Lubrication Systems

Application & Installation Guide

LEBW4957-05

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1 Introduction

This section of the Application and Installation Guides describes the requirements and options available for lubrication of the engine's crankcase. Additional engine systems, components and dynamics are addressed in other sections of the Application and Installation Guides.

Systems and components described in this guide may not be available or applicable for every engine. Consult the applicable engine model price list and/or parts reference guide for information on specific model option availability or compatibility.

1.1 References

The following sources may provide additional information regarding subjects covered in this guide.

- SEBD0640: Oil and Your Engine
- LEBW4958: Application and Installation Guide – Crankcase Ventilation
- SEBU6251: Caterpillar Commercial Diesel Engine Fluids Recommendations
- SEBU6400: Caterpillar Gas Engine Lubricant, Fuel and Coolant Recommendations
- SEBU7003: 3600 Diesel Engine Fluids Recommendations for Lubricants, Fuels and Coolants
- PEDP7036: S•O•S Fluid Analysis

1.2 Changes since last revision

- Updated to new template.
- Re-ordered some sections to develop a more consistent flow between topics.
- Re-ordered some topics within sections to better group similar considerations together into a single thought and eliminate redundancies.
- Section 6.4.1.2: Added information about use of P-traps in connections for oil heaters.
- Sections 4.0 and 6.5: Added oil compatibility guidance.

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2 Lubrication Systems

The engine's lubrication system is a key critical system that enables it to function. Even the basic early conception of the reciprocating piston internal combustion engine faced the issue of how to manage wear and friction on the myriad moving parts of such a complex machine. The challenge in the engine is compounded by the extreme temperatures that are realized in the combustion chambers and exhaust system, which over time have lead to the sophisticated processes that exist today.

By name, the lubrication system is needed to address the friction issue, but in reality it must manage three distinct purposes to be effective:

- Minimize friction between the moving parts inside the engine
- Cool areas of the engine not effectively managed by the cooling system
- Clean the engine by flushing away wear particles from the contact areas.

Additionally, the lubricating oil itself performs important functions:

- It cushions the engine's bearings from the shocks of cylinder firing
- It neutralizes the corrosive agents created during combustion
- It protects the engine's metal surfaces from oxidation.

The pressurized oil systems that have been developed for reciprocating engines do address these many functions. To make this work they must keep the oil clean, free from abrasive particles and corrosive compounds. The lubricant (oil) must exhibit sufficient film strength to withstand bearing pressures and be tolerant of the high temperatures to which it will be exposed while on the piston and cylinder walls. These needs lead to the advanced chemical formulation that is a modern engine lubricating oil. In fact, the type of engine can affect the optimal formulation for the oil; different oils are typically used for gaseous-fueled engines versus for diesel engines.

The fact that the lubricating system involves pressurized oil also presents the opportunity for clever uses beyond those described above. Pressurization allows the oil to be forced into the demanding bearing surfaces of the crankshaft, camshaft, and turbochargers, but it also enables it to be used to cool the underside of the constantly-moving pistons and as a hydraulic fluid to drive some on-engine systems unrelated to lubrication (hydraulically-actuated fuel injectors are an example).

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3 Lubricating System General Layout

The design for the flow path of the lubricating oil is specific to each engine model, but many of the components and processes are common across many different engine models. A general representation of the oil flow path is shown in Figure 3.1. The image and accompanying caption provide a basic understanding of the main components along the flow path; additional details may also be found in the descriptions that follow.

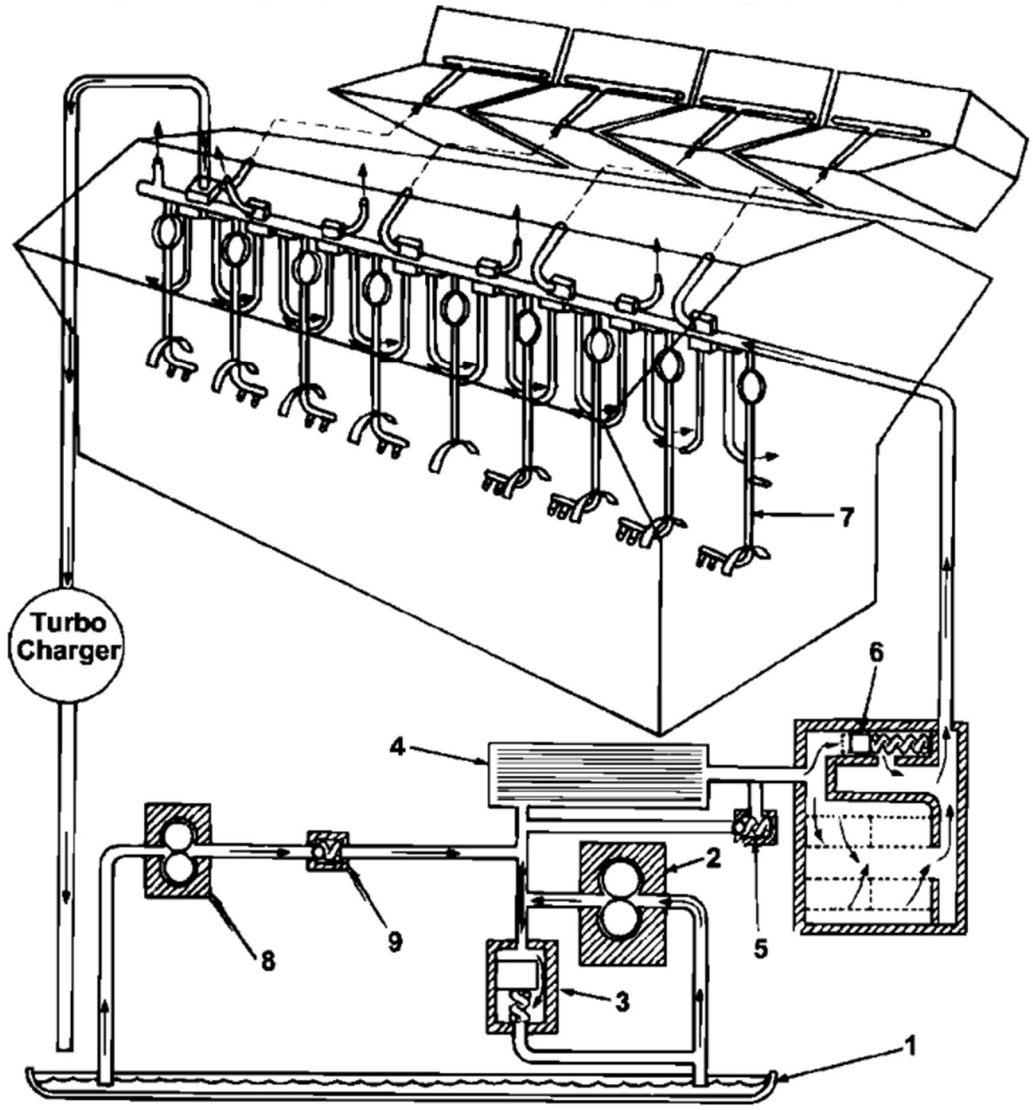
3.1 Oil Sump

The “sump” is a term for the location where the lubricating oil is stored and kept ready for use during engine operation. It is common for the sump to be an integral oil pan fastened to the bottom of the cylinder block. In such a design it is the low point in the system to enable oil pumped through the system to return to the sump by gravity.

This type of sump is sometimes referred to as a “wet” sump because the oil is stored in the same location that is used to gather the oil being discharged from the lubricating system. A wet sump is designed to keep the oil level below the moving parts of the engine that are also near the bottom of the engine (primarily the crankshaft). When the crankshaft does contact the sump oil fill, it produces two undesirable effects: drag on the crankshaft, for it has to move through the dense oil fill, and frothing of the oil, causing air bubbles to become entrained in the oil. The crankshaft drag represents a parasitic loss that limits engine power at the flywheel. The oil frothing is potentially more serious because the air bubbles can affect oil flow in the system and can compromise the oil’s function in the bearings. Pressure-lubricated bearings depend on incompressible oil to provide the cushion necessary to prevent direct metal-to-metal contact in the bearings, which is critical to managing wear and extending bearing life. Compressible air bubbles cause this oil cushion to break down, leading to increased wear and possible bearing failure.

It is important to note that a wet sump designed with clearance between the oil and crankshaft typically assumes the engine is operated in a level position, because gravity determines the resting surface of the oil fill. Some applications involve tilting of the engine, which changes the relationship between the crankshaft and the oil fill surface. Recognizing this effect of tilt, the engine will typically have specified tilt angle limits. Such limits can be different for a temporary tilt condition, such as in a marine vessel moving in the waves, or a permanent tilt where the connection to the drive shaft requires the engine be placed at an angle. Note also that different limits can exist for the engine’s longitudinal direction (“pitching” fore-to-aft along the crankshaft centerline) and lateral direction (“rolling” from side-to-side). The numeric values for these limits may be found in TMI and are specific to

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1. Sump	6. Lube Oil Filter
2. Lube Oil Pump	7. Engine Oil Passages
3. Oil Pressure Regulating Valve	8. Prelubrication Pump
4. Lube Oil Cooler	9. Prelubrication Check Valve
5. Oil Cooler Bypass Valve	

Figure 3.1 **Main components of an engine lubricating system**

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an engine model and particular oil pan, so changes to the oil pan can alter the limits. If a project requires more extreme tilt capability, it may be possible to alter the oil sump configuration to one that enables operation under such conditions. Such alternative options may be available in a price list, or they may require custom engineering work to create. Contact Caterpillar if the documented capability is not adequate for a specific project.

3.2 Main Oil Pump

The main engine oil pump is, for most arrangements, a direct gear-driven pump that is mounted to the engine. However, Caterpillar does offer engine models that use off-engine mounted electric pumps for the lube oil system. The product description in the price lists will clarify the nature of the lubrication pump used on a particular engine model.

3.3 Pressure Regulating Valve

Output for a gear-driven oil pump will vary with engine speed. Flow volume and generated system pressure can be much lower at start-up and low idle speeds than they are at rated speed. For this reason, the pump is designed to provide adequate flow to properly supply the bearings under these low speed conditions. A bypass valve arrangement is then placed on the pump outlet to manage the pressure and flow available for full rated speed operation. Excess flow is returned to the sump.

3.4 Oil Cooler

Lubricating oil acquires a significant amount of heat as it travels through critical working surfaces within the engine. At the same time, a given grade of oil will have a maximum temperature limit beyond which the oil may be damaged. To help avoid this, an oil cooler is incorporated into the lubricating circuit to manage oil temperature.

Oil cooler designs can vary from engine-to-engine. Many engines include an onboard shell-and-tube oil cooler, but engine size or application may drive a change to alternative designs. Multiple cooler bundles may be used to increase the cooling capacity of larger models of an engine family, or off-engine mounted plate-and-frame coolers may be used for larger engines.

3.4.1 Diesel 3616 or C280-16 with Front-Mounted Turbochargers

The front-mounted turbocharger (FMT) arrangement offered on certain models of these engines uses a remote oil cooler and a different priority valve than that used on other configurations from the same engine families. To maintain proper operating conditions in

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the lubricating circuit of these FMT arrangements, special guidelines are needed for the installation design for the oil cooler.

