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Study of the Effect of Temperature on the Rheological Characteristics of Composite Fuel

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The article is devoted to the study of the patterns of change in the rheological characteristics of composite fuels based on low-ash anthracite at a mass fraction of the solid phase of 40%, an oil phase concentration of $C_o = 49\%$, a water concentration of $C_{H2O} = 10\%$, and 1% of a chemical additive with an increase in temperature from 10 to 70 °C. It has been established that the dependence of the rheological characteristics of composite fuel on temperature indicators is complex. When the temperature changes from 20 to 30 °C, a plateau is observed (the change in the $K_{\mu t}$ coefficient is ≈0.9), which has a significant deviation from the approximation dependence for calculating the $K_{\mu t}$ coefficient. From the data obtained, it can be concluded that this type of fuel can successfully compete with traditional types of liquid fuel.

Introduction

An increase in the consumption of petroleum products in the transport and energy systems, as well as the active development of a group of industries (especially petrochemical and oil refining) leads to the accumulation of numerous wastes in the form of used oils, oil sludge and other oil-containing liquids. It is possible to solve the problem of waste disposal by using it as an organic component of fuel when burned at thermal power stations in order to obtain thermal and electrical energy.

The technology for producing highly concentrated composite fuels used as liquid fuel in power generating installations is associated with thermal engineering requirements: maximum filling of the emulsion dispersion medium with combustible components (for example, dispersed coal). In this case, the system must be stable (for a long period) and have a viscosity that allows easy transportation of emulsions through pipes, storage and sawing with nozzles (at a viscosity of up to 2 Pa·s) [1–2].

For composite fuel, the most important characteristics that determine its properties as a liquid fuel are rheological parameters and stability indicators. The value of the rheological characteristics of coal suspensions makes it possible to predict and control the technological properties of fuel dispersed systems necessary for their storage, transportation and successful combustion in furnaces.

One of the main factors of external influence on composite fuels is temperature. It is necessary to consider this influence taking into account the technology of preparation, transportation, storage and use of fuel. It is known that the viscosity of water with a change in temperature from 0 to 20°C decreases by 1.8 times, but the effect of temperature changes on composite fuels has not been studied enough.

The effect of temperature on the rheological characteristics of water-coal suspensions based on coal of various degrees of metamorphism was studied in [3–5]. For composite fuels (one of which is oil-water-coal fuels), such studies have not yet been carried out.

Experimental part

In order to create a composite fuel and study the effect of temperature on systems, oil-water-coal fuels based on Comma Xtech 5W-30 oil with a concentration of C_s = 49 wt.% were obtained, and low-ash anthracite with a concentration of C_c = 40 wt.%, water C_{H2O} = 10 wt.%, 1% ResinAnt 2 was used as a chemical stabilizer.

Initial coal with a particle diameter of d=1 mm was grounded in a roller mill using ceramic balls in a porcelain drum with a capacity of 2 dm3. Then the coal was sieved on SLM 200 sieves to eliminate the influence of the factor of different dispersion on the rheological behavior of dispersed systems and a bulk material of the same particle size distribution was obtained, the best ratio of which was determined [6]: fraction 250–160 microns – 40%, 160–100 microns – 20 %, 100–63 microns – 5%, 63–40 microns – 32%. Technical and elemental analysis of coal is presented in **Table 1**.

Table 1. Technical and elemental analysis of coal

Technical analysis, wt.%			Elemental analysis, % in daf				
W^a	A^d	V^{daf}	C	H	N	O	S
3.2	5	3.8	95.7	2.3	0.4	1.1	0.5

Structural and sorption characteristics of coal powders were calculated by the Brunauer-Emmett-Teller method [7] from the results of measurements of low-temperature nitrogen adsorption on a Quantachrome Nova specific surface analyzer: density ($\rho = 1.3$ g/cm^3), specific surface ($S_{sp} = 1.386$), specific pore volume ($V_{pore} = 0.053$ cm^3/g) and effective pore diameter ($d_{pore} = 7.670$ nm) Distribution of surface functional groups (functional group content consisted of –COOH 0.09 mg-eq/g; –OH 0.32 mg-eq/ g; C=O 0.21 mg-eq/g) acidity was determined knowing the total exchange capacity (POE = 0.15 mg-eq/g) of coal, taking into account the results of neutralization of these groups 0.1 n. aqueous solutions of NaOH, Na_2CO_3 and $NaHCO_3$ [7]. The inorganic component of coal according to X-ray phase analysis (DRON 2 refractometer) is represented mainly by quartz, kaolinite and hydromica.

