# WHITE PAPER

THE BOTTOM LINE: ENGINE OIL IMPACT ON GAS-POWERED ENGINE RELIABILIABILITY

PETRO-CANADA

Beyond today's standards.™

# Optimizing Gas-Powered Engine Performance

In order to achieve strong plant efficiencies and profits, operations and service managers of natural gas-powered engines need to be focused on how to minimize engine downtime, maximize drain intervals and optimize performance.

The natural gas engine oil (NGEO) used to lubricate the engine is one key component that can address each of these objectives. In fact, the lubricant can be viewed as part of the engine design. It is sometimes referred to as the "lifeblood" of the engine because it circulates throughout performing critical functions necessary to maximize engine performance. It also carries information about the engine condition that can be seen via an oil analysis.

By going beyond today's standards with lubricants that maximize service life, engine cleanliness and wear protection, engine operators can reduce unnecessary maintenance costs and downtime. Additional savings can be realized by taking a proactive approach to consolidating a plant's lubricant product offering.

This white paper examines the critical role lubricants play in engine reliability and a plant's bottom line with specific focus on:

1. Drain intervals that provide reduced downtime and maximize efficiency and profitability
2. Deposit control and engine cleanliness that contribute to engine optimization and efficiency to optimize energy usage

## NGEOs: specially formulated to meet engine demands

In contrast to other fuel types (such as low and high quality diesel fuels), stationary gas engines traditionally burn cleaner and hotter and operate at a constant speed. As such, NGEOs must be specially formulated to address these unique characteristics.

The following table highlights how a stationary gas engine operates and the corresponding special requirements of NGEOs:

| Stationary Gas Engine Characteristic | Effect on Engine or Oil | Ideal SGEO Attributes |
|---|---|---|
| Burn cleaner | No soot contamination of oil, requiring different dispersancy | Formulated with lower ash levels |
| Burn hotter | Oxidation and nitration of the oil are increased as is engine valve wear | Increased oxidation and nitration resistance |
| Operate at constant speed | Engine is more prone to retaining deposits | Outstanding deposit control and engine cleanliness |

(versus diesel-fueled engines)

Each of these NGEO attributes is examined in greater detail in this white paper.

# Drain Intervals

## How does drain interval affect engine reliability?

Drain interval – or oil change frequency – is closely linked to engine reliability. NGEOs with extended drain capability can withstand factors that break down the oil and cause it to degrade. Longer oil life allows the engine to perform consistently, reduces maintenance cycles and provides cost savings.

## What is an optimal drain interval?

Drain service intervals are designed to provide maximum engine protection under various conditions. Also referred to as "drain time," it is measured as the number of hours an engine can efficiently run before the oil needs to be changed.

The timing of the oil drain is determined by the results of a used oil analysis. The limits for the used oil are defined by the Original Equipment Manufacturer (OEM) of the gas engine. These intervals vary due to factors such as:

- Mechanical design of equipment
- Application
- Environment
- Condition of gas

Optimal drain intervals allow the engine to run for an extended period before oil change is necessary without compromising engine durability.

## Field testing confirms extended drain life for maximum uptime

SENTRON™ LD 8000, a revolutionary new NGEO from Petro-Canada Lubricants, shatters the accepted drain interval standard.

The breakthrough technology in SENTRON LD 8000 helps **operations extend drain intervals by up to 300%** when compared to the leading global conventional competitor NGEO.

**Results are illustrated in Table 1:**

| | DRAIN CAPABILITY | |
|---|---|---|
| Parameter Averages | SENTRON LD 8000 | Leading Global Mid-Tier Competitor |
| % Viscosity increase, TBN Remaining, AN increase percent, Metals (Fe,Pb,Cu) | 7,000-8,000 hours | 1,900 hours |
| Oxidation, IR (abs/cm) | 7,000-8,000 hours | 900 hours |
| Nitration, IR (abs/cm) | > 8,600 hours | 4,200 hours |

In a trial on a Caterpillar G3500TALE stationary gas engine, SENTRON LD 8000 reached up to 8,000 hours in a stationary gas compression application with pipeline gas quality, under high load (>90%) conditions.

*"Yesterday, 8,000 hours between drains in such an engine was unthinkable. Suddenly, anything less could be unacceptable."*
– Sharanie Patterson, Marketing Category Manager, Petro-Canada Lubricants Inc.

SENTRON NGEOs are high-performance, long-life oils used in stationary gas engines and compressors in a wide variety of applications with a key focus on power generation and gas compression.

