Shell Lubricants

THE PERFECT PARTNER

HOW GAS-TO-LIQUIDS (GTL) BASED TECHNOLOGY CAN HELP TO ENHANCE THE RELIABILITY OF YOUR TRANSFORMER

Technical paper, May 2014

PURE, PREDICTABLE AND WITH NO SULPHUR[1] AND VERY LOW AROMATIC AND UNSATURATES CONTENTS, SHELL'S GTL BASE FLUIDS HAVE HIGHER FLASH POINTS, LOWER DENSITIES AND TYPICALLY MORE EFFECTIVE THERMAL PROPERTIES THAN CONVENTIONAL MINERAL OILS.

[1]Below the detection limits according to ISO 14596/ASTM D2622

This white paper was written solely by Shell and not with or on behalf of any consortium with which it is involved.

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TRANSFORMING TRANSFORMER RELIABILITY

Power transformers are very expensive, business-critical assets for which reliability is paramount. Failures can be catastrophic, as the economic losses and non-delivery penalties that may be incurred during power interruptions can be severe. Shell recently introduced the first transformer oil to be based on GTL technology and it believes that this, coupled with scientific findings from a major research programme, could help to revolutionise the reliability and lifespan of transformers now and in the future.

The world's transformer fleet is relatively old (the average age of a transformer in many countries is 30–40 years) and many companies are operating transformers close to their original recommended lifespans. Some are even being run beyond their expected lifespan, and the high capital cost involved in replacing a unit, up to $4 million, means that there is an economic incentive to do this if the unit's reliability can be managed.

Shell is aware of these issues and has been investing in research programmes with leading universities, technical institutes and private companies to accelerate the innovation process.

For instance, in 2012, it joined a major European research consortium that is investigating transformer design and operation and the influence of the oil on ageing and reliability characteristics.

The research, which is one of the biggest academic exercises in this field in Europe, is being led by the University of Manchester's School of Electrical and Electronic Engineering, a recognised technical centre of expertise and excellence for electrical research on transformer oils and transformers in the UK. The consortium also includes transformer manufacturers, utility companies, testing laboratories, insulation material manufacturers and Shell, which provides its oils for research (Figure 1).

Shell believes that this programme could help to revolutionise the lifespan of the transformers of the future because it is enhancing the body of scientific knowledge in this specialist area. For instance, it has provided better understanding of how oils and transformers age, and has helped to identify the key attributes that need to be improved to increase the reliability and longevity of both oil and transformer in service.

In addition, tests at the university have helped to validate Shell's latest GTL-based, inhibited transformer oil – Shell Diala S4 ZX-I. For example, one test simulated the effects of high-voltage transients due to lightning strikes and switching operations in power systems and assessed the resilience of different oils to the effects of such transients.

FIGURE 1: Dr Qiang Liu, Lecturer in Power System Plant, and Zhongdong Wang, Professor of High Voltage Engineering, University of Manchester, and Dr Peter Smith, Technology Manager, Shell Global Solutions, in front of the lightning impulse generator. Shell and the University of Manchester are involved in a consortium that is investigating transformer design and operation and the influence of the oil on ageing and reliability characteristics.

AS SHELL DIALA S4 ZX-I IS DERIVED FROM PURIFIED NATURAL GAS, IT HAS A TIGHTLY SPECIFIED HYDROCARBON CHEMICAL STRUCTURE. IN CONTRAST, THE COMPOSITION OF CRUDE-BASED OILS CAN VARY SIGNIFICANTLY DEPENDING ON THE SOURCE AND THE REFINING PROCESS.

FIGURE 2: The needle-sphere electrode configuration used for lightning impulse breakdown testing.

In this test two oils, Shell Diala S4 ZX-I (inhibited GTL oil) and Shell Diala S3 ZX-I (conventional inhibited oil), both of which have a water content of <10 ppm, were assessed for their lightning impulse breakdown in needle-sphere and needle-plane geometries. The needle-sphere electrode configuration used (gap typically 25 mm, using positive and negative impulses) is shown in Figure 2. An eight-stage impulse generator with a maximum voltage of 800 kV and 4 kJ energy was used to deliver a standard lightning impulse of 1.2/50 µs.

