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Technological Basis for the Production of Compounded Boiler Fuel with Improved Operational Properties

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Abstract

The article discusses both theoretical and practical studies on increasing the efficiency of boiler fuel use by enhancing its viscosity and temperature properties. This improvement is achieved by blending fuel oil grade 100 with a fraction produced at 250-350°C, obtained by pyrolysis of recycled polymeric raw materials (a 1:1 mixture of LDPE and HDPE) or with used semi-synthetic oil SAE 10W-40 API SG/SJ. It is also suggested to blend boiler fuel following a scheme that involves constant closed-loop pumping of the mixture through a steam heater (40-80°C) and a tank for 30-45 minutes. This process has enabled the production of boiler fuel with superior performance properties, simplifying its use during winter boiler operation, while utilising recycled raw materials to help improve the country's environmental situation and enhance energy independence.

Keywords: *Boiler fuel; Polymers; pyrolysis; Fraction; Used oil; Compounding; Low-temperature properties.*

1. Introduction

Today, it is difficult to imagine the operation of industrial enterprise infrastructure without oil-fired boilers—systems of units and process equipment that heat the coolant to specified parameters by burning fuel oil. The primary fuel for such boilers is grade 100 fuel oil, a residue (boiling point above 360°C) produced at primary oil refineries under atmospheric pressure. Compared to other liquid fuels, fuel oil is low-cost and provides good fire protection, but it has a strong, unpleasant odour and emits various harmful pollutants into the environment. Additionally, due to its physical and chemical properties, transporting fuel oil in winter at low temperatures presents challenges. Therefore, research aimed at enhancing the environmental and operational qualities of fuel oil is of significant importance.

2. The objective of the research

Producing fuel oil with enhanced operational properties will significantly improve its efficiency as a boiler fuel, particularly significant in the era of energy conservation and rational utilisation of energy resources [1-3]. Difficulties in using fuel oil during winter, when its consumption peaks, are mainly due to its high viscosity (up to 80 mm^2/s at 100°C) and pour point (up to +35°C) [4-5].

The viscosity of fuel oil influences the energy required to pump through pipelines, the spray effectiveness of injectors, and the time needed to drain fuel oil from tanks, tankers, and other containers. Usually, the viscosity of fuel oil prevents efficient pumping from tanks and spraying through nozzles. Therefore, to enhance its flowability, fuel oil is often heated to 60- 70°c using water vapour or electric heaters [6-7]. Heating melts solid paraffin and ceresin, lowering viscosity. However, stopping the heating process causes the fuel oil to return to its original viscosity [8]. Viscosity reduction can also occur when the medium is exposed to microwave radiation in the presence of nanocatalysts. In this case, maximum viscosity reduction of up to 96.81% can be achieved when the water content is 50 % by mass, under microwave heating at 614 W, a temperature of 68°C, and a nickel nanocatalyst concentration of 0.8 % by mass [9]. According to [10], methods for chemically reducing the viscosity of hydrocarbon media include emulsification, oil-soluble viscosity reduction, catalytic enhancement and viscosity reduction technologies. Using ultrasonic processing and viscosity reducers shows promising results for lowering the viscosity of heavy hydrocarbon media [11]. The findings provide a theoretical foundation for the industrial application of ultrasound and viscosity reducers to reduce heavy oil viscosity.

An important parameter that influences the efficiency of fuel oil transportation, pumping, and discharge is its pour point, which depends on the production technology. A high pour point is typical for fuel oil produced by direct distillation of crude oil, particularly during the cracking process [12]. If the temperature of the fuel oil is equal to or above the pour point, it loses its mobility and must be heated to be transported through the fuel oil pipelines.

The most common method to lower the pour point of oil and oil products worldwide is to use depressant additives. These additives ensure that crude oil and oil residues stay pumpable even below their natural pour point. Essential for winter transport of crude oil and fuel oil, depressant additives are crucial in maintaining fluid flow [13]. These additives include [14] substances based on various aromatic hydrocarbons, vegetable oils, polymers, and copolymers. The content of these depressant additives in fuel oil usually does not exceed 2000 ppm.

