Cambridge Viscosity
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Real-Time Viscosity Tracks Oil Condition

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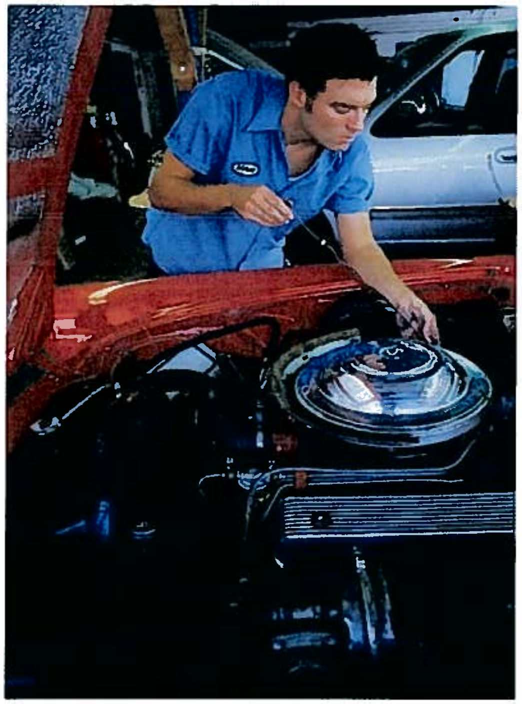
Cambridge Viscosity

Without oil breakdown, contaminants, or auxiliary equipment failures there would be little need to monitor the condition of lubricating and hydraulic oils in operating equipment. Unfortunately, Murphy lives: things can and frequently do go drastically wrong.



The breakdown of the base lubricating oil, its additive package or the included detergents is the primary cause of lubricant replacement. Lubricating oil health is also affected by wear contaminants from internal moving parts such as the rings, bearings, and hoses. Combustion by-products and gaps in the air system allow debris to enter the oil system, which can have a very serious effect on lubricating oil quality. High concentrations of airborne dust such as found in Southwest Asia, quickly turns lubricating oil into sludge. Fuel leaks, coolant leaks or equipment temperature problems can also affect oil characteristics.

All these failures impact the viscosity of the oil. Contamination from wear or debris increases the viscosity. Incomplete combustion, fuel leaks, coolant leaks, overheating, additive loss and detergent breakdown tend to decrease the oil viscosity before complete failure cooks the lubricant causing its viscosity to increase. Viscosity also indicates whether the correct oil is being used for engine lubrication. Early detection of any of these conditions allows the issue to be addressed before it becomes a problem.

As indicated in this paper, viscosity is a good early indicator of certain aspects of oil health, and with other indicators can be effectively used in an early detection and pre-treatment program to head off potential disasters.

To fully capitalize on this, viscosity must be monitored on-engine or on-equipment. Such a sensor must be fundamentally rugged, accurate and reliable. It can not cause more trouble than it is worth: the sensor must be self-cleaning so that it works in the background and is essentially trouble-free throughout the lifetime of the equipment. It must be able to measure temperature and correlate it with viscosity so that the impact of temperature fluctuations on viscosity can be normalized. Significant changes in temperature are typical in the operating cycles of engines and other equipment, and viscosity is changes as temperature changes regardless of the condition of the fluids.

Temperature-Normalized Viscosity

In order to determine whether oil is failing, it is essential to normalize the viscosity readings to a single temperature. At the normalized temperature one can then readily see a change due to contamination or degradation. An example of the temperature-viscosity relationship is shown in Exhibit 1. In that Exhibit, the pink line indicates the characteristic viscosity values for a 10W30 lubricating oil at temperatures ranging from 30°F to 100°F. The yellow line normalizes the viscosity values to a single temperature, in this case 80°C. Obviously the same oil at the same temperature has the same viscosity value of 18 cP. Temperature-normalized measurements above or below the yellow line, indicate problematic oil characteristics. In this way we can use actual running data at all of the operating temperatures, normalize them and then know if the oil is within the proper range. We refer to these normalized viscosity values as "Temperature Compensated Viscosity" or TCV.

