Maximizing Frac Pump Power-End Life

SPM™ Oil & Gas
A Caterpillar Company

SPM Oil & Gas Lubrication White Paper

An optimal lubrication system holds the key

By Ben Shuck, Pump Principal Engineer at SPM Oil & Gas and John McCrady, Senior Engineer at PSM Oil & Gas.

Modern hydraulic fracturing operations are placing increasingly rigorous demands on equipment. Multiwell pad drilling, round-the-clock completion operations, longer horizontals, more stages, higher-pressure requirements, and greater proppant consumption per well have significantly increased the operational intensity of completions. There is growing demand to maximize equipment uptime and reduce cost by optimizing maintenance intervals.

Because frac pumps are one of the most crucial items of equipment in a hydraulic fracturing operation, they must be designed to deliver improved performance and reliability under the 24/7 operating conditions and extended exposure to high-rate, abrasive, proppant-laden fluids. While hydraulic fracturing has provided access to hydrocarbons once considered impossible to produce, continuing to lower the cost of operating a frac pump is critical to reducing the cost per barrel of oil in a tight market.

Importance of the lubrication system

A complete pumping system or "package" consists of the frac pump; an engine, transmission, and trailer; and essential support systems, such as the lubrication system (including filtration and cooling). The pump is the prime mover of fluid in fracturing operations, and the lubrication system is critical for maximizing pump efficiency and power-end life. Clean and cooled oil is required to

- create a film of sufficient thickness to protect bearing and gear components by preventing metal-to-metal contact, thereby reducing wear
- remove heat and debris particles from the power end.

With greater than 75 percent of bearing failures related to the lubrication system, as shown in **Fig. 1**, the importance of this system's design and maintenance cannot be overstated.

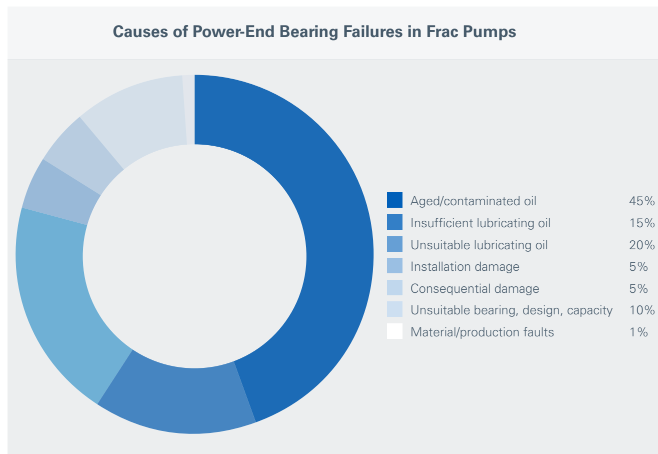

Fig. 1. Oil contamination and other factors related to the lubrication system are a major cause of bearing failures in frac pumps. Among the factors within an end user's control, lubricant quality, temperature, and cleanliness have the greatest impact on pump life. (Source: Antriebstechnik 18 (1979) No. 3, 71–74)

Essential design considerations

Oil type

The lubricating oil type—fully synthetic, semisynthetic, or mineral based—and grade are critical because they determine the oil's viscosity across the operating temperature range. If the oil does not have enough viscosity at higher temperatures, the film thickness will be unable to reduce metal-to-metal contact sufficiently and wear will accelerate. Conversely if the oil is too thick, very little will penetrate the bearing clearances and the components will plow through the thin film, again expediting wear.

ISO 220 oils, for example, have higher startup and maximum operating temperatures, ideal for Texas and other hot climates. However, they are potentially too viscous at ambient temperatures in cold climates, rendering them unsuitable for pump startup in those geographies.

The lower viscosity of ISO 150 oils, on the other hand, is suitable for cold starting conditions. Viscosity decreases with increase in temperature, reducing the oil film thickness and therefore the maximum operating temperature and precluding use of these oils in hot climates. Additive packages, such as an extreme-pressure additive (EP) package, must also be carefully selected to optimize performance.

Cooling

Because oil viscosity and hence the thickness of the oil film are directly related to temperature, a properly designed cooling system and thermostat are essential to maintain the oil within the appropriate temperature and viscosity ranges under normal operating conditions. The cooling system design must take into consideration the oil properties and the maximum heat load that must be removed across the full range of operating flow rates.

