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## Study of composite coal–water fuel rheological properties

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**Abstract.** The rheological characteristics of composite water-coal fuel, as well as the possibility of reducing the viscosity of composite water-coal fuel due to the use of nanomaterials, are studied. Improved rheological properties of composite fuel containing small additions of these substances: carbon nanomaterial at a concentration of 0.005 wt. % or 0.3 wt. % of the dehydrated carbonate slurry. Possible mechanisms for changing the viscosity properties of fuel are considered.

### Introduction

Taking into account the need to increase the share of coal in the fuel and energy balance of Russia and the environmental problems arising from its use, the creation of coal processing and processing technologies that will maximize its benefits and minimize the complexity of its application is a promising direction for the development of energy. In addition, for the needs of small-scale energy, the priority is to use local fuels, which include low-grade coals, peat, shales, bitumen, heavy oil residues. Direct combustion of the listed types of fuels is inefficient and is accompanied by pollution of the environment due to the incompleteness of their combustion. More promising is the preparation on their basis of water-containing liquid composite mixtures, which are much more effective and environmentally friendly in the production of thermal and electrical energy [1,2].

One of the directions for coal power engineering can be the transition from direct coal combustion in various combustion plants to the preparation of coals of various grades, including coal waste, water-coal fuel. The water-coal fuel (CWF) has properties that allow it to replace solid, liquid or gaseous fuels in various fuel-using units without significant reconstruction, and if necessary, the use of coal and other fuels - fuel oil, coal, gas [3- 5].

For water-coal fuel, the most important characteristics that determine its properties as a liquid fuel are rheological parameters. Rheology shows the regularity, to which the fluid is subjected under the action of a deforming force on it. Depending on the values of the rheological parameters, the water-coal suspensions display both the properties of Newtonian and the properties of non-Newtonian liquids. The value of the rheological characteristics of coal suspensions makes it possible to predict



and regulate the technological properties of WTT necessary for storage, transportation and its efficient combustion in boiler furnaces. As is known, the temperature has a significant effect on the rheological characteristics of liquids. The behavior of Newtonian fluids during flow depends solely on viscosity, which is only a function of temperature [6,7].

When using VUT, the main problem is the high viscosity of the suspension at the required concentration of crushed coal. Therefore, the development of methods for controlling viscous characteristics due to a change in the composition of the VUT is a very urgent problem [8-15]. One way to change the viscosity is to add nanostructures, which in many cases leads to a radical transformation of the properties of traditional materials, practically without changing their chemical composition, only due to the tendency of the molecules in the presence of nanoparticles to self-organize and self-assemble. These effects lead to the appearance of ordered structures [16, 17] and a change in the functional characteristics of the starting materials. In particular, the use of the mechanisms of spontaneous self-ordering of atoms around nanoparticles in liquid disperse systems can lead to an additional supramolecular structure formation, the consequence of which can be a decrease in viscosity due to the transition to layerwise shear flow.

The purpose of this study was to study the effect on the rheological characteristics of VUT additives of some nanostructured materials and the ability to reduce the viscosity of mixed fuel due to their use.

### **Materials and methods**

As nanoparticles, we chose carbon nanotubes (CNTs), which have already been used with great success in various fields of energy. Despite the fact that carbon nanotubes are biodegradable nanoparticles, they completely burn with fuel, because they consist of pure carbon, and their catalytic properties lead to a more complete combustion of other components of the fuel, which may be important for eliminating the negative consequences of using heavy fuel. At present, the production of carbon nanomaterials, which include different types of carbon nanotubes, has gone beyond laboratory and semi-industrial installations, which makes it possible to assume the economic feasibility of their use. For the experiments, we chose carbon nanotubes of carbon nanomaterial "Taunit" (<http://www.nanotc.ru>), characterized by their relative cheapness and availability. This choice was also facilitated by the earlier obtained results on reducing the viscosity of fuel oil when CNTs were added, which made it possible to reduce energy consumption and production costs in technological processes [17-20].

Before adding to the fuel to uniformly distribute the volume of the sample and to prevent their re-adherence, multi-walled carbon nanotubes are dispersed in surfactant solutions [21-23]. We used aqueous dispersions of sodium dodecyl sulfate (SDS, anionic surfactant) with a concentration of 100 mM, whose properties in pure form [24-27] and in the presence of CNTs [28-29] have been thoroughly studied. The concentration of the carbon nanomaterial was changed to 0.0125 wt. %.

