

From field data to innovation: enabling fill-for-life wind turbine gearbox oils

How do you develop a long-life wind turbine gear oil that can outlive a gearbox and have confidence that it will continue to perform year after year, decade after decade? Shell Lubricants' Ulf Rieper, Lubricants Product Application Specialist for Wind & Industrial Products, and Rihard Pasaribu, Lubricants Product Application Specialist and Team Leader, reveal how a decade-plus of operational data are helping them validate and unlock fill-for-life gear oil.

Gear oil is the lifeblood of geared wind turbines. Yet, as turbine technology has advanced and the expectation of longer life and less maintenance has grown, the performance of current lubricants has struggled to keep up.

Larger gearboxes, bearings and drive trains have introduced new performance challenges for gear oils, including the need to last longer. For wind farm operators, particularly those managing large fleets or offshore assets, lubricant performance and lifetime directly affect maintenance planning, operational efficiency and asset economics.

Developing oils that maintain long-life performance is challenging, as is having the confidence to guarantee such performance. However, a little over 10 years ago, Shell did just that. In a bold move, the lubricant developer offered the industry's first oil life warranty. More than 10 years later, that same gear oil continues to perform in the field and set the standard for long-life oils.

Beyond the performance accolades, of even greater value are the 10-plus years of real-world operating data and insights. These are being used to design an accelerated testing procedure that mimics real field data, develop a booster formulation and implement oil-life-extension technology.

The innovation imperative

The case to reinvent wind turbine gear oil was a clear one. 'Fifteen years ago, there were no oils specifically designed for wind turbines, so the industry relied on generic industrial gear oils,' explains Ulf.

'Everyone hoped they would work, but they were unable to meet the unique lubrication demands of wind turbine operations. Consequently, they often suffered foaming and degradation issues that led to costly bearing failures, power loss and frequent oil changes every three to five years.'

What was needed was a fit-for-purpose oil that offered reliable and predictable long-term performance, so the team set about developing just that.

Combining field data from an existing lubricant technology, which was already lasting between five and six years, with oil-ageing simulations, Shell developed its Omala S5 Wind 320 gear oil, and with it a bold claim: 'Extrapolating our data, we were confident that our new oil could last for at least 10 years,' says Ulf. 'In fact, we were so confident, we offered the industry's first oil life warranty that guaranteed a 10-year oil life.' [1]

In April 2015, Shell started field tests, deploying its Omala gear oil in a cluster of turbines in Spain. More than a decade and zero oil changes later, the lubricant in these turbines is still performing as it should be.

'Our models promised 10 years, but it's now been more than that. What's more, these turbines were previously filled with an alternative oil which left degraded residuals in the gearbox. This is a worst-case scenario, but our oil still performed.'

Exceeding 10-year oil life has significant implications for original equipment manufacturers (OEMs) and wind turbine owners. Oils that last longer require fewer changes or top-ups, thereby reducing costly downtime. They also perform at their peak for longer, offering longer-term protection from metal wear and gearbox failure.



