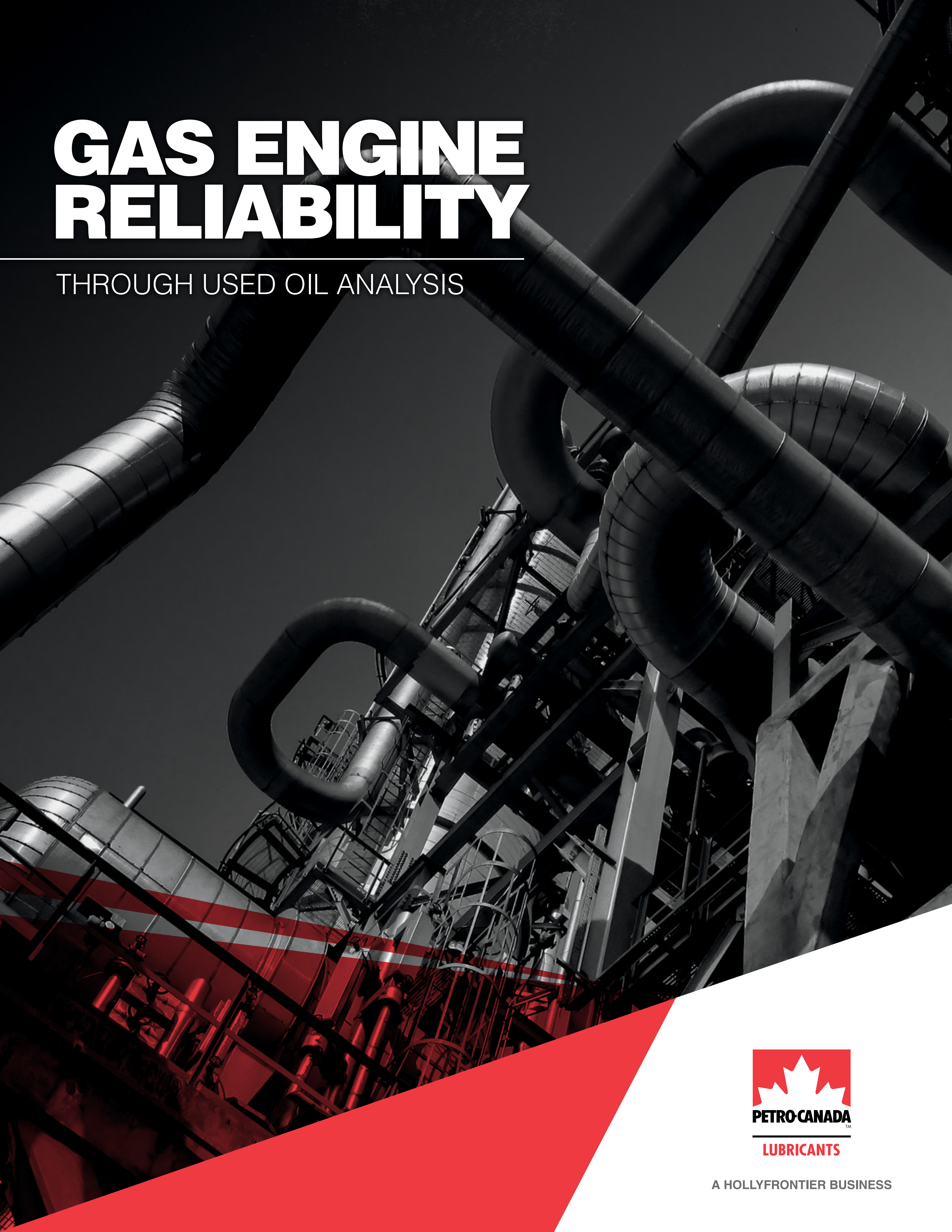
GAS ENGINE RELIABILITY

THROUGH USED OIL ANALYSIS



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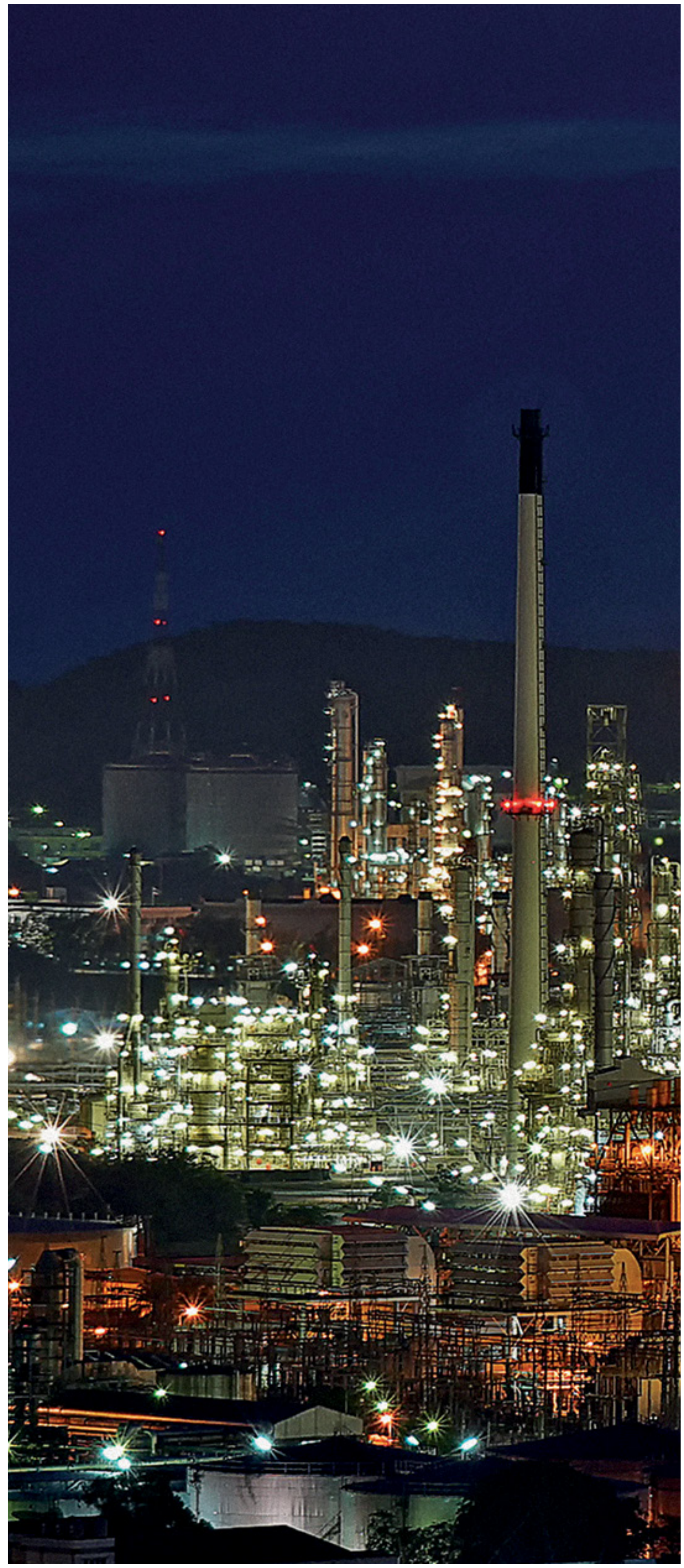
GAS ENGINE RELIABILITY
THROUGH USED OIL ANALYSIS

Used oil analysis can be used as a predictive maintenance tool for engines, as a method for monitoring lubricant health and to proactively identify contaminants and conditions that can be detrimental to both lubricant performance and engine health.

