Natural Gas Engine Lubrication

Natural gas engines (NGE) are commonly used to power natural gas compressors, standby electric generators, fire water and irrigation pumps and are increasingly being used to power primary cogeneration electrical power plants. NGE are also finding increase use in mobile application too.

The main advantages of a natural gas engine over a diesel engine are the lower exhaust emissions of nitrogen oxides (NOx), carbon monoxide (CO), particulates and in some cases, lower fuel costs.

These stationary gas engines are available in various configurations and sizes. The characteristics include:

- Two- or four-stroke designs
- Less than 100 HP to a maximum of 16,000 HP (800 to 1,500 HP are most common)
- One to 20 power cylinders
- Oil sump capacities of 14 to 6,000 liters (300 to 800 liters (80 to 200 U.S. gallons) are most common)
- Engine speeds ranging from 300 RPM low-speed units to 2,000 RPM high-speed units. Most operate at 800 to 1,200 RPM
- Piston bores as large as 22.5 inches (572 mm) in the low-speed units with bores of 3.5 to 9.45 inches (89 to 240 mm) common in high-speed units
- Inlet air may be naturally aspirated or turbocharged (two-thirds of new engines are turbocharged)
- Stoichiometric or lean burn (a relative term for an air-to-fuel ratio higher than stoichiometric) to reduce NOx emissions
- Engines and compressor units may be either separates, that is, joined end-to-end at the crankshaft by a coupling, or integrals, in which the engine and compressor have a single common crankcase

The fuel typically used in these engines is sweet, dry natural gas (sales gas, greater than 85 percent methane). In some cases, in the gas production fields, raw sour natural gas containing hydrogen sulfide (H₂S) (up to 8,000 ppm), carbon dioxide (CO₂) and nitrogen (N) is used. There is also an increase in the use of digester gas collected from sewage systems and landfill gas that is being used as fuel. Both of these are much poorer quality fuels with lower methane content (50 percent) and may contain as much as 5 percent silicon-based compounds as well as fluorides, chlorides, copper, tin, iron, hydrogen sulfide and up to 50 percent CO₂. Fuels with low energy content, high corrosive nature or abrasives (should be prefiltered to less than 0.5 micron) will affect engine performance.
Natural gas engine oils (NGEO) used in these engines have special formulations that differ from diesel and gasoline engine oil formulations. This is because natural gas engines perform the following:

- burn cleaner, with no soot contamination of the crankcase engine oil. This requires less detergency/dispersancy and allows these lubricants to be formulated with lower ash levels.
- burn gaseous fuel. Therefore, there is no fuel dilution and preventing viscosity increase of the oil is more critical.
- burn hotter (165°C to 235°C/300°F to 400°F higher exhaust temperature) than diesel. Therefore, oxidation and nitration of the oil are increased as is valve wear.
- operate at constant speed. Therefore, the engine is more prone to retaining deposits and plug fouling.

NGEOs do not have American Petroleum Institute (API) minimum performance designations as are common with diesel and gasoline engine oils (for example, CI-4, SL). Most equipment manufacturers specify oils by the characteristics of the oil. Some equipment manufacturers refer to older API “CC” or “CD” diesel engine oil designations to try to establish a minimum performance level, but the use of diesel engine oil performance specifications to classify natural gas engine oils is questioned by many people. Several engine manufacturers have developed their own natural gas engine tests, but for the most part, performance is still measured by field performance. Dresser-Rand and Waukesha cogeneration applications have the only two published approval lists for brands of oils. There has been discussion about developing API NGEO performance designations since the late 1980s, but only limited progress has been made. Therefore, at this time, the user of natural gas engine oils must rely on the integrity of his oil supplier to provide a good quality, true natural gas engine oil and not a rebrand of a diesel engine oil.

Figure 1. V12 Waukesha engine
NGEOs are generally available in two viscosity grades, an SAE 30 (Society of Automotive Engineers) and an SAE 40, although historically most 30-weight oils were blended at the borderline between a 30- and a 40-grade. The monograde 40-weight oils are the most common. Multigrade NGEOs are available in a 15W-40 grade. These are receiving some acceptance in the market where frequent low-temperature start-ups are used or where sump heaters are unavailable or unreliable. Multigrades will provide better low-temperature starting capabilities and may offer reduced oil consumption (lower emissions) and improved fuel economy. However, they may be prone to increased nitration (degradation) of the oil and may not be recommended for use in the governor by the original equipment manufacturer (OEM).

