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Assessment of using unleaded fuel in the harsh environment of the United Arab Emirates

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Abstract

The service life of lubricating oil produced in the United Arab Emirates (UAE) was examined using a car fueled with leaded or unleaded gasoline of the same grade in harsh local conditions. In addition, the economic impact of using leaded vs. unleaded gasoline via the effects on the useful life of engine oil was investigated. Every 500 km that the car was operated, the physical properties of the oil were examined to determine the optimum oil life before replacement. It was found that relative to unleaded gasoline, leaded gasoline resulted in a faster deterioration of lube oil properties and a reduced useful life of the oil. Many of the effects of use on the physical properties of oil became apparent from the beginning of its service, especially when leaded gasoline was used. Our findings indicate that the recommended useful life of oil when using leaded gasoline is 2500 km. With unleaded gasoline, deterioration of the physical properties of the lubricating oil became a concern after 3000 km. Thus with unleaded gasoline, it is recommended to have an oil change every 3500 km. These findings indicate that the decision of the UAE government to stop using lead compound additives to improve the octane number of gasoline will not only protect the environment from the harmful effects of lead compounds, but will also extend the useful life of oil. This extension will reduce the amount of used oil that is disposed of by up to 4678 tons/year. This reduction in oil use translates to a cost savings of about 23.4 million UAE Dirhams (= $6.37 million US Dollars) per year.

Keywords: Lubricant; Leaded gasoline; Unleaded gasoline

1. Introduction

Lubricating oil is one of the most important factors affecting the life of the engine. Any change in its composition or physicochemical properties during the service life can be classified as an aging process. As oil circulates through the engine it collects a variety of contaminants, including dirt and heavy metals (Zinbo et al., 1995). Contaminated oil can clog engine parts and this may result in the need for motor repair and part replacement.

The appropriate interval between oil changes depends heavily upon the engine's operating conditions and temperature. With use, the detergent dispersant, anti-wear, oxidation, and rust and corrosion additives in oil eventually become depleted, and the oil loses much of its ability to prevent deposits from accumulating on critical engine parts. Contaminants can alter the viscosity of oil, preventing proper lubrication. Soot, dirt, sludge, and oxidation products can make the oil too thick; conversely, dilution with unburned fuel may make the oil too thin (Turner and Austin, 2003).

Total acid number (TAN) is a measure of the condition of the base-oil. It changes when organic acids build up in the oil due to oxidation. Herguth and Philips (1994) showed that the TAN in lubricants tested did not increase the antioxidant concentration of lubricating oil. Synthetic hydrocarbon lubricant however represents an exception to this property. In fact, the antioxidant concentration of synthetic hydrocarbon lubricant began to increase at the first sampling, and continued to increase throughout the aging process. The viscosity values for most of the lubricating oils tested remained relatively constant until the antioxidant additives in the lubricants were depleted.

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Total base number (TBN) describes the acid neutralization ability of the oil. That is, higher TBN oils provide longer lasting acid neutralization capability, which allows for extended drain use. Many mineral motor oils are formulated with a TBN in the range of 6–12 mg/g, and synthetic motor oils generally have a TBN in the range of 9–11 or higher. TBN numbers below 6 mg/g signal a need to change the oil more frequently to prevent acid buildup. TBN measurements are frequently used to predict the useful remaining life of engine oil (Kaufman, 2000). He showed that a lower flash point increases the tendency for oil to suffer vaporization loss at high temperatures and as a result to burn off onto hot cylinder walls and pistons. The flash point can be an indicator of the quality of the base stock used to produce the oil. In essence, the higher the flash point the better the oil. Kaufman showed that the absolute minimum flash point temperature to prevent possible high consumption is considered to be 200 °C, although the flash point of oil used in this work was 190 °C.

