Section 5

HYDRAULICS

Hydraulic Systems

A hydraulic system is a way of transmitting power. It's not always efficient or practical to use a mechanical linkage, or electrical power, or pneumatic (air) power to move an object. With the press of a button and the whir of a pump, the pressure of the hydraulic fluid can lift the boom of a heavy crane. Or with some physical energy, a person with a strong arm and a hydraulic jack can lift a car.

Pascal's Law says that the pressure inside a container will be the same at all points in the container. That means that if you sat on a piston and put 200 pounds of pressure on it, there would be 200 pounds of fluid pressure throughout the entire cylinder. In a hydraulic jack, every push of the lever puts a few pounds of fluid pressure into the cylinder which raises the car ever so slightly. With this hydraulic leverage, even a 90-pound weakling can lift a car weighing over a ton.

There are two basic types of hydraulic systems. The simplest is the hydrostatic system – an example is the hydraulic jack for lifting a car. The force applied to the small piston is transferred to the greater area of the large piston. The second hydraulic system is the hydrodynamic type in which the velocity imparted to the fluid by a pump is converted to energy when the rapidly moving fluid strikes against some driven member. Hydraulic couplings and converters are examples of this type.

A typical hydraulic system is illustrated in the following diagram and consists of the following major components:
Reservoir which stores cools and allows contaminants to settle.
Hydraulic fluid which transmit the power in the system and lubricates cools, and carries contaminants to the filter
Pumps which create flow and not pressure, which is resistance to movement, are the heart of the system
Fluid conductors which transport the fluid through the system and consist of tubing, pipe, hoses, and fittings
Pressure control valves which help regulate the pressure in the system such as the pressure control valve which prevents the system from over pressurizing
Filters which maintain oil cleanliness to prevent contamination of the sensitive valves in the system
Flow control valves which help regulate the flow rate through the system
Directional control valves which regulate the flow direction of the pressurized fluid resulting in the direction of movement for the working element
Working element which is a piston in a cylinder which moves or holds the load

Hydraulic System

<u>Pumps and Components</u>

The heart of a hydraulic system is the pump. Hydraulic pumps convert the mechanical energy transmitted by a prime mover (electric motor, internal combustion engine) into hydraulic working energy or hydraulic horsepower.

All positive displacement pumps generate an increasing volume at the suction side and a decreasing volume at the pressure side. While flow is created by increasing and decreasing volume, pressure is created by restrictions in the lines or the fluid working against an actuator (the working element). This makes sense because liquid flows freely without pressure until there is something to stop it. Interestingly, as hydraulic flow increases, the pressure stays the same, provided there is no increase in resistance.

The positive displacement pump is the type of pump used in most industrial hydraulic systems. The output of a fixed displacement pump is independent of pressure. That means that with each rotation of the pump, a fixed amount of fluid is moved. Three of the most common positive displacement pumps are vane, piston and gear pumps.

Vane pumps generate a pumping action by causing vanes to track along the inside of a ring.

Visualize a shaft (called a rotor) spinning inside a cylinder. The rotor is significantly smaller than the cylinder so there is empty space between the shaft and the inside wall of the cylinder. Cut about six longitudinal slots into the sides of the rotor. Insert flat blades (called vanes) into the slots so they can move freely in and out. When the rotor spins inside of the cylinder, centrifugal force flings the vanes out so they scrape against the inside of the cylinder wall. The volume of the space between each of the vanes is the same as its neighbor's.

Now move the rotor off center so that it almost touches the cylinder wall. Now there are different sized chambers between the vanes. Where the rotor is close to the cylinder on the bottom, the volume of the space is very small. At the top of rotation, where the rotor is far away from the cylinder, the volume is large. Remember that increasing and decreasing volume causes pumping action. If the cylinder is enclosed, except for a small area where fluid could get sucked in and another where it could be pushed out, you have made a vane pump.

The beauty of a vane pump is that by varying the distance of the cam ring (the cylinder in our example) to the rotor, it is easy to control the output of the pump.

A vane pump consists of a rotor, vanes, ring, and a port plate with kidney-shaped inlet and outlet ports. The rotor is positioned off-center to the ring. As the rotor is turned, an increasing and decreasing volume is formed within the ring.

The vanes can generate a lot of wear on the ring since they scrape all the hydraulic fluid off the walls of the ring. For this reason, most hydraulic oils for vane pumps have anti-wear additives that form a molecular carpet to protect the ring.

