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IMPROVING THE QUALITY OF PETROL FUEL FOR INTERNAL COMBUSTION ENGINES

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ABSTRACT

The design of an automobile electromagnetic vibration cavitator created for the cavitation treatment of water-petrol fuel is described. Its use will allow not only saving fuel, but also increasing the completeness of combustion of the water-petrol fuel mixture; in other words, it will contribute to improving the environment. An experimental study of effectiveness of the fuel mixture cavitation treatment was carried out using A95 petrol and distilled water for automobile internal combustion engines. Cavitation treatment of the fuel mixture with a water-to-petrol ratio of 17 to 83% allows for an increase in the savings of expensive petrol by 15–20% during the operation of engines on flat and downhill roads and in city traffic jams. At the same time, the engine power is reduced by only 6–7% due to the cavitation treatment.

Keywords: fuel, petrol, water, cavitation disturber, electromagnetic drive, combustion completeness

INTRODUCTION

The development of automobiles with an electric drive does not eliminate the need to improve automotive internal combustion engines. Petrol engines will be used for a long time to drive large-tonnage vehicles, particularly special military equipment, as well as for motorised household devices. Therefore, research into operational characteristics of petrol engines will remain relevant.

The studies aimed at protecting the environment will always be of utmost importance, in particular the studies into reducing the level of emissions caused by incomplete combustion of engine fuel to the maximum extent possible. After all, incomplete combustion of fuel in engine cylinder chambers is the main cause of the harmful carbon dioxide, which leads to the ‘greenhouse effect’ and environmental pollution.

The vast majority of scientific studies aimed at improving the quality of automotive engine fuel and its complete combustion have focused on finding additives that promote combustion, primarily based on bioethanol (Phuangwongtrakul, Wechsatol, Sethaput, Suktang & Wongwises, 2016; Abikusna, Sugiarto,

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Monasari & Yamin, 2018). A rather progressive direction has emerged towards creating new fuel mixtures, in particular by adding ethanol (Liu, Wang, Long & Wang, 2015; Catapano, Sementa & Vaglieco, 2016) or alcohols (Wang, Liu, Long, Wang & He, 2015) to the main petrol mass. However, according to the results of these studies, this approach significantly increases the final cost of fuel. Therefore, it is more suitable for specialised automotive transport such as race cars.

There is a more economically viable approach focused on direct physical or physico-chemical influences on automotive fuel that improve its characteristics, particularly combustion completeness. Among physical influences on fuel, ultrasonic treatment has proven to be the most effective method of preventing diesel fuel from losing its fluidity at low temperatures (Mysyura, 2018).

Along with the quality of petrol, the injection of the air-fuel mixture into the working chamber has a decisive influence on the completeness of fuel combustion in the working chamber of the cylinders of internal combustion engines. Insufficient completeness of combustion is caused predominantly by insufficient oxygen in the air-fuel mixture. At the same time, the dispersion degree of the fuel provided by the carburettor or injection nozzles is also important. The higher the dispersion of the petrol fed into the combustion chamber, the better it mixes the with air (Lugovskoi, 1997). The better the conditions for fuel complete combustion, the higher the power of the engine and the lower the degree of environmental pollution (Lugovskoi, 1998).

The scientists of the National Technical University of Ukraine "Igor Sikorsky Kyiv Polytechnic Institute" have proposed cavitation ultrasonic devices for increasing the dispersion of the air-fuel mixture injected into the working chambers of engine cylinders (Lugovskoi, 2000). Their operating principle is based on dispersing jets of fuel via vibrating dispersers at ultrasonic frequencies. This is done immediately before the air-fuel mixture enters the engine's combustion chamber (Lugovskoi, Chopny & Epemenko, 1998). The authors claim that ultrasonic cavitation treatment of fuel improves its energy and consumption characteristics. This is ensured by the following: as the cavitation bubbles in the microvolumes burst, high temperatures and pressures develop, which create prerequisites for the emergence of electric charges, whose significant energy is provided by dissociated and ionised molecules as well as atoms and free radicals, which improves the fuel combustion process (Lugovsky, Chorny & Eremenko, 1997; Chorny, Lugovsky & Prilipko, 2001). The authors claim that this process increases the power of engines by 10–15% without significantly increasing their dimensions and weight. In addition, it allows for a reduction in the level of emissions of the harmful carbon dioxide into the atmosphere by almost a quarter.