New SENTRON LD 8000 is a premium low ash SAE 40 lubricant suitable for use in:

- 4-stroke engines operating on natural pipeline gas, pre-treated sewage/bio-gas and selective pre-treated process gases
- co-generation operation under high operating temperatures

## Raising the bar on drain intervals

SENTRON LD 8000 sets a new industry standard in drain intervals while still maintaining engine cleanliness and durability – going beyond SENTRON LD 5000, which raised the NGEO performance bar in 2004. (See Table 1.)

While drain interval hours can vary in terms of application, engine type, environmental conditions and condition of gas, SENTRON LD 8000 shows better performance versus leading global conventional competitors.

SENTRON LD 8000 meets and exceeds the standards of many different OEMs. For instance, a typical drain recommendation for a Waukesha F3521 GSI engine is 500 hours (based on conventional products, engine appetite and application). During a 6-month test period, SENTRON LD 8000 achieved more than 4,500 hours before being drained (co-generation service with pipeline gas quality fuel). (See Table 2.)

**Table 2. SENTRON LD 8000 Field Test – Waukesha F3521 GSI Used Oil Analysis**

| | DRAIN CAPABILITY |
|---|---|
| **Parameter Averages** | **SENTRON LD 8000** |
| % Viscosity Increase, TBN Remaining, TAN increase percent, Metals (Fe,Pb,Cu) | > 4,600 hours |
| Oxidation, IR (abs/cm) | > 4,600 hours |
| Nitration, IR (abs/cm) | > 4,600 hours |

SENTRON LD 8000 shows excellent results in terms of used oil analysis in the Waukesha F3521 GSI engine under a high heat co-generation application.

## Why are extended drain intervals important?

NGEOs that offer extended drain intervals reduce the need to change oil as frequently, which results in reduced downtime and increased uptime. As there is a strong correlation between continuously operating engines and a plant's bottom line, minimizing downtime is a key objective for operators of natural gas-powered engines.

In addition to reducing oil change downtime, SENTRON LD 8000's extended drain intervals lead to lower maintenance costs and less used oil to dispose of. The result is a more efficient and profitable operation.

## What factors affect drain intervals?

Drain intervals are dictated by the rate of oil degradation. As the oil degrades, it takes on certain characteristics; as it reaches specific maximum levels that are dictated by the OEMs, the oil is condemned and needs to be changed.

Several factors cause oil to degrade, including:

- Oxidation of the oil
- Acids that form in the oil
- Base reserve in the oil to neutralize the acids
- Nitration of the oil
- Trace metals and other contaminants found in used oil

## Oxidation

Oxidation occurs in engine oils when oxygen molecules chemically join with oil molecules. This causes the oil to thicken, form acids and lose fresh oil qualities. Oxidized oil can lead to deposits on pistons and valves, threatening engine life.

As with most chemical reactions, oil oxidation is accelerated by heat and pressure. Hence, oxidation is an issue for stationary natural gas-powered engines – both older engine types and new lean burning engines in high temperature, high pressure operations.

Heat, in particular, will speed up the oxidation process. In addition, engine loads influence the levels of oxygen and pressure within the engine, which can accelerate:

- Acid formation
- Corrosion
- Viscosity (oil thickening)
- Deposit formation and, ultimately,
- Wear

