REAL-TIME VISCOSITY ANALYSIS WITH ROBUST TECHNOLOGY FOR PROCESS OPTIMIZATION

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VISCOSITY MEASUREMENT, OSCILLATING PISTON TECHNOLOGY, PROCESS VISCOMETER, ASPHALT MEASUREMENT AT HIGH TEMPERATURES, REFINERY PROCESS OPTIMIZATION, CORRELATION TO LAB MEASUREMENT.

ABSTRACT

Viscosity is one of the most critical measurements of product quality for virtually every refinery product. With real-time viscosity measurements, refineries are able to realize significant improvements in production quality, cost, and output. The oscillating piston method is one technology used by process instruments to measure the viscosity of a variety of products, including the more difficult ones such as asphalt and high-temperature applications. This technology is preferred due to its durability, long-term calibration, built-in mixing, and insensitivity to outside environment.

The oscillating piston technology is available in a process viscometer that measures under process conditions and then utilizes temperature compensated viscosity calculations to achieve correlation to the lab. In this presentation, the applications for this viscometer will be discussed, typical results, and the benefits it provides for refineries. In addition, an in-depth case study focusing on the installation of a process viscometer to measure asphalt at high temperatures for a major refinery in the northeast United States will be discussed. This will include an overview of the installation, the process measurements and their correlation to the lab measurements, and the overall benefits the refinery achieved.

OSCILLATING PISTON METHOD ANALYZES THE VISCOSITY OF ASPHALT IN HIGH-TEMPERATURE PROCESSES

Within the petroleum industry, refineries are under continuous pressure to streamline and speed up production, increase yield, and operate more efficiently. While each refinery delivers a unique output, one barrel of crude oil is expected to yield about 50% gasoline, 15% fuel oil, and 12% jet fuel, with the remaining 23% being used for other products like diesel, asphalt, lubrication oil, and various refined products.

Viscosity is a critical measurement of product quality for every refinery product. New developments in viscosity measurement are enabling refineries to realize significant improvements in production quality, cost, and output. These new developments and their respective benefits are discussed within this paper.

CHALLENGES IN ASPHALT PRODUCTION

According to the European Asphalt Paving Association and the National Asphalt Paving Association, in 2007, more than 1.6 trillion metric tons of asphalt was produced worldwide. Asphalt typically requires bitumen that has specific characteristics relating to consistency, adhesion, hardness, brittleness, and viscosity at a specified temperature.

In addition to being used for the construction and maintenance of roads highways around the world, asphalt is used for airport runways, parking areas, bridges, cycle paths, athletic complexes, and play areas. These varying uses are subject to radically different environments around the world and throughout the year. Each one will require asphalt with specifications suitable for the purpose, condition, and location where the asphalt is being used.

This can cause challenges, since the raw material used for making asphalt is typically the least valuable and last refined from a barrel of crude oil. This means the material used for asphalt may be non-homogenous, varying significantly with each barrel depending on the source of the crude and variations in refinery process conditions.

ANALYZING THE VISCOSITY OF ASPHALT DURING THE REFINING PROCESS

International standard test methods, like ASTM and ISO, have designated standard test methods to control the quality of the asphalt product based on its end use. These test methods utilize standard laboratory test equipment, with testing done periodically throughout the production process. The process is adjusted based on the laboratory test, with a test-and-reblend methodology being used until the product meets the required customer specifications.

Because the asphalt characteristics may develop variations between laboratory tests due to fluctuations in raw material and process manufacturing, as shown in Figure 1, periodic testing does not truly represent the asphalt being produced. Because of this, refineries must spend a significant amount of time and money on post-process blending to meet the minimum targets of any given specification.