Also, under the leadership of Professor I.M. Fedotkina, a study of the effect of cavitation on fuel quality was conducted. Theoretical and experimental studies have shown quite good results (Fedotkin & Nemchyn, 1984). In particular, the ability of cavitation to positively influence the improvement of fuel quality has been established. This is explained by the destructive effect of cavitation on fuel clots, as well as fuel degassing from non-combustible gases dissolved in it. At the same time, cavitation also promotes high-quality mixing of certain fuel fractions (Fedotkin, 1979; Fedotkin, 2000).

Various methods were used to improve the completeness of fuel combustion, in particular by admixing the air--fuel mixture fed into the working chamber of engines with certain proportions of distilled water. Under the influence of high combustion temperatures of carbon compounds, including petrol, water molecules break up, releasing several gases. Along with water vapour, a number of flammable gas compounds are formed in this process. Among them are combustible compounds of oxygen and hydrogen and their possible combinations. This is why, in the case of fires caused by the combustion of carbon compounds, in particular lubricants, diesel and petrol fuels, it is not recommended to use water as a fire extinguishing agent (Shevchuk, 2013; Shevchuk, 2014).

However, the main obstacle to the industrial implementation of this progressive idea is the still-unsolved problem of clear dosing ratios of petrol, water and air and ensuring their high-quality mixing.

The purpose of this study is to develop a design of a low-frequency vibration resonance device for cavitation treatment of the water-fuel mixture before it is fed to the combustion chambers of petrol engines.

The research tasks include:
– Creation of an experimental installation for low-frequency cavitation treatment of a water-petrol mixture as fuel.
– Development of a technological scheme for preparing the water-fuel mixture for automobile internal combustion engines.
– Development of the design of an automobile vibrocavitator for cavitation treatment of the water-fuel mixture or fuel before it is fed to the engine combustion chambers.
– Study of the influence of the percentage ratio of components in the water-petrol mixture on the stability of the internal combustion engine.

MATERIAL AND METHODS

The effect of cavitation treatment on operational characteristics of the water-petrol mixture was studied using the carburettor internal combustion engine of a VAZ-21083 vehicle. In the first stage, distilled water and A95 petrol were mixed in the working area of the experimental low-frequency vibro-resonance cavitator built according to predefined proportions. This mixture was subject to cavitation treatment for a fixed time. In the second stage, the water-petrol mixture processed in the cavitator was directed into the carburettor of the working car engine. Important parameters of the engine were recorded via the readings of the indicator devices on the car's dashboard.

The technological scheme of the experimental laboratory installation for the cavitation treatment of the water-petrol fuel mixture is shown in Figure 1. From the storage tanks (*1*, *2*), petrol and distilled water in certain percentage ratios are supplied by pumps to the working area of the vibrocavitator (*3*). After filling the working area of the cavitator with petrol and water, the regulating valves are closed (*4*). The closed network of circulation of the water-petrol mixture is opened with the regulating throttle (*5*). At the same time, the electromagnetic drive (*8*) of the vibrocavitator (*3*) and the pump (*7*) located in the storage tank (*6*) are started. The regulating throttles (*5*) and (*9*) ensure uniform circulation of the water-petrol mixture between the storage tank (*6*) and the working chamber of the cavitator. The technological cycle of cavitation treatment of the fuel mixture involves continuous circulation of the mixture between the storage tank (*6*) and the working area of the vibrocavitator (*3*), which ensures continuous mixing and cavitation treatment of petrol and water.

