ACCURATE VISCOSITY MEASUREMENT UNDER EXTREME PRESSURE AND TEMPERATURE CONDITIONS

INTRODUCTION

Standard Cambridge Viscosity high pressure viscometers such as the VISCOlab PVT™ are rated for continuous service at pressures from ambient to 20,000 psi and temperatures from ambient to 190°C. The heart of these products is Cambridge's SPL-440 sensor. This sensor provides continuous measurements, in real time, at an accuracy ranging from 1% at ambient conditions to 5% at the extreme conditions. This paper describes the high pressure and temperature calibration of the sensor and presents measurement results at these extreme conditions.

CAMBRIDGE MODEL SPL-440 VISCOMETER

Cambridge viscometers are fundamentally simple, rugged, accurate and repeatable despite extreme operating environments. The viscosity measuring technology is based on a simple and reliable electromagnetic concept, as shown in Figure 1. Two coils move a piston back and forth, within a chamber, magnetically at a constant force. The motion of the piston is controlled and the piston's two-way travel time is measured to determine absolute viscosity. As the viscosity is increased the travel time is also increased. All wetted parts are corrosion-resistant alloys (inconnel 718, hastelloy C276 and stainless steel 17-4PH) and the constant motion of the piston mechanically scrubs the measurement chamber. A temperature detector is included in the measurement chamber so that both temperature and viscosity are known for every measurement.

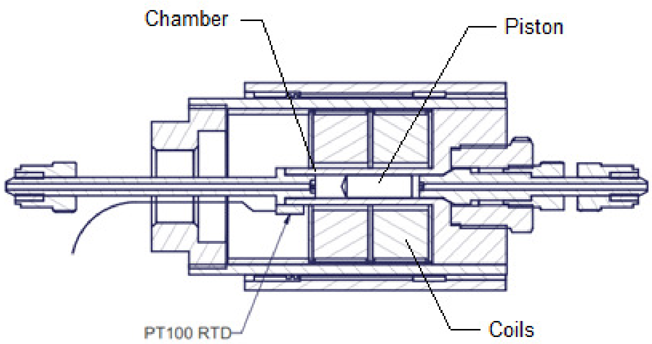

Figure 1: Schematic of the Cambridge Viscosity SPL-440 Sensor

Cambridge Viscosity viscometers are noted for using a small sample size, repeatability of better than 0.8% and accuracy of better than 1%. Their accuracy has been well established at ambient conditions with over 10,000 units installed worldwide over the last 25 years. They have become the industry standard in HPHT measurement meeting ASTM standard D7483.

The model SPL-440 viscometer has a range from 0.2 to 20,000 cP. To achieve this large range, several different size pistons are used in the sensor. Each piston provides a useful range of about one order of magnitude of viscosity measurement. For low viscosity measurements, a large piston is used providing only a small clearance between the piston and the chamber wall (4 mils for the 2 cP piston). For high viscosity measurements, a smaller piston is used to provide a greater annular clearance (8.5 mils for the 20 cP piston).

At elevated pressure, the chamber wall expands due to the stress of containing the fluid. This increases the clearance between the piston and the chamber wall. Established stress-strain relationships for cylindrical geometry can be used to estimate the expansion of the chamber under pressure. The chamber expands 0.8 mils at 20,000 psi. This increases the annular spacing, increasing the speed of piston for the same viscosity fluid. In effect, the piston becomes a higher range piston than it was at lower pressures. For the 2 cP piston, the annular spacing is increased from 4 mils to 4.8 mils as the pressure is increased to 20,000 psi, increasing the full scale reading to 3.2 cP.

The effect of increased pressure on the viscosity measurement with the 2 cP piston is shown in Figure 2. This figure shows test results when using Toluene and N-Decane as reference fluids. These fluids were used because their viscosity at high pressure is well known and documented as NIST (National Institute of Standards and Technology) standards. Accuracy of the reference viscosities varied from 2% to 4% over the range of conditions tested. The sensor compensation is linear, as predicted from the stress-strain analysis.

