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ENHANCED TURBINE OIL PERFORMANCE UTILIZING GAS TO LIQUID BASE OILS

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Turbine oils must be able to handle demanding conditions to support maximum efficiency and reliability. To help lower total cost of ownership, turbine operators are also looking towards oils that can increase oil drain intervals. Turbine oils must resist oxidation, separate air and water quickly and be low foaming. In years past, turbine oil development has focused on the use of traditional base oils including Group I, II and more recently Group III base oils. Technology is now available that utilizes gas-to-liquid (GTL) base oils. GTL base oils are derived from natural gas and the manufacturing process allows the base oil to have a very narrow molecular range in comparison with traditional base oils. GTL base oils are essentially contaminant free and respond very well to additives such as antioxidants. Because of its purity, GTL base oil has excellent surface properties including very rapid air release, excellent anti-foaming behavior and minimizes varnish. This paper will focus on the manufacture and performance properties of GTL base oils as well as physical and performance properties of turbine oils which contain GTL base oils.

Global Energy Challenge

The world today faces many challenges that will be propelled by a rising global population (9 billion people by 2050, up from today's 6.7 billion or so) and strong economic growth in developing countries. That is consistent with the long-term trend of rising demand for energy. By 2050, energy demand could double or even triple from its level in 2000 if the world continues to use energy in the same way that it does today. **(Reference needed)**

Keeping pace with this demand will be extremely tough and will likely be partly met through advances in energy efficiency. By 2050, everything from cars to homes will be even more energy efficient than they are today.

These changes are also expected to have an impact in the industrial sector. Industrial machinery is being built to be more efficient with smaller oil reservoirs but provide higher power output. Because there is less oil, the oil has to work harder and be more resistant to thermal and oxidative breakdown. In the meantime, customers are demanding higher lubricant performance at the same or reduced costs. This can present a major challenge for formulators of industrial products including turbine oils.

Challenges for Turbine Operators

Turbine operating conditions have become more severe than ever. Power outputs have increased while the amount of oil in the system has stayed the same or decreased resulting in a more stress on the lubricating oil. Peaking turbine units operate in a cyclical stop-start mode resulting in a wide variation between higher operating temperatures and much cooler ambient conditions. These large differences in temperatures can result in varnish deposition on critical surfaces, particularly in gas turbines which can cause turbines to trip resulting in significant added costs for the power supplier.

Turbine oil performance is critical to turbine oil reliability. In a recent Shell poll, more than 50% of turbine operators indicated that their main concern was the cost of an unplanned shutdown during turbine operation. These same turbine operators also are expecting longer oil life from their lubricants.[1]

For these turbine operators, oil selection has become more important than ever. Lubricant performance focus on enhanced protection, longer oil life and increased operating efficiency all can help increase productivity and reduce maintenance. Optimization in this area can be a challenge for traditional mineral based lubricants, but new technology can offer improvements in this area.

Turbine Oil Functionality

In its simplest form, the basic function of a turbine oil is to reduce friction and wear, remove debris and heat that is formed in the bearing area and to prevent the formation of rust, varnish and system related deposits. In many power generation systems, the lubricating oil also acts as a seal oil, sealing hydrogen in the generator and in some applications, must function as a hydraulic oil in control systems. In gas turbines, the turbine oil must exhibit excellent thermal and oxidational stability in base load and peaker operations. In steam turbines, the turbine oil must be able to operate in wet conditions. In both steam and gas turbines, the lubricating oil must show exceptional stability over long periods of operational service.

In today's economy, there are several themes and applications which are undergoing substantial changes as customers are reducing the cost of operation in order to stay commercially competitive. Today it is finding the best, most efficient and cost competitive solutions. Turbines are becoming more efficient, facing higher loads, higher pressures, higher operating temperatures, and in some cases, smaller oil reservoirs. This means that the both oil and hardware must work much harder.

Customers demand higher lube performance, at the same or reduced costs to remain competitive. The modern turbine oil must be multifunctional being able to effectively lubricate steam, gas and hydroelectric turbines, turbo compressor systems, non-antiwear (lower pressure) hydraulic systems, mist oil systems and many large circulating systems. While lubricant price is always an issue, the customer should consider lubricant performance and look beyond the initial cost of the lubricant.