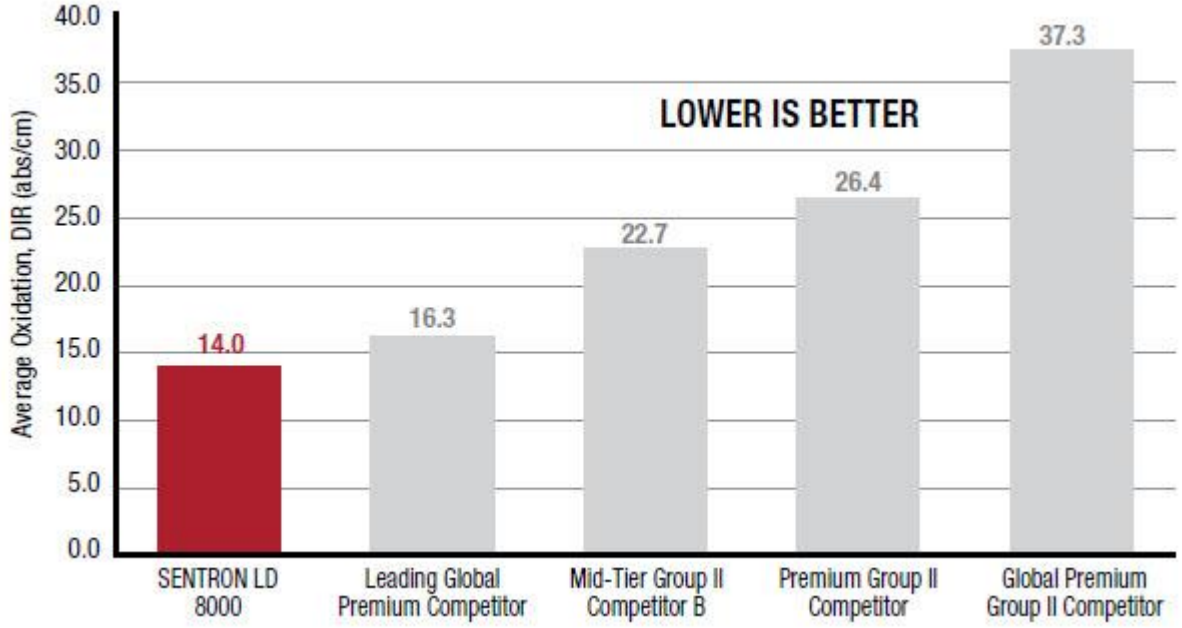
High levels of oxidation impede optimal engine performance as a result of:

- Increased deposits and varnish that will affect wear rates of contacting surfaces
- Increased viscosity and sludge buildup

- Corrosive attack
- Reduced drain intervals

For this reason, the majority of new engines today require oil with higher oxidation resistance (the oil's ability to resist breakdown). As seen in Figure 1, in lab testing, SENTRON LD 8000 demonstrates high resistance to oxidation (due to its anti-oxidant package and high quality base oils) and thus potential exceptional oil life.

**Figure 1. Oxidation – Oil Aging Test**




In this oil age test, the sample is exposed to heat, similar to an IP48 test; however, instead of oxygen that is bubbled through, it is a mixture of NOx / O2 / Air that simulates typical natural gas exhaust gas contents.

## Neutralizing Acid Formation

The concept of oxidation is closely tied to acid, which forms as a result of the combustion process. Oxidation reduces the oil life and its ability to neutralize acid. If not neutralized, acid can attack metal engine parts, threatening service life and durability.

As such, NGEOs need:

- strong acid neutralization capability (Total Acid Number – TAN) and
- good base retention (Total Base Number – TBN)

As it relates to engine reliability, increased acid control contributes to longer drain intervals and minimizes wear.

SENTRON LD 8000 goes a step beyond SENTRON LD 5000 in terms of oxidation resistance and acid neutralization, delivering an enhanced ability to prevent the effects of acid formation.

In real-life field testing, SENTRON LD 8000 offers better TAN control in a CAT G3500TALE engine (See Figure 2). versus the leading global conventional competitor with pipeline gas quality, under high loads (>90%) in gas compression service. Better TAN control can enhance corrosion prevention.

Total base number (TBN) retention is another measurement that helps define an oil's acid neutralization properties. Put simply, the greater the TBN retention, the greater the ability of the oil to neutralize acid. By neutralizing the amount of acid attacking the metal of the engine, the formation of deposits could be minimized – as could pitting and corrosion.

SENTRON LD 8000 also offers better TBN retention with pipeline gas quality fuel, under high loads (>90%) in gas compression service in a Caterpillar G3500TALE engine compared to leading conventional competitors. (See Figure 3.)