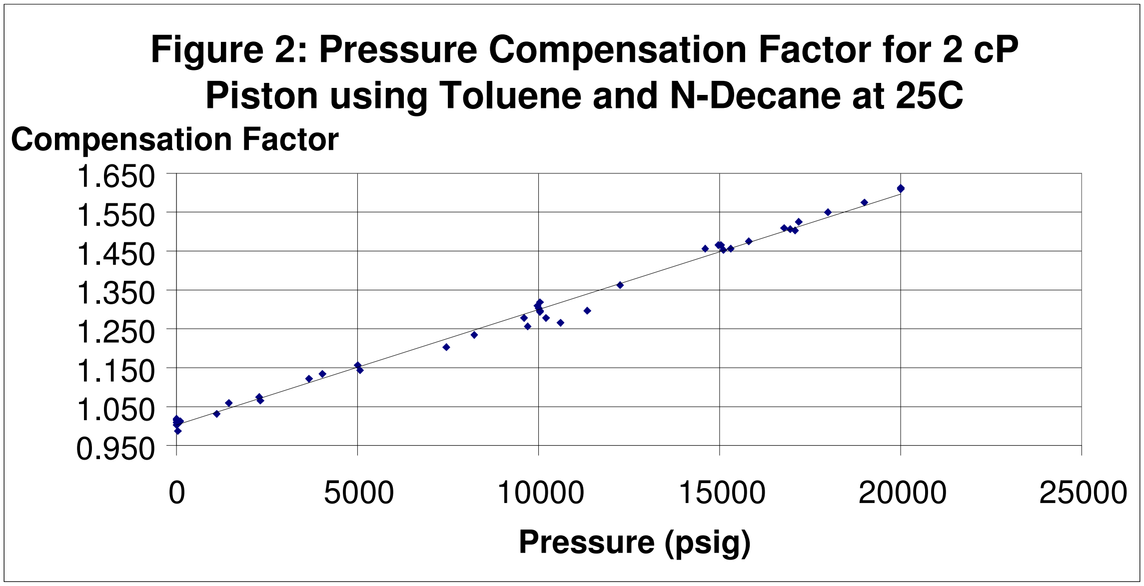

Figure 2: Pressure Compensation Factor for 2 cP piston

Higher range pistons are less affected by the increase in pressure. For example, the 20 cP range piston the clearance of 8.5 mils between the piston and the chamber wall at ambient conditions is increased to 9.3 mils at 20,000 psi. This is an increase of 9% compared to 20% for the 2 cP piston. Hence a much smaller compensation is required for this range piston. Pressure compensation is provided in the SPL-440's software when an external pressure measurement is provided to the system.

A similar effect occurs at elevated temperature. The chamber and the piston both expand as the temperature is increased from ambient. This expansion increases the annular spacing between the chamber and the piston. However, this expansion is less than that for increased pressure since the piston is also expanding with temperature. This expansion and the change in the annular spacing are readily calculated for the cylindrical geometry using the known properties of the appropriate metal alloys.

Figure 3 shows the required compensation for the 2 cP piston. This figure shows test results when using Toluene and N-Decane as reference fluids. Again these fluids were used because their viscosity at elevated temperature is well known and documented as NIST standards. The compensation required of the sensor is linear, as predicted from the stress analysis. Similar compensation factors were determined for the other pistons in the sensor. The 2 cP piston is most sensitive to the change in temperature and the 20 cP piston least sensitive. This temperature compensation is automatically provided by the SPL-440's software using the internal temperature measurement.