This white paper, "Gas Engine Reliability Through Used Oil Analysis," takes a close look at proper oil sampling procedures needed for reliable data trending, and the results you may expect to find. Furthermore, this paper explores Inductive Coupled Plasma (ICP), the method used to identify and quantify the different elements found in a used oil analysis report and what these can mean for the health of your engine.



WHERE DOES USED OIL ANALYSIS FIT IN MY MAINTENANCE PROGRAM?

Used oil analysis is a vital maintenance process that enables operators to monitor and optimize the life of an engine and its lubricating oil. Used oil analysis does not replace but complements other recommended maintenance practices such as:

- Monitoring and trending daily engine oil consumption
- Performing regular borescope inspections of combustion chambers to document wear and cleanliness
- Regular visual inspection of oil filter media
- Regular exhaust emission tuning

In other words, it is important to combine the aforementioned practices with used oil analysis rather than relying strictly on used oil analysis alone. These practices work together to offer insight into lubricant performance and engine health.

HOW TO APPROACH USED OIL ANALYSIS IN STATIONARY GAS ENGINE OILS

Simply put, used oil analysis is the act of gathering usable data from the oil and analyzing it to make informed decisions. It is a reliable and cost-effective way to extract the greatest amount of value from your lubricant investment and is an effective tool in monitoring the health of both your engine and lubricating oil. To accurately analyze oil, a suite of standardized, industry-accepted test methods are recommended and have been set by the American Society for Testing and Materials (ASTM), the International Organization for Standardization (ISO) and, for European engine manufacturers, Deutsches Institut für Normung (DIN). These tests can allow the engine's overall condition to be trended through wear metal analysis and provides an evaluation of the lubricant's physical and chemical condition.

What can used oil analysis look for and find?

Physical properties such as viscosity can be tested, while chemical properties such as oxidation and nitration degradation and any subsequent increases in acidity can be detected. Finding traces of water, coolant and dirt can also reveal contamination while identifying cross contamination with another lubricant is also possible. It is important to review the analysis holistically, rather than focusing on certain parameters (e.g., wear metals). Used oil analysis is only of value if proper oil sampling procedures are followed. These steps help ensure a representative sample is taken:

- Take samples from the same location and at the same interval.
- The sample valve should be installed after the engine oil pump but before the oil filters.
- Take samples while the engine is running at normal operating temperatures and load.
- Thoroughly purge the sample valve and related tubing/piping prior to filling the oil sample container. Ensure sample container is kept clean prior to taking samples.
- Ensure all relevant engine and oil information is included during sample registration, including brand name of oil in use and total engine hours. In addition, include oil service hours and indicate if the fluid was changed or not after the sample was taken.

Once these steps have been followed, it is vital that, when reviewing oil analysis data, there is a new oil reference sample listed on the analysis report so that the properties can be compared between the used fluid and the new fluid. The rate an engine consumes oil is also an important factor to consider, as higher consumption rates (and subsequent higher oil makeup rates) have a sweetening effect on the fluid's health, whereas an engine with minimal consumption may degrade the oil sooner. It is important to adhere to your engine original equipment manufacturer (OEM) sampling frequency, but Petro-Canada Lubricants recommends sampling large gas engines monthly, immediately before an oil drain and then one hour after an oil change. When analysis results indicate the development of an abnormal condition, it is prudent to re-sample more frequently in order to closely monitor increased wear rates and fluid degradation.

Let's now consider the properties and related tests used when carrying out used oil analysis in stationary gas engines.

WHAT TO MEASURE TO MONITOR A FLUID'S CONDITION AND DEGRADATION

We have listed below the key properties that are typically measured and tests that are typically performed when analyzing stationary gas engine oils.

