

RESEARCH ON TEMPERATURE PREPARATION OF DIESEL BIOFUEL IN AN ENERGY VEHICLE FUEL TANK

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ДОСЛІДЖЕННЯ ТЕМПЕРАТУРНОЇ ПІДГОТОВКИ ДИЗЕЛЬНОГО БІОПАЛИВА В ПАЛИВНОМУ БАКУ ЕНЕРГОЗАСОБУ

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ABSTRACT

The expediency of using diesel biofuel heating in a fuel tank at low ambient temperatures has been substantiated. The article represents a mathematical model of dynamics of diesel biofuel heating in a fuel tank, with the help of a cooling liquid, of the internal combustion engine. Comparative experimental and theoretical studies of diesel biofuel heating in a fuel tank have been made. On the basis of the obtained data, a mathematical dependence has been generated to determine the additional operating costs of diesel fuel associated with the use of diesel biofuel on the basis of fatty acids as the main fuel. The work presents the results of the carried out tests.

РЕЗЮМЕ

Обґрунтовано доцільність використання підігріву дизельного біопалива в паливному баку при низьких температурах навколишнього середовища. В статті представлено математичну модель динаміки нагріву дизельного біопалива в паливному баку за допомогою охолоджуючої рідини двигуна внутрішнього згорання. Виконано порівняльні експериментальні та теоретичні дослідження процесу нагріву дизельного біопалива в паливному баку. На основі отриманих даних сформовано математичну залежність для визначення додаткових експлуатаційних витрат дизельного палива пов'язаних з використанням в якості основного палива дизельного біопалива на основі жирних кислот. Робота представляє результати проведених випробувань.

INTRODUCTION

Lack of energy resources, high prices and environmental problems associated with the use of fossil fuels encourage the production and use of alternative energy sources derived from renewable raw materials. Diesel biofuel based on fatty acids of vegetable or animal fats manufactured using the reaction of transesterification, has the most similar properties in comparison with standard fuel of diesel engines. Physical and chemical properties allow using diesel biofuel with minimal changes of constructions and settings of existing diesel engines.

Mentioning the advantages of using diesel biofuel, a number of shortcomings should be noted, which should include high indicators of kinematic viscosity, temperature of turbidity and hardening in the first place (Agarwal A.K., Gupta J.G., Dhar A., 2017; Alptekin E., Canakci M., 2009; Dunn R.O., 2009). The analysis of physical and mechanical properties of diesel biofuel obtained from various vegetable and animal fats indicates problems associated with the use at temperatures below plus 10 degrees (Pérez Á., Casas A., Fernández C., Ramos M., Rodríguez L., 2010; Sandhya K. Vijayan, Mary Naveena Victor, Abinandan Sudharsanam, Velappan Kandukalpatti Chinnaraj, Vedaraman Nagarajan, Sandhya K. Vijayan, 2018). The use of diesel biofuel at low ambient temperatures leads to blockages of filters and fuel lines (Kerschbaum S., Rinke G., Schubert K., 2008; Ramos M.J., Fernandez C.M., Casas A., Rodriguez L., Perez A., 2009; Park J. Y., Kim D.K., Lee J.P., Park, S.C., Kim Y.J., Lee, J.S. 2008), the appearance of uncharacteristic vibrations (Lapuerta M., Herreros J. M., Garcia-Contreras R., Briceno Y., 2008) in structural elements of fuel equipment, the formation of soluble and insoluble precipitates in fuel tanks and storage tanks (Kerschbaum S., Rinke G., Schubert K., 2008; Dwivedi G., Verma P., Sharma M.P., 2016).

Peculiarities of low temperature of biofuel are associated with the length and branching of the fatty acids structural chain, the location of double bonds along the length of the chain and the degree of

unsaturation of the molecules (Dunn R.O., 2009; Sierra-Cantor J.F., Guerrero-Fajardo C.A., 2017; Ramos M.J., Fernandez C.M., Casas A., Rodriguez L., Perez A., 2009; Yuan M.H., Chen Y.H., Chen J.H., Luo Y.M. 2017). Nowadays quite a lot of studies have been carried out allowing to improve the low-temperature properties of diesel biofuel to some extent, but the proposed methods will require the implementation of additional technological operations (Knothe G., Krahl J. & Gerpen J Van., 2015; Pérez Á., Casas A., Fernández C., Ramos M., Rodríguez L., 2010), additional components (Maximo G.J., Magalhães A.M.S., Gonçalves M.M., 2018; Udomsap P., Sahapatsombat U., Puttasawat B., Krasae P., 2008; Ali O.M., Mamat R., Abdullah N.R., Abdullah A.A., 2016; Lapuerta M., Herreros J. M., Garcia-Contreras R., Briceno Y., 2008) and leads to a decrease in the output of the finished product (Pérez Á., Casas A., Fernández C., Ramos M., Rodríguez L., 2010), which negatively affects the profitability of production and the economic attractiveness of this fuel for the end user.