Figure 3 shows that Shell Diala S4 ZX-I has a significantly higher lightning impulse breakdown voltage than the inhibited conventional oil it was tested against using both electrode geometries and positive and negative polarities. This test therefore indicates that Shell Diala S4 ZX-I has a greater capacity to withstand severe in-service voltage transients, such as those due to switching operations or lightning strikes, compared with the other oil tested.

"As a multinational utility company that owns almost 500 high-voltage substations, we have a large number of oil-filled assets such as power transformers and it is vital that we use oil on which we can rely. We have an acute interest in prolonging the lifespan of our transformers as well as maximising their reliability, as this helps us to provide the best value to our customers while ensuring they get the electricity they need. We know that the oil we use plays a vital role in the reliability and lifespan of a transformer, so this programme is extremely important to National Grid."

Gordon Wilson, Technical Specialist in Insulating Liquids, National Grid plc

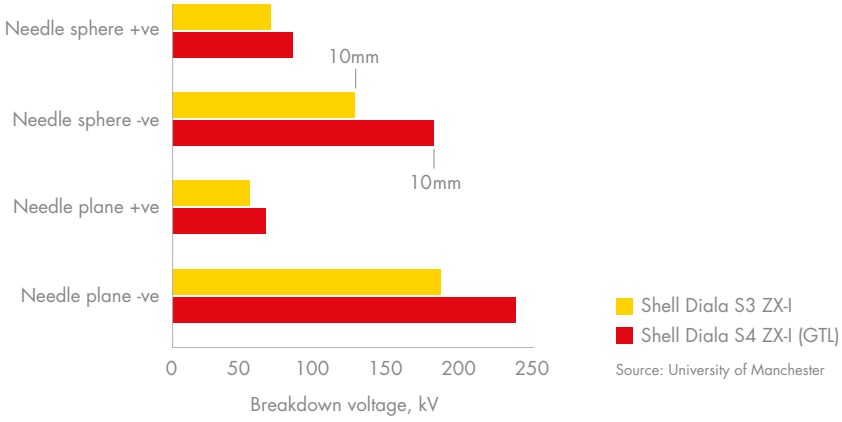


FIGURE 3: Average lightning impulse breakdown voltage of inhibited GTL oil (Shell Diala S4 ZX-I) versus conventional inhibited oil (Shell Diala S3 ZX-I) with a 25-mm electrode gap, unless otherwise specified.

GTL TECHNOLOGY: MANUFACTURING A DESIGNER HYDROCARBON TRANSFORMER OIL WITH ENHANCED PERFORMANCE CHARACTERISTICS

Shell GTL base oil is a manufactured hydrocarbon (primarily isoparaffinic in structure) derived from natural gas rather than from crude oil. Natural gas is purified and then converted into a range of liquid products using proprietary technology.

First, the methane is reacted with oxygen to create synthesis gas, a mixture of hydrogen and carbon monoxide (Figure 4). This synthesis gas is then catalytically converted into liquid waxy hydrocarbons via a Fischer–Tropsch process.

$$(2n + 1)\ H_2 + nCO \longrightarrow C_nH(2n+2) + nH_2O$$

Finally, the liquid waxy hydrocarbons are upgraded (hydrocracked) using specially developed technology involving novel catalysts and then distilled into a wide range of products, including transport fuels, base oils and feedstocks for the chemical industry. Crucially, these products are essentially free from impurities and inorganic substances such as sulphur.

Because its starting materials are mostly carbon and hydrogen, the resultant fluid is almost entirely pure hydrocarbons. The GTL process ensures that those hydrocarbons are overwhelmingly saturated paraffins. The absence of sulphur[2] and very low levels of aromatic and unsaturated hydrocarbons, which can be present at significant levels in conventional crude-oil-derived mineral oil, give GTL products superior properties compared with conventional mineral oils that are particularly relevant to their application as base fluids for transformer oils.

"Shell's GTL-based transformer oil is such an interesting proposition because it has essentially zero sulphur and very low aromatic and unsaturates contents. Consequently, it offers superior additive response, exceptional resistance to degradation and outstanding thermal properties, which can translate into increased transformer reliability and efficiency."