To obtain a composite fuel, coal powder was homogenized with Comma Xtech 5W-30 engine oil (**Table 2**) and water and 1% rheological additive by weight of the solid phase (**Table 3**).

Table 2. Technical properties of engine oil [8]

Characteristics of oils	Oil brand
	Comma Xtech 5W-30
Viscosity class,	5W-30
Density at 20°C (68°F),	0.848 g/cm^3
Viscosity at 40°C	55 mm^2/s
Viscosity at 100°C	9.9 mm^2/s
Viscosity index	166
Pour point	-36°C / -33°F
Flash point	230°C / 446°F
Sulfated ash content	1.1% masses
Base number	10.0 mg KOH/g

The purpose of homogenization was to create a time-stable homogeneous structure in a multiphase system and to eliminate concentration microheterogeneities, as a result of which an improvement in the rheological properties of suspensions is observed. Homogenization was carried out on a laboratory rotary paddle mixer at a homogenization rate of 2000 rpm for 5 min.

It should be noted that the studied composite fuels did not delaminate within a week when stored under static conditions, even in the absence of stabilizing reagents. This can be explained by the formation of a spatial network in the system with a strong fixation of anisometric coal particles without loss of sedimentation stability.

The main rheological parameters of the composite fuel – the effective viscosity η_{eff} (Pa·s) and the shear stress τ (Pa) – were determined on the Rheotest'2 device in a special temperature-controlled cell using coaxial smooth cylinders of the S/S2 measuring system at 12 different fixed rotation speeds rotor in the range of 0.278–243 rpm, which corresponds to a change in shear rate from 1.0 to 437.4 s^{-1}. Thermostating was carried out using a U15C circulating liquid thermostat of the MLW series (Germany) for 15 min. Viscometric measurements for each of the temperatures were carried out with a new portion of the composite fuel, having previously mixed it at a fixed temperature for 10 min. The temperature regimes were set in the range of 10–70 °C, the measurement step was uniform – 10 C.

Table 3. Characteristics of the rheological additive

Additive	View	Consumption, % of the mass of the working solution	Appearance	Density, g/cm3	pH 1% solution	Solubility		
						in water	in oil	in an organ. solvent.
ResinAnt 2	Dispersant-wetting agent	1	viscous liquid	1	7	+	+	-

Results and discussion

The rheological properties of composite fuels are determined by the mass fraction and granulometric composition of the solid phase, as well as the physicochemical properties of the dispersion medium and the type of chemical reagents used [1].

In the study of the rheological characteristics of composite fuels based on low-ash anthracite at a mass fraction of the solid phase of 40%, the concentration of the oil phase $C_o = 49\%$, the concentration of water $C_{H2O} = 10\%$ and 1% of the chemical additive with an increase in temperature from 10 to 70 °C, was observed a decrease in the viscosity of the studied systems (**Table 4**). As can be seen from **Fig. 1**, curves are concave, which indicates the pseudoplastic type of colloidal systems.

Table 4. Rheological characteristics of composite fuel based on anthracite at various temperatures.

	t=10° C	t=20° C	t=30° C	t=40° C	t=50° C	t=60° C	t=70° C
D, c-1	**η, Па·с**	**η, Па·с**	**η, Па·с**	**η, Па·с**	**η, Па·с**	**η, Па·с**	**η, Па·с**
1	2,09	1,85	1,79	1,70	1,20	1,19	1,19
1,8	1,99	1,76	1,39	1,16	0,76	0,80	0,76
3	1,96	1,23	1,13	0,82	0,70	0,62	0,60
5,4	1,86	0,98	0,88	0,57	0,54	0,42	0,36
9	**1,76**	**0,81**	**0,70**	**0,47**	**0,37**	**0,29**	**0,25**
16,2	1,59	0,72	0,62	0,42	0,33	0,22	0,15
27	1,38	0,64	0,54	0,39	0,29	0,19	0,13
48,6	1,08	0,57	0,48	0,35	0,24	0,17	0,11
81	0,92	0,52	0,44	0,31	0,21	0,13	0,10
145,8	0,79	0,44	0,37	0,28	0,18	0,11	0,07
243	0,73	0,40	0,34	0,24	0,15	0,09	0,05
437,4	0,70	0,36	0,31	0,22	0,13	0,08	0,03