Viscosity is a fluid's thickness or resistance to flow and is what primarily provides separation of metal surfaces in relative motion to each other. As an example, a fluid's viscosity at operating temperature is what provides separation between the engine crankshaft and main and connecting rod journal bearings during operation. The Society of Automotive Engineers (SAE) defines the viscosity grade of gas engine oils. Generally, the viscosity is a mono-grade SAE 40 (sometimes SAE 30) but can also be a multi-grade 15W-40, 10W-40, etc. depending on the engine manufacturer's requirements. In a used oil analysis report, viscosity is typically reported in centistokes (cSt) at both 40ºC and 100°C, the latter being of primary importance for engine oils. Most engine OEMs list a specific limit on the minimum and maximum required viscosity at 100°C, such as a 3 cSt or 30 percent increase. A general rule of thumb is to replace the fluid if it moves up or down one SAE viscosity grade as outlined in Table 1: SAE J300. As the gas engine oil protects vital metal surfaces in the engine, it is exposed to extremely high temperatures as well as harmful exhaust gasses that enter the engine crankcase via blow-by past the piston ring and liner interface. Because of this, gas engine oils experience eventual chemical degradation over time. Fourier Transform Infrared Spectroscopy (FTIR) is an efficient test method that identifies multiple degradation modes as well as certain contaminants. FTIR, in essence, takes a fingerprint of the used oil spectrum and compares it to the new fluid's spectrum. The difference between the used and new fluid spectrums indicate what form of degradation is ongoing and to what degree it has occurred.

Oxidation is a form of degradation that occurs when the lubricating oil is exposed to high temperatures and oxygen, and is measured through FTIR. Catalysts such as copper (and other wear metals) or water can accelerate this process. The oxygen source can come from blow-by exhaust gases such as in a lean burn gas engine, but can also be drawn into the crankcase if the crankcase pressure of the engine is set too low. Oxidation can cause the oil to thicken. Additionally, oxidation can cause sludge, varnish and deposit formation; carbon deposits in piston ring grooves and on the backside of piston rings; to and the formation of acids that can lead to corrosive wear. Higher oil temperatures and overextended drain intervals can increase the rate of oxidation. Oxidation is primarily reported in absorbance per centimeter (abs/cm). Multiple OEMs list a limit of 20–25 abs/cm.

Nitration is similar to oxidation except that it is a form of degradation related to the oil's exposure to nitric oxides (NOx) as found in gas engine exhaust gases and is measured via FTIR. All gas engines will have some level of nitration in the used oil, but it is more pronounced in stoichiometric gas engines, as they produce high levels of NOx in the exhaust gas. Similar to oxidation, nitration can also cause thickening of the oil, sludge, varnish and deposit formation, as well as the formation of acids that can lead to corrosive wear. Nitrated sludge is very difficult to remove from an engine and will send oil service life in a downward spiral. Oil temperatures that are too cool can actually speed up the absorbance of nitric oxides into the engine oil. An oil temperature around 85°C/185°F is ideal to limit this. Reducing NOx concentration in the exhaust gas via air/fuel ratio and ignition timing adjustments can significantly reduce the rate of nitration degradation. Nitration is primarily reported in absorbance per centimeter (abs/cm). Multiple OEMs list a limit of 20–25 abs/cm.

Total Acid Number (TAN) measures the level of corrosive acids that have formed in the oil from oxidation and nitration. TAN is a required test, especially when extending oil drain intervals. In fresh oil, TAN values start off lower and then gradually increase over the life of the fill as oxidation and nitration increase. If TAN rises and exceeds allowable levels, it is often accompanied by an increase in viscosity and an increase in some wear metals such as iron, lead and copper due to corrosive wear. TAN is measured in mg KOH/g (milligrams of potassium hydroxide per gram of oil sample). Condemning limits vary by OEM, ranging from a maximum of 3 or an increase of 3 over the new fluid value. Initial pH (ipH) of a fluid complements TAN measurement and can identify the formation and level of strong acids even earlier, which is particularly important in landfill and biogas applications. As the ipH value trends down (meaning acidity is increasing), it is often accompanied by an increase in certain wear metals such as iron, lead and copper due to corrosive wear. Some OEMs require a minimum of 4 ipH; any lower, and the fluid would need to be replaced.

