Експериментальним шляхом досліджено вплив ультразвукової, надвисокочастотної електромагнітної і механічної обробки сумішевого біодизеля на його в'язкість. До складу сумішевого біодизеля входить дизельне пальне і метиловий ефір ріпакової олії. Установлено, що сумісна ультразвукова і надвисокочастотна електромагнітна обробка обумовлює зменшення його в'язкості на 15...17 % по відношенню до необробленого пального. По відношенню до мінерального дизельного пального в'язкість в даних сумішах зменшилась на 2...9 %

Ключеві слова: ультразвук, електромагнітна обробка, дизельне пальне, метиловий ефір ріпакової олії, в'язкість біодизеля

Экспериментальным путем исследовано влияние ультразвуковой, сверхвысокочастотной электромагнитной и механической обработки смесевого биодизеля на его вязкость. В состав смесевого биодизеля входит дизельное топливо и метиловый эфир рапсового масла. Установлено, что совместная ультразвуковая и сверхвысокочастотная электромагнитная обработка обуславливают уменьшить его вязкости на 15...17 % по отношению к необработанному топливу. По отношению к минеральному дизельному топливу вязкость в данных смесях уменьшилась на 2...9 %

Ключевые слова: ультразвук, электромагнитная обработка, дизельное топливо, метил эфир рапсового масла, вязкость биодизеля

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RESEARCH INTO EFFECT OF ULTRASONIC, ELECTROMAGNETIC AND MECHANICAL TREATMENT OF BLENDED BIODIESEL FUEL ON VISCOSITY

R. Kushlyk
Postgraduate student*
E-mail: kushlyk@mail.ru
I. Nazarenko
Doctor of Technical Sciences, Professor, Head of Department*
E-mail: Nazarenko-64@mail.ru
R. Kushlyk
PhD, Associate Professor*
E-mail: kushlykroman@mail.ru
V. Nadykto
Doctor of Technical Sciences, Professor, Vice-Rector
Department of using machines in arable farming**
E-mail: imesh@zp.ukrtel.net
*Department of Electrotechnology and thermal processes**
**Tavria state agrotechnological university
B. Khmelnytskogo ave., 18, Melitopol, Ukraine, 72310

1. Introduction

According to the forecast of the International Energy Association (IEA), the world production of biofuels will increase by 2030 to 92–147 million tons [1].

Creation of fuel for diesel engines from organic raw materials will make it possible to transform plant growing from the industry, which is the main consumer of light oil, into the industry that produces ecologically clean motor fuel from renewable sources of energy. The commonest of all fuels of plant origin in Ukraine is the biodiesel fuel based on rapeseed oil [2–4].

Practical use of biodiesel fuel in Ukraine is officially approved by the national standard DSTU 4840:2001 «Diesel engine fuel of high quality. Technical specifications», which implies the certification of diesel fuel with a 5 % additive (B5) of methyl esters of fatty acids.

Since 2010, the acting national standard in Ukraine is DSTU 6081:2009 «Motor fuel. Methyl esters of fatty acids of oils and fats for diesel engines. Technical requirements». This document is harmonized with the European standard EN 14214:2003 «Fuel for cars. Methyl esters of fatty acids for diesel engines. Requirements and methods of analysis».

As shown by practice, with an increase in the share of methyl ester of vegetable oils (MEVO) in diesel fuel (DF) exceeding 5 %, the viscosity of biodiesel (that is, a mixture of MEVO and DF) grows. This results in the coking of fuel equipment, reduction in the capacity of diesel engine and rise in its fuel consumption [5, 6].

Due to this, the development of methods and devices that would reduce the viscosity of biodiesel fuel whose formulation includes more than 5 % of MEVO is absolutely relevant today.

2. Literature review and problem statement

Alternative fuel should have renewable raw materials, not be inferior to oil fuels in energy indicators, but possess environmental properties more acceptable for the environment.

Thus, in article [7] it was noted that preference should be given to products of plant origin – biofuels. The exhaust gases of such fuel contain less carbon monoxide CO and CO_2 [8].

Despite the small amount of sulphur, biodiesel is characterized by good lubricating parameters [9]. At the same time, it should be borne in mind that when internal combustion engines operate on vegetable oil, specific indicator fuel consumption increases by 40–60 g/(kW·h), maximum pressure of gases inside the cylinder grows by 8 %, indicator factor of performance efficiency decreases by 5–8 % [10].

In the transition to the fuel of rapeseed oil, it is recommended to increase advance angle of the fuel feed by 2–3°. Temperature of the rapeseed oil in the power supply of the diesel engine has to be maintained at the level of 40–45 °C. It is recommended to use sprayers with effective passable cross section increased by 10 % [11].

