity turndown. However, they are still affected by this change in area and the user will see a shift in the meter's output as a result.

In order to extend the meter's application range further, we need to employ viscosity compensation using the concept of dynamic similitude.

Reynolds Number and Similitude

Webster's dictionary defines Similitude as: "a correspondence in kind or quality" or "a point of comparison". Similitude is a means of creating a comparison.

From the NASA Quest website (http://quest.arc.nasa.gov):

Two experiments involving fluid dynamics are DYNAMICALLY SIMILAR if and only if the Reynolds Numbers are equal. This means that it is possible for an experiment with a helium-filled balloon 100 cm in diameter rising in air to be dynamically similar to a 9.60 cm plastic ball falling in water if the Reynolds Numbers are the same.

Dynamic similitude is used to predict the results of a scenario using a simulation that is "dynamically similar" to the actual scenario. Some good examples of this are wind tunnel testing and flow loop testing.

This concept uses Reynolds number as the basis for comparison. Reynolds number is a dimensionless quantity that numerically describes the relationship between the inertial forces to viscous forces of a flow stream. Reynolds number is calculated by the following equation:

$$Re = \frac{\rho V D}{\mu}$$

Where:

Re = Reynolds Number
ρ = Fluid Density
V = Fluid Velocity
D = Pipe Diameter
μ = Fluid Dynamic Viscosity

Normally, turbine meter performance curves are constructed with flow rate on the X axis and either K-Factor or Meter Factor on the Y axis. This is fine for viewing the meter's performance on a single set of product characteristics. However, because helical turbine meters are typically used in applications where the product characteristics vary, a different means of viewing the meter's performance is needed. Constructing the meter's performance curve using Reynolds Number on the X axis allows the graph to take into account both flow rate and viscosity.

This graph is typically constructed using flow test data from multiple sets of product characteristics and is called a universal performance curve because once constructed, it can be used to estimate the meter's performance on any set of product characteristics that fall within the range covered by the data.

The Reynolds Number (Re) range is calculated using the following simplified equation and based on the worst-case conditions:

$$\mathrm{Re} = \frac{(2214^{*})(Q)}{(MS)(\nu)}$$

Where:

Q = Flow Rate (BPH)

MS = Meter Size (in)

ν = Kinematic Viscosity (cSt)

* 2214 is a constant which incorporates the unit conversions for flow rate, meter size and kinematic viscosity

From the customer's data, the following information is determined:

- Minimum flow rate and maximum viscosity to yield the minimum Reynolds Number
- Maximum flow rate and minimum viscosity to yield the maximum Reynolds Number

A test plan is then constructed that will incorporate multiple tests on different viscosities to provide meter performance data covering this application range. The testing is carried out and the universal performance curve is generated. This universal performance curve is then programmed into the compensating device via a polynomial equation.

For multiple product applications, a live viscometer is used to measure the actual product viscosity. As a simplified explanation, based on this viscosity input and the frequency input from the turbine meter pickup coil, the compensating device determines the current point of operation on the universal performance curve and calculates a compensation factor which is applied to the pulse output. The result is a significant improvement in the linearity of the turbine meter which ultimately leads to an improved rangeability of the meter over varying viscosities.

If the application covers a single product with viscosity variations being produced as a result of temperature changes, the current product viscosity can be determined by measuring the product temperature and comparing it to a temperature – viscosity curve of the product.

The compensating device may also be able to increase the pulse resolution of the helical turbine meter to better fit the application. For example, if the customer already has a stationary ball prover in their installation, the pulse resolution of the turbine meter may need to be increased in order to provide the API recommended 10,000 pulses per proving run. This is accomplished, not by a simple pulse multiplier, but by pulse chronometry which is an accepted method of pulse interpolation.

Application

In order to show the effectiveness of viscosity compensation, an example of a past customer application will be highlighted.

This particular application was for a 12" helical turbine meter with a flow range of 1,900 BPH to 18,000 BPH and a viscosity range of 5.74 cSt to 253.7 cSt. Based on this information, the minimum and maximum Reynolds numbers are calculated:

Minimum Re = 1,381 (253.7 cSt @ 1,900 BPH)
Maximum Re = 607,129 (5.74 cSt @ 18,000 BPH)

Next, a series of flow tests are conducted that cover this Reynolds number application range. Raw results of the tests are shown in Figure 2.