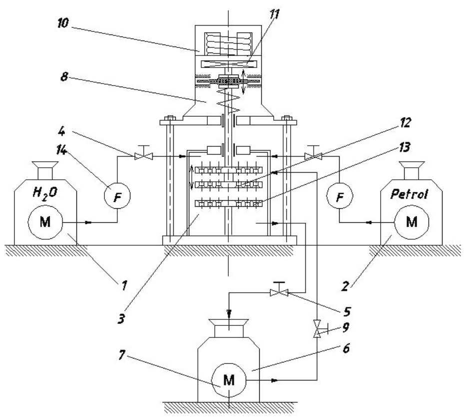

Fig. 1. Technological scheme of an experimental installation for mixing and cavitation treatment of a water-petrol mixture for internal combustion engines: *1*, *2* – storage tanks, *3* – vibrocavitator, *4* – valves, *5*, *9* – regulating throttle, *6* – tank, *7* – pump, *8* – electromagnetic drive, *10* – electromagnet, *11* – disc, *12*, *13* – cavitation disturbers, *14* – filters

Source: own work.

Cavitation treatment of the water-petrol mixture was carried out for 3–10 min. The variable parameters in the study were the percentage ratio between water and petrol in the fuel mixture, the duration of the treatment, and vibration parameters of the cavitation disruptors, namely their oscillation amplitude and frequency. The results of an experimental study of cavitation treatment of the water-petrol mixture are shown in Table 1.

Table 1. Research of cavitation treatment of a water-petrol mixture as fuel

Ratio of the components of the fuel mixture		Duration of cavitation treatment of the fuel mixture [s]	Vibration parameters of cavitation disruptors	
petrol [%]	distilled water [%]		oscillation frequency (f) [Hz]	amplitude (A) [mm]
95	5	90	48	1.0
90	10	86	45	1.1
85	15	80	50	1.2
83	17	75	52	1.0
80	20	70	47	1.2

Source: own work.

Field studies were conducted in the following sequence. A storage tank filled with a cavitationally processed water-petrol mixture was fixed above the car engine on a special device. A pipeline connected the storage tank to the engine carburettor, and the car engine was started at idle. Changes in the frequency of rotation of the crankshaft of the engine were observed on the instrument panel of the car using the tachometer readings. With the help of a timer, the amount of time required for the engine to burn a fixed amount of fuel mixture with a volume of 10^{-4} m^3 was monitored, observing the stability of engine operation when using the cavitationally treated water-petrol mixture as fuel. The results of the experimental study are shown in Table 2.

Table 2. Results of the study of automobile engine operation using a cavitationally treated water-petrol mixture as fuel

Ratio of petrol and water in the fuel mixture [%]	Engine crankshaft rotation frequency [min^{-1}]	Duration of engine operation per 10^{-4} m^3 of fuel mixture [s]	Engine stability
95/5	1,100	90	stable
90/10	1,050	86	stable
85/15	1,000	80	stable
83/17	970	77	unstable
80/20	950	75	with interruptions

Source: own work.

This experimental research established that the presence of up to 15% of distilled water in the cavitation-treated fuel does not significantly affect the stability of the car's engine in the 'idle' mode of operation. At the same time, the crankshaft rotation frequency is reduced by only 5–7%. It was also established that as the water content increases by 6–8%, the duration of engine operation on a fixed 10^{-4} m^3 volume of the fuel mixture is reduced.

Figure 2 shows the basic structural scheme of the automobile vibrocavitator. The function of this vibrocavitator is to cavitate petrol and form a water-petrol mixture as fuel. This vibrocavitator can be installed directly into the engine. It is appropriate to use a standard voltage frequency regulator to power its electric drive, which is electrically connected to the car battery. The car's onboard computer can be tasked with regulating the vibrocavitator's operating modes and switching it on and off.

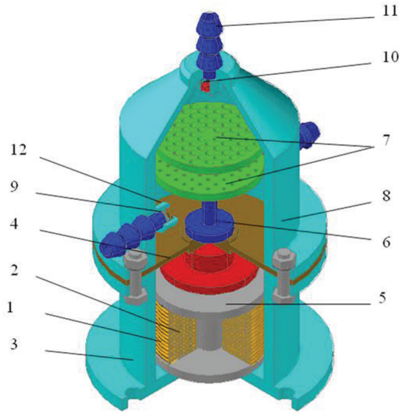

Fig. 2. Schematic diagram of a vibrocavitator for mixing water and petrol for an automobile engine: *1* – electromagnet, *2* – winding, *3* – housing, *4* – membrane, *5* – armature, *6* – rod, *7* – cavitation disturbers, *8* – cover of the housing, *9*, *12* – valves, *10* – spring plunger, *11* – fitting

Source: own work.