In order to improve operational indicators when using rapeseed oil in the internal combustion engines, its mixing with petroleum diesel fuel is applied. The work of diesel engines on the blended fuel provides for a reduction in emission with exhaust gases by 1.7–36 % by carbon oxide [12]. A transition to the mixture of diesel fuel and vegetable oil makes it possible to reduce smokiness by 12.2–42 % [13]. Indicators of «rigidity» in the work of a diesel engine on blended fuels are lower than those on the mineral fuel. Thus, the mean and maximum rate of pressure rise in gases in the blended fuels is 15.4–23 %, respectively. In the diesel fuel – 16.4–24.5 %, respectively [14]. Effective performance efficiency in the blended biodiesel is lower and is within 0.3–0,318. When the diesel engine operates on mineral fuel, efficiency is 0.303–0.329 [15]. Studies conducted in paper [16] demonstrated that effective engine power reduces by 7.0–9.8 %. Hourly fuel consumption increases by 7.0–8.6 %.

A more efficient way to utilize biofuel by internal combustion engines is the use of mixtures of mineral diesel fuel not with vegetable oils but with methyl esters received based on them. At present, the most common of them is methyl ester of rapeseed oil (MERO) [17, 18].

An analysis of the research results [19] revealed that effective engine power under nominal mode reduces by 0.8–3.1 %. Hourly (l/h) and specific (g/kW · h) fuel consumption in this case increases by 1.9–4.2 % and by 2.5–7.5 %, respectively. At the same time, the content of hydrocarbons in exhaust gases is reduced by 1.8–8.3 % relative to the work on mineral diesel fuel.

In Ukraine they also use methyl ester made of sunflower oil (MESO) is used. Experimental studies established [20, 21] that an increase in the amount of MESO in its mixture with DF increases the acceleration time of ploughing unit. Thus, if, during the work of tractor's engine on pure diesel fuel, the value of this parameter was 4.8 s, then when using the mixture of 50:50, the acceleration time of the unit increased to 5.6 s, that is, by 16.6 %.

When running the engine on pure MESO, acceleration time of the examined ploughing unit MTA increased to 7.2 s. This is higher than when working on the mixture and on DF by 28.5 and 50.0 %, respectively.

Most of the researchers, when using the mixtures of diesel fuel and rapeseed oil or methyl ester, experimentally established that in order to intensify the process of obtaining high-quality biodiesel, only mechanical, cavitation or thermal treatment is not enough. A further search is needed for resource-saving technologies of obtaining such fuel through a multifactor influence on the reagents of external power fields of different physical nature. Of special interest in this area is the technical solutions aimed at creating the mixtures of biodiesel with simultaneous cavitation and ultrahigh frequency (UHF) electromagnetic impact on its physical and chemical properties. The very fact that the studies into such processes were not conducted predetermines their relevance and high practical significance.

3. The aim and tasks of the study

The aim of present experimental study is to reveal the influence of ultrasound, ultrahigh frequency (UHF) electromagnetic and mechanical treatment on the viscosity of blended biofuel, which consists of diesel fuel and methyl ester of rapeseed oil (MERO). This will make it possible to increase the amount of MERO in diesel fuel, which will enhance the capacity of internal combustion engine and reduce fuel consumption.

To achieve the set aim, the following tasks are to be solved:

– to define the influence of ultrasound on the viscosity of biodiesel fuel depending on the time of treatment;

– to determine the effect of UHF electromagnetic field on the viscosity of biodiesel fuel depending on the time of treatment;

– to define the impact of fuel treatment in a mechanical homogenizer on the viscosity of biodiesel fuel depending on the time of treatment;

– to detect a compatible effect of ultrasound and UHF electromagnetic field on the viscosity of biodiesel fuel depending on the time of treatment;

– to determine a change in the tangent of angle of dielectric losses (tgδ) in the untreated mixtures and mixtures treated with ultrasound, in a UHF module and in a homogenizer.

4. Materials and methods for examining the influence of ultrasonic, UHF electromagnetic and mechanical treatment on the viscosity of blended biodiesel

4. 1. Materials, equipment and devices used in the experimental research

The study was carried out using commercially available mineral diesel fuel L-0.2-62 and rapeseed oil methyl ester, which was produced by the company TOV «Bionafta Ukraine» (Pavlograd, Ukraine).

Research into ultrasound influence on the blend of diesel fuel and MERO was conducted using the ultrasonic generator UZG-0.4 and the magnetostrictive transducer (made in Russia) at frequency 22 kHz. Effect of UHF electromagnetic field was examined by using UHF-module (made in Ukraine) at frequency 2.45 GHz. Effect of mechanical treatment was explored in the blend of diesel fuel and MERO by using the homogenizer MRW-302 (made in Bulgaria) with rotation frequency of the mixer at 9000 rpm.

Experimental samples of the blends were prepared from diesel fuel and MERO in percentage: 90 % DF + 10 % MEVO (blend 1), 80 % DF + 20 % MERO (blend 2), 70 % DF + 30 % MERO (blend 3), 60 % DF + 40 % MERO (blend 4), 50 % DF + 50 % MERO (blend 5). The treatment of blends lasted for 5, 10 and 15 minutes. For thermostating the treated samples of fuel blend at temperature 20 °C, we used the water thermostat UH-8 (made in Germany). Measuring the viscosity of the treated blends was carried out with the help of the viscometer VPZh-4 (made in Ukraine).

