Mike Johnson / Contributing Editor

POSITIVE DISPLACEMENT COMPRESSORS:

Selecting the correct lubricant

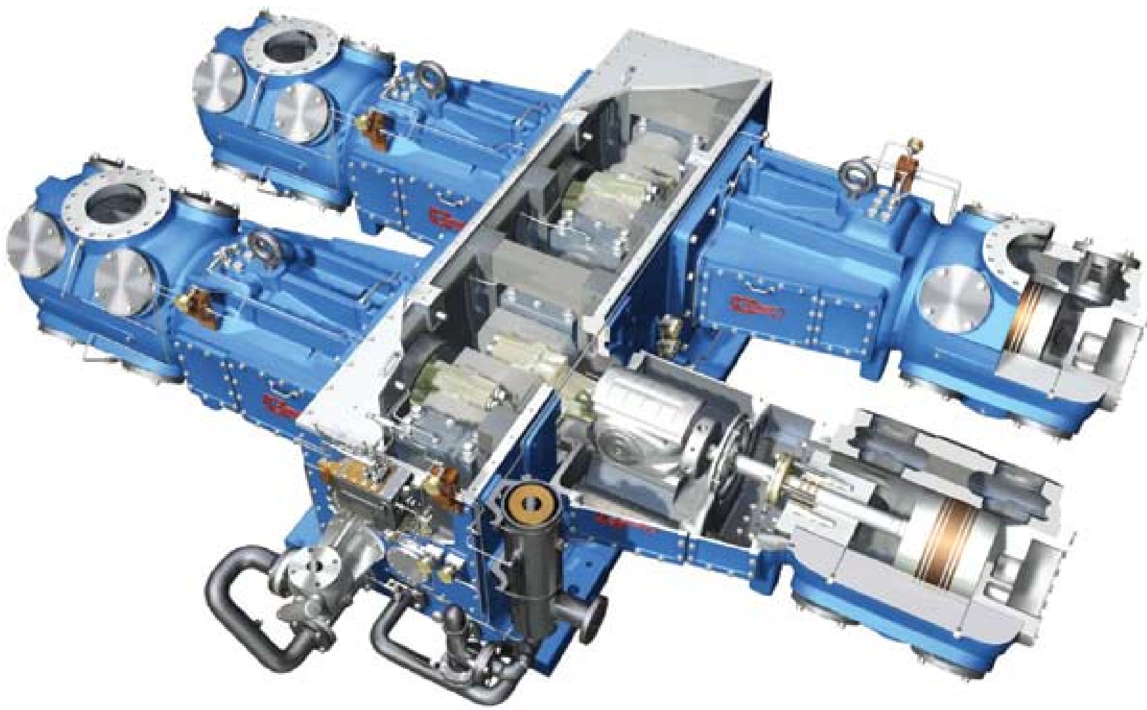

Photo Credit: Ariel Compressor Corp.

KEY CONCEPTS:

- Each of the two types of compressor design, positive displacement and dynamic, has distinct characteristics that must be considered when selecting a lubricant.
- Responsibilities for compressor lubricants in every component application include reducing friction and wear, removing heat and contaminants and preventing corrosion.
- Lubricant selection for rotary helical-lobed compressors is different from reciprocating machines because of the continuous interaction of the compressed gas and the lubricant.

Compressor design and application type have tremendous influence over lubricant selection decisions

Compressors are mechanical devices that pressurize and circulate air and various gases for applications that provide power for controls, maintain mechanical tension, enable chemical reactions, move raw materials and supply energy through gas pipelines to homes scattered throughout industrialized nations.

Without refrigeration compressors, the ability to supply food to entire nations would be lost. These same types of compressors make living in hot, humid climates more tolerable by supplying cool air for homes and offices.

