ABSTRACT

There is a need in today’s market for significant improvements in base oil quality. Engine oils in particular require high quality base oils in order to meet tight volatility specifications such as ACEA A3/B3 and proposed ILSAC GF-3. Formulations based on VHVI base oils from fuels hydrocracker residues may be more cost effective than other high quality base oils like PAOs in satisfying these quality requirements. The UCO lube process developed by SK Corporation and Raytheon Engineers and Constructors is an economical route for producing high quality VHVI base oils from fuels hydrocracker bottoms. The quality of these lube base oils is similar to PAO in general performance. According to an application study, 15% PAO in ACEA A3/B3 SAE 10W/40 formulation can be replaced by 18% VHVI base oils from the UCO lube process. The study also showed that it is possible to develop a heavy duty diesel oil such as API CG-4/SH SAE 10W/40 utilizing UCO base oils. The demand for VHVI base oils is increasing rapidly because their availability is increasing. Severe hydrocracking for the manufacture of VHVI base oils will maintain its position as a leading technology into the next century.

INTRODUCTION

There has been a clear change in automotive engine oil specifications to lighter viscosity multigrades in order to achieve better fuel economy and low temperature performance. In the North American market, this trend has been driven by CAFE (Corporate Average Fuel Economy) regulations. In Europe, the move to lighter viscosity multigrades has been slower than in North America, but the regulations and product specifications are expected to evolve in a similar fashion. The market in Asia, especially Japan and Korea, has also followed this direction to satisfy the regulations both internal and in the passenger car export countries.
The above has lead to an increased use of high quality base oils like PAOs and VHVI base oils. Top-tier European SAE 10W-40 engine oil formulations have to contain high quality base oils in some amount in order to meet the tight volatility specification. The amount of high quality base oils is normally minimized in the formulations due to the high price of these special base oils in Europe. The proposed ILSAC GF-3 specification is also expected to increase the demand for high quality base oils. With their availability rapidly increasing, VHVI oils produced by severe hydrocracking are an economical choice to satisfy the above mentioned market needs.

This paper discusses a cost-effective hydroprocessing route to produce high quality VHVI base oils, their physical properties and some applications in top-tier automotive engine oils, as well as the market trends for these VHVI oils.

NEW REQUIREMENTS FOR LUBE BASE OILS

The major forces driving the change in the automotive lubricant industry are higher fuel economy, further low temperature improvements, longer drain intervals and emission system durability. Increased use of lighter viscosity multigrade oils to achieve better fuel economy and low temperature performance has made base oil properties key factors in lubricant design. Today, the more severe demand for volatility and low temperature properties requires full integration of base oils and formulation technologies. Conventional mineral base oils alone are no longer adequate to meet the top requirements among North American and European specifications, especially volatility. These trends will be further tightened in future specifications such as ILSAC GF-3.

AN ECONOMIC ROUTE FOR VHVI BASE OIL MANUFACTURE
A VHVI base oil is defined as a high quality hydrocarbon lubricant having an inherent viscosity index of 120 or above. There are several approaches to producing VHVI base oils. Generally, VHVI base oils are produced by severe hydrocracking of vacuum distillate fractions in a fuels hydrocracker. Another route for VHVI base oil production is hydro-isomerization, in which slack wax, produced by solvent dewaxing is converted to branched chain paraffins under hydro-isomerization conditions with an appropriate catalyst. The conversion rate of the process is about 80 - 85%, and the residual wax is typically removed by solvent dewaxing to improve the low temperature fluidity of the finished product. Gas, Naphtha and gas oil are formed as by-products.

Gas-to-liquids conversion technologies are providing another option to PAO or VHVI based lubricants. These Extra High Viscosity Index (XHVI) base oils have an inherent viscosity index of 140 and above.