Fortunately, oils and many other fluids exhibit characteristic relationships between temperature and viscosity. These relationships are readily modeled mathematically, allowing the temperature–compensated viscosity for any point to be calculated at a selected reference temperature. In Exhibit 1, for instance, the reference temperature was set at 80° F. Every viscosity-temperature data point is then recalculated mathematically assuming the reference temperature. In this exhibit, the 10W30 oil shows a temperature compensated viscosity (TCV) of 18 cP at the 80° F reference temperature across the whole range of the instantaneous temperatures and viscosity measurements. Readings above the black TCV line indicate a thicker-than ideal viscosity for 10W30, possibly caused by debris of one type or another, while the red TCV line indicated below target viscosity which could be caused by a fuel or coolant leak, for instance. Adjusting all viscosity-temperature values to TCV allows trends in oil viscosity to be spotted readily.

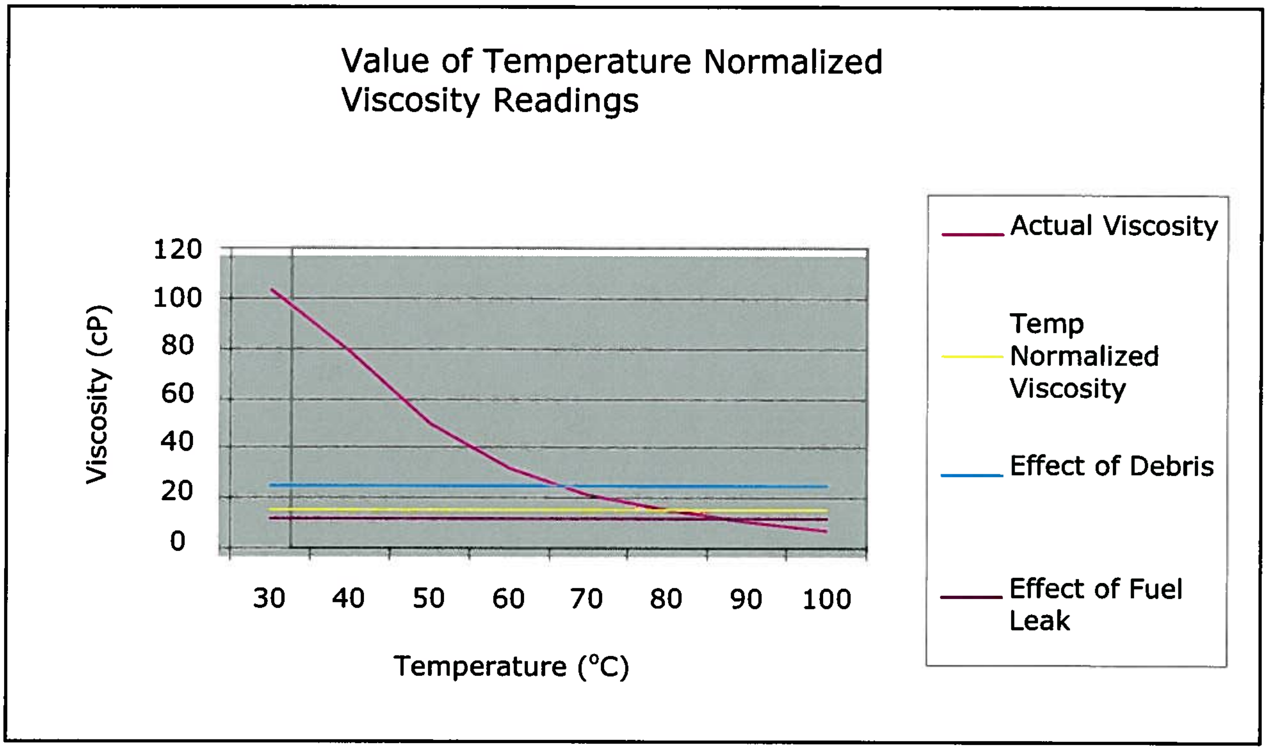


Exhibit 1: Temperature and Viscosity Relationship for a 10W30 Lubricating Oil

Cambridge Viscometers

General Motors' Electro Motive Division uses Cambridge viscometers on their latest H-series 6000 horsepower engines to monitor fuel dilution and other characteristics of their lube oil real time. In addition to GM, Ferrari, Lubrizol, Equilon, Tecumseh, the US Navy, US Army and a number of others have found Cambridge viscometers ideal for monitoring lubrication and hydraulic oils to monitor oil health and predict failures. Cambridge viscometers are fundamentally simple, rugged, accurate and repeatable despite operating environments with significant vibration. A key to the company's technology is its use of a single, non-contact moving part both to clean and measure. The motion of the piston is controlled so that it monitors the fluid viscosity and keeps the sensor's measurement chamber clean, so that the sensor requires minimum operator attention. A temperature detector is also included in the measurement chamber so that both temperature and viscosity are known for every measurement. The company's patented self-cleaning characteristic enables the Cambridge sensors to operate trouble-free in-line and on-engine.