The work (Trehub M.I., Chuba V.V., 2008; Golub G.A., Chuba V.V., Pavlenko M. U., 2012) considers the temperature aspects of using pure diesel biofuels and their mixtures with petroleum fuels. The authors propose the use of pre-heating diesel fuel in a fuel tank during the cold season in order to optimize viscosity to ensure fluidity and filtration. In terms of quality of the filtration process - the best filtering of diesel fuel with coarse filters and fine purification occurs when the kinematic viscosity of fuel in the range 2.5-4.0 mm²/s. For diesel biofuels, this kinematic viscosity can be reached in the temperature range from 30 to 45^oC, and heating of fuel to this temperature range can be achieved without significant changes to existing fuelling systems of the internal combustion engine.

The goal of this work is to increase the efficiency and assess the use of diesel biofuel by substantiating the performance indicators of the heating system.

MATERIALS AND METHODS

To determine the cloud point and pour point the fuel samples were previously dehydrated. After dehydration, the fuel was poured into two transparent glass tubes. The test tube, which had double walls, was placed into a cooling thermostat, the other one served as a standard. When the temperature dropped by 0.1^oC the tubes were lit, with signs of cloudiness it was recorded the appropriate temperature. With further cooling, the tube was periodically pricked, when the fuel lost mobility at an angle of 45 degrees, the pour point was fixed.

Viscosity of diesel biofuel and its mixtures with diesel fuel of oil origin was determined using liquid viscometers, which were placed into a thermostat maintaining a constant set temperature.

To study the effectiveness of diesel biofuel heating, the fuel system of the tractor type “MT3-100” was modernized according to the scheme (Golub G.A., Trehub M.I., Chuba V.V., Pavlenko M. U., 2018). A diesel fuel tank is equipped with a liquid heat exchanger, which is included in the small circle of the cooling system of the diesel engine for internal combustion (fig. 1).

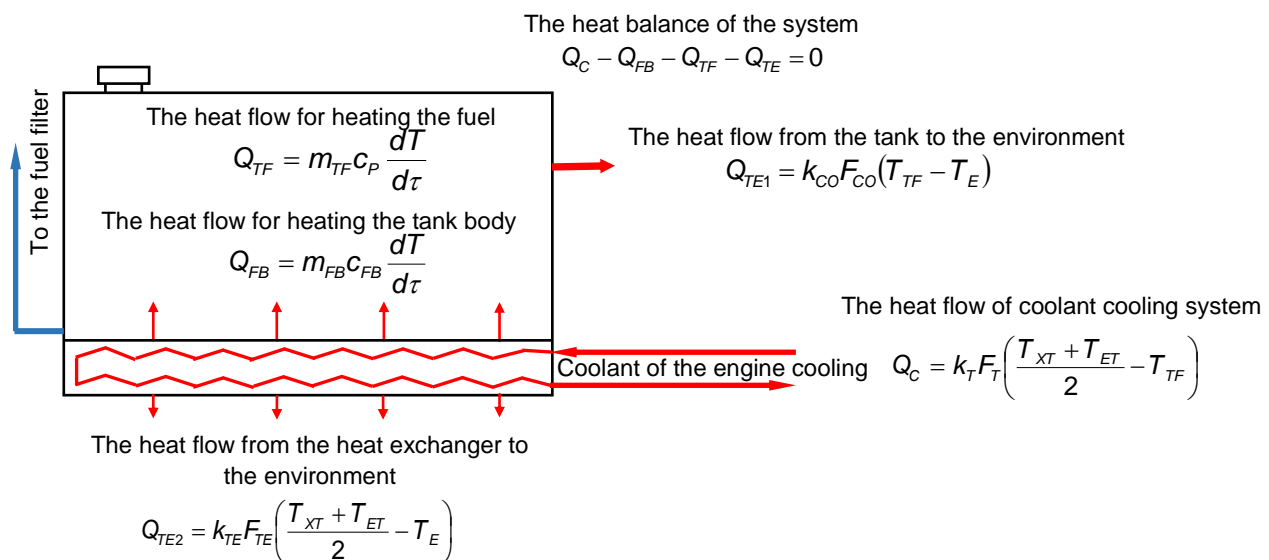


Fig. 1 - Scheme for calculating diesel biofuels heating:

The notations in the figure are:

Q_C – the heat flow that gives the heat-carrier during the passage of the heat exchanger, W; Q_{FB} – a heat flow transmitted to the fuel tank body, W; Q_{TF} – a heat flow transmitted to fuel, W; Q_{TE} – a heat flow lost to the environment, W; m_{TF} – is the fuel mass in a tank, kg; c_P – specific heat of fuel, J/kg°C; m_{FB} – tank mass, kg; c_{FB} – specific heat of a tank material, J/kg°C; k_T – a coefficient of heat transfer through a flat wall between the heating medium and fuel, W/m²°C; F_T – the area of heat exchange between the heating medium and the fuel in the tank, m²; T_{XT} – the temperature of the coolant at the inlet to the heat exchanger, °C; T_{ET} – temperature of the cooling fluid at the outlet of the heat exchanger, °C; T_{TF} – the fuel temperature in the tank, °C; k_{CO} – the coefficient of heat transfer through the outer walls of the tank to the environment W/m²°C; F_{CO} – the area of the external surface of the tank in contact with the environment, m²; T_E – ambient temperature, °C; k_{TE} – a coefficient of heat transfer through the external wall of the heat exchanger to the environment, W/m²°C, F_{TE} – the area of the external surface of the heat exchanger in contact with the environment, m².

To measure the temperature of the fuel in the fuel tank, the temperature of the coolant at the inlet to the heat exchanger and at the exit from it, a thermocouple is installed. The temperature change recording was carried out continuously with the help of program- hardware complex on the basis of the personal computer "ASUS" and a temperature meter "Regmik". The coolant flow through the heat exchanger was fixed using a liquid flow meter. The velocity of air motion in the basin area of the tank was measured using an anemometer. General view of experimental equipment during research is shown in fig. 2.



Fig. 2 - General view of experimental equipment during research

a - general view of a tractor with a biofuel tank with heating; b - diesel biofuel tank with heating

Before the measurement, the engine was heated to the working temperature, and the ambient and fuel temperatures in the fuel tank were recorded. After reaching the working temperature, the engine opened the supply of the heated coolant to the heat exchanger of the fuel tank and the changes in fuel temperature in the fuel tank were measured, as well as the temperature of the coolant at the inlet and outlet of the heat exchanger. The research was carried out at engine idling mode at constant turnovers, and during the study period the coolant flow rate and air flow velocity were determined.

Using the experimental data obtained, a theoretical modelling of the diesel fuel heating time in a fuel tank was performed. A comparison of the obtained theoretical and experimental dependence has been performed. On the basis of the obtained data, a mathematical dependence has been generated to determine the additional operating costs of diesel fuel when using biofuels.

RESULTS

The obtained indicators of the cloud point and pour point of diesel biofuels produced from the main oilseeds of Ukraine for determining the maximum temperature range of the use of diesel biofuels are shown in table 1. The cloud point of diesel biofuel characterizes the appearance of particles that can clog the fuel line and the filter elements of the engine.

Table 1

Cloud point and pour point of diesel biofuel

Indicator	Diesel biofuel based on		
	soybean oil	sunflower oil	rapeseed oil
Cloud point, °C	10.0	9.6	7.9
Pour point, °C	2.7	0.9	-0.8

The analysis of the obtained results allows asserting the inexpediency of the use of diesel biofuel at a temperature of less than 10°C.

An important parameter that provides fuel filtration is the kinematic viscosity. We have performed comparative studies to determine the effect of temperature on the viscosity of diesel biofuel produced from rapeseed and soybean oil depending on temperature (table 2). It should be noted that in order to improve the low-temperature properties, diesel biofuel based on soybean oil is additionally frozen.

