SERVICE PROPERTIES OF FUELS AND OILS

TRIBOCHEMISTRY OF JET FUELS


For a number of rubbing pairs in the fuel systems of gas-turbine engines, the fuel being handled also plays the role of a lubricant. An analysis of fuel-system parts removed from service because of excessive wear has shown that the rubbing pairs operate under boundary-lubrication conditions. Under these conditions, the lubricity of the medium is governed by its ability to form a boundary film on the metal (adsorption or physical aspect of lubrication) and distinct chemical compounds of the metal with components of the medium (tribochemical aspect of lubrication).

The absolute and relative intensities of the adsorption and chemical processes are determined not only by the frictional conditions, but also by the concentrations of the active components and the conditions for diffusion of these components to the contact zone.

It should be noted that the solid-phase reaction products that are formed when the metal reacts with the fuel are generated on the surface not in the form of a dense, continuous film, but as isolated formations at the sites of the greatest degree of metal activation. Depending on the frictional conditions, these islands of the new phases may either grow or diminish.

The working film that is formed as a result of these processes has a decisive influence on the intensity of metal wear.

From these considerations, it became evident that a study of the nature of the processes occurring in the friction zone would be of very definite practical interest, as would a study of the composition, structure, and properties of the products that are formed. The present work represents the first undertaking of the authors in this direction.

A number of years ago, attention was directed [1] to the important role of chemical (especially oxidative) processes occurring in the dry friction of metals. The role of oxidative processes in the friction of metals in hydrocarbon media was first pointed out by the authors of [2], who established that oxygen can reach the metal surface layers not only from the bulk oil, where it exists in the dissolved state, but also from organic compounds of the oil [3].

Studying oxidative processes, the authors of [4] concluded that such processes have a dual role in the friction of metals in hydrocarbon media. On the one hand, any reinforcement or acceleration of oxidative processes and of the related increase in oxide layer thickness will lead to increased wear; on the other hand, as scuffing of the steel becomes more evident, the wear that results from this process may be reduced by intensifying the oxidation processes.

Studying the process of metal friction and wear in hydrocarbon media (under severe boundary-friction regimes), G. V. Vinogradov and co-workers noted that the process of metal seizure (in a four-ball tester using low-viscosity hydrocarbon media) resulted in the formation of a brown deposit of high-viscosity resinous product on the surfaces of the wear scars and in their immediate vicinity. This observation enabled them to conclude that this formation of resinous deposits is the specific reason why breakaway or termination of the seizure can occur with comparative ease in the friction of steel in these media.

They observed a similar phenomenon at elevated temperatures in high-viscosity oils.

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The phenomenon of resin formation in a friction zone can be explained in various ways [5-7].

An attempt to study the "friction polymer" has been made by the authors of [8]. They established that the structure of the hydrocarbons determines not only the level of wear, but also the nature of the wear products. For example, in the presence of saturated hydrocarbons, these products consist mainly of iron oxides (Fe₂O₃ and Fe₃O₄), whereas unsaturated and aromatic hydrocarbons favor the appearance of an amorphous solid substance similar to "friction polymer." This substance proved to be insoluble in ordinary solvents, and it gradually carbonized when heated. The IR spectrum and chemical analysis indicated that it is an organic compound. Elemental analysis showed C 77.7%, H 6.6%, and Fe 4.1%. The IR spectrum of the polymer established the presence of carbon–hydrogen bonds, carbon–oxygen bonds in the form of carbonyl (C = O), and carboxyl groups (COO) [8].

The mechanism of polymer formation is interpreted by the authors of [8] in terms of catalytic conversion of hydrocarbons on clean metals.

These authors were studying tribochemical processes under severe conditions of boundary lubrication in sliding friction, with loads close to the critical. In contrast, we have studied the compounds formed under mild frictional conditions—in the rolling friction of ShKh-15 [ball-bearing] steel. This form of friction is characterized by relatively small tangential loads.

As a result of many observations, we have established that distinctive films are formed on the frictional surfaces; these vary in color from a light to a dark brown or even to black. The color of the products is determined both by the frictional regime and by the chemical composition of the fuel. These factors also govern the amounts of new compounds that are formed.

Figure 1a is a photograph of a typical friction surface with films of organic compounds. If this surface is treated with pyridine, the dark-colored film disappears (see Fig. 1b). Apart from the films that are washable (soluble) in pyridine, an insoluble film is formed on the surface, as can be clearly distinguished in Fig. 2. This film evidently has a rather strong adhesion to the metal; it is thin, transparent, and elastic.

These data make it possible to conclude that the compounds that are formed have a multilayer structure and are exceedingly complex in chemical composition.

Attempts to study the chemical composition of the structures formed directly on the frictional surface have not been successful.

A more promising approach is to study the chemical composition of the structures that are formed by means of analysis of the wear products. This was accomplished by the use of electron diffraction analysis and IR spectroscopy.

The amounts of wear products required for analysis were accumulated by centrifuging the fuels after test.

To obtain the IR spectra, the wear products were tableted in potassium bromide. The spectra were taken on a UP-10 spectrometer with the following parameters: slit program 4, spectrum scan rate 150 cm⁻¹/min, chartscale 12 mm/100 cm⁻¹, full-scale pen response time 10 sec.