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▶ BY PAUL MICHAEL, BENZ OIL

IN THE FLOW

How viscosity affects grinding oil performance.

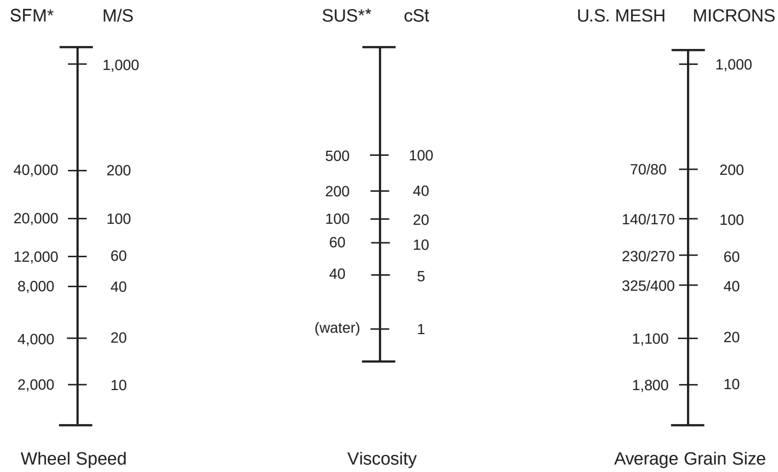
If you're like most people, you put a solution of water and antifreeze in your car's radiator and oil in its crankcase. The reasons are simple: Water is an excellent coolant, and oil is a first-rate lubricant. And, like most people, you probably don't use these liquids interchangeably.

Those who grind parts have more options. Either a water-based coolant or straight oil can be applied when grinding. The best one for a specific application depends on a variety of factors, including wheel speed, desired material-removal rate and depth of cut.

Water-based coolants typically are used for centerless and reciprocating grinding, operations in which the depth of cut is less than 0.05mm. A low depth of cut means heat generation is minimal. Surface integrity can be maintained as long as sufficient coolant is applied to flush away grinding debris and cool the wheel.

BenzGrind HP 15 flute grinding in an ANCA RX7.

Grinding Oil Viscosity Nomograph



Example: For a wheel speed of 100m/s and a grain size of 100 microns, the minimum viscosity required is 20 cSt. Benz Grind HP 15 has a nominal viscosity of 15 cSt at 40˚ C (104˚ F) and a viscosity of 20 cSt at 30˚ C (87˚ F). In this particular instance, Benz Grind HP 15 would be a good selection as long as the oil temperature is less than 30˚ C.

*Approximation of formula 0.00333 wheel speed (m/s) x 0.6 grain size (microns) = viscosity (centistokes)

**Saybolt Universal Seconds

All images: Benz Oil

Figure 1: To determine the minimum viscosity required for a grinding oil, draw a line between wheel speed on the left and abrasive size on the right. The point at which the line crosses the center axis is the minimum requirement.

Straight oils usually are used for creep-feed grinding and HEDG (high-efficiency deep grinding), where the depth of cut is between 0.1mm and 30mm. The heat generated at the workpiece surface during these volume-grinding applications is far greater than what develops in cutting operations such as milling, turning and drilling. (The primary reason is that grinding wheels produce smaller chips than cutting tools.)

"Temperatures as high as 600° C at the grinding interface are not uncommon," said Dr. John Webster, research associate at Saint-Gobain Abrasives' Higgins Grinding Technology Center, Worcester, Mass. "And they can exceed 1,000° C when grinding dry."

Excessive heat can lead to workpiece surface damage, including metallurgical and cosmetic grinding burn. High temperatures also increase wheel-dressing frequency and shorten wheel life.

Straight oils reduce friction and, thereby, heat generation, said Douglas Gaulin, product manager at Edgetek Machine Corp., Farmington, Conn. In a CBN grinding application, straight oil can extend wheel life 100 times.