Table 2

Fuel type	Temperature, C					
	0	3	8.5	14	17.5	20
Diesel fuel	10.22	8.43	6.13	5.27	4.85	4.5
Diesel biofuel from rapeseed oil	17.42	13.31	10.97	8.92	8.2	7.64
Diesel biofuel from soybean oil	14.23	11.06	8.5*	7.21	6.68	6.15

* – data is recorded at a temperature of 8.2 °C.

It was found that in the studied temperature range from 14 to 20°C the kinematic viscosity of diesel biofuel from rapeseed and soybean oils when compared to diesel fuel is higher by 70% and 37%, respectively. When comparing diesel fuel with biofuel from soybean oil, the viscosity of diesel biofuel from rapeseed oil is higher by 24%.

One of the directions of diesel biofuel use is the use of mixtures with diesel fuel of oil origin. We have researched the effect of temperature on the viscosity of mixtures of diesel biofuels based on soybean and rapeseed oils with the addition of 30 and 50 percent of diesel fuel of oil origin (table. 3).

Table 3

Fuel	Temperature, °C				
	0	3	8	14	19
70 % biofuel from rapeseed oil +30 % diesel fuel	15.23	11.34	8.96	7.36	7.22
70 % biofuel from soybean oil +30 % diesel fuel	11.92	9.97	7.74	6.42	6.27
50 % biofuel from rapeseed oil +50 % diesel fuel	14.83	10.83	8.29	6.94	6.02
50 % biofuel from soybean oil +50 % diesel fuel	11.42	9.31	7.18	6.09	5.91

The analysis shows that the kinematic viscosity of fuel mixtures also decreases with increasing fuel temperature. Fuel mixtures with 30% of diesel fuel content have a kinematic viscosity higher by 2-8% when compared to a mixture containing 50% of diesel fuel depending on the temperature. This proportion is typical for both rapeseed and soybean oil biofuels.

Studies have shown that at a temperature of 19°C, the addition of biofuel from rapeseed oil and 30% of diesel fuel leads to a decrease in the viscosity of the mixture by 5.5%, and the addition of 50% of diesel fuel reduces the viscosity of the mixture by 13 %. When the temperature drops down to 14°C the difference in kinematic viscosity increases up to 17% and 27%, respectively. The addition of diesel fuel to biofuels from soybean oil reduces the kinematic viscosity by 2 % and 4 % at 19°C, respectively, for mixtures containing 30% and 50% of diesel fuel and 11% and 17% at 14°C. Consequently, the addition of diesel fuel leads to a certain decrease in the kinematic viscosity of diesel biofuel, but does not allow increasing its kinematic viscosity at low temperatures.

In Ukraine, a significant number of technological operations of agricultural production are carried out at an ambient temperature below 10°C. In this case, the most appropriate way to improve the efficiency of diesel biofuels use is its heating in the fuel tank.

Taking into account the expressions for determining the heat flow, the equation of heat flows balance of a fuel tank with a liquid heat exchanger takes the form:

$$\left(m_{TF}c_p + m_{FB}c_{FB}\right)\frac{dT}{d\tau} = (k_T F_T - k_{TE} F_{TE})\left(\frac{T_{XT} + T_{ET}}{2}\right) - (k_T F_T + k_{CO} F_{CO})T_{TF} + (k_{TE} F_{TE} + k_{CO} F_{CO})T_E \quad (1)$$

Having solved the differential equation (1), we obtain the equation for changing the final temperature of fuel in the tank from the values of the parameters of the heat transfer equation:

$$T_{FTT} = \frac{(k_T F_T - k_{TE} F_{TE}) \left(\frac{T_{XT} + T_{ET}}{2} \right) + (k_{TE} F_{TE} + k_{CO} F_{CO}) T_E}{(k_T F_T + k_{CO} F_{CO})} \times$$

$$\times \left(1 - \exp \left(- \frac{(k_T F_T + k_{CO} F_{CO})}{(m_{TF} c_p + m_{FB} c_{FB})} \tau \right) \right) + T_{ITT} \exp \left(- \frac{(k_T F_T + k_{CO} F_{CO})}{(m_{TF} c_p + m_{FB} c_{FB})} \tau \right) \quad (2)$$

where:

T_{ITT} – the initial temperature of fuel in the tank, °C;

T_{FTT} – the final temperature of fuel in the tank, °C;

τ – time of fuel heating in the fuel tank, s.