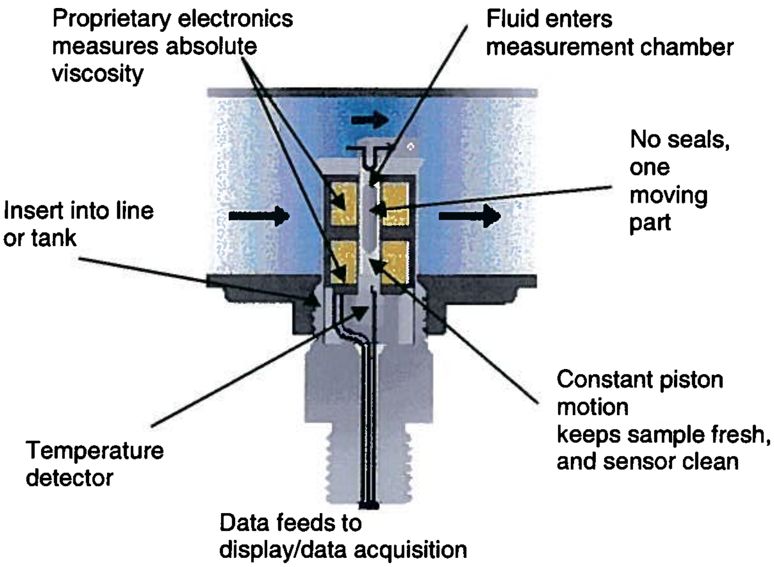


Exhibit 2: A schematic of a Cambridge sensor operating in-line

Cambridge Viscosity viscometers use proprietary circuitry to analyze the piston's travel time to measure absolute viscosity and monitor temperature. With all wetted parts stainless steel, the constant motion of the piston keeps the measurement sample fresh while mechanically scrubbing the measurement chamber. Cambridge has more than 7,000 sensors installed worldwide in many applications where viscosity knowledge and management is critical. A schematic of the operating characteristics of a typical Cambridge viscometer sensor are shown in Exhibit 2.

Exhibits 3 and 4 show viscosity trends from engines instrumented with Cambridge viscometers. In each case, Cambridge sensors predicted significant oil quality issues leading to engine problems and failures.