Ash
Most equipment manufacturers specify engine oil based on its ash content and viscosity grade. The ash is the portion of the lubricant that is left behind as a deposit after complete burning of the oil. It is whitish-gray and comes from the metallic detergents (calcium and barium) and antiwear (zinc) additives. The ash content of NGEOs is available in four general levels: ashless (less than 0.1 percent sulphated ash), low ash (0.2 to 0.6 percent), medium ash (0.7 to 1.2 percent) and high ash (greater than 2.0 percent). The ash directly provides valve protection in four-stroke engines. The detergent additives (which are bases) neutralize acids. Therefore, the oil with the lowest ash content that will provide the necessary valve protection and acid neutralization is desired. The use of higher ash oils may cause more deposits to accumulate in the engine. Too much ash deposit may be caused by using an oil with too high of an ash content, overlubrication or many other mechanical factors. This may result in reduced heat transfer, preignition and/or detonation, ring sticking or breaking, plug fouling and valve burning.
Four-stroke engines typically require either a low or medium ash oil to provide the sacrificial protective layer of ash on the exhaust valves and seats to prevent valve recession. Older Waukesha four-stroke engines are the only engines that require high ash oils due to the high valve angles that were used. Higher ash oils, with higher base numbers are also used to neutralize highly corrosive fuels. Two-stroke engines do not have intake or exhaust valves and generally require an ashless or very low ash oil to minimize exhaust port blockage. These two-stroke engines typically have large bore cylinders and have oil injection ports feeding oil directly into each cylinder. The most universal oil is a low ash oil, making it the best choice in a situation where multiple types of engines are supplied from one lube oil tank.

Exhaust valve recession and torching (guttering) are major issues with engine operators. Valve recession is the pounding of the valve back into the cylinder head by the repeated closing action of the valve (Figure 3). The valve, as well as the insert seat in the head, is damaged. It can be caused by lubricant-related factors such as insufficient ash level of the oil and/or insufficient oil feed down the valve stem, and ash composition. Nonlubricant-related valve recession can be caused by many mechanical and operational factors. Guttering and torching valves (cutting of a channel across the valve face) can result from both lubricant (too much ash) and nonlubricant factors, as well as from valve recession itself (Figure 2). This is a complicated process as these factors are intertwined with each other, which makes the process of finding the root cause of a valve failure difficult.
Nitration

Oxidation and nitration of the oil are both mechanisms which degrade NGEOs. Nitration is a degradation of the oil which occurs due to the reaction of the oil with gaseous NO\textsubscript{x} created during combustion. It is discussed here because unlike oxidation, nitration is somewhat unique to natural gas engine oils, especially stoichiometric engines, due to the combustion conditions within these engines.

To understand nitration, two processes need to be considered. First, the formation of NO\textsubscript{x} and second, the reaction of NO\textsubscript{x} with the oil (nitration).

NO\textsubscript{x} formation is related to the air-to-fuel ratio, peak combustion temperatures and engine RPM as well as engine spark timing, load, ambient air conditions and aftercooling.
These NO\textsubscript{x} gases may leave the combustion chamber with the exhaust or react with the oil film on the cylinder wall or with the oil in the crankcase sump to form various complex liquid nitration products. The reactions in the oil that cause nitration are different from those occurring in the oxidation process and are not as thoroughly understood.

Nitration of the oil is affected by:

- The exhaust gas scavenging efficiency - Better exhaust gas scavenging (removal of exhaust gases from the combustion chamber), as would occur in turbocharged units, reduces the interaction of NO\textsubscript{x} with the oil and reduces nitration.
- The cylinder wall temperature - The reaction between NO\textsubscript{x} and the oil, which causes nitration of the oil, occurs partially on the thin layer of oil on the cylinder wall. The liquid nitration products, which form in the oil, are apparently destroyed at cylinder wall temperatures above 150°C (300°F), therefore lower cylinder wall temperatures are needed for oil to nitrate. These lower temperatures are more common in lower speed and naturally aspirated four-stroke engines.
- Piston ring efficiency - Reduced blow-by would reduce NO\textsubscript{x} contact with the oil in the sump.
- Crankcase ventilation - Better crankcase ventilation would have the same positive effect as improved scavenging by reducing the contact between NO\textsubscript{x} and the oil.
- The oil sump temperature - Nitration of the oil from NO\textsubscript{x} in the blow-by gases that enter the sump is increased at lower oil sump temperatures, below 80°C (175°F) (and increasing as sump temperatures approach 70°C (160°F). This is different from oxidation, which becomes significant at oil temperatures above 90°C (190°F) and increases with temperature.
- The base oil type - Certain base oil types seem more susceptible to nitration than others. Base oils with saturated hydrocarbon structures, such as PAO synthetics and hydrotreated paraffinic oils, seem to be less prone to nitration. Lower viscosity base oils and viscosity index improver additives, used in some multigrade oils, may be more prone to nitration.

If the oil is exposed to severe nitration conditions, the nitration products in the oil will cause:

- the viscosity to increase
- the acidity of the oil to increase
- the insolubles to increase. This includes varnish in hot areas of the engine, and sludge in cooler areas of the engine which may lead to ring sticking and filter plugging, respectively.

Nitration is a concern primarily in older, lower speed, naturally aspirated, four-stroke stoichiometric engines operating with cool oil sump temperatures. Two-stroke engines, generally do not have a problem with nitration due to the significant amount of oil that is removed from the crankcase and fed
to the combustion cylinder oil injection system which scavenges most nitration products out the exhaust ports. Also, fresh make-up oil to the crankcase is increased.

![Figure 7. Oil pan shows very low to absent varnish and sludge](image)

Nitration is controlled by regulating the operational factors mentioned above. From an oil formulating perspective, nitration can be controlled only by the nitration-resistant components selected for use in the oil. There are no additives known at this time that can be added to an oil to inhibit the nitration process.

Oil change frequencies or drain intervals are recommended by each engine manufacturer and are typically in the range of 750 to 1,500 hours. The use of poorer quality fuels, as mentioned above, plus many other mechanical factors (for example, coolant leaks, poor filtration, high loads) can significantly reduce these drain intervals. They can also be extended, but require good maintenance and operational practices, and oil monitoring through used oil analysis. Additional oil testing, such as Fourier transform infrared spectroscopy (FTIR) to monitor oxidation and nitration, base number (BN) to monitor detergency additive depletion from acids neutralizing the reserve alkalinity, and acid number (AN) to monitor the buildup of organic acids that form should be used to monitor the oil when extending drain intervals.
Standard spectrographic analysis is still required to monitor wear metals, and the standard tests for viscosity, water, glycol, etc. should be performed as well. Some two-stroke engines rarely, if ever, require an oil change because oil is taken from the engine sump and injected into the combustion chambers for lubrication and the high rate of make-up oil required in the sump virtually changes out the oil on a regular basis. Filtration on these units is therefore important. Overextended oil drains can cause head damage, varnish and sludging, ring wear and sticking, liner wear, higher maintenance costs and shorter filter life.
Filtration

The filters typically provided with a natural gas engine by the OEM have historically been large-depth sock filters containing cellulose. Centrifugal filters, installed on a side-stream of the circulating oil, are now being used in conjunction with the canister filter and are gaining significant acceptance. Inadequate filtration will cause varnish and sludge build-up, wear, shortened oil life and ring sticking.

Catalysts

Catalyst systems can reduce emissions even further and generally fall into three categories: nonselective catalytic reduction (NSCR) systems are the most common and are used on stoichiometric engines, selective catalyst reduction (SCR) systems which are used on lower air-to-fuel ratio lean burn engines, and oxidation catalyst systems which are used on lean burn engines to reduce hydrocarbon and carbon monoxide emissions. With most catalyst systems, catalyst element poisoning by phosphorous compounds (zinc antiwear, ZDDP) and ash is a concern and is related directly to the lube oil used. For this reason, the specific manufacturer of the catalyst may have limits on these compounds, such as 300 ppm phosphorous maximum, as well as oil consumption.