The oil cooler must be installed near enough that the total line length involved does not exceed 15 m, based on a recommended line ID of 100 mm (4 in.). This limit will include remote oil filters when they are used. The maximum external restriction in this system should not exceed 176 kPa (25 psi) so that with the added restriction of the engine-mounted eight-element oil filter (approximately 24 kPa or 3.5 psi) the total circuit restriction does not exceed 200 kPa (29 psi). Failure to meet these limits can result in unacceptable fluctuations in oil pressure.

The following reference values may help when designing this external circuit. For an oil flow of 1100 l/min at 85°C, these component restrictions can produce a successful design:

- Plate-type oil cooler: -22 kPa
- Oil thermostat: -22 kPa
- Optional duplex six-element oil filter: -42 kPa
- Engine-mounted simplex eight-element oil filer: -24 kPa

3.5 Oil Cooler Bypass Valve

Heat exchangers may rely on small internal passages to promote efficient heat transfer from oil to coolant. As a result, it is relatively easy for them to be a point of restriction when oil viscosity is high (at low oil temperature) or when debris in the oil plugs some passages. This poses a significant risk because low downstream oil pressure at the bearings can rapidly lead to bearing damage. To avoid this, a bypass valve is added to the oil cooler to allow oil to flow around the cooler when the pressure differential across the cooler becomes too great.

3.6 Oil Filter

In addition to cooling and lubricating duties, the lubricating oil also helps to carry loose particles (e.g., dirt or wear materials) away from the working surfaces the oil protects. These particles are removed from the oil by an oil filter.

3.7 Engine Oil Passages

After the lubricating oil flow has been properly conditioned by the component described above, it is routed into the engine to perform its duties. The oil paths through the inside of the engine are largely integral passages that are both cast and machined into the structure

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of the engine, through the cylinder block, cylinder heads, their interconnecting pieces, and even through the crankshaft, connecting rods, and pistons.

3.8 Prelubrication Pump

Used primarily on larger engines, prelubrication systems lubricate all critical bearing journals before energizing the starting motors. Prelubrication is mandatory for 3600/C280/G3600 engines and especially important after periods of idleness, oil changes and filter changes.

3.9 Prelubrication Check Valve

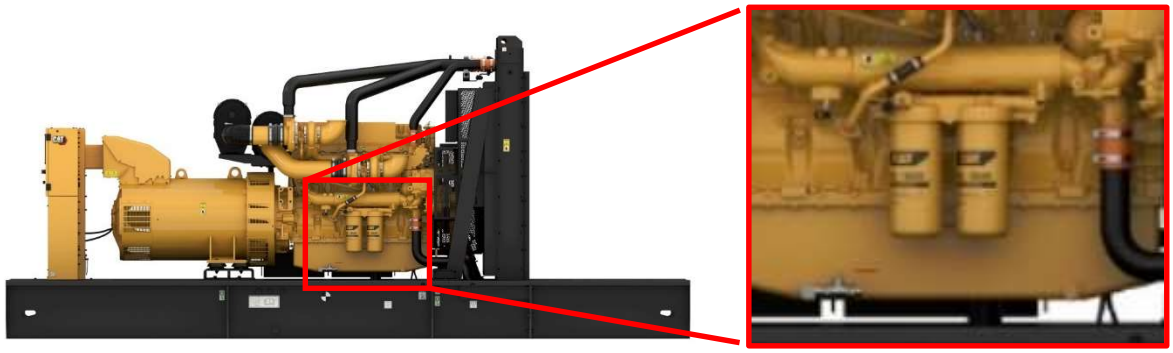
As used in the system shown, this check valve prevents oil back flow through the prelubrication system when the prelubrication pump in inactive.

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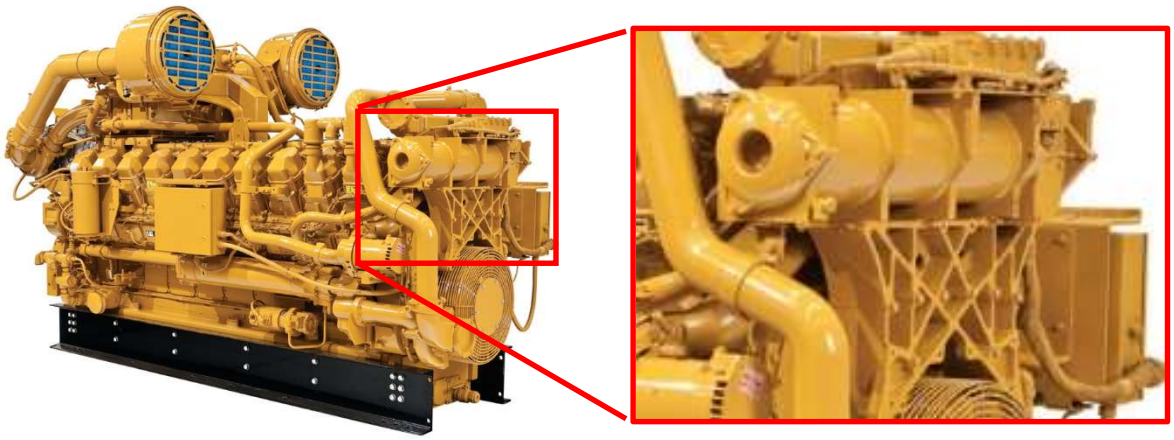
4 Oil Filters and Related Components

The primary oil filter on Cat engines is a mechanical separator with replaceable filter elements. The filter arrangements are sized to provide estimated filter change intervals that coordinate well with the overall servicing scheme for that engine. In practice, filter changes should be part of a maintenance plan that accounts for the published recommendations for the specific engine model, the particular application, and the duty cycle. It is recommended to use genuine Cat filter elements for optimum protection of the engine.

The type of filter used can vary from engine to engine. Many smaller engine models use a "spin-on" filter, an individual disposable part comprised of the filtration media inside a structural canister. This type of filter gets its name from the way it is spun onto a threaded post to install the filter. Larger engines may use a dedicated housing on the engine that is loaded with replaceable filter elements. Examples of each may be seen in Figure 4.1.



Engine oil filter arrangement showing spin-on filters



Engine oil filter arrangement showing canister filter housing

Figure 4.1 **Examples of engine primary oil filters**

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Certain types of lubricating oil require specific oil filters due to incompatibility of the oil with certain material in the filter. Consult the Operation and Maintenance manual for your engine to be certain of appropriate selections for oils and filters.

4.1 Oil Filter Differential Pressure Gauge

Measurement of the differential pressure across the oil filter provides an important check for the condition of the filter, helping to protect the engine from inadequate downstream pressure by detecting restriction at the filter. Differential pressure measurement may be incorporated into the engine's protection system, but for some arrangements oil filter differential pressure gauges may be available as an option. Oil filter differential pressure measurement is recommended as simple yet effective protection for the engine.

4.2 Duplex Oil Filters

Some engines may offer a duplex oil filter arrangement, either in the standard consist or as an option. A duplex filter arrangement incorporates a second filtration chamber and a switching valve that allows selection between the primary or secondary filters. This duplex arrangement enables the operator to change the primary filter elements while the engine is running by routing the oil flow through the secondary filter. Such capability may be a requirement imposed by a customer specification or may result from the need to comply with the points of a marine classification society certification.

While simple in concept, using a duplex oil filter arrangement requires attention to certain details. Air must be purged from the either filter chamber before they are switched into service on a running engine. Air trapped in the filter chamber can get entrained into the oil flow, and entrained air bubbles pose a significant risk to critical bearings. Entrained air introduces compressibility into the oil, which can compromise the load-bearing capability of the oil film in a bearing.

Another issue arises when the engine is coupled to a close-mounted radiator. The cooling fan air flow can make it difficult to control loose oil that will naturally be present while draining filter housings and handling filter elements. This creates a risk that oil will be blown onto hot surfaces where it may ignite. For this reason, filter changes during engine operation should not be performed where a close-mounted radiator is present.

4.3 Remote Oil Filters

In certain applications it may not be possible to guarantee adequate space for servicing the oil filters. The mobile land drill rig is an example of an application where this sort of issue

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has come up. For such circumstances it may be advantageous to locate the oil filters away from the engine, in a location that permits adequate access for proper servicing.

Some Cat engines will be able to be fitted for a remote oil filter. Because oil filtration is so very critical to maximizing the service life of the engine, Caterpillar requires prior authorization before any modifications are made to the engine lubricating system. Adding a remote oil filter to the system increases the opportunities for leaks. However, that risk can be minimized by adhering to certain practices:

- Use procedures designed to maintain oil system cleanliness during removal and installation of oil filters and lines. Keep all openings covered until final connections are made. Refer to Caterpillar Flushing and Pickling Guidelines.
- Use quality pipe or medium pressure, high temperature 120°C (250°F) hose that is equivalent to, or exceeds, the SAE 100R5 specification.
- Keep oil lines as short as possible and at least as large as engine connections.
- Support hoses as necessary to keep from chafing or cutting on sharp corners.
- Use care in connecting oil lines so the direction of oil flow is correct.

Always be aware that improper connection of a remote oil filter can result in engine damage.

4.4 Auxiliary Oil Filters

An auxiliary oil filter is sometimes offered with an engine to provide added oil capacity for the sump. On Cat rich burn (stoichiometric) gas engines, or on engine arrangements with a shallow oil pan, an auxiliary oil filter may be offered as an option to extend oil change intervals. By effectively increasing the oil sump volume, the normal rate of contamination of the oil is reduced in proportion to the increase in volume. Such a strategy is highly effective when the extension in oil change intervals serves to reduce the frequency of site visits needed for routine maintenance. This auxiliary filter strategy is not typically used with larger sump engines because the further extension of oil change intervals does not align well with other required servicing, and thus its added cost and space claim on site are not advantageous for such an engine.

In most cases the auxiliary oil filter is a free-standing attachment that is shipped loose with the engine for final installation on site. The filtration provided with this option is similar in nature to the bypass filters described below, but in the case of the auxiliary filter the added oil capacity is a key feature. The filter elements provided with this optional system do not replace the primary oil filters and thus they should be considered supplemental at best. For auxiliary oil filter arrangements that do not have a published nominal oil change interval,

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periodic oil sampling and analysis is recommended to establish a change interval appropriate for that site.

4.5 Supplemental Bypass Oil Filters

The name of the supplemental bypass filter explains a lot about its nature and purpose relative to the engine's oil filtration. It is "supplemental", meaning it provides additional filtration capability to the primary system in place on the engine. It also operates on a "bypass" flow path, meaning that it is not in-line with the primary oil circulation path. Such supplemental oil filtration is rarely deemed necessary and thus is almost always included to augment the primary oil filtration.

Supplemental oil filters generally fall into two categories: centrifugal and absorptive. Each seeks to improve the performance of the engine's lubricating oil system in a specific way.

NOTE: If a supplemental filter is used the system must include a feature to prevent drain-back during engine shutdown. A 3.175 mm (0.125 in) or smaller orifice capable of limiting flow to 7.57 L/min (2 gpm) must also be present. Refer to engine general dimension drawings for recommended locations for oil supply to the filter and return to the sump.