The given equation (2) determines the relationship between the technological and structural parameters of a fuel tank and a liquid heat exchanger for heating fuel in a fuel tank.

In order to verify the obtained theoretical dependence (2), experimental research of the process of diesel fuel heating in a fuel tank was carried out at engine running at idle speed, the parameters of the heat exchange process (Table 4) were determined, and an experimental dependence of the temperature change of fuel in a fuel tank (Fig. 3) was obtained. Heat transfer coefficients (Table 4) are calculated in accordance with the well-known formulas and empirical dependencies.

Using the dependence (2), on the basis of the parameters of the heat exchange process and the structural parameters of the fuel tank (Table 4), the theoretical modelling of the fuel heating process in the fuel tank was made, and the theoretical dependence of the heating fuel dynamics (Fig. 3) was constructed.

The value of the deviation of the experimental and theoretical values of the fuel temperature is estimated by the determination index, which is $\eta^2 = 0.953$, which gives an opportunity to draw a conclusion on the correctness of the chosen method of theoretical calculations. The discrepancy between experimental and theoretical data is due to the fact that during theoretical research, due to the complexity of the determination, the heat loss wasn't taken into account during the heat transfer between the tank and the tractor body parts at the points of the tank fixing.

Table 4

Constructive and technological parameters of the heat exchange process of diesel biofuel heating during theoretical calculation

No	Parameter name	Parameter marking and measure unit	Parameter value
1	The area of the tank outer surface	F_{CO} , m ²	0.388
2	The thickness of the tank wall	δ_{TW} , m	0.004
3	The thermal conductivity coefficient of the tank wall material	λ_{TC} , W/m °C	51.5
4	Air movement speed	V_{AM} , m/s	2
5	The coefficient of heat transfer through the tank outer wall to the environment	k_{TV} , W/m ² °C	13.275
6	The area of heat exchange between the heating medium and fuel in the tank	F_T , m ²	0.08
7	Coolant flow rate	V_T , m/s	0.01683
8	Heat transfer coefficient from the heating medium to the fuel	k_T , W/m ² °C	220.196
9	The area of the heat exchanger external surface in contact with the environment	F_{TE} , m ²	0.268
10	The coefficient of heat transfer through the heat exchanger exterior wall to the environment	k_{TE} , W/m ² °C	13.295
11	The temperature of the engine coolant at the inlet to the heat exchanger	T_{XT} , °C	81
12	The temperature of the engine coolant at the output of the heat exchanger	T_{ET} , °C	77
13	Ambient temperature	T_E , °C	13
14	Initial fuel temperature in the fuel tank	T_{ITT} , °C	13
15	Mass of fuel in the tank	m_{FB} , kg	25
16	Specific heat of diesel biofuel	c_p , J/kg °C	2100
17	Tank mass	M_{BK} , kg	30
18	Specific heat capacity of the tank material	c_{FB} , J/kg °C	462