**Figure 2. Caterpillar G3500TALE Field Trial**

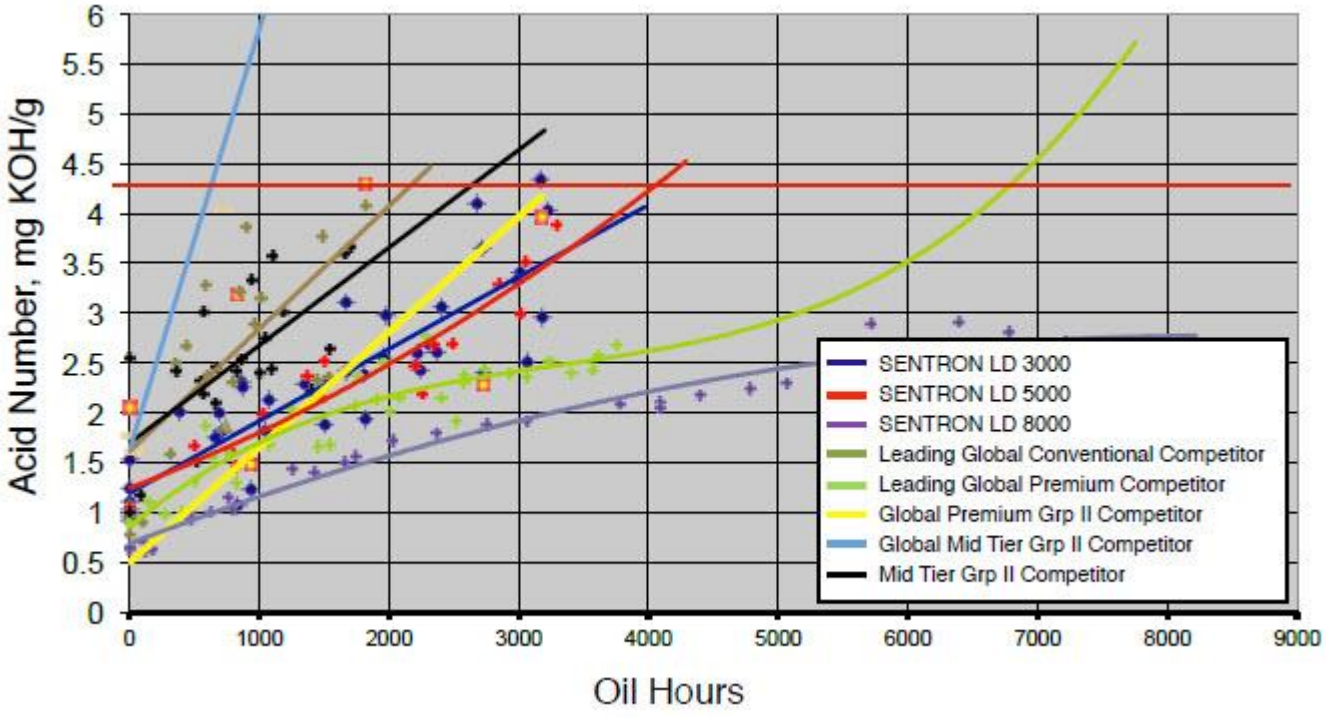
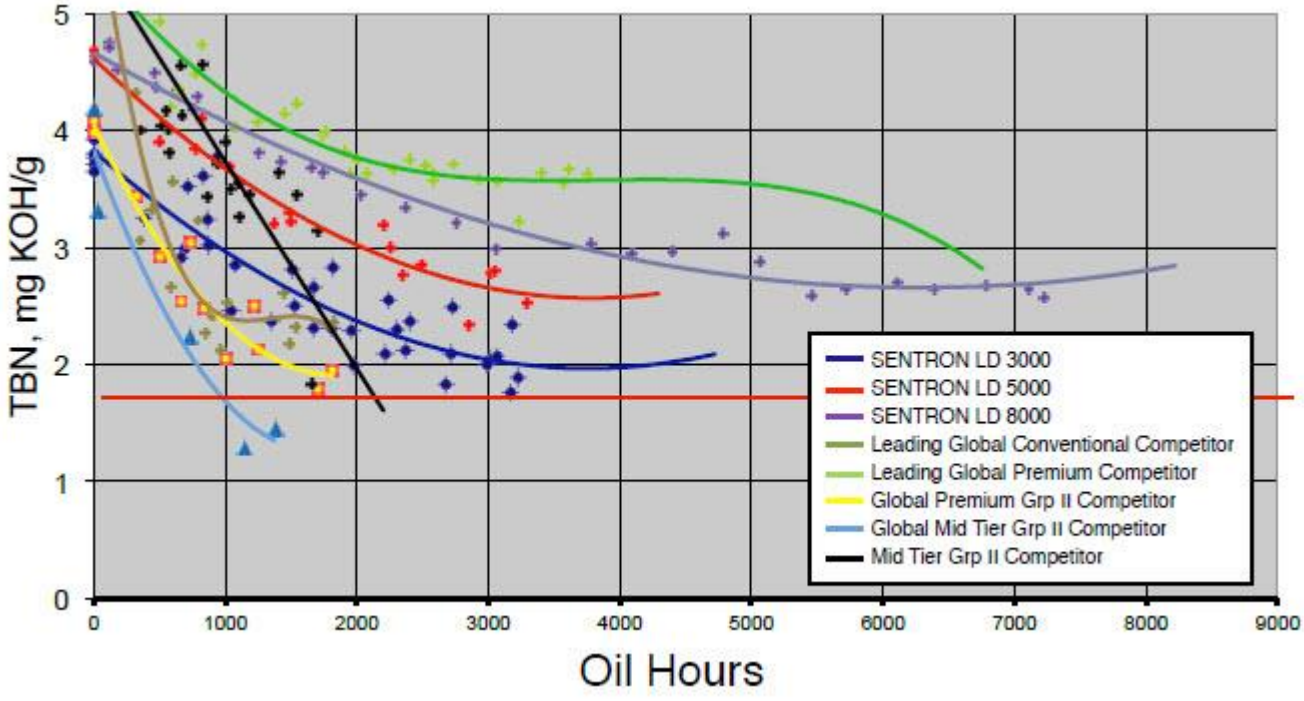