At the same time, the simplest, cheapest, and equally effective method, compared to the above, is the technique of reducing the viscosity and pour point of fuel oil by blending (partial dissolution) it with liquid hydrocarbon fractions and oil products. We can propose using a hydrocarbon fraction obtained from the pyrolysis of secondary polymeric raw materials, which has a boiling point of 250-350°C; for oil products, used lubricating oils (hydraulic, turbine, industrial, motor, etc.) are suitable. Since these components have significantly lower viscosity and pour point values compared to fuel oil grade 100, blending them with fuel oil will markedly improve the viscosity and temperature properties of the resulting mixture—the compounded boiler fuel. The stability of this mixture will be maintained because the liquid hydrocarbon components are similar to fuel oil, sharing comparable chemical compositions. Furthermore, the use of secondary raw materials significantly reduces the cost of the final compounded boiler fuel. An additional benefit of utilising recycled materials is the environmental impact, achieved by recycling hazardous waste products such as polymers and used oil.

3. Materials and methods of the research

Materials. The main materials of the study are commercial fuel oil grade 100 according to DSTU 4058-2001; a fraction with a boiling point of 250-350°C obtained from a mixture of high-density polyethylene (HDPE) and low-density polyethylene (LDPE); used all-season semi-synthetic motor oil SAE 10W-40 API SG/SJ.

Methods. The fraction with a boiling point of 250-350°C was obtained by pyrolysis of a mixture of HDPE and LDPE in a 1:1 ratio in a laboratory reactor-type unit using the method described in [15-16], which were published earlier.

The used oil SAE 10W-40 API SG/SJ was taken directly from the engine of a Škoda Rapid 1.2 TSI (oil life was 10135 km) during its regular maintenance. After being drained from the vehicle, the oil was settled at 80°C for 3 hours to remove mechanical impurities (dust particles and wear products of friction surfaces) and water.

After preparation, fuel oil grade 100 was blended with either fraction or oil in various volume ratios (95:5, 90:10, 85:15, 80:20 and 75:25) using a mechanical stirrer (rotation speed up to 500 rpm) at 40 °C (when using fraction 250-350°C) and 80°C (when using SAE 10W-40 API SG/SJ oil) for 2 hours.

Further, for the obtained samples of compounded boiler fuel, the physicochemical quality indicators were determined according to the following standard methods: density at 20°C (ISO

3675); kinematic viscosity at 100°C (ISO 3104); pour point (ISO 3016); sulphur content (ISO 14596); fractional composition (ASTM D86); calorific value (ASTM D240).

4. Results and discussion

Results of experimental studies showing how the kinematic viscosity at 100°C (v100, mm^2/s) and the pour point (tp.p., °C) of compounded boiler fuel depend on the fuel component content (x, %) are presented in Figs. 1-2.

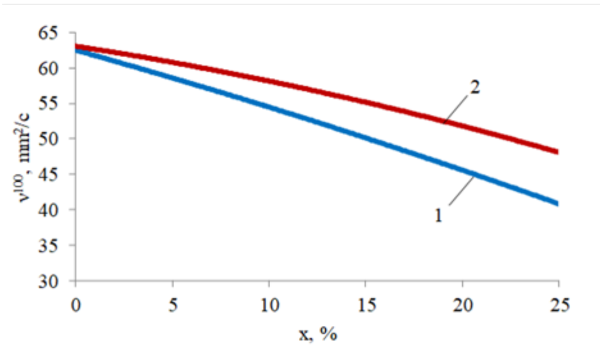

Figure 1. Dependence of v^{100} on x for compounded boiler fuel: 1–fraction 250-350°C; 2–oil SAE 10W-40 API SG/SJ.