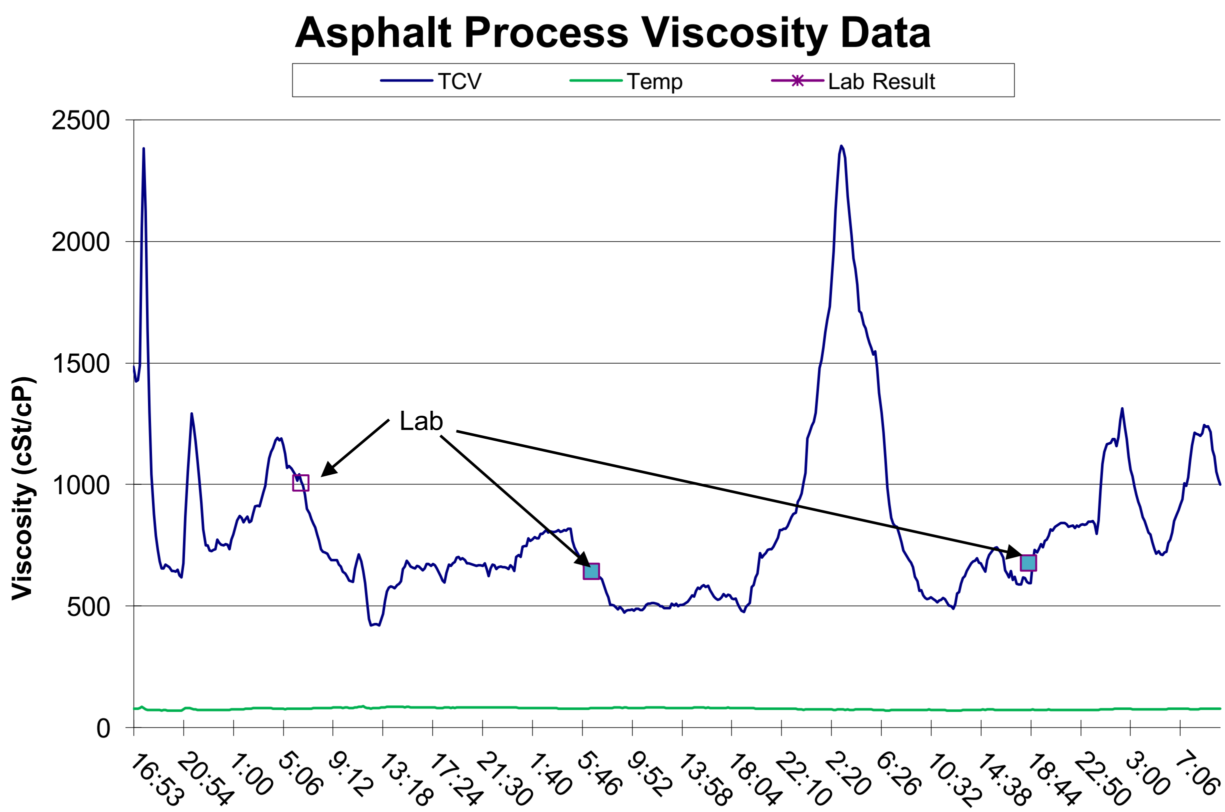

FIGURE 1. INLINE VISCOSITY TESTING COMPARED AGAINST LABORATORY VISCOSITY TESTING POINTS SHOW SIGNIFICANT VARIATION BETWEEN LAB TESTS.

METHODS OF IN-LINE VISCOSITY ANALYSIS

There are three technologies that are most commonly used for in-line viscosity measurement: capillary, vibrational, and oscillating piston. Capillary systems use high-precision pumps for accuracy, but also require frequent and costly maintenance and recalibration. Vibrational viscometers have no moving parts, making them more rugged, but this type of viscometer can cause resonance frequencies in fluids and are subject to process equipment vibrations that can result in incorrect data.

The oscillating piston viscometer uses a free-floating piston in a magnetically influenced chamber to measure changes in the piston speed caused by viscous drag. A controlled magnetic field drives the piston in an oscillatory motion within the measurement chamber. A shear stress is imposed on the liquid (or gas) due to the piston travel, and the viscosity is determined by measuring the travel time of the piston. The construction parameters for the annular spacing between the piston and measurement chamber, the strength of the electromagnetic field, and the travel distance of the piston are used to calculate the viscosity, where the changes in the travel speed are directly proportional and calibrated to the viscosity of the fluid. This oscillating-piston viscometer is the preferred method due to its accuracy, reliability, ease of installation, small size, and low maintenance requirements.

All three of these technologies typically require conditioning of the fluid being tested in terms of temperature, flow, and particles so that it is as consistent as the lab samples. However, through a technique called temperature compensated viscosity (TCV), process instruments can provide real-time process viscosity information at the laboratory reference temperature without sample conditioning.

TCV determines the viscosity of a fluid at a reference temperature that is different from the actual process temperature. It mathematically removes the variation in viscosity that is caused by temperature to determine if the change in viscosity is being altered by the percent of solids present.

