Study on the engine oil's wear based on the flash point

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Abstract. Increasing energy performance of internal combustion engines is largely influenced by frictional forces that arise between moving parts. Thus, in this respect, the nature and quality of the engine oil used is an important factor. Equally important is the effect of various engine injection strategies upon the oil quality. In other words, it’s of utmost importance to maintain the quality of engine oil during engine’s operation. Oil dilution is one of the most common causes that lead to its wear, creating lubrication problems. Moreover, at low temperatures operating conditions, the oil dilution with diesel fuel produces wax. When starting the engine, this may lead to lubrication deficiencies and even oil starvation with negative consequences on the engine mechanism parts wear (piston, rings and cylinders) but also crankcase bearings wear. Engine oil dilution with diesel fuel have several causes: wear of rings and/or injectors, late post-injection strategy for the sake of particulate filter regeneration, etc. This paper presents a study on the degree of deterioration of engine oils as a result of dilution with diesel fuel. The analysed oils used for this study were taken from various models of engines equipped with diesel particulate filter. The assessment is based on the determination of oil flash point and dilution degree using the apparatus Eraflash produced by Eralytics, Austria. Eraflash measurement is directly under the latest and safest standards ASTM D6450 & D7094), which are in excellent correlation with ASTM D93 Pensky-Martens ASTM D56 TAG methods; it uses the Continuous Closed Cup method for finding the Flash Point (CCCFP).

1. Introduction
The trend of increasing energy conservation and the reduction of green-house gases means improvement in fuel consumption of automotive engines. Even if, for modern engines, the useful work loss due to internal engine friction is relatively small, the reduction of all energy losses, including friction, remains as a valuable contribution to overall efficiency improvement. Improvement of fuel economy has been one of the most important challenges for the automotive industry. A small gain in fuel consumption reduction, even by 1% over existing levels, is an important achievement [1].

Currently, lubrication is a key methodology to reduce energy consumption and emission, which is very important to create a sustainable society. In this regard, to reduce friction and wear, new technologies, novel lubrication oils and additives are being developed [2].

To improve the energy efficiency of engines, even increasing capacity lubricating fuels is a topic for researchers. For example, Perekrestov A. P. in [3] proposes the development of additives for diesel fuels with very low sulfur content.
One disadvantage of diesel compared with gasoline engines is that they generate greater problems regarding emissions. In respect to this, new specific depolluting strategies are required. According with new emission regulations, additional equipment for diesel after-treatment such as catalytic convertor, particulate filter (PF), exhaust gas recirculation, NOx after treatment etc. is need to be added. Using a PF has become somewhat standard with Euro 4 norms which halved the mass of particulate emissions compared with Euro 3. For this reason, many Euro 4 diesel cars are equipped with PF and starting with Euro 5, all diesel powered cars have PF.

Non-combustible ash can be deposited on channel walls through the full length of a diesel particulate filter (DPF). This type of ash can affect the exhaust condition and heat transfer process during the periodical soot regeneration of DPF [4].

The regeneration process involves continuing the combustion in the filter. To continue the combustion in the exhaust manifold, in the filter, it can be done in two ways: a) using the 5th additional injector which is mounted ahead of the oxidation catalyst; b) the second way of regenerating particulate filter without using an additional injector involves adding to the fuel injection one post-injection (or even more) during the power stroke so that combustion to occur in the PF.

Late post-injection strategy for the sake of particulate filter regeneration could be a cause of degradation of engine oil contamination with diesel.

The contamination of oil with fuel (diesel) has the effect of lowering the viscosity implying poor lubrication of moving parts. For instance, it may cause oil washing on the surface of the cylinder, and thus accelerates the wear of the piston and the cylinder. It also lowers the temperature of the oil flammability (flash point) which can produce its auto-ignition. Severe dilution reduces the concentration of additives in diesel oil and, as such, it reduces their effectiveness. At the same time worsening the lubricating conditions (the scaling in the rings area), appears a circulation of gas within the cylinder to the oil sump and to the combustion zone (increasing oil consumption).