Fig. 2 shows how the oil grade and temperature affect roller bearing life; other wear components show similar behavior. Within the normal operating range, between 140°F and 160°F, a higher-viscosity oil can increase the life of wear components by approximately 20% to 30%. Within the same operating range, a 10°F increase in temperature can reduce the life of wear components by approximately 20% because of the decrease in the viscosity ratio—the ratio between the actual and rated viscosities. A minimum viscosity ratio of 1 is required to separate the bearing contact surfaces; targeting a ratio between 1 and 4 ensures sufficient film thickness. Because the viscosity ratio is an indicator of film thickness, the graph illustrates how bearing life decreases as film thickness is reduced.

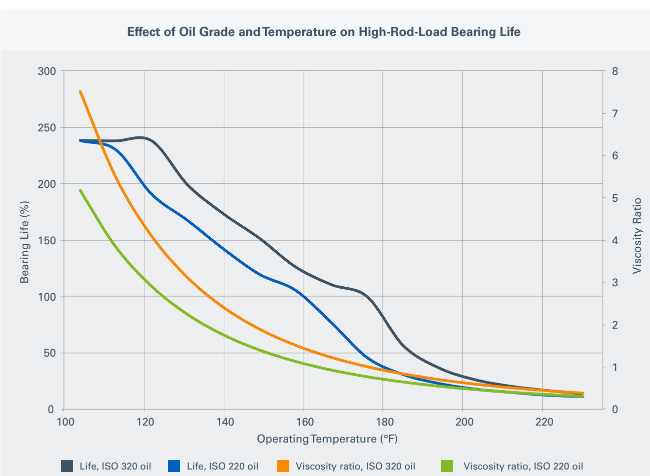

Fig. 2. Lubricant viscosity and film thickness decrease with increasing temperature, reducing bearing life

Cleaning

Dealing with contaminants is an inherent role of the lubrication system. As the gears mesh together and the pump wears over time, debris increases. Foreign matter entering the system (through open covers, for example) accelerates the situation. These particles must be removed to avoid damaging the power-end bearings and gears and shortening their useful lives.

Fig. 3 illustrates the decrease in bearing life with increasing lubricant contamination at a given rod load, for a specific bearing material. Although gear ratios, pump rpm, bearing materials, and bearing geometry all affect the shape of the curves, the detrimental effect of lubricant contamination typically creates similar separation between the curves. The effect may be even more dramatic if good bearing design practices or materials are not used.

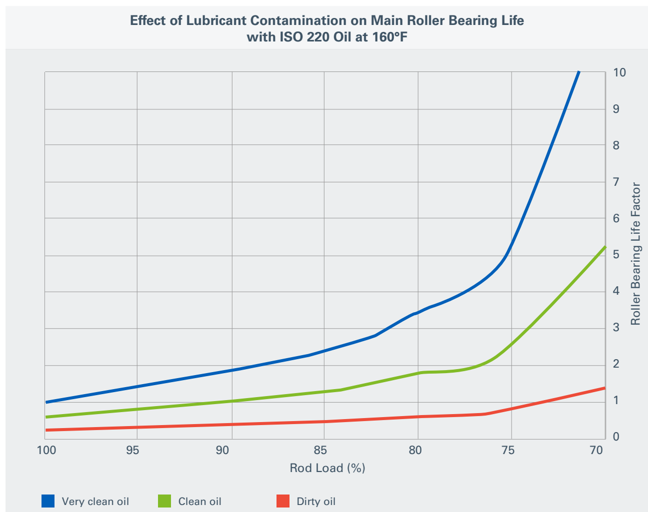

Fig. 3. For a given rod load, bearing life decreases with increasing lubricant contamination (as illustrated for a proprietary SPM Oil & Gas bearing material).

Debris may be harder (e.g., metal particles, sand, dirt) or softer (e.g., fibers, silicone, plastics from seals or O-rings) than the wear component under consideration. Both kinds reduce the life of the component by reducing oil film thickness and creating localized stresses. Water is another potential contaminant; it not only damages the pump components it comes into contact with, it also dramatically alters the lubricating properties of the oil.

Measurement of oil cleanliness

ISO 4406:1999 is an international standard that specifies the code for defining the quantity of solid particles in a lubricating oil. Three code numbers indicate the number of particles ≥4 μm, ≥6 μm, and ≥14 μm, respectively, in each milliliter of fluid. Each increment in the code number represents a doubling of the corresponding particle concentration. Examples are given below.

Measurement of oil cleanliness

Code 18/16/13	Code 19/17/14
>1,300 to 2,500 4-μm particles/ml	>2,500 to 5,000 4-μm particles/ml
>320 to 640 6-μm particles/ml	>640 to 1,300 6-μm particles/ml
>40 to 80 14-μm particles/ml	>80 to 160 14-μm particles/ml

Because particles <6 μm do not present a significant threat to wear components, only the last two numbers of the ISO 4406 code need to be taken into account for frac pumps.