Dr Peter Smith, Technology Manager, Shell Global Solutions

REDUCING THE RISK OF COPPER CORROSION

Corrosive sulphur species in conventional transformer oils have caused transformer failures, but Shell Diala GTL transformer oils are manufactured from pure GTL base oil, which is essentially sulphur free. Consequently, the risk of oil-related-sulphur copper corrosion in the transformer is removed and, thus, higher reliability is possible.

[2]Below detection limits, according to ISO 14596/ASTM D2622

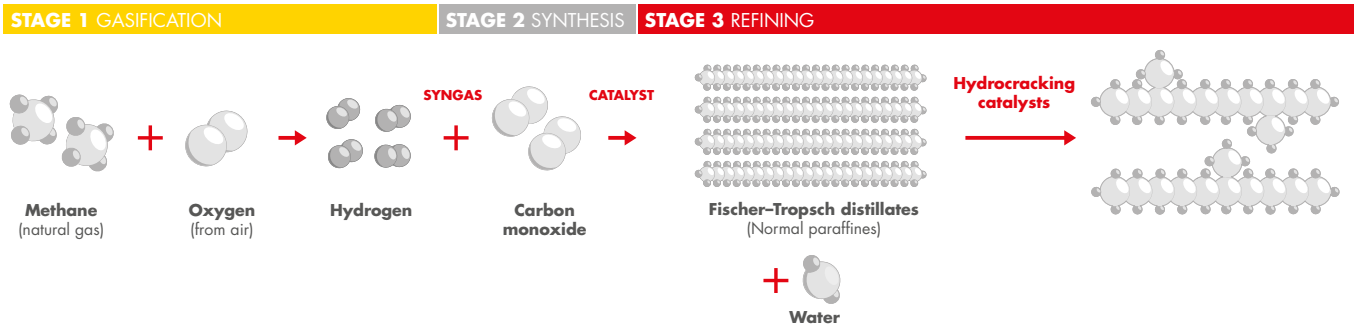


FIGURE 4: Shell's GTL base fluids are made from synthesis gas, a mixture of hydrogen and carbon monoxide, rather than from crude oil.

BECAUSE SHELL DIALA S4 ZX-I IS ESSENTIALLY FREE FROM SULPHUR, THE RISK OF OIL-RELATED CORROSIVE SULPHUR DEVELOPING AND CAUSING COPPER CORROSION IS MINIMISED.

RESISTANCE TO DEGRADATION

With modern transformers getting smaller and operating at higher voltages, the stresses placed on the oil are higher than ever before. Shell Diala GTL oils have an excellent response to antioxidant additives, which means that they have outstanding resistance to degradation in even the most demanding applications.

In addition, they show lower acidity and sludge formation on ageing, and have an oxidative stability performance level more than five times better than the highest standard requirements.[3] Consequently, they can help to enhance the lifespan of the paper insulation.

MODELLING PREDICTS GOOD-TO-SUPERIOR COOLING IN SERVICE

Effective cooling in a transformer is determined chiefly by two oil parameters: its thermal properties (specific heat capacity and thermal conductivity) and its fluidity or viscosity. An oil's thermal properties are proportional to its density. Calculations and measurements show that specific heat capacity and thermal capacity values are typically higher for Shell Diala S4 ZX-I than for conventional transformer oils, which indicates better thermal properties. This may provide cooling benefits for transformers in operation, and enable either higher loading or a reduced requirement for forced cooling, or some other design optimisation such as a reduction in transformer size.

Another important parameter that influences the ability of an oil to provide cooling in a transformer is its fluidity or viscosity across the usual transformer operating temperature range. The usual temperature ranges are defined in various specifications, see, for example, IEC 60076 Part 1, which defines the normal ambient lower temperature limit for power transformers as –25°C. Figure 5 plots fluidity (viscosity) versus temperature for inhibited GTL transformer oil (Shell Diala S4 ZX-I) compared with conventional oils: uninhibited (Shell Diala S2 ZU-I ngt) and inhibited (Shell Diala S3 ZX-I).

