TRIBOLOGY ENHANCEMENT OF LUBRICANT QUALITY AND SAFETY

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Abstract: *A question of huge importance of applying tribology is the development and creation of higher quality of lubricants and additives to them, which influence equipment reliability and life, energy and raw material savings, as well as provide safety solutions to many environmental tasks. The paper stresses on the repair-regeneration oil additives. Added to oils or greases they form a thin protective layer, diminishing friction and wear, and assuring partial regeneration of worn surfaces under special friction conditions. Most interesting are the organic oil-soluble additives. An illustration with one of the newest additives, the oil-soluble metal-plating composite additive called "Valena", manufactured in Kazakhstan, is presented in the paper. The influence of this additive on the enhancement of the tribological parameters of contact pairs lubricated by oils and greases was studied as per the tasks of the International Faculty Agreement between the Faculty of Mechanical Engineering at the University of Belgrade, Serbia and the Faculty of Industrial Technology at the Technical University of Sofia, Bulgaria.*

Key Words: *tribology, lubricant quality, reliability of contact systems, environmental safety.*

1. INTRODUCTION: BACKGROUND AND FUTURE TRENDS

One of the most important problems in science and technology is to plan consumption and savings behavior over the long-term, and intend to balance them in the best possible. A way in solving that can be followed by the application of tribology. Tribology has always been at center of the struggle to increase reliability and quality, to reduce maintenance costs and to extend the service life of technical systems.

The outline in the proposed topic embraces the application of tribological knowledge, firstly, as enhancement of lubricant quality for better interaction between working surface and lubricant and for improvement of friction and wear as focusing the longevity and stabilization of lubricant, and secondly, from the point of view of green tribology, studying the issues to eliminate the lubricant as *one* of the main sources of environmentally hazardous affect [1–7].

Following these lines, the paper seeks to bind down tribology, reliability, quality and safety in the application of lubricants with additives based on general review and specific examples.

1.1 Lubrication and lubricants [8,9]

Lubrication is the process, or technique employed to reduce wear of two surfaces in close proximity (in contact), and moving relative to each other, by interposing a substance called lubricant between the surfaces. The interposed lubricant film can be a solid, (e.g. graphite, MoS_2), a solid/liquid dispersion, a liquid, a liquid-liquid dispersion (a grease) or a gas.

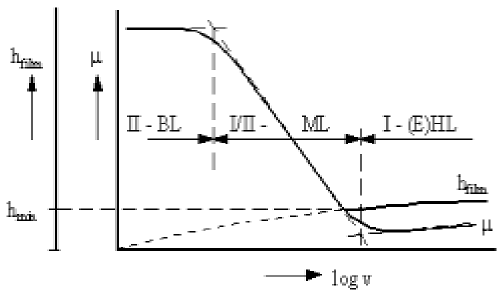

Figure 1. Stribeck curve

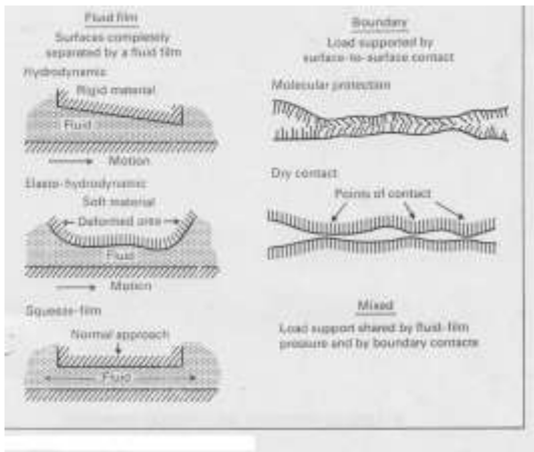

Figure 2. Lubrication modes

As the mechanical stress increases on the contacting surfaces, three regimes of lubrication can be observed (figs. 1 and 2): fluid film (elastohydrodynamic and hydrodynamic lubrication (E)HL), mixed lubrication ML, boundary film lubrication BL.

A question of huge importance of applying tribology is the development and creation of higher quality of lubricants and additives to them, which influence equipment reliability and life, energy and raw material savings, as well as provide safety solutions to many environmental tasks.

1.2 State-of-the-art in the development of lubricants directed to ecological sustainability

The continually increasing equipment temperatures and enlarged demands on lubricant life and operation raise the question as to whether today's lubricant technology will be able to satisfy future applications over the next decades [10-12].

For example, the global population is projected to increase from 7 billion to 8.3 billion by 2030. This is an increase of less than 1.2 percent. But income is likely to double over the same period. This significant disparity between projected population and income growth will drive a consumption outburst in the economies [13].

What are the **newest trends** connected with tribology of today [10-12].