There are many different designs that enable this work to be done. Each design has strengths and weaknesses that make it suitable for its respective application. Compressors may be classified according to the following output or discharge pressures:

- High pressure, greater than 2,000 kPa, gauge/290 PSIG
- Intermediate pressure, equal to 800–2,000 kPa, gauge/116–290 PSIG
- Low pressure, equal to 100–800 kPa, gauge/14.5–116 PSIG[1]

Blowers and fans provide gas at large volumes but at pressures below 100 kPa, gauge.

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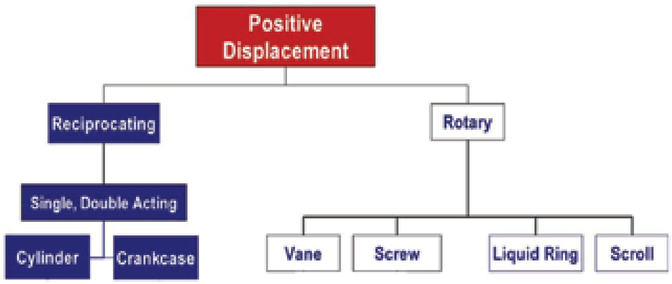


Figure 1 | **Compressor Types and Descriptions**

There are two categories of designs: positive displacement and dynamic (continuous flow). This article differentiates between the two types and addresses lubricant selection for the positive displacement designs, which is most common for industrial plant service. Next month we'll address dynamic compressors.

TYPES AND DESIGNS

There are a variety of compressor types and designs. As shown in Figure 1, the first broad division between compressor types is continuous flow type vs. positive displacement-type designs. A difference in lubricant construction and selection requirements begins at this point. Continuous flow compressors are like fans. Fans create pressure and flow by pushing the gas with a blade. Under normal operation, the lubricant doesn't interact with the air or gas being pushed through the machine.

Positive displacement compressor designs include reciprocating, sliding vane and rotary screw compressors and lobed blowers. In these designs, gas is drawn into a fixed volume cavity, a cylinder or chamber, and then is squeezed by the motion of the mechanical components into a smaller unit area, creating pressure.

RECIPROCATING COMPRESSORS

Reciprocating compressors achieve increased gas pressure by drawing gas into a fixed dimension chamber and then moving a piston to squeeze the gas into a smaller area. The orientation of the cylinder and movement of the piston can be vertical (perpendicular to the ground) horizontal or at an angle.

The temperature of the squeezed gas increases in a highly predictable manner. Gas can be squeezed on only one side of a cylinder (single-acting) or on both sides (double-acting). Reciprocating compressors may operate with or without oil in the compression chamber. Units without oil are referred to as oil-free compressors, but the oil-free condition does not apply to the bearings, crank and crosshead components used to cycle the pistons.

Gas pressure can be created using a single or multiple cylinders (single-stage, multistage). Low-hp, shop-type air compressors are typically single-stage. As the expected amount and pressure of the gas increases, multiple compression stages are typically employed. A multistage compressor works the same as a single-stage unit, except that it contains two or more cylinders and pistons working in unison.

Single-stage units are employed where air volume requirements are low, and pressure requirements are less than 100 PSIG (pounds per square inch gauge. 1 PSIG = 14.7 pounds per square inch atmosphere. Normal air pressure at sea level is 14.7 psia). When the amount of compressed air increases and when the air pressure is above 100 PSIG, then gas compression involving two or more stages is more energy-efficient.

Two-stage, double-acting compressors have been used in industrial environments to provide plant air for many years. In these units, the first stage pressurizes the gas to 25-40 PSIG. The gas is cooled and then directed to the second stage to bring the gas to operating demand pressures (100–200 PSIG). Efficiency and compressor longevity is achieved by allowing the heat to dissipate from the gas with the use of an intercooler positioned between the stages.