SK Corporation (formerly Yukong Limited) has developed a new technology which offers the refiners who operate fuels hydrocrackers an alternative to produce high quality VHVI base oils from a variety of crudes. Some refineries are known to be producing VHVI base oils using the unconverted oil generated by a fuels hydrocracker. However, those plants have several disadvantages caused by uneconomic integration of the fuels hydrocracker with the lube process such as: storage and transportation of the waxy fuels hydrocracker bottom oils between the hydrocracker and the conventional lube oil plant, cooling and reheating of the hydrocracker bottoms stream.

The objective of the development of the UCO lube process was to solve the integration difficulties and develop a process which uses the hydrocracker bottoms efficiently, while improving the overall utilization on the hydrocracker as well as the lube base oil plant.

The first commercial facility, designed by Raytheon Engineers & Constructors, came on stream at SK's Ulsan refinery in October 1995 and produces 3,500 bpd of VHVI base oils sold under
the YUBASE name. SK's UCO Lube Process (UCO standing for unconverted oil) is a unique, patented process to produce VHVI base oils from fuels hydrocracker bottoms.

Figure 1 depicts the operation of the hydrocracker prior to the installation of the lube plant: 35000 bbl of feed, consisting of 30000 bbl of fresh feed and 5000 bbl of recycle, are fed from the feed vacuum tower (V1) to the hydrotreating reactor (R1) (all flows in the following description are in feed equivalent volume). Reactor R1 effluent is joined by 15000 bbl of recycle to make a total of 50000 bbl to reactor R2. Reactor R2 effluent is separated in the fractionator (F) into 30000 bbl of diesel and lighter products and 20000 bbl of recycle. 5000 bbl of recycle are sent to the feed vacuum tower V1, in order to reject to the vacuum residue a portion of the refractory components and polynuclear aromatics which would otherwise accumulate and cause a rapid decline in catalyst activity.

Figure 2 shows the hydrocracker operation with lube production. A portion of the UCO originating from the existing fractionation section is fed at a controlled rate and temperature to a new vacuum tower (D), where it is fractionated into product-quality distillate cuts having the desired viscosity, flash point and volatility characteristics. Each cut is cooled and sent to intermediate storage prior to catalytic dewaxing. The excess distillates are combined, reheated to the unconverted oil temperature and sent, together with the remainder of the unconverted oil, to the reactor section in the hydrocracking unit.

The lube processing scheme results in a reduced quantity of unconverted oil that must be purged from the product fractionator (F) bottoms stream. This frees capacity in the feed vacuum tower (V1) and the hydrocracker feed system, permitting the replacement of unconverted oil by fresh feed, thereby allowing the hydrocracker fuel production rate to be maintained at design quantities.

The downstream dewaxing technology originally selected for the commercial facility was conventional catalytic dewaxing. In order to improve dewaxed oil yield and quality, the catalyst was replaced with a new isomerization type catalyst in June 1997.
The UCO lube process results in investment and operating costs which are dramatically lower compared to conventional lube processing. Typical investment and operating costs based on 5000 bpd lube base oil production from an existing fuels hyrocracker are shown in Table 1.

PRODUCT QUALITY

The UCO lube process produces 3 viscosity grades in 2 quality levels with viscosity indices in the range of 110 - 130. Table 2 shows some key properties of these base oils. The base oils produced by the UCO lube process have many desirable properties: high viscosity index, low volatility, low aromatics and low hetero-atoms content. Tables 3 and 4 compare the properties of typical 150N grade base oils produced by various means: the UCO process, conventional solvent refining, and lube hydrocracking.

The UCO process product is superior in main performance areas such as viscometrics, low temperature properties, volatility and oxidation performance. The main components of the UCO process product are paraffins and mono-/di-naphthenes, which give good viscosity-temperature behavior and excellent oxidation stability. Oxidation stability or anti-oxidant response is important in the performance of most lubricants. Screening test results by RBOT and PCT demonstrate that the UCO process product has much better oxidation stability than conventional mineral base oils. The UCO process products contain much higher saturates and lower sulfur, which are beneficial for oxidation stability and give good response to antioxidants, respectively. The narrow hydrocarbon distribution of the UCO process products results in a very low volatility, similar to that of PAOs.

