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UV irradiation testing of biodiesel from the Alhagi oil and diesel-biodiesel mixtures

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Abstract. *The chemical stability of fuels is one of the key factors in ensuring the proper operation of combustion engines. Progressive destruction of components of diesel-biodiesel fuels during storage and transportation can adversely affect their physical and chemical parameters. Besides, the destruction of petroleum products under sunlight and the formation of toxic compounds have ecological importance. The purpose of the presented work is to investigate the influence of UV irradiation (λ = 300–450 nm) on the chemical content of petroleum diesel and B5, B10, B20, B50, and B100 fuel blends for the 24 h. As biodiesel, the product of transesterification of non-edible Alhagi oil with methanol was used. Chemical changes after irradiation were controlled by the BRUKER FT NMR spectrometer. The relationship between changes in the chemical composition and important physicochemical parameters (density, viscosity, flash point, and cetane index), before and after photochemical destructions was discussed. Based on the obtained results, it was determined that the B20 fuel mixture has more chemical stability after UV irradiation than conventional diesel and other diesel-biodiesel mixtures.*

Keywords: *UV irradiation, photo-destruction, biodiesel, Alhagi oil*

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CHEMICAL TECHNOLOGY

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Тестирование УФ-облучением биодизеля из масла верблюжьей колючки и дизель-биодизельных смесей

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Аннотация. *Химическая стабильность топлив является одним из ключевых факторов обеспечения исправной работы двигателей внутреннего сгорания. Прогрессирующая деструкция компонентов дизель-биодизельных топлив при хранении и транспортировке может отрицательно сказаться на их физико-химических показателях. Кроме того, разрушение нефтепродуктов под действием солнечных лучей и образование токсичных соединений имеет экологическое значение. Целью представленной работы является исследование влияния УФ-облучения (λ = 300–450 нм) на химический состав нефтяного дизельного топлива и топливных смесей B5, B10, B20, B50 и B100 в течение 24 ч. В качестве биодизеля использовали продукт переэтерификации непищевого масла верблюжьей колючки с метанолом. Химические изменения после облучения контролировали с помощью ЯМР-спектрометра FT BRUKER. Изучена взаимосвязь изменений химического состава и важных физико-химических параметров (плотность, вязкость, температура вспышки, цетановое число) до и после фотохимической деструкции. На основании полученных результатов установлено, что топливная смесь B20 обладает большей химической стабильностью после УФ-облучения, чем обычное дизельное топливо и другие дизель-биодизельные смеси.*

Ключевые слова: *УФ-облучение, фотодеструкция, биодизель, масло верблюжьей колючки*

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INTRODUCTION

Despite the use of diesel fuel having a clear negative impact on the environment, it still remains the leader in terms of consumption among all commercial liquid fuels. The increasing demand for fuel, depletion of fossil fuels, and protection of the environment from the harmful effects of fossil fuels are forcing us to find new alternatives to petroleum fuels. One of the alternative fuels for internal combustion engines is biodiesel. Biodiesel fuels have the potential advantages of lower emissions, longer engine life due to better lubrication, biological decomposition, high cetane number, absence of aromatic, nitrogen and sulfur compounds [1–3].

One of the main factors that ensure the proper operation of diesel engines is the chemical stability of the fuel. During the transportation, storage and ecological pollution, petroleum products are regularly exposed to sunlight, which leads to the progressive destruction of components of fuels with the formation of toxic compounds. Except these, chemical changes seriously affect the physicochemical and exploitation parameters of the fuel, resulting in engine failure [4].

As we know, diesel fuel is a complex mixture obtained from the fractional distillation of crude oil and consists of a mixture of aliphatic, aromatic and olefin hydrocarbons [5]. Biodiesel, one of the most environmentally friendly and alternative fuels, is obtained by transesterification of saturated and unsaturated fatty acids with simply alcohols. Diesel and biodiesel fuels contain a certain number of unsaturated compounds with high reactivity. It can lead to chemical changes in the chemical composition of fuels during long-term storage, transportation and pollution. Also, ultraviolet rays from the sun accelerate the decomposition of organic compounds and subject them to photo-destruction [6]. The destruction of components of diesel and biodiesel fuels also has a negative impact on physical and chemical parameters, which in turn can lead to some problems with the regular operation and performance of combustion engines [7].