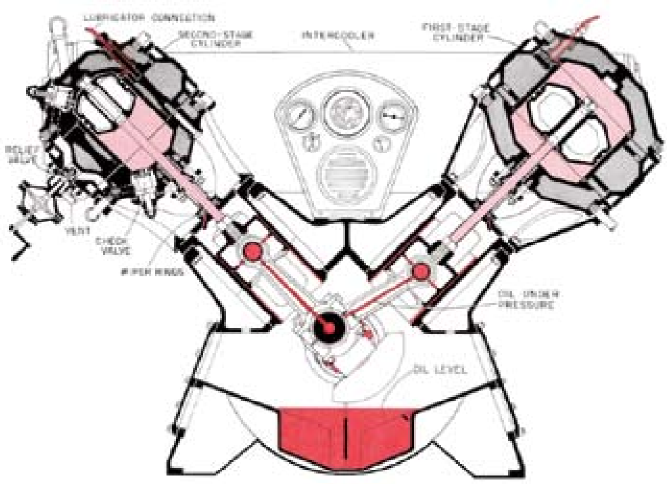


Figure 2 | **V-Type Double-Acting, Two-Stage Compressor Showing Key Components** (Courtesy of ExxonMobil Oil Corp.)

Figure 2 provides a view of the internal components of a large, V-type double-acting, multistage reciprocating compressor, including views of the compression cylinder, the crosshead and the crankcase and main crank.[2]

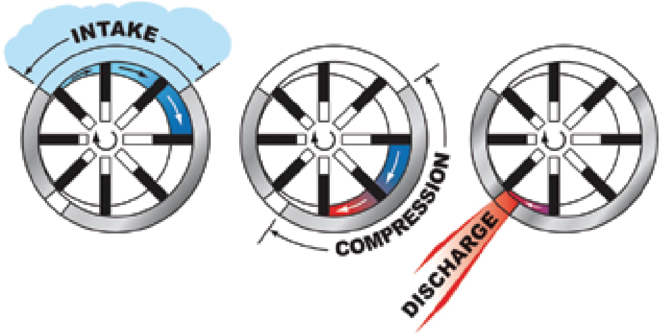


Figure 3(a) | **Operation of a Vane Compressor Suction, Pressurization and Discharge Cycles**

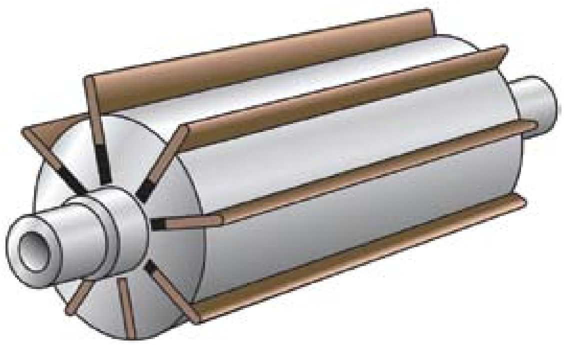


Figure 3(b) | **The Position of Vane Placement Within a Rotor Under Operating Conditions**

The piston is driven by a rotating shaft that is attached through a connecting rod and a crosshead. The crosshead is a stabilizing component designed to minimize transverse forces to the piston since the connecting rods move from side-to-side with the rotary motion of the crank. Transverse forces could cause significant wear on the piston and cylinder, as well as increasing overall friction and reducing compressor efficiency if not eliminated, particularly for double-acting machines. The crosshead converts all rotary motion to pure linear motion.

ROTARY SLIDING VANE COMPRESSORS

Rotary sliding vane compressors are comprised of a rotor mounted offset within a cylindrical housing. The rotor contains multiple vanes that slide in and out of the rotor as it turns within the housing. Vane materials are both metallic and non-metallic. The vanes press against the cylinder walls by centrifugal force. As the rotor turns, the air trapped in the quadrant between the vanes is squeezed into a smaller space by the convergence of the rotor with the cylinder wall. The compressed air is released when the leading vane crosses the delivery port, as shown in Figure 3(a). Figure 3(b) describes the normal position of vane placement within a rotor under operating conditions.