Ulf Rieper



Rihard Pasaribu

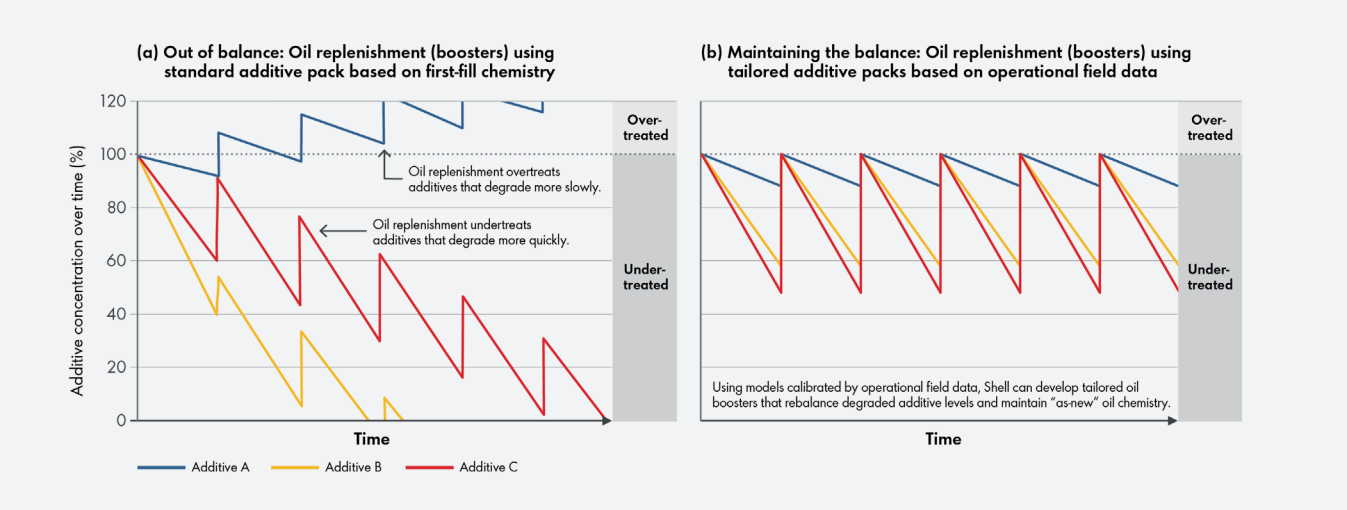


Figure 1: Comparison of changes in additive balance following successive oil boosters. (a) Standard booster packages can result in increasingly unbalanced additive chemistry over time. (b) Tailored additive boosters can maintain a balanced, 'as-new' chemistry across multiple decades of use. Note: This is a conceptual figure representative of a Shell study on oxidative stability improvements with different re-additisation strategies

Why real-world data matters

Real-world data is vital for validating oil life models. Wind turbines operate under highly diverse conditions, from extreme temperatures and varying load profiles to different gearbox designs and operating strategies. While laboratory testing remains an essential part of lubricant development, long-term field experience provides a unique level of validation that cannot be fully replicated in a test environment.

For example, artificial ageing tests cannot entirely replicate degradation caused by movement and loads exerted on gears and bearings, or contamination from wear metals. This is particularly important as wind turbines continue to scale. Larger turbines introduce different manufacturing tolerances and structural flexibility, which influence the dynamic conditions in the gearbox. Only through long-term field testing can the impact of these variables on gear oil life be properly understood.

'We still rely on extrapolation models based on regular oil condition monitoring to predict long-term oil behaviour, so they need to be accurate,' Ulf explains. 'However, to build a reliable model and be confident in our oil life claims, we need a complete record of how our oil behaves in the real world. Our Omala field tests give us this. We now have over a decade of direct operational data that we can use to calibrate our models, giving us the accuracy, insights and confidence we need.'

Field tests reveal enormous amounts of information through oil condition monitoring, deep chemical analysis, maintenance records and field inspections. When combined, these data sets provide valuable insights into lubricant behaviour, degradation mechanisms, additive performance and overall asset health.

Today, more than 17,000 wind turbines around the world use Shell's Omala oil, many of which are providing the real-world data needed to better understand how to extend oil life and offer more predictable performance.[2]

The secret to long-life oil

Shell's field data is crucial, but what does it reveal about oil behaviour and the potential of oils to last for 25 years, or even the full life of a gearbox?

To answer this, it is important to understand the internal operating environment of a wind turbine and how this impacts oil behaviour over time.

As Rihard explains, wind turbines experience changing loads related to variable rotation speeds, frequent stopping and starting and flexure, placing unique demands on gear oils. For example, while a turbine is stationary, cool oil collects at the bottom of the gearbox, leaving only a thin film of protection between metal components. This leaves the system vulnerable to metal wear when the turbine starts to rotate and gears start to move. However, as gears accelerate and the temperature rises, oil is distributed throughout the system, forming a sufficiently thick film that protects gearbox components.

Cycle after cycle, gear oils are heated and cooled, loaded and unloaded, placing enormous demands on lubricant chemistry and design. Over time, components such as anti-foaming and anti-corrosion additives start to degrade, unbalancing the chemistry and reducing performance. Ideally, degraded molecules are filtered out. However, in older technologies, these molecules become trapped in the filter, which results in foaming and performance loss.

Therefore, to inhibit degradation and preserve performance, gear oils need to: (1) maintain a balanced chemistry and (2) enable effective filtering to remove degraded molecules. So, how does the field data evidence this?

'The key to extending oil life is replenishing degraded molecules and maintaining the designed ratio (or balance) of additives,' says Rihard. 'However, different additives in an oil degrade at different rates, so understanding how to maintain this balance is one of the biggest challenges. And this is what our field data has enabled us to do.'

Rihard explains that conventional oil boosters typically involve replenishment using the original oil package. However, this can be counterproductive, because slower degrading additives may be overtreated, while faster degrading ones may be undertreated (Fig. 1a).

Instead, replenishment should be tailored so that each additive component is replenished by the correct amount. Rihard likens it to vitamin supplements for the body: 'Many of us take multivitamins without knowing our vitamin levels, meaning we may overtreat ourselves with vitamins we don't need, or undertreat ourselves with the vitamins we do need. Having a blood test can tell us exactly what we need and in which dose.'