By utilizing the TCV technique, process viscosity analyzers eliminate the effects that the process temperature can have on the product and achieve a correlation between on-line and lab results. The mathematical relationship that is used for the TCV calculation is based on the ASTM standard D341 that is accurate for liquid hydrocarbons and most other Newtonian fluids. This method is a procedure for determining the viscosity-temperature relationship of petroleum oil and providing viscosity data at a reference temperature that is different than the actual process temperature, as shown in Figure 2.

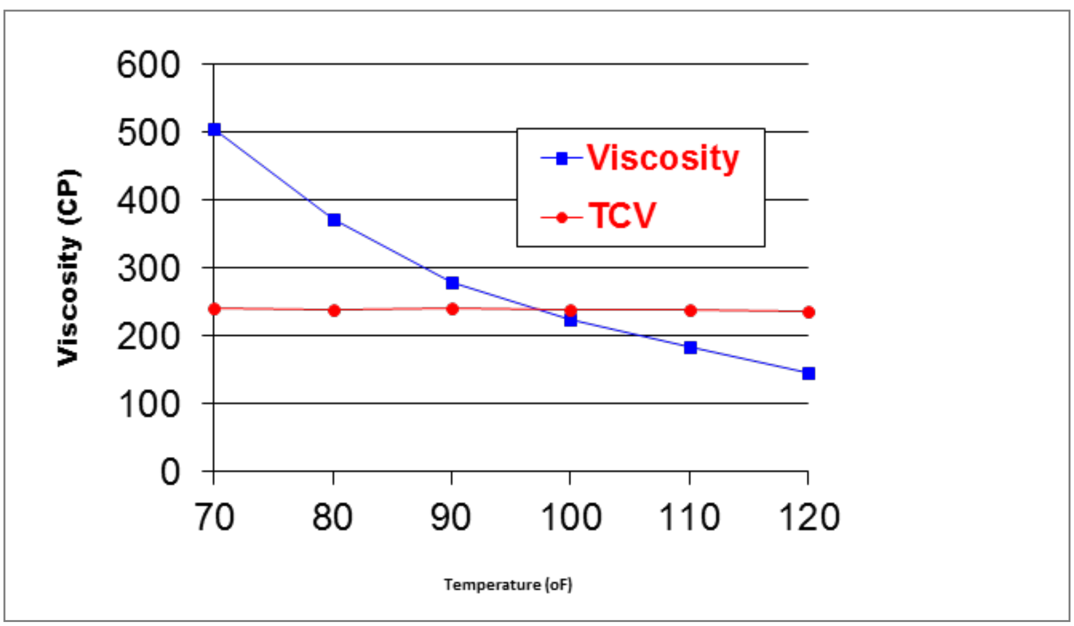

FIGURE 2. TEMPERATURE COMPENSATED VISCOSITY (TCV) DETERMINES THE VISCOSITY OF A FLUID AT A REFERENCE TEMPERATURE THAT IS DIFFERENT FROM THE ACTUAL PROCESS TEMPERATURE.

HARDWARE: OSCILLATING PISTON VISCOMETER FOR ASPHALT MEASUREMENTS

In a typical asphalt process, an oscillating piston viscometer is installed in the main asphalt line or in a bypass to the asphalt line. This allows real-time viscosity measurement, and a savings in installation, maintenance, material, processing time, and labor. A typical asphalt process diagram is outlined below (see Figure 3). This viscometer is located in a 2" bypass line of a 12-inch mainline and is used to maintain the diluent addition to achieve the ideal customer specification the first time.

