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Analysis and classification of physical and chemical methods of fuel activation

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Abstract. The offered article explores various research studies, developed patents in terms of physical and chemical approaches to the activation of fuel. In this regard, national and foreign researches in the field of fuels activators with different principles of action were analysed, evaluating their pros and cons. The article also intends to classify these methods and compare them regarding diverse desired results and types of fuels used. In terms of physical and chemical influences on fuels and the necessity of making constructive changes in the fuel system of internal combustion engines, an optimal approach was outlined.

Keywords: fuel activation, physical and chemical methods, combustion engine.

1. Introduction

With each year, the problem of saving fuel and energy resources becomes more relevant. This issue is often defined within the two perspectives: ecological and economic. However, the requirements remain the same in both cases: burning a lesser amount of fuel with the conduct of the same amount of work performed.

In the process of technological development, the requirements related to the exploitation of transport vehicles change often. For instance, with the change of altitude to 10-12 km and the consequent temperature decrease to -55 C^0, the problem of low-temperature crystallization of fuel appeared. It has two solutions. The first solution is the deparaffinization of fuel, meaning the change of its chemical composition. The second solution is a constant reheating of fuel in order to prevent crystallization of paraffins, which results in structural changes in the fuel system of an aircraft.

Although the problems of low-temperature crystallization of fuel and its saving differ essentially, the authors of this article consider that the solution of these problems remains relevant. First of all, it is essential to realize what has to be changed: the structure of internal combustion engine or the chemical composition of the fuel. Only after making this decision, the optimal method of improvement can be found.

2. Formulation of the problem

The option of developing an entirely new design of internal combustion engine with a higher coefficient of internal combustion is not actual, at present. On the other hand, resolving the problem through the change of the chemical composition of the fuel is not fully successful yet. Since the production of single-component hydrocarbon fuels is economically disadvantageous, it should be discarded. Fuels developed on the basis of monohydric alcohols have a range of disadvantages (low calorific value, low antiwear properties are a few among them) [1], which do not allow them to be used for as fuels in their pure form in the contemporary internal combustion engines.

Thus, none of the mentioned above options can be used to resolve the problem of the fuel saving. Consequently, the “golden middle” approach between these two methods should be examined. Analysis of scientific studies demonstrated that in the process of practical testing of any device, designed for the activation of fuel, serious structure changes in fuel system of internal combustion engine do not occur and the chemical composition of fuel does not change. Changes are characteristic only to operational properties related to the process of combustion [2-19].

Since there is a great deal of methods that change operational properties of fuels, first of all, the most effective method that would require minimal changes in the design of engine’s fuel system should be

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identified. The **purpose** of this paper is to conduct analysis and classification of physical and chemical methods aimed at the activation of hydrocarbon fuel with the further identification of the most optimal method, which can be potentially suitable for the activation of not only hydrocarbon fuel but also biological ones based on monohydric alcohols.

3. Discussion of Problem Resolution

Based on analysis and systematization of literature [2-22], the methods used for activation of fuel can be classified by three criteria:

1. By the nature of influence – the increase of molecular activity.
2. By the substance that is directly influenced.
3. By the type of physical and chemical influence on the substance.

The nature of influence is determined by the increase of molecule activity, compositional changes of fuel on the physical level and simultaneous changes in the composition and activity. Under the classification by the substance is meant the influence of these methods on fuel directly, through the activated air or on the fuel-air mixture. The classification of methods according to the principle of physical-chemical influence is the most actual. It can be the infrared radiation, electromagnetic field, ultrasound, electrostatic field, cavitation, heating, and the use of solid catalysts. Consequently, the authors of this article consider the classification by physical-chemical influence on the substance is of particular importance that is why this category should be explored in detail analyzing and systemizing of patent developments.

The use of electrostatic field envisions a direct contact between the substance and the charged electrodes and is usually used to activate the fuel-air mixtures [2, 3]. However, the examples of its use for fuel activation before mixing with air are also known [4]. The application of this method allows receiving a fuel-air mixture, in which fuel is in a gaseous state, and the air is partly ionized [5]. This is possible due to the contact between fuel and an isolated electrode, while the air contacts with an open insulated electrode. In the process of conducting three-stage electrode handling of a fuel-air mixture [2], in its composition, the molecules containing hydroxyl groups are formed, and in the combined action of fields a fuel-air mixture becomes more homogeneous. In this regard, the electrostatic field is applied at the first and the third stage of treatment, while at the second stage alternating field of high frequency, which causes dissociation of molecules, is applied.