Gear pumps generate a pumping action by causing gears to mesh and unmesh.

A gear pump consists of housing with inlet and outlet ports, and a pumping mechanism made up of two gears. One gear is attached to a shaft, which is connected to a motor or engine, and it drives the other gear. The action of teeth meshing and unmeshing generates an increasing and decreasing volume. And wherever you have increasing and decreasing volume, you can have pumping action.

An internal gear pump consists of one gear that is shaped like a ring with teeth on the inside of the ring. These teeth mesh with another gear that is inside the ring. This type pump is sometimes referred to as a gear-within-gear pump. The most common type of internal gear pump in industrial systems is the generator pump.

Piston pumps generate pumping action by causing pistons to reciprocate within a piston bore.

The piston pump basically consists of a cylinder barrel, pistons with shoes, swashplate, shoeplate, shoeplate bias spring, and port plate.

Several pistons are arranged in a cylindrical barrel, much like bullets in a revolver. The bottom of each piston has a shoe that sticks down out of the cylinder. All the shoes ride on a single round plate called a swashplate. If the cylinder was vertical and the swashplate sat flat, the pistons wouldn't move up and down if the cylinder were rotated. But the swashplate is at an angle.

As the cylinder barrel is rotated, the piston shoes follow the surface of the swashplate. (The swashplate does not rotate.) Since the swashplate is at an angle, it pushes the pistons up and down within the bore. This generates increasing and decreasing volume.

Piston (reciprocating) pumps can generate the highest pressure of the three positive displacement pumps.

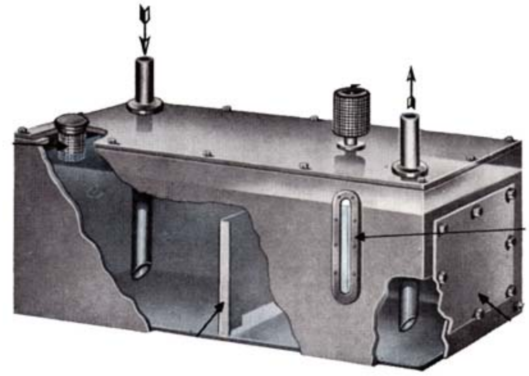
Centrifugal pumps do not work on the principle of increasing and decreasing volume. They spin the fluid, just like a pinwheel. The spinning motion can generate some thrust loads so most centrifugal pumps have a radial and a thrust bearing. Centrifugal pumps operate at low pressures and are generally not used in hydraulic systems.

Actuators in a hydraulic system convert the fluid pressure to motion, or, in other words, they convert hydraulic energy into mechanical energy. They generally fall into two categories – cylinders, which transmit linear motion, and motors, which transmit circular motion. A hydraulic motor can be a pump set up in reverse; instead of a prime mover driving a pump to produce fluid flow, the fluid drives the hydraulic motor to produce rotary motion.

Pressure relief valves protect the system from dangerous over-pressurization. Other valves that might be found in a hydraulic system include brake valves, sequence valves, loading and unloading valves, proportional valves and solenoid valves. Balancing valves in each suction line can balance the flow between pumps in parallel.

Reservoirs also play an important part in a hydraulic system. The typical components of a reservoir are:

1. Reservoir tank
2. Cleanout cover
3. Suction, return and drain lines
4. Oil level gauge
5. Filler/breather cap
6. Baffles
7. Filters, screens and strainers
8. Vent



Baffles are an important component in a hydraulic reservoir. They allow the fluid time to cool, de-aerate, and to settle out water and dirt. A good rule of thumb to use for residence time in a reservoir is 2 to 3 times the pump output. If the system is highly contaminated, residence time may be 10 times the GPM (gallons/minute) of the pump.

Return lines into the reservoir should be larger than the intake line and should generally be positioned below the surface of the oil to minimize air entrainment. Locate the return line as far away from the suction as possible to allow the oil as much residence time as possible. If this is not possible, install a baffle or weir between the suction and discharge lines. One suggestion to improve oil flow in the reservoir is to cut the return line at an angle so that it directs flow back toward the tank wall.

Fluid conductors, the pipes and hoses needed to transport the fluid through the system, can have a significant impact on the system's efficiency. Some suggestions for connectors that can help minimize leakage between piping are straight threat, flare weld, o-ring and flange connectors. NPT (National Pipe Taper or National Pipe Thread) designations can be found on many fluid conductors.