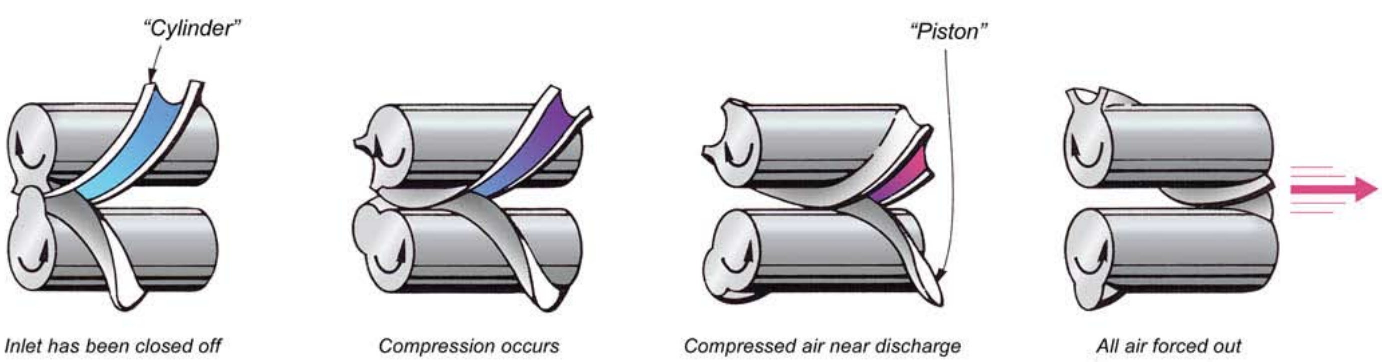
The action of the vane sliding against the cylinder wall at high-speeds creates high surface rubbing conditions between the face of the cylinder and the end (tip) of the vane. The sliding frictional condition creates a hydrodynamic oil film. The rotor is supported by element bearings and an elastohydrodynamic oil film. Further, the heat of compression can be high and can cause lubricant degradation and formation of oil deposits and residues.

Maintaining an adequate oil supply volume is crucial to avoid friction and bearing and vane wear. An automatic oil supply system provides a constant supply to the cylinder and bearings, with the volume based on the total amount of cylinder surface in contact with the sliding vane. Fixed oil feed rates are provided by the compressor manufacturer based on machine speeds, rotor or piston size, maximum air pressures and discharge temperatures. The lubricant is discharged with the gas and must be separated from the gas to assure that it doesn't interfere with plant processes. For this reason, optimizing the lubricant supply is important.

ROTARY SCREW COMPRESSORS

Rotary screw compressors were initially developed in the 1930s but did not become commonplace in manufacturing and industrial environments until the 1960s. This compressor type could be more accurately described as a helical-lobed compressor, but the term rotary screw is commonplace.