Considering the above indicated, the purpose of this study is to investigate changes in the chemical composition of diesel and diesel-biodiesel mixtures under ultraviolet irradiation (300–450 nm) and their influence on exploitation properties. Testing of chemical changes under UV was investigated by using NMR spectroscopy.

MATERIALS AND METHODS

Samples of diesel fuel and Alhagi oil used for the study were obtained from a gas station and a pharmacy in Baku, Azerbaijan.

To stimulate natural solar irradiation, a visible and UV-emitting model PRK2-IV-59 model using a lamp with a wavelength of 300–450 nm was used.

NMR experiments were performed on a BRUKER FT NMR spectrometer (UltraShieldTM Magnet) AVANCE 300 (300.130 MHz for ^{1}H and 75.468 MHz for ^{13}C) with a BVT 3200 variable temperature unit in 5 mm sample tubes using Bruker Standard software (TopSpin 3.1). The ^{1}H and ^{13}C chemical shifts were referenced to internal tetramethylsilane (TMS). NMR-grade $CDCl_3$ was used for the analysis of fuel blends.

The procedure for preparation of biodiesel. For the synthesis of biodiesel (B100), 0.69 g of KOH was dissolved in 37.5 ml of methanol (CH_3OH) without heating (at room temperature). After complete dissolution, 50 g of non-edible Alhagi oil was added to this mixture. The reaction was carried out in a conical flask equipped with a reverse refrigerator and magnetic stirrer at 55 ºC for 6 h (rotation speed was maintained at 1000 rpm). After mixing, the reaction mass was kept in the separator funnel for at least 12 h. The reaction mass was divided into 2 layers using a separating funnel: biodiesel in the upper layer and glycerin in the lower layer. It was washed several times with water to remove untreated biodiesel catalysts. 5 g of Na_2SO_4 was added to the pure biodiesel and filtered through filter paper after 12 h of storage. B5, B10, B20, and B50 diesel-biodiesel mixtures were prepared on the basis of received diesel fuel and diesel fuel obtained from filling stations. Biodiesel and diesel-biodiesel mixtures synthesized from non-edible Alhagi oil have been characterized in accordance with the American Test and Materials Standard (ASTM) methods (relative density – D1298, kinematic viscosity – D445, flash point – D93).

Samples of Experiments of UV irradiation. 3 ml of each of B0, B5, B10, B20, B50, B100 samples, prepared in the appropriate proportions with crude diesel and Alhagi biodiesel and were added to the closed glass ampoules. The samples were irradiated for 24 h at room temperature (20 °C) by means of a model lamp PRK2-IV-59, which emits visible and UV (300–450 nm) rays. Within 24 h, visible changes occurred in each of the samples (Fig. 1 and 2). Samples were analyzed on a BRUKER FT NMR spectrometer to determine changes in chemical composition.

RESULT AND DISCUSSION

As known, diesel fuel is a complex mixture of aliphatic, aromatic, and olefin hydrocarbons. In diesel fuel, aliphatic hydrocarbons are in the form of normal paraffinic, isoparaffinic, and cycloparaffinic, while aromatic hydrocarbons are benzene and its derivatives: alkylbenzenes, benzo cyclopentane, benzo cyclopentene, tetralin, biphenyl, naphthalene, fluorenes, phenanthrene, etc. [8, 9]. Biodiesel fuel consists of alkyl esters of various fatty acids, which, depending on the oil obtained, contain 1, 2 or 3 unsaturated double bonds [1, 2]. The presence of large amounts of unsaturated compounds with π electrons in diesel and biodiesel fuels confirms the possibility of oxidation, polymerization and other destruction reactions of double bonds, which are commonly accepted mechanisms of photo-destruction during UV irradiation. As a result of the absorption of ultraviolet and visible light, photons collide with π electrons, and these π electrons easily become excited. These changes are likely to indicate that photo-destruction processes are taking place in fuel components under the influence of UV rays [5, 8]. The energy of photons in UV rays with a wavelength of 300–450 nm varies in