It is important to choose fluid conductors that are rated with a burst pressure above the pressure of the system. The burst pressure is at the point at which a hydraulic line yields.

An accumulator is often added to a hydraulic system if there is a need for instantaneous fluid flow. It can be a bladder that holds excess fluid under pressure that can be released as needed. It can also serve as a buffer to absorb impulses. Accumulators can fail because of poor padding, incompatible bag materials, improper installation, over-pressurization or overheating.

Hydraulic fluids

Principal requirements of a hydraulic fluid are:

- Satisfactory flow properties
- A high viscosity index

- Low compressibility
- Good lubricating properties
- Low vapor pressure
- Compatibility with system materials
- Chemical stability
- Protection against corrosion
- Rapid air-release and demulsibility
- Good thermal conductivity
- Fire resistance
- Electrically insulating
- Environmentally acceptable

One of the most important characteristics of a hydraulic fluid is its viscosity. Most vane type pumps use an ISO VG 32, 46 or 68, while piston pumps use ISO VG 100. There is considerable variation in this recommendation based on temperature, pressure and application.

The **viscosity index** of most hydraulic oils is generally 90 or above. However, viscosity index means little for systems with a relatively constant temperature. Mobile systems, where temperatures may range from below 0°F to over 100°F, use oils with much higher V1 to avoid having to change the oil with the seasons.

The most common hydraulic oil anti-wear additive is based on zinc, sulfur and phosphorus. These three chemicals form a base that is strongly attracted to a metal surface. Attached to this base is a long chain of hydrogens and carbons. As these molecules line up with the zinc compound on the metal and the hydrocarbon tail waving in the oil, they form a carpet that is hard to scrape off the metal surface.

There are other anti-wear additives that do not contain zinc. Some are based on sulfur, and some on fatty materials. Anti-wear additives, as a rule, are not as aggressive as extreme pressure additives. Oils that contain anti-wear additives are often called AW oils in the US or carry the HLP designation in Europe.

Oxidation inhibitors are added to extend the life of the oil. Oxygen reacts with the oil to produce weak acids that can pit surfaces. Oxidation inhibitors slow the rate of oxidation.

Rusting and corrosion - In the context of a hydraulic system, corrosion refers to a deterioration of a component surface due to a chemical attack by acidic products of oil oxidation. Rusting refers to the process of a ferrous surface oxidizing due to the presence of water in oil. Oils that contain rust and oxidation inhibitors are known as R&O oils in the US, and HL oils overseas.

Most oils contain **foam inhibitors** that work by altering the surface tension of the oil. It allows bubbles to combine and break. Foam inhibitors are either based on silicone or are organic antifoam agents.

Pour point of a hydraulic fluid is the lowest temperature at which it will pour under an ASTM laboratory test. Pour point of oil should be at least 20°F below the lowest expected temperature.

Rapid **air release and demulsibility** are necessary to minimize cavitation and inaccurate pressure response.

Hydrolytic stability is the ability of the oil to resist degradation in the presence of water. This is important because any hydraulic system open to the atmosphere will be exposed to some moisture from humidity and condensation. Some ester-based fluids have relatively poor hydrolytic stability and will rapidly turn acidic in the presence of water.

Aerial lift devices, also known as cherry pickers and bucket trucks, are used around electrical power lines. For this reason, it is important for the oil to resist conducting electricity. In case the boom touches a live power line, this protects the person from being electrocuted. Most non-detergent oils have inherently high dielectric strength.

Dielectric strength is not a legitimate test for this application and was voted out of the ANSI standards. The test is designed for electrical insulating oils, and is measured across electrodes that are less than a tenth of an inch apart. Since hydraulic lines are much longer than a tenth of an inch, the test does not apply. It is more important for the oil to be clean and dry, to have a high viscosity index, low pour point, good anti-wear performance, and to be non-detergent.

Fire resistance is important when a hydraulic fluid is used around extremely high temperatures, for example hydraulic lines that travel over hot ingots in a steel mill. Fire resistant hydraulic fluids will burn, but they don't propagate the flame back to the source. This is important if a line bursts and hydraulic fluid sprays into a hot area. The fire is contained in the small area and does not cause the entire system to explode.

The major types of fire resistant hydraulic fluids are oil-in-water emulsion, water-in-oil invert emulsion, water-glycol, phosphate ester and polyolester.