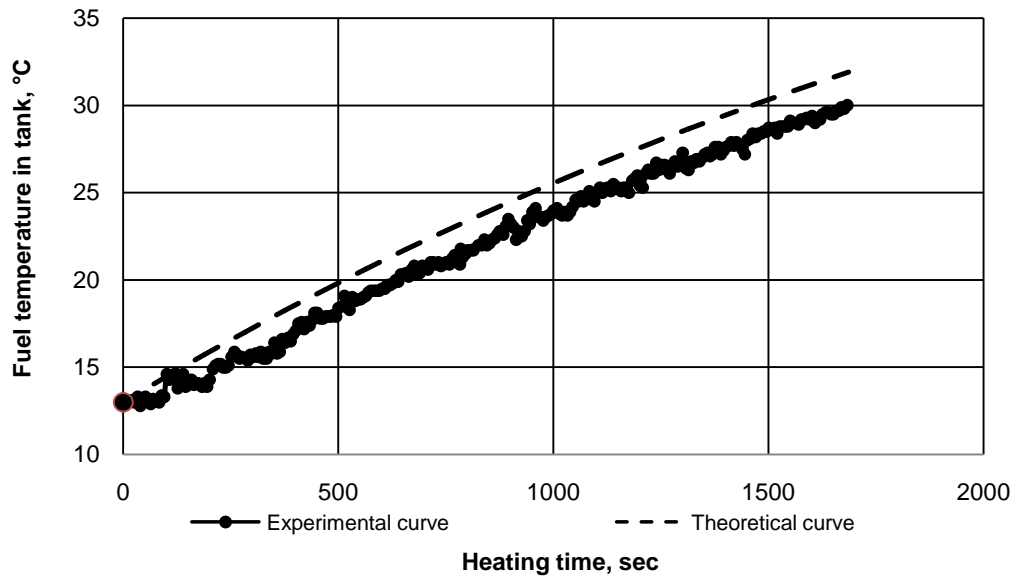


Fig. 3 - Dynamics of the process of heating diesel fuel in a fuel tank

In order to prevent the introduction of diesel biofuel into motor oil, the start of diesel engine while working on diesel biofuel should be carried out only on diesel fuel. The variable consumption of diesel fuel associated with starting of the engine can be determined based on the design features, in the formula:

$$Q_{DF}^V = k_{RR} (V_{CFF} + V_{FFF} + V_F + V_{IVHP}) \quad (3)$$

where:

Q_{DF}^V – variable diesel fuel consumption for engine start, l ;

k_{RR} – reserve coefficient, relative unit;

V_{CFF} – volume of a coarse fuel filter, l ;

V_{FFF} – volume of fine fuel filter, l ;

V_F – internal volume of fuel lines, l ;

V_{IVHP} – internal volume of the head of the high pressure fuel pump, l .

The variable fuel consumption of diesel fuel when the diesel fuel tank is heated at an ambient temperature below 10°C can be determined as follows:

$$Q_{DF}^H = t_H G_{HF} \quad (4)$$

where:

Q_{DF}^H – variable diesel fuel consumption for engine start and fuel heating in the fuel tank, l ;

t_H – an operating time of the engine on diesel fuel, required for heating diesel biofuels in a fuel tank, h ;

G_{HF} – hourly fuel consumption, at the operation mode of the engine in the heating of diesel biofuel, l .

The total additional consumption of diesel fuel when diesel oil is replaced by biofuel, can be determined based on the consumption of diesel fuel as follows:

$$Q_{DF}^D = \frac{Q_{DF}}{Q_{VF}} \left[k_{DF} k_{RR} (V_{CFF} + V_{FFF} + V_F + V_{IVHP}) + (1 - k_{DF}) t_H G_{HF} \right] \quad (5)$$

where:

k_{DF} – is a coefficient of diesel fuel consumption distribution, in accordance with the maximum temperature of diesel fuel without heating, relative unit;

Q_{DF} – amount of diesel fuel spent on the execution of the unit or volume of work, l ;

Q_{VF} – average fuel consumption variable, l .

The obtained dependence (5) allows calculating the consumption of diesel fuel due to the operational features of the use of diesel biofuel and the need for its heating at low temperatures.

CONCLUSIONS

The results of studies on the cloud point and pour point, as well as the kinematic viscosity of diesel biofuels and its mixtures with diesel fuel at temperatures ranging from 0 to 20°C , indicate that the effective range of use of diesel biofuels, in which the properties of biofuels will not significantly affect the operation of

the diesel engine, is at a temperature higher than 10°C. At ambient temperatures below 10°C, to ensure fuel filtration, it is advisable to use preheating of fuel in the fuel tank.

The differential equation of diesel biofuel heating in a fuel tank has been defined, which connects the design parameters of the fuel tank, the temperature conditions of the environment and the parameters of the heat exchange process.

The comparative theoretical and experimental studies allow stating the adequacy of the solution of the differential fuel heating equation in the fuel tank. The obtained mathematical dependence can be used in further research on operation modes of the internal combustion engine and the heating of a fuel tank, from an optimization method of diesel biofuel heating time in a fuel tank.

As a result of the analysis of the diesel engine performance when using diesel biofuel, an expression has been obtained to determine the additional operating costs of diesel fuel associated with starting the engine and heating diesel fuel in a fuel tank.

The obtained results allow to design the operating modes of the engine during diesel fuel heating in a fuel tank at low ambient temperatures and to evaluate the additional operating costs of diesel fuel of oil origin.