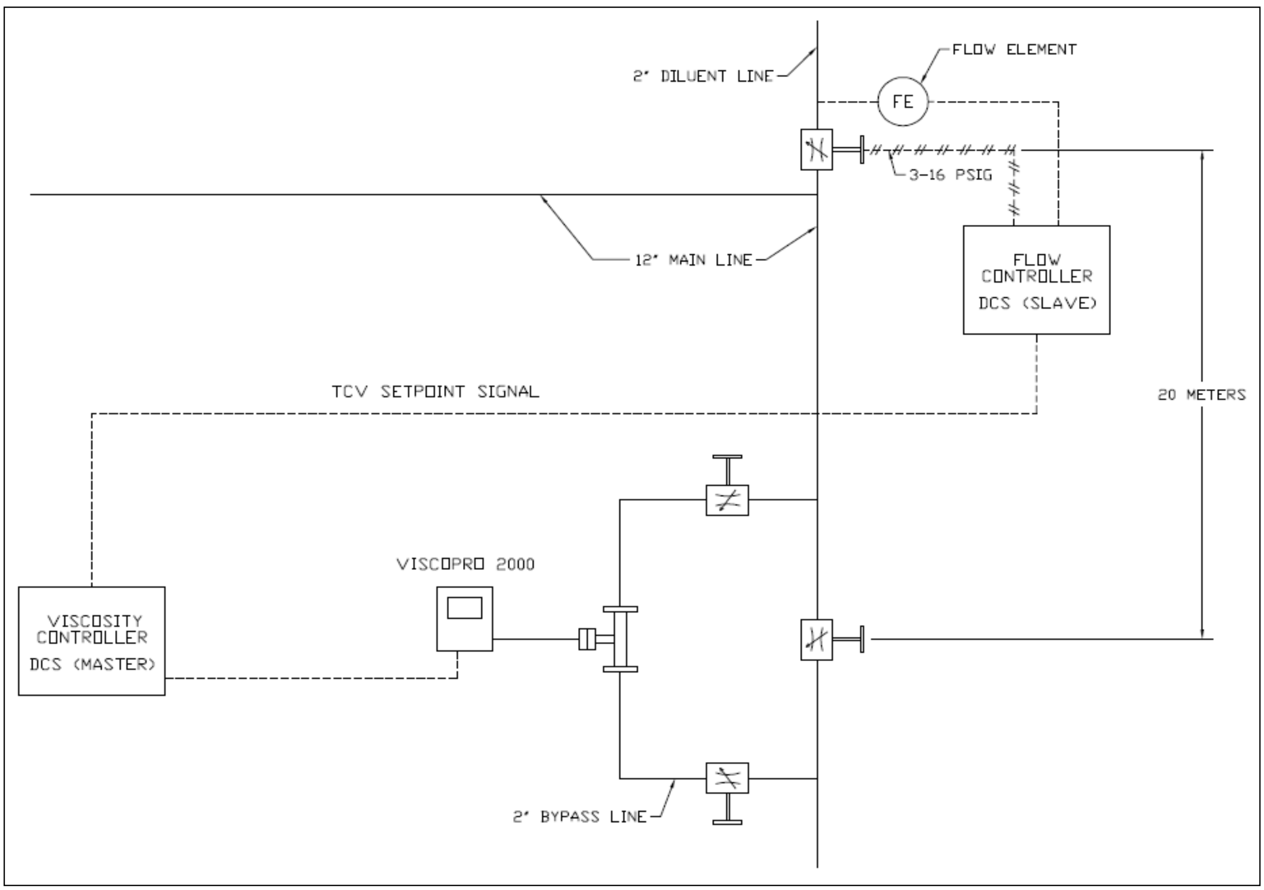

FIGURE 3. IN A TYPICAL ASPHALT PROCESS, A VISCOMETER, LOCATED IN A 2" BYPASS LINE OF A 12" MAINLINE, IS USED TO MAINTAIN THE DILUENT ADDITION TO ACHIEVE THE IDEAL CUSTOMER SPECIFICATION ON THE FIRST RUN.

CASE STUDY: REFINERY IN THE EAST COAST UNITED STATES USES VISCOMETER TO OVERCOME VARIABILITY AND NON-CORRELATION ISSUES

An east-coast asphalt refinery with a capacity of approximately 75,000 bpd was experiencing problems with viscosity variability as determined by lab analysis. Specifically, they wanted to reduce rework and send less to the slop tank; however, the sampling and response time from the laboratory was not fast enough for process control. One of their biggest challenges was a lack of visibility into the process, specifically what occurs in between sample pulls. Additionally, they used feedstock from two continents, and they suspected that the variability in crude oils was complicating the process.

The refinery opted to install a process viscometer on one of its two crude units. The unit had a temperature range of 330°-390° C, and processed lighter crudes into three grades of asphalt. Since this was a process optimization application, it was more important to see the changes to the product, rather than have perfect correlation to the laboratory test method. To simplify the installation, the refinery selected the oscillating piston process viscometer and used ASTM temperature viscosity curves to correlate to the laboratory with a goal of correlating +/- 5% of the laboratory.

TABLE I. THE VISCOSITY RANGES OF THE GRADES OF ASPHALT PRODUCED AT UNIT 1.