"High water base fluid", "HWBF", "95:5 oil", "soluble oil", and "oil-in-water emulsion" are all terms to describe water base hydraulic fluid made up of water emulsified with 1-10% oil. These fluids are usually milky. They are mostly used in leaky systems because they are inexpensive. Their main disadvantages are that they contain 95% water, and therefore have poor lubricity and grow bacteria.

An invert emulsion is generally a creamy-white liquid made up of 60% oil and 40% water. Since oil is the dominant liquid, the equipment sees the oil rather than the water. Oil is a better lubricant and provides better rust protection than water. When switching from petroleum oil to a water base fire resistant fluid, some problems could occur with protective coatings. If a reservoir interior is protected with petroleum compatible paints and varnishes, a water base fluid may dissolve the coating.

Water glycol fluids are usually red, have excellent fire resistance, and can be used over a wider temperature range (0°F to 140°F) than invert emulsions. However, they can be used only for moderate pressures and are incompatible with other fluids. Their viscosity may increase as water evaporates. They're also not compatible with zinc, cadmium and magnesium, and they have poor corrosion protection. They contain 35 to 50% water.

Phosphate ester hydraulic fluids are sometimes used instead of mineral-based fluids in certain high-risk applications such as aviation flight-control hydraulics and steam turbine electro-hydraulic control systems. They are not compatible with many seal materials. Different references recommend different seal materials. Some recommend fluorinated materials such as Viton, while others recommend ethylene propylene (EPR, EPM, EPDM), Nylon or polyethylene.

Detergents are not commonly recommended for industrial systems because they typically absorb water. Water should be kept out of a system because it promotes rust and oxidation. Water can also plug filters and affect oil viscosity. Most industrial fluids drop water to the bottom of the sump where it can be drawn off.

Mobile hydraulic systems, such as construction equipment hydraulics, use detergent engine oils because of product consolidation and because of the higher zinc content in some engine oils. They also have relatively small sumps that can be changed frequently. Hydraulic systems in food plants require oils that meet the former USDA standards H1 and H2. H1 defines oils that are suitable for incidental food contact. An H2 lubricant may come into the plant, but may have no food contact. These oils often made of white mineral oils and contain food grade additives.

Contamination Control

There are many causes of hydraulic pump failures, such as improper installation, poor maintenance practices, and improper fluid selection, but one of the most controllable root causes is contamination. Although a hydraulic fluid may appear clear and bright, without any sign of visible mechanical impurities, it may still contain excessive amounts of microscopic particles.

Like most industrial equipment, there are four major sources of contamination. First, machining swarf, rust protectants and residual lubricants can remain from when the pump was manufactured. Second, wear particles are generated during assembly, break-in and operation. Third, dirt can come in from the outside, and fourth, contamination can be introduced during maintenance.

To protect against contamination that might be left over from the manufacturing process, it is a good idea to flush the hydraulic system before adding the full charge of new oil. One procedure is to flush with light rust and oxidation-inhibited oil, operate the system at maximum flow rate to generate turbulent flow, bypass control valves if necessary to ensure flow to all parts of the system, check and change filters as necessary, and refill with the operating charge. New oil typically should be filtered through 5 to 10 micron filters.

It is important to install filters and strainers in the system to prevent damage from internally generated contamination, and from dirt from the outside. Some suggested locations for filters and strainers are:

Pump strainer (coarse filter on end of suction line)
Off-line (side loop) filter
Fine mesh pressure filter
Return line filter

If the pump is being used in a very dusty environment, it might be wise to choose a gear pump since they seem to be the most tolerant of particle contamination.

Temperature should be controlled in hydraulic systems for several reasons. First, if the system is too hot or cold, the viscosity of the fluid may be too low or too high, respectively. When the viscosity is too low, there may be wearing caused by metal-to-metal contact. If the viscosity is too high, the system may become sluggish. High temperatures also increase oil oxidation rates and shorten the life of the oil.

Cavitation occurs when bubbles rapidly decompress in an area of low pressure. This can occur in a pipe bend or in a pump. Evidence of cavitation is a sound that is similar to marbles rolling around inside the pump, along with vibration and wear.

