The purpose of this document is to generate awareness of real-time monitoring of engine oil health on diesel and natural gas engines in various applications.

With advancements in IoT (Internet of things), AI (artificial intelligence), machine learning and sensor technologies, connected industry is moving forward with Condition Based Maintenance (CBM) by disrupting traditional interval-based maintenance to provide a more comprehensive understanding of the machine health. This disruptive technology is driving a paradigm shift with the use of sensors for monitoring vibration, temperature, pressure, fluid health and other important machine parameters.

With CBM, traditional ways of checking fluid health are being replaced or enhanced by real-time monitoring solutions. Using a sensor-based, data-driven approach enables a virtual mechanic to continuously monitor fluid health and contaminants.

Fleetguard® is known for being the leading filtration brand in diesel and natural gas engines. The new disruptive initiatives of FleetguardFIT™ provide the industry an opportunity to step up their game in maintenance practices by providing real-time information of oil health and engine consumables such as filters and fluids.
Engine oil is an essential consumable in an Internal Combustion (IC) engine. Some experts even call it the life blood of the engine. In an IC engine, both lube oil and coolant are circulated in a closed loop system lubricating and cooling vital organs of the engine. Apart from lubricating, engine oil performs other functions such as transferring contaminants, sealing the combustion chamber and the cooling of moving parts. Oil filters are used to capture and contain most of the debris in the oil flow. Both engine oil and filters are typically changed at recommended oil-drain intervals set by fleets or OEMs.

Many fleets periodically collect oil samples from the engine and send them to a laboratory for detailed fluid analysis. There are tradeoffs with periodic sampling that have highlighted the need for real-time oil health monitoring. Real-time oil degradation data helps engine operators identify potential issues much sooner and can help with oil sampling strategy, saving time and money by maximizing uptime.
First, let’s take a moment to follow the journey of oil through a single oil-drain interval. When new oil is put into use, we would think it is as fresh as it was in the container, right? Wrong! The traces of earlier aged oil, which is likely chemically degraded and contaminated, can still be present in the lubrication system. Due to the design of the sump, various channels/conduits of the system retain about 5-10% of the “old” oil which gets mixed with the new oil. As this new oil starts to flow, it traverses the path through the sump, oil pump, cooling system and filter to vital parts of the engine such as pistons, shafts, turbo(s), bearings, etc. via the oil rifle. These vital components are in motion with or against other parts set apart by a nominal clearance. The oil also sees a range of temperature and pressure changes causing shear stresses and additive depletion as it flows through these systems. It is not uncommon to have some portion of oil be consumed through burning and/or leakage. The new oil protects the system and replenishes the trace oil that was once subjected to possible loss of shear stability, oxidation and additive depletion. New oil is formulated with additive packages that aid in prolonging the life of the oil. Oils are typically formulated with antioxidants, corrosion inhibitors, detergents/dispersants, anti-wear, viscosity improvers, alkalinity improvers and extreme pressure additives. For reference, oils are also identified by API grades. CK-4 and FA-4 are the newest API oil grade for diesel engine oils. API grade CK-4 was designed to meet 2017 Cummins model year and Tier 4 non-road exhaust greenhouse gas emission standards. API grade CK-4 is backwards compatible and designed to provide enhanced protection against oil oxidation, loss of shear stability and oil aeration.

Now Let’s talk about the contamination and degradation of the oil in a single oil-drain interval. According to most tribologists, oxidation is the primary indicator of oil ageing. As oil goes through heat and pressure cycles, interaction with oxygen, moisture and other contaminants, the anti-oxidant suppressants are depleted yielding oxidation. While the oil is oxidizing the acidity of the oil goes up resulting in increased TAN (Total Acid Number) and depletion of TBN (Total Base Number). Increased oxidation increases viscosity which could result in sludge and deposit formation. Thus, through oxidation as a primary process, if not monitored beyond extreme limits oil degradation could lead to corrosion, deposit formation on vital engine parts (mechanism shown in fig. 2) that could lead to loss in efficiency, increased filter restriction, engine reliability issues or even catastrophic failure.

The engine oil system also shares its boundaries with other fluids such as fuel, exhaust gases (soot), coolant, atmosphere (dust and air), etc. Although most of these boundaries are sealed, these fluids often get mixed with oil in a small amount even in normal operation. In abnormal events such as leaks/system failure, a disproportionate amount of these contaminates could ingress in the oil.
Let’s see how these contaminants get into the oil in a little more detail.