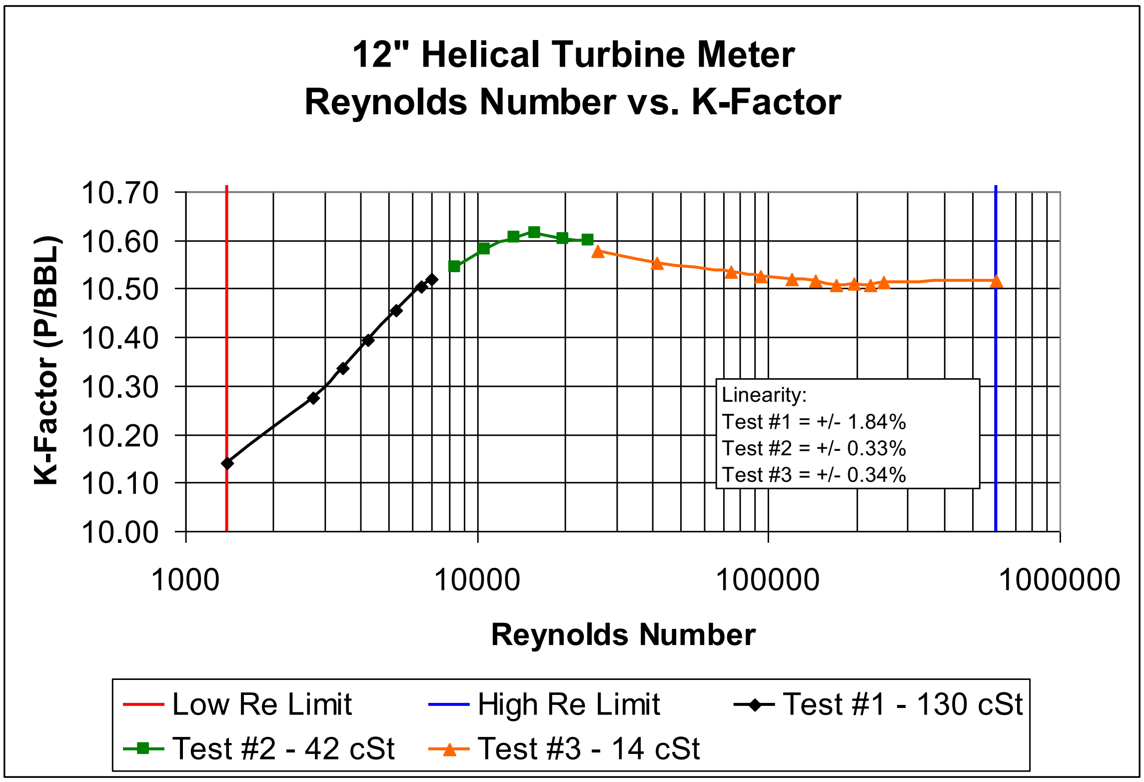


Figure 2 – Raw Test Results

Next, these individual test results are combined to form a single composite curve, or universal performance curve as shown in figure 3.