- Equipment design

The new trends in equipment design include higher-power machines that are often lighter and smaller with reduced fluid reservoir sizes. With the trend in the direction of compacted engines continues, there will be a continual need for lubricants that perform better; e.g. future hydraulic fluids will require additive packages with greater performance in properties that include thermal oxidative stability and air release to compensate for the added stress put on the hydraulic fluid in the compact hydraulic system.

- Development in surface treatment

There have been antifriction metal-hardening treatments on the market for many years that either eliminate or greatly reduce the need for lubricants in some applications. Examples include carburizing, nitriding and boriding. A recent development is ultra-fast boriding, largely developed by STLE-member Prof. Ali Erdemir, senior scientist at Argonne National Laboratory [14]. Engineers will implement new sophisticated materials and surface finishes, i.e., on bearing materials such as DLC (diamond-like coating) to lower friction. This will require lubricants which are adapted to the new materials and surfaces designs.

- Longer periods of lubricant changes [11,12]

In general, the trend toward longer and longer oil change intervals (up to above 30 000 km in automotives) is due to better fluid performance, better machinery engineering and more sophisticated fluid analysis.

A fill-for-life fluid is not actual issue, because the main functions of oil are lubrication, temperature control and cleaning. So, a never changed lubricant should do all this for the expected life of the engine, which is a rather high requirement.

- Better fuel efficiency and alternative fuel vehicles [15,16]

Generally, fuel efficiency improves when there is less friction. But less friction means a lower viscosity lubricant and possibly less protection for machinery parts. Researchers are currently working on lubricants and additives that provide a meaningful increase in fuel efficiency without compromising protection. Combining low viscosity lubricants with low boundary friction technologies enables greater savings in fuel consumption.

Alternative fuels include bio-based, natural gas-derived, synthetic and hydrogen. A 2013 report says that sales of all-electric vehicles are limited by continued fuel economy improvement in other vehicle types, as well as some unfavorable features of the electric vehicles, such as improper space and costs, etc. Manufacturers are now moving toward hybrids and away from electric. This affects the future lubricants market in various ways. For example: All-electric vehicles do not use any engine oil; specialized engine oil for alternative fuel vehicles is to be created, etc.

- Implementation of environmental regulations

For the markets in the USA, Western Europe and Japan, any growth in the lubricant market will be motivated by the stricter implementation of environmental regulations [17-19].

Innovations in the next 30 years will be driven by high levels of regulatory pressure for emission reduction and fuel consumption, and sustainability should be a strong driver behind every new lubricant technology.

2. BASESTOCK AND ADDITIVES AVAILABILITY

The base stock oil is refined mineral oil that contains no additives. There are an increasing number of applications where conventional hydrocarbon base fluids cannot be employed anymore. One example is aviation turbine lubricants where, due to superior stability, specific ester base stocks are used instead of mineral oils. Higher requirements for thermo-oxidative stability, longer fluid life and higher thermal, mechanical and tribological loads on lubricants are projected for the future. The demand for high quality base oils with low viscosity is more and more increasing [8,9,12,18].

Saturation with hydrocarbons in lubricant development is however **not** reached. There are combinations between additives and base oils that are yet to be exploited. This is the case facilitated if hardware design incorporates additive/lubricant development at the conception stage of any new engine and machine.

Traditional additives (extreme pressure, antiwear, dispersants, anti-oxidants) have to comply with improved stability and calculated decomposition between surfaces and bulk phases.

The development of commercially workable green additives is an obvious need that could expand the current market for biobased and biodegradable lubricants. There are combinations between additives and base oils that are to be exploited. This is facilitated if hardware design incorporates additive/lubricant development at the conception stage of the new machines. [12,14].

2.1 Effect of the metal-cladding additives on the lubricating oil oxidation and thickness

Lubricating oil service time depends on its antioxidant property, i.e. its resistance to changes of phyico-chemical and service properties during operation and storage. Lubricating oil antioxidant stability is one of the most important properties determining its service period. The less stability is the more often the oil should be changed during operation.

The term *metal-plating lubricant* appeared in 1962 in connection of the invention by D.N. Garkunov in Russia, about a lubricant capable of realization of selective transfer of material between the contacting surfaces [20]. The development continued with the work of Prof. G. Polzer, Prof. V. Babel, Prof. R. Marczak, etc researchers in the field of selective transfer [20-24]. This class of lubricants contains 0.1 to 3 % of additives: metal powders, allows and oxides, salts and metal-organic complexes, so called metal-cladding additives. The metal-plating lubricant assists to the realization of selective transfer as result of which a friction surface film is formed that is subjected to small oxidation. The film is formed of metal atoms introduced in the contact zone with the lubricant used, varying from several atom plies to 2 - 4 μm.

