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Influence of additives blended with motor base oils on the braking torque under an auxiliary external DC electric field

Juliusz B. Gajewski, Marek J. Głogowski*

Institute of Heat Engineering and Fluid Mechanics, Wrocław University of Technology, Wybrzeże Wyspiańskiego 27, 50-370 Wrocław, Poland

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ABSTRACT

The paper presents the results of experiments upon the influence of tribocharging of PAO and PAG synthetic motor base oils blended with different additives—friction modifiers (FM) and antiwear agents (AW)—and the effect of an external DC electric field on the braking torque. The experiments are carried out in a rotating shaft–oil–lip seal system which represents a specially built experimental facility to be a simplified model of an engine crankcase in the interior of which a metal shaft rotates. The research is especially aimed at the braking torque of a rotating shaft sealed with a lip seal and a possibility of reduction in the torque under external DC electric fields. DC voltage is applied between the stiffening ring of lip seal and a rotating, earthed shaft. The braking torque of rotating shaft is measured as a function of the oil–additive blend's temperature, the shaft's angular velocity, and the absolute value of the external DC voltage. In general, it is found that an external DC electric field causes the braking torque to change with the increasing DC voltage. The change depends on the additives and base oils used in their blends which in turn causes the torque to increase in the case of the PAO–additive blends or to decrease for the PAG–additive blends.

1. Introduction

Modern fully formulated engine oils consist of base stock and a number of additives such as anti-wear and extreme pressure additives, friction modifiers, antioxidants, detergents, dispersants, etc. Each additive affects the physical and chemical properties of either a metallic surface or base stock. The base stock (mineral, semi-synthetic and synthetic oils) has been used widely until recently but now research is directed to the introduction of new engine oils into the market that are based on polyalkylene glycols (PAGs) [1–4].

These base oils have several unique properties and among them especially important are excellent oxidative and thermal stability, a very high viscosity index (VI), low toxicity, and improved biodegradability which results in environmental friendliness [5,6]. The higher polarity of the PAGs than PAO makes them highly surface-active. They form stable lubricating films which minimize a metal-to-metal contact, thus reducing wear. At high temperatures and heavy loads these lubricating films are persistent. Unfortunately, the high polarity of PAGs leads to some disadvantages such as: aggressiveness towards some coatings and elastomers, and incompatibility with lubricant additives of low polarity. The PAGs are used as base fluids to formulate compressor lubricants, gear oils, engine oils, lubricating greases, brake fluids, metalworking fluids, fire resistant hydraulic fluids, industrial lubricants, and refrigeration lubricants [7].

Polyalphaolefins (PAOs) belong to the most popular synthetic base oils. One of the reasons for the popularity of the PAOs is their similarity to the hydrocarbon base oils, but without the presence of naphthenics and aromatics that negatively affect such properties as a viscosity index, volatility, and oxidation stability. The main benefit of the good VI is that the PAO does not need any viscosity improver to maintain the same viscosity at high temperatures. The PAO synthetic motor oil is characterised by the low level of polarity. To improve their compatibility with the highly polar additives e.g. rust, and anti-wear, extreme pressure agents as well as corrosion inhibitors the alkylated naphthalene is added. These oils are used to formulate engine oil, hydraulic fluids, compressor oils, high temperature gear and bearing industrial lubricants.

The antiwear additives and friction modifiers are used in engine base oils to form a relatively thick film on lubricated surfaces and to reduce internal engine wear and friction.

Antiwear (AW) additives are such types of agents that provide a good boundary lubrication and have the ability to build a durable boundary lubrication under severe load conditions.

Zinc dialkyldithiophosphates (ZDDPs) operate mainly as AW agents and antioxidants as well as have mild extreme pressure

* Corresponding author. Tel.: +48 71 3202793.
E-mail address: marek.glogowski@pwr.wroc.pl (M.J. Głogowski).

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characteristics. The AW agents react with surface asperities to reduce the contact between metal parts and to protect metal surfaces against corrosion. When the load is high enough to break down the oil film, the ZDDP reacts with the entire metal surface to counteract welding and to reduce wear. The ZDDP film composition and thickness are directly related to the temperature and the extent of surface rubbing. For the relatively low temperature as 40 °C the ZDDP is adsorbed physically on metal surface to form a monolayer. For the higher temperatures (>150 °C) a protective film is formed which is a highly electrically insulating layer. This layer can exert influence on tribocharging in any metal-to-metal system. Most of the AW additives have weak friction-modifying properties while the friction modifier (FM) additives have ability to reduce the friction coefficient and wear in a relatively thin film.

The FM protective layers are formed by the chemical reaction of an additive with the metal surface to build up a very low shear strength film. However, the primary difference is that the reaction has to occur under the relatively mild conditions (temperature and load) of the mixed lubrication regime. These conditions require a fairly high level of chemical activity as reflected by the phosphorus and sulphur chemistry applied. The FM lubricant films are built up of the orderly and closely packed arrays of multimolecular layers loosely adhering to one another and with the polar head anchored on the metal surface. The outer layers of the film can be easily sheared off allowing for a low coefficient of friction [8].