When setting target ISO fluid cleanliness codes, the pump manufacturer should keep in mind the objectives to be achieved:

» maximizing equipment reliability and safety
» minimizing repair and replacement costs
» extending the useful life of the oil
» satisfying warranty requirements
» minimizing production downtime.

The end user benefits by putting in place a process to achieve the target ISO code, monitor oil cleanliness, and maintain contaminant levels within prescribed limits.

Effective oil filtration

Most frac pumps do not feature onboard filters and rely on the filtration built into the lubrication system supplied by the packager. A dual-filtration system, consisting of filtered main lines running to the pump and a kidney loop filter, is the optimal solution and is shown in Fig. 4.

The main system filters the oil as it flows from the tank through the cooler to the pump and returns to the tank. A multistep filter system—a suction strainer followed by a 25-μm filter and finally a 10-μm filter—has a longer operating life and improves cleaning efficiency compared with a single 10-μm or 25-μm filter.

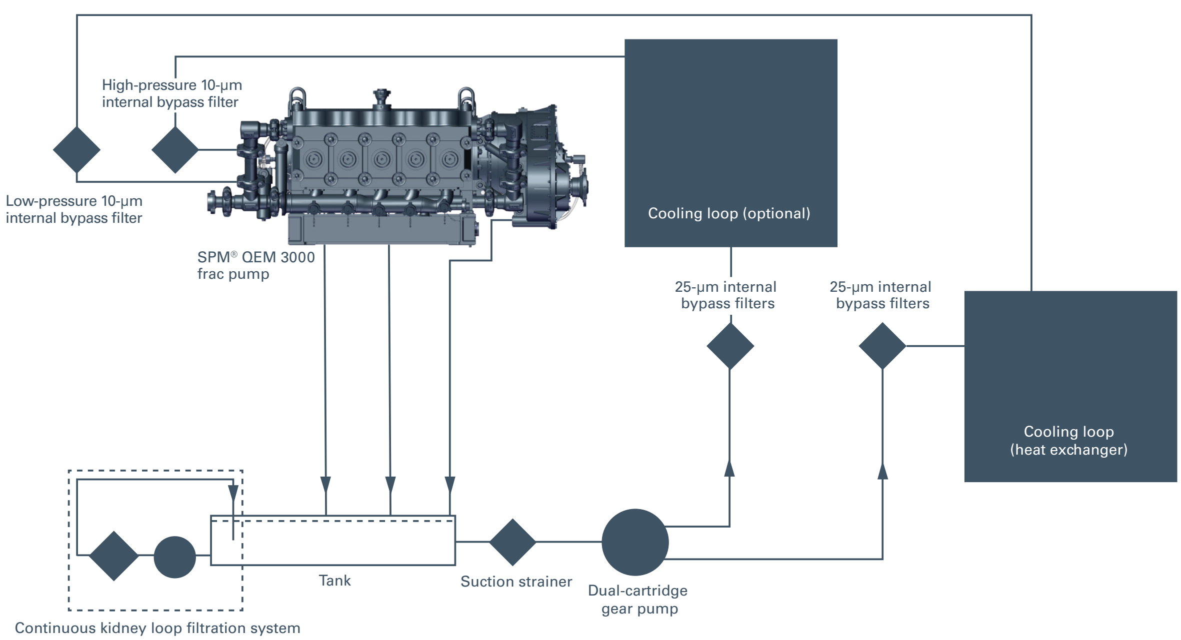

Fig. 4. A dual-filtration system is the optimal choice for cleaning frac pump lubrication oil.

In addition, the filter assembly should incorporate an internal bypass to eliminate the possibility of the pump running dry in the event of a clogged filter. A return-to-tank bypass simply allows the oil to flow back to the tank if the filter is blocked and does not protect the pump, causing severe damage.

A secondary kidney loop filtration system continuously polishes the oil, supplementing the cleaning provided by the main system. Oil flows out of the tank through a pump and loops back through this filter; the recommended rate of circulation is 4–12 tank volumes/hr.

Not all filters are created equal and particle-size specification alone is not sufficient to ensure results. Choosing filters with an Absolute rating provides 99.9% filtration efficiency.

An alternative to compromise

Different system components compete for oil and have varying requirements. Rod journal shell bearings, for example, require higher pressures to force the oil between the metal components and create an oil film of the appropriate thickness. The oil flow rate is typically lower. Conversely, main journal roller bearings and gear meshes are bathed in large volumes of low-pressure oil, which must be continuously renewed, requiring a high flow rate.