Classifying Oils

Selecting an engine oil for your car can be as easy as checking your owner's manual. It recommends an SAE grade, such as 10W-30, 5W-30 or 5W-20. Selecting an oil for high-volume grinding is more difficult.

Oils required for grinding carbide, camshafts and gears are so low in viscosity as to defy definition within the SAE viscosity system. When describing a grinding oil, it is customary to talk in terms of centistokes (cSt)—a fundamental unit of viscosity.

Kinematic viscometers often are used to determine the viscosity of oils. Testing involves measuring the time needed for a certain volume of oil, at a controlled temperature, to flow through the capillary section of the viscometer.

For grinding oils and other industrial lubricants, the ISO specifies a test temperature of 40.0° (±0.1°) C. Typical viscosities of grinding oils range from 4 to 68 cSt, at 40° C. (Note: The viscosity of pure water is 1 cSt, at 40° C.)

Finding the 'Sweet Spot'

If you're behind the wheel on a rainy night in Georgia, you should probably slow down. At high speeds, water can literally lift your tires off the road. Driver-education instructors call this phenomenon "hydroplaning." Tribologists refer to it as "hydrodynamic lubrication."

In hydrodynamic lubrication, a separating lift, or pressure, is generated as a fluid film is drawn into the converging surfaces of a rotating bearing. This forces the surfaces apart, thereby reducing surface contact and friction. Higher-viscosity oils generate more hydrodynamic pressure, because they better resist being "squeezed" out of the contact zone.

When viscosity is too low, there is insufficient hydrodynamic pressure to keep surfaces apart. This leads to a high level of friction and grinding burn. When viscosity is too high, there is excess hydrodynamic pressure, which can cause dimensional variation. Between these two extremes is a "sweet spot," where friction is at a minimum.

Abrasive size is another factor influencing how well an oil can control friction. To illustrate how, imagine that rainy night in Georgia again and you're driving an old beater with bald tires. Tire treads permit water to escape from between your car and the road. But with bald tires, your car will hydroplane at a lower speed.

In high-volume grinding, fine-grain wheels behave much like bald tires. They trap fluid in the grinding zone, thereby raising the hydrodynamic pressure. Consequently, in carbide grinding applications with fine-grain diamond wheels, for example, lower-viscosity fluids are preferred in order to maintain dimensional accuracy.

Coarse grinding wheels, on the other hand, require a higher-viscosity oil to generate an optimal level of hydrodynamic pressure. As a result, such oils are used in applications like the grinding of HSS tools, where wheels made from relatively coarse grains are employed.

Simplifying Selection

Determining the optimal grinding oil viscosity historically has been a matter of trial and error. Recently, though, a professor of mechanical engineering at the University of Delaware-Newark, Dr. Andras Z. Szeri, developed models for predicting hydrodynamic pressure in the grinding zone. In testing these models, Szeri and his colleagues found that preventing turbulence within the grinding zone was the key to optimizing hydrodynamic pressure.

The mathematics behind the model is complex. (No less complex than Szeri's models for blood flow through an artificial heart!) To simplify the viscosity selection process, a chart was developed that enables the user to determine the minimum viscosity required to optimize hydrodynamic pressure during grinding (Figure 1).

As shown in the chart, the minimum viscosity requirement is a function of wheel speed and abrasive grain size. To determine the minimum viscosity, locate the wheel speed on the left scale and the average grain size on the right. Draw a line connecting those two points. The minimum viscosity corresponds to the point at which the line intersects the viscosity (middle) scale. It's that simple.

However, keep in mind that viscosity is temperature-dependent, so it is necessary to ascertain the temperature of the grinding fluid.

Table 1 lists several high-volume grinding applications where viscosity has been optimized through trial and error. In each instance, the actual viscosity is above or closely correlates to the minimum requirement found when using the chart. Temperature, of course, has a tremendous effect on viscosity. A mere 10° C decrease in oil temperature can produce a 50 percent increase in viscosity. Consequently, temperature for most high-volume grinding applications is controlled with oil chillers.