Total Base Number (TBN) is a measure of a fluid's reserve alkalinity or acid-combating potential. Over-based detergent additives contribute to this alkalinity. As these detergents neutralize harmful acids, the fluid's TBN value decreases, generally somewhat inversely to that of TAN. This test is most relevant to diesel engine oils that have higher amounts of detergents, but can and should be used in stationary gas engine oils as required by the manufacturer for extended oil drain intervals. It is measured in equivalent units of mg KOH/g (milligrams of potassium hydroxide per gram of oil sample). If utilized, it is recommended to use ASTM test method D2896. OEM limits vary between 30 percent to 50 percent remaining of new oil value.

Water is a very detrimental contaminant in a gas engine oil. Not only does it reduce the film strength of the oil, it is also a catalyst for oxidation, and the presence of water in an engine increases the rate of corrosive wear and can contribute to hydrolysis, the withdrawal of certain additives in the presence of water. The Crackle Test generally identifies water in quantities, but the Karl Fischer method can give a very accurate amount in ppm or percentage. Although it sounds counterintuitive, excess water contamination can actually increase the oil's viscosity, albeit at the same time reducing the load-carrying capability of the fluid film as it forms an emulsion. OEM limits for water vary, ranging from 1,000 to 5,000 ppm.

TABLE 1. SAE J300

SAE Viscosity Grade	Low Temperature Cranking Viscosity, Max (cP @ °C)	Low Temperature Pumping Viscosity, Max (cP @ °C)	Kinematic Viscosity @ 100°C, Min (cSt)	Kinematic Viscosity @ 100°C, Max (cSt)	High Shear Rate Absolute Viscosity @ 150°C, Min (cP)
0W	6,200 at -35	60,000 at -40	3.8	—	—
5W	6,600 at -30	60,000 at -35	3.8	—	—
10W	7,000 at -25	60,000 at -30	4.1	—	—
15W	7,000 at -20	60,000 at -25	5.6	—	—
20W	9,500 at -15	60,000 at -20	5.6	—	—
25W	13,000 at -10	60,000 at -15	9.3	—	—
8	—	—	4.0	<6.1	1.7
12	—	—	5.0	<7.1	2.0
16	—	—	6.1	<8.2	2.3
20	—	—	6.9	<9.3	2.6
30	—	—	9.3	<12.5	2.9
40[1]	—	—	12.5	<16.3	3.5
40[2]	—	—	12.5	<16.3	3.7
50	—	—	16.3	<21.9	3.7
60	—	—	21.9	<26.1	3.7

[1] 0W-40, 5W-40 and 10W-40 grades
[2] 15W-40, 20W and 25W-40 grades

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ELEMENTS IN USED OIL ANALYSIS AND WHAT THEY MEAN

Used oil analysis uses a method known as Inductive Coupled Plasma (ICP) to identify and quantify different elements such as those found in additives, contaminants and wear metals. It is important to understand that ICP identifies elements that are ~0–8 micron in size. In ICP, the elements in a sample of oil are exposed to a high-temperature plasma flame. Each element is excited to a higher state and gives off a specific wavelength of light/energy that correlates to the periodic table.

Additive elements often found in gas engine oils include calcium, zinc, phosphorus, magnesium, molybdenum and boron and are the elements often found in detergent and anti-wear additive packages. Keep in mind that some elements such as boron can also be used in some engine coolants and molybdenum can be used as a high-temperature coating on piston rings. It is important to trend additive elements, as they can help identify top-up with a different fluid. An increase in additive concentration can also be indicative of overextended oil drains and can have an impact on the actual sulfated ash level of the oil; large increases in calcium or magnesium indicate increased sulfated ash, which can have a negative effect on combustion chamber cleanliness. Elements identified via ICP are not necessarily active additive compounds. These can be inactive remains of the additives.