At higher temperatures, most of the oils have a good low and comparable viscosity, which facilitates good cooling. At lower temperatures, most oils will thicken significantly, which reduces their flow rate and cooling ability. As can be seen from Figure 5, the inhibited GTL oil thickens significantly less at lower temperatures than the conventional oils tested. This means it will maintain its good fluidity and flow properties better, even under extreme conditions.

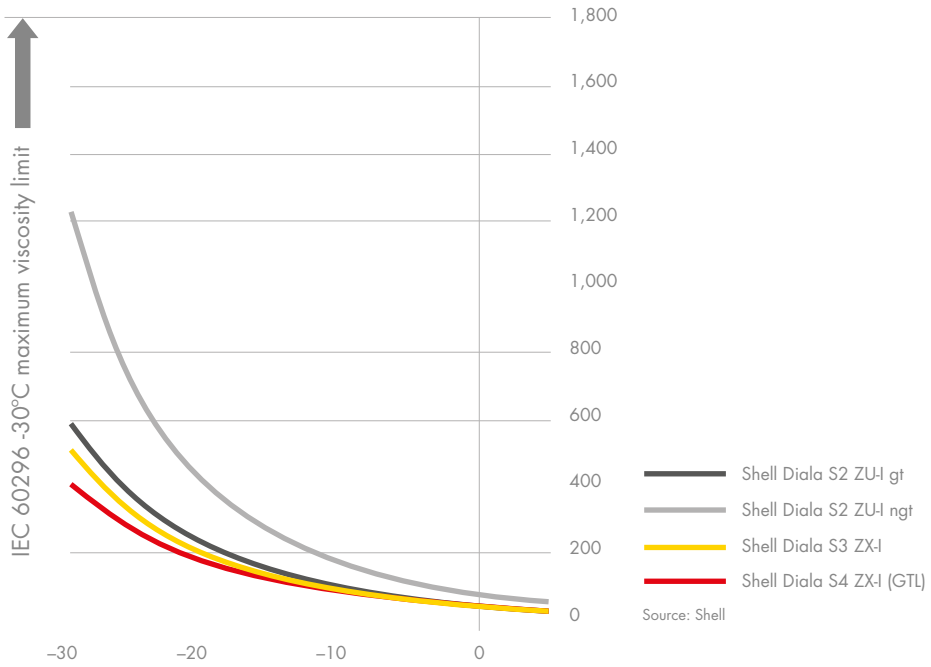


FIGURE 5: Fluidity (viscosity, cSt) versus temperature (°C) for inhibited GTL transformer oil (Shell Diala S4 ZX-I) compared with conventional oils: uninhibited (Shell Diala S2 ZU-I ngt) and inhibited (Shell Diala S3 ZX-I).

[3]IEC 60296:Ed 4 2012 (Chapter 7.1)

ALLEVIATING COMPATIBILITY AND MISCIBILITY CONCERNS

Compatibility and miscibility are not the same. Two fluids are miscible if they form a clear fluid when they are mixed. Compatibility goes much further than this. Obviously, compatible fluids have to be miscible, but to be compatible they must have no negative effects on each other. One fluid's performance must not be diminished by the other's.

When testing for compatibility, pairs of fluids are mixed and observed under different conditions to see if they are miscible. Then, using performance tests, they are assessed to see whether any pair behaves differently. Incompatibility can show itself through the formation of deposits, the worsening of oxidation stability or differences in any of the electrical properties of the fluid pairs.

Shell has commissioned a series of tests on miscibility, compatibility and solvency issues, and has concluded that GTL-based transformer oils can be used alongside traditional hydrocarbon oils (Figure 6).

Moreover, it is also possible to see positive effects, as appears to be the case when GTL-based fluids are added to aged oils. Some improvement is expected when adding a fresh fluid to an aged one. However, with the GTL-based fluids a bigger improvement is realised than would seem likely from the proportion of fluid added (see right: GTL fluids: Enhanced miscibility and compatibility characteristics).