Metal plating lubricants are employed for heavy loaded friction couples in machines, airplanes, cars, etc. Their use doubles or triples durability, makes two times decrease of friction losses and lubricants costs, and promotes machine efficiency. Mostly applied are metal plating lubricants that form Cu, Sn and lead films on the frictional surfaces. The metal-cladding additive application has been mostly realized in Russia, Germany and Poland, but also in other countries.

For example, metal mixture collodium has been used in USA for a long time [20]. It decreases bearing friction and renews the worn out surfaces when added into lubricant. Adding collodium into emulsion applied during metal cutting increases cutting speed and decreases wear of tool. Their mixture contains 70% copper, 30% lead, silver, tin and tellurium additives.

The use of copper-plated cast iron rings was suggested as a way of preventing "scuffing" in internal combustion engines and tests are described which support the practicability of this suggestion. The tests indicate that all the rings on a piston must be copper-plated to prevent rapid wear of the copper should an unplated ring scuff the liner. Tests showed that piston ring copper coating made engine cylinder wear 500 times less [25].

2.2 VALENA additive

This paper focuses on a study of one of the newest additives, the oil-soluble metal-plating composite additive called "Valena", manufactured [23] by the company "Rudservice" from Kazakhstan. The influence of this additive on the friction parameters of contact pairs lubricated by oils and greases, and the formation of frictional coating in the process of selective material transfer in the working contact have been investigated in the Tribology Laboratories of the Technical University Sofia and the Faculty of Mechanical Engineering of Belgrade University [22]. Research on friction and interface temperature in frictional couples lubricated by motor oil, transmission oil, and greases was carried out without and with additive.

Longevity of lubricant oil depends on the antioxidant property and the service properties during operation and storage. Influence of temperature and air oxygen assist oil aging, supposed it is not contaminated with wear debris. Hence lubricant oil antioxidation stability is most important for its service life. Less stability means also that it should be changed more often. During machine operation oil oxidation is intensified.

In order to reduce oil oxidation, metal-cladding oil additives realizing selective transfer of materials were developed. One of the newest is the oil-soluble metal cladding additive VALENA. V. Babel used inorganic salts, halides, as oil additives for improving tribological properties of the surfaces. As metal halides are insoluble in mineral oil, organic compounds were used to dissolve salts and give stable compositions when combined with oil. Alcohols meet these requirements. Alcoholic solutions of metal halides were injected into the base oil obtaining lubricant compositions. The negative influence of their acidity could cause corrosive effect, so industrial anticorrosive additive were added into the compositions [20].

The authors spotlight on the phenomenon of self-organization during selective transfer of materials in the contact of friction surfaces during the formation of a frictional coating on the surfaces, initially studied by D.N. Garkunov, G. Polzer, V. Babel, R. Marczak, etc. [24]

Characteristic for the process of selective transfer of material between frictional surfaces is the formation of secondary layer with low shift resistance in the contact. This protective layer cannot accumulate dislocations and is highly antifrictional. The self-organization phenomena in this case depend on the interface energy and the material exchange. That is why generation of that layer requires particular combination of materials of the contact surfaces, as well as special lubricant between them.

Repair-regeneration oil additives have an important place in the application of lubricants. Added to oils or greases they assure partial regeneration of worn surfaces under special friction conditions. At the same time they decrease the moment of friction and the coefficient of friction in the contact pairs of machines. Most common are the organic oil-soluble additives.

Examples referring to the study of friction in ball bearings illustrate the influence of the presence of VALENA additive in the lubricant [22]

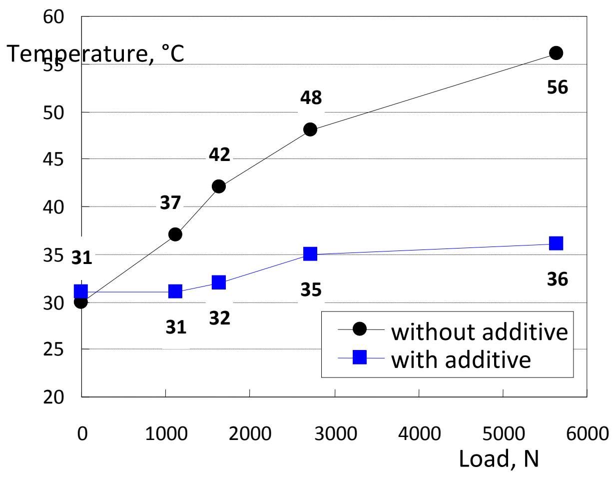

Figure 3. Variation of temperature of oil in bearing during friction with different loads