To measure the angle of dielectric losses in the diesel fuel, MERO and blends, we used the installation «Tangent-3M-3» (made in Ukraine) [22–24].

4. 2. Method for determining the viscosity of diesel fuel, MERO and their blends

The method for determining the viscosity of diesel fuel, MERO and raw blends comprised the following. Before starting the work, vessels, in which the samples were prepared, test tubes, vessels of the magnetostrictor, of the UHF module and the homogenizer, as well as the viscometer, were washed with a solvent and dried in the air. 300 ml of blended fuel was poured into each of 5 vessels. This fuel consisted of:

1) 30 ml MERO and 270 ml DF;
2) 60 ml MERO and 240 ml DF;
3) 90 ml MERO and 210 ml DF;
4) 120 ml MERO and 180 ml DF;
5) 150 ml MERO and 150 ml DF.

The blend was stirred with a laboratory electric mixer for 2 minutes. Using the viscometer VPZh-4, 5 times repeatedly at temperature 20 °C, we determined viscosity of DF, MERO and their blends. It was established that the mean viscosity of DF of grade L-0.2-62 equaled 4.301 mm^2/s, and that of MERO – 11.630 mm^2/s. Mean viscosity of the blended fuels is given in Table 1.

Table 1

Mean viscosity of blended fuels

Indicator	Concentration of MERO in the diesel mineral fuel,%				
	10	20	30	40	50
Viscosity, mm^2/s	4.664	5.047	5.587	6.392	7.004

A procedure for determining the viscosity of blended biodiesel treated with ultrasound was as follows. A vessel of the magnetostrictor was filled with one of the prepared samples of biodiesel fuel (300 ml) and then the ultrasound generator UZG-3-04 was turned on. The generator was preset on the resonance frequency of magnetostrictive transducer (22 kHz). Then we enabled a stopwatch for registering the duration of treatment, which lasted for 5, 10 and 15 minutes. After the end of the specified time, we disabled the ultrasound generator and the treatment of samples was over.

A specimen of the treated samples was poured into a test tube, cooled to room temperature, thermostated at 20 °C for 15 min, and then we measured viscosity of the examined sample.

A procedure for determining the viscosity of blended biodiesel treated in the UHF module included the following. A vessel was filled with one of the prepared samples of biodiesel fuel (300 ml) and placed under the horn of the UHF module. We enabled the air hole from the remote control console and supplied voltage to the UHF module that was placed in a protective shell. Then the stopwatch was turned on to measure the duration of fuel treatment, which lasted for 5, 10, 15 minutes. When the specified time expired, we disabled the UHF module power and the treatment of sample was over. A specimen of the treated samples was poured in a test tube, which was cooled to room temperature and thermostated at temperature 20 °C for 15 minutes. Finally, we measured viscosity of the examined sample.

In order to determine the viscosity of blended biodiesel treated in the homogenizer, we conducted the following. A vessel of the homogenizer was filled with one of the prepared samples of biodiesel (300 ml). The control unit ST-2-2 (made in Bulgaria) was turned on. By using the unit's regulator, we alternately set the duration of mechanical treatment at 5, 10 and 15 minutes. When the specified time expired, the control unit automatically disabled the homogenizer and the treatment of control sample was over. A specimen of the treated sample was poured into a test tube, and then this specimen was cooled to room temperature, thermostated at 20 °C for 15 minutes and then we measured viscosity of the examined sample.

5. Results of examining the viscosity of blended biodiesel fuel

5. 1. Results of examining the viscosity of blended biodiesel fuel treated with ultrasound

Results of determining the viscosity of blended biodiesel fuel treated with ultrasound for 5 minutes are shown in Fig. 1. An analysis of the data demonstrates that over the time of observation, viscosity of all blends of fuel first decreases and then sets at almost the same level. Moreover, with a decrease in the share of MERO, the period of constant viscosity of the blend arrives later. Thus, for example, for blend 5 (curve 6, Fig. 1), the period of stable viscosity comes after the third day. For blend 1 (curve 2, Fig. 1), such period occurs not later than the seventh day of observation.

Quite interesting is the fact that blends with a lower share of MERO display a higher intensity in the decrease of its viscosity. Thus, the viscosity of blends 1 and 2 (curves 2 and 3 in Fig. 1) after 1.5 days of observation becomes lower than the viscosity of pure diesel fuel (line 1, Fig. 1).