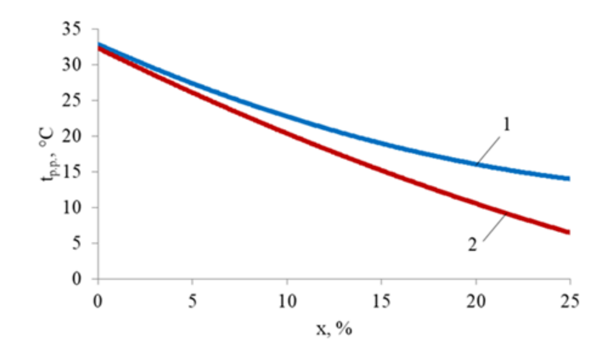

Figure 2. Dependence of $t_{p.p.}$ on x for compounded boiler fuel: 1–fraction 250-350°C; 2–oil SAE 10W-40 API SG/SJ.

The results shown in Figs. 1-2 indicate a decrease in the values of v100 (by 23 mm^2/s for the 250-35°C fraction and by 15 mm^2/s for SAE 10W-40 API SG/SJ oil) and tp.p. (by 19°C for the 250-35°C fraction and by 27 °C for SAE 10W-40 API SG/SJ oil) as the proportion of x (from 0 to 25 %) in the composition of the mixed boiler fuel increases. Additionally, a much greater reduction in the kinematic viscosity of the mixed boiler fuel is observed with the 250-350 °C fraction. The decrease in the pour point is achieved by SAE 10W-40 API SG/SJ waste oil due to its extensive dewaxing and the presence of depressant additives [17].

In addition to these physicochemical quality indicators, it is also necessary to study the effect of the content of fuel components on the calorific value (Q, MJ/kg) of compound fuel, its density at 20°C (ρ^{20}, kg/m^3), flash point ($t_{f.p.}$, °C) and sulphur content (S, ppm). The results of the relevant studies are presented in Figs. 3-6.

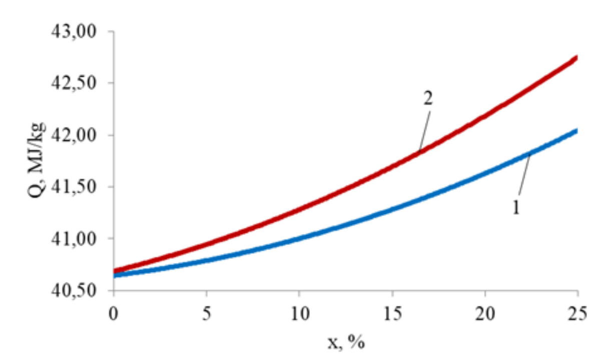

Figure 3. Dependence of Q on x for compounded boiler fuel: 1–fraction 250-350°C; 2–oil SAE 10W-40 API SG/SJ.

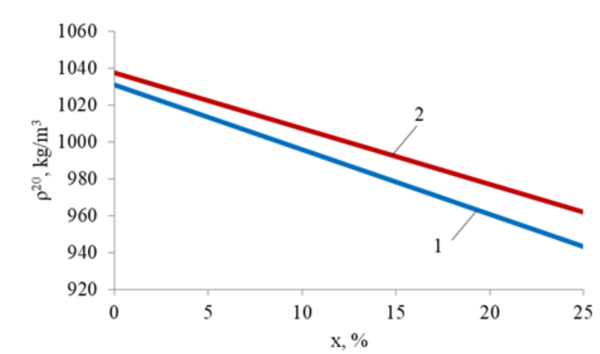

Figure 4. Dependence of ρ^{20} on x for compounded boiler fuel: 1–fraction 250-350°C; 2–oil SAE 10W-40 API SG/SJ.

It is clear that increasing the content of the components listed above in boiler fuel (see Fig. 3) leads to a rise in the key indicator Q (by 1.3 MJ/kg for the 250-350°C fraction; by 2.1 MJ/kg for SAE 10W-40 API SG/SJ oil), which is very positive for improving boiler plant efficiency. Additionally, the value of ρ20 (see Fig. 4), which indicates the commercial quality of the fuel and is used to determine tank volume and the energy needed for heating, drops significantly (by 88 kg/m³ for the 250-350°C fraction; by 70 kg/m³ for SAE 10W-40 API SG/SJ oil). Lowering the ρ20 of the blended boiler fuel also makes spraying through nozzles easier and enhances water separation during settling.