The components of the automobile vibrocavitator are an electromagnet (*1*) with a winding (*2*) rigidly fixed in the lower part of the housing (*3*). On the elastic membrane (*4*) above the electromagnet (*1*), the armature (*5*) of the electromagnet and the rod (*6*) are fixed. On this rod (*6*), the cavitation disturbers (*7*) are installed on the disk. Through the flanges, a cover is placed over the membrane (*4*) of the case and is hermetically connected to the lower part of the case (*3*), for example, with a bolted connection.

In the cover (*8*) of the housing (*3*), there are two inlet valves (*9*). For example, spring-loaded (*10*) petal valves. The inlets of the valves are equipped with a fitting (*11*) for connecting to the pipeline to supply water or petrol to the cavitator. On the upper part of the cover (*8*) of the housing, namely above the oscillating cavitation disturbers (*7*), there is an exhaust valve (*12*). This valve is connected through a fitting to the pipe connecting the cavitator to the car engine's carburettor or fuel distribution bar.

When applying the variable sinusoidal voltage transformed by the converter of the frequency regulator to the winding (*2*) of the electromagnet (*1*), the iron of the electromagnet is magnetised. Overcoming the elasticity of the membrane (*4*), the electromagnet attracts the anchor (*5*) to itself. Simultaneously with the anchor, the rod (*6*) rigidly connected to it moves along with the cavitation disruptors (*7*) attached to it. When the sinusoidal voltage of the electromagnet is reduced from its maximum value to zero, the elastic force of the elastic membrane (*4*) returns the anchor (*5*) to the original home location. At the same time, the rod (*6*) and the cavitation disruptors (*7*) are moved to the upper initial position simultaneously with the anchor. The spatial movements of the membrane (*4*), the anchor (*5*), the rod (*6*) and the cavitation disturbers (*7*) are repeated in a similar order in each subsequent half-cycle of the sinusoidal alternating voltage of the electromagnet winding. Finally, these movements are transformed into harmonic oscillatory motion of the armature (*5*) of the electromagnet and the cavitation disruptors connected to it. The frequency of these oscillating movements is equal to twice the frequency of the alternating voltage of the electromagnet winding.

It was established that the optimal modes of oscillatory movements of cavitation disruptors are the amplitude of 1.0–1.5 mm and the frequency between 47–52 Hz.

Figure 3 shows an updated technological scheme of a fuel preparation and supply network to the combustion chambers of the engine cylinders. A typical fuel supply network is equipped with a cavitator for processing the water-petrol mixture and a water supply subsystem with its regulation equipment. Like the traditional fuel supply scheme, the proposed one includes a storage tank (*1*), a petrol supply pump (*2*), a regulating throttle (*3*), and a filter (*4*). However, petrol is not supplied to the carburettor, but first to the cavitator (*5*). Through a similarly arranged network with a pump, a regulating throttle, and a filter a certain portion of distilled water is supplied to the cavitator from the additionally equipped storage tank (*6*). To ensure the predetermined percentage ratio of water and petrol in the fuel mixture, the amount of water supply is regulated by the adjusting throttle (*3*). The distilled water and petrol undergo cavitation treatment in the cavitator, mix with each other and are fed to the car's carburettor or distribution bar (*8*) through the outlet pipeline. As in the traditional fuel supply scheme, for example the fuel injection scheme, the water-petrol mixture formed in the cavitator (*5*) is saturated with air and enters the combustion chambers of the engine cylinders through the nozzles (*11*).