Another kind of particles used by us that change the rheological properties of fuel and contribute to reducing harmful emissions into the atmosphere [30, 31] are particles of dehydrated carbonate sludge, which is a waste of the process of chemical water purification of water treatment facilities of CHP plants and boiler houses. Previous studies have shown that the use of expensive nanoparticles as additives to hydrocarbon fuels can to some extent be replaced with additives of microparticles of dehydrated carbonate sludge - waste generated during coagulation and liming of natural waters in thermal power plants. As an additive to fuel, a fine fraction of anhydrous carbonate slurry with a particle size of not more than 0.09 mm with a total content of calcium and magnesium carbonates of not less than 85% was used. The choice of carbonate slurry as an additive was dictated by the good results obtained earlier by us on improving the rheological properties of fuel oil using this additive [32-34].

Samples of water-coal fuel were made on the basis of lean coal of the Kuznetsk deposit. For the preparation of samples of water-coal suspension, the crushed coal from the hopper was directed to grinding into a vibrating mill. The obtained coal dust was subjected to screen analysis on the vibration unit and subsequent fractionation. Particles with certain dimensions were weighed and

fed into a mixer into which distilled water was dispensed from a measuring container and a water-coal suspension was prepared by mixing the components.

Samples of water-coal fuel, coal-water fuel mixtures with carbonate mud and nano additives were investigated using a Rheomat RM 100 rotational viscometer to determine the values of dynamic viscosity at different shear rates. The determination of the dynamic viscosity consisted in measuring the shear stress arising in the test sample of the VUT. The angular velocity varied from 50 to 300 s<sup>-1</sup>. Viscosity measurements of VUT were performed at several temperatures in the range of 30-35 ° C and different shear rates. Measurements began with a minimum speed. At all rotational speeds of the rotor, the value of the torque (shear stress) corresponding to the equilibrium value was recorded, i.e. So, when the spinning moment stops changing in time. The work of the viscometer was controlled from a personal computer via the software "VISCO-RM SOFT".

### Experimental results and their discussion

The data obtained during the experiments are shown in Fig. 1 and 2. It should be noted that the results observed for VUT are very dependent not only on the concentration of nanoparticles and their dispersion medium, but also on the chemical and fractional composition of the coal dust of the fuel suspension, where a certain role is also played by the features of adsorption interactions on the surface of energy coals [ 35].

Changes in the dynamic viscosities of the VUT samples with addition of carbonate slurry from the shear rate correspond to the graphs shown in Fig. 1. A fraction of 0.125 mm of coal particles was selected. The carbonate slurry content in all the samples was 0.3 wt. %.

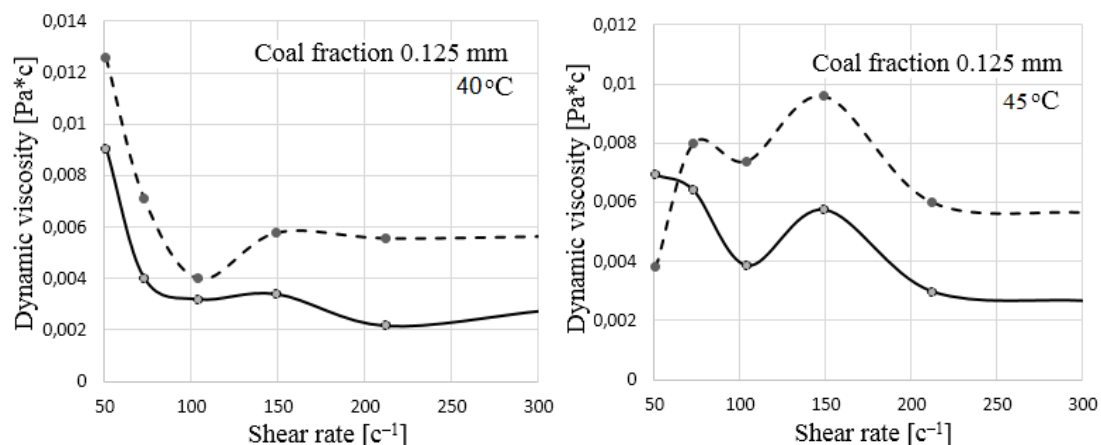


Fig. 1. Dependence of the dynamic viscosities of VUT samples on the basis of coal particles 0.125 mm in size on the shear rate at different temperatures (carbonate slurry concentration is 0.3% by weight)

When analyzing the obtained curves, a rather strong change in the conditional viscosity of composite water-coal fuel was found, depending on the concentration of the additive and the temperature of the sample (Fig. 1). The viscosity of the initial samples of VUT was practically independent of the temperature and was 0.0065-0.009 Pa s. With the addition of 0.1 wt. % of the carbonate slurry, the viscosity of the samples remained almost unchanged (40 ° C, 45 ° C). The increase in the proportion of the additive - carbonate sludge up to 0.3% by weight in water-coal fuel resulted in a marked decrease in the conventional viscosity. However, a further increase in the concentration of the additive again led to an increase.

