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O. Radchenko, A. Matskevitch, S. Khanmamedov, S. Tuev
Odesa national maritime academy, Didrihson str. 8, Odesa, Ukraine,65029
Kiev state maritime academy, Repin str.3, Sebastopol, Ukraine, 99045
Institute of transportation problem of Russian academy of science, 12-th Line VO, 13, St. Petersburg, 199178
E-mail: rom1643@mail.ru

RHEOLOGICAL ASPECTS OF MARINE FUEL TREATMENT ONBOARD

Rheological properties of industrial fuel oil were analyzed. Temperature conditions of fuel oil treatment onboard were analyzed. The link between the microstructure of fuel environment and the quality of injection was found. The impact of alternating electric field is tested for the improvement of the combustion into real ship's power plant.

Keywords: *Ship's power plant, fuel treatment, industrial fuel oil, rheological properties, alternating electric field.*

Ship's heavy fuel oils, as a complex compound of various oil fractions, which have special physical properties. Disperse systems are stabilized and optimized by supplement of additives as known, consists of dispersing liquid – distillate fractions – light fuel oil (30 %) and dispersing medium – oil distillation residual fraction (70 % or more). Assuming that both phases of dispersion source retain their physical properties, moreover two-phase mixture has relatively "fluid" part and conditionally "amorphous". Accordingly, to provide enough fine dispersion of "amorphous" (i.e. the heavy phase) and a satisfactory stability of the mixture, it was possible to believe that there are only achieve the desired viscosity of the fuel by heating and fuel should be ready to use.

On the principles of the physical behavior of the mixture were founded all the processes employed from treatment and filtration to activate processes. However, the study of shear stress for petroleum products showed thixotropic of mixture [1]. That why raised the question of studying liquid crystal structure at the medium [2].

The rheological model proposed at the Odessa National Maritime Academy in the initial stage of the research process fuel processing was confirmed by microscopic analysis [3]. There was a microscopic analysis of both distillate and high-viscosity marine fuel due to polarization method at 280x-400x increase, at that case in the fuel founded the variety of bulk and surface defects in the structure, as a proofed characteristic of liquid crystals.

So we can see in Figure 1 proved liquid crystal volumetric defect, named ring disclination. The dimension of the defect is 20-40 microns. The abundance of defects observed in the fuel is produced new question of what proportion of the total volume occupied by liquid crystal structures? Moreover, the comparative analysis of defects in light and heavy marine fuels didn't show any significant difference in the quantitative distribution of defects in the media. This means that the distribution of liquid crystals, in both light and heavy fuel oils to be assessed at the same order.

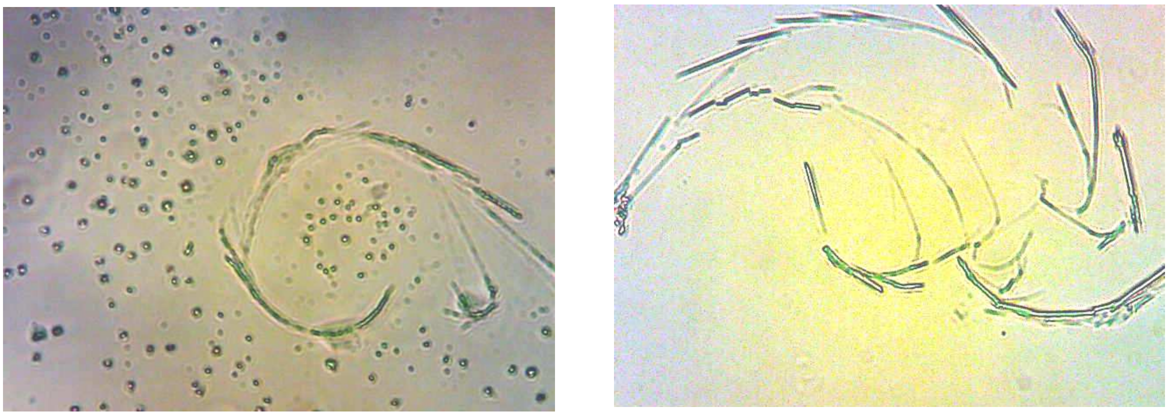

Fig.1 – Micrographs of fuel environment (MDO at the Left side with temperature 20º C,
– marine heavy fuel oil IFO-360 at the right with temperature 52 ºC)

In order to make more thoroughly assess of the crystal structures distribution effect of thermal expansion of the fuel is investigated in this study. This approach was based on the following assumptions. The intensity of defects distribution in samples during performing microscopic analysis, at the media we have majority of a structured environment. Also, known position, which explained crystalline structures unlike ideal fluids and metal cause thermal expansion is the accumulation of defects (discontinuities) for summing up the heat energy.