An increase in shear stress at the same temperature is accompanied first by a sharp, and then a more gradual drop in viscosity to certain shear values, when the viscosity becomes the smallest and then remains constant (Fig. 1). In the areas of bias voltage up to 20 Pa, the viscosity of the suspension sharply decreases, with intensive destruction of bonds in the structure. At 30–60 Pa, the system behaves like a Newtonian liquid with a constant viscosity, which corresponds to the complete destruction of the structural network of suspensions. In this range of change in the bias voltage, there is a limiting destruction of the structure in the flow and its insignificant restoration. This regularity is observed in all systems at the studied temperatures.

To estimate the degree of change in the effective viscosity of composite fuels in the temperature range characteristic of the process of moving the dispersed system under study through pipes, there was used the coefficient $K_{\mu t}$ [9]:

$$K_{\mu t} = \mu_{ei}/\mu_{e20}$$

where μ_{ei} – is the effective viscosity at a given temperature; μ_{e20} – is the effective viscosity at a temperature of 20 °C. The corresponding dependence is plotted in **Fig. 2**.

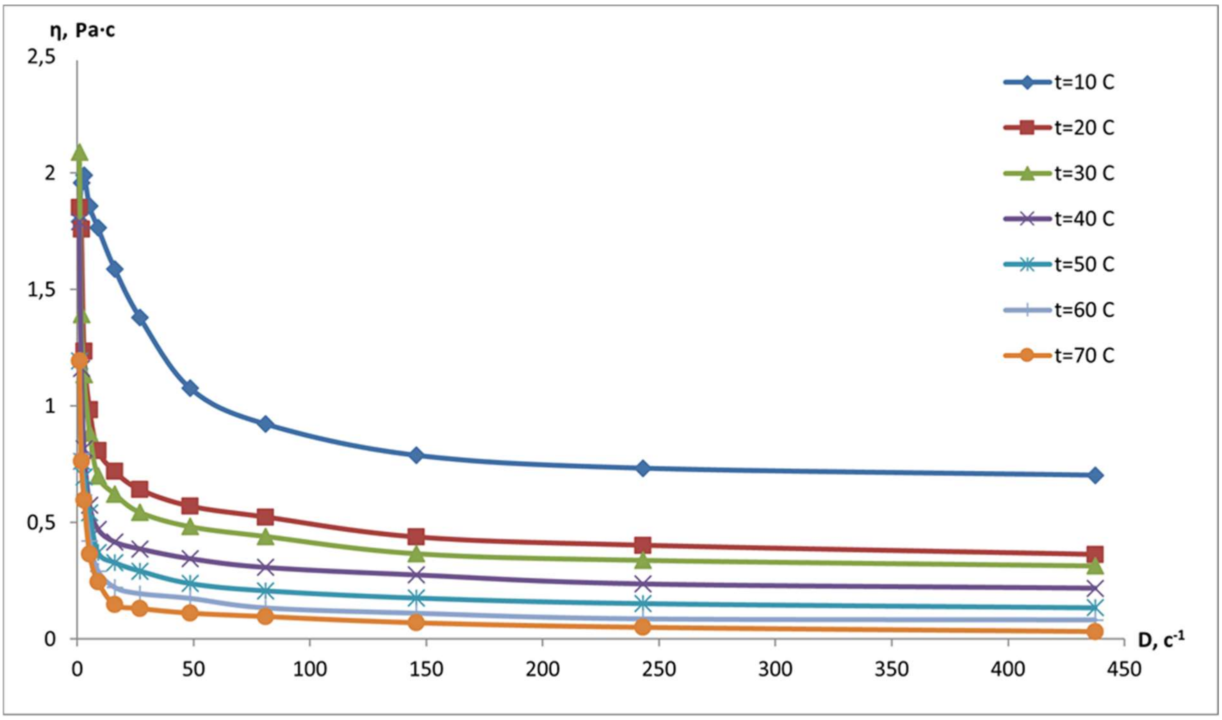

Figure 1. Dynamic viscosity curves of composite fuels based on grade A coal and waste engine oil at temperature changes of 10–70 °C.