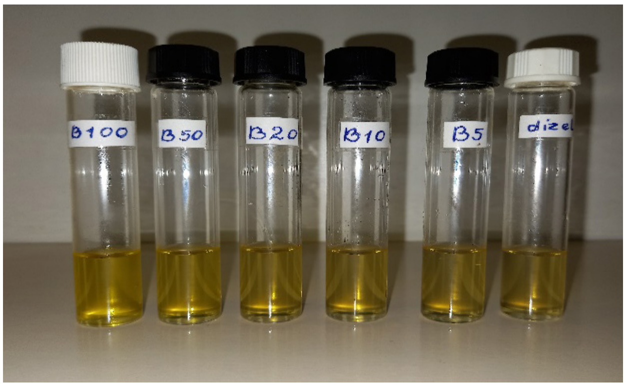


Fig. 1. Diesel, B5, B10, B20, B50 and B100 blends before the UV irradiation

Рис. 1. Дизель, смеси B5, B10, B20, B50 и B100 до УФ-облучения

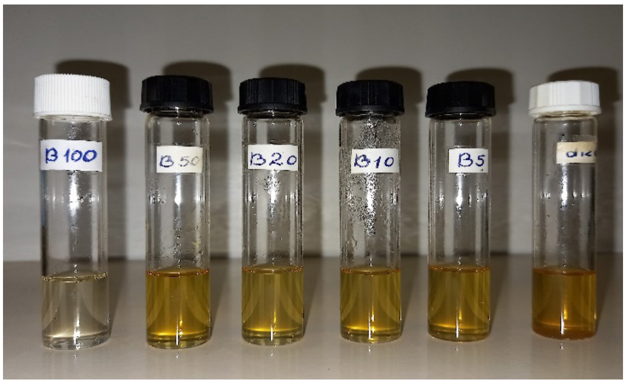


Fig. 2. Diesel, B5, B10, B20, B50 and B100 blends after the UV irradiation

Рис. 2. Дизель, смеси B5, B10, B20, B50 и B100 после УФ-облучения

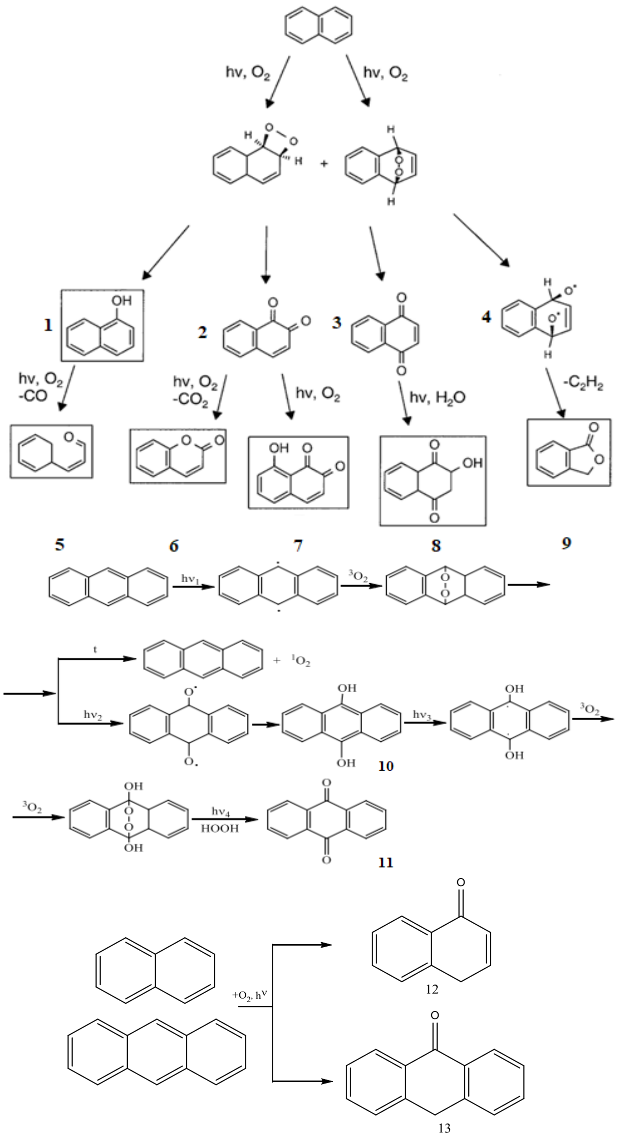
the range of about 266–400 kC/mol. During this excitement, physical and photochemical changes occur and photo-destruction processes take place in diesel and biodiesel components [10–12].