For VUT with addition of carbonate sludge, the greatest effect is achieved with its concentration of 0.3 wt. %. In the case of the addition of carbonate sludge, one more feature should be noted: an increase in viscosity (with the exception of a temperature of 45 ° C) in the range of low concentrations of this additive. The observed increase in viscosity can be explained by the absorption and binding of water, the most liquid fraction of the dispersion medium, and,

correspondingly, to an increase in the viscosity of the VUT [11]. Further increase in the additive concentration to 0.3 wt. % leads to the formation of internal structure formation around the particles of the slurry. This concentration promotes the formation of structures with low-strength coagulation contacts along the planes, which determine the considerable development of plastic deformations leading to layerwise shear flow and a decrease in viscosity.

However, the use of carbonate slurry at this concentration increases the ash content of the fuel. The requirements to reduce ash content and to increase the ecological compatibility of combustion give preference for the concentration of the additive in 0.1 wt. %. In particular, the use of this additive in this concentration to fuel oil allows to reduce the viscosity of fuel oil, as well as to reduce the sulfur content in emissions and improve the structure of deposits, increasing the ash content of fuel oil is negligible. The results of industrial tests conducted for boiler fuel indicate a decrease in the mass fraction of sulfur oxides emitted by 36.5% [30]. It is possible that similar results should be expected when using VUT.

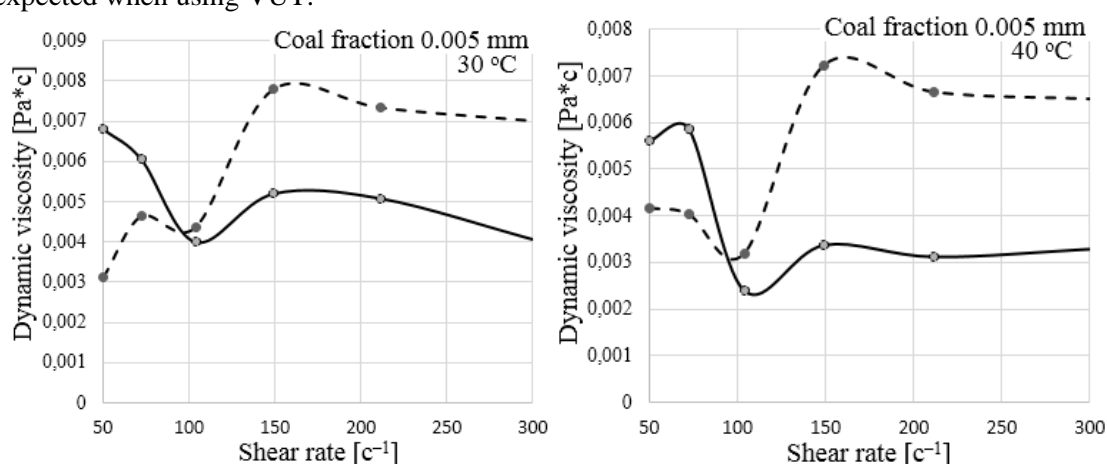


Fig. 2. Dependence of the dynamic viscosities of the VUT samples on the basis of coal particles of 0.005 mm in size with the addition of 0.005 wt. % Of CNT dispersed in a 100 mM sodium dodecyl sulfate solution, on the shear rate at various temperatures

Changes in the dynamic viscosities of the VUT samples with the addition of carbon nanomaterial at a concentration of 0.005 wt. % Of CNT dispersed in a 100 mM sodium dodecyl sulfate solution from the shear rate correspond to Fig. 2. In the presence of carbon nanotubes, the dynamic viscosity of water-coal fuel was higher than the initial dispersion medium (water-coal fuel) at low shear rates and decreased markedly as the flow velocity increased. This behavior indicated the occurrence of additional structure formation in the entire volume of the sample observed when carbon nanotubes were introduced, i.e. the appearance of heterospheres and their adhesion, and then their partial destruction with increasing shear rate and their complete destruction at shear rates greater than 230 s<sup>-1</sup>.

In addition, it should be assumed that there is a synergistic effect from the combined use of these additives. We hope that the joint use of CNT and carbonate sludge will reduce the amount of harmful emissions into the atmosphere and reduce the content of the pricing additive - the carbon nanomaterial "Taunit" in this sample.

### Conclusion

The possibilities of reducing the viscosity of composite water-coal fuel by using nanomaterials: carbon nanotubes and dehydrated carbonate sludge were investigated. Improved rheological properties of composite fuel containing small additions of these substances: carbon nanomaterial at a concentration of 0.005 wt. % or 0.3 wt. % of the dehydrated carbonate slurry. Possible mechanisms for changing the viscosity properties of fuel are considered. When designing industrial technological complexes, one should take into account the obtained viscosity dependence on

temperature and, with technical feasibility and economic expediency, it is necessary to use devices for heating the pumped suspension to a temperature of 350 ° C.

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