Cooling Systems

Cooling systems have a direct impact on the engine operating temperature and thus the engine oil. Systems need to be monitored and maintained. The water needs to be of a better quality than conventional drinking water because minerals (calcium and magnesium) in the water, as measured by water hardness, are less soluble in higher temperature water and will deposit on the hottest parts of the engine (cylinder head, etc.) and form an insulating layer. Many mechanical failures (valve...
sticking) which are initially attributed to the oil, have their root cause related to the glycol cooling system.

**Cogeneration**
Cogeneration usually refers to generating energy from both the power at the crankshaft and heat recovery from the remainder of the engine. Cogeneration is becoming more common for electrical power generation. A generator is powered off of the crankshaft and heat from the exhaust, a glycol cooling system and the oil cooler are used to create steam or heat another process. Overall energy efficiency is increased from 33 percent to approximately 85 percent. The additional demands placed on the engine create higher operating temperatures which place higher demands on the engine oil and may contribute to valve recession and engine liner scuffing.

**Gas Engine Oils - A Question of Balance**
The use of gas engines for power generation has become more widespread in recent years. With estimates that up to 30 percent of worldwide electricity demand will be generated from gas by 2020, this trend seems set to continue. Their growing use has accelerated both commercial and technical demands on gas engine lubricants, and encouraged engine operators to increasingly demand performance expectations beyond the minimum required by the manufacturers. These factors have pushed traditional gas engine oil (GEO) formulations to their limit, and have highlighted the performance limitations of traditional additive solutions. A careful rebalancing of advanced additive and base oil systems is set to deliver improved performance over traditional lubricants to meet the challenges of current and future gas engine design.

To ensure trouble-free operation of their engines, engine manufacturers essentially dictated minimum performance requirements for GEOs which consequently evolved with engine design. However, today’s engine operators are also demanding performance features beyond those minimum levels to enable them to achieve cost-effective engine operation. While the engine manufacturers’ requirements are mandatory, those of the engine operators allow lubricant manufacturers to differentiate their products on performance grounds.

**Engine Manufacturers’ Requirements**
One of the key requirements of engine manufacturers who need trouble-free operation is the avoidance of knocking, which can lead to the destruction of the cylinder unit. In large gas engines, the formation of deposits in the combustion bowl is known to initiate knocking. Lubricants designed with low sulfated ash content reduce this risk. Gas engine manufacturers specify the range of sulfated ash content that is suitable for each engine they market. This ranges from less than 0.1 percent ash by weight - known as ashless, less than 0.5 percent ash by weight described as low ash, through less than 1 percent ash by weight referred to medium ash, up to greater than 1 percent ash by weight regarded as high ash.
To endorse any lubricant, engine manufacturers require proof of performance in field trials from 4,000 to 10,000 hours in an approved installation. The main areas of interest for the field performance of a GEO include:

**Resistance to Oxidation and Nitration**

GEOs need to have the ability to neutralize the acidic by-products of oxidation and nitration. The effects are visible on lubricant parameters such as viscosity, rise in acid number, drop in base number, infrared analysis of used oil, and on engine parameters such as engine cleanliness and bearing corrosion.

**Control of Deposits**

The oil must deliver virtually no deposit to the combustion bowl given the engine sensitivity to knocking. Control of Corrosion This is particularly important when the gas is especially corrosive, and where engines are fitted with bearing technology known for its sensitivity to corrosion.

These data give formulators the information they need to design new GEOs and are provided as guidelines to engine operators to indicate drain intervals. Assurance of these guidelines requires continuous condition monitoring by used oil analysis.

**Recent Trends**

In an effort to increase engine load and mechanical efficiency, there have been several recent developments in gas engine technology. One key improvement is the increased use of electronics, possibly combined with dual fuel operation, for better combustion control. This involves ignition by diesel fuel rather than a spark plug. So far, these advanced designs have not led to alteration in the manufacturers’ requirements for the lubricant. However, future changes will need to support control of emissions, exhaust gas deposits and knocking.

**Engine Operators’ Requirements**

Engine operators expect more from a lubricant than simply trouble-free engine operation. Because engine components have become more durable, it is often the end of the lubricant’s lifetime that requires maintenance work to be performed during scheduled outages. A lubricant’s ability to reach very long drain intervals (4,000 hours) in any engine model is highly desirable. Because traditional additives and conventional base oil systems have reached their limit in that respect, particularly in the smaller engines, the focus has turned to using higher performance base oils. However, traditional additive chemistries often struggle, particularly in terms of deposit control, in these higher performance base oils. Like any engine oil, a GEO is a combination of additives and base oil. Given
the importance of oxidation/nitration control on the performance assessment of a GEO, appropriate selection of both is essential.