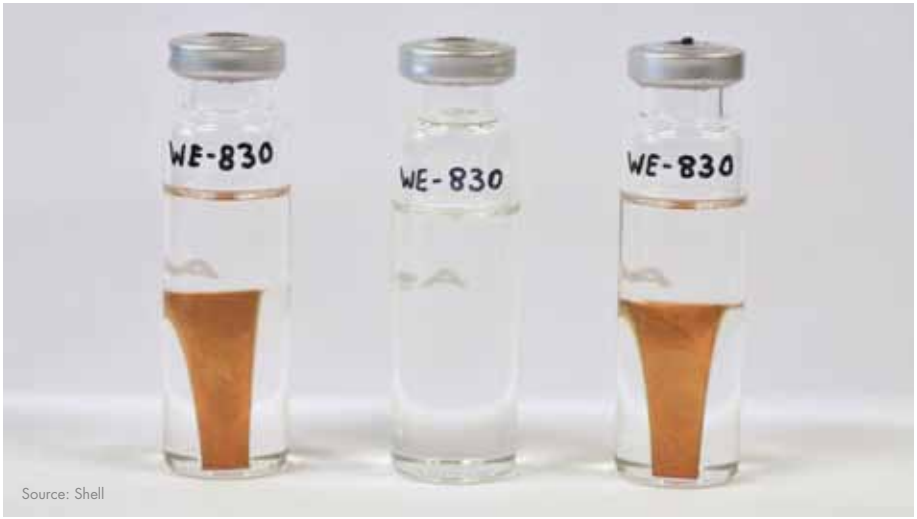
"Laborelec has tested and evaluated Shell Diala S4 ZX-I and can confirm that it meets and exceeds the inhibited transformer oil specification IEC 60296:2012 Edition 4, including the requirements for Section 7.1 in terms of highest oxidative stability and low sulphur. These characteristics can have a positive effect on the lifespan and reliability of the transformer."

Steve Eeckhoudt, Technology Manager, Insulating Fluids and Lubricants (Oils), Laborelec (GDF Suez)

GTL FLUIDS: ENHANCED MISCIBILITY AND COMPATIBILITY CHARACTERISTICS

To evaluate the effect of mixing transformer oil types in service, the properties of several mixed inhibition and unmixed inhibition test oils, both aged and unaged, and in different ratios and combinations, were tested. Table 1 shows the results for 15% aged uninhibited naphthenic oil mixed with 85% GTL inhibited oil. The mixture of 85% GTL fluid with 15% aged naphthenic oil still shows the highest oxidation stability. The GTL-based product compensates for the decreased performance of the aged oil: more than if the test had been conducted using a conventional inhibited oil.

For a copy of the complete paper on this issue, please contact Shell.



Source: Shell

Figure 6: GTL-based transformer oils can be used alongside traditional oils. The photo shows a blend of Shell Diala S4 ZX-I (GTL) after 164 hours at 100°C: left: aged with copper and sealed, centre: aged without copper; right: aged with copper and unsealed.

SHELL DIALA S4 ZX-I CAN BE ADOPTED EASILY BECAUSE IT IS MISCIBLE AND COMPATIBLE WITH TRADITIONAL HYDROCARBON OILS. ADDING IT TO SOME MINERAL OIL GRADES CAN EVEN HELP TO IMPROVE THEIR PERFORMANCE.

			100% aged naphthenic oil	15% naphthenic; 85% GTL	100% GTL
Oxidation stability	IEC 62535	164-hour test			
Total acidity	mg KOH/g		0.81	<0.01	
Sludge	% mass		0.27	0.01	
Dielectric dissipation factor		90°C	0.070	0.002	
Oxidation stability	IEC 62535	500-hour test			
Total acidity	mg KOH/g			0.02	0.02
Sludge	% mass			<0.01	<0.01
Dielectric dissipation factor		90°C		0.013	0.001

Source: Shell

Table 1: Adding Shell Diala S4 ZX-I oil can boost other conventional mineral transformer oils' performance.

INHIBITED VERSUS UNINHIBITED

In chemical terms, an inhibitor is a synthetic antioxidant added to a transformer oil to slow down the process of oxidative degradation. If allowed to proceed unchecked, this process would shorten the fluid's life and decrease its performance.

Depending on the level of refining, the mineral oils produced from crude oils contain sulphur-based chemical species that can act as mild inhibitors for oxidation. These are exploited in so-called "uninhibited" oils. Strictly speaking, they are not uninhibited oils but they do not have any added synthetic inhibitor.