The fact that this energy exceeds the dissociation energy of certain unsaturated compounds in diesel and biodiesel fuels leads to the formation of radical centers, resulting in many chemical reactions [13]. Polycyclic aromatic hydrocarbons in heavy fuels are the most sensitive to photo-oxidation and are easily destroyed when exposed to sunlight [14]. Solar irradiation and the presence of oxygen cause the oxidation of these hydrocarbons, including various oxygenated hydrocarbons, aliphatic and aromatic ketones, aldehydes, carboxylic acids, fatty acids, esters, epoxides [15].

As shown in Scheme 1 during the photo-oxidation of polyaromatic hydrocarbons, aromatic ketones are formed, which first carry one oxygen atom and then combine two or more oxygen atoms. The deeper the photo-destruction, these polycyclic ketones can be converted into smaller acids, ketones and epoxides.

In addition to photo-oxidation, polyaromatic hydrocarbons undergo a dimerization reaction under the influence of UV irradiation (Scheme 2) [16–17].

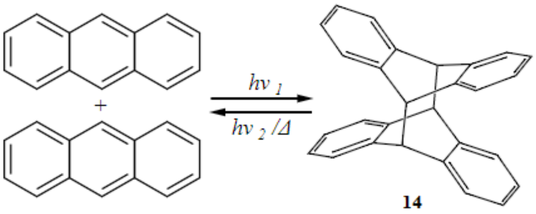
Like polyaromatic hydrocarbons, alkylbenzenes in diesel fuel can be converted into oxygenated compounds such as aromatic ketones and alcohols [18–22]. For example, in the presence of air, under the influence of ultraviolet rays, 1-methylnaphthalene is initially converted to oxidized compounds in the side chain, such as 1-naphthaldehyde, 1-naphthoic acid and 1 naphthalenemethanol and in the next step to the products opened by the ring. Significant dimerization occurs when the reaction is carried out in an inert atmosphere (Scheme 3) [23].



Scheme 1. Photo-oxidation products of naphthalene and anthracene

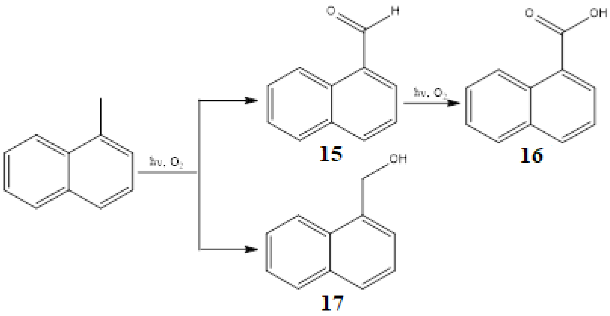
Схема 1. Продукты фотоокисления нафталина и антрацена

In addition to diesel fuel, biofuels obtained from



Scheme 2. Photo-dimerization product of anthracene

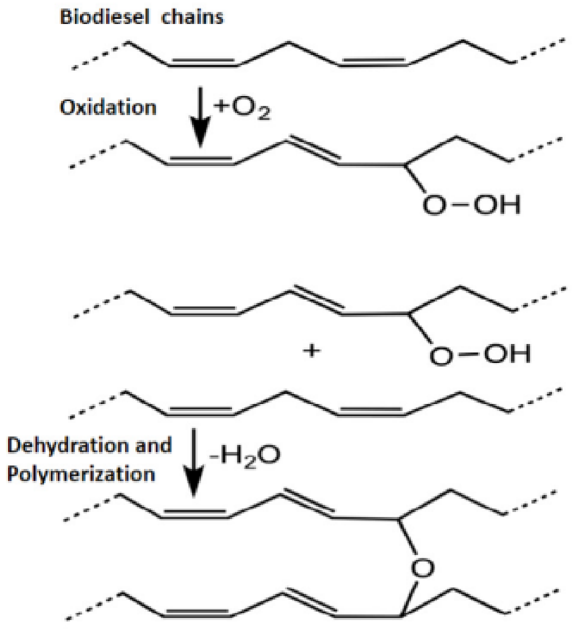
Схема 2. Продукт фотодимеризации антрацена the transesterification of fatty acids with simple alcohols can also undergo photochemical transformations. Alhagi oil has the highest percentage of linoleic acid (50–54%), oleic acid (23–29%) and palmitic acid (7–8%) among the additional fatty acids [24]. The unsaturated compounds have a strong effect on the stability of biodiesel. Polyunsaturated esters are more sensitive to oxidation than saturated or unsaturated esters. This is due to the fact that the double bonds in the fatty acid esters are not in the conjugated structures, but in the configuration isolated with methylene. The bis-allicity in these structures is sensitive to the abstraction of hydrogen by free radicals, which easily form hydroperoxides with elemental oxygen. The resulting peroxides are relatively unstable, reacting intramolecularly to break down the double-bonded compound into low-molecular-weight radicals, which then form acids, aldehydes, ketones, alcohols, olefins, and alkanes. These species, in turn, undergo reactions to form oligomeric and polymer products (Scheme 4) [25–27].