ASPHALT TYPE	VISCOSITY RANGE @ 140° F
PG70-22	4500-5000 poise
PG64-22	1900-2500 poise
PG64-28	1700-2100 poise

The new viscometer was calibrated to 10-200 cP and measured the flowing viscosity which had a viscosity of 100-150 cP at the process temperature between 300° F and 350° F. To correlate with the laboratory the temperature compensated coefficient (TCC) was configured to convert the result to a viscosity at a reference temperature of 140° F using the ASTM D341 standard.

USING A VISCOMETER TO ADDRESS KEY CHALLENGES

The viscometer was installed into a 3" custom tee section, which included ports for flushing the sensor tee (see Figure 4). The pipe and tee were steam-traced to provide stable temperature for the measurement. The sensor was installed into the line at a 45° angle. (For processes that are known to have high particle content, a horizontal sensor installation is preferred to prevent particle buildup inside the measurement chamber.)

FIGURE 4. THE VISCOMETER IS INSTALLED ON THE ASPHALT MAINLINE

The viscometer had two main purposes:

1) Track inline viscosity variability
2) Eliminate post process blending to fix out of spec product.

The refinery needed to monitor product variation. Inconsistent raw material was causing challenges, because periodic laboratory samples were different from the actual asphalt being produced. Once the viscometer was installed, the customer needed to determine how to best correlate their measurements to the laboratory, which was testing at a much lower temperature.

MEASURING FLOWING VISCOSITY WITH TCV AND CALIBRATION CURVES

The refinery was tracking TCV through their distributed control system (DCS). The 4-20 mA outputs for viscosity and temperature were taken from the online viscometer into the DCS. The DCS was programmed to include the TCV correlation, which allowed the customer to have different models for different asphalt grades. It was found that different crude oils used within the units were causing the TCV levels to shift unexpectedly. This indicated the TCV model was changing with the different products. Having the model programmed into the DCS allowed the ease of changing the model for a given product being run.

The next challenge was to find the proper TCC. Some products have a mild curve or slope, which means they are not significantly impacted by temperature. A sharp slope indicates the product is highly affected by the temperature. The refinery could have a temperature variation of 20° F in any direction, which meant an improper TCC could cause large errors in the TCV measurement (see Figure 5).