It is well known that any charged particle having an excess of electric charge and placed in an external electric field moves along the field lines at a rate dependent on its radius, a viscosity of the medium in which it is located, and the electric field strength.

The effect of an external DC electric field applied between the rotating shaft and the stiffening ring of a lip seal on the braking torque of the shaft is examined. The DC electric field is used to compensate for the natural electric field generated by the net charge of mobile ions and molecules in the zone between rotating metal shaft and the lip of a lip seal.

The motivation for doing such research is the introduction of the new PAG-based engine oils into the market and the PAG's quite good biodegradability [2,5,6,9].

The research results presented here are obtained for the range of oil temperatures and shaft angular velocities that are come across in everyday practice. The range of low temperatures and angular velocities is especially important when car engines are started up again after a while or when these are ticking over when vehicles are stationary (their crankshafts work at low angular velocities). Therefore, these ranges are 60–110 °C and 500–2000 rpm.

2. Experimental materials and measurement

2.1. Materials tested

The experiments are conducted for the following synthetic base oils: PAO 6 produced by NESTE OIL N.V., Beringen, Belgium and ROKOLUB® 68 (PAG) produced by PCC ROKITA, Brzeg Dolny, Poland. A specification of the oils tested is shown in Table 1. ZDDP Lubrizol 1395 (antiwear) produced in Austria by LUBRIZOL and IRGALUBE F10A (friction modifier) produced in France by CIBA are additives popularly used in motor and gear oils.

The steel shaft roughness is 0.32 μm. An 88-mm diameter fluorocarbon lip seal is used in all tests.

2.2. Measurements

The experiments on the influence of the external electric fields on the torque of rotating shafts for oils and their blends are performed in the experimental set-up built on the basis of a model engine, which is shown in Fig. 1.

Table 1
Specification of the base oils tested.

Quantity and unit	ROKOLUB 68	PAO 6
Kinematic viscosity		
At 40 °C	66.5	30.2
At 100 °C [mm^2 s^{-1}]	10.5	5.8
Viscosity index [–]	146	138
Density at 15 °C [kg m^{-3}]	990 at 20 °C	825
Resistivity		
At 40 °C	1.3×10^7	2.6×10^{11}
At 100 °C [Ω m]	3.5×10^6	6.4×10^{10}
Relative permittivity		
At 40 °C	5.8	1.9
At 100 °C [–]	5.1	1.9

It consists of: the housing of an oil chamber (1); a seal's stiffening metal ring (2); the lip seal tested (3); an insulator (4); the oil tested (5); an air bearings (6); the sensor of a torque meter (7); an electric engine (8); a steel shaft (9) earthed through carbon brushes; a microprocessor-based system for controlling the angular velocity and for measuring the braking torque of the shaft and the temperature of oil (10); a DC power supply (11); an oil heater (12), and a thermocouple (13). The chamber is filled with the oil tested up to a geometrical axis of the rotating shaft. The whole chamber is a simplified model of the part (oil sump or crankcase) of a real car engine.

The braking torque M is measured with a torque meter which is connected with its sensor mounted on an earthed rotating metal shaft. The DC voltage U_{DC} is applied between the seal's stiffening ring and the earth to produce a DC electric field; here the rotating shaft is precisely earthed as is the housing of an oil chamber.

3. Experimental results

The braking torque M measured is presented here as a relative one M_r (a dimensionless value) to enable the comparison of the torques between themselves for different oils and their blends with additives of different viscosities. The relative torque M_r means the ratio of the braking torque M_{DC} measured under the action of the DC electric field of both polarities (+/−) to the braking torque M_{NDC} without any external DC electric field applied: $M_r = M_{DC}/M_{NDC}$. The trends of the relative dimensionless value of the braking torque M_r as a function of the DC voltage U_{DC} of both polarities are shown in Figs. 2–9. The graphic symbols used for the data points mean: △ – pure base oil, □ – base oil and 0.1 wt% additive agent, ○ – base oil and 0.5 wt% additive agent for the negative DC voltage, ▲ – pure base oil, ■ – base oil and 0.1 wt% additive agent, ● – base oil and 0.5 wt% additive agent for the positive DC voltage. The research results shown here are selected out of many other obtained during

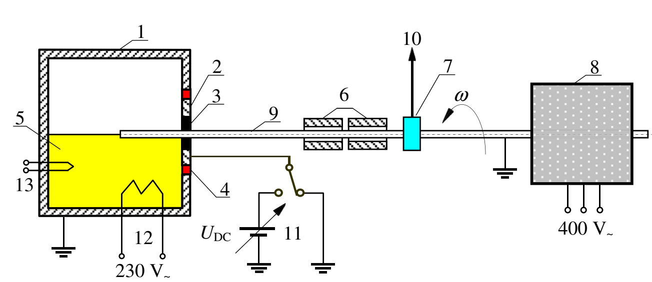

Fig. 1. The test stand for measuring the braking torque with and without an external DC electric field.