Scheme 3. Photo-oxidation products of alkylbenzenes

Схема 3. Продукты фотоокисления алкилбензолов

Changes in the samples are clearly visible at first glance for B5, B10, B20, B50, and B100 fuels made from diesel and non-edible Alhagi oil are exposed to UV rays (300–450 nm) for 24 h. After ultraviolet irradiation, the color of the fuel samples darkens (brown), turbidity and a small amount of brown sediment is observed at the bottom of the sample container (Fig. 1 and 2). This precipitation is likely to be caused by the gum formation of fuel compounds [4, 5]. Along with conventional petroleum diesel, visible changes in the color of biodiesel samples are also observed, which indicates that serious chemical transformations are taking place in the fuel. To discuss these changes, before and after UV irradiation using the ^{1}H NMR spectroscopy method amounts of alkanes, olefins, and aromatic hydrocarbons in diesel and biodiesel fuel samples were determined (Tab. 1). Analyzing the obtained data, we can see different changes in the amounts of paraffin, aromatic, and olefin hydrocarbons in the content of diesel-biodiesel mixtures under UV rays for 24 h.



Scheme 4. Photo-oxidation products of biodiesel

Схема 4. Продукты фотоокисления биодизеля

As seen from Tab. 1, while the concentration of some hydrocarbons decreases, others increase. It is believed that these changes are due to processes such as photo-oxidation, destruction, and polymerization by UV irradiation.

Comparing the NMR ^{1}H spectra of diesel fuel before and after ultraviolet irradiation, we can see the amounts of paraffin hydrocarbons increased under the influence of UV rays, while the amount of aromatic and olefin hydrocarbons decreased. This indicates the possibility of the conversion of aromatic and olefin hydrocarbons to saturated hydrocarbon fragments as a result of the photo-destruction of unsaturated

Table 1. Determination of hydrocarbon content of fuel blends from the 1H NMR spectra before and after UV irradiation

Таблица 1. Определение содержания углеводородов в топливных смесях по спектрам ЯМР ^{1}H до и после УФ-облучения

Before UV irradiatin	PH	OH	AH	After UV irradion	PH	OH	AH
Diesel	95.1	0.5	4.7	Diesel	96.4	0.0	3.6
B5	95.5	0.7	3.3	B5	94.8	0.8	1.9
B10	94.2	0.8	2.6	B10	94.6	1.2	1.7
B20	97.0	1.1	1.9	B20	96.5	1.7	1.3
B50	92.9	4.3	2.4	B50	96.1	3.1	0.9

Note. *PH – paraffinic hydrocarbons; OH – olefinic hydrocarbons; AH – aromatic hydrocarbons.

compounds in diesel fuel. It can be explained that (Scheme 1 and 2) firstly in diesel 2 and 3 ring aromatic hydrocarbons, such as naphthalene, anthracene, and pyrene are photo-destroyed by UV irradiation. In this case, as a result of oxidation of polyaromatic hydrocarbons (PAHs) obtained products carrying 1 oxygen atom, such as naphtone (**12**) and anthrone (**13**), NMR signals shift to the right in the ^{1}H spectrum to paraffinic hydrocarbons. The decrease of the aromatic and increase of paraffinic hydrocarbons is connected by the formation of **1**-**3**, **5**-**9**, **11**-**14** type hydrocarbons and saturation of double bonds.

We can note that, as a result of such destruction processes, changes in the physical and chemical parameters of the fuel are also observed: density, flashpoint (for B10, B20 and B100), viscosity, and cetane number decrease. The results of the physical parameters also confirm the results of the ^{1}H NMR. In diesel fuel, the components are destructed to low-viscosity and density compounds compared to primary substances (Tab. 2 and 3). Cetane number of diesel fuel is decreased as a result of the formation of oxygen-containing compounds, such as ketones, alcohols, etc.