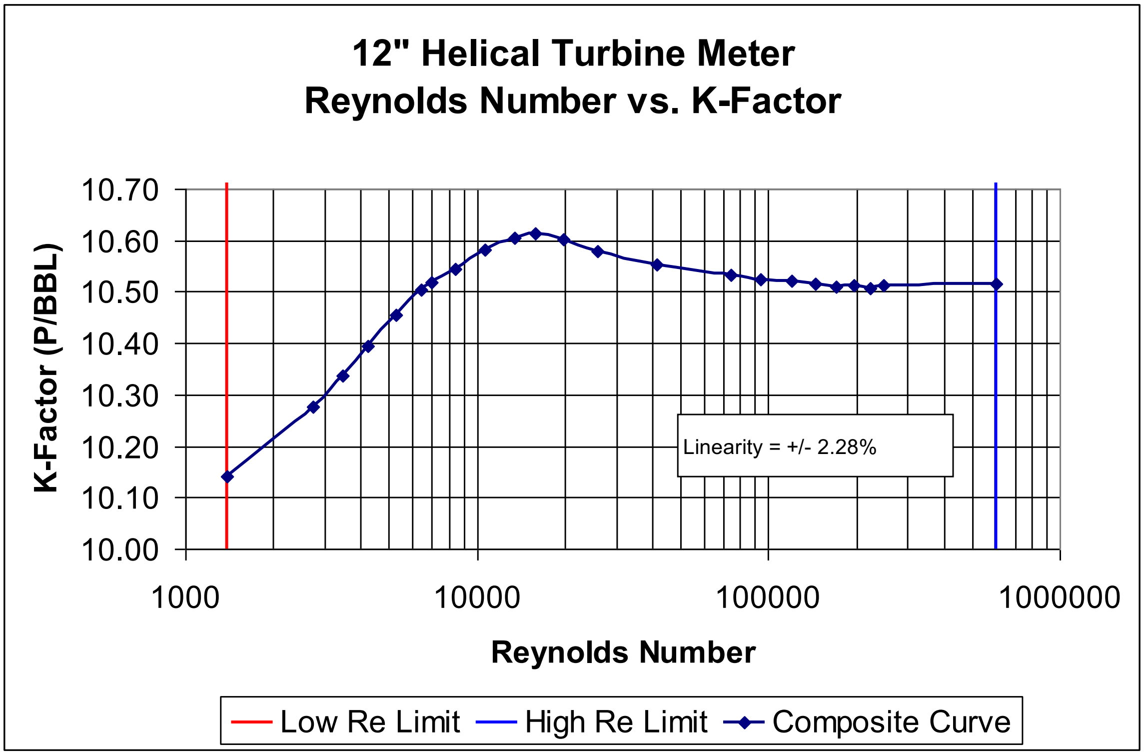


Figure 3 – Universal Performance Curve

This universal performance curve is then programmed into the compensating device and the testing is replicated utilizing a live viscometer input to verify proper operation of the device. In this case, the customer also requested that the meter have a compensated pulse output resolution of 333 pulses / BBL in order to collect 10,000 pulses per proving run with their existing stationary prover.

Figure 4 shows the final testing results with the viscosity compensation and pulse resolution enhancement active:

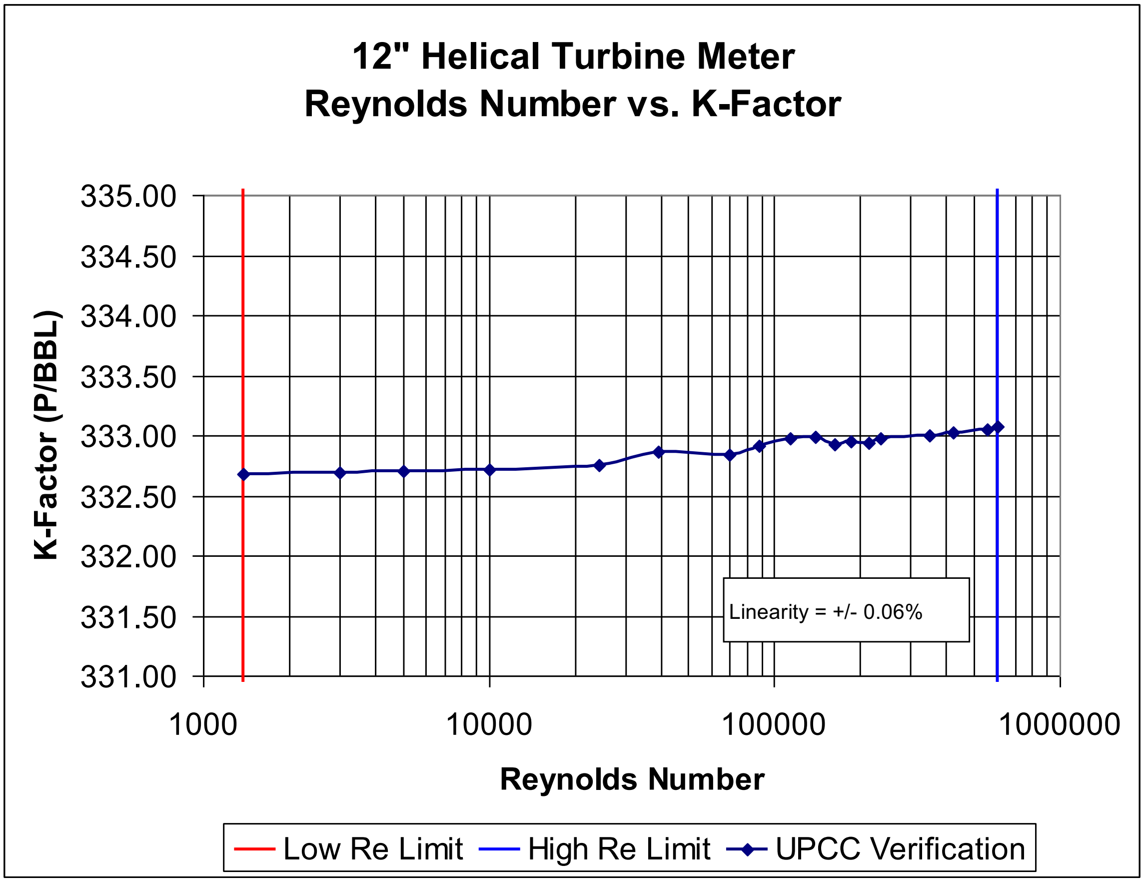


Figure 4 – UPCC Verification Test

Conclusion

As evidenced by the application example shown, viscosity compensation can significantly improve the linearity of a helical turbine meter when used over a varying viscosity range. In this particular case, linearity over a 440:1 Reynolds number turndown range was improved from +/- 2.28% to +/- 0.06%, thus extending the rangeability of the helical turbine meter far beyond the traditional capabilities of turbine meter measurement.