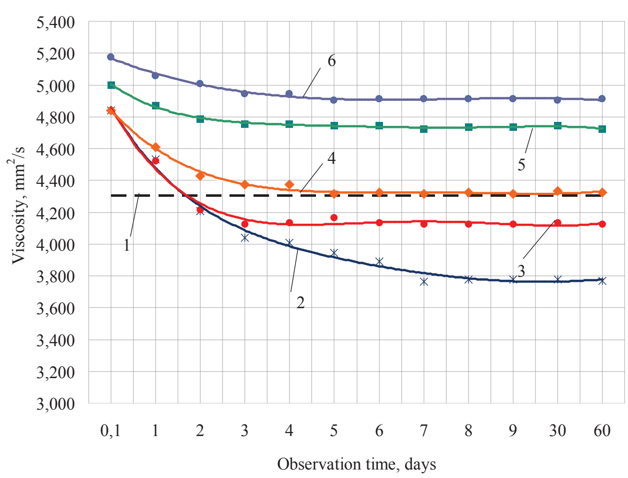


Fig. 1. Dependences of viscosity of the blended biodiesel fuel on the time of observation after treatment with ultrasound for 5 minutes: 1 – DF; 2, 3, 4, 5 and 6 – blends 1, 2, 3, 4 and 5, respectively

Results of the defined (resulting) viscosity of the biodiesel, treated with ultrasound for 5, 10 and 15 minutes are shown in Fig. 2.

Fig. 2 shows that the increase in the treatment time of all five of the examined blends with ultrasonic field for longer than 5 min does not yield considerable benefits. As it turned out, a slight increase in the viscosity of biodiesel during a 15-minute ultrasound exposure does not exceed a measurement error of this parameter.

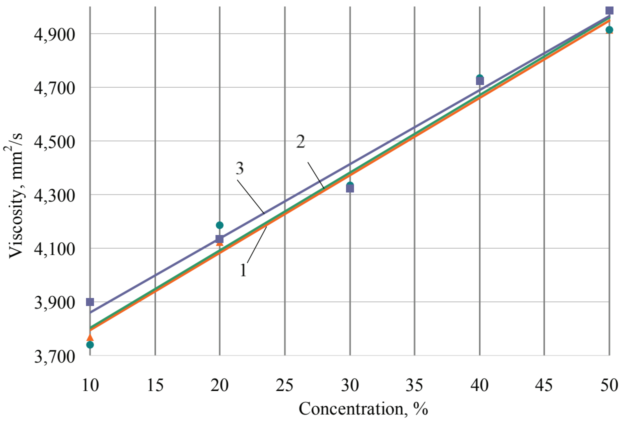


Fig. 2. Dependences of resulting viscosity of the blended biodiesel fuel at its treatment with ultrasound for: 1 — 5 min; 2 — 10 min; 3 — 15 min

5. 2. Results of examining the viscosity of blended biodiesel fuel treated in a UHF module

We controlled temperature of the samples when treating the blends of biodiesel fuel in the UHF module. Results obtained in this process are shown in Fig. 3.

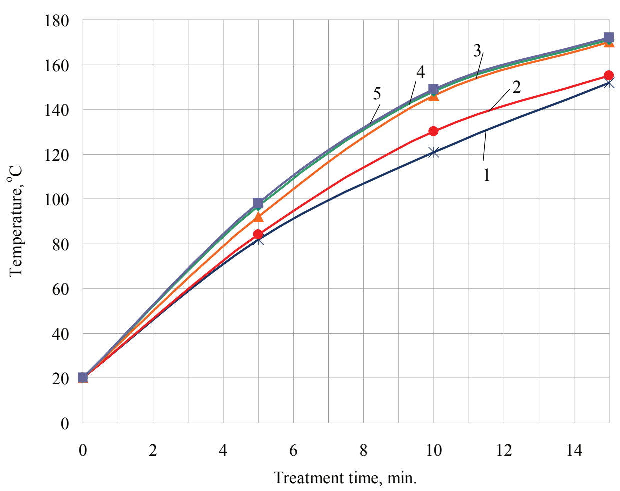


Fig. 3. Dependences of temperature of the blend of DF and MERO on the time of treatment: 1, 2, 3, 4 and 5 — blends 1, 2, 3, 4 and 5, respectively

An analysis of data in Fig. 3 reveals that the larger the proportion of MERO in the samples of diesel fuel and the longer the heating time of blends, the higher their temperature is. For example, when treating the blends of diesel fuel and MERO for 5 minutes, temperature of the samples was in the range of 82–98 °C, 10 minutes – 121–149 °C and 15 minutes – 152–172 °C.

Results of determining the viscosity of blended biodiesel fuel treated in the UHF module for 5 minutes in the respective proportions of the observation period are shown in Fig. 4. In this case, on the right side of Fig. 4 are results of viscosity of the untreated samples, and on the left side are the results of viscosity of treated samples in the UHF module.

It should be noted that after treating blend 1 (curve 2), viscosity of the fuel decreased by 5.2 % relative to the untreated sample. For blend 2 (curve 3), this indicator decreased by 4.9 %, for blend 3 (curve 4) – by 6.8 %, blend 4 (curve 5) – by 14.6 % and for blend 5 (curve 6) – by 18.8 %.