The investigation has been an assumption that the value of the thermal expansion ΔV (volume increase) in the temperature range from zero to the absolute temperature T is equal of the total defects volume. Based on the assumptions that at T = 0 K structure has no defects, as well as the dependence of the temperature is linear, were prepared according to the relative increment of the volume ΔV against T for a wide range of oil densities, are shown in Fig. 2. Based on the MAN-B&W recommendations, fuel is allowed to engine suction only when the kinematic viscosity handled of at least 15 cSt (area of acceptable temperature range for different fuels is well known at the recommended charts "temperature-viscosity").Line of constant maximum viscosity for different fuels (line passing through the points corresponding to some marine fuels MDO, IFO-30, 60, 180, 380, 720 at the maximum allowable viscosity in Figure 2) has been obtained on the standard marine fuels ISO 8217 basis and a number of high-quality fuels certificates.

Accordingly, the allowable viscosity at fuel supply circuit for different fuels is fully consistent with the same level of "destroying" structures. In other words, for any marine fuel with 15 cSt viscosity corresponds to the same volume fraction of defects – 20-21 %. Also attracted interest result of calculating the incremental volume for distillate fuels (density is about 0,83-0,86) at the end of the boil 630 K increments of volume up to 40-43%. This means that for taking the result as possible destruction of the structure, during the injection, we should have half destroyed lattice of structured fuel, if take into consideration that the coefficient of thermal expansion at temperatures close to the boiling is not linear, so the amount of destroyed structures may be even large.These results confirm the predominance structure throughout the volume of any marine fuels. However, it would be wrong to assume that all amount of the energy supplied to the medium during heating will go on the destruction processes of the crystal. Input energy is converted into: increasing the energy of the vibrational motion of the molecule about its equilibrium position, changing the energy of the intramolecular rotation, performing of electrons skipping to singular orbitals.

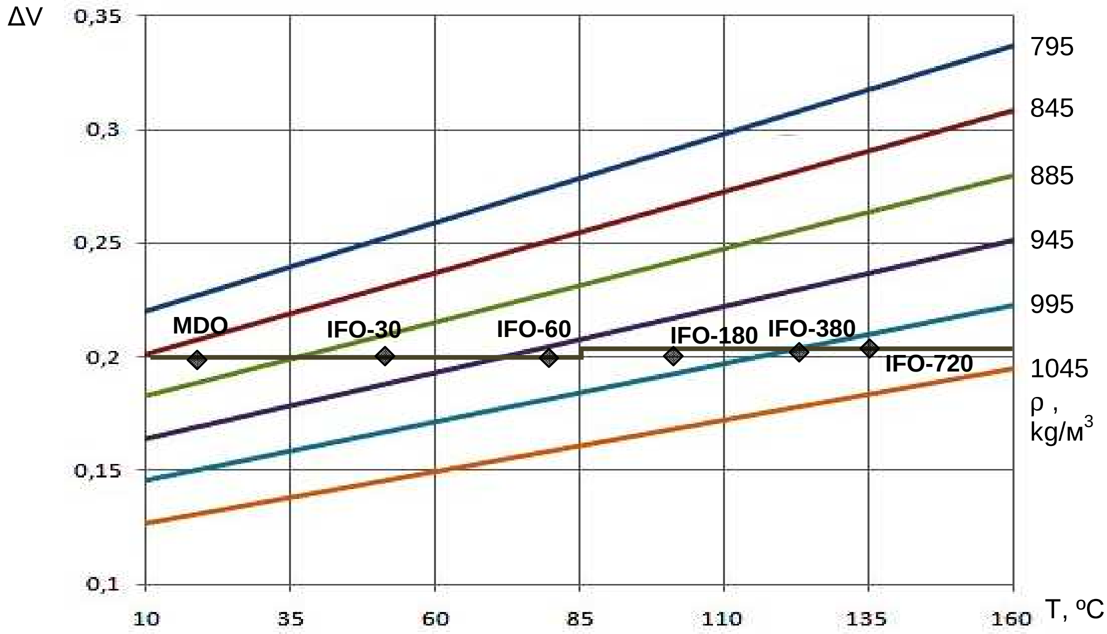

Fig. 2 – Diagram of the volume fraction dependence of ΔV defects of temperature for various petroleum fuels characterized by a density ρ (markers show the corresponding points for some marine fuels at the maximum allowable viscosity)

These intramolecular processes are coupled; forming a structural defect is only a particular outcome of these processes. The kinetic theory of dispersed liquids is a detailed study of quantum mechanics. At this article estimating of the deformation structures energy passes through Frenkel's holes theory. For estimate of macro energy parameters of a simple zero-dimensional defect (a hole, vacancy) applies calculating of the activation energy (loosening).