In order to improve the combustion of fuels, the authors [6] considered the use of the electrostatic field to supply a fuel-air mixture in the form of ions into the combustion chamber. In this regard, in order to avoid the recombination of ions back into molecules, they were isolated by the molecules of water. This technology also envisions the use of fuel ionization during the passing through the porous electrically conductive layer, division into separate streams of cations, anions and recombined molecules, recirculation of recombined molecules, interaction of ions with the water molecules for the isolation of differently charged ions.

In the case of the influence of the electrostatic field exclusively on fuel, polarization of molecules for the increase of activity takes place, if it is not a direct contact [4], and ionization during the direct contact [3], with the aim of forming a homogeneous mixture when mixed with air. The necessity of serious structural changes during the application of the electrostatic field for the processing of fuel-air mixtures makes the application of this approach impossible at present; and polarization of fuel is possible with the use of electromagnetic field. That is why in the new developments [7, 8] this method is applied to process air for the purpose of partial ozoning of oxygen in its composition before its feeding into the combustion chamber. Of course, ozoning is not the only approach used to influence the fuel.

There device of fuel combustion in the combustion engines [9] separates nitrogen and oxygen before the feeding to the combustion chamber. The separation is conducted due to the centrifugal force and electromagnetic field; therefore, this method requires major changes in the design of an engine.

Literature review demonstrated that the influence of the electrostatic field on air, fuel and their mixture for the purpose of a better mixing, activation through polarization or ionization depending on the type of a device used decreases fuel expenses not more than by 10 percent. It also should be noticed that in the practical application of the aforementioned methods, the problem of the pollution of the cathode surface in the course of exploitation occurs. The solution of this problem is often not addressed by the authors of studied patents. In this regard, essential changes in the design of the engine are required, and the authors of this article consider it being a substantial disadvantage.

As it was mentioned above, the electromagnetic field is also used for polarization of fuel. The application of the electromagnetic field for the activation of fuel does not envision the direct contact of operational elements with fuel, unlike in the case of the electrostatic field. It is worth mentioning that the principle of electromagnetic treatment is based solely on the polarization of nonpolar hydrocarbon molecules. The phenomena of ionization and recombination of ions are absent. Polarized molecules are less active than ions, but they are more stable that is why a larger number of them get into the combustion chamber in an activated form. Polarization increases chemical activity of the molecules and, as a result of interaction of polarized molecules and the field, homogenizes the fuel, molecules of which are in a more intensified movement under the influence of the field. As a result, a more homogeneous fuel-air mixture is created. The simplest designs also envision the application of only a single pair of magnets [10]; respectively, this is the main reason for the low efficiency of their use.

The use of two and more magnetic pairs located in a bipolar position increases the effectiveness of the treatment by the reverse of the magnetic field [11]. Exactly during the reverse of the magnetic field, the movement of polarized molecules takes place, resulting in a more homogeneous fuel. The impact of the speed of movement of fuel on the process of activation and inductions of the magnetic field are worth mentioning. Induction should be not less than 0.5 T, and the speed of fuel movement should not exceed 0.2 m/s. The numeric value of the multiplying of induction on the speed must be in the range of 0.05 to 0.25. Moreover, the lines of the magnetic field should correlate to the direction of fuel at an angle of at least 60^0.

In general, modifications of this method are related to the change of the location of magnets. Thus, the magnetic pairs can have a monopolar location regarding the direction of fuel flow [12]. The distance between magnetic pairs should meet the requirements of obtaining of resonance magnetostriction effect that disintegrates polymerized hydrocarbons. In other words, this effect makes fuel more homogeneous without the reverse of magnetic field.