Oil dilution with diesel, operating in low temperatures conditions may cause waxing. This can lead, at starting moment, to low oil pressure and starvation.

In this paper we have conducted a study on a number of samples of used oil that was used on engines containing PF. One single engine has the 5th injector. The emission norm of the engine was min. EURO 4. It was determined the degree of dilution through Flash Point. Also, a study on viscosity variation depending on vehicle’s mileage was performed.

2. Viscosity
Viscosity is a measure of a fluid’s resistance to flow at a given temperature. In the case of lubricants, it is commonly perceived as the “thickness”, of the oil.

Used oil analysis laboratories, lubricant manufacturers rely on viscosity measurements as a key parameter in determining the condition of used oil, or specification of a new oil. For example, changes in viscosity of used oils can be an indication of lubricant degradation (increase/decrease in viscosity), oil dilution (decrease in viscosity).

2.1. Equipment description
The U-VISC is a fully automatic system that uses glass capillary viscometers to measure the kinematic viscosity of Newtonian fluids. It can be applied for mineral and synthetic oils (fresh and used) and for any fluid within the viscosity range of the instrument. Figure 1 shows the equipment and its principal components.
The instrument can be equipped with 2 types of viscometer tubes: a) narrow range tubes with two sensors and 1 measuring bulb, offering approximately the ability to measure over a range of 1-10 mm²/s; b) wide range tubes with 3 sensors and 2 timing bulbs, which have 2 measuring sections: the upper section for lower viscosities, and the lower section for higher viscosities; this type of tubes offering approximately the ability to measure over a range of 1-100 mm²/s. Figure 2 shows both type of tubes.

![Figure 1. U-VIsce - viscometer](image)

The thermal sensors are responsible for accurately detecting the sample when it passes, allowing for the accurate timing of the sample’s flow time, and are essential to the correct operation of the instrument. This type of sensor measures the specific heat of the sample and is suitable for both transparent and opaque samples.

![Figure 2. Viscometer tubes](image)

a) narrow range tube

b) wide range tube
2.2. Method description

Standard Test Method for Kinematic Viscosity of Transparent and Opaque Liquids D 445 is under the jurisdiction of ASTM Committee D-2 on Petroleum Products and Lubricants. This test method specifies a procedure for the determination of the kinematic viscosity of liquid petroleum products, both transparent and opaque, by measuring the time for a volume of liquid to flow under gravity through a calibrated glass capillary viscometer.

The time is measured for a fixed volume of liquid to flow under gravity through the capillary of a calibrated viscometer under a reproducible driving head and at a closely controlled and known temperature. The kinematic viscosity is the product of the measured flow time and the calibration constant of the viscometer [5].

The time it takes for the sample to flow through a section of the tube is proportional to viscosity as follows:

\[ \nu = C \cdot t \]

Where:
\( \nu = \text{kinematic viscosity [mm}^2/\text{s]} \)
\( C = \text{viscometer constant [mm}^2/\text{s}^2] \)
\( t = \text{flow time [s]} \)

The viscometer constant \( C \) is determined by measuring the flow time of a sample of accurately known viscosity or certified reference standard.

For the wide range tube, which has 2 separate measuring sections, each section has its own calibration constant and needs to be calibrated separately.

As described in ASTM D445 / D446, in order for a kinematic viscosity measurement to be reliable, the flow has to be fully laminar and without turbulence. In real terms, this means the fluid has to move slowly down the capillary, with an evenly distributed velocity profile. If the sample flows too quickly, turbulence will occur which will affect the flow time of the sample.

In order to correct for this kinetic energy effect, the result should be corrected. Following Hagenbach and Couette theory [6], the result should be corrected as follows:

\[ \nu = C \cdot t - E /t^2 \]

The kinetic energy factor \( E \) [mm\(^2\)•s], though is not a constant, can be derived from the tube’s dimensions, such as capillary length and diameter.

ASTM D445 states that a kinetic energy effect can be significant for tube constants under 0.05 mm\(^2\)/s\(^2\), if flow times shorter than 200 seconds are used. The kinetic energy correction term, \( E/t^2 \), is negligible if the flow time is more than 200 s.