APPLICATIONS OF UCO PROCESS PRODUCTS

European Passenger Car Motor Oil
One of the advantages of VHVI base oils is their excellent cost-performance feature. Top-tier European SAE 10W/40 engine oil formulations need to be blended with some amount of a high quality base oil, PAO or VHVI, to meet the tight volatility specification. The amount of high quality base oil is normally kept to a minimum to reduce the cost of the formulation. To improve the economics of SAE 10W/40 engine oil formulations, it is usually possible to replace PAOs with carefully selected, less expensive VHVI base oils.

In order to make SAE 10W/40, ACEA A3/B3 grade engine oils, about 15wt% of PAO-6 should be blended into the finished products. In the course of a recent study, SK was able to replace the 15wt% PAO with 18wt% VHVI base oils produced by the UCO lube process. The base oil interchange guideline for ACEA engine oils permits the replacement of up to 30wt% of an API Group IV base oil (PAO) by a Group III oil, with only one additional engine test. Some critical engine tests were conducted both for the performance qualification and for OEM approval. Tables 5 and 6 give comparisons of physical properties and some engine performance tests for both VHVI and PAO blended engine oils. The VHVI and PAO blended oils are equivalent in properties like volatility, low temperature properties and high temperature viscosity. Both in the ASTM Sequence VE engine test, which is the minimum engine test required by ACEA base oil interchange rules, and in the VW 1302 engine test, which is one of the engine tests required to qualify for VW 500/505 specifications, the VHVI blended oil satisfied all the specification of detergency, oxidation performance and wear performance.

The above indicates that VHVI base oils from fuels hydrocracker residues are more cost effective than PAO-based oils in achieving the synthetic performances of top quality European 10W/40 engine oils.

North American Heavy Duty Diesel Engine Oil

SAE 10W/40 diesel engine oils offer many advantages over SAE 15W/40 oils, one of the most important being wear reduction just after engine starting by shortening oil supply time at
low temperature. In spite of this, engine manufacturers are still reluctant to use lighter viscosity oils in this service, because it sometimes results in higher oil consumption and more bearing wear than SAE 15W/40 oils. SK has shown that this can be prevented by using VHVI base oils. Two API CG-4 diesel engine oils were compared: an SAE 15W/40 oil containing conventional mineral base oils (150 and 500 solvent neutrals) and an SAE 10W/40 oil containing a VHVI base oil produced using the UCO lube process (YUBASE-6).

The properties and engine performance tests results of these two oils are given in Table 7 and Table 8. The Noack volatility of the SAE 10W/40 oil is 8.7wt%, even less than that of SAE 15W/40, 11.1wt%. The SAE 10W/40 oil results in a reduced oil consumption in both Caterpillar 1N and Sequence E engine tests, due to its low volatility.

Modern diesel engines also require lubricants with excellent soot control ability. Mack T-8 and GM 6.2L engine tests evaluate soot-induced viscosity increase and soot-induced wear, respectively. When soot-loading increases, the viscosity increase and the filter plugging are much higher for the conventional mineral based oil than for the VHVI based oil. In the GM 6.2L engine test, wear is at the same level for both oils. In case of the VHVI based SAE 10W/40 oil, low temperature startability and pumpability are also excellent compared with the conventional mineral based 15W/40 oil as shown by the low CCS (cold cranking simulator) viscosity.

White Oils

The UCO process products are also very good feedstocks for the production of high quality white oils. The UCO products can be classified as technical white mineral oils satisfying the FDA regulation 21 CFR 178.3620(b). In order to be used as food grade white oils as defined in the 21 CFR 172.878 and 21 CFR 178.3620(a) regulations, these products must be further refined by conventional white oil processes.
With the acid treating process, these feedstocks provide high yields (in excess of 95 %) of high quality white oils characterized by low contents of normal paraffins and hydrocarbon chains smaller than C18.