4.5.1 Centrifugal Oil Filters

A centrifugal oil filter may sometimes be referred to as a "spinner" filter. That is because the filter's design induces a high rotational velocity inside the filter, using centrifugal action to separate heavier sludge and solid particles from the lighter oil. By pulling these solids out of the oil flow, the centrifugal filter can extend the service life of the primary oil filter elements because those elements will accumulate debris at a reduced rate.

As this description suggests, a centrifugal oil filter will add value on an engine that will expose the oil to a greater quantity of solid particles, such as the carbon particles that form the soot in diesel engine exhaust. Centrifugal filter arrangements are available for 3500 or larger diesel engines for this reason. For gas engines there has been little demonstrated advantage to the use of a centrifugal filter, as gas engines do not characteristically produce much soot – gas engine exhaust particulate levels are very low by comparison to diesels.

If a centrifugal oil filter is obtained from a source other than Caterpillar, the user is responsible for ensuring the quality and performance of that centrifuge unit. Care should be taken to ensure the manufacturer's guidance is followed in equipment selection and sizing, application, and installation. Solid bowl separators should not be used for lubricating oil service; instead, self-cleaning centrifuges should be specified to better deal with the volume of material that can be pulled out by the centrifuge. Any manufacturer's requirements for

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fresh water or clean air must be addressed, and the centrifuge should include an automatic sludge discharge with a direct gravity feed to the sludge tank.



Figure 4.2 **Centrifugal oil filter fitted to an engine**

When a centrifugal oil filter is required, it is common to provide each engine with its own centrifuge. This approach has the advantages of simplicity and of avoiding interconnection of the lubricating oil systems of different engines. For some installations, however, it may be deemed advantageous to use a single centrifuge for more than one engine. For such a design, the following guidelines apply:

- Consult Caterpillar before proceeding with a multi-engine centrifuge application.
- No more than four engine oil sumps may be connected to a single centrifuge.
- The centrifuge selected must be oversized for the specific needs of the installation.
- Programmable logic controllers (PLCs) and automatic valves must be used to control the switching of sumps connected to the centrifuge.
- The system must include a redundant centrifuge system, complete with all piping, valves, and controls for its proper operation.

Some centrifuges may require a supply pump, either mechanically or electrically driven. Such a pump must be sized according to the centrifuge manufacturer's instructions or be sourced from the manufacturer as a matched component for the centrifuge. The centrifuge installation should pull oil from the rear of the engine and return it to the front, in a way that returns the cleaned oil as near to the engine's oil pump suction as possible.

An oil preheater may also be part of the centrifuge arrangement, as specified or provided by its manufacturer, and thus the details of the heater sizing should then be as arranged by the manufacturer. The specified oil temperature from the heater outlet may range from 80°C to

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90°C (176°F to 194°F) and may vary with the grade and type of oil used. The oil temperature should be 99°C (210°F) for a centrifuging during engine operation. If the centrifuge is to operate when the engine is not running, the heater must be able to maintain the oil temperature by itself, accounting for the heat normally supplied by the running engine. A thermostatic control should be present to regulate oil temperature to the centrifuge with 2°C (4°F) of the target operating temperature.

It can be important to check the efficiency of the centrifuge by sampling the upstream and downstream oil flows. A typical sampling connection is shown in Figure 4.x below.

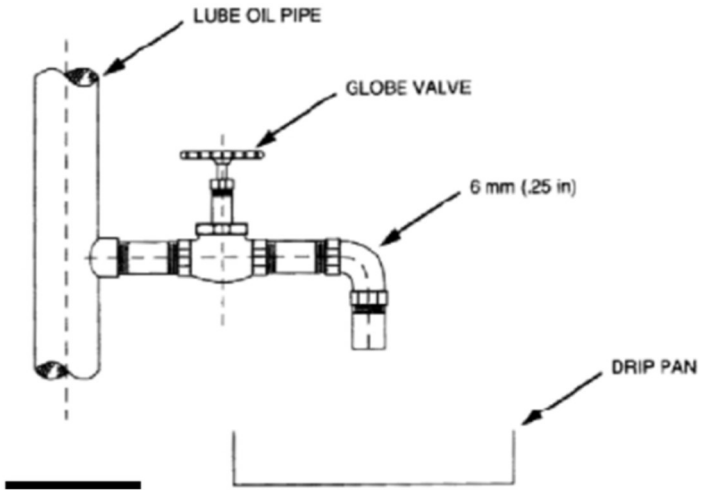


Figure 4.3 **Centrifugal oil filter sampling port**

4.5.2 Absorptive Oil Filters

An absorptive oil filter uses very specific media to extract acids or water from the oil. In this manner an absorptive oil filter may be able to extend the service life of the oil fill by reducing the rate at which acid or water degrades the oil's quality. By keeping the oil's measurable properties within the acceptable limits, an absorptive oil filter can add value in reducing the costs of oil replacement and frequency of site visits for servicing.

As suggested by this explanation, any modifications to the oil fill servicing must be validated by periodic oil sampling and analysis. A study run with relatively frequent sampling intervals can reveal the trend for the oil's rate of degradation, enabling informed decisions regarding such servicing.

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5 Auxiliary and Remote Sumps

The most basic form of the oil sump is an underslung oil pan, located directly beneath the engine block. While the form of the oil pan may vary among mobile or marine applications to stationary installations, its function remains constant as a place to collect and store the engine's lube oil. The underslung design is simple because that direct connection between the engine block and oil sump allows capture of all returned oil by gravity alone. However, circumstances may require a different configuration or location for the oil sump.

Engine room space, tilt requirements, or the desire to extend oil change periods may dictate the use of a remote oil sump (see examples in Figures XX to XX). Regardless of the reason for pursuing a remote oil sump, a single common oil sump for multiple engines should never be used. In addition to numerous ways such an interconnected sump could cause issues among the engines, any issue on a single engine that could compromise the oil would then affect all engines operating from that same sump.

5.1 Remote Sump with Gravity Drain

One basic form of remote sump moves the main oil pan out from under the engine, yet it still relies on gravity for the primary collection of the oil draining back to the sump. Figure 5.1 shows a simple remote sump, with a collection pan directly attached to the engine block. Drain passages route the oil from the collection pan into the sump. The pickup lines for a remote sump must be routed out of the pan back to the engine's oil system.

Considerations for this type of remote sump include:

- Differences in thermal expansion and in relative movement between the engine and remote sump must be accounted for in the design. Drain connections from the engine's collection pan to the sump should be flanged, flexible, and compatible with engine lube oil at high temperature, typically around 130°C (266°F), as well as fuel, coolant, and other chemicals that may be used on the engine (example: engine wash solution).
- Drains from the engine to the sump should terminate below oil level and be located as far as practical from the oil pickup suction bell.
- Each oil suction pipe should be fitted with a bell mouth to minimize pressure losses. Suction losses in the piping from the sump to the engine oil pump must be less than 1.3 m (51 in) of XXXX. Piping to the engine's oil pump should use flanged joints to allow for inspection before use.

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- The oil fill volume must allow oil returned to the sump to remain there long enough to allow air bubbles to escape the oil (degassing). The sump must include at least 150mm (6 in) between the top of the oil fill and the top of the sump to support adequate degassing.
- Transverse structures located inside the tank must permit the oil to move freely across the sump volume; bulkhead-style structures must include holes large enough to avoid partitioning the sump volume into “compartments”.
- The remote sump should provide access for cleaning prior to initial fill or after repairs. Surfaces inside the sump that will be above the minimum oil level must be protected from corrosion.
- The remote sump must have a sounding tube for measuring oil level in the sump and a low oil level alarm contactor.
- Two vent tubes should be positioned at opposite ends of the sump (fore and aft for marine applications), with diameters adequate to ensure proper ventilation of the sump.
- Marine remote sumps should use cofferdam construction to separate the sump walls from the outer shell.

5.2 Remote Sump with Scavenging Pump

Where a gravity drain will not work, a scavenging pump may be included to move oil from the engine collection pan to the remote sump. Remote sumps are often used where the foundation structure height is small and does not permit a close-mounted sump or gravity-drain remote sump.

The scavenging pump must be capable of moving oil fast enough to prevent excessive accumulation in the collection pan. Excess oil volume can result in the crankshaft throws contacting the oil resulting in oil foaming and possible dynamic problems in the crankshaft during operation.

Because the gravity requirement is removed there can me more freedom in locating a remote sump with a scavenging pump. However, there are some limitations that must be considered:

- The oil level in the remote sump must be kept below the engine collection pan to prevent leak-back when the engine is not operating.
- The practical location for an engine-driven scavenging pump is the auxiliary drive that is commonly used for an auxiliary water pump. Both pumps cannot be used on the same application.

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- Marine classification societies (MCS) may require back-up pumping systems, due to the critical nature of the engine's lubricating system. MCS may also have specific requirements for the type of electric motor that may be used for an oil pumping system. The interconnections of these multiple pumping systems can become complex.

In many cases the same limitations that made a scavenging pump remote sump attractive can also end up making it an impractical solution. The additional considerations for such a remote sump can end up occupying more space than other designs, which can burden an installation where space is already in short supply. For such installations it is worthwhile to study whether a simpler design can be made to work.

5.3 Other Remote Sump Considerations

Remote sump tank piping must be short with the least number of bends possible to minimize pressure losses between the sump and the engine oil pump. The piping from sump to pump should have a continual upward slope towards the pump. These details help to avoid pump cavitation. A check valve should be present in the piping to prevent the oil from flowing backwards when the engine is stopped. The pipes must be properly supported and have flexible connections at the engine and auxiliary connecting points. Vent and drain connections must be provided at all high and low points of the system.

A suction strainer should be included in the piping between the remote sump and the engine oil pump to protect the pump from large debris that may collect in the sump. The screen should have a stainless steel basket with 650 micron (0.025 in) perforations and magnetic inserts. A differential pressure gauge should be used to indicate when manual cleaning of the strainer is required.

5.4 Auxiliary Sump

A design solution that includes a remote oil tank for a different purpose is an auxiliary sump. Rather than displacing the primary sump to a location away from the engine, the auxiliary sump supplements the standard engine sump to increase the oil fill volume. Because the combined oil volume of the main engine sump and auxiliary sump is greater than the engine sump alone, the rate of degradation of the oil decreases and the oil change interval can be extended. However, there are considerations that can limit how much this strategy can effectively extend the oil change intervals. One clear consideration is the service life of the oil filters, as adding sump volume will not increase the filter life. Also, there are oil attributes that are more time-dependent and are not as easily delayed by increased oil fill volume. If

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an auxiliary sump may be useful to a given installation, the oil change intervals for that installation should be confirmed by oil condition trending analysis.

Considerations for an auxiliary sump include:

- The oil source line should be connected to the auxiliary tank as close to the engine oil pump as possible.
- The auxiliary oil sump tank must be full prior to starting the engine and remain full at all times. Upon engine start, the auxiliary oil sump overflows, returning the oil to the engine; exactly compensating for the oil removed through the oil source line to the auxiliary tank.
- Use hoses and fittings as described in Remote Sump Tanks. An orifice may be required in the line to achieve appropriate oil flow for the system.
- A check valve should be installed in the oil pump discharge line. Set the valve to open at 75% of the measured pressure at the line connection point, when the engine is at operating temperature and maximum operating speed.