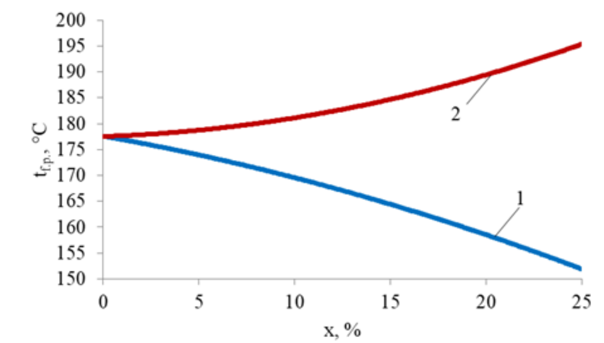

Figure 5. Dependence of $t_{f.p.}$ on x for compounded boiler fuel: 1–fraction 250-350°C; 2–oil SAE 10W-40 API SG/SJ.

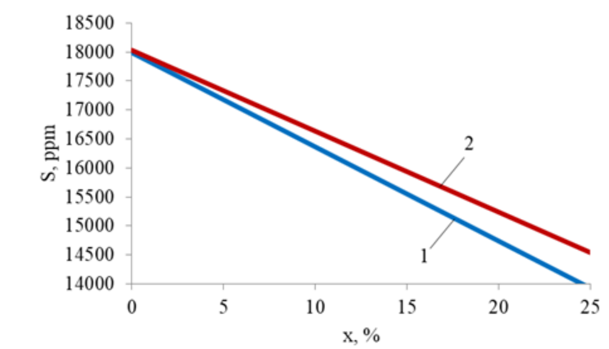

Figure 6. Dependence of S on x for compounded boiler fuel: 1–fraction 250-350°C; 2–oil SAE 10W-40 API SG/SJ.

The value of tf.p. (see Fig. 5) with an increase in the content from 0 to 25% mass in boiler fuel, fraction 250-350°C, gradually decreases (from 178°C to 152°C), which is a negative aspect that increases the fire hazard of fuel oil during its use, storage, pumping, and transportation [18]. Conversely, with an increase in the content of SAE 10W-40 API SG/SJ oil in boiler fuel, the values of tf.p. increase (from 178°C to 195°C).

Sulphur content (see Fig. 6), which greatly influences the rate of corrosion of boiler equipment (sulphur dioxide in combustion products reacts with oxygen and water vapour to form sulphuric acid, leading to corrosion) [19], decreases by 3974 ppm in the 250-350°C fraction and by 3451 ppm for SAE 10W-40 API SG/SJ oil as the proportion of fuel components in the compound boiler fuel increases.

Regarding the environmental emissions generated by the combustion of the proposed compound boiler fuel, it should be noted that their neutralisation will be fully ensured by flue gas cleaning systems (afterburners, catalysts, etc.) [20], which are currently successfully operated in industry.

Based on our theoretical and experimental studies, we propose a schematic diagram of the production of compounded boiler fuel (see Fig. 7), which can be implemented at the production sites of oil refineries and oil depots.