SUPPLY AND DEMAND OF VHVI BASE OILS

VHVI Base Oils Supply

There are 7 plants in Europe that produce high quality VHVI lube base oils. Many of those plants are using the severe hydrocracking route to produce quality fuels and lube base oils from a wide range of crude oil sources. Some plants also produce quality lube base oils by hydro-isomerization of slack wax. Fully formulated brand products using those base oils were introduced in the market in the early 1980's.

There are 4 plants in Japan, all of them using different VHVI base oils manufacturing technologies, allowing these companies to differentiate the performances of the finished lubricant products.

In North America, the Group II base oil capacity is presently about 25 % of the total lube base oil capacity. So far, the production of Group III base oils has remained low due to their limited market there.

In other areas, a few plants produce VHVI base oils. Their combined capacity, however, is less than 1,000 bpd.

At present, it seems that SK has the largest capacity, with around 3,500 bpd.
The total worldwide VHVI manufacturing capacity was about 12,000 bpd in 1996 and is expected to grow to around 22,000 bpd in 2000. Figure 3 shows the current and predicted VHVI base oils supply capacity. It is expected that the manufacturing capacity will grow by about 20% per annum. This does not mean, however, that there will be 22,000 bpd of VHVI base oils on the market in year 2000. Most VHVI base oils are produced in blocked operation and producers can switch their operation back to conventional mineral base oils when there is not enough market for VHVI base oils.

About 79% of VHVI base oils were manufactured by severe hydrocracking in 1996. We expect that severe hydrocracking will maintain its position as a leading technology in year 2000.

VHVI Base Oils Demand

Severe market requirements for lower emissions and energy saving and increase in VHVI base oils availability are the major factors influencing VHVI base oils demand. The market share of VHVI based lubricating oils is therefore expected to grow, particularly in automotive applications.

The ILSAC GF-1 volatility limit specification was max. 25%, GF-2 is max. 22%. In the latest ILSAC GF-3 proposed specification, the volatility of 5W/10W-xx products is limited to max. 15%, which is almost the same level as in the European ACEA specification. These changes will make it even more difficult to formulate oils from conventional mineral base oils. Formulators will need to use at least high quality API Group II or Group III base oils to meet the tightened volatility specification of ILSAC GF-3.

On the basis of previous market trends, the demand growth rate for VHVI base oils, in the most likely case, is around 20% per annum as shown in Figure 4.
Europe, Asia and Australia are the current main markets for VHVI base oils. The market in North America is at present very limited. Several companies in North America have announced plans to modify their current base oil plants or to build new lube base oil plants to produce higher quality base oils, mainly API Group II base oils. These and the existing hydrocracker-based plants may also have the capability to make Group III base oils. Manufacturing capacity of VHVI base oils has been, and is expected to remain, higher than demand. But it is likely that many of the suppliers will not sell their VHVI base oils in order to differentiate their own finished products, or at least will not sell them at a low price.

Present and Future of VHVI Base Oils

Today, although VHVI base oils are comparable in quality to PAOs and are more economical than PAOs in their applications, most lube manufacturers still prefer PAOs because they are easy to buy and easy to use while the viscosity grades of VHVI base oils are limited, from 3cSt to 8cSt at 100°C.

In the future, it is expected that API Group I base oils will maintain their position as main base oils, though they will probably lose market share to Group II base oils, and the demand for high quality Group II and Group III VHVI base oils will be increasing rapidly, perhaps at double digit annual rates. PAO synthetic base oils will likely maintain their position as the first choice for blending synthetic lubricants.

CONCLUSIONS

SK has developed a new technology which offers refiners with fuels hydrocrackers a method of producing high quality lube base oils from a variety of crudes. The UCO process produces higher quality lube base oils at lower investment and operating costs than conventional solvent refining or lube oil hydrocracking.
The demand for high quality base oils is expected to grow rapidly to satisfy the new quality requirements. This study shows that the high quality VHVI base oils produced via the UCO technology can offer end users comparable performance to PAOs at a lower price.

The process is offered by Raytheon Engineers and Constructors, Inc. SK offers the possibility of pilot plant testing of various potential feedstocks for product quality and yield determination.

REFERENCES