For one molecule using next equation $E = 4\pi\sigma r^2$, where σ – surface tension, r – average radius of the molecule. For petroleum products at 20 ºC, $\sigma = 30 - 40\, mN/m$, in view of $r = 10^{-9}\, m$, and receive $E = 44\, kJ/mole \cdot {}^{o}\mathrm{C}$ for one mole of a substance.

For determine the proportion of the total heat energy ΔQ is converted to the activation energy ΔE at heating oil to 10 ºC more, assume that $\Delta E/E$ is equal to the coefficient of thermal expansion. So received next $E = 0.0006E = 26.5\, kJ/mole \cdot {}^{o}\mathrm{C}$. Molar heat capacity of heavy fuel oil molecule at an average medium molecule's molar mass near $600\,gr/mole$ for $t < 1000$ °C is corresponded to 1.2 $kJ/mole \cdot {}^{0}\text{C}$, in this case the portion of activation energy is 2.2 %.

At this point a number of alternative methods of enhancing the impact of the activation energy are developed and implemented without significant cost increase in the internal energy, as it did in simple heating. There are homogenization, dispersion, activation, magnetic treatment, etc. Moreover, the present authors believe that traditional processes of filtration and separation are also increased number of defects in medium. However, all of these effects have a significant drawback: the existence of defects generated by them too shortly.

Taking into account that the crystal structures occupy the main volume of the fuel media, its necessary to determine their effect on the spray result from the fuel injector nozzle. Defects in the structure shown in Figure 1, to allow make conclusion that fracture processes of the crystal by Griffith's guideline for crack growth, suggests the further destruction of the crystal and the development of inner heterogeneity, provided with the shear stress index

$$\tau = \frac{F}{a^2}\sqrt{\frac{a}{l}},$$

where a and l – linear dimensions of heterogeneity, F – the force of interaction between the elements of the crystal lattice. Thus, the voltage shifts provided by the fuel atomization nozzles continue during injection started defective structural failure.

Our previous transactions of injection [4] are provided an opportunity to assess the diameter of the particles resulting from fuel spray pattern. In fact, for example, for nozzles with a hole diam. 0.3 mm with working injection pressure of 32 MPa distribution of the number sputtered particles with the same volume as shown in Fig. 3.

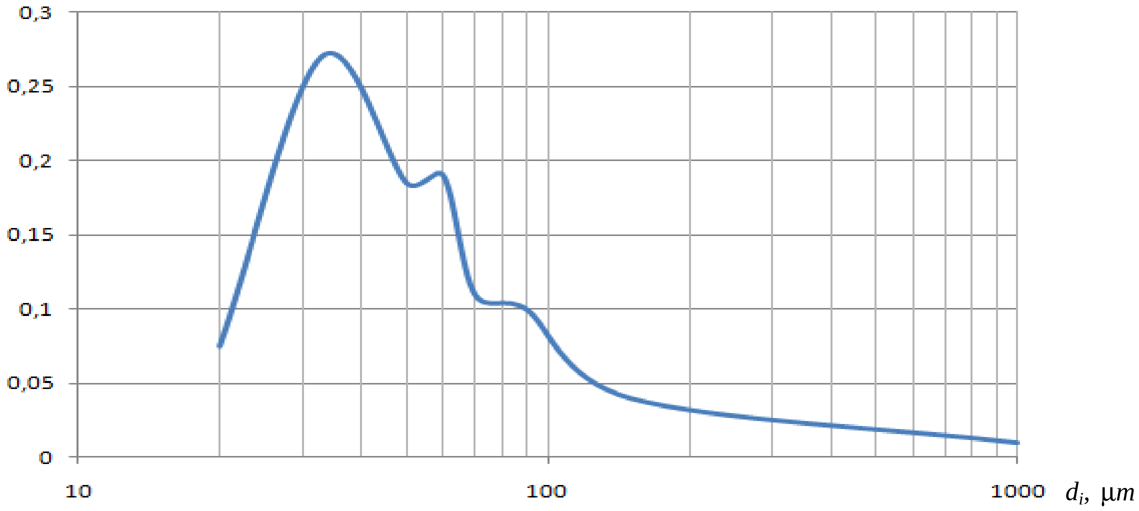

Fig. 3 – Dependence of the fuel oil globules quantity with the same size as a resulting of spray through nozzles holes with 0.3 mm diameter