After UV irradiation in B5 fuel, a decrease of aromatic and paraffinic hydrocarbons is observed, but an increase in olefin hydrocarbons is observed. Based on obtained results, it is assumed that increasing of olefins is connected to the 5% presence of FAME Alhagi oil with the double bonds. The reason of the decreasing of paraffinic hydrocarbons is due to the replacement of hydrogen in the $–CH_2–$ group with $–CH–OOH$-type hydrogen in the paraffinic hydrocarbons. Decreasing amounts of aromatic hydrocarbons are connected by the formations of **1**-**3**, **5**-**9**, **11**, **14** type compounds. Changes in the physical and chemical parameters of B5 fuel are also observed as in conventional diesel fuel (Tab. 2 and 3).

An increase in the amounts of methyl esters of fatty acids in diesel fuel (B10) resulted in an increase in the amount of paraffin and olefin hydrocarbons after UV irradiation and a decrease in aromatic hydrocarbons. Decreases were observed in the physical and chemical parameters of the fuel, such as density, viscosity, flash point, cetane number. The decrease of the aromatic and increase of paraffinic hydrocarbons also is connected by the formation of **1**-**3**, **5**-**9**, **11**-**14** type hydrocarbons and reaction of double bonds.

A decrease in the amount of paraffin and aromatic hydrocarbons in the B20 mixture was observed, but a slight increase in the amounts of olefin hydrocarbons was observed. Changes in hydrocarbon content can be explained by a decrease in paraffin hydrocarbons and an increase in olefin hydrocarbons, as in the case of B5 fuel. Thus, the density and viscosity of these compounds are lower than those of the original substances.

According to the results obtained from the ^{1}H NMR spectra, the photochemical changes observed in the B50 fuel mixture are in the direction of increasing the amounts of paraffin hydrocarbons and decreasing the amounts of olefins and aromatic hydrocarbons. As seen, the B50 fuel contains 50% of diesel and 50% methyl esters of fatty acids. The decrease of the aromatic and increase of paraffinic hydrocarbons also can be is connected by the formation of **1**-**3**, **5**-**9**, **11**-**14** type hydrocarbons and saturation of double bonds. But a decrease in the amounts of olefins in the B50 fuel is likely connected to the dimerization and polymerization reactions, the formation of more heavy products than primary (Scheme 2–4). At the same time, the presence of dimerization polymerization reactions manifests itself in physical properties (increase density, viscosity, cetane number, flashpoint) (Tab. 2, 3).

As a result of the high absorption of methyl esters of fatty acids in fuel B100, the fuel lost its color after UV irradiation (Fig. 1). This visible change is reflected in the ^{1}H NMR data. Thus, the amount of C18:2 before UV irradiation was 52%, C18:3 1%, and after UV irradiation

Table 2. Properties of biodiesel and diesel samples before UV irradiation

Таблица 2. Свойства образцов биодизеля и дизельного топлива до УФ-облучения

Properties	Diesel	B5	B10	B20	B50	B100
Density at 20 °C, g/cm³	0.848	0.852	0.856	0.862	0.866	0.899
Viscosity, at 20 °C, mm²/s	5.142	5.309	5.424	5.515	6.065	9.012
Viscosity, at 40 °C, mm²/s	3.128	3.348	3.422	3.561	3.781	6.230
Cetane number	43.350	43.236	43.081	42.949	43.764	47.350
Flash point, °C	77	89	98	104	119	177

Table 3. Properties of biodiesel and diesel samples after UV irradiation

Таблица 3. Свойства образцов биодизеля и дизельного топлива после УФ-облучения

Properties	Diesel	B5	B10	B20	B50	B100
Density at 20 °C, g/cm³	0.845	0.849	0.852	0.855	0.868	0.897
Viscosity, at 20 °C, mm²/s	4.797	5.206	5.106	5.376	6.197	7.419
Viscosity, at 40 °C, mm²/s	3.017	3.237	3.273	3.317	3.880	4.637
Cetane number	42.290	42.857	42.675	43.058	43.880	44.643
Flash point, °C	87	101	94	97	122	163

C18:2 43%, C18:3 0.1%. As can be seen, the process of photo-destruction of more unsaturated (C18:3) FAMEs occurs first. At the same time, the formation of ketone, aldehyde, and alcohol types compounds is influenced to the physical properties of B100 (decrease density, viscosity, cetane number, flashpoint) (Tab. 2, 3).