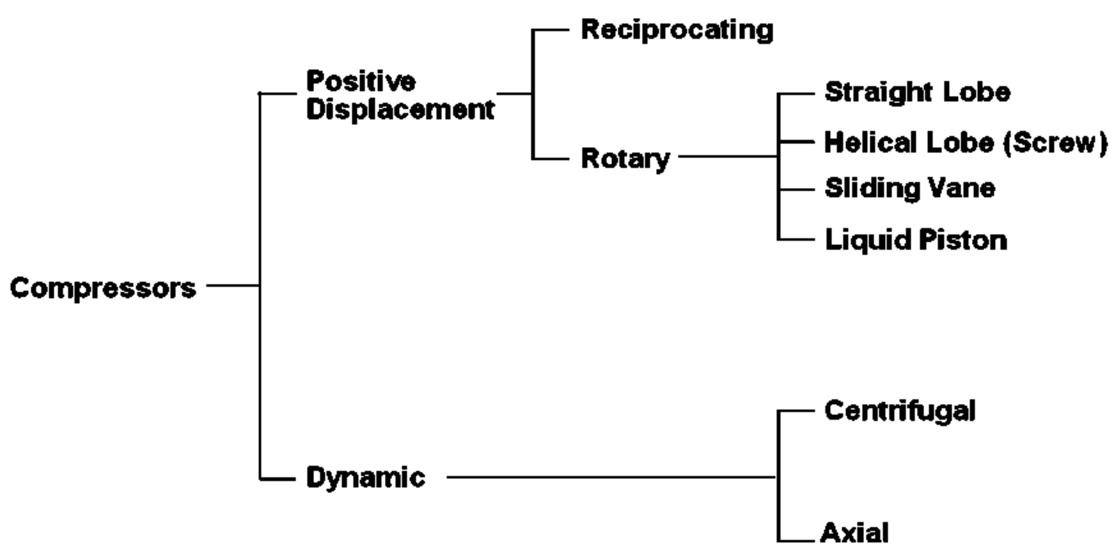
Section 7
COMPRESSORS

Compressors

Compressors move air and other gases. In more specific terms, compressors convert the mechanical energy transmitted by a prime mover (electric motor, internal combustion engine) into potential energy of compressed air. Impact wrenches, jack hammers and many other applications are driven by compressed air. Gases are also transmitted along long lines by the use of compressors.

The following are the various compressor types.

COMPRESSOR TYPES



Reciprocating compressors compress gas by a piston moving back and forth within a cylinder. It is the most common type of positive displacement compressor found in an industrial pneumatic system.

Here is the sequence of events that occur in a reciprocating compressor.

Piston moves down, volume increases.
Inlet valves opens.
Air is drawn into cylinder through inlet valve.
Piston reaches bottom of stroke.
Inlet valve closes, discharge valve opens.
Piston returns – volume decreases.
Air is compressed.
Air is expelled out of the discharge valve. Discharge valve closes.
Piston reaches top of stroke.

Single acting compressors are simple. As the piston comes down, the volume in the cylinder increases and it draws gas in the intake. As the piston goes up, the volume decreases, and it pushes the gas out the exhaust.

As air is compressed it gets hot. Excessive heat degrades the lubricant and compressor components. To reduce the amount of heat of compression, many compressors have several stages where the gas is compressed, allowed to cool, and then compressed again. By compressing in stages, higher pressures can be reached at lower temperatures.

Double acting compressors work on the principle stated above. They compress gas on both strokes of the piston. Someone figured out that as the piston is coming down in the cylinder and expanding the volume above it, the volume is actually decreasing below it. If there was a way to harness this motion, then as gas was being compressed and exhausted out the chamber at the top, the rising piston could be drawing air into another chamber at the bottom. For this to happen there is usually a stuffing box and piston rod seal to prevent gases from escaping around the rod that drives the piston.

Rotary compressors, like hydraulic systems, fall into two main categories, positive displacement and dynamic. Positive displacement compressors move air from a high volume area and squeeze it into a low volume area where it is discharged under pressure. Dynamic compressors use rotary motion like a blower to impart energy to the gas.

Rotary compressors are preferred in some applications over reciprocating compressors because they are generally quieter, more compact and cheaper to operate.

Lobe compressors consist of two lobes. They can be different shapes, but the simplest to explain is a figure eight. If two figure eights were side by side and one started to spin, its bottom would knock the top of the other one and it would start to spin. As it turned upside down, the second one's bottom would knock the top of the first eight, and so on. If the eights are enclosed, this motion creates areas on the outside of the eights that get larger and smaller in volume as they rotate. Air is sucked in and pushed out. This type of compressor is often used for blowers and is generally lubricated with ISO 220 synthetic PAO oil.