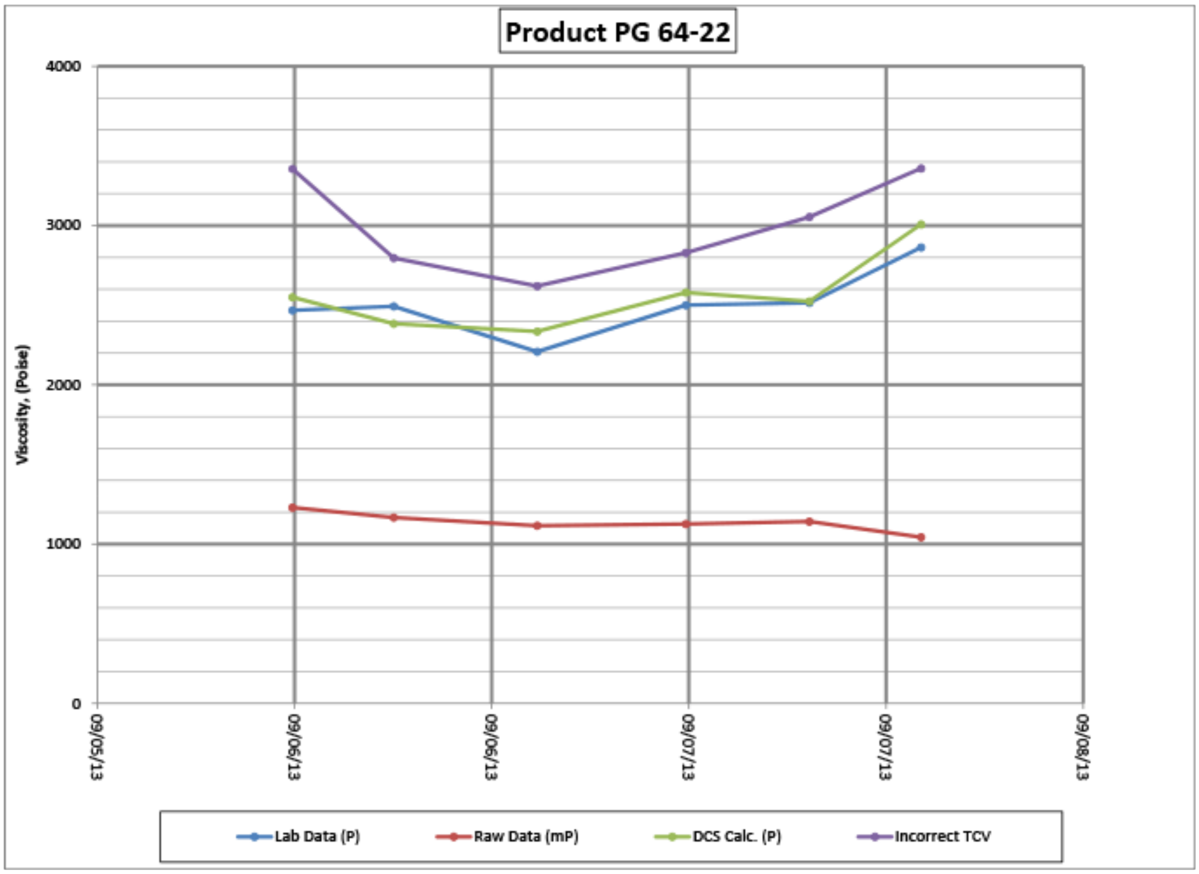

FIGURE 5. THE RED LINE INDICATES RAW DATA, WHILE THE BLUE LINE REPRESENTS THE LAB DATA. THE PURPLE LINE SHOWS THE INCORRECT TCV CALCULATION, WHILE THE GREEN LINE IS THE DCS CALCULATION.

A TCV correction was developed from several days of data the customer provided. It included raw measurement data and the equivalent lab sample data. Based on this data, it was possible to develop a proper fit for the given asphalt products.

The viscometer that was used requires a temperature compensated co-efficient to be pre-programed. For multiple products with different viscosity profiles, it is important to use the correct TCC value. It is common for refiners to use one generic value to describe all their products, which is acceptable if the temperature correction is less than 20° to 40° C, but for a large temperature correction, it's important to get the right value for each product (see Figure 6). Doing this on the DCS rather than the viscometer is beneficial, because the DCS tracks which product is being processed and can apply the correct curve. If an incorrect value is used, or if a value isn't changed when the product is changed, it is likely that the measurement will be correct under the process conditions, but when the math is applied, it will provide the wrong value. This will affect the correlation to the lab results.