**Soot:** The exhaust blow-by gases carries with them soot from unburnt fuel which gets mixed with oil in the sump. Soot can be detrimental to the engine in multiple ways. It can increase the viscosity of oil, which is a measure of resistance to the flow. A higher viscosity can inhibit proper oil flow, especially in cold start conditions and can increase the time it takes for the oil to reach critical engine parts, such as the valvetrain. Soot, agglomerated in clumps can also lead to abrasion by causing wear of valvetrain, ring and liners.

**Fuel:** Defective injectors, excessive idling and frequent start-stop operation tend to increase fuel escaping through the piston rings to oil crankcase. Modern diesel engines are equipped with a DPF (Diesel Particulate Filter), which needs to be regenerated through an in-cylinder dosing of fuel in some of the cases (external fuel dosing for DPF regeneration is used in other cases). During this process the fuel is injected in the combustion chamber, but combustion is deliberately not achieved to push this fuel to the exhaust system, which could be used to burn the ash and particulates on the DPF. During this process, a certain amount of fuel could escape to and then mix with oil in the crankcase through clearances between the piston and engine block. Fuel pumps are also lubricated with oil, which could be another source for fuel dilution in oil. The fuel dilution in oil results in decreasing viscosity of the oil, which could lead to metal-on-metal contact between components, hence increasing wear and tear. It also increases corrosivity of oil.

**Coolant:** Coolant flows through separate conduits and plays a vital role in controlling the temperatures of the engine and oil through heat exchangers/oil cooler. As the sealing between the fluids (oil cooler, head gasket) get misaligned or defective, coolant can become mixed with oil.
**OIL DEGRADATION PROCESS AND CONTAMINANTS**

In extreme amounts, the coolant mixing with the oil can create a thick “mayonnaise” consistency emulsion which can be detrimental to the engine parts. Also, if allowed to run such emulsion for a long time, it can also lead to sludge formation. Figure 3 shows a visual color difference between oil samples with 1% of coolant dilution and another with 5% coolant dilution.

![Figure 3: Oil Samples with Coolant Dilution](image)

**Water and Dirt:** The ingress of these contaminants takes place through various openings as well as during oil change or top-off events. Dirt increases abrasion, while water bubbles can cause the same through cavitation.

**Engine Wear Elements:** Moving engine parts contribute to changing oil chemistry. Engine block, piston, bearings, etc. contribute to Iron (Fe) and alloy particles, while the oil cooling system contains Copper (Cu). As the oil becomes more acidic and viscous, the engine wear rate also tends to increase due to erosion and new particles in the oil. This, too, increases the abrasion, which could lead to failure of vital engine parts.

Given time, the above-mentioned oil contaminants can cause a system failure both slowly and catastrophically depending on their rate of ingress and their source. Hence a health check of oil could be used to diagnose the status of the “blood” of the engine.

Traditionally, only oil sampling methods were used to check oil health. Oil sampling has limitations of logistics and results-delay, manual intervention and lower frequency of sampling results. But with advent of IoT, sensors and data computing, the traditional method could be complimented, enhanced, or even replaced by a real-time monitoring of oil degradation.
TRADITIONAL OIL SAMPLING AND LIMITATIONS

Oil samples are recommended for understanding the detailed chemical composition of oil and wear analysis. For the best oil sampling results, a meticulous process is recommended to avoid erroneous results. Specifically:

1. Correct, consistent method of sampling and volume of sample
2. Sealing, paperwork and shipment of the sample (logistics)
3. Frequency and timing of the oil sampling
4. Checking the trend of sampling and correlation with service records/engine duty cycle

Flow of an oil sample

For best results, oil should be drawn and sampled from ports with an approved procedure determined by each OEM or fleet. Generally, the initial quantity of stagnant oil near the sampling port needs to be discarded or returned to the fill tube as this stagnant oil may contain contaminant, debris, sludge, etc. and may misrepresent the oil flowing through the system. While taking the oil sample, the engine needs to run at high idle at normal oil operating temperatures so a homogeneous sample is collected. The oil sample is divided into even smaller quantities for different testing in the lab, so an insufficient sample could hamper completion of certain tests. Typically, the oil sampled is a very small snapshot of the entire lube system volume, especially in large high-horsepower engines, so capturing a homogenous sample is of utmost importance for making oil health decisions.

Figure 4: Flow of an Oil Sample

Figure 5: Example Oil Sampling Method
Once the oil sample is collected, care must be taken to seal it appropriately. Allowing for ingress of atmospheric contaminants could affect the composition of oil samples, and the leakage from the oil sample bottle could reduce the volume required for testing. Leakage could also damage the paperwork containing important information needed by the lab technician. At a minimum, the sample should include information about the equipment or engine serial number from which oil was taken, odometer/engine hour reading when sample was taken and information on oil grade/type. The oil analysis labs receive hundreds of such samples every day, so missing information on these fields could affect identifying an oil sample properly from a certain equipment, which negates all the effort taken for sampling. The delay in oil sampling to oil receipt by lab should be minimum. It is also important to read and react to the results as soon as available as some contamination events could be catastrophic.