In order to specify the final result of the measure, we use “The Max. % difference expresses” which is the maximum difference allowed between 2 successive determinations compared to their average value. (For example, consider a sample which is measured 2 times. The first viscosity result is 100.0, the second is 100.05. This means the difference between the first and second result equals 0.05 / 100.025 = 0.05%).

If the relative difference between the 2 results is less than the Max % difference specified, the test will be regarded as complete. If not, another measurement will be performed and compared to the second result. This continues until 2 successive measurements fall within the Max % difference. In our case Max% =0.13%.

3. Flash Point and Dilution

In order to determine the oil flash point and dilution degree Eraflash apparatus produced by Eraletics, Austria was used. Eraflash measurement is directly under the latest and safest standards ASTM D6450 & D7094), which are in excellent correlation with ASTM D93 Pensky - Martens ASTM D56 TAG methods. It uses the Continuous Closed Cup method for finding the Flash Point (CCCFP).
3.1. Equipment description
In figure 3 is presented the Eralytics analyser.

4. Experiment
Figure 4 shows the measuring chamber inside where are the electrodes and sensors for temperature and pressure measuring.

4.1. Method description
The standard method which was used (ASTM D7094) is an extremely versatile flash point method that can be used for the accurate flash point measurement of almost every sample: gasoline, diesel, fresh oil, used oil, asphalt, tar, bitumen, hydrocarbon solvents, different types of paint and varnish and many other types of solids and liquids.

This standard method ASTM D7094 can be used even to determine the influence to the flash point of highly flammable fractions in samples like gasoline in diesel or diesel in oil or gas in oil.

The repeatability and reproducibility data from ASTM D7094 is better than with another standard method, like ASTM D93.

When the start temperature is reached the sample cup is lifted. After the sample cup is lifted the measurement is initiated. The electric arc ignites in the preprogramed interval steps. For this case, the interval is 1 second.

Depending on the selected method (ASTM D7094) and the current temperature, fresh air is automatically introduced into the measurement cup to keep up a sufficient oxygen level.

When the pressure after ignition, in the measurement chamber, is 20kPa or higher, the flash point was detected.

4.2. Experimental settings
Sample cup for ASTM D7094 is for volume of 2 ml sample.

In order to keep a homogeneous sample, it was necessary to put a stirring magnet into the sample cup as it can see in figure 5.

For standard flash point measurements, the following parameters have to be set:

*Measuring Range (“T range”)*

This parameter appears and is valid only when the expected flashpoint is selected for calculating the measurement range. Then, the measurement range (“T initial” and “T final”) is automatically calculated according to the “T range” parameter. “T initial” is automatically set according to the definition of the selected standard method and “T final” = “T initial” + “T range”.

Figure 3. Eralytics analyser

Figure 4. Measuring chamber
In our case, we don’t know the expected flashpoint, so the initial temperature “T initial” and final temperature “T final” were chosen (figure 6). The temperature of the cup must be below the start temperature.

**Ignition Frequency (“Step”)**

This parameter defines the temperature interval between two ignitions of the arc. It is defined by the standard method (1 second as we mentioned above).

**Ignition Energy (“Ignition”)**

The ignition length of the arc is also fixed by the standard methods.

In this paper, we determine oil dilution within diesel fuel. Thus, it was necessary to measure reference fuel dilutions and draw the dilution curve.

5. Results and discussion

The analysed oils used for this study were taken from various models of engines equipped with DPF. There are two types of oil: Castrol Magnatec 5w40 and Castrol Edge 5w30.