When analyzing these results, it should be noted that viscosity of the treated samples decreased relative to the untreated ones. However, it did not become lower than that of the diesel fuel – that is 4.301 mm^2/s (curve 1).

Results of the established (resulting) viscosity of biodiesel treated in the UHF module for 5, 10 and 15 minutes are shown in Fig. 5.

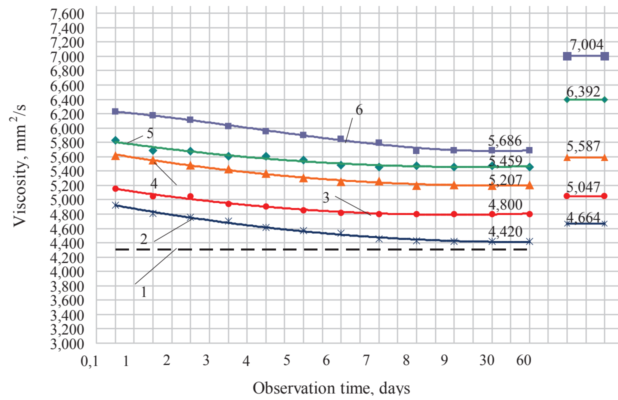


Fig. 4. Dependences of viscosity of the blended biodiesel fuel on the time of observation after treatment in the UHF module for 5 minutes: 1 — DF; 2, 3, 4, 5 and 6 — blends 1, 2, 3, 4 and 5, respectively

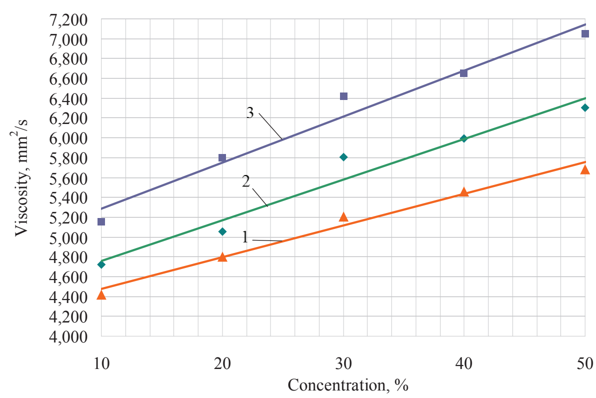


Fig. 5. Dependences of resulting viscosity of the biodiesel fuel on the concentration of MERO and the time of exposure to UHF waves for: 1 — 5 min.; 2 —10 min; 3 — 15 min

Fig. 5 shows that the observed dependences are of linear character. Moreover, an increase in the treatment time of blended fuel affects the change in its resulting viscosity. Thus, when treating in the UHF module the prepared samples for 10 minutes, the resulting viscosity of all samples increased by 6.4 % on average relative to the samples treated for 5 minutes. A treatment of prepared samples for 15 minutes led to the growth in the resulting viscosity by 14.2 % relative to the samples treated for 5 minutes.

5. 3. Results of examining the viscosity of blended biodiesel fuel, treated in a homogenizer

We controlled temperature of the samples when treating the blends of biodiesel fuel in the homogenizer. Results obtained in this process are shown in Fig. 6.

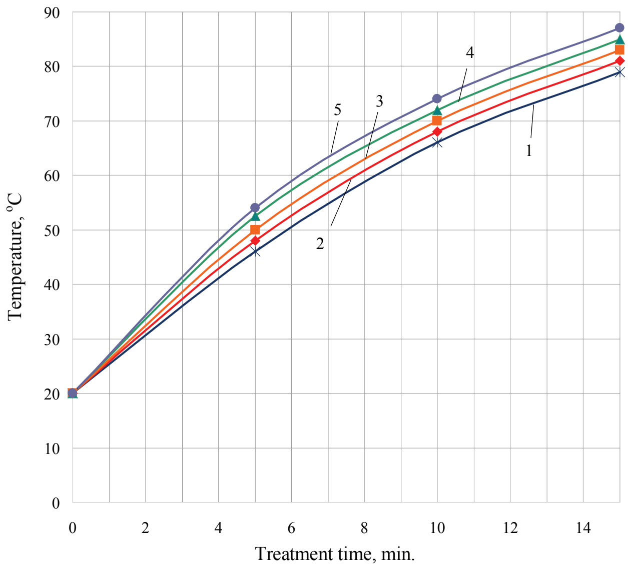


Fig. 6. Dependences of temperature of the biodiesel fuel on the time of its treatment: 1, 2, 3, 4 and 5 – blends 1, 2, 3, 4 and 5, respectively

It should be noted that the larger the proportion of MERO in the samples of diesel fuel and the longer its treatment time, the higher is the temperature of heating the samples. Thus, when treating the biodiesel fuel blends for 5 minutes, temperature of the samples was in the range of 46–54 °C, at treatment time of 10 minutes – 66–74 °C and 15 minutes – 79–87 °C.

Results of determining the viscosity of blended biodiesel fuel treated in the homogenizer for 5 minutes are shown in Fig. 7. On the right side are results of viscosity of the untreated samples, and on the left side are results of viscosity of the samples treated in the homogenizer.