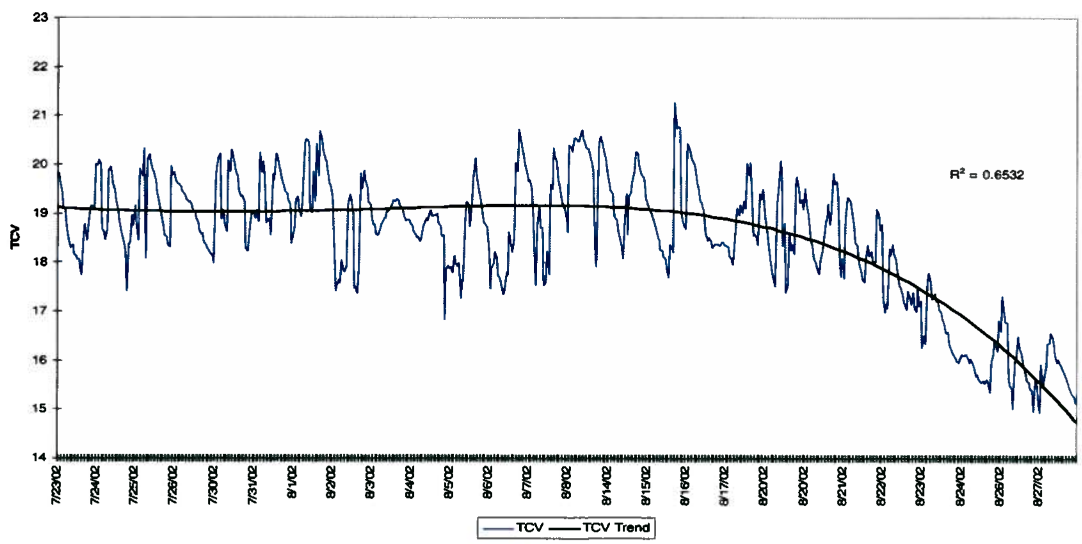


Exhibit 3: Cambridge viscometer forecasting engine failure due to fuel dilution

Sensing Fuel Dilution in Lubricating Oil

A standard on-engine mounting location for the Cambridge viscometer is in the lubrication oil return line. Exhibit 3 shows the results on one such engine. As you can see, even with temperature compensation, the viscosity varies roughly +/- 1 cP around its trend line of 19.2 cP. This trend line begins to drop around 8/14/02. The trend clearly continues down, crossing 18 cP in 4 days and almost 2 weeks to drop to 15 cP. The engine continued to failure due to fuel dilution.

The viscosity data shown in Exhibit 3 indicates the detection of a fuel leak more than a week before it became a serious problem. The data shows a maximum 20% drop in viscosity which correlated to about 6% fuel dilution (engines in the type tested typically are designed to run with up to a 4% dilution. In this case, notifying the operator of the problem could have easily avoided the catastrophic failure which occurred.

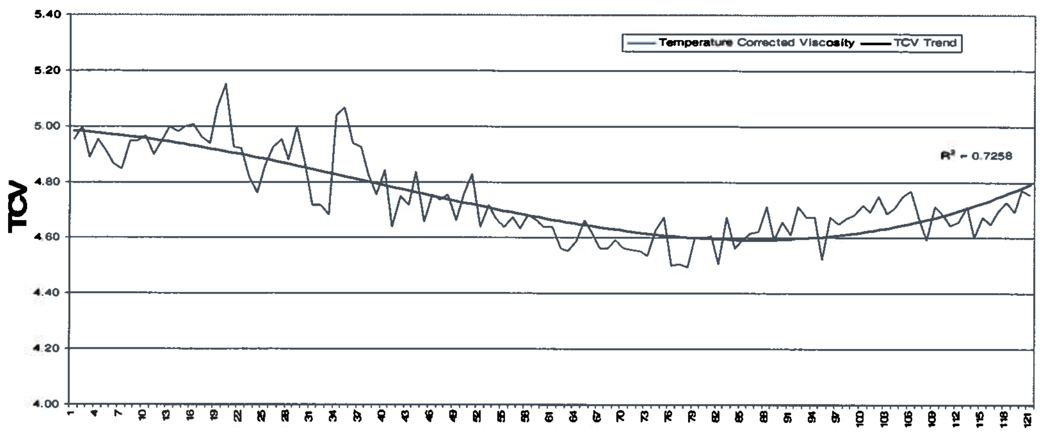


Exhibit 4: Viscosity impact of lubricant failure

Sensing Additive Breakdown and Oxidation in Lube Oil

Exhibit 4 shows real-time viscosity trending in the lubrication oil on a different engine. This engine was being tested to track failure by lubricant breakdown. The long term trend in temperature-compensated viscosity had been above 5 cP. After sustained operation, the lubricant additive package began to fail, and the viscosity dropped, indicating permanent shear-thinning. This failure allowed the oxidation of the oil to increase to the point that the viscosity begins to trend up, prior to predictable engine failure.

This exhibit highlights two factors. When oil conditions deteriorate significantly, failure modes can mask one another. Prior to the problems becoming extreme, however, viscosity trending allows problems to be identified at an early enough stage so that it can be highlighted as such and proper maintenance can be scheduled prior to failure.

The installation of Cambridge sensors on-engine is simple. They are typically mounted just downstream of the oil filter or in the oil filter assembly, with the electronics driven from the vehicle's on-board power. This allows simple retrofit of existing vehicles or design in for new vehicles.

Conclusion

Viscosity is a real indicator of oil health. Real-time dynamic viscosity measurements and trending can provide an early warning of oil and equipment failures. This information can be used for immediate problem solving or highlight the need for more detailed lab analysis to clarify the situation further so that the problem can be solved on an appropriate maintenance schedule rather than one caused by catastrophic failure.