ECONOMIC AND ENVIRONMENTAL BENEFITS OF USING CAVITATION TREATED FUEL IN VEHICLES OF INTERNAL COMBUSTION ENGINES

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Resume

The results of an experimental study of efficiency of the cavitation treatment of a fuel mixture, based on A-95 gasoline and distilled water, for automobile internal combustion engines are presented. Cavitation treatment of this fuel mixture at a percentage of water/gasoline of 17/83 % allows increasing the cost of gasoline