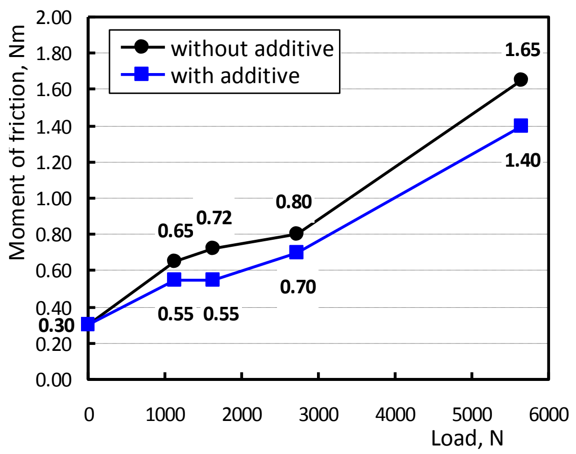

Figure 4. Variation of moment of friction in bearing with different loads during friction for oil with and without additive

From Figs. 4 and 5 it can be seen that the values of the moment of friction and coefficient of friction are for each load lower in the case of oil that contains "Valena" additive.

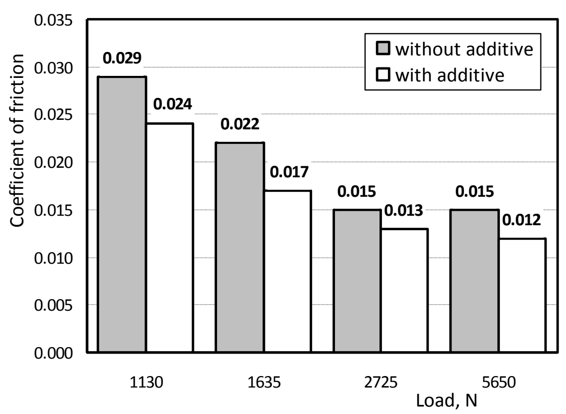

Figure 5. Dependence of the coefficient of friction on load for motor oil without and with additive

The reduction of the coefficient of friction by using "Valena" additive varies (from 13 to 23 %) with the applied load, and the average reduction is 18.3 %.

The results for oil temperature measurement (Fig. 3) show that in the case of motor oil with additive the temperature increases only 5 °C from unloaded to fully loaded conditions, while in the case of motor oil without additive temperature increases 25 °C for the same load increase. This suggests that the decrease of moment friction and coefficient of friction in the case of motor oil with "Valena" additive is not due to oil viscosity reduction at higher temperature, but due to the physic-chemical surface effects in the contact region during friction. The wear of the balls and rings also diminishes by the presence of additive because of its positive effect on friction properties.

After dismantling, the presence of thin copper film on shaft surface was observed. It has been formed during the friction process, due to physic-chemical and mechanical phenomena of selective transfer of copper on the steel shaft surface. The metal-plating additive "Valena" contains copper ions which are transferred on the shaft under the specific conditions of the experiment. The formed film compensates the roughness on the surface, and due to the small tangential resistance it makes the plastic deformations during friction in the surface layers easier. The presence of the copper thin film on the frictional surfaces is repeatedly observed in the case of greases containing "Valena" additive.

Friction, wear and temperature decrease in the contact joints when the lubricant contains "Valena" additive show that this additive plays in ecologically friendly direction: enhancement of longevity of lubricant layer, thus longer and more stable working period and elimination of that lubricant from the list of most hazardous contaminators.

3. CONCLUSION

The paper reviews the latest state in the reflect lubricants market and in the coming decades. The purposes are enhancement of tribological knowledge application as enhancement of lubricant quality in two directions: for better interdependence between working surface and lubricant and improved affect on friction and wear of the contact joint, improving thus the longevity and stabilization of the lubricant, and also highlighting the environmental issues to eliminate the lubricant as one of the main sources of environmentally hazardous pollution.

The needs of consumers, government agencies and equipment producers are in continuous progress, as well as the requirements of lubricant manufacturers and additive developers as regards lubricants quality at a higher level.

Future lubricants will require significant research and development expenses. Engineering a new lubricant requires a considerable investment without a sure payout. This is especially valid also for the development of commercially workable green additives. Partnership between the big chemical companies, the lubricant producers and developers, and the researchers from universities would be of great benefit.

An illustration of a modern development of lubricants and additive is done in the paper by the studied of the oil-soluble metal-plating composite additive "Valena" created and manufactured in Russia and Kazakhstan, and studied in the Tribology Laboratories of the Faculty of Industrial Engineering at the Technical University Sofia and the Faculty of Mechanical Engineering of Belgrade University.

The results have shown that the values of the tribological characteristics moment of friction, coefficient of friction and wear are for each load lower in the case of oil and grease that contain "Valena" additive, e.g. the reduction of the coefficient of friction in the case of motor oil was app. 20%.

The results for oil temperature measurement confirmed that the decrease of moment friction and coefficient of friction in the case of oil with "Valena" additive is not due to oil viscosity reduction at higher temperature, but due to the physic-chemical surface effects in the contact region during friction.

The obtained results stimulate a future systematic study of the influence of "Valena" additive in tribosystems operating under various conditions and various characteristics.

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