Figure 4 | **Single-Lobe Diagram Explaining the Motion of the Screw Compressor**



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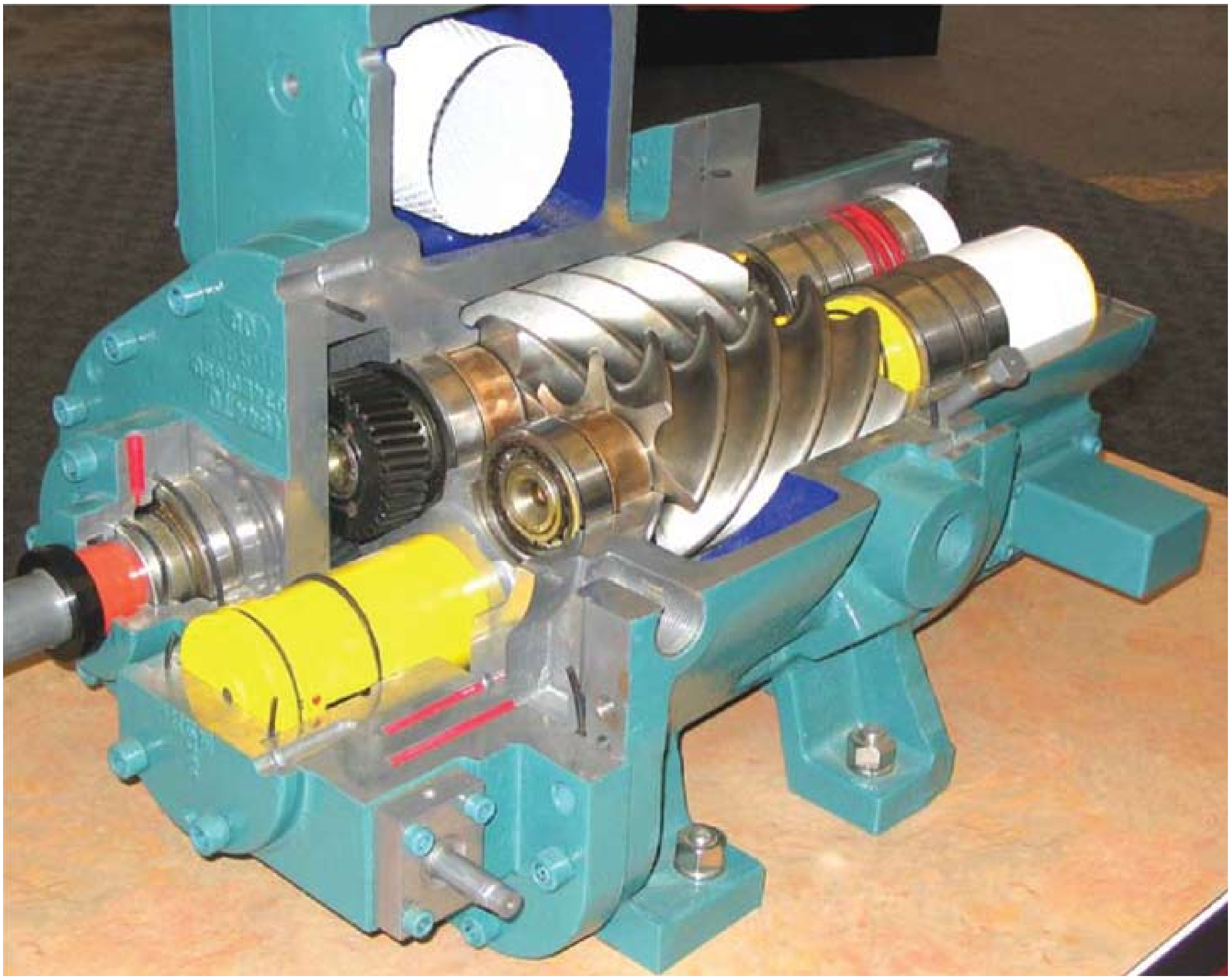

Figure 5 | **Cutaway View of a Piston and Lube Rotor Set, including Timing Gear**

The rotary screw is a constant-discharge positive displacement machine. As shown in Figure 4, profiled rotors in close-fitting case mesh to form cylinders and pistons in rotary screw machines.[3] In this illustration, the rotor shows only a single mesh. Air is supplied at the end of the rotor where the rotor and helical receiver mesh. As the meshing rotors turn, the gas is compressed and moved toward the discharge section of the end off the rotor.

Most compressors have two rotors. One rotor will have four or five rounded lobes, and the other will have a compliment of helical-shaped pockets that receive the lobes. By design the lobes mesh with the helical pocket and the air in each pocket is compressed. When the appropriate air pressure is achieved, air passes to the discharge port and into the system piping. With the lobes compressing and discharging five or six times per rotation, and rotating at 20 times per second, the discharge is nearly constant.[4]

Screw compressor designs include lubricated and non-lubricated lobes. A non-lubricated lobe configuration requires the use of a timing gear to drive the two lobes in sequence and will tend to run at higher speeds than lubricated versions. Dry screw compressors may be attractive for process applications that would be harmed by accidental contamination with a lubricant such as with blow molding containers for use in food processing.

