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Characterization of the properties of diesel-base oil-solvent-waste oil blends used as generic fuel in diesel engines

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ABSTRACT

Foreign-dependent pricing policy in petroleum sector has led the market opportunists and transportation sector drivers to seek alternative cheaper fuels for diesel engines in Turkey. A new generic fuel blend of virgin/nonstandard base oils and/or low taxation wastes (waste lubricants, mineral oils, heavy solvent formulations etc.) with diesel fuel called number 10 lube (NTL) has been widely used for such purposes in public transportation vehicles or trucks over the last decade. Therefore, this study was conducted to characterize the fuel properties of NTLs to evaluate the probable impacts on engine performance and exhaust emissions. All tests (density, viscosity, flash point, pour point, water content, sulfur content, volatile content, acid number, base number, corrosiveness, color and Fourier Transform Infrared Spectroscopy analysis) were conducted at an accredited fuel analysis laboratory. The results showed a large fluctuation in NTL properties among the dealers or location. The outlier values observed for various physicochemical parameters indicated adulteration with different types of waste oils (vegetable, cooking, engine, mineral) and solvents in NTLs which make them unsuitable for diesel engines. Such an adulteration case is exceptional but fuel misuse is a common problem in the world, hence, should be managed properly and tackled with implementation of appropriate taxes.

1. Introduction

The depletion of fluid fossil fuels looms as a worldwide concern for the future. In today's world, on the other hand, fuel quality is an important ingredient of environmental and public health, particularly for developing countries. This is because the performances and emissions of engines are sensitive to the fuel used as they are designed to run on fuels with certain specifications. The specifications of the fuels produced by the refineries should comply with regulatory constraints. However, due to unstable pricing policy in oil importing countries, fuel dealers have shown interest in participating in fuel blending activities generally referred to adulteration. Financial incentives arising from differential taxes adopted for crude oil products and wastes are generally the primary cause of this commercial activity [1]. This problem is common to most developing countries in South Asia and has also been reported in Greece, Brazil and African countries [1–4]. The topic of concern presented in this study is completely different from the observed adulteration case around the world. A new generic fuel blend of virgin/nonstandard base oils and/or low taxation wastes (waste lubricants, mineral oils, heavy solvent formulations etc.) with diesel fuel called "number 10 lube" was introduced into the diesel fuel market in Turkey after 2004 and this issue emerged in the following years due to higher tax rate on diesel fuel compared with that on lubricants [5,6].

Number 10 lube (NTL) is the name given to lubrication-grade base oils due to their property of best functioning as diesel substitute. Theoretically, they contain group I type base oils namely, SN100 as a major constituent (90–100%) plus SN150 and SN500 with minor percentages (2–10%) in the formulations [7]. However, the type/group of base oils used in the preparation of this generic fuel is vague and NTLs may include waste lubricating oil, waste motor oil, illegal fuel, used cooking oil, aged olive oil, white spirit, solvents, and even end of life transformer oil in practice. The majority of medium- to heavy-duty truck or public bus drivers have preferred such generic fuel in the commercial form of base oil, base oil + diesel mixture or base oil + diesel + solvent + oil industry wastes. In a study conducted by the Turkish Petroleum Industry Association (TPIA) [6], the NTL samples taken directly from the fuel tank of truck or from the commercial market in tin were observed to have varying fuel properties when compared to national diesel standard (TS EN 590). Uyaroğlu et al. [8] have pointed out the long term damage in pistons' material strength and, thus, shortening of periodic maintenance time with increasing operating expenses due to physicochemical properties of NTLs. Eryılmaz et al. [9], on the other hand, showed decrease in power and moment values, and increase in specific fuel consumption when fuelling single cylinder, four cycle, direct injection, and rate power of 15 HP engine with NTL. They also reported comparable CO, CO_2, NO_x, SO_2 and higher HC emissions during the use of NTL in diesel engine compared to diesel fuel. Other than these studies, there has not been much information reporting the use of non-standard fuels in diesel engines [10–13]. Excluding the practices on diesel fuel-

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waste oil blends for use in diesel engines [10,11], the use of base oils directly or with a blending of solvents and oil industry wastes for such purposes is uncommon [14]. Therefore, the characteristics and constituents of such fuels are of great importance in terms of the pollutants they emit into the atmosphere [12].

In Turkey, it is reported that there are greater than 4.5 million trucks or buses currently in service in 2014 [15], and most of them are diesel fuelled vehicles. Therefore, the demand for diesel fuel would be increased as expected to happen in typical/standard market conditions. It also means that a potential grows for NTL producers or dealers, since there is around a 0.30$ difference per liter between the NTL and diesel fuel prices in the current market. The NTL market would seem to continue to grow and evolve since the estimated number of diesel vehicles fuelling by NTL accounts for 30% of total in service [16]. At present, it is traded under a different name called “number 5 lube” in which more solvent is added to improve fuel flow properties under cold or winter-like conditions [16]. Thus, a number of newspaper articles highlighting the NTL issue and written questions submitted to the Turkish Grand National Assembly seeking detailed information on national scale [17] wonder “why and how” such a fuel is in market and its likely impacts on human and environmental health. Therefore, an investigation was carried out to determine the physical and chemical properties of NTLs used as alternative diesel fuel and the typical forms of adulteration by comparing the results with those of conventional diesel and lubricant standards. The data were discussed together with base oil/diesel/waste oil characteristics and the probable impact on engine performance and exhaust emissions.