With a single-line pump feed, one line delivers oil to the various components. To meet the conflicting demands, the orifices through which the oil exits the lubrication system are precisely designed to deliver flow rates and pressures as close to the required values as possible. However, some compromise is inevitable.

The proprietary dual-pressure system developed by SPM Oil & Gas addresses this challenge, delivering high-pressure, low-rate oil through one line and low-pressure, high-rate lubricant through the other, providing an optimized solution and maximizing pump life. The SPM QEM 3000 frac pump illustrated in Fig. 4 is the only pump in the industry to feature this unique, fit-for-purpose system.

Lower total cost of ownership

Oil changes at arbitrarily selected fixed intervals are often too late or too early. Operating the pump with lubricant that has degraded beyond prescribed limits results in subpar performance and equipment damage. In the worst case, the pump may need to be replaced, a major expense that can easily be avoided. Changing the oil too often may protect the pump, but it is unnecessary and also has a negative impact on the total cost of ownership.

Use of an oil condition monitoring program to establish the oil change interval is the most cost-effective solution. Sending power-end oil samples for laboratory analysis on a regular basis enables timely oil changes and early detection of any issues, extending equipment life, enhancing performance, minimizing downtime, and lowering total cost of ownership.

A typical guideline for initial oil sampling frequency is every 250 loaded pump hours. After 500 hrs, the oil should be sampled every 100–150 hrs until the analysis indicates that the oil should be changed. Once the operator has established a statistical average for the life span of the oil and acquired a better understanding of how the pump, the selected oil, and the field conditions affect oil life, the sampling frequency can be reduced. Pump hours are approximately 50%–60% of engine hours but vary with an individual operator's use of the pump under load.

Oil type also plays a key role in determining the oil change interval. Synthetic oils, while more expensive, generally last longer than conventional mineral-based oils.

A laboratory analysis examines multiple parameters.

- It determines the applicable ISO 4406 code, which can be compared with the target value to determine if oil cleanliness is within prescribed limits. Depending on the results, a filter change may be all that is required instead of a costlier oil change.
- An elemental analysis of the solid particles in the oil sample helps identify how the pump is wearing. For example, presence of copper or tin might indicate high wear on a rod journal bearing, while steel or an iron alloy would point to a roller bearing or gear.
- The oil viscosity is measured to ensure that it is within an acceptable range.
- The flash point is monitored because solvents and other contaminants can reduce it, creating a potential hazard.
- Water content is measured; too much water can have a detrimental effect on the properties of the lubricating oil.
- Total Acid Number (TAN) indicates oil acidity, which can be harmful to components. This number is a good indicator of overall oil health.

The monitoring program can be extended across the operator's entire fleet to maximize the benefits.

Conclusion

75%–80% of frac pump bearing failures are related to the lubrication system; oil contamination is the single biggest cause. A correctly designed lubrication system, innovative technologies, regular oil monitoring, and timely oil changes can dramatically increase pump life, improve efficiency, and lower operating expenditure.

The lubricating oil is selected to ensure suitable viscosities across the entire operating range. Lubrication systems designed for a particular climate should not be used in a different climate without reviewing important design parameters, including the oil type and thermostat. Effective oil cooling, filtration, delivery pressure, and flow rate are critical to operations.

About SPM Oil & Gas

SPM Oil & Gas provides superior products and service solutions to make our customers more efficient and lower total cost of ownership. More customers choose our pressure pumping solutions than any other. We provide well service and stimulation pumps, flow control products, replacement expendable parts and supporting engineered repair services. Our products and services are well positioned to optimize frac pump performance in the toughest conditions.

The Authors

Ben Shuck

Ben Shuck is a Pump Principal Engineer at SPM Oil & Gas and has been with the company for more than 10 years. His areas of expertise include design and manufacture of pump test, hydraulic, and lubrication systems. He is a member of the team that developed the SPM QEM 3000 pump and a technical product advisor for developing truck-mounted integrated pumping systems. He has a BS in Manufacturing Engineering and a Master’s degree in Quality and Engineering Management.

John McCrady

John McCrady is a Senior Engineer at SPM Oil & Gas, with an Engineering degree from West Texas A&M. Prior to joining SPM Oil & Gas, he worked for more than 30 years in automotive HVAC systems design, heavy-duty diesel engine integration, and secondary hydrocarbon recovery. He has played a key role in the bearings and lubrication system design for the QEM 3000 pump, as well as subsequent testing and validation.