It is very important to determine when to take an oil sample and observe the trend. Typically, oil samples are taken at regular intervals, but most of them do not lead to detecting any potential issues due to following reasons:

a. Sample is taken when oil is relatively fresh (early in the service interval)
b. Sample is taken at regular intervals, but deviations or spikes in the trend which essentially could indicate a problem are not caught during that sampling event
c. Ignoring a spike in the oil analysis for a certain parameter, or assuming it’s an instrument error/mis-representative oil sample. There could truly be an issue with the engine or oil, but any trace of when such an event occurred is untraceable due to lack of data
d. Lack of training to interpret/respond to lab results by the maintenance personnel

Finally, although oil lab analysis results are comprehensive and quantitative, the availability of results to the end user after a delay means that any abnormality captured has happened in the past (sometimes 2-4 weeks later). In between sampling and reporting, many things can happen such as oil top-offs, maintenance events or even an oil change. So, although detailed oil information is available, it may not be useful as the event has already occurred.
REAL-TIME OIL HEALTH MONITORING AND ADVANTAGES

Real-time monitoring of the oil is possible with advancements in sensor technologies and IoT. It can help overcome some of the limitations of traditional lab analysis mentioned above. The real-time system consists of a sensor or group of sensors monitoring key oil health parameters and/or detecting contaminants or wear metal.

The real-time monitoring may not give detailed information of oil quality with quantification of different contamination or degradation parameters, but it can help indicate that there’s a problem. Think about it this way: Real-time monitoring is like a CT scan/ MRI machine that can detect presence of anomalies in your body, while lab analysis is like a biopsy taken based on CT scan findings to confirm the root cause of the anomaly.

With FleetguardFIT™ technology, users will be alerted of oil-health issues; following up with oil sampling, users can then deduct what is causing the oil’s health to deteriorate.

Real-time monitoring of oil health can be divided into 2 categories (refer fig 2 for operational domain of each category):

**Category 1 sensors** are response technologies (permittivity, impedance) which shows signature change of chemical degradation (oxidation, TBN, viscosity) of oil or dissolvable/molecular-level contamination like coolant and fuel dilution. As these properties are primary indications of overall oil degradation, using the Category 1 sensors helps in catching oil degradation in its the early phases.

**Category 2 sensors** are wear metal sensors, which can help in counting/catching wear particles and even identifying their classification based on micron size, ferrous/non-ferrous group, etc. Category 2 sensors can help identify any severe component-level failure if oil health degrades beyond operational domain of Category 1 sensor. Understanding engine lubrication system issues can be problematic due to sudden component failures without any primary signs in chemical properties. This could be attributed to system design, age of the engine, metallurgical properties of vital parts, etc. A real-time monitoring solution of wear metal helps in catching such failure, although time to act could be substantially less in this phase.

The FleetguardFIT™ oil health monitoring solution is a Category 1 type technology. Its proprietary output parameters, Cumulative Degradation Number (CDN) and Kinematic Viscosity at 100°C (KV100) respond to chemical degradation of oil (Oxidation, TBN, Viscosity etc.) and react to contamination like fuel, coolant, soot, etc.
REAL-TIME OIL HEALTH MONITORING AND ADVANTAGES

Figure 8 shows how CDN and KV100 track oil health throughout life of an engine. For around 700k miles of real-time monitoring with intermittent oil sampling analysis, CDN can be seen responding with key oil health parameters like oxidation, while KV100 can be seen approximating lab analysis results while showing changes due to winter grade change or oil degradation.

Figure 7: FleetguardFIT™ oil health monitoring for 700k miles
REAL-TIME OIL HEALTH MONITORING AND ADVANTAGES

Theoretical models of response from FleetguardFIT™ oil health monitoring is shown below as well in cases of certain contamination ingress. As oil degradation is multi-dimensional, different contamination exhibits different signatures in real-time monitoring parameters. Also, one-time ingress versus continuous ingress may also show variations in response (refer figure 9-12). Having access to such real-time continuous information may help end users to identify / rectify gaps in maintenance and system issues.