CONCLUSIONS

This article is devoted to testing the chemical stability of diesel, diesel-biofuel (from the Alhagi oil) mixtures B5, B10, B20, and B50 against UV irradiation for 24 h. The results showed that photo-destruction processes occur under the influence of UV irradiation, which affects the physico-chemical and exploitation properties of the fuel. As seen from the obtained data, photo-oxidation by UV is negatively influenced the stability of fuels. Including indicated taken place gum formation processes. It can lead to a malfunction of the fuel engine. However, one of the most important contributions of this work was to obtain a more physicochemical stable fuel mixture under the conditions studied. Obtained data, shows that B20 more stable fuel blend, than diesel (B0), B5, B10, B50, and B100. We think the most effective ratio of diesel to biodiesel can be a mixture of B20, which is the least susceptible to structural changes under the action of UV irradiation. B20 causes only a 4% change in its chemical composition after UV irradiation, and in the quality parameters of the fuel, it retains its properties more than other fuels (Tab. 1). The reported work may be interesting when studying the application of diesel, biodiesel, or their mixtures in different storage, and transportation conditions, and also it has environmental importance.

REFERENCES

1. Mamedov I., Huseynova S., Javadova O., Azimova N., Huseynova R., Gasimova S. Testing of pine oil and glycerol ketal as components of B10 fuel blend. *Energy, Environment and Storage*. 2010;11:11–14.

2. Mamedov I. G., Javadova O. N., Asimova N. V. Preparation of diesel fuel blends and study of their physical properties. *Izvestiya Vuzov. Prikladnaya Khimiya i Biotekhnologiya = Proceedings of Universities. Applied Chemistry and Biotechnology.* 2020;10(2):332–338. https://doi.org/10.21285/2227–2925–2020–10–2–332–338.

3. Janaun J., Ellis N. Perspectives on biodiesel as a sustainable fuel. *Renewable and Sustainable Energy Reviews.* 2010;14(4):1312–1320. https://doi.org/10.1016/j.rser.2009.12.011.

4. Rafał J., Kołomański K., Wądrzyk M., Lewandowski M., Dudek M., Suwała W., et al. Degradation of petroleum diesel fuel accelerated by UV irirradiation: the impact of ageing on chemical composition and selected physicochemical properties. *E3S Web of Conferences.* 2019;108:1–14. https://doi.org/10.1051/e3sconf/201910802003.

5. Gad S. C. Diesel Fuel. *Encyclopedia of Toxicology*. 2014;1:115–118.

6. Andrea P., Claudia D., Elke Z. UV irradiation of natural organic matter (NOM): impact on organic carbon and bacteria. *Aquatic Sciences.* 2012;74(3):443–454. https://doi.org/10.1007/s00027–011–0239-y.

7. Bouilly J., Mohammadi A., Iida Y., Hashimoto H., Geivanidis S., Samaras Z. Biodiesel stability and its effects on diesel fuel injection equipment. *Search Technical Papers.* 2012;17:2688–3627. https://doi.org/10.4271/2012–01–0860.

8. Zhang H., Jin D., Zhao X. J. UV Induced degradation of crude oil in polluted water based on analysis of environmental materials. *Advanced Materials Research.* 2012;534:333–336. https://doi.org/10.4028/www.scientific.net/AMR.534.333.

9. Chang S. H. Diesel fuel analysis. *Encyclopedia of Analytical Chemistry: Applications, Theory and Instrumentation*. 2002;9:6613–6622. https://doi.org/10.1002/9780470027318.a1806.

10. Emad Y., Raghad H. Photodegradation and photostabilization of polymers, especially polystyrene: review. *Springer Plus*. 2013;398(2):1–32. https://doi.org/10.1186/2193–1801–2–398.

11. Richard F. L. Photo-oxidation and photo-toxicity of crude and refined oils. *Spill Science & Technology Bulletin*. 2003;8:157–162. https://doi.org/10.1016/S1353–2561(03)00015-X.