When the lobes are lubricated, the compressor is called a flooded screw and may or may not incorporate the use of a timing gear. Flooded screw compressors operate with an oil injector supplying a spray of oil into the chamber at the suction inlet. The oil is the same as that used to protect bearings and the timing gear. Figure 5 provides a cutaway view of a standard configuration, including the use of the bearings and timing gear.

LUBRICATING POSITIVE DISPLACEMENT COMPRESSORS

The lubricant has four key responsibilities in every lubricated component application, including reducing friction and wear, removing heat, removing contaminants and preventing corrosion, which is essential to production of clean, pressurized air and long component lifecycles. There's a fifth routine lubricant function, providing hydromechanical power transfer, but it does not apply.

Appropriately selected and applied lubrication is essential to:

Reciprocating Compressors. Lubrication requirements for reciprocating machines fall into three categories.

- Cylinder lubricant, which addresses all parts that come in contact with pressurized air, including the piston rings, cylinder walls, suction and discharge valves and packing. The cylinder area is supplied by an automatic lubricator designed to provide a constant volume of lubricant per each square foot of swept surface area.

  The lubricant functions for the cylinder in the sliding vane compressor are very similar to that of a reciprocating cylinder. Both operate in thin film hydrodynamic conditions, are exposed to high rates of evaporation and highly oxidizing conditions and require a carefully optimized supply rate to avoid fouling the downstream components and piping.

- Bearing and crankshaft lubricant, which addresses all mechanical parts associated with the rotating action of the machine, including the main crank bearings, the connecting rod bearings and pins and the crosshead. The crankshaft and crosshead components operate with either a pressurized oil supply or are splash lubricated by components running in a bath of oil. Higher speeds and higher break horsepower machines warrant forced-feed oil supply.

- Combined splash lubrication is common for low-hp compressors and includes all components in the crankcase and cylinder area.

Cylinder Lubricants, Sliding Vane Compressors. Reciprocating and rotary vane type cylinder lubricants are precisely metered into the cylinder and packing gland area (if applicable) of the compressor by an external system. The amount of lubricant is dependent on several factors, and the flow rate is calculated and should be tightly controlled. Cylinder feed rates will be addressed in a subsequent article.

The cylinder lubricant operates in a continuous thin film condition at a purely sliding frictional interface. Although the cylinder walls are generally liquid-cooled, the heat from compression is still very high and is transferred into the surface cylinder metals, piston and suction and discharge valves. Cylinder lubricants must withstand these highly oxidizing and degrading conditions.

The cylinder lubricants' primary tasks are to control friction and wear, create and maintain a seal between the piston and cylinder wall, or between the piston rod and the packing, and to control corrosion. For reciprocating cylinders, the maximum stress on the lubricant occurs when the piston reaches the end of the stroke and must change directions.[5] Loss of continuous movement may cause momentary loss of oil films and metallic contact.

To combat these well understood conditions, the cylinder lubricant should be highly fortified for wear resistance, oxidation resistance and deposit formation resistance. It is a good idea to consult with highly reputable lubricant suppliers, preferably with extensive experience in compressor lubricant development, when selecting the cylinder lubri-

Figure 6 | **DIN 51 506–VDL Lubricating Oil Minimum Performance Requirements**

Lube Oil Group	VDL Severe Service Duty				
Viscosity Grade	ISO 32	ISO 46	ISO 68	ISO 100	ISO 150
Kinematic Vis (Din 51561 / 51562-1) cSt @ 40C	28.8 to 35.2	41.4 to 50.6	61.2 to 74.8	90 to 110	135 to 165
cSt @ 100C	5.4	6.6	8.8	11	15
Flash Point, °C (COC), min. (Din ISO 2592)	175	195		205	210
Pour Point, °C, max (DIN ISO 3106)	-9				-3
Ash, % wt., max. (DIN 51575)	Sulf. Ash to be stated by supplier				
Water Sol. Acids (DIN 51558 Part 1)	Neutral				
Neut. Number (AN), mg KOH/g, max (DIN 51558 Part 1)	To be stated by supplier				
Water, % (DIN ISO 3733)	0.1 max				
Aging Characteristics % CRC max. after air aging (DIN 51352 Part 1)	Not Required				
% CRC max. after air/Fe_2O_3 aging (DIN 51352 Part 2)	2.5			3.0	
Distillation Residue % CRC max. of 20% Distillation residue (DIN 51356 / 51551)	0.3				0.6
Kinematic Vis at 40C max. of 20% distillation residue (DIN 51356 / 51561 / 51562-1	Maximum of five times the value of the new oil				