Lubricant performance is optimized when a formulation is based on a high quality base oil used in combination with select additives designed to enhance the performance of the finished product. The formulation performance is highly dependent on the choice of base oil so the performance characteristics of the base oil must be carefully considered. Traditionally, turbine oils have been formulated with Group I or II base oils and only recently have GTL base oils been available. The properties inherent to GTL base oils offer enhance turbine oil performance.

Gas-to-Liquid (GTL) Technology

Shell GTL (Gas-to-Liquid) technology advances the development of a new generation of lubricants. The GTL process is an integrated process that sequentially converts natural gas to synthesis (syn) gas to hydrocarbon liquids through the Fischer-Tropsch process and finally to GTL products [2] (Figure 1).

The GTL process consists of three stages:

In the first stage, synthesis gas, a mixture of hydrogen and carbon monoxide, is manufactured from natural gas by partial oxidation. Impurities are removed from the syngas.

A second stage converts the synthesis gas into liquid hydrocarbons using a catalyst. In this stage, a liquid is formed which looks and feels like wax at room temperature.

The final stage is cracking and isomerisation, which 'cuts' the molecule chains into shorter lengths. This yields high quality liquids such as diesel, kerosene and lubricant oil.

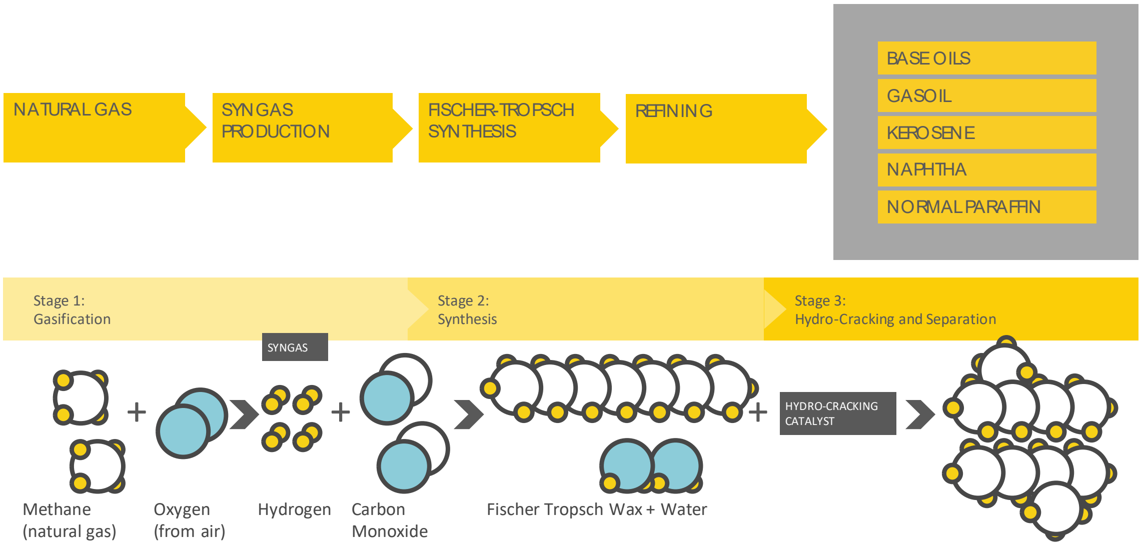


Figure1.The GTL process

The GTL process results in generation of several highly-demanded liquid hydrocarbons, including gas oils, kerosene, naphtha, paraffin and base oils. Compared to base oils refined from a crude mineral oil, which results in huge variations in composition and performance, GTL base stocks are colorless and odorless with very low levels of impurities like sulfur, aromatics and nitrogen.[3] A comparison of physical and chemical properties of GTL base oils with traditional Group I, II and III base oils is provided in Table 1. Therefore, they can be used as high-quality ingredients for finished lubricants. Because of the uniform chemical structure and high purity, GTL base oils exhibit excellent surface properties such as rapid air release, low foaming and quick water separation. For instance, GTL base oils exhibit low foaming tendency compared to Group I/II/III base oils in ASTM D 892 foaming test (Figure 2).

Table 1. Comparison of typical physical and chemical properties of commercially available Group I, II, III and GTL base fluids.