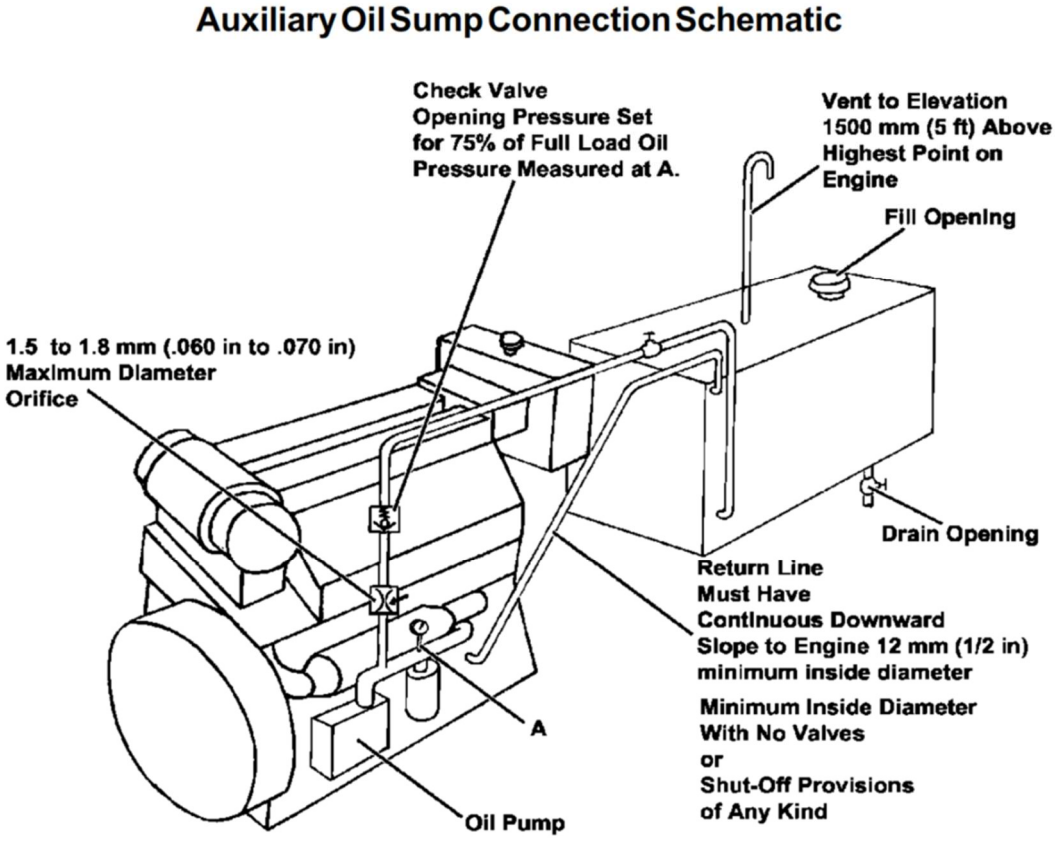


Figure 5.1 **Example of an auxiliary oil sump**

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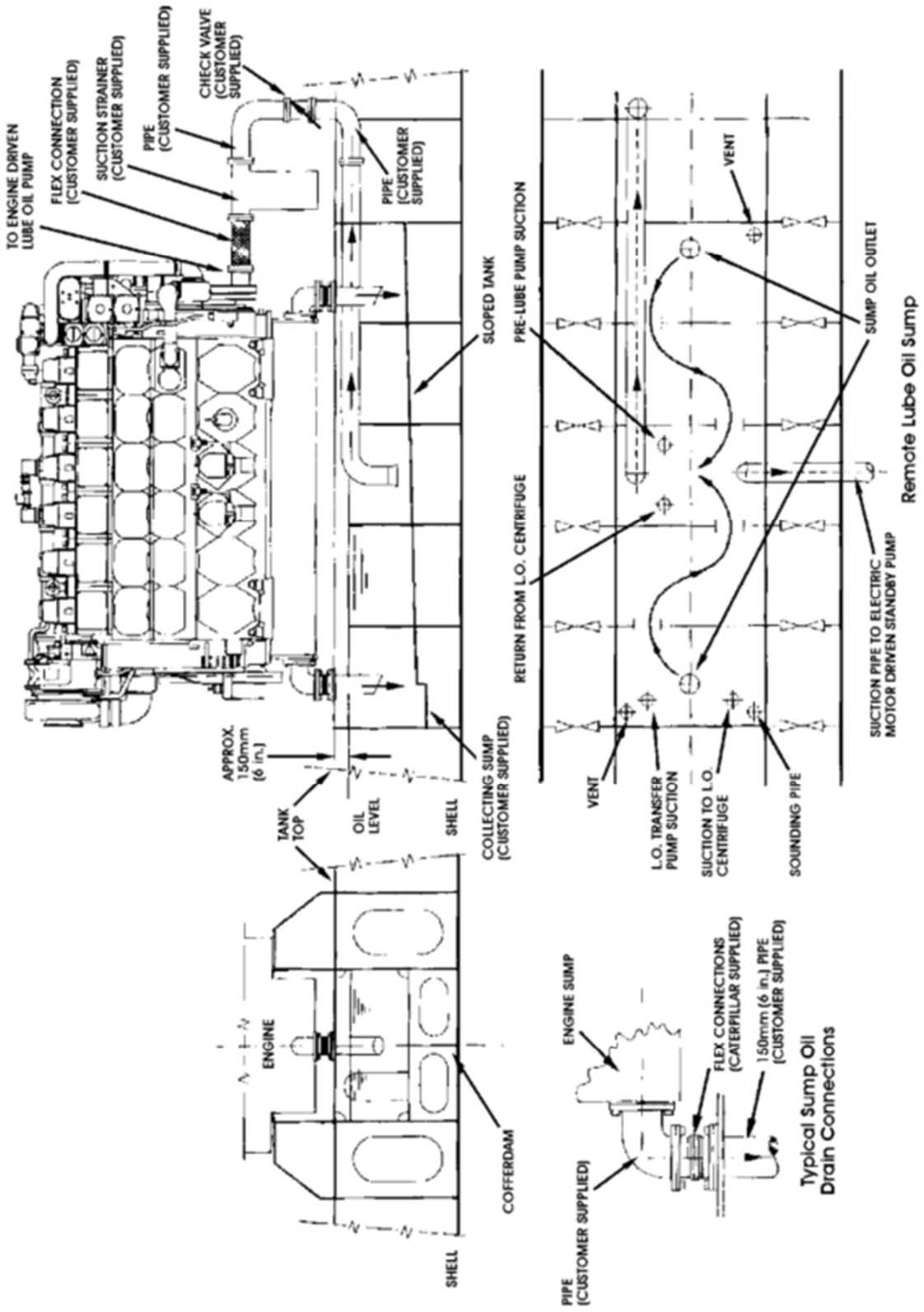


Figure 5.2 **Example of a gravity-drain remote oil sump**

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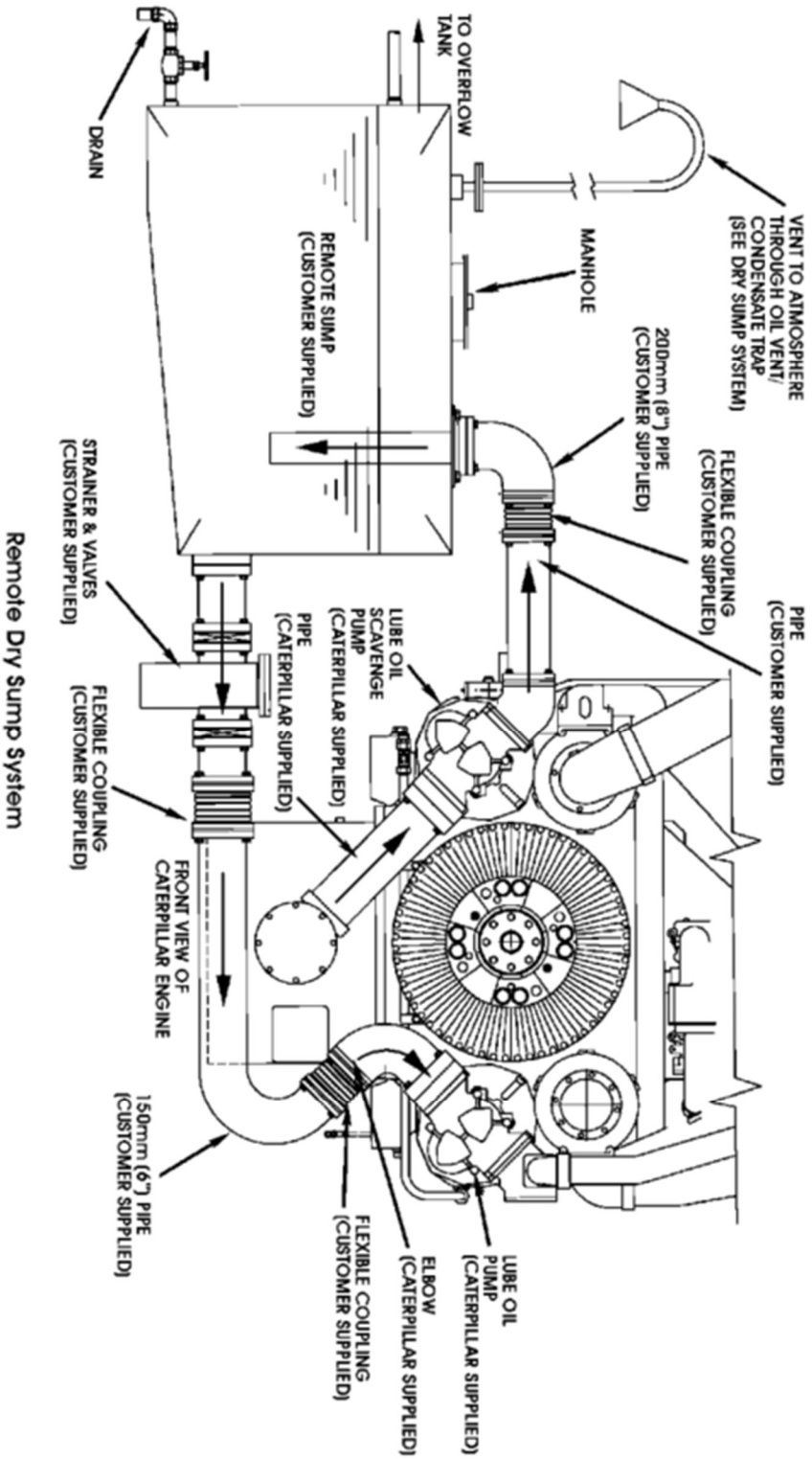