cant. Additional impartial advice is available via the ISO/DP 6521 and DIN 51506 Standards. The VDL portion of the DIN 51506 Standard is shown in Figure 6. This pertains to the product requirements for more severe service applications, recommending enhanced wear and deposit resistance performance. Viscosity grades are dependent on operating speeds and must be selected in accordance with the OEM guidelines.

Bearing and Crankshaft Lubricant. The mechanical functions of the balance of the machine are simplistic. Positive oil flows and splash distribution enables thorough coverage of linkage and rotating components. Since there is no interaction between the frame of the crankcase/crosshead and the compressed gas, the interferences common with cylinder lubrication are not present at the crankcase.

The cylinder lubricants' primary tasks are to control friction and wear, create and maintain a seal between the piston and cylinder wall and to control corrosion.

Simple AW/R&O circulation oils are typically adequate. Again, the viscosity question must be addressed in conjunction with the OEM guidance for machine speeds.

Combined Splash Lubrication. In many designs of small or portable compressors, the OEM designs cylinder lubrication to be performed from the crank reservoir. The lubricant splashes or is pumped to the cylinder surfaces and drains back to the sump. These small-hp machines are designed to be lubricated by light-grade engine oils such as those used for gasoline and diesel engines. While this is a long-standing practice, some agents in the gasoline/diesel engine lubricants hinder moisture separation. Long-term service with these types of products may increase the risk of surface wear and corrosive wear and shorten the lifecycle of some compressor components.

Again, viscosity selections are dependent on model and operating speed and to a large extent the risk of cold-start, low flow conditions. Consult the OEM maintenance guide when addressing these concerns.

ROTARY SCREW COMPRESSORS

Lubricant selection criteria for a rotary helical-lobed compressor is quite different from a reciprocating machine due to the nature of the continuous interaction between the compressed gas and the supplied lubricant. In flooded screw applications, the oil remains in direct contact with the gas at design temperatures, typically 80 C-100 C. After mixing with the gas, the lubricant is carried downstream and must be removed from the gas by demisters and separators, and returned to the supply tank.

The stress on the lubricant is appreciable. The oil must separate quickly from water and have a low tendency to create foam. If the compressed gas medium is air, exposure to hot oxygen accelerates the oxidative stress and degradation. The lubricant also requires strong wear-resistance properties and strong deposit and sludge formation resistance.

Lubricating properties noted in Figure 6 align favorably for these requirements. Additional details for corrosion resistance (ISO 3016, Minimum 1b), rust resistance (ISO/DP7120A, No Rust), foaming tendency (ISO/DP 6247, Sequence 1: Tendency, 300 ml max., Stability–nil) are important to round out rotary screw lubricant performance.[6]

Viscosity selection is machine dependent. Most flooded screw compressors operate with initial viscosity grades between 32 and 68, with the final selection influenced by cold-start conditions. At operating temperatures, there is little difference in actual viscosity between oils beginning at ISO 32 and 68 grades.

Most compressor manufacturers provide compressor oils based on synthetic polyalphaolefin, polyolester, diester and polyglycol type basestocks. Each of these offers strengths and weaknesses, including that of gas solubility in the lubricant. Modern, high-quality turbine oil based on hydrocracked Group II and Group III mineral oil basestocks also offer attractive long-term properties. TLT

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6. Ibid 4, ISO/DP 6521 Compressor Lubricants Performance Requirements, p. 315.

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