In the camshaft grinding application, a 15 cSt (at 40° C) oil was chilled to a constant 30° C. Cooling this oil to 30° C actually raised the operational viscosity one full viscosity grade, to 22 cSt, which is within 1 cSt of the predicted viscosity requirement.

A portable power monitor with data-acquisition capabilities was used to measure grinding energy during a HSS fluting operation. The wheel ran at a speed of 84 m/s and had an average grain size of 192µm. Two oils, differing only in viscosity, were compared. The peak spindle energy for the oil with an operating viscosity of 22 cSt was 10 percent higher than the oil with an operating viscosity of 32 cSt (Figure 2).

The benefits of reducing grinding energy through viscosity optimization extend beyond lower power-company bills. Lower grinding energy can also equate to a higher production rate, longer time between dressings and better surface integrity.

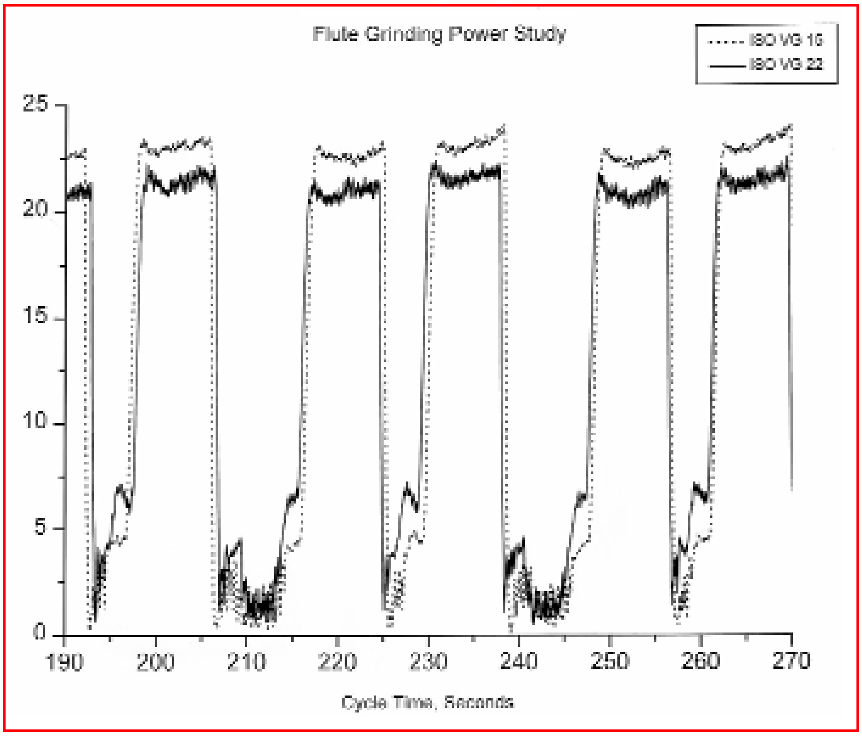


Figure 2: Spindle energy can be reduced by as much as 10% in a high-speed steel flute grinding operation by selecting the correct viscosity.

Field data	Wheel speed (m/s)	Grain size (average µm)	Calculated viscosity (cSt)	Actual viscosity @operating temp. (cSt)
Turbine blade grinding	60	210	25	33
Cast iron camshafts	90	126	23	22
Carbide blade grinding	28	91	6	11
HSS tools	84	192	32	32
Transmission gears	30	165	10	17

Table 1: Shown are several high-volume grinding applications where viscosity has been optimized through trial and error. The calculated viscosities, found by using the chart depicted in Figure 1, closely correlate to the actual operating viscosities of the applications.

About the Author

Paul Michael is technical director at Benz Oil, Milwaukee. For information about the company's line of grinding fluids, call (414) 442-2900 or visit www.benzoil.com.