Screw compressors have two intermeshing screws that push the air down their length as they rotate. They are quite often lubricated by an ISO 46 PAO oil, or turbine quality R&O oil in viscosity grades ISO 32 through 68.

Vane compressors work on exactly the same principle as a vane type hydraulic pump. Blades called vanes fit into slots that are set into a rotor. As the rotor spins, the vanes are flung out by centrifugal force and are stopped by a ring. The rotor is offset in the ring so there are compartments of varying volumes between the vanes. Vane compressors normally use turbine type R&O oils.

Centrifugal compressors can run at very high speeds. They are similar to an enclosed fan and impart kinetic energy to the air. Since they operate at such high speeds, they generally use petroleum oil with fairly low viscosity.

Lubricants

There are two main areas of a piston compressor that need to be lubricated. The first is the area that contacts the gas such as the pistons and rings, cylinders and valves. These are often lubricated on a "once-through" basis where the oil mixes with the gas and goes out the discharge. Normally the oil is applied by use of a force feed lubricator.

The second covers the parts that do not contact the gas such as the crankcase bearings and connecting rods. These parts are generally splash lubricated from the crankcase, or may be circulated by the oil pump. Crankcase lubricants can remain in service for many thousands of hours.

Oxidation stability is important in most compressor applications because of the heat that is generated. Oxidized oil can create deposits that build up on discharge valves allowing them to stick open. This causes hot air to get sucked back into the compression chamber where it is recompressed. The air can generate enough heat to ignite the deposits and cause a fire or explosion. Use of synthetics can minimize this possibility.

Zinc-containing anti-wear oils are generally not recommended for air compressors because the anti-wear package may compromise the oxidation stability of the oil.

Many reciprocating compressors, particularly portable models, use automotive or commercial crankcase oils. The oils are readily available and have detergency that helps keep discharge valves clean. However, detergents have their disadvantages. Detergents move deposits downstream where they may build up on heat transfer surfaces in coolers.

Detergent oils absorb water. If water is allowed to build up in the oil, it will cause rust and will accelerate oxidation. Compressors generate water because humidity from the air condenses as the air is compressed. It is generally removed in a coalescer or knockout drum, but some water gets into the oil. For this reason, detergent oils are only used in limited applications.

It is more common for stationary reciprocating compressors to use non-detergent rust and oxidation inhibited oils. The viscosity varies according to the design of the compressor, but a high percentage use an ISO 100 turbine-type lubricant, which is approximately the viscosity of SAE 30-engine oil. Cylinder oils are very often the same oil that is recommended for the crankcase, with some exceptions.

High-pressure gas requires cylinder oils of much higher viscosity and lubricity. If wet gas is compressed, the oils generally should be compounded with a fatty additive.

Hydrocarbon gases, like methane, ethane and propane, dissolve into petroleum oils and tend to lower their viscosity over time. The oils can thin down so much that compressor cylinders and valves wear prematurely and excess oil ends up in the coalescer. There are two ways to combat this. One is to start out with fairly viscous oil such as steam cylinder oil. The second is to use oil that is not soluble in hydrocarbon gases, like glycol.

Oxygen is obviously considered a strong oxidizer. Hydrocarbon gases are not recommended for compressing oxygen. These compressors are generally non-lubricated with graphite seals. If a lubricant is required, the products of choice can be silicone or fluorocarbon based.

Refrigerant gases such as ammonia, halocarbons, and the new halocarbon-free refrigerants, take special lubricants. Ammonia reacts with acidic additives such as some rust inhibitors to form a mayonnaise-like substance. Freon type lubricants must be tested according to the Freon floc test to ensure that wax will not form at cold operating temperatures. And the latest refrigerants that are designed to be ozone-friendly requiring new synthetics such as specially formulated polyol esters.

The oil in oil flooded rotary compressors lubricates the gears, bearings and also the contacting surfaces of the rotors. The proper oil is critical for these compressors because, not only does it lubricate the elements and keeps them cool, it also forms a seal to prevent gas leakage around the elements.

Maintenance

It is important to keep compressor lubricants as clean, cool and dry as possible. To accomplish this, it is recommended that air is filtered on intake, intercoolers used to remove heat, and high quality non-detergent oil be used where water may condense into the oil.