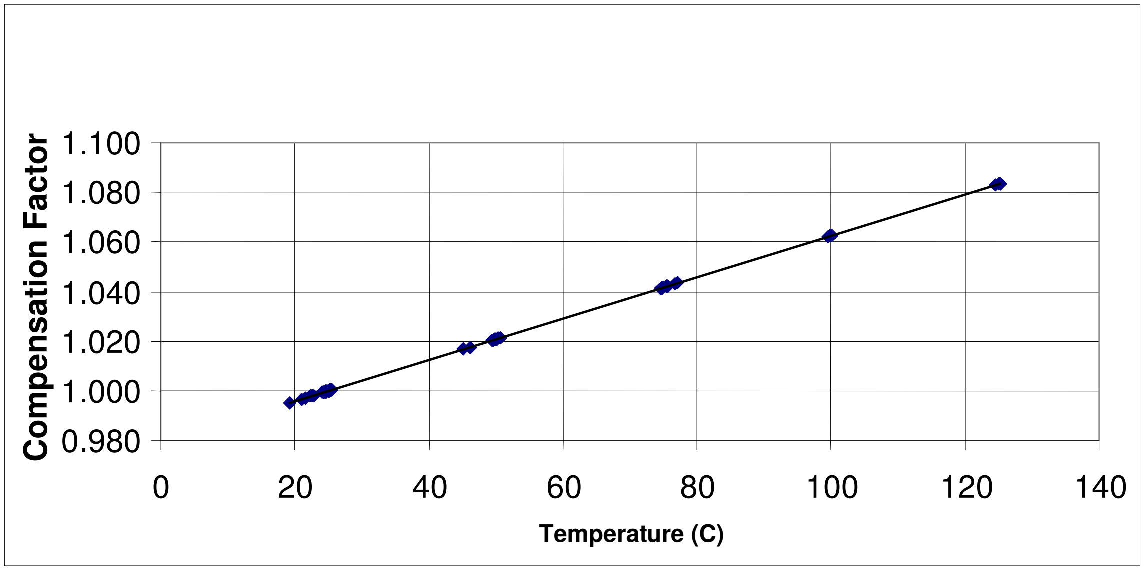

Figure 3: Temperature Compensation Factor for the 2 cP Piston

Figure 4 shows the accuracy of the SPL-440 sensor measuring viscosity at elevated pressures and temperatures. This figure shows measurements for pressures ranging from ambient to 20,000 psi and temperatures ranging from ambient to 125°C. Reference fluids are not available for viscosities over 4.5 cP, limiting the range of the sensor calibration at elevated temperature and pressure.

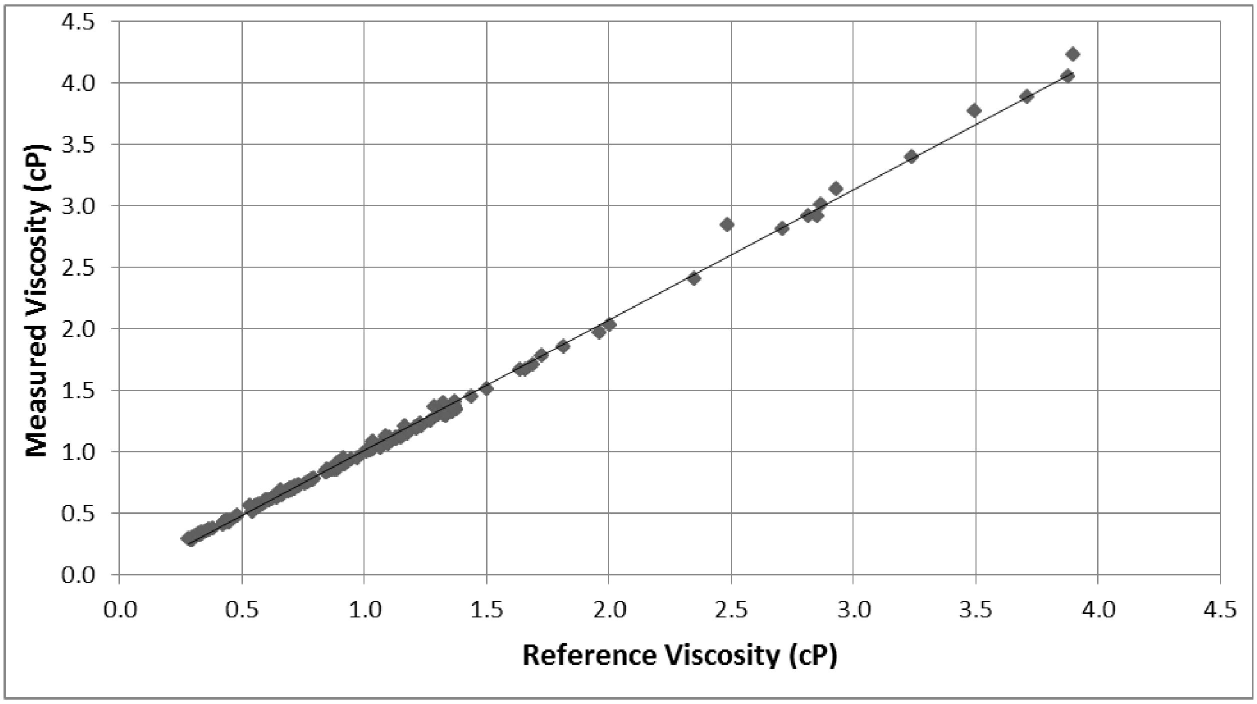

Figure 4: Results of calibration testing of the SPL-440 sensor

Cambridge Viscosity incorporates the SPL-440 sensor into its high pressure viscometers, including the VISCOlab PVT™. This enables continuous real-time measurement of viscosity under extreme pressure and temperature. The standard SPL-440 sensor accurately measures viscosity at pressures up to 20,000 psi and temperatures up to 190°C. Compensation for elevated pressures is incorporated when an external pressure measurement is provided to the system. Compensation for elevated temperatures is directly incorporated in the sensor using the internal temperature measurement.

About Cambridge Viscosity by PAC

With more than 8,000 installations worldwide, Cambridge Viscosity is the proven leader in viscosity management technology. With over 25 years of experience, Cambridge Viscosity understands and meets the needs of laboratory researchers and process engineers in a wide range of industries whose jobs depend on the quality, accuracy, and reliability of viscosity measurement equipment. Cambridge Viscosity is part of the PAC team. For more information please visit www.paclp.com .