2. Materials and methods

2.1. Sampling

A total of 30 samples from 25 provinces in Turkey [18] were collected between October 2012 and March 2013 from truck/bus stations, vehicle maintenance facilities, and commercial markets in the roadsides that were considered to be the main business sites. Sampling from four different provinces was also conducted at different time intervals to represent the variability of product contents. The origin and trade mark of the samples are kept confidential. The visual appearances of the samples were from light yellow to dark red. NTL samples being sold as bulk or in tins were placed into plastic bottles (1–2 L) and stored at 4 °C until analysis.

2.2. Physicochemical analyses

NTL samples were analyzed for physical and chemical properties according to Turkish (TS), American Society for Testing and Materials (ASTM) or International Organization for Standardization (ISO) standard procedures. All tests were conducted at fuel/petroleum analysis laboratory of İnönü University accredited according to ISO 17025. Briefly, density was determined at 15 °C according to the TS EN ISO 12185 using KEM DA-505 density meter. Kinematic viscosity was determined at 40 °C according to the TS 1451 EN ISO 3104 using a TANAKA AKV-202 measuring system. Flash point was determined following the TS EN ISO 2592 using an automated Cleveland open cup flash tester, TANAKA ACO-7. Pour point was determined following the ASTM D 6749 using a TANAKA MPC-102. Water and sulfur contents were measured using a METTLER TOLEDO/DL 39 and SPECTRO XEPOS 03 STD gas systems according to the TS 6147 EN ISO 12937 and TS EN ISO 8754. Nonvolatile content of NTL samples was determined according to the ASTM 1259-06. While base number was determined according to the TS 5655 ISO 3771 using a METTLER TOLEDO DL28, acid number was determined according to the ASTM D 664 using a METTLER TOLEDO/T50. TS 2741 EN ISO 2160 copper strip test was applied to evaluate the corrosiveness of samples. Color was determined according to the ASTM D 6045 using a LOVIBOND/PFX195 measuring system. The infrared spectrum for each sample was measured using BRUKER/TENSOR 37.

2.3. Data processing and interpretation

Since there is no methodology on the production of NTLs or the constituents being used in the preparation of such generic fuel, the analytical quality of data was established by representative and comparable information provided by the laboratory. The fuel properties of NTLs were first compared to national standards for diesel to ascertain the suitability of the fuel, and then, for base oils to determine whether it has fundamental characteristics or not. Additionally, obtained results were further compared to oil industry wastes in the literature to highlight the adulterants of concern. Data analysis was completed for each property with Excel 2007 (Microsoft, Redmond, WA, U.S.A.) software to calculate statistical values. Pearson correlation was used and coefficients were calculated using SPSS (Statistical Package for the Social Sciences) Statistics 17.0 software.

3. Results and discussion

3.1. Physical and chemical properties

The diesel engine has an excellent status for fuel efficiency, reliability and durability [19]. These characteristics find the meaning and value with long term efforts expended on the improvement of engine technology and fuel quality. The efforts on fuel content or quality may sometimes invalidate the reputation of diesel engines as is the case for NTLs. Therefore, the physical and chemical properties of NTLs given in Table 1 were discussed in context with diesel (TS EN 590, column 8) and base oil (TS 13369, column 9) standards, and/or commercial base oil (column 10), and waste oil (column 11) to comment on their probable impact on emissions in the following subtopics.

3.1.1. Density

Density is an important fuel property considering the working principle of diesel engine designing to have volumetric fuel economy and maximum power. The density of diesel fuel, thus, affects the amount of fuel processed in the combustion chamber and subsequent products emitted to the atmosphere. The limits were set in national diesel fuel standard ranging from 820 to 845 kg/m^3 to regulate fuel quality. As can be seen from Table 1, the density of NTL samples varied from 836 to 928 kg/m^3, which means a 1.57% variation. While the highest density level was detected in a sample obtained from Zonguldak, which is one of the main routes of trucks used for coal transportation, lower variation was observed in samples collected from the eastern part of Turkey. Almost all NTLs (97%) used as a diesel substitute did not comply with the ranges specified in diesel fuel standards. Such spatial heterogeneity between the parts of the country suggests poor control measures adopted by the local authorities on commercial NTL activities.

There is no value specified for density in the national standard of petroleum-/synthetic-based base oils. On the other hand, the density of samples is almost similar to (excluding one outlier) those measured in a set of 38 mineral base oils (median: 870 kg/m^3; min–max: 828–906 kg/m^3) routinely used in the industry [20], and analyzed as 891 to 901 kg/m^3 for used/waste lube oil or engine oil in the literature [21,22]. The outlier value in the data may probably be the result of mixing waste/used engine oil with commercial base oils. This speculation is important to determine the potential impacts that might be associated with the use of NTLs since waste engine oils contain relatively more pollutants e.g. metals, oxidation products, and aromatics [23]. An increase in fuel density may lead to injection of greater mass of fuel into the combustion chamber, an advance in fuel injection timing considering the injection system of diesel engine working on a volume basis [8,24,25]. This may cause a poorer combustion and unstable