Modifications were also conducted to change the speed of passage of the fuel during the activation by the change of sectional area of the fuel channel [13, 12]. The ability to carry out modifications by changing the sectional area of fuel channel and the location of magnet pairs expands the scope of application of this method in the case of commissioning of non-hydrocarbon fuels. Although this method is designed primarily for the activation of fuel, there are variations of it aimed at the influence of fuel-air mixtures [14] and air processing [9]. In the use of this method, fuel savings can reach 30 percent [12] depending on the type of fuel and the design of a device.

Methods of electromagnetic and electrostatic activation of fuel are enlisted with the first of the four groups since during their application both homogenization of fuel and increase in its activation on the molecular level without the change of the chemical composition of fuel take place.

The second group consists of methods aimed primarily at the influence on physical properties of fuels, with the purpose of homogenization of their composition and improvement of mixing with air. The simplest device designed for homogenizing of fuel fulfilled the function of heating the fuel before its mixing with air [15]. This method is the simplest way of homogenization, but not the only one. For the same purpose ultrasound processing of fuel is used [16]. It is also worth mentioning that, during this process, molecules' activity increases slightly, that is why such division of methods of improving fuel properties is conditional.

Analysis of literature [2-8, 10-16] demonstrates that the application of homogenization phenomenon is often used to resolve problems related to polymerization of hydrocarbon fuels. However, the authors of this paper consider that such devices will not be effective for the treatment of fuels based on monohydric alcohols.

The third group of methods consists of methods that influence exclusively molecules without changing the intermolecular composition of fuels. The simplest of them is the use of a catalyst tube manufactured of the alloy of different metals as a part of fuel line [17]. A more complex variant of catalyst application is the use of a porous catalyst as a filter element [18].

Except for the solid catalysts, the activity of fuel molecules can be increased by the infrared radiation of fuel [19]. The use of this group of methods results in 20 percent of fuel saving. The only difference is that the application of catalyst reduces the emission of carbon monoxide by 65 percent, while infrared activation – only by 35 percent. The methods designed for molecular activation have a wider scope of application than the previous group of methods and can be used for the activation of fuel of non-petroleum origin. However, the level of fuel saving and reduction of emission of harmful substances are not as high as in the case of electromagnetic activation. This phenomenon can be explained by the absence of the phenomenon of homogenization. It can be also assumed that methods of this group will be more effective in activation of fuels based on monohydric alcohols.

The fourth group consists of methods aimed at the change of chemical composition of the fuel. Among these methods is cavitation treatment of fuel. According to some research [20], in the process of cavitation the isomerization of ordinary alkanes takes place. The distinctive feature of the method is that the process of isomerization of the radical mechanism continues for some time after the end of treatment. In other words, the fuel fed to the combustion chamber has free radicals that significantly increase its reactivity.

In the use of cavitation treatment, 25 percent of fuel savings. Such an effect can be achieved when the treatments of the magnetic field and sound vibrations are combined [21]. In this regard, the composition of the fuel also changes and the fuel saving is maximized to 20 percent. It should be outlined that the methods of this group are more suitable for preparing fuel for its storage and transportation. It also should not be forgotten that the process of isomerization just as homogenization will not influence fuels based on monohydric alcohols.

Table 1 is based on a comprehensive analysis of the classification of methods of fuel activation. It demonstrates practical advantages of each method and gives an opportunity to choose a particular method for the right task. As Table 1 demonstrates, all methods aimed at the activation of the fuel are divided into four groups according to properties of influence. The first category includes those that simultaneously have a noticeable impact on molecules or, as a result of the change in the composition of the liquid. It is electrostatic and electromagnetic treatment of fuel.

Table 1. Classification of physical-chemical methods of fuel activation

The result of treatment	Physical-chemical impact	The field of application
1. Activation of molecules and homogenization of fuel	Electrostatic treatment	Fuel, air, mixture
	Electromagnetic treatment	Fuel, air, mixture
2. Homogenization of fuel	Heat treatment	Fuel
3. Activation of molecules	Catalytic treatment	Fuel
	Infrared treatment	Fuel
4. Changing of qualitative characteristics of fuel	Cavitation treatment	Fuel
	Magnetic-acoustic treatment	Fuel

Activation methods of the second group are aimed exclusively at changes in physical properties of hydrocarbon mixtures; thus, the influence on the very activity of molecules is insignificant and often collateral. The third group includes methods aimed at increasing molecular activity. Methods of the fourth group change qualitative characteristics of fuel on a permanent basis, changing the chemical composition of the fuel.