Figure 5.3 **Example of a scavenged remote oil sump**

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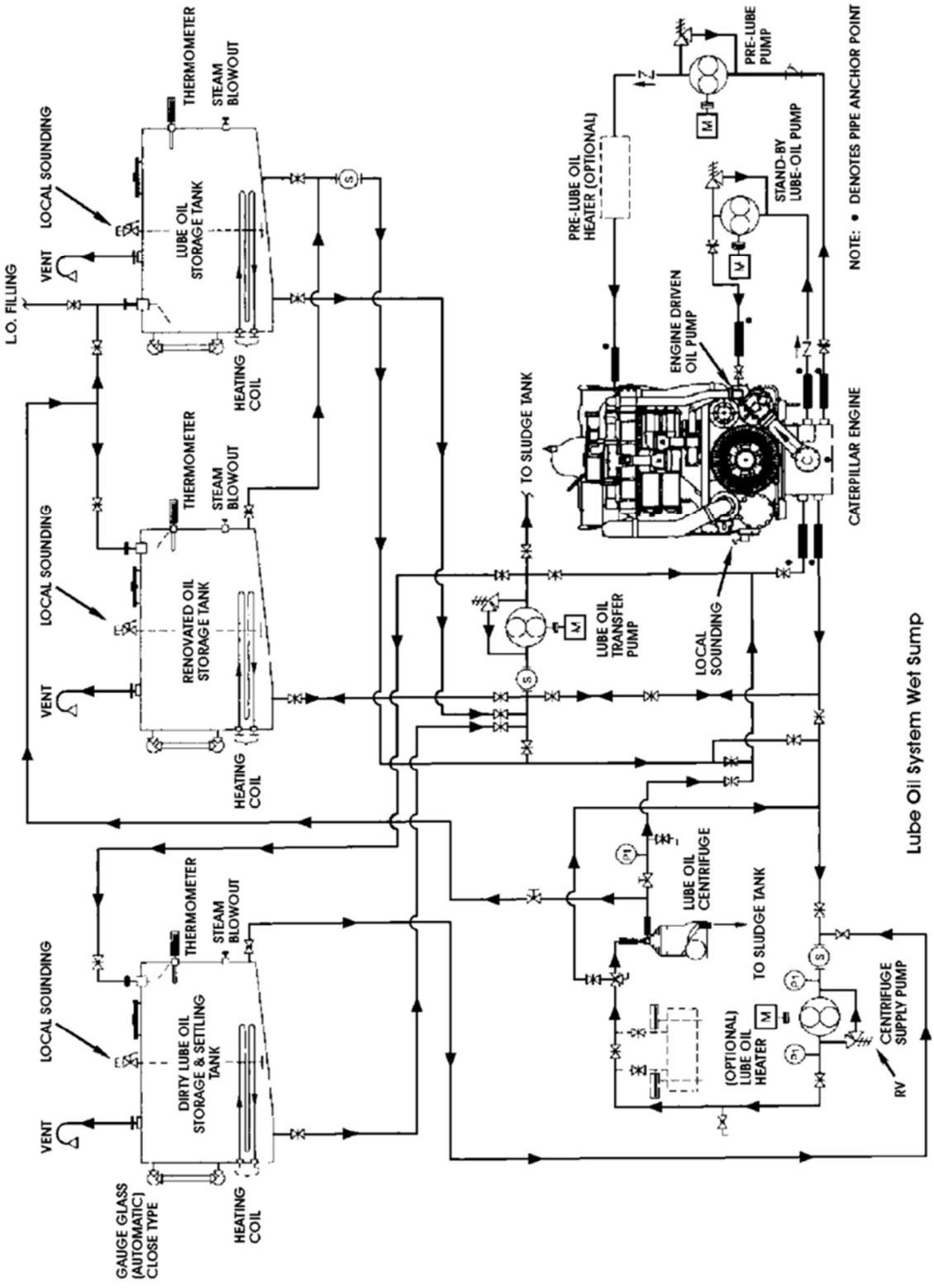


Figure 5.4 **Wet sump layout for 3600/C280/G3600**

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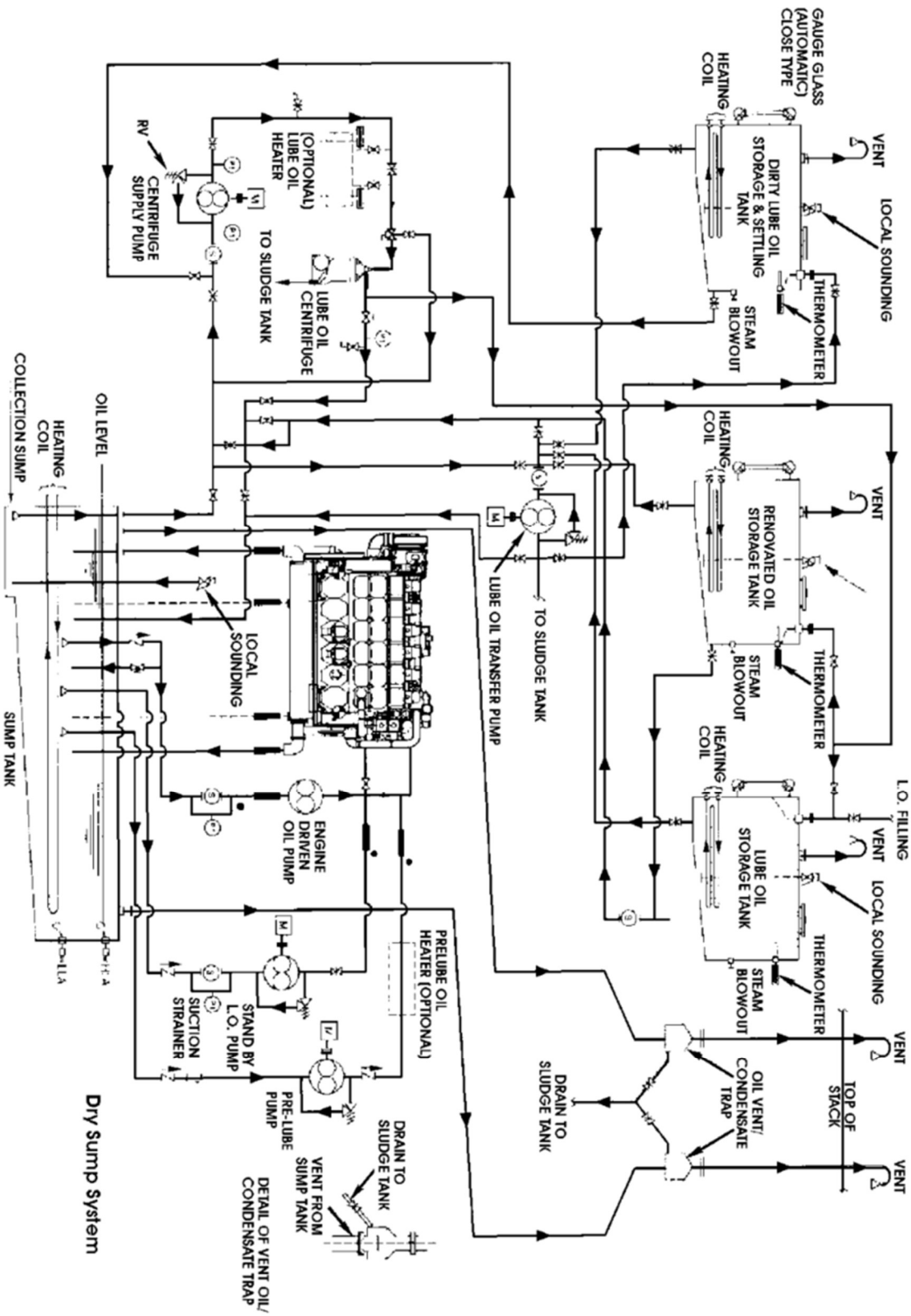


Figure 5.5 **Dry sump layout for 3600/C280/G3600**

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6 Oil Condition Management and Monitoring

Because the lubrication system is so critical to the optimal performance and service life of the engine, many supplemental systems and devices may be present to help maintain the condition of the system, and of the oil itself.

6.1 Oil Level Gauge (Dipstick)

The common “dipstick” may be the simplest component of the lubrication system. It is a simple insertion gauge that enables reading the level of the oil in the oil pan without direct access to the sump area. The dipstick is typically a long, flexible metal strip marked with graduations that indicate the critical oil levels in the pan: the “full” mark to indicate the design fill level and the “add” mark to indicate the minimum acceptable fill level for engine operation.

For Cat engines with displacement of 32 liters or less the engine must be stopped to check the oil level with the dipstick. For Cat engines larger than 32 liters displacement the dipstick will typically include markings for oil levels for both the “engine running” and “engine stopped” conditions. For engines installed with a permanently tilted orientation, not uncommon in marine or offshore installations, the dipstick level must be checked and recalibrated if necessary to adapt to the altered oil fill level created by the tilt of the engine.

6.2 Crankcase Breathers

While not directly a part of the lubrication system, the crankcase breathers do assist in maintaining optimal conditions for the system. The crankcase breather represents a path by which fumes from the crankcase (the area above the sump) may escape that enclosed volume, and in the process relieve the increased pressure that is present. If that pressure were not released the elevated pressure in the crankcase could lead to diminished engine performance and increased stresses on gasketed joints. A properly designed and connected crankcase breather system manages the crankcase pressure while maintaining the crankcase as an essentially “closed” volume, thereby preventing the introduction of dirt or moisture that can affect the system’s performance.

6.3 Oil Pressure Regulation

Oil pressure is one of the key critical operational parameters for an engine’s lubricating oil system. For most of the lubricated bearings in the engine, the bearing’s load capacity is a function of the oil pressure being supplied to it. Any reduction or fluctuation in oil pressure

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can have consequences for the bearings and thus for the performance and service life of the engine.

In most engines the oil pressure is managed by an excess flow valve at the outlet of the pump. That spring-loaded valve manages the delivery of a constant oil pressure into the lubrication system by discharging any excess oil directly back to the sump. In fact, because the engine's bearings need to function properly regardless of engine speed, load, or temperature, this simple valve is typically sized so that oil bypass begins relatively early in that overall operating range.

6.3.1 Priority Valve

The 3600/C280/G3600 engine families use a special variation in their oil pressure regulating valves called a "priority valve". The priority valve regulates oil pressure at the cylinder block main oil gallery rather than at the oil pump, making the main oil gallery pressure independent of the pressure drops that occur at the oil filters and oil cooler. The priority valve also provides for separate regulating passages for the bearing oil supply and for the piston oil cooling jets. While the piston cooling jets help to alleviate the risk of detonation in the cylinders, the bearing surfaces enable the operation of the engine with minimal damage between moving parts. This multi-stage valving places a higher priority on the regulated pressure to the bearings than to the piston cooling jets based on the relative importance of each to the engine. A cross-sectional view of the priority valve appears in Figure 6.1.