Property	Test Method	Group I	Group II	Group III	GTL
Viscosity, cSt @40°C	ASTM D445	30.8	41.2	46.6	45.4
Viscosity, cSt @100°C	ASTM D445	5.17	6.40	7.67	7.73
Viscosity Index	ASTM D2270	95	104	132	139
Flash point - PM, °C	ASTM D93	213	224	233	242
Pour point, °C	ASTM D97	-15	-15	-15	-36
Saturates content, %	IP368	79.7	> 99	> 99	> 99
Carbon Distribution - Cp, %	ASTM D3238	64.9	68.7	79.7	93.4
Sulfur content, mg/ kg	ASTM D5453	1140	8	2	<1
Nitrogen content, mg/ kg	ASTM D4629	10	1	1	<1
Air release, mins @50°C	ASTM D3427	2.9	1.3	2.2	0.2
Foaming characteristics: Seqn I tendency/ stability, ml	ASTM D892	520/ 0	190/ 0	240/ 0	0/ 0

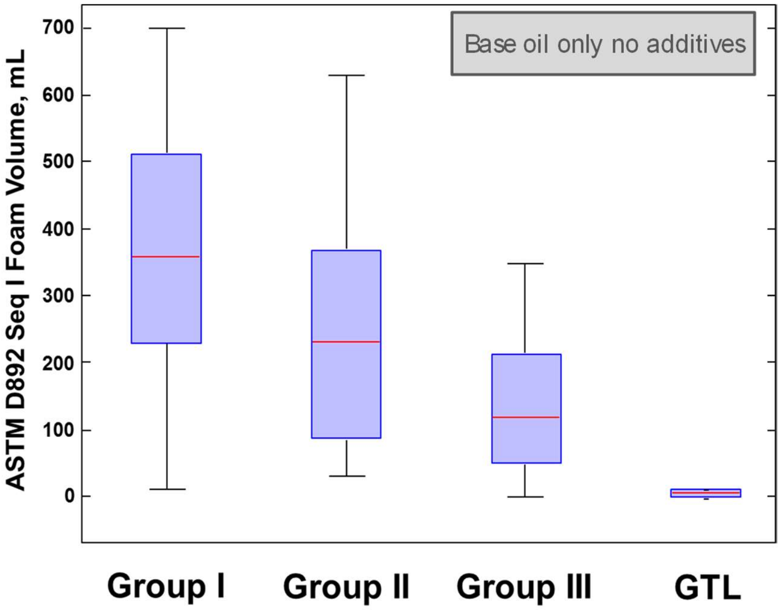


Figure 2. Comparison of Foaming Behavior of Group I, II, III and GTL base fluids.

GTL base oils also respond very well to performance enhancing additives such as antioxidants and solvency improvers, allowing the lubricant manufacturers to control the vital performance and to achieve longer oil life and better resistance to deposit formation.

Modern Turbine Oil Formulations

To achieve the highest levels of performance in turbine lubricants, there must be an inherent understanding of base oil and additive interactions. Understanding these interactions helps to match required turbine oil performance against the requirements of the machinery and the operating conditions. As indicated earlier, turbine oil formulations must be multifunctional and must provide reliable performance without causing system performance issues. Therefore, formulating turbine oils requires a delicate balance of the correct base oil and additives, (Figure 3).