Very highly refined mineral oils and synthetic oils contain no natural inhibitor, so are prone to oxidation if chemical inhibitor is not added. This may appear to be a disadvantage but it is actually a benefit: the complete system is more consistent and behaves in a more predictable and measurable way when ageing occurs than do uninhibited (naturally inhibited) mineral oils. Furthermore, inhibited transformer oils, with their greater purity and predictability, are made to be far more oxidation resistant than uninhibited oils. This is becoming essential, as the combination of longer oil life expectancy and transformer design and operation (for example, smaller transformers and higher voltages and loads) dramatically increases the stress on the fluid.

"Our laboratory and field testing of transformer oils show that inhibited oils offer enhanced performance compared with uninhibited oils."

Ivanka Hoehlein, Manager, Material Testing Laboratory, Siemens

PERFORMANCE ADVANTAGES OF SHELL GTL-BASED TRANSFORMER OILS

Transformer oils based on GTL technology offer some clear improvements over traditional mineral-based products.

These include:

- **increased reliability.** Because GTL-based transformer oils are free from sulphur,[4] the risk of oil-related corrosive sulphur causing copper corrosion is minimised. In addition, modelling predicts good to superior cooling in service.
- **longer life.** They have exceptional resistance to ageing and degradation and perform more than five times better than the highest industry standard oxidation test requirements. They have an excellent ability to withstand severe voltage transients.
- **simple implementation.** They are miscible and compatible with traditional hydrocarbon transformer oils. In fact, adding them to some mineral oil grades can help to improve their performance.
- **consistency.** They have a consistent, narrow molecular structure range that provides predictable performance, and they are globally available. They contain only GTL base oil and antioxidant. They do not require and so are free from other additives such as copper passivators and dibenzyl disulphide.

Nowadays, inhibited oils typically have greater purity and predictability than uninhibited oils. This is becoming essential, as the combination of longer oil life expectancy and transformer design and operation (for example, smaller transformers and higher voltages and loads) dramatically increases the stress on the fluid.

Consequently, Shell's GTL-based transformer oil, Shell Diala S4 ZX-I, is gaining traction worldwide. The number of original equipment manufacturer approvals is growing and utilities around the world are selecting the oil for their transformers.

[4]Below detection limits, according to ISO 14596/ASTM D2622

SHELL DIALA S4 ZX-I IS GAINING TRACTION WORLDWIDE. THE NUMBER OF ORIGINAL EQUIPMENT MANUFACTURER APPROVALS IS GROWING, AND UTILITIES AROUND THE WORLD ARE SELECTING THE OIL FOR THEIR TRANSFORMERS.

"When considering safety, environment and economic impacts, the implications of a transformer failure can be extremely severe for a power utility, especially one that owns, operates and maintains a population of ageing transformers. Therefore, it is of vital importance to understand transformer reliability and the influence of oil on ageing and reliability characteristics. The University of Manchester, a centre of excellence in transformer research, is delighted to work with a group of world-leading technological companies, including Shell, on advancing technology and knowledge in this field. GTL inhibited oil is one of the oils we have chosen to include in our research programme and we see its potential to enhance transformer reliability."

Zhongdong Wang, Professor of High Voltage Engineering, University of Manchester, UK

"GTL technology is the product of some 40 years of research and technology driven by Shell. The company holds more than 3,500 patents for it. Earlier this year (2014), Shell introduced the first transformer oil to be based on Shell GTL technology – Shell Diala S4 ZX-I. It is extremely exciting because this technology offers so much value for our customers and the new oil is gaining traction worldwide. It continues to gain equipment manufacturers' approvals and reference projects. Numerous tests are demonstrating that it offers major advantages compared with conventional oils."

Selda Gunsel, Shell Vice President for Lubricant Technology

APPROVALS

Shell Diala S4 ZX-I meets the requirements of most major European original equipment manufacturers and utility companies. It has been validated and approved by, among others:

- Siemens
- ABB
- Alstom
- CG Power Systems
- Hyundai Heavy Industries (Bulgaria)
- Maschinenfabrik Reinhausen (MR)
- Starkstrom-Gerätebau (SGB).

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