Contaminant elements can include sodium and potassium (which are both found in engine coolants), as well as silicon. Silicon is often associated with dirt or dust contamination and may sometimes be accompanied by increases in iron and/or aluminum — elements that are found in dirt and dust, although dust ingress can also cause greater wear of engine components. In landfill gas applications, silicon is a very detrimental and abrasive contaminant, as it enters the engine via fuel gas in the form of organo-silicon compounds. Positive results for sodium and/or potassium should trigger further testing for the presence of coolant (often via gas chromatography). Most OEMs will condemn a fill of oil with any glycol present, as glycol becomes acidic at high temperatures and can cause soft bearing metal (Pb and Sn) corrosion. The source of the leak would need to be resolved immediately.

Wear metal elements most often observed in gas engines include aluminum, iron, copper, lead and tin. Less often, elements such as chromium and molybdenum (see section on additives) may also be found. Wear metals should be trended over time to establish what is normal for a particular engine. Where the trend deviates from "normal" or if wear metal levels exceed the OEM listed limits, further action should be taken. When an increase in wear metal is observed, it is always good to see where oxidation, nitration and TAN are trending, as a more degraded fluid can contribute to corrosive wear. It is good practice to re-sample an engine oil when the results are atypical to ensure a representative sample is driving the decision to inspect certain components. As mentioned previously, ICP measures elements ranging in size from ~0–8 micron (8 micron being about the size of a red blood cell. The human eye can generally see from ~40 micron and up). Regularly inspecting oil filter media can provide a more holistic view of the amount of ongoing wear in a given engine.

TABLE 2. ELEMENTAL ORIGINS

Element	Potential Origin	Element	Potential Origin
Aluminum (Al)	**Wear:** Pistons, bushings, bearings **Containment:** Road Dust	Molybdenum (Mo)	**Additive:** Friction modifier, antioxidant **Wear:** Valve stems/guides, piston ring inserts
Barium (Ba)	**Additive:** Alkaline-based detergent	Nickel (N)	**Wear:** Valve stems/guides, piston ring inserts
Boron (B)	**Additive:** Anti-Wear, Extreme Pressure (gear oil), Detergent **Containment:** Coolant inhibitor additive	Phosphorus (P)	**Additive:** Anti-wear, EP
Calcium (Ca)	**Additive:** Alkaline-based detergent	Potassium (K)	**Containment:** Coolant additive
Chromium (Cr)	**Wear:** Shafts, rings, roller element bearings, liners, piston rings	Silicon (Si)	**Containment:** Dirt/dust, sealant, anti-foam additive in other oil types. Sand-casted parts.
Copper (Cu)	**Wear:** Bearings, bushings, oil coolers, thrust plates, anti-seize	Silver (Ag)	**Wear:** Bearing overlay, needle bearings, wrist pin bushings in older EMD engines, silver solder
Iron (Fe)	**Wear:** Engine liners and rings, gears, shafts, valve train, pumps	Sodium (Na)	**Containment:** Coolant additive, process salt water
Lead (Pb)	**Wear:** Journal bearings, babbitt, alloyed bronze busings, solder	Tin (Sn)	**Wear:** Bearings, babbitt, piston-overlay, solder
Magnesium (Mg)	**Additive:** Alkaline-based detergent	Zinc (Zn)	**Additive:** Anti-wear **Wear:** Brass (Cu+Zn)

SUMMARY

In this white paper, we have briefly explored the fundamentals of used oil analysis in stationary gas engines, including sample taking, physical and chemical properties, elemental analysis and different test methods. Commitment to systematic analysis is the key to ensuring regular data is received, which can then be acted on. Consistent and reliable sample taking and regular review and trending of the analysis data in its entirety is the foundation upon which used oil analysis can build confidence in the condition of your lubricant and engine fleet, especially when combined with oil consumption trending, visual inspections and filter debris analysis.

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