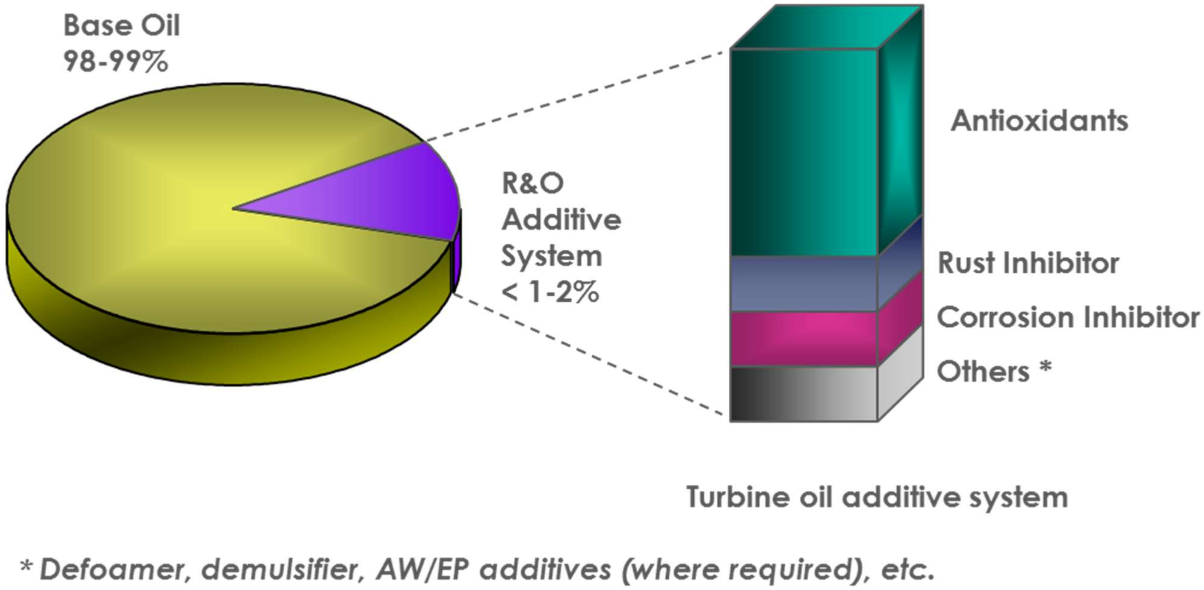
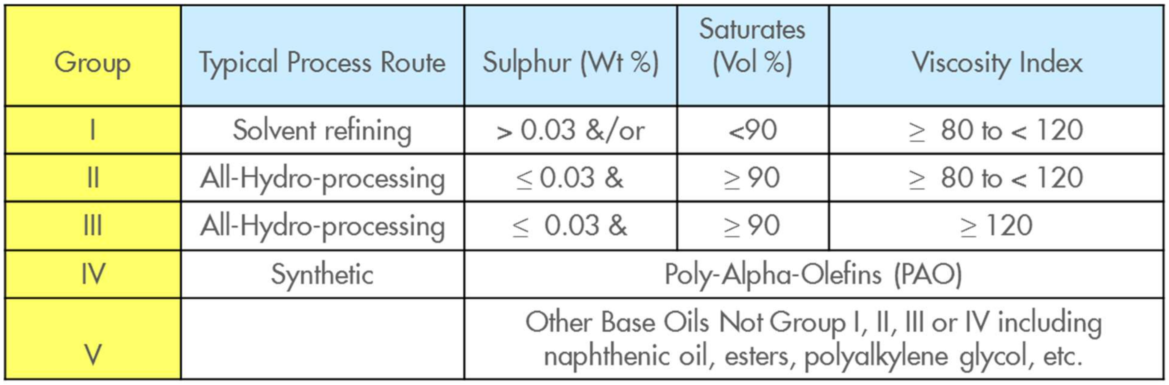


Figure 3. Typical turbine oil formulation

In the past, the most unreliable or problematic part of a turbine oil formulation was the thermal instability of the base oils used in its manufacture. Years ago, base oil processing left behind aromatic hydrocarbons and heterocyclic compounds, which when exposed to heat and/or temperature cycling would breakdown resulting in the formation of system sludge and varnish. In just about every finished lubricant area, internal combustion engines, automatic and manual transmissions, hydraulic, industrial gear, turbine, etc. there was a significant need to improved base oil quality. As a result, refining technology has undergone significant changes over the past 40 years or so. Base oil refining technology has resulted in the production of new high-quality base stock that are either catalytically hydro-processed and/or synthesized from waxy feed stocks or gaseous hydrocarbons, such as gas-to-liquids process.

Established first in 1995, base oil definitions have evolved to the present API classification presented in Table 2, which reflect base oil processing.

Table 2. API Base Oil Classification



Group	Typical Process Route	Sulphur (Wt %)	Saturates (Vol %)	Viscosity Index
I	Solvent refining	> 0.03 &/or	<90	≥ 80 to < 120
II	All-Hydro-processing	≤ 0.03 &	≥ 90	≥ 80 to < 120
III	All-Hydro-processing	≤ 0.03 &	≥ 90	≥ 120
IV	Synthetic	Poly-Alpha-Olefins (PAO)		
V		Other Base Oils Not Group I, II, III or IV including naphthenic oil, esters, polyalkylene glycol, etc.		

In today's market, proper base oil selection is essential to the manufacture of high quality finished lubricants. Different product lines require different performance features of the various API Base Oil Classifications above. Because of high performance requirements and cost considerations, most modern turbine oils are formulated with either API Group II or Group III base oils. With the exception of Group V base oils, which can vary significantly in performance, in general, for a given additive formulation and concentration, the performance of the turbine oil increases as the API base oil group increases. See Figure 4 below.