REFERENCES

- [1] Agarwal A.K., Gupta J.G., Dhar A., (2017), Potential and challenges for large-scale application of biodiesel in automotive sector, *Progress in Energy and Combustion Science*, 61, pp. 113-149;
- [2] Ali O.M., Mamat R., Abdullah N.R., Abdullah A.A., (2016), Analysis of blended fuel properties and engine performance with palm biodiesel-diesel blended fuel. *Renewable Energy*, 86, pp. 59-67;
- [3] Alptekin E., Canakci M., (2009), Characterization of the key fuel properties of methyl ester-diesel fuel blends. *Fuel*, 88 (1), pp. 75-80;
- [4] Dunn R.O., (2009), Effects of minor constituents on cold flow properties and performance of biodiesel. *Progress in Energy and Combustion Science*, 35, pp. 481–489;
- [5] Dwivedi G., Verma P., Sharma M.P., (2016), Impact of oil and biodiesel on engine operation in cold climatic condition. *Journal of Materials and Environmental Science*, 7 (12), pp. 4540-4555;
- [6] Golub G.A., Chuba V.V., Pavlenko M. U., (2012), Areas of improvement of production and use of diesel biofuels (Напрямки удосконалення виробництва і використання дизельного біопалива). *Collection of scientific works Vinnytsia National Agrarian University (Збірник наукових праць Вінницького державного аграрного університету)*, 10 (1), pp. 20-23;
- [7] Golub G.A., Trehub M.I., Chuba V.V., Pavlenko M. U., (2018), *Fuel heating system for diesel internal combustion engine (Система нагріву палива для дизельного двигуна внутрішнього згорання)*. Patent No. 116375. Ukraine;
- [8] Kerschbaum S., Rinke G., Schubert K., (2008), Winterization of biodiesel by micro process engineering. *Fuel*, 87(12), pp. 2590–2597;
- [9] Knothe G., Krahl J., Gerpen J Van., (2015), *The Biodiesel Handbook* (2nd. ed.). Urbana, Illinois: AOCS Press;
- [10] Lapuerta M., Herreros J. M., Garcia-Contreras R., Briceno Y., (2008), Effect of the alcohol type used in the production of waste cooking oil biodiesel on diesel performance and emissions. *Fuel*, 87(15-16), pp. 3161-3169;
- [11] Maximo G.J., Magalhães A.M.S., Gonçalves M.M., (2018), Improving the cold flow behaviour of methyl biodiesel by blending it with ethyl esters. *Fuel*, 226, pp. 87-92;
- [12] Park J. Y., Kim D.K., Lee J.P., Park, S.C., Kim Y.J., Lee, J.S., (2008), Blending effects of biodiesels on oxidation stability and low temperature flow properties. *Bioresource Technology*, 99 (5), pp. 1196-1203
- [13] Pérez Á., Casas A., Fernández C., Ramos M., Rodríguez L., (2010), Winterization of peanut biodiesel to improve the cold flow properties. *Bioresource Technology*, 101(19), pp. 7375-7381;
- [14] Ramos M.J., Fernandez C.M., Casas A., Rodriguez L., Perez A., (2009), Influence of fatty acid composition of raw materials on biodiesel properties. *Bioresource Technology*, 100(1), pp. 261–268;
- [15] Sandhya K. Vijayan, Mary Naveena Victor, Abinandan Sudharsanam, Velappan Kandukalpatti Chinnaraj, Vedaraman Nagarajan, (2018), Winterization studies of different vegetable oil biodiesel, *Bioresource Technology Reports*, 1, pp. 50-55.
- [16] Sierra-Cantor J.F., Guerrero-Fajardo C.A., (2017), Methods for improving the cold flow properties of biodiesel with high saturated fatty acids content: A review. *Renewable and Sustainable Energy Reviews*, 72, pp. 774-790;

- [17] Trehub M.I., Chuba V.V., (2008), Method of using biodiesel fuel, made on basis of vegetable oil (Спосіб використання біодизельного пального, виготовленого на основі рослинної олії). NSC «IAEE» *"Mechanization and electrification of agriculture: collected papers"*, (92), pp. 312 - 318;
- [18] Udomsap P., Sahapatsombat U., Puttasawat B., Krasae P., (2008), Preliminary research on cold flow improvers for palm-derived biodiesel blends. *Journal of Metals, Materials and Minerals*, 18(2), pp. 99-102;
- [19] Yuan M.H., Chen Y.H., Chen J.H., Luo Y.M., (2017), Dependence of cold filter plugging point on saturated fatty acid profile of biodiesel blends derived from different feedstocks. *Fuel*, 195, pp. 59-68.