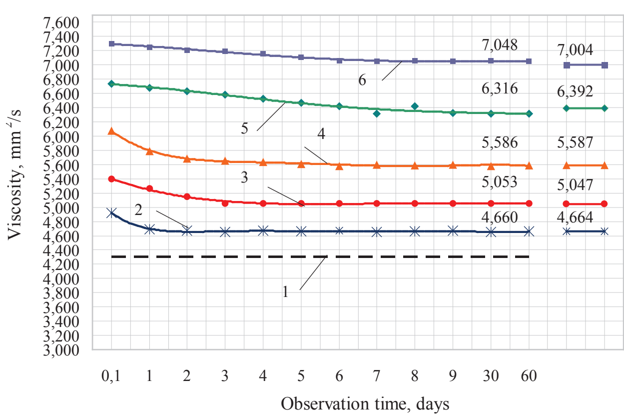


Fig. 7. Dependences of viscosity of the blended biodiesel fuel on the time of observation after treatment in the homogenizer for 5 minutes: 1 – DF; 2, 3, 4, 5, 6 – blends 1, 2, 3, 4 and 5, respectively

It should be noted that the resulting viscosity value of blended biodiesel fuel, treated for 5 minutes in the homogenizer, did not change relative to its untreated state.

Results of the final viscosity of biodiesel fuel treated in the homogenizer for 5, 10 and 15 minutes are shown in Fig. 8.

One can see that all dependencies are linear in character. With an increase in the concentration of MERO, viscosity of biodiesel fuel increases, moreover, an increase in the treatment time of the blended fuel does not affect the change in the resulting viscosity.

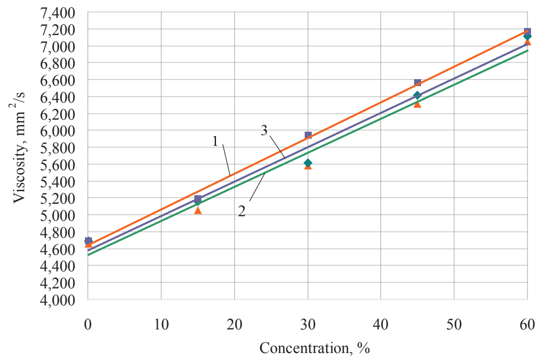


Fig. 8. Dependences of change in the resulting viscosity of biodiesel fuel at its treatment for: 1 – 5 min.; 2 – 10 min.; 3 – 15 min.

5. 4. Results of examining the combined influence of ultrasound and UHF electromagnetic field on the biodiesel viscosity

In order to determine a combined impact of ultrasound and UHF electromagnetic field on the viscosity of biodiesel fuel, the samples of blends 1, 2 and 3 taken in advance were treated by ultrasound for 20, 60 and 180 s. Results of determining the viscosity of blended biodiesel fuel for this case are shown in Fig. 9.

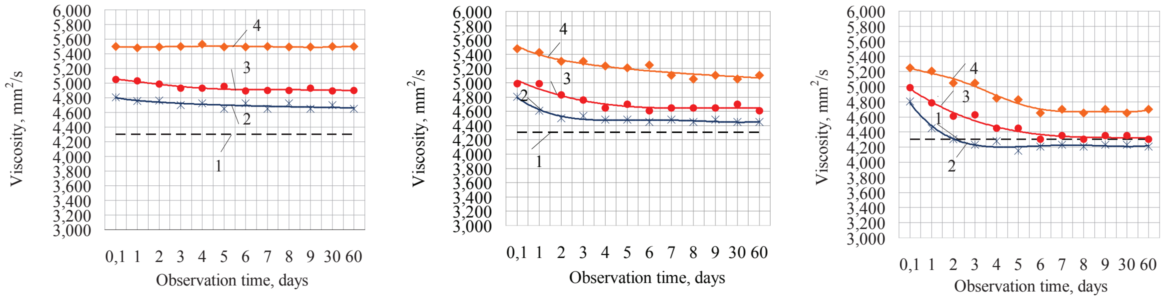
It should be noted that at an increase in the time of fuel treatment from 20 to 180 s, the resulting value of viscosity improved. At the same time, at 3 minutes of treatment, indicators of fuel viscosity are worse than those when it is treated for 5 minutes (Fig. 1).

Results of examining the combined influence of ultrasound and UHF electromagnetic field on the viscosity of biodiesel fuel when treating the samples of blends 1, 2 and 3 for 3 minutes are shown in Fig. 10.

It should be noted that when treating the blended biodiesel fuel with ultrasound and UHF waves for 3 minutes, its viscosity improved. When treating the fuel with ultrasound only at the same time duration (Fig. 9), the results are worse. Viscosity of the biodiesel fuel that was exposed to the ultrasound and UHF waves during 3 minutes has about the same values as when it was treated only with ultrasound for 5 minutes. This fact predetermines the prospect of applying under industrial conditions the mode of combined (ultrasound and UHF waves) treatment of biodiesel fuel that would last no longer than 3 minutes.