**Figure 3. Caterpillar G3500TALE Field Trial**



## Nitration Shortens Engine Component Life

Nitration is another factor that contributes to oil life and drain interval. This naturally occurring process results when oil is exposed to heat, oxygen and nitrogen oxides (NOx). In natural gas-fueled engines, nitration occurs when the oil comes in contact with nitrogen oxide compounds. The result is the formation of sludge, varnish and deposits, which could cause wear and reduce engine efficiency. These deposits also cause oil rings to stick, increase oil consumption and shorten engine component life.

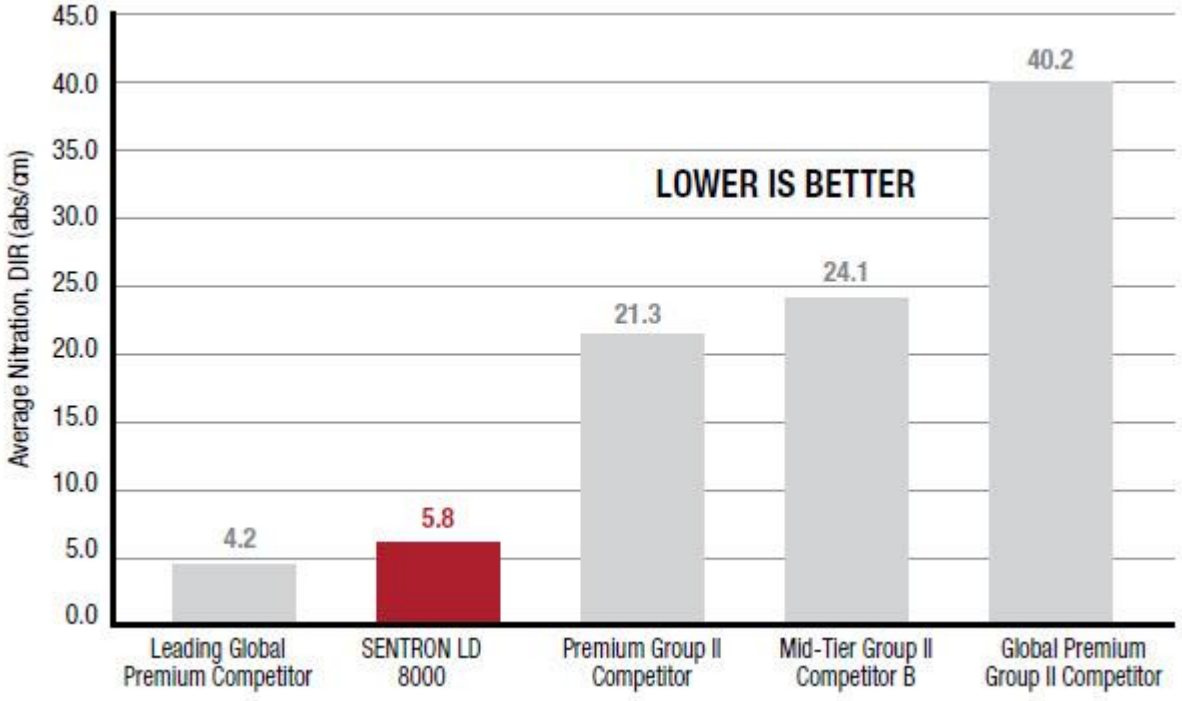
Similar to the effects of oxidation, high nitration levels do not allow for optimal engine performance due to:

- Increased viscosity
- Change in TAN, which leads to corrosive wear
- Formation of harmful varnish and deposits on engine parts
- Reduced drain intervals

Since oil type can define nitration resistance, it's important to select a high-quality oil that is able to resist breakdown caused by temperature, nitrogen oxides and other contaminants.