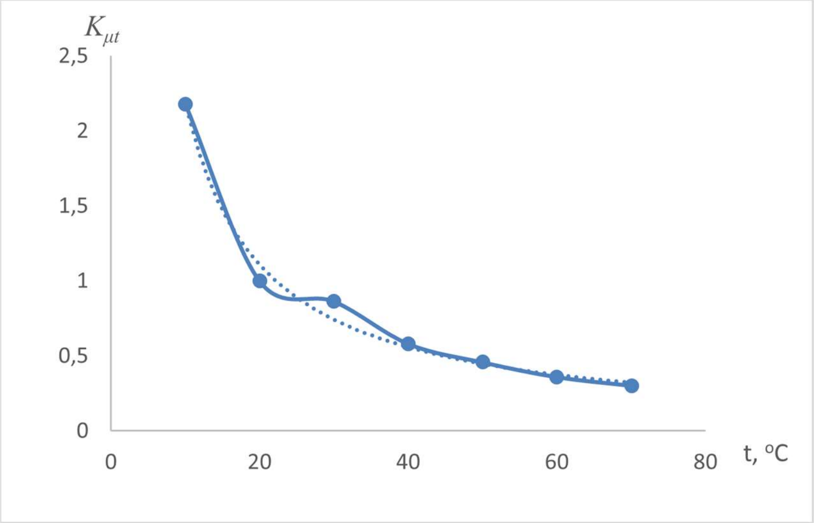

Figure 2. Dependence of the coefficient ($K_{\mu t}$) of the effective viscosity change on the temperature of composite fuels.

Analysis of the curves shown in **Fig. 2**, made it possible to establish that the nature of the dependence of the $K_{\mu t}$ coefficient on temperature is complex. From the analysis of the dependence, it follows that in the temperature range from 10 to 20 °C, there is a sharp change in the rheological characteristics of fuel systems (2 times), which is due to the degree of change in the viscosity of the engine oil. However, an increase in temperature to 30 °C leads to a significant decrease in the change in effective viscosity (a plateau is observed). With a further increase in temperature in the range from 30 to 50 °C, a decrease in the rate of change in rheological characteristics is observed. It should also be noted that the approximation dependence for calculating the coefficient $K_{\mu t}$, proposed in [9], has a significant deviation at a temperature of 30 °C.

Conclusions

In the course of the analysis of the results of the studies carried out to determine the dependence of the rheological characteristics of the composite fuel on temperature, it was found that there is a sharp decrease (up to 2 times) in the viscosity of the medium with an increase in temperature from 10 to 20 °C. A further increase in temperature from 20 to 30 °C does not lead to a significant decrease in the change in effective viscosity (a plateau is observed, the change in the $K_{\mu t}$ coefficient is ≈0.9). With a further increase in temperature in the range from 30 to 50 °C, a decrease in the rate of change in rheological characteristics is observed.

Since 49% of the composite fuel is used engine oil, the change in viscosity is due to the degree of change in the viscosity of the engine oil. The influence of temperature on the viscosity of an oil depends on its chemical composition. It is known [10] that the viscosity coefficient is a dimensionless conditional value that characterizes the degree of change in oil viscosity depending on temperature, the slope of the viscosity-temperature curve. That is, the flatter the viscosity-temperature curve, i.e., the less the viscosity changes with temperature, the higher the viscosity coefficient. Oil containing a significant amount of asphalt-resinous, pelicyclic compounds, depending on the cutting temperature, changes its viscosity, and oil from paraffinic oil changes its viscosity slightly.

To improve the viscosity-temperature properties, i.e., to increase the viscosity coefficient, so-called thickened oils are prepared that have good viscosity-temperature properties (i.e., these oils change their viscosity little with temperature changes) due to the addition of viscosity additives. Unthickened oil changes its viscosity with temperature more dramatically than thickened oil.

Used engine oil Comma Xtech 5W-30 refers to synthetic oils that contain a balanced amount of additives that complement each other's action. They allow the oil to maintain unchanged viscosity-temperature parameters at any load and temperature (as manufacturers say). However, it can be seen from the data obtained that stability is observed only in the temperature range from 20 to 30 °C, it can be assumed that the addition of 1% rheological additive leads to a decrease in the influence of additives on the stability of the viscosity-temperature properties of the oil.

Thus, the addition of a 1% rheological additive and an increase in temperature reduce the viscosity of highly concentrated composite fuels based on low-ash anthracite, which helps to reduce energy costs when transporting such dispersed systems through pipes and using them in power plants when sprayed through nozzles.

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