We measured the tangent of angle of dielectric losses (tgδ) in the diesel fuel, MERO and their blends by the installation «Tangent-3M-3 [22]. Results of the measurement of this indicator are shown in Fig. 11.

It should be noted that when treating the blends of diesel fuel and MERO with ultrasound and UHF electromagnetic field (curves 2 and 3, Fig. 11), tangent of angle of dielectric losses is smaller than in control samples (curve 1). This indicates the improved purity and quality of the product after its treatment. At the same time, when treating the blends of diesel fuel and MERO in the homogenizer (curve 4, Fig. 11), tangent of angle of dielectric losses is larger than in control samples (curve 1).



a *b* *c*

Fig. 9. Dynamics of change in the viscosity of biodiesel fuel after treatment with ultrasound: *a* — 20 s; *b* — 60 s; *c* —180 s; 1 — DF; 2, 3, 4 — blends 1, 2 and 3, respectively

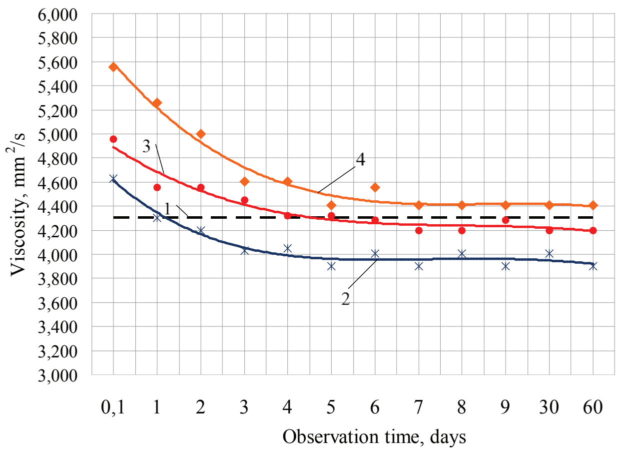


Fig. 10. Dependences of viscosity of the blended biodiesel fuel on the observation time after treating the fuel with ultrasound and UHF waves for 3 min.: 1 — DF; 2, 3, 4 — blends 1, 2, and 3, respectively

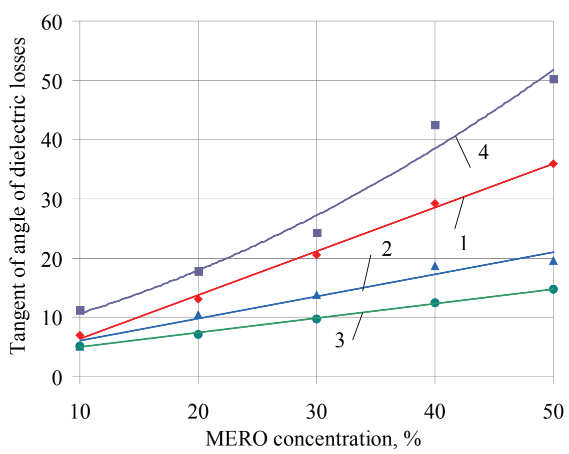


Fig. 11. Dependences of tangent of the angle of dielectric losses on the concentration of MERO in diesel fuel: 1 — before treatment; 2, 3, 4 — after treatment with ultrasound, UHF module and homogenizer, respectively

This result indicates worsening of the purity and quality of the product, which should be considered when developing an electrotechnological complex for studying the influence of electromagnetic field on the blended biofuel.

6. Discussion of results of examining the influence of ultrasound, UHF electromagnetic field and mechanical homogenization on the biodiesel fuel viscosity

With an increase in the share of MERO in diesel mineral fuel, as evidenced by the obtained results (Table 1), its viscosity grows. This causes the coking of fuel equipment, separation of fuel into the starting components, reduction in engine power, increase in its fuel consumption, etc. This results in the increased wear of conjugated parts, sealing of the calibrated openings, carbon black and soot formation, which leads to frequent replacement of filters and motor oils [5–7].

At present, researchers propose various methods and technologies that allow changing the physical-chemical parameters of petroleum fuel products. To influence the kinetics of processes that proceed in petroleum products is possible by both chemical substances (catalysts, surface-active substances, additives) and physical fields (thermal, ultrasonic, electromagnetic). As a result of such intervention, radius of the core and thickness of the adsorption-solvent membrane of a complex structural unit change, which is part of petroleum disperse system. However, treating an oil product with chemical substances leads to the accelerated wear of technological equipment and it is a hard-to-control process.

A special attention is now paid by many researchers to the methods of intensive treatment of petroleum products in order to increase the output of light fractions in their distillation, reduction of sulfur content, viscosity and density. Underlying the technologies that use the effect of cavitation on oil products is the method of pulse energy impact through acoustic waves and cavitation. Cavitation destroys bonds between separate molecules and affects a change in the structural viscosity of oil products. Under the influence of cavitation of large intensity for a long time, the C–C bonds in paraffin molecules are destroyed. As a result, there are changes in the physical-chemical composition of an oil product. This leads to a decrease in molecular weight, temperature of crystallization, as well as to a change in the properties of an oil product (viscosity, density, flashpoint temperature, etc.) [25, 26].