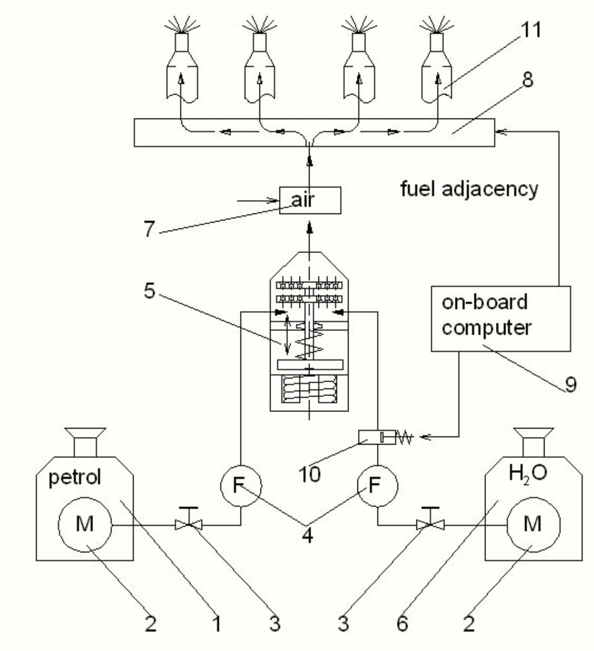

Fig. 3. Technological scheme of the network for preparation and supply of cavitated water-fuel mixture to the combustion chambers of the cylinders: *1* – storage tanks, *2* – pump, *3* – regulating throttle, *4* – filter, *5* – cavitator, *6* – tank, *7* – air, *8* – car carburettor, *9* – on-board computer, *10* – regulator, *11* – nozzles

Source: own work.

It is reasonable to predict that adding distilled water to the fuel mixture may decrease its torque and certain dynamic characteristics in difficult engine operating modes. Therefore, in cases of forced engine operation, it is advisable to temporarily switch off the water supply and return to the classic petrol supply scheme. In modern cars, it is advisable to entrust this function to the onboard computer (*9*), which will turn the water supply network's electric valve on and off (*7*) at certain moments of load changes.

RESULTS AND DISCUSSION

The main times of using the water-petrol mixture will be during ‘light’ modes of engine operation – the ‘idle’ mode, engine warm-up, driving on flat and sloping areas, etc. Most often, however, these are times of slow car movement in traffic jams that are prevalent in modern cities. In such relatively frequent traffic situations, it is critical to improve the modes of operation of automobile engines, because high expenditure of expensive fuel under the circumstances is inappropriate, whereas cheaper fuel mixtures, for example, the proposed water-petrol mixture semm to be a good replacement. Moreover, the saving of expensive petrol in the range of 10–15% is guaranteed to cover the costs of equipping cars with the proposed system for cavitating the water--petrol mixture (Aftanaziv & Shevchuk, 2022; Patent of Ukraine for Invention No. 125799).

Unlike previous studies by scientists in the field of physical effects on internal combustion engine fuel aimed at improving its properties, which were mainly focused on the use of various additives (Catapano et al., 2016; Phuangwongtrakul et al., 2016) and atomisation of microdroplets of fuel directed into the combustion chamber (Lugovskoi, 1997; Mysiura, 2018), this method of preliminary cavitation treatment of the water-fuel mixture has significant advantages.

First and foremost, it contributes to environmental protection by reducing petrol consumption by 15–17% and decreasing the release of extremely harmful combustion products into the atmosphere due to a higher level of combustion completeness. Another critical factor for vehicle users is the estimated 10–15% reduction in petrol expenses.

The results of experimental studies provide grounds to conclude that it is cavitation that contributes most to the improved combustion of the water-fuel mixture. Cavitational mixing of water and fuel promotes the formation of OH_1 radicals and hydrogen peroxide (H_2O_2) from the water. These substances possess high oxidative capacity, enhancing the mixture’s combustion conditions in the engine’s combustion chambers.

From a scientific perspective, the novelty of this study lies in the experimentally confirmed ability to induce cavitation processes and phenomena not only in homogeneous liquids, but also in water mixtures with the liquids that are difficult to mix with water, such as petrol.

The practical significance of this study is confirmed by the proposed new design of the vibrocavitator for preparing the water-fuel mixture in internal combustion engines, as well as the technological scheme for integrating it into the vehicle’s fuel supply system. The novelty of these technical solutions is confirmed by the Ukrainian patent for the invention obtained by the co-authors of this study (Aftanaziv & Shevchuk, 2022; Patent of Ukraine for Invention No. 125799, 2022).