Each group of methods includes methods different by the psychic-chemical nature of activation. The table also demonstrates the field of application of each method. The scope of the field of application demonstrates the potential capacities of methods applicable in the future. Thus, after reaching the maximum effect during the electromagnetic treatment, the issues of the increased activity and/or concentration of an oxidant will have to be addressed. That is why the field of application is an important criterion.

Among demonstrated above methods, the most effective ones out of the different groups were chosen for comparison [3, 8, 15, 17, 19-21]. The criteria chosen for their comparison were fuel saving and the reduction of emission of harmful substances. Diagram (Figure 1) visually demonstrates their comparative characteristics through a histogram.

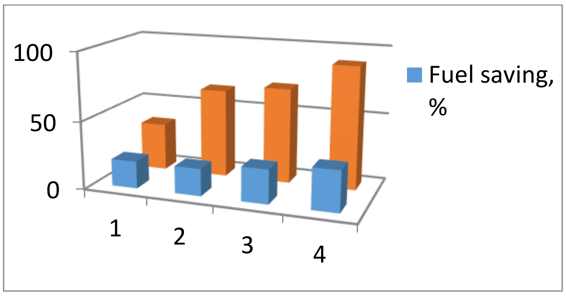

Figure 1. The compared effectiveness of activators of a different physical-chemical nature: 1 – infrared treatment; 2 – catalytic treatment; 3 – cavitation treatment; 4 – electromagnetic treatment.

Diagram demonstrates that in terms of such criteria as the emission of harmful substances and fuel saving, the most promising method is electromagnetic activation of fuel. The results of cavitation treatment are less impressive than the electromagnetic treatment, and cavitation method requires a more complex device. Changes in the composition of fuel in the process of treatment allow using this method more widely than other methods. For instance, it can be also used for the preparation of raw materials for the secondary processes of oil refining [22], and also for the additional processing of petroleum products as the final stage of oil refining.

4. Conclusion

From the analysis of physical-chemical methods of fuel activation and classification developed by the authors of this article, the following conclusions can be made.

1. Choosing a method, the gradual increase of demand for fuels based on monohydric alcohols and the continuous use of hydrocarbon fuels should be taken into account. The authors of this paper consider that in the future combinations of these two types of fuels with the predominant part of alcohols will be used. Taking this into account, the method chosen for the further exploration and implementation should reduce expenses of both types of fuels and their mixtures. Taking this into account, the second group of methods aimed exclusively at the elimination of shortcomings particular for hydrocarbon fuels should be disregarded. The fourth group is aimed at doing qualitative changes in the composition of hydrocarbon fuels. In this case, the impact on alcohol fuels will be insignificant or absent at all.
2. In the application of infrared radiation, the reduction of the emission of the harmful substances is insufficient. Regarding catalytic influence, the problem of using fuels of different origin arises. Hydrocarbons and monohydric alcohols are substances that are characterized by different nature, so the application of the same catalyst with the same efficiency for the both types of fuel or their mixtures is impossible. For this reason, the third group of methods should be also disregarded.
3. The first group of physical-chemical methods of fuel activation can influence not only the fuel but air and fuel-air mixtures. This characteristic allows expanding the field of application of the means in designing of the fuel systems of new generations. The use of the electrostatic field is applicable for activation of air. However, new developments of the application of this method for the alternative purposes were not found.
4. In the application of electromagnetic treatment, changes in the structure of engine's fuel system were not required mainly because the necessity of direct contact between fuel and operational elements. This means that such devices often do not require changes in the design of fuel system during the installation.
5. The application of the electromagnetic field demonstrates the best results regarding saving fuel and the reduction of emission of harmful substances. These results are applicable exclusively for hydrocarbon fuels. However, the polarization effect of the electromagnetic field is capable of increasing combustion heat of alcohol fuels and increasing their vaporizing capacities which are the primary disadvantages of alcohol fuels. The degree of these changes and their feasibility should be studied further.

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