It should be noted that the conducted experimental studies have confirmed the theory of destruction of bonds between separate molecules in the blend of diesel fuel with MERO. When summing up, due to the action of cavitation, viscosity of the fuel decreased in all the samples by 20 % on average. Obviously, such a mechanism of influence of ultrasound on biodiesel fuel is the factor that improves physical and chemical indicators of the blended fuel.

Comparison of the treatment time of blended biodiesel fuel testifies to the effectiveness of this process. Thus, the experimental research conducted into the treatment of different blends for 5, 10 and 15 minutes (Fig. 1, 2) demonstrated that the examined characteristics have the same character and in order to obtain a positive result, 5 minute-exposure to ultrasound is enough. Therefore, in contrast to the research results published in [22–24], we carried out additional research into treatment of the biodiesel fuel blends with ultrasound for 20, 60 and 180 s. (Fig. 9). Results of determining the viscosity of biofuel over a specified treatment period confirmed that the optimal time for its treatment with ultrasound does not exceed 5 minutes.

Of particular interest in terms of the improvement of physical and chemical indicators of the blended fuel is the effect exerted on biodiesel by UHF electromagnetic field. One of the most promising areas in the application of UHF electromagnetic treatment is the treatment of petroleum and petroleum products. In particular, [27] described experimental study on physical modeling of the processes of heating substances of varying viscosity that simulate heating of petroleum products. If instead of the traditional methods of heating, heating using UHF energy oscillations is employed, then energy conversion into heat occurs not at the surface, but inside its volume.

Due to this, it is possible to achieve a more intensive growth in temperature at the larger uniformity of heating in comparison with the traditional means of temperature influence on a petroleum product. The latter circumstance in some cases leads to the improvement of its quality [28].

The positive impact of UHF waves on biodiesel fuel demonstrated (Fig. 4, 5) that the viscosity of blends 1, 2 and 3 when treated for 5 minutes decreased relative to the untreated fuel by 5.6 % on average. However, it did not become less than the same indicator (4.301 mm^2/s) for the diesel fuel. In particular, it was found that with an increase in the heating time of blends from 5 to 15 minutes, temperature of their samples rose to 172 °C. As a result, light fractions of the blended fuel evaporated and viscosity of the product treated for 10 minutes increased by 6.4 % on average relative to the samples treated for 5 minutes. A treatment of samples for 15 minutes led to the growth in resulting viscosity by 14.2 % relative to those samples, which were subject to the influence of UHF waves for 5 minutes.

Given these circumstances, we conducted experimental research into combined impact of ultrasound and UHF electromagnetic field on the dynamics of biodiesel viscosity at its treatment for 3 minutes. It was established that the viscosity of biodiesel, treated for 3 minutes with ultrasound and UHF waves (Fig. 10), has the same values as the biofuel treated with ultrasound for 5 minutes (Fig. 1).

However, the argument about a possibility of implementing the obtained results at the industrial installation for treatment of the blended biofuel with ultrasound and UHF waves for 3 minutes is premature. Thus, at present, there are a number of unresolved issues in determining the effect of ultrasound and UHF waves on viscosity of the fluid that moves in the control object. Conducting further studies would be very appropriate, as it would extend our understanding of the processes that occur under dynamic mode of the biofuel treatment.

7. Conclusions

1. In order to reduce viscosity of the blend of diesel fuel with MERO by 20 % on average, it is sufficient to expose it to the ultrasound for 5 minutes.

2. Effect of UHF electromagnetic field on the blends of diesel fuel with MERO for 5 minutes makes it possible to reduce their viscosity by 5.6 % on average.

3. A treatment of blends of biodiesel fuel in the mechanical homogenizer did not lead to a decrease in the viscosity of the fuel and after 60 days of observation, it remained at the same level as prior to the treatment.

4. It was found that the combined influence of ultrasonic and UHF treatments on blend 1 and blend 2 for 3 minutes allowed reducing the viscosity of biodiesel fuel by 16.3 % and 15.8 %, respectively. Viscosity in the given blends, relative to the mineral diesel fuel, decreased by 9.3 % and 1.2 %, respectively.

5. In blends 1–5, treated with ultrasound, tangent of the angle of dielectric losses (tgd) decreased relative to control samples by 20.67–45.11 %. In the same blends, but treated in the UHF-module, the magnitude of tgd decreased by 25.21–58.94 %, which unequivocally testifies to the improvement in purity and quality of the fuel. At the same time, in the blends of fuel treated in the homogenizer, the tangent of the angle of dielectric losses increased relative to control samples by 11.24–50.28 %, which indicates deterioration in the fuel quality.

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