In some engine designs, the NOx created in combustion is much higher since there is stricter air/fuel ratio control (stoichiometric conditions). This leads to greater creation of NOx and thus nitrates (less free oxygen). As a result, there is greater likelihood of condemnation based on nitration or nitric acid formation. SENTRON LD 8000 is equipped to effectively control nitration in these particular environments, minimizing their impact on the oil. (See Figure 4.)

**Figure 4. Nitration – Oil Aging Test**




In this oil age test, the sample is exposed to heat, similar to an IP48 test; however, instead of oxygen that is bubbled through, it is a mixture of NOx / O2 / Air that simulates typical natural natural gas exhaust gas contents.

## Trace metals and other contaminants in used oil

Trace metals, coolant leaks, dust, dirt and contaminants in the fuel found in used oil also affect drain interval. Metals such as iron, lead and copper come from metal-to-metal contact or metal corrosion/ erosion attack of the engine.

A high-performing lubricant such as SENTRON LD 8000 protects the engine from these harmful contaminants, which can reduce drain intervals and minimize downtime. Any excessive levels of contaminant ingress need to be addressed as soon as possible; steps taken to control, reduce or potentially eliminate this ingress ensures longevity of the engine.

## Achieving outstanding drain intervals for engine reliability

In summary, extended drain intervals contribute to engine reliability. A product such as SENTRON LD 8000 that features excellent acid control plus oxidation and nitration resistance can help a plant achieve minimum downtime and lower maintenance costs, leading to a more efficient and profitable operation.

# Deposit Control and Engine Cleanliness

## How does deposit control and engine cleanliness affect engine reliability?

As discussed previously, the formation of deposits (including sludge and varnish) leads to reduced engine efficiency and increased wear. These deposits can also increase oil consumption, and shorten engine component life.

A top-performing NGEO can play a significant role in minimizing deposits and wear on valves, ports, pistons, liners and rings. It can also help to control valve recession. This can lead to:

- Extended engine life with reduced maintenance cycles and cost savings
- Engine cleanliness for optimal engine efficiency and reduced oil consumption
- Minimized de-rating of engines for top performance and maximum profit potential

## How do deposits form?

Natural Gas-powered engines are designed to run at 100% under optimal pressures and temperatures. As they work, however, deposits inevitably grow in the engine. This occurs as a result of many things, including the oxidation and nitration processes mentioned earlier. Because stationary gas engines operate at a constant speed and temperature, they are also prone to creating deposits. The type of engine duty cycle and the environment it operates in also play a role in deposit formation.

## Why is it important to minimize deposits and keep engines clean?

It is essential to reduce excessive deposit formation in order to operate at the highest efficiency and gain minimal downtime and maximum profit. When engines are burdened with deposits, engine efficiencies are impacted, which could result in:

- even higher engine temperatures
- loss of energy to either create power or compress gas
- pre-detonation and
- engine damage

Due to this potential engine damage, operations de-rate the engine and reduce loads. This reduction of load will reduce engine outputs and may affect the bottom line.

Deposits can also lead to higher wear when they form in the groove rings so that the rings can no longer move.

## Energy consumption

Deposits can cause pre-combustion, which creates instability in the engine. This robs an engine of its efficiency.

For example, if pistons can't move freely up and down, more energy is utilized. The result is that the engine has to work harder to achieve the same result, consuming more energy in the process, which could add to operating costs.

## Engine de-rating

When an engine is de-rated, it is not performing at optimal levels. This is often due to the presence of deposits. As a result, there is additional stress on the engine and output is reduced. As an engine is de-rated, temperatures are lower, resulting in incomplete combustion and more formation of deposits onto the metal surface that remain on the engine.

An NGEO that contributes to engine cleanliness can help to minimize engine de-rating and maximize engine performance.

## Are some deposits (ash) necessary?

Not all deposits (ash) are unwanted and harmful.

Some deposits, in the form of ash, are needed to protect valves and prevent valve recession (the premature compression and wear of the valve seat in the cylinder head and valve tulip).

Ash residue, which remains after the oil is burned during operation, helps to prevent premature valve recession by forming a protective, sacrificial layer on the valve seat and valve tulip to absorb the impact of the two coming into contact.