**Figure 8:** One-time coolant dilution

**Figure 9:** Continuous Coolant dilution

**Figure 10:** One-time fuel dilution

**Figure 11:** Continuous fuel dilution
Advantages of real-time monitoring can include but are not limited to:

1. Continuous feedback to help optimize oil-drain intervals
2. Doesn’t require recurring manual intervention and logistics
3. Captures details (Oil chemistry changes due to sudden events better captured)
4. Early problem indication
5. Fills gaps in manual sampling
6. Better insights with synchronizing engine parameters/location with real-time measurement of oil properties

1. Continuous feedback to help optimize oil-drain intervals:

As the sensor is monitoring oil signals every “X” number of seconds (depending on sensor/telematics used), which could be visualized through IoT UX feature (web portal/app), it provides faster results than any traditional lab analysis results, which can help in optimizing oil-drain intervals. Fig 13 below is an example where a sensor-based oil degradation parameter from FleetguardFIT™ is showing degradation of oil health for 3 oil-drain intervals. The real-time parameter captured all the small details (even top-off events) continuously. More importantly, the output is real-time, versus the lab results which were trailing by weeks.

Figure 12: Lagging nature of lab analysis
REAL-TIME OIL HEALTH MONITORING AND ADVANTAGES

2. Doesn’t require recurring manual intervention and logistics

The only downtime required by real-time monitoring is when the hardware (sensor + harness + gateway) is installed/connected with the engine. Once hardware is installed for the real-time monitoring, it doesn’t need the regular downtime and labor associated with frequent oil sampling.

3. Captures details of changes in oil chemistry

With real-time monitoring, a continuous scan of the oil is possible. This means small changes in oil condition, which could be missed by periodic sampling are captured. Continuous sampling can help indicate the point of entry of a contamination ingress. Many oil-related events like top-offs, drains and a sudden increase of certain contaminant can be identified using real-time monitoring. Figure 13 below shows viscosity tracking done with FleetguardFIT™ oil health monitoring technology. All the small variations in the viscosity due to contamination ingress, evaporation and oil change were captured in full detail.

![Figure 13: Oil health sensor capturing fuel dilution and evaporation events in detail](image)
REAL-TIME OIL HEALTH MONITORING AND ADVANTAGES

4. Early Problem Detection to prevent failures

Having access to real-time data means better chances of catching failures. Most of the catastrophic failures start with small events which, if ignored, turn into equipment breakdown events or unplanned downtimes. The relationship between repair expenses and time at which problems are detected is exponential. Hence, real-time monitoring of oil has the potential to avoid such scenarios by indicating the problems in the earlier phase of oil degradation. The plot below shows testing done with FleetguardFIT™ oil health monitoring technology. Sludge formation was seen in this example due to coolant contamination and rapid oxidation. But, increasing viscosity from the sensor hinted at the abnormal condition much earlier before the oil had to be changed.

Figure 14: Coolant leak and oxidation leading to sludge formation
REAL-TIME OIL HEALTH MONITORING AND ADVANTAGES

5. Fills Gaps in Sampling
Although there are pitfalls of low-frequency sampling, traditional lab analysis from periodic sampling provides quantitative and detailed analysis. Sometimes if lab analysis shows spiked readings, the end user may not trust the results as the trend is missing. The real-time monitoring provides fillers for the missing trend.

6. Better insights with synchronizing engine/equipment parameters
Another advantage of real-time monitoring is the possibility to synchronize other logged or monitored equipment operating parameters through telematics or data collection devices. Combining oil health with system parameters such as pressure, flow rate, fueling, coolant temperature, fueling, torque, etc. may provide insights into root cause analysis of a malfunction.

Figure 15: Filling gaps in sampling
CONCLUSION

Real-time monitoring of fluid health is an effective tool in equipment maintenance practices. Combined with IoT, machine learning and lab analysis, it can play a vital part in detecting fluid abnormalities before catastrophic events/unplanned downtime. Although real-time monitoring may not be as comprehensive as traditional lab analysis, it more than makes up for shortcomings by providing quick and continuous scans of a fluid health to enable the end user to make timely decisions. Cummins Filtration is proud to offer FleetguardFIT™: a real-time monitoring system for engine consumables and oil health.

FleetguardFIT™ Oil Condition Monitoring system can be used on applications using diesel and natural gas engines. The FleetguardFIT™ system also offers monitoring of other consumables such as air filters, lube filters and fuel filters using smart sensors and algorithms.

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Reference document:
Websites
https://cumminsfiltration.com/Fleetguard
https://cumminsfiltration.com/

Videos
https://www.youtube.com/user/FleetguardFiltration/videos
FleetguardFIT™ system Animation: https://www.youtube.com/watch?v=EFrp1SYmksY
FleetguardFIT™ system installation: https://www.youtube.com/watch?v=beT_WCIPE2M&t=28s
FleetguardFIT™ LED air restriction sensor: https://www.youtube.com/watch?v=QD0yMwerIlo