As can be seen from the graph, the distribution of diameter in the range of 20 to 100 microns quite correspond with the linear size of defects, defining their as a primary basis for the further destruction of the structure. In that way, it can be argued that the destruction of the crystal structures during the injection is due to further break on the existing defects in the fuel structure. The formation and size of the particles formed as a result of fuel injection into the combustion chamber are directly related to the amount and the linear dimensions of the available prior to injection of defects in the crystal structure of the fuel.

This conclusion emphasizes the role of the energy parameter as the activation energy discussed above. As you know, in today's traditional approach to fluid mechanics processes of preparation of fuel injection to the energy balance reduces to the Bernoulli equation. To account for the peculiarities of the crystal structures behavior this balance should be supplemented by activation energy, so the energy balance equation without losses can be written as follow:

$$\frac{mv^2}{2} + mgh + PV + E = const,$$

where m – mass; v – velocity; V – volume of fuel in a stream; g – acceleration of gravity; h – height; P – static pressure. Here by, the researching results are showed that the use of high-viscosity fuels is necessary to consider the rheological properties of fuels to ensure optimal injection conditions. There is an important tool for optimizing the rheology of fuel usage onboard, wich could be next impact of such practices for modern cases of fuel environment, such as ultrasound and electrical fields. The authors suggest that these effects can significantly alter the rheology foundations of fuel environment.

At this item, to evaluate the possibility of service performance changing of fuel applied alternating electric field. This investigation were performed on the power plant basis of M/T "Natali" (IMO № 8915794) under Murmansk Shipping Company management. For the impact on IFO-380 marine fuel was used device proposed by the Institute of Transportation Problems based on Russian Academy of Sciences [5]. As a result of the fuel processing were obtained changing the viscosity characteristics in compliance with the temperature changing. Kinematic viscosity of the medium at the operating temperature range (115 ... 128 ºC) was decreased to 0.5-1.0 cSt. Also observed changes of fuel performance figures. The temperature of exhaust gases on the internal-combustion engine was reduced, as well as change the color of gases from black to blue-gray at low running mode. According to preliminary estimates fuel economy was 6.7 %. Also when impact of alternating electric field had place we would be observed a decreasing of fuel kinematic viscosity from 12 to 11 cSt. This suggests that the impact of the proposed mechanisms are activated rheological changing of combustion behavior.

Key findings:

1. Microscopic analysis of heavy fuel oils shows the presence of a structural defect which are formed in the fuel as a result of fuel treatment and heating.
2. Absorption heat fuel is a direct consequence of gradual accumulation of defects in the crystal lattice, i.e. its gradual degradation.
3. Liquid-crystal structures action for the rheological properties of the fuel disperse system can be considered decisive.
4. In the energy balance of the hydro-mechanical fuel treatment processes are advisable to take into account the activation energy of the fuel temperature at which our measurements reaches about 2-3 % of the internal energy in the operating temperature range.
5. The impact of alternating electric field are changed the rheology behavior of heavy marine fuel and can achieve more efficient combustion process in the four-stroke internal-combustion engine.

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Радченко О.П., Мацкевич А.Р., Ханмамедов С.А., Туев С.В. Реологічні аспекти підготовки палива на судні

Аналізуються реологічні властивості суднових високов’язких палив і температурні умови підготовки палива в суднові силові установці. Зазначено взаємозв’язок про меж об’єктами паливної середи, що є молекулярними структурами, та якістю розпилу палива. Дію змінного електричного поля на суднове високов’язке паливо протестоване в умовах реальної суднової енергетичної установки.

Ключові слова: суднова силова установка, підготовка палива, високов'язке суднове паливо, реологічни властивості, змінне електричне поле.

Радченко О.П., Мацкевич А.Р., Ханмамедов С.А., Туев С.В. Реологические аспекты подотовки топлива на судне

Анализируются реологические свойства судовых высоковязких топлив и температурные условия топливоподготовки в судовой энергетической установке. Проводится взаимосвязь между структурированными объектами топливной среды и качеством распыла топлива. Воздействие переменных электрических полей на судовое высоковязкое топливо опробовано в условиях действующей судовой энергетической установки.

Ключевые слова: судовая энергетическая установка, топливоподготовка, судовые высоковязкие топлива, реологические свойства, переменные электрические поля.