## What does field testing show?

SENTRON LD 8000 helps prevent excessive deposits and reduce wear and contact on metal parts – deposits that could otherwise result in high oil consumption.

In real-life field testing, SENTRON LD 8000 showed outstanding deposit control, with anti-wear protection that enhances reliability and minimizes service downtime. These results show excellent piston cleanliness, which can contribute to controlled oil consumption and longer equipment life at extended drain intervals. (See Tables 3 and 4.)

**Table 3. SENTRON LD 8000 Field Test – Waukesha F3521 GSI Summary of Engine Operating Conditions**

| DEMERIT RATINGS (except where noted) | SENTRON LD 8000 |
|---|---|
| Sludge (merit out of 10) | 9.8 |
| Fireface Deposits | 16.9 |
| Piston Top Deposits | 19.5 |
| Total Piston Deposits | 64.5 |

SENTRON LD 8000 demonstrates low total piston demerits in the Waukesha F3521 GSI Engine under a high heat co-generation application.

In field testing, SENTRON LD 8000 also demonstrated outstanding cleanliness and deposit control in a Caterpillar G3500TALE stationary gas engine, gas compression application with pipeline gas quality fuel under high loads (>90%) in gas compression service. (See Table 4.)

**Table 4. SENTRON LD 8000 Field Test – Caterpillar G3500TALE Series – Summary of Engine Operating Conditions**

| DEMERIT RATINGS (except where noted) | SENTRON LD 8000 | SENTRON LD 5000 | Leading Global Mid-Tier Competitor | OEM Acceptance Limit |
|---|---|---|---|---|
| Sludge (merit out of 10) | 9.9 | 9.9 | 9.6 | 9.6 min |
| Fireface Deposits | 25 | 27 | 22 | n/a |
| Piston Top Deposits | 23 | 27 | 26 | n/a |
| Total Piston Deposits | 42 | 19 | 107 | 170 max |

In this field test, SENTRON LD 8000 outperforms the leading global mid-tier competitor in terms of total piston demerits and sludge formation.

SENTRON LD 8000 was also tested in a new Caterpillar G3516TALE stationary gas engine in a gas compression application. The engine was inspected after 8,645 hours of service with its drain interval lasting as long as the durability length of the engine test. (See Figures 5 to 11.)

**Figure 5. Pistons**

Very clean without any sludge or lacquer. Minimal deposits and varnish can be seen on the lands and ring grooves.

**Figure 6. Top of Piston/Cylinder Head Fireface**

Minimal excess ash deposits.

**Figure 7. Combustion Chamber (no valves)**

Very little residue, full seating and minimal excess deposits on the valve seats.

**Figure 8. Valves**

Minimal varnishing on the valve stems, free of excess ash deposits and symmetric patterns on the valve stem to indicate free movement.

**Figure 9. Spark Plugs**

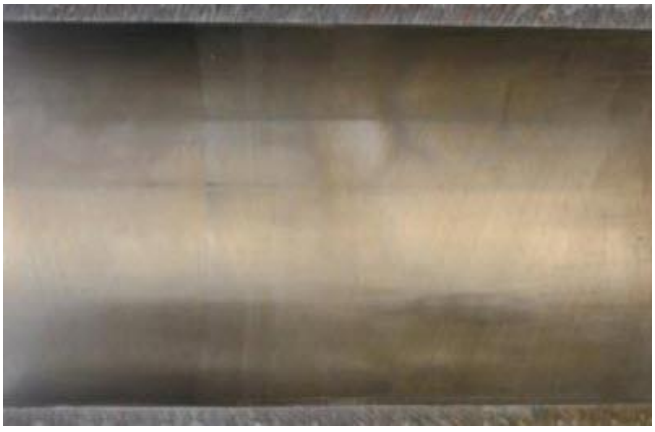
Free of excess deposits.


**Figure 10. Piston Undercrown**

Immaculate.

**Figure 11. Cylinder Liner**

Negligible bore polish with cross hatching intact.



After a 6,500-hour field test on a MAN E2842 LD322 stationary gas engine, with 420kW output at 1500 rpm with pipeline gas, SENTRON LD 8000 left a very thin and beneficial ash deposit on the cylinder heads, valves and pistons. Cylinder liners were in good condition with cross hatches easily visible.

Excessive deposits can result in higher material and maintenance costs and impact both engine reliability and the bottom line.