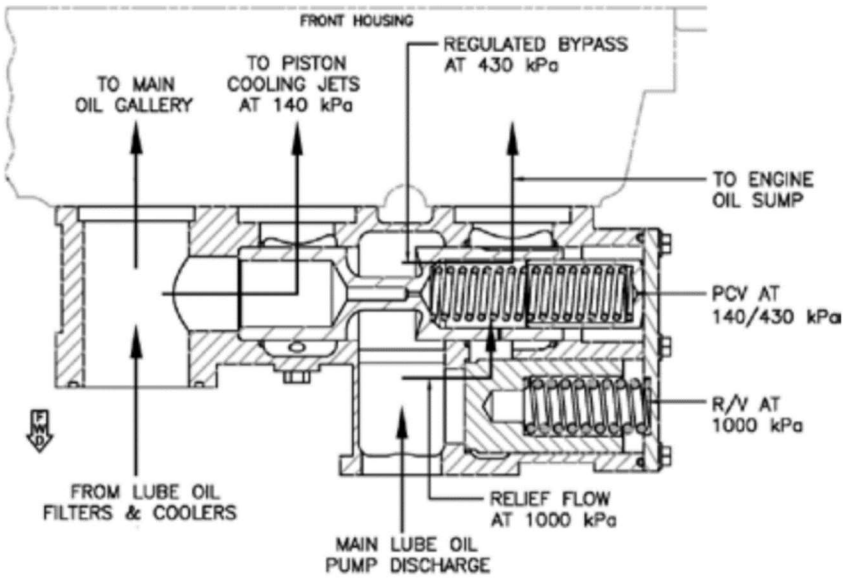


Figure 6.1 **Priority valve**

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6.4 Oil Temperature Regulation

Closely related to oil pressure is oil temperature, and oil temperature regulation is another of the critical operational parameters for an engine's lubricating oil system. Many Cat engines require a straight-weight lubricating oil – variable viscosity oils are not allowed. Since oil viscosity varies with oil temperature, careful regulation of temperature becomes critical to managing the optimal performance of the oil in the engine's bearings. And this temperature issue is a concern at both extremes: oil that is too hot will decrease in viscosity until the bearings are unable to support the loads they are required to carry, while oil that is too cold can have a viscosity that is so high that the oil has difficulty flowing into and through the bearings. Either condition can compromise bearing performance and result in significant engine damage.

Because the oil travels through many of the most sensitive areas inside the engine, one important job of the oil is to carry heat away from those areas. Lubricated surfaces around the combustion chamber and under the piston expose the oil to the very high temperatures of combustion, while oil flowing through the bearings of the crankshaft, camshaft, and valves also acquires a lot of heat.

To manage high oil temperatures the engine uses an oil cooler. The oil cooler is placed upstream of the oil filters to help prevent damage to the oil filter media by excessive oil viscosity within the filters. Many Cat engines include temperature regulators on the oil path for greater control over the achieved oil temperature.

6.4.1 Lubricating Oil Preheaters

As noted above, cold lubricating oil can be as big of a concern as very hot oil. And because the engine's design is optimized for temperatures that stabilize around the combustion process, the threshold temperature for "cold" oil can be a lot higher than one might realize. As a general guideline, Cat recommends oil heaters to be used when the ambient temperature will be 10°C (50°F) or lower.

To some degree, the importance of managing low oil temperatures depends on the size of the engine. For many smaller engines it is acceptable to crank the engine with the oil at rather low temperatures. While the cold oil will flow more slowly, the light residual lubrication of the bearing surfaces coming from a shutdown condition is adequate to prevent undue wear during cranking. However, for larger engines the components involved (particularly the crankshaft) become significantly larger and heavier, and the concerns for damage during cranking increase accordingly.

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A simple answer exists in the form of a lubricating oil preheater. The oil preheater does exactly what the name says, heating the oil in advance of cranking to ensure an optimal oil temperature is reached after a much shorter period of engine operation. Designs for oil preheaters vary, from relatively inexpensive passive immersion heaters to more complex thermostatically controlled circulating heater systems.

6.4.1.1 Immersed Element Oil Heaters

Most lubricating oil heaters rely on electricity to generate the heat used to warm the oil. An immersed element oil heater is sometimes called a “passive” heater because it depends on the oil to transmit the heat across the entire oil fill. This design uses a resistive element to generate heat from an electric current, and because this element is immersed in the oil the heat passes into the oil. Dispersion of the heat is through conduction within the oil, and for some systems through induced circulation of the oil by natural convection. A convection-circulation system is sometimes called a “thermosiphon” system due to the way the rising warmed oil draws the colder oil up into the heater.

A key concern for a passive immersed-element oil heater is the risk of damaging the oil by passing too much heat into the oil too quickly at the point of contact between the oil and the heater element. To limit this risk, heater elements should be sized so their surface temperatures do not exceed 150°C (300°F), and their thermal density or heat flux (the rate at which heat is passed into the oil) is no greater than 1.24 W/cm^2 (8 W/in^2).

6.4.1.2 Circulating Oil Heaters

Clearly, migration of the heat into the entire oil fill is a limitation of an immersed-element oil heater. And one solution is to actively circulate the oil using a pump. Active oil circulation not only increases the movement of heat through the entire oil fill, but it also lowers the risk of excessive heat transfer at the point of contact between the oil and the heater element. Of course, the addition of a circulating pump increases the cost of the system, so circulating oil heaters tend to be more common on larger engines or on installations where severe environmental conditions drive the need for the more effective solution.

Lubricating oil heaters should be systems designed specifically for that purpose. Improper heating of the oil (heating that raises the oil's temperature too much in a localized area) can damage the oil, leading to premature breakdown of the oil and possibly allowing damage to the engine. A proper oil heater system should include a thermostatic control to manage the oil temperature. Circulating systems that include an oil pump to move the heated oil through the engine's sump are generally more effective and thus are recommended.

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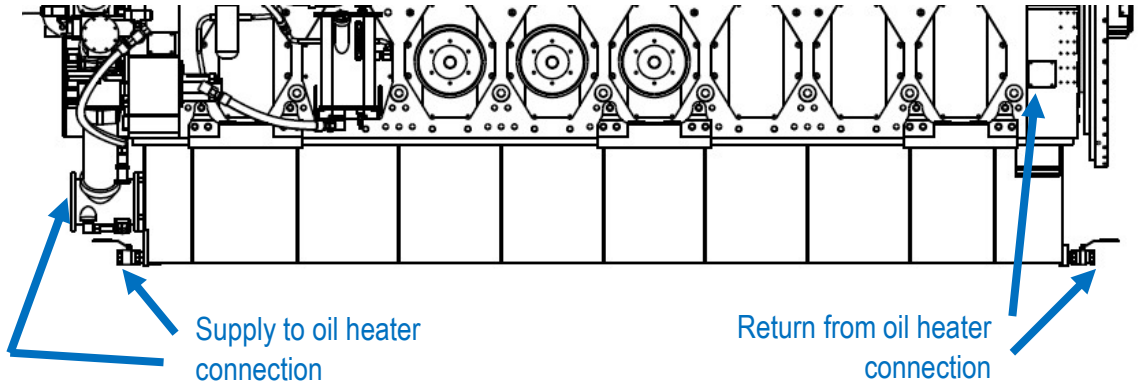


Figure 6.2 **Examples of circulating oil heater connection points**

The oil heating system should include a pressure switch to shut off the heater and circulating pump when the engine is in operation. The connections for the oil circulating system should be located on opposite ends of the engine sump to ensure the entire oil fill is heated uniformly. Care must be taken to locate those connections so they do not interfere with the proper operation of the oil makeup system.

Lube oil heater connections also need to work well with the available connection locations on the engine. The heater manufacturer's instructions for placement and routing of the connecting lines should serve as the primary guidance. Such instructions are important, as an incorrect heater system installation may lead to improper pump priming, fluids draining down to the sump, and as a result a dry system. These systems running dry can result in failures of the jacket water heater or oil heater elements.

This issue of interconnecting lines between the engine and the heater that are empty of oil also presents an unobstructed path between the crankcase and the heater. This is not acceptable because it allows combustible vapors to travel to the heater unit, creating a potential hazard. For this reason, the oil heater supply and return lines should include a P-trap with a minimum of a 127 mm (5 inch) drop and rise. This distance will isolate the engine crankcase gases from the oil heater element. The supply line to the heater should also have a check valve installed to limit oil from draining back to the sump when the heater is not in operation.

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While circulating oil heaters do pump oil while the engine is not in operation, they are not designed for the tasks of prelube or postlube. Circulating oil heater systems should never be used for these functions without specific design approval from the heater system's manufacturer and from Caterpillar. Some of the larger Caterpillar engine models will require a dedicated prelube/postlube system for proper operation.

6.5 Oil Level Regulation (Oil Makeup System)

A final condition ensuring proper operation of the lubrication system is the availability of adequate oil to the oil pump. At its simplest, this is done by periodically checking the dipstick to ensure the oil level has not fallen below the lower limit mark. However, for many installations it simply is not practical to station personnel at the site to make such in-person oil level checks.

Like many systems on the engine, a simple system can be devised to automatically maintain the oil level in the sump at the desired level. A common oil makeup system design uses an elevated fresh oil tank to enable a gravity feed into the sump. The remaining key piece is an oil level regulator, which commonly takes the form of a float valve placed level with the desired oil level in the sump. When properly installed and connected, the oil level regulator will open a valve when the oil level falls below the desired level, allowing new oil to flow into the sump. When the added oil restores the desired sump oil level, the regulator closes the valve to halt the flow of new oil.

The automatic oil makeup system adds even more convenience when level detection sensors are incorporated into the design. Level switches near and at the low sump oil level serve to detect and report a low oil level alarm and, if necessary, shutdown to the site controls. This is useful to avoid major engine damage when the elevated oil storage tank runs empty undetected. Be aware that some modern oils are not compatible with certain materials and can cause them to degrade and fail. Make certain the system’s materials are compatible with the oil selected.

The simplicity of this design makes it inexpensive to design and build, but it also places a high importance on the accurate placement of the oil level regulator and the level detection switches relative to the engine. Their position relative to the oil level in the sump is the key factor in whether the system will perform as designed or produce false readings that result in premature alarms or undetected low oil levels. Another key connection on the oil level regulator is the vent line, a tube or hose that communicates to the regulator the pressure in the crankcase above the oil level. An oil level regulator with an improper vent connection will not reach an oil level that matches that inside the engine. The vent line must not have a

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localized low point between the regulator and the engine, as oil can get into the vent line and can accumulate in the low point, blocking the line. As always, the installation instructions and guidelines from the oil level regulator's manufacturer must be followed to achieve proper system performance.

It is important that the connection point for the oil line from the oil level regulator to the engine's sump is not placed too near other oil system components, such as the pickup location for a prelubrication system. Such systems can cause the oil level in that area of the pan to be lower than in the rest of the pan, and the float valve in the oil level regulator will respond to that localized low level, ultimately resulting in overfilling of the oil pan. The oil makeup system should also include a manual shutoff valve between the elevated storage tank and the oil level regulator to allow the tank to be disconnected for engine servicing.

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7 Prelubrication and Postlubrication

Prelubrication is a process that helps to avoid excessive wear during start-up. Postlubrication helps to avoid thermal damage following a shutdown. Both are typically performed by dedicated systems that are largely separate from the engine's main lubrication system, and yet each can range from a basic manual prelube to a fully integrated automatic system.

Prelubrication ("prelube") is accomplished by pumping lube oil into the engine's oil passages while the engine is not running. Unlike during operation, where the main oil pump must push oil under pressure into the bearings, a prelube system only seeks to fill oil passages that have drained down while the engine was stopped. If those passages are full of oil, as soon as engine cranking begins, the main oil pump will push oil under pressure everywhere in the system, including into the critical bearing surfaces. This simple act of refilling the oil passages can tremendously reduce the wear that can occur at start-up by nearly eliminating the period during which metal parts are in direct contact because the oil hasn't yet built sufficient pressure to create the operating cushion they rely on.