The adverse effects of water in oil include the following: lubricant breakdown, through oxidation and additive precipitation; change in viscosity, affecting the ability of a lubricant to maintain the film thickness necessary to protect the lubricated surfaces; and corrosion, accelerated fatigue of lubricated surfaces. Moisture contamination within the lube oil will thus result in increased viscosity, decreased TBN, acid formation, accelerated oxidation and nitration. Barnes (2001) showed that the presence of water in oil can augment oxidation tenfold, resulting in premature aging of the oil, particularly in the presence of catalytic metals such as copper, lead and tin. Certain additives such as anti-wear, extreme pressure and phenolic antioxidant additives are readily hydrolyzed by water, resulting in both additive motility and the formation of acidic by-products. These formations can cause corrosive wear. Other additives such as demulsifying agents, dispersant detergents and rust inhibitors can be washed away by excessive moisture. This results in sludge and sediment build up; filter plugging and poor oil/water demulsibility.

Camy (2004) found that oxidation reactions are influenced by antioxidants. Even after consumption of the antioxidants, the hydrocarbon chains can be oxidized by a radical mechanism and an exothermic effect can clearly be seen. Khonsari and Booser (2003) showed that oxidation additives are consumed slowly during the initial oxidation period. The addition of inhibitor during this time frame lengthens the induction period and delays acceleration of oxidation reactions by breaking down the hydro-peroxides that form during the initial oxidation step. As shown in Eq. (1), the Arrhenius principle applied to lubricant life, the life of oil L (h) drops by a factor of two for each 10 °C rise between 100 and 150 °C (Khonsari and Booser, 2003).

$$\log L = K + \frac{4750}{T + 273}, \tag{1}$$

where K is a factor that depends on oil type and it is related to the oxidation life of mineral oils under ideal conditions. The oil should be changed when one of the following criteria have been reached: (1) its acidity has risen by 0.2–0.3 mg KOH/gm above that for new oil or (2) when the viscosity has changed by more than 5% from that of new oil and oxidation products are forming due to decomposition of the oil at high temperature and in the presence of oxygen.

Among the waste products of oil consumption are aldehydes, ketones, alcohols, carboxylic acids, anhydrous esters and ethers. The mixture of these compounds is considered sludge. As these compounds build up, oil viscosity increases which causes an increase in the pressure differential across the filter. This in turn shortens both oil and filter life.

Barnes (2003) used Fourier transform infrared spectroscopy to precisely analyze base oil oxidation. He found that oxidation of the base oil results in the formation of carboxylic acids which can cause corrosion. An increase in TAN is usually a harbinger of an even more damaging chemical process, the formation of sludge and varnish. These materials form when oxygenated reaction by-products, such as hydroperoxides and carboxylic acids, combine to form larger molecular species. Any degree of polymerization will result in an increase in the measured viscosity. Garage (2003) considered various theories related to oil change interval and concluded that the following Ted Kublin equation provides an acceptable method to determine oil change timing:

$$\begin{aligned}&(\text{Virgin TBN})(10)(\text{Oil capacity})\\&\quad\times\left[\frac{\text{Cubic inches}}{\text{Horsepower}}\right](\text{Mpg}) = \text{oil change.}\end{aligned} \tag{2}$$

This equation divides cubic inches by horsepower as an indicator of the engine's natural stress level. A high output engine will be harder on oil than a low-output engine. Then it multiplies that by the miles per gallon of the specific engine being tested. Then it multiplies these by the oil capacity, as a greater oil capacity means the work is spread over a greater volume, and multiplies these by ten times the virgin oil's TBN (representing the oil's ability to handle the stress loads) to arrive at the oil change interval.

Carey and Hayzen (2001) and Turner and Austin (2003) showed that the dielectric constant is another important indicator of oil quality that is easy to measure on-site. This test can reflect the presence of contaminants, such as water or particles, or changes in oil chemistry due to additive depletion or oxidation.

The environmental impact of discharged used oil is related firstly to its inherent physical and chemical properties, and secondly to the quantity disposed and method of disposal. The most relevant physical and chemical properties of used oil are: opacity of color, viscous consistency, metal particle content resulting from abrasion, contents of minerals and other contaminants and specific density relative to water (Muller, 1989).