It is also advisable to consider the undeniable environmental benefit: a car equipped in this way will burn about 150 L of petrol less per year due to partial petrol replacement with water. This approximate figure is obtained from the calculation that the annual mileage of a passenger car is about 20×10^3 km on average, and half of this is spent on city trips and downtime in inevitable traffic jams, where the engine operates at low speed or in ‘idle’ mode. And for a city with a million inhabitants, where, according to statistics, there is one passenger car per every four residents, the environment will not be polluted by the combustion products of almost 18×10^6 L of petrol. This calculation conditionally considers that the number of cars with petrol and diesel engines in the city is approximately the same.

CONCLUSIONS

- Experimental research confirmed the possibility to use cavitation for intensive mixing of difficult-to-mix water and petrol at specific mass ratios. The water-petrol mixture produced by cavitation is suitable for ensuring stable operation of automobile engines in light modes, for example in the idle mode. The ratio range that provides stable operation of an engine is between 15–17% of water and 85–83% of petrol.

– It was experimentally established that when increasing the mass of water in a water-petrol cavitationally treated fuel mixture, the engine crankshaft rotation frequency decreases by 15–20%. A proportional decrease in its torque will accordingly decrease engine power.
– A working chamber with disc cavitation disruptors is the basis of the proposed design of the low-frequency vibro-resonant cavitator for mixing and cavitation treatment of the water-petrol mixture. Oscillating movements of the cavitation disruptors are forced by an electromagnetic drive powered by the car's battery. It was established that the optimal mode of oscillatory movements of the cavitation disruptors is an amplitude of 1.0–1.5 mm and a frequency of 47–52 Hz.
– The improved technological scheme for supplying a cavitationally treated water-petrol mixture as fuel to the cylinders of an internal combustion engine includes the addition of the traditional petrol supply network with an electromagnetic vibrating cavitator for mixing the water-petrol mixture and an additional water supply network with a storage tank.
– The 'light' modes of engine operation, in particular the idle mode, driving in city traffic jams, driving on straight and downhill roads etc., are the best times to use the water-petrol mixture.

Authors' contributions
Conceptualisation: I.A.; methodology: I.S.; validation: I.K.; formal analysis: I.S.; investigation: N.K.; resources: Y.R.; data curation: V.R.; writing – original draft preparation: I.A. and L.S.; writing – review and editing: I.A. and L.S.; visualisation: N.K.; supervision: R.H. and Y.S.; project administration: S.B.; funding acquisition: I.K.

All authors have read and agreed to the published version of the manuscript.

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POPRAWA JAKOŚCI PALIWA BENZYNOWEGO DO SILNIKÓW SPALINOWYCH

STRESZCZENIE

W artykule opisano konstrukcję samochodowego elektromagnetycznego kawitatora wibracyjnego stworzonego do rozdrabniania kawitacyjnego paliwa wodno-benzynowego. Jego zastosowanie pozwoli nie tylko zaoszczędzić paliwo, lecz także zwiększyć stopień zupełności spalania mieszanki paliwowo-wodnej, czyli przyczyni się do poprawy stanu środowiska przyrodniczego. Przeprowadzono eksperymentalne badanie skuteczności rozdrabniania kawitacyjnego mieszanki paliwowej na bazie benzyny A95 i wody destylowanej do silników spalinowych samochodowych. Rozdrabnianie kawitacyjne tej mieszanki paliwowej przy stosunku procentowym woda/benzyna 17/83% pozwala zwiększyć oszczędność drogiej benzyny o 15–20% podczas pracy silników na płaskich i pochyłych odcinkach autostrad oraz w korkach miejskich. Jednocześnie moc silnika zmniejsza się tylko o 6–7% dzięki rozdrabnianiu kawitacyjnemu.

Słowa kluczowe: paliwo, benzyna, woda, zakłócacz kawitacji (kawitator elektryczny), napęd elektromagnetyczny, stopień zupełności spalania