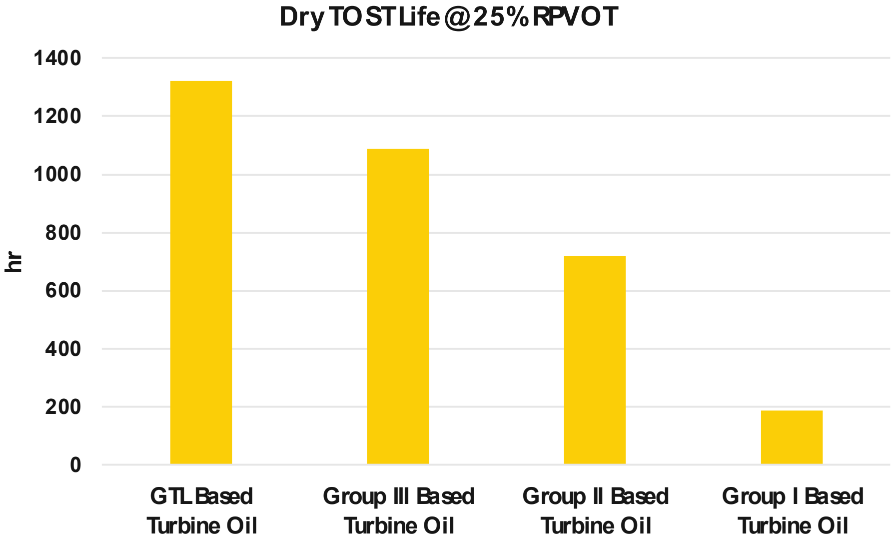


Figure 4. Comparison of Turbine Formulations using the Dry TOST Method (D7873) using commercially available base oils with the same additive system.

While the data in Figure 4 might suggest that higher API base oil group categories will outperform the lower API base oil groups – the results can be very different with different turbine oil formulations. Therefore, while proper base oil selection is critical, just as essential is the development of a balanced additive package. Studies show that older tests like D943 *Standard Test Method for Oxidation Characteristics of Inhibited Mineral Oils* and D4310 *Standard Test Method for Determination of Sludging and Corrosion Tendencies of Inhibited Mineral Oils*, which are effective steam turbine oil tests, can't effectively predict whether turbine oil will form deposits, or how long the oil will last in service in modern gas turbines. However, combining the newly developed D7873 *Determination of Oxidation Stability and Insolubles Formation of Inhibited Turbine Oils at 120 °C* with other key thermal and oxidative tests is crucial in formulating modern turbine oils.

Just as base oil technology has changed over the years, additive technology has changed significantly as well. Additive screening and the interaction of the additive with themselves and well as the response to different base oils takes years to complete. Traditionally, the antioxidant system has been a balance of phenolic and aminic antioxidants. As turbine oil formulations shift more to gas turbine usage, the formulation approach has been to less volatile phenolic antioxidant and aminic antioxidants that are more soluble in the formulation as it ages.

When formulated with the correct antioxidant system, Group II and especially Group III base oils have excellent thermal and oxidative stability and can lead to the development of long-lasting, clean-running, balanced turbine oils. Other additives, corrosion inhibitors, rust inhibitors, etc. also need to be more thermally stable than in the past and must remain soluble over the lifetime of the turbine oil. Maybe not so obvious, in service turbine oil formulations are expected to degrade with service. The key to long oil life and trouble free operation is the rate of oil and additive degradation and the management of the by-products that may form from the turbine oil. Formulations, which can keep additive by-products soluble in the fluid are preferred.

The third part of a modern balanced turbine oil formulation is its solvency. API Group II, Group III and Group IV base stocks have less natural solvency, when compared other base oil classifications. Higher formulation solvency will improve additive functionality and will help additive degradation materials to remain in solution for longer periods of time, resisting the formation of varnish and system deposits. However, the solvency additive chosen should not negatively affect the formulation. For example, for many years, esters, diester and polyesters have been used to improve solvency and to act as seal swell additives in finished lubricants; however, the addition of these materials may negatively affect turbine oil performance since these materials can react with water under certain conditions forming weak organic acids. Thus, the selection of the solvency additive to the modern balanced turbine oil must be done with great care and rigorous testing.