Postlubrication ("postlube") is performed for a very different reason. Rather than focusing on wear avoidance, postlube primarily focuses on the oil's other task of carrying away heat. Turbochargers are an ever-present part of modern heavy-duty engines because they add so much value in the form of increased power and improved efficiency. However, they operate at very high temperatures and so rely heavily on the oil circulation to keep core surfaces (particularly the bearings) from overheating. Following a shutdown, the engine's main oil circulation is stopped well before the turbos have cooled adequately. Postlube provides a continuing flow of oil to bring turbo temperatures down to acceptable levels.

For either activity the engine's gear-driven oil pump is both unavailable much too large. Neither prelube nor postlube needs to build pressure to push oil into the bearings. Prelube only needs to make certain the lubricating system is filled with oil at the time the engine starts to crank, and postlube only needs to continue oil circulation for a period of time. Both requirements point to a separate oil system that is much smaller than the main oil pump.

7.1 Prelube Systems

A key thing to remember about prelube is that it is accomplished while the engine is stopped. While this means the prelube pump must be driven by some means other than engine power, it also means that means can take many forms. The simplest form of prelube is a "manual" prelube, and that name is quite literal. Manual prelube uses a hand pump to

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push the oil into the lubrication system. While relatively slow, manual prelube allows this key function to be completed without any supplemental power source.

Adding a motor to drive the prelube pump makes this much easier and quicker. Prelube systems are commonly seen with electric motors, air motors, or hydraulic motors, depending on the specifications of the installation. Even with a motor present the prelube system may be manually activated or fully automatic. A manually activated system requires that an operator push a button to start the prelube sequence; an automatic prelube is typically engaged by a master controller, either in the engine's controls or as part of a site control setup.

While a simple timed cycle may be an acceptable operating strategy, many prelube systems account for variabilities in pumping cold oil by automatically detecting that oil has been pushed through the entire lubricating path. This automatic detection enables a fully automated starting sequence in which the prelube cycle is immediately followed by engagement of the starting motors to crank the engine. Caterpillar considers prelube to be optional on many G3500 engines, but it is deemed a requirement on the 3600/C280/G3600 and larger models due to the sheer size and weight of the lubricated components (such as the crankshaft).

Even among automated systems prelube can take many forms. Consider the following options:

7.1.1 Intermittent Prelube

An intermittent prelube system is engaged immediately prior to engine start-up and will run until an appropriate signal indicates the cycle is complete and can end. As noted above, this most commonly takes the form of a sensor placed near the far end of the oil path from where the pump flow is introduced, often high on the engine to ensure the oil has filled the passages in the block.

7.1.2 Continuous Prelube

Some installations require that the engine be kept in a state that is ready for cranking. One piece that helps achieve that readiness is continuous prelube. A continuous prelube system is designed to operate whenever the engine is not running. The control logic for switching a continuous prelube "on" or "off' is often a pressure sensor placed downstream of the main engine oil pump. When that sensor detects the increased pressure delivered by the main oil pump it determines the engine is now running and disables the prelube pump. That sensor continues to be active so that when the engine is shut down it can signal the continuous prelube system to once again start pumping oil.

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7.1.3 Redundant Prelube

A redundant prelube system combines the continuous and intermittent prelube systems, offering the benefits of both. Under normal circumstances, the continuous prelube pump keeps the engine ready for immediate start-up by maintaining the level of oil in the engine's oil passages. The intermittent prelube pump will only operate if the continuous pump fails.

This system is typically selected for black start or emergency generator applications, when it is critical that the engine can be started on command.

7.1.4 Quick Start Prelube

The quick start prelube system is similar to the redundant prelube above, with two pumps, one that operates as a continuous prelube and another that operates as a booster. This second pump is the key difference in that it is not just a backup to the continuous prelube pump, it is an integral part of the system.

The continuous pump system operates as described for the continuous and redundant systems, maintaining the oil level in the lubricating passages when the engine is not running. When the engine start command is given the continuous pump will stop and the booster pump will take over, rapidly raising the oil pressure to a level that enables immediate cranking.

Quick start prelube time will vary with oil temperature. Typical quick start prelube times, measured from the start initiate signal to starter engagement, are 5 to 7 seconds with 25°C (77°F) oil.

7.2 Postlube

Postlube is commonly offered for engines that include an intermittent prelube system and a fully automated starting sequence. For such engines (including redundant and quick start arrangements) the postlube starts automatically with a normal engine shutdown and runs for programmed time period. An important detail in this statement is that postlube is automatic for a "normal shutdown". Postlube will not function when the emergency stop (E-stop) is activated, and this is done intentionally. Because the E-stop is intended to be used only for emergency purposes, automated systems like postlube are disabled to prevent them from aggravating the emergency situation. This is one of the reasons it is strongly advised that the E-stop never be used to initiate a normal shutdown: by design, the postlube will not run following an E-stop and thus the turbo will not get a cool-down oil flow cycle.

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7.3 Prelube/Postlube Components

7.3.1 Pump

The prelube/postlube pump is typically driven by either an electric or air motor, and the choice of which type is often linked to the type of starting system selected. Electric power generation engines will typically use electric prelube motors, while other applications (such as gas compression) may more commonly use air motors driven by compressed air or gas.

The prelube pump is commonly located near the oil pan, with its own piping for oil pickup (from the sump) and oil discharge into the engine's lubrication system. Automated systems will include electrically actuated relays or valves to enable control of the pump motor by the engine management system.

7.3.2 Prelube Spill Valve

While most of the prelube/postlube activity is a straightforward as it sounds, one portion of the engine's lubrication circuit requires special attention. The turbocharger bearings are commonly a special design that only seals the oil path while the bearings are turning. These dynamic bearings do not effectively seal the oil when the turbocharger wheel is not spinning, and under those conditions the oil flow delivered by the prelube/postlube pump can bleed through the bearings and into the combustion air path.

To prevent this, a valve must be placed in a location to interrupt the flow to the turbochargers only when the engine is not cranking or running. This last condition is critical, as any interruption of oil flow to the turbochargers during normal cranking or operation could cause significant damage to the turbo bearings. This spill valve arrangement is configured to quickly detect when engine cranking begins to immediately enable oil flow to the turbos.

7.3.3 Turbocharger Oil Accumulator

Engines that do not include an intermittent prelube system can still enjoy some of the protection offered to the turbocharger bearings by postlubrication. A turbocharger oil accumulator is a special attachment that provides a limited duration oil flow to the turbo bearings without the use of a pump.

The heart of a turbo oil accumulator is a pressurized gas charged canister (often a common inert gas such as nitrogen). The pressurized gas is captured behind a flexible diaphragm that partitions the canister between gas and oil volumes. When the engine's main oil pump is operating, the oil pressure is sufficient to push the diaphragm into the gas volume, compressing the gas as it moves. This creates a limited volume of pressurized oil that is kept in place as long as the main oil system pressure is maintained. Once the engine is

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stopped, the system oil pressure falls and the gas once again returns the diaphragm to its original position. The accumulator is positioned so that the oil displaced from the canister following a shutdown is directed to the turbo bearings to provide some postlube flow.

This type of arrangement is particularly helpful for engines that may experience a “hot shutdown”, such as an E-stop or other rapid stoppage of the installation. Because such emergency shutdowns stop the engine’s rotation very quickly, the pressurized air trapped downstream of the turbo’s compressor wheel will seek to discharge the pressure by flowing backward through the turbo. This backward flow can rotate the compressor backwards in an action referred to as “windmilling”. Because the oil flow is disabled at shutdown, windmilling can be damaging to the turbo bearings. The limited flow from the turbo oil accumulator can be enough to avoid significant damage.

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8 Additional Considerations

8.1 Emergency Systems

Many standby generators, fire pumps, and marine applications require the capability to connect an emergency lubricating oil pump into the engine's lube oil system. Many Cat engines can be provided with these optional connections when necessary.

This is a specific requirement of marine classification societies for sea-going single propulsion engine applications. The purpose is to ensure lubricating oil pressure and circulation in the event of an engine lubricating oil pump failure. The emergency oil pump allows the single propulsion engine to operate and the ship to reach port for engine repairs.

Guidelines for emergency lubricating oil system operation:

- Keep pressure drops to a minimum by using short, low restriction lines.
- Use a line size at least as large as the engine connection point.
- Install a low restriction strainer in front of the emergency oil pump.
- Install a low restriction check valve between the emergency pump discharge and the engine inlet connection.
- Use a pressure limiting valve in the emergency system set at the maximum oil pressure limit of the engine.

8.2 Transmissions

Marine classification societies that require emergency lubricating oil pumps for single propulsion engine applications also require emergency lubricating oil pumps for the associated marine transmissions to meet the unrestricted service classification. In these cases, refer to the transmission manufacturer's operation manual for instructions, oil flow and pressure requirements and follow the guidelines listed above.

8.3 Piping Systems and Flexible Hoses

In addition to the emergency lubricating oil system requirements described above, marine classification societies have specific requirements relating to the materials used in the installation of these systems. Although these systems are not typically offered by Caterpillar, they are still critical to the overall success of a given installation. Therefore, piping system and flexible hose material considerations are discussed in the Piping Systems section of this guide.

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8.4 Lube Oil Storage and Transfer Systems

Figure 13 and Figure 14, at the end of this section, show typical piping schematics for an operational lubricating oil storage and transfer system.

The system consists of three storage tanks, a centrifuge system and a transfer pump arranged as follows:

8.4.1 Clean Oil

Clean oil from the storage tank is piped to supply the engine sump (or sumps), either by gravity, via the centrifuge, or by the transfer pump.

8.4.2 Dirty Oil

Dirty lube oil is removed from the engine sump (or sumps), by the transfer pump and discharged to the dirty lube oil storage and settling tank.

8.4.3 Renovated Oil

Contaminated oil can be cleaned using the lubricating oil centrifuge and discharged to the renovated oil tank.

8.4.4 Transfer Pumps

The lube oil transfer pump is used to move oil from the engine sump (or sumps), the clean oil storage tank, the dirty oil storage and settling tank and the renovated oil tank. The pump can discharge oil to the dirty oil storage and settling tank, the sludge tank and the engine sump (or sumps).

The transfer pump should be a gear-type pump and include a relief valve. Transfer pump sizing is based on project specific requirements. The following transfer pump characteristics are provided only as a sample.

- Pump Flow Rate – 190 lpm (50 gpm)
- Pump Pressure - 345 kPa (50 psi)
- Operating Fluid Temp. – 130°C (266°F)
- Viscosity for sizing electric motor – 1000 cSt

8.4.5 Storage Tanks

Each tank should be configured with the following:

- Fill Port
- Vent Location
- Local Sounding Port

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- Gauge Glass
- Heating Coil
- Thermometer (with well)
- Transfer Pump Suction Port
- Drain Port
- Steam Blowout Port
- Manhole
- Ladder (if required)

Heating coils should raise the lubricating oil temperature to approximately 38°C (100°F). When heating with steam or water, the heating coils must be manufactured from corrosion resistant material.

Note: Heating elements in direct contact with lubricating oil are not recommended due to the danger of coking. To avoid coking when heating oil, heater skin temperatures must not exceed 150°C (300°F) and heater elements must have a maximum heat density of 1.24 W/cm^2 (8 W/in^2).

The engine can be filled with oil from the storage tank via the centrifuge, by the transfer pump (with a strainer), through the forward or aft simplex drain valves, or through the filling cap located on the engine crankcase cover.