## Outstanding engine cleanliness and durability

In summary, the severe operating conditions common to natural natural gas-fueled engines demand an NGEO that delivers performance and extended oil life while helping maintain excellent control of engine deposits.

According to field testing, SENTRON LD 8000 can lead to some of the cleanest engines in terms of deposits. Its advanced additive technology and pure base oil formulation contribute to the longevity of the engine through enhanced durability and cleanliness.

# Spotlight on SENTRON LD 8000

## Enhancing engine reliability

As the industry designs new engines, innovative lubricants are also developed to protect them. SENTRON NGEOs from Petro-Canada Lubricants are high-performing products that have a proven track record of successful use under a wide range of conditions.

SENTRON LD 8000 was developed to raise the performance bar once again, allowing Petro-Canada Lubricants to retain its leadership position in the NGEO market by delivering increased oxidation and acid control, reduced preventative costs and enhanced deposit control.

## Key benefits

The ground-breaking technology in SENTRON LD 8000 provides operations and service managers with a revolutionary low ash SAE 40 lubricant built from 99.9% pure base oils – among the purest in the world, with the following key benefits:

- **Extended drain intervals of up to 300% longer** when compared to the leading global conventional competitive NGEO in natural natural gas compression applications with pipeline gas quality, under high load (>90%) conditions[1]
- Specialized additive mix provides **greater TBN retention to help neutralize acids** that can attack metal surfaces. The greater the TBN retention, the greater the

ability of the oil to neutralize acid, extend drain life and minimize wear, corrosion and deposits

- **Deposit prevention** at an optimized ash level to reduce wear on metal engine parts, which enhances reliability and minimizes service downtime

## Application

The ground-breaking technology in SENTRON LD 8000 provides operations and service managers with a revolutionary low ash SAE 40 lubricant built from 99.9% pure base oils – among the purest in the world, with the following key benefits:

- 4-stroke engines in natural pipeline gas, pre-treated sewage/bio-gas and selective pre-treated process gas fuel sources
- High nitrating and low nitrating environments. This allows operations to consolidate NGEO inventory as it removes the need to carry a separate product for high nitrating engine types
- Higher temperatures and pressures in more modern engine designs
- Engines with smaller engine oil sumps or engines that have very low oil consumption rates (< 0.2 g/kWh)

## Approvals/Verifications

SENTRON LD 8000 meets and exceeds the standard of many different Original Equipment Manufacturers (OEMs) with added selective OEM approvals or verifications, including:

- Caterpillar G3300-G3600 TALE engine verification
- MAN Nutzfahrzeuge M 3271-2 approval in natural gas applications
- BR MTU-4000 (pre) approved in pipeline gas applications

# Conclusion

In summary, NGEO drain intervals, which include oxidation and nitration resistance, deposit control and engine cleanliness all play a critical role in engine reliability and a plant's bottom line.

Specifically:

1. Extended drain intervals reduce downtime and maximize efficiency and profitability
2. Outstanding deposit control and engine cleanliness provide excellent engine optimization

## Select the best NGEO to maximize engine reliability and bottom line performance

In order to achieve maximum engine reliability and bottom line performance, operations and service managers must choose an NGEO that features an extended drain interval and outstanding deposit control.


Field testing shows that SENTRON LD 8000 shatters the accepted drain interval. What was once thought of as unattainable – up to 8,000 hours between drains[2] – will soon be the new standard. SENTRON LD 8000 also shows outstanding deposit control and anti-wear protection. Overall, the result is enhanced reliability, durability and cleanliness. Using SENTRON LD 8000 minimizes wear, leading to reduced downtime and maintenance costs and helps extend the life of an engine.

## References and Sources Used in the Development of this Paper

ComGen Power Solutions Blog. 2 Engine Oil Killers, Revolutions Per Minute. February 25, 2010.

Extending Oil Drain Intervals – Addressing the Root Cause. Lubetrak Newsletter. 2004.

Leugner, Lloyd. Natural Gas Engine Lubrication and Oil Analysis – A Primer in Predictive Maintenance and Condition Monitoring. Machinery Lubrication. 2004.

Scott, Robert. Stationary Natural Gas Engine Lubrication. Machinery Lubrication, 2004.

SENTRON LD 8000 Field Trial Documentation (LUB3091)

- Trial 1: CAT G3516TALE
- Trial 2: CAT G3606TALE
- Trial 3: MAN E2842LE322
- Trial 4: Waukesha F3521 GSI