In table 1 the samples and the particularities of the cars are presented, respectively the engines which used this oils.

| ID_sample | Model car    | Year of car production | Kilometers total performed | Kilometers covered with oil | Period of oil use [month] | Mark and type of used oil | Pollution norm (EURO...) | Mark and type of fresh oil | 5th injector |
|-----------|--------------|-------------------------|----------------------------|-----------------------------|----------------------------|---------------------------|----------------------------|-----------------------------|--------------|
| TEST 1    |              |                         |                            |                             |                           |                           |                            |                             |              |
| sample_6  | Audi A5      | 2009                    | 160269                     | 15000                       | 13                        | Castrol Magnatec 5W40 DPF | 4                          | Castrol Magnatec 5W40 DPF | NO           |
| sample_4  | VW Passat    | 2006                    | 269208                     | 15000                       | 12                        | Castrol Magnatec 5W40 DPF | 4                          | Castrol Magnatec 5W40 DPF | NO           |
| sample_5  | Fiat Ducato  | 2006                    | 420323                     | 15000                       | 13                        | Castrol Magnatec 5W40 DPF | 4                          | Castrol Magnatec 5W40 DPF | NO           |
| TEST 2    |              |                         |                            |                             |                           |                           |                            |                             |              |
| sample_9  | Audi         | 2015                    | 30000                      | 30000                       | 5                         | Castrol Edge 5W30         | 6                          | Castrol Edge 5W30          | YES          |
| sample_8  | Audi         | 2011                    | 105000                     | 22000                       | 6                         | Castrol Edge 5W30         | 5                          | Castrol Edge 5W30          | NO           |
| sample_1  | Audi         | 2013                    | 119000                     | 15000                       | 4                         | Castrol Edge 5W30         | 5                          | Castrol Edge 5W30          | NO           |
| sample_6  | Audi         | 2013                    | 126000                     | 15000                       | 3                         | Castrol Edge 5W30         | 5                          | Castrol Edge 5W30          | NO           |
| sample_3  | VW           | 2012                    | 151000                     | 15000                       | 4                         | Castrol Edge 5W30         | 5                          | Castrol Edge 5W30          | NO           |
In order to determine the oil dilution with diesel fuel is necessary to measure the flash point. The first step for dilution determination is to realize the dilution curve for each type of oil.

In figure 7 there are presented the obtained dilution curves for the two types of oil: Castrol_Magnatec_5w40 and Castrol Edge_5w30.

![Dilution curves](image)

**Figure 7. Dilution curves**

As seen from figure 8, there are 2 samples in TEST2, sample8 and sample9, which have a value of flash point bigger than reference value. One possible explanation would be that the car owner has completed the oil, between the two exchanges, with an oil with flash point higher than the reference oil. For sample8, the viscosity is bigger than reference, too (figure 9). Diesel fuel inserts in engine oil unsaturated aromatic molecules that are pro-oxidants. Viscosity value may increase due to oil oxidation. We know that the number of kilometers covered with this oil is considerably higher than the other samples (22000 km for sample8 and 30000 km for sample9). Also, the vehicle corresponding for sample9, ran its first 30000 km. Thus, it is about a new engine which has the 5th injector (table1). It is possible for this oil to be contaminated with other wear elements.

![Flash Point and Dilution](image)

**Figure 8. Flash Point and Dilution**
Castrol Magnatec 5W40 DPF oil dilution was, on average, higher than the Castrol Edge 5W30 oil for an equal number of kilometers covered with it, 15000 km.

![Figure 9. Viscosity](image1)

![Figure 10. Average variation of viscosity](image2)

Maintaining a more constant viscosity is an important requirement. In the studied case, it is observed (figure 10) that oil Castrol Edge 5W30 has a viscosity average decrease of 7.11% compared to the oil Castrol Magnatec 5W40 DPF that has 27.23%.

6. Conclusions
This work aimed a study on variation of viscosity and degree of dilution for two types of oil depending on the degree of engine wear. The results do not show an expected trend. In conclusion, it is necessary to study a larger number of samples and correlating the results with other engine parameters (piston-rings-cylinder assembly, in-cylinder misfire etc). For the same number of kilometers covered with the same oil, duration of use is very important in terms of parameters variation studied. The study shows that a short time using causes less average variation of oil viscosity and less level of oil dilution. For a future study it is important to perform a comparison on the matter of the degree of variation of viscosity and oil dilution, between engines with PF and engines featuring the fifth injector.

7. References
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