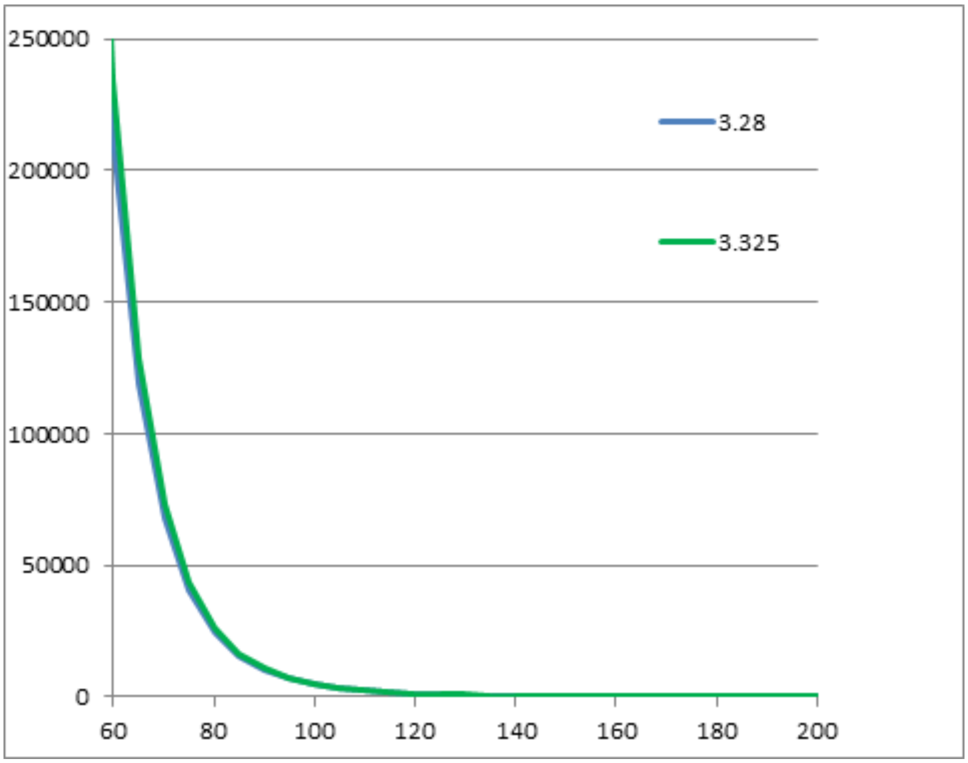

FIGURE 6. WITH A VISCOSITY READING OF 100cP AT 175° C (350° F), THE 3.325 VALUE WOULD REPORT A TCV VALUE OF 2345 POISE (234500 cP), WHILE THE CORRECT 3.28 VALUE REPORTS A 2140 POISE (21403 cP). THE DIFFERENCE OF 10% IS RELATED TO USING THE CORRECT TCC VALUE FOR EACH PRODUCT.

To calculate the proper TCC, the customer was required to provide inline viscosity and temperature information, along with correlating laboratory measurements. Having this information made it possible to compare the inline viscosity measurements, which were at temperatures over 300° F, against the laboratory measurements, which were being measured at 140° F. This information made it possible to create and implement the appropriate TCC model.

Initially, the refinery was concerned about the inline viscosity variability that the viscometer was reporting. To address this issue, the refinery increased their lab sampling rate and determined that the product actually was changing, and that the inline measurements were matching the laboratory results.

To obtain a good correlation, it is necessary to have several time-stamped lab samples measured each day that can be correlated to inline measurements. Not having enough samples may not reveal the fluctuations that are occurring in the process line throughout the day. Time stamping is important, because it helps to ensure results do not get mixed up. Another way to ensure a good correlation is to measure lab samples as soon as possible once they are removed from the line, because product characteristics can change over time, skewing the results.

Another issue that was presenting challenges at the unit was how the refinery was tracking lab sample pull times. The sample draw was scheduled to occur at three set times per day – at 6:30 a.m., 2:00 p.m., and 11:30 p.m. The actual samples were being pulled at any time within the range of an hour, and the exact time was not being recorded. Because they did not know exactly when the lab sample was taken, they could not accurately compare it to a point on the in-line viscosity data. The refinery implemented a process to track the exact time a lab sample was pulled, so they could get a tighter correlated result.

RESULTS

The refinery reported excellent results. First, they noted the importance of reviewing the raw viscosity, as well as the TCV. The raw viscosity provides a snapshot of the stability of the data. The TCV can magnify the errors making it difficult to determine system stability, especially when improper TCC values are used.

Second, they discovered that applying proper TCC fine tunes the measurement and adjusts for bias. In their case, it demonstrated that all grades of asphalt were within 5% of the laboratory measurements.

Third, they determined that it is best if the DCS collects temperature and viscosity data at the same interval. This makes it easier to review and evaluate system performance.

DICUSSION AND LESSONS LEARNED

While asphalt is often considered to be one of the more difficult applications to measure, this project allowed the customer to develop best-practices guidelines for an ideal viscometer installation. First, the sensor needs to be installed horizontally, preferably in a vertical section of pipe to assure that the pipe is fully flooded. This prevents particulate build up in the measurement chamber, reducing required maintenance on the instrument. The sensor should be located 10 pipe diameters away from a bend in the pipe, to reduce flow turbulence. If there is a filter in place, the sensor should be located after the filter.

The temperature also needs to be stable. To help achieve this, the sensor should be well insulated and heat traced, which will improve accuracy by eliminating thermal gradients. The flow rate also should be stable, and the ideal flow rate is 0.5-1 feet/second. Finally, a path to flush the solvent and light oil through the tee and sensor reduces the likelihood of complications during changeovers and provides a way to clean the instrument in place.

CONCLUSIONS

In refinery asphalt applications, which tend to be more complicated to measure, oscillating piston viscometers are the preferred method of viscosity measurement due to their inherent accuracy and reliability. Because the material used for asphalt may be highly variable depending on process conditions and temperature, traditional manual sampling methods are unreliable. When combined with TCV and TCC measurements, refiners are finding that the oscillation piston viscometer is the best solution to correlate lab and process data.

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