After the formulation has been thoroughly tested in the laboratory, the final step in product development is field testing of the formulation. Thus, it takes many years to develop and field test a new turbine oil formulation. Finally, turbine oils are very susceptible to contamination, from other lubricants (particularity formulations containing detergents and surfactants, i.e. motor oils) and supplemental additives. A relatively small amount of contamination can significantly affect the surface properties and service life of turbine lubricants. Therefore, great care must be taken at all stages of these lubricants during manufacture, handling and usage.

Performance enhancements of turbine oils with GTL base oil

Gas turbine end users are looking for three benefits when selecting turbine lubricants: enhanced protection to their system, extended oil life, and excellent system efficiency.

a. Enhanced protection

Turbine oils are designed to lubricate the rotating bearings and provide protection to bearing surface. GTL-based turbine oils are able to maintain viscosity even at extreme operating temperatures due to its high viscosity index. This means at all operating conditions, GTL-based turbine oils can maintain sufficient oil film to separate the surfaces of bearing and turbine shaft, preventing metal contact and wear formation. Rapid water separation together with addition of corrosion and rust inhibitors helps protect system components from ingression of dust, water and other contaminants.

b. Extended oil life

GTL-based turbine oils inherit the excellent thermal and oxidation stability of GTL base stocks. Typically, they are also formulated with optimized antioxidant system to further prevent oil degradation when system is under stress. Presence of degradation products in the oil can act as a catalyst to further accelerate oil breakdown and shorten oil life. Turbine oils formulated with GTL base stocks combined with a balanced additive system exhibit longer oil life even under severe operating conditions. This is proved by ASTM D943 turbine oxidation stability test (TOST). GTL based turbine oil lasts significantly longer than 10,000 hrs.

Oil degradation products are generally polar with higher molecular weight and easy to form insoluble materials on metal surfaces which reduce bearing clearance. The addition of solvency enhancer can dissolve degradation products and prevent deposit formation when oil degradation occurs. ASTM D7873 Dry TOST method can be used to predict deposit potential of a turbine oil. GTL-based turbine oil results in much cleaner test tube after 1008 hrs at 120°C, compared to conventional turbine oils (Figure 5).

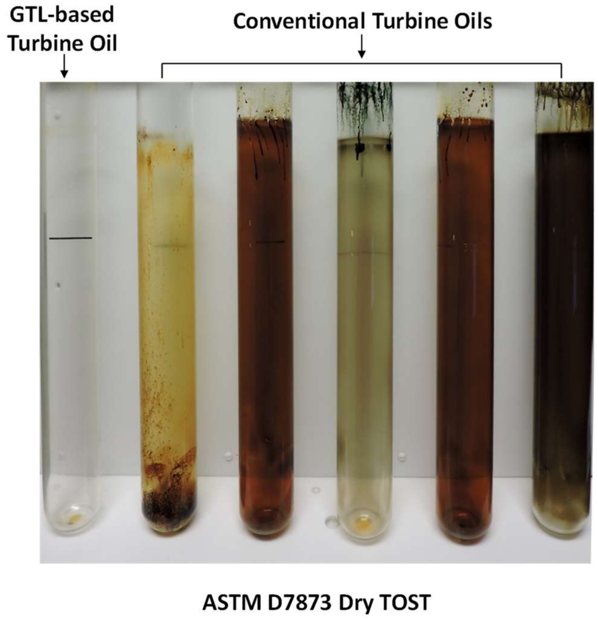


Figure 5. Comparison of GTL based turbine oils vs. conventional fluids

c. Excellent system efficiency

Turbine oils need to lower friction, control foam build-up, readily separate from air and water ingress in the system to provide excellent system efficiency. GTL-based lubricants are designed to maximize friction control and keep component cool and moving smoothly. The inherited properties from GTL base stocks, such as rapid air release, good foaming control and fast water separation, can prevent build-up of excessive foam and emulsion and thereby enhance system efficiency.

Conclusion

Customers demand higher lube performance, at the same or reduced costs to remain competitive. The modern turbine oil must be multifunctional and must exhibit excellent thermal and oxidational stability for long service live and maximum performance. GTL-based turbine oils with an advanced additive technology are designed to provide turbine end user with enhanced protection to their system, extended oil life, and excellent system efficiency. Customer field trials have shown that using a GTL-based lubricant can significantly reduce the total cost of ownership by enhancing system reliability and reducing the costs associated with maintenance and unplanned turbine shutdown.

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