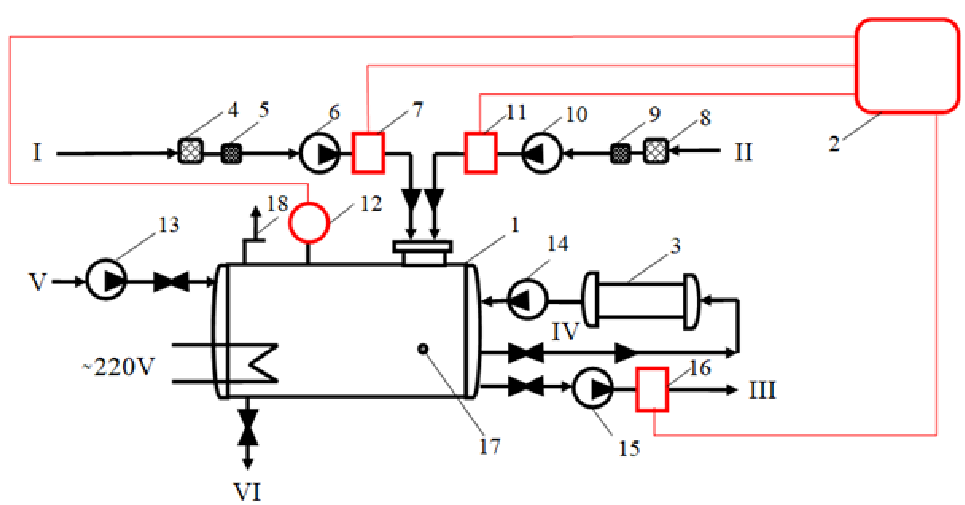

Figure 7. Schematic diagram of compounded boiler fuel production: 1 – tank; 2 – programmable logistics controller; 3 – steam heater; 4, 8 – coarse filter; 5, 9 – fine filter; 6, 10, 13, 14, 15 – pumps; 7, 11, 16 – flow meters; 12 – level sensor; 17 – thermocouple; 18 – outlet valve; I, V – fuel oil grade 100; II – fuel component; III – compound boiler fuel; IV – recycle; VI – drainage

According to the diagram above (see Fig. 7), fuel oil from the pipeline (flow I) or from the railway and road tanker (flow V) is fed into the compounding tank (1) via metering pumps (6 or 13), a coarse filter (4), a fine filter (5), and a flow meter (7). The fuel component (flow II), along with fuel oil grade 100, enters the tank (1) through a coarse filter (8), a fine filter (9), and a flow meter (11), using a dosing pump (10). The system of coarse filters (4, 8) and fine filters (5, 9) is designed to remove mechanical impurities from the fuel oil and fuel component streams, which could cause premature wear of process equipment and impair the quality of the resulting compounded boiler fuel. In tank (1), at a temperature of 40-80°C, the mixture is pumped (flow IV) by pump (14) through steam heater (3), where the compounding of fuel oil grade 100 and the fuel component occurs. The tank (1) is equipped with a level sensor (12), which is monitored by the programmable logic controller (2) to oversee the tank's level. When the tank is full, the outlet valve (18) opens, allowing excess fuel to be discharged. The resulting fuel mixture can be heated by an electric heater located in the lower part of the tank (1), with a thermocouple (17) installed to regulate the temperature. To clean the tank (1) from sludge, a drainage system is included in its design (at the bottom) (flow VI). After the completion of the compounding process (lasting 30-45 minutes), the commercial boiler fuel (stream III) is pumped through a flow metre (16) to the main product pipeline or to railway and road tankers. The flow meters (7, 11, 16), installed on the material flows of fuel oil grade 100, fuel component, and compounded boiler fuel, transfer their readings to the programmable logic controller (2), which calculates their consumption. Check valves are placed on all material flows within the system to prevent backflow. In case of emergency, the system can be operated manually using valves and gate valves located on each material flow.

5. Conclusions

Theoretical and practical studies in the field of modern technologies for producing and utilising boiler fuels have enabled the identification of ways to enhance their efficiency by improving viscosity and temperature properties. This can be achieved by blending fuel oil grade 100 with a fraction obtained at 250-350°C from the pyrolysis of recycled polymeric raw materials (a mixture of LDPE and HDPE in a 1:1 ratio) or with used semi-synthetic oil SAE 10W-40 API SG/SJ.

It has been established that with an increase (up to 25 %) in the composition of boiler fuel components (250-350°C fraction and SAE 10W-40 API SG/SJ oil), there is a decrease in viscosity (by an average of 15-23 mm^2/s), pour point (by an average of 19-27°C), density (by an average of 70-88 kg/m^3), and sulphur content (by an average of 3451-3974 ppm). At the same time, there is a certain increase (1.3-2.1 MJ/kg) in the calorific value.

The production of compounded boiler fuel can be achieved using the proposed schematic diagram, which involves mixing fuel oil grade 100 with fuel components in a horizontal steel tank by continuously pumping the mixture through a steam heater (40-80°C) and the tank for 30-45 minutes.

The results indicate a positive impact on the physical and chemical parameters of the boiler fuel quality of the aforementioned components, enabling the production of compounded boiler fuel from available secondary raw materials. This method will help improve the country's environmental situation while enhancing its energy independence.

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