Oil analysis, like a wind turbine blood test, performs the same role. Indeed, oil analysis data from the Omala field test has revealed important trends in additive degradation, which has helped the team build evidence-based models that can accurately forecast degradation levels over time. And this is key, because it enables Shell to design tailored oil boosters with the correct balance of additives to maintain oil chemistry as if the oil were new (Fig. 1b).

In combination with maintaining oil chemistry balance, it is equally important that gear oil remains in good overall shape. Building on Rihard's vitamin analogy, Ulf explains: 'Supplements alone are not enough to keep our bodies healthy; we need to keep them in good shape with exercise and the right nutrition. For wind turbines, this means

effectively filtering out degraded molecules to keep the oil healthy and contaminant-free.'

By maintaining 'as-new' chemistry through periodic additive boosters and effective filtering, the Shell team is confident that its gear oil can last as long as 25 years, or more, enabling 'fill-for-life'. Shell has already demonstrated extended oil life in the field, and with the operational data gained and extensive laboratory testing of used oil, the Shell team can confidently formulate a booster package to target an oil life of more than 25 years.[3]

Collaboration is key

The team says that collaboration is key to accelerating lubricant innovation and is an approach that Shell champions.

Today, Shell has several development partnerships across the wind industry focused on developing and validating its new booster solution. Academic partners, such as Imperial College London, have helped the team develop a unique testing methodology to determine when to add a booster and in what volume. Such studies give Shell's lubricant technology the versatility it needs to perform for longer in a wide range of operating conditions and wind turbine systems.

'Our data shows that gear oil degradation is quite similar across about 80% of operating scenarios, so our additive booster works in the majority of situations,' explains Rihard. 'For the other 20%, which have more demanding operating conditions and lubrication needs, we can tweak the booster treat rate and frequency so it is specifically tailored for a wind farm. If an OEM or wind farm owner is looking for optimisation through our oil-life-extension technology, we can work with them to develop the most suitable solution.'

Shell is also working with several OEMs to field test its oil technology. These real-world tests are crucial to calibrating and validating its extrapolation models. As Ulf explains: 'The only way to have true confidence in the life of an oil is to measure how it performs in the real world. And this is what we're doing with our OEM partners.'

Fill-for-life gear oil is possible, and we are closer than you think

As the demand for wind energy continues to grow, longer-life lubricants will play an increasingly crucial role in increasing turbine reliability, reducing maintenance downtime and potentially helping to lower the levelised cost of energy. And operational data is the proof point.

'A decade-plus of data from our field test reveals unprecedented real-world insight,' says Ulf. 'Every year of successful operation adds to our understanding of lubricant behaviour, equipment protection and the factors that influence long-term oil performance.'

As turbines get larger and operating lives extend, asset owners need the assurance that new technologies will perform not only in testing environments but throughout years of demanding service. Real-world operating experience helps provide that certainty.

'We want to push lubricant technology beyond what we currently think is possible,' says Rihard. 'Validating 10-year oil life is notable, but we are not stopping there. Indeed, we have a solution that can extend oil life to 25 years or more. And by continuing to capture and integrate operational data, we can start making fill-for-life wind turbine gearbox oil a reality.'

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References

[1] Shell Lubricants warrants that Shell Omala S5 Wind 320 gear oil: (i) meets Shell Lubricants' then current specifications at the time of product manufacture, and (ii) will remain suitable for use in the main gearbox of a wind turbine for 10+ years from the filling date of the main gearbox, provided all warranty conditions are met in full. Upon a valid warranty claim, Shell Lubricants will: (i) replace Shell Omala S5 Wind 320 gear oil, and (ii) pay costs to repair eligible main gearbox damage proven to have been directly caused by Shell Omala S5 Wind 320 gear oil. Terms and conditions apply. See your Shell Lubricants representative for complete details.

[2] Based on Shell Omala S5 Wind sales volume and estimates of turbine first-fill demand from major global wind turbine OEMs.

[3] Shell has been working with external partners on oil-life extension by introducing booster additives to extend its service life. Laboratory test results have shown promising outcomes, indicating that additive levels can be rebalanced to help extend oil life when implemented properly and proactively. Actual oil life may vary depending on equipment design, operating conditions, contamination levels, maintenance practices, and the implementation of Shell oil-life-extension technologies. Any references to a 25-year oil life or fill-for-life performance represent development objectives and projected performance under defined conditions only, and should not be interpreted as a warranty, guarantee, or commitment regarding the performance, service life, or suitability of any Shell Omala product or service in actual operating conditions.