Performance properties of a gas engine oil

To lubricate a gas engine properly, an oil must prevent wear, reduce corrosion, inhibit oxidation and nitration, control deposits, and help cool the engine parts

Prevent Wear

Natural gas compression engines often operate continuously under heavy loads. This type of operation increases metal-on-metal contact and can result in increased wear to important components. To help reduce metal-on-metal contact and prevent wear, a natural gas compression engine oil must have sufficient film thickness and the right amount of sulfated ash content.

Ash is added to natural gas engine oils to prevent wear. The metallic elements account for much of the ash content, which are mostly derived from the lubricant's detergent additives. These metallic elements leave a solid material (ash) when the lubricant burns. Ash can help prevent valve recession by coating the valve faces and their contact area on the seats to help prevent metal-on-metal contact

Anti wear additives and ash content in the lubricant can help prevent wear.
Reduce Corrosion

The combustion by-products in a gas engine can be highly acidic. Any increase in acid levels in the lubricant can lead to corrosion, particularly in the softer, non-ferrous metal components such as bearings and bushings. The high acid levels being generated require that gas engine oils have a high base, or alkalinity reserve. To counteract acid levels, gas compression engine oils are formulated with ash-containing detergent additives, which typically have a high basicity level.
The acid levels in gas engines vary depending on the type of fuel used. Landfill gas or alternate fuel gas may contain sulfur, chlorine, or other acid-generating compounds. Gas engine lubricants generally are classified according to their ash level because it is critical to match the ash level of the oil to the fuel composition. An oil with too little ash cannot neutralize the acids effectively, while too much ash content can lead to ash build-up that can cause performance problems.

**Ash-containing detergent additives are used in gas engine oils to reduce corrosion**

**Inhibit Oxidation and Nitration**

Natural gas engine oils require good oxidation control. High operating oil temperatures can speed up the oxidation process that leads to lubricant decomposition. The presence of wear metals and other acidic combustion by-products can also accelerate oxidation.

Natural gas engine oils also require protection against nitration, which is a process that occurs predominantly within natural gas engine oils. In this process, nitrogen oxides are absorbed in oil causing a chemical reaction that leads to lubricant decomposition. Common causes of nitration include lean air/fuel ratios, high blow-by, over-extended oil service, and low operating oil temperatures.

Zinc compounds in the lubricant helps prevent oil degradation caused by oxidation and nitration. These zinc containing inhibitors help slow the thickening of the oil by preventing oxygen and nitrogen compounds reacting with the oil. By slowing oil degradation, these zinc compounds help extend the life of the lubricant.
A gas engine lubricant must be formulated to control oxidation and nitration

Control Deposits

Deposit formation is a common problem in natural gas engines. Deposits can affect the operation of the pistons, valves, and spark plugs. Piston deposits cause ring sticking, which can lead to such problems as an increase in oil consumption and cylinder liner scuffing. Valve deposits can cause valve sticking, which can lead to burnt valves. In addition, a build-up of ash deposits on spark plugs and valves can lead to problems such as spark plug fouling and burnt valves.

To prevent carbon and varnish deposit formation on the pistons, valves, and other engine components, natural gas engine oils are formulated with detergent and dispersant additives. Dispersant additives help keep dirt and solid particles in suspension and prevent them clumping together into larger particles, which may form deposits, increase wear, and increase the oil viscosity. Dispersants are especially effective in preventing low temperature deposits. Detergent additives help prevent formation of deposits on the piston and valves at high temperature. Detergent additives can also help neutralize acidic combustion by-products and prevent wear.

To prevent detrimental ash deposits, the sulfated ash level of the gas engine oil must be chosen carefully to match the particular application.
An engine oil must be formulated to control deposits, such as carbon, varnish, and sludge.

**Cool Engine Parts**

Natural gas compression engines experience high temperatures that can help accelerate the oxidation process and deposit formation.

Natural gas engine oils must be formulated with a combination of base oils and additives that will minimize high temperature degradation.

An oil should be formulated to help dissipate heat away from the critical parts of the engine.