Many variables go into establishing tank capacity. The number of engines installed, sump volume, and lubricating oil consumption are just a few. The lubricating oil storage tank capacity table is provided only as a ample to show the size relationship between tanks.

Tank Volumes	Liters	Gallons
Lubricating Oil Storage Tank	7500	2000
Dirty Oil Storage and Settling Tank	3750	1000
Renovated Oil Storage Tank	3750	1000

Figure 8.1 **Example of relative volumes along tanks**

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9 Lubricating Oil

Bearing failure, piston ring sticking, and excessive oil consumption are classic symptoms of oil-related engine issues. There are numerous ways to avoid these problems, including Scheduled Oil Sampling (Cat S•O•S), regular maintenance of the lubrication system, and the selection of the correct lubricant for each application.

This section describes the basic properties of lubricating oil and the consequences of oil contamination and degradation. Also discussed are methods of identifying contamination and degradation, and preventive measures that can help protect the engine against oil-related failures.

Please note that this information is supplemental and in no way replaces specific lubricating oil requirements for your application; nor does it preclude the need for oil analysis. For model-specific information, refer to the Operation and Maintenance Manual for each engine.

Lubricating oil must perform a number of tasks under severe conditions without failing. It must maintain protective film between working surfaces to minimize friction and wear, and at the same time conduct excess heat away from those areas. It must help to keep those working surfaces clean by carrying away dirt and wear particles that result from the normal operation of the engine. It must protect surfaces from chemical attack in the extreme environment of the combustion chamber while retaining its basic properties under the severe mechanical stresses exerted by rapidly moving machine parts. And it must be able to continue to perform in this manner for extended periods to limit engine down time.

As this description suggests, oil formulation is complex, involving many characteristics. An awareness of the components of the oil's formulation and the meaning of its characteristic properties is the starting point for understanding engine oils.

9.1 Lubricating Oil Formulation

The "formulation" of an oil is, put simply, the recipe for an oil that exhibits specific characteristics. To the extent that those characteristics describe the oil's suitability for use in specific applications, the formulation is the oil's pedigree such use, and it will vary to meet the specific needs of each application.

Engine oils begin with a base stock, a core mix of heavier hydrocarbon fractions that are derived from crude oil and are predominantly alkane compounds. Of specific interest for lubricating oils are longer chain molecules that are heavier than natural gas and the liquid fuels (gasoline, diesel, kerosene, jet fuel) but lighter than the even longer chain fractions of

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paraffin wax, asphalt, and bitumen. The specific fractions isolated for engine oil are selected for their characteristic lubricating properties, and advances in petroleum refining technology have resulted in progressively better oil base stocks. In general, oils refined from crude are labeled as “mineral oils”, which helps in distinguishing them from oils that are manufactured by molecular manipulation, referred to as “synthetic oils”.

Whereas the base stock provides the core building block for the oil, the additives package determines its formulation. Additives are chemical compounds that alter the performance characteristics of the oil, essentially optimizing the oil for specific end uses. Additives impart important properties to each oil formulation, including:

- Detergents, to control sludge formation
- Corrosion inhibitors, to aid in limiting oxidation of metal surfaces
- Antioxidant compounds, to slow oil degradation through oxidation
- Alkaline compounds, to help neutralize acids that can break down the base stock oil
- Viscosity modifiers and pour point depressants to manage the oil’s flow characteristics across extremes of temperature
- Friction modifiers, to alter the lubricity of the oil
- Anti-wear compounds, to improve the wear protection properties of the oil
- Dispersants, to manage soot accumulation in the oil
- Anti-foam and anti-mist agents, to maintain the film integrity of the oil

This list is provided as a very general reference, simply to aid in awareness of the scope and complexity involved in formulating oils for specific uses. This exposure to the topic should also serve to raise awareness of why it is important that each specific oil be validated in its performance in an engine.

9.2 Lubricating Oil Properties

To gauge the performance of an oil, a number of measurable properties have been defined.

9.2.1 Viscosity

Viscosity is defined as “the resistance of a fluid to changes in shape or flow”, but in practical terms for engine oil it indicates the oil’s flow behavior. Viscosity changes with temperature. Oil that flows poorly at low temperatures will flow more freely at higher temperatures. Because viscosity is a fundamental and critical characteristic of an oil, engine oils are commonly classified by their viscosity. The grading system established by the Society of Automotive Engineers (SAE) is widely used and thus familiar. It establishes 11 single grades for engine oil (0W, 5W, 10W, 15W, 20W, 25W, 20, 30, 40, 50, 60) based on standardized tests of flow behaviors at specified temperatures. These single grades may

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also be seen in combinations, such as “5W-30” or “10W-40”. Such designations indicate multi-grade oils, and such oils very commonly include viscosity indexers, compounds that alter the temperature-viscosity relationship of the oil. Oils that use viscosity indexers cannot be labeled as single grade oils.

9.2.2 Viscosity Index

Viscosity index (VI) is a measure of how much viscosity changes with a change in temperature. A low VI value indicates an oil that will experience a greater change in viscosity for a specified change in temperature.

9.2.3 Pour Point

Pour point provides a reference to the minimum temperature at which the oil will flow freely.

9.2.4 Flash Point

Flash point describes the temperature at which the oil becomes flammable as a vapor in air.

9.2.5 Total Acid Number (TAN) and Total Base Number (TBN)

Total Acid Number, or TAN, is a measure of the acids present in the oil. Total base number, or TBN, is a measure of the reserve alkaline capacity of an oil. The alkaline compounds in the oil are gradually consumed as they neutralize acids generated in the engine, a process that protects the oil from acid decomposition and degradation. While each tells a specific nuanced detail of the oil’s condition, in general the TAN will increase and TBN will decrease over time. The relationship of the two can be used as a determinant for whether the oil has degraded to the point of needing to be changed.

9.3 Oil Consumption

Oil consumption is a consequence of normal engine operation. Some portion of the oil directed to the moving parts around the combustion chamber will be lost to combustion. This oil needs to be replaced, and it is common for this to be needed between maintenance intervals. Typical oil consumption rates will vary from engine-to-engine, but values are normally available help with predicting the quantity and cost of the make-up oil needed. In practice, many factors will affect oil consumption including load profile, maintenance practices, fuel quality, and the particular oil selected.

The rate of oil consumption is typically reported as brake-specific oil consumption (BSOC), with values presented as mass of oil consumed per unit of power per unit of time. This allows the BSOC value to be applied independent of operating load. To calculate a volume

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per hour basis, the engine load and oil density must also be known. The following formula may be used to estimate oil consumption:

$$L/hr = Engine\ Load\ (bkW) \times \frac{BSOC\ (g/bkW \cdot hr)}{Oil\ Density\ (g/L)}$$

$$gal/hr = Engine\ Load\ (bhp) \times \frac{BSOC\ (lb/bhp \cdot hr)}{Oil\ Density\ (lb/gal)}$$

Oil density values are typically provided as part of the technical documentation for the oil selected. If none is readily available, a typical engine oil density of 899 g/L (7.5 lb/gal) may be used.

Oil consumption increases over time due to wear, thus the oil consumption rate can be an indicator of the wear condition of the engine. However, oil consumption variations can result from a number of parameters so oil consumption rate alone is not a very robust indicator. Caterpillar recommends a more comprehensive strategy, trending engine load, specific fuel consumption, and cylinder pressures to contribute to a more nuanced picture of the engine's operating condition.

As noted above, adding fresh oil to the sump may be needed to keep the oil fill within the required limits throughout the oil change interval. However, oil changes are still needed due to continual degradation of the oil by engine operation. Recommended oil change intervals can be found in the Operation and Maintenance manual, part of the service literature available for each engine model or family. As an alternative, oil change intervals can be established through oil condition trending as part of a comprehensive engine maintenance program.

9.4 Contamination and Degradation

Lubricating oil performs a critical function in the engine while operating under extremely harsh conditions that create ample opportunity for damage to the oil. Even though engine oils are formulated for those extreme conditions, exposure to engine operation does steadily degrade the condition of the oil. Some typical contaminants are described below, along with details about each. For a more thorough discussion of this topic, refer to the Cat service publication SEBD0640, "Applied Failure Analysis – Oil and Your Engine".

9.4.1 Copper

Copper can get into the oil through wear of the thrust washer or bearing. High concentrations of copper may indicate abnormal wear indicating a problem.

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9.4.2 Silicon and Silicates

Some silicon may be present in the oil formulation as part of the additives. Anti-foaming agents often use silicon compounds. High levels of silicon can point to issues with leaks in the lube system, and silicon content may result from dirt entering the system. Silicon compounds can take a hard crystalline form that can produce abrasive wear in the moving surfaces of the engine.

Silicon-bearing silicates can be present from rust inhibitors in coolant that has leaked into the oil. A presence of sodium or carboxylic acid can also point to this cause. Coolant in the oil can result in a thickening of the oil that damages its lubricating properties and can produce piston ring sticking or oil filter plugging.

9.4.3 Lead, Tin, and Aluminum

These metals are typically found in bearings and when found in the oil can be an indicator of wear in the bearings. This is why they are often among the “wear metals” measured in an oil analysis.

9.4.4 Iron

Much of the engine’s core structure is made with iron so it should not be unusual to detect iron in the oil. However, a notable amount of iron in the oil may indicate a severe wear condition such as excessive liner wear, or it may result from rust formation during periods of inactivity (such as engine storage).

9.4.5 Soot

Soot is a carbon particulate formed by combustion, so it is not typically indicative of a failure. The oil’s additives are designed to manage soot accumulation to prolong the oil’s life, but over time increasing soot contamination can result in plugging of the oil filters. More rapid soot contamination may result from poor engine tuning, poor quality fuel, or severe duty cycles.

9.4.6 Water

Water can get into the oil through various leaks in the system, but more commonly it is through condensation in the crankcase. Because the crankcase contains many rapidly moving parts, condensed water can become mixed with oil to form an emulsion with poor lubricating properties and which can also plug the filter. Typically, the engine’s hot operating state will limit condensation of water vapor in the blowby gas in the crankcase so high water concentrations may indicate a leak. Water can also lead to the formation of strong acids that can attack metals in the engine.

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9.4.7 Diesel Fuel

Diesel fuel is similar to the base stock oil, both being alkane hydrocarbons but of differing molecular length. Diesel fuel that leaks into the oil fill can thin the oil, reducing its film strength and degrading its lubricating properties, potentially leading to bearing failure.

9.4.8 Sulfur

Sulfur levels in the oil can increase due to sulfur in the fuel. Both diesel and natural gas fuels can contain sulfur. Sulfur can react to form strong acids that can corrode metals in the engine.

9.5 Monitoring Oil Quality

Selecting a high-quality lubricating oil with additives matched to the engine type and application is very important to achieving long engine life. An effective oil monitoring strategy can also play an important role, and a key part is periodic oil sampling and analysis. Caterpillar offers oil analysis as part of its S•O•S services program.

Cat S•O•S oil analysis examines oil samples to measure and document oil condition and contaminant levels. Repeated analyses are used to build prognostic trends for rate of oil degradation as well as to detect indicators for engine issues or excessive wear. Oil degradation trend data can be used to optimize oil change intervals, potentially lowering the long-term cost of operating the engine. Advance detection of hidden engine issues can also decrease costs by addressing issues before they can result in an expensive failure.

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