12. Silva C. W., Castro M. P. P., Perez V. H., Machado F. A., Mota L., Sthel M. S. Thermal degradation of ethanolic biodiesel: physicochemical and thermal properties evaluation. *Energy*. 2016;114:1093–1099. https://doi.org/10.1016/j.energy.2016.08.052.

13. Denisov E. T., Tumanov V. E. Estimation of the bond dissociation energies from the kinetic characteristics of liquid-phase radical reactions. *Russian Chemical Reviews*. 2005;74(9):825–858. https://doi.org/10.1070/RC2005v074n09ABEH001177.

14. Prince R. C., Lessard R. R. Crude oil releases to the environment: natural fate and remediation options. *Encyclopedia of Energy*. 2004;1:727–736.

15. Zodiatis G., Lardner R., Spanoudaki K., Sofianos S., Radhakrishnan H., Coppini G. et al. Operational oil spill modelling assessments. In: *Marine Hydrocarbon Spill Assessments*. 2021; p. 145–197. https://doi.org/10.1016/B978–0–12–819354–9.00010–7.

16. Bouas-Laurent H., Castellanb A., Desvergnea J.-P., Lapouyade R. Photodimerization of anthracenes in fluid solution: structural aspects. *Chemical Society Reviews*. 2000;29(1):43–55. https://doi.org/10.1039/A801821I.

17. Lennartson A., Roffey A., Moth-Poulsen K. Designing photoswitches for molecular solar thermal energy storage. *Tetrahedron Letters*. 2015;56:1457–1465.

18. McConkey B. J., Hewitt L. M., Dixon D. G., Greenberg B. M. Natural sunlight induced photooxidation of naphthalene in aqueous solution. *Water, Air, and Soil Pollution*. 2002;136:347–359. https://doi.org/10.1023/A:1015223806182.

19. Peter P. F., Qingsu X., Xin S., Hongtao Yu. Phototoxicity and environmental transformation of polycyclic aromatic hydrocarbons (PAHs) — light-induced reactive oxygen species, lipid peroxidation, and DNA damage. *Journal of Environmental Science and Health. Part*

C, *Environmental Carcinogenesis & Ecotoxicology Reviews*. 2012;30(1):1–41. https://doi.org/10.1080/10590501.2012.653887.

20. Roberts A.P., Alloy M.M., Oris J.T. Review of the photo-induced toxicity of environmental contaminants. *Comparative Biochemistry and Physiology. Part C: Toxicology & Pharmacology.* 2017;191:160–167. https://doi.org/10.1016/j.cbpc.2016.10.005.

21. Richard F.L. Photo-oxidation and photo-toxicity of crude and refined oils. *Spill Science & Technology Bulletin.* 2003;8:157–162. https://doi.org/10.1016/S1353–2561(03)00015-X.

22. Shankar R., Shim W.J., An J.G., Yim U.H. A practical review on photooxidation of crude oil: laboratory lamp setup and factors affecting it. *Water Research*. 2015;68:304–315. https://doi.org/10.1016/j.watres.2014.10.012.

23. Feng Y.-L., Nandy J.P., Hou Y., Breton F., Lau B., Zhang J., et al. UV Light induced transformation of 1-methylnaphthalene in the presence of air and its implications for contaminants research. *Journal of Environmental Protection*. 2012;3(11):1519–1531. https://doi.org/10.4236/jep.2012.311168.

24. Fathi-Achachlouei B., Azadmard-Damirchi S. Milk thistle seed oil constituents from different varieties grown in Iran. *Journal of the American Oil Chemists' Society*. 2009;86(7):643–649. https://doi.org/10.1007/s11746–009–1399-y.

25. McCormick R. L., Westbrook S.R. Storage stability of biodiesel and biodiesel blends. *Energy Fuels*. 2010;24:690–698. https://doi.org/10.1021/ef900878u.

26. Christensen E.D., McCormick R.L. Long-term storage stability of biodiesel and biodiesel blends. *Fuel Processing Technology*. 2014;128:339–348. https://doi.org/10.1016/j.fuproc.2014.07.045.

27. Bruna E.A., de Rezende D.B., Pasa V. Aging and stability evaluation of diesel/biodiesel blends stored in amber polyethylene bottles under different humidity conditions. *Fuel*. 2020;279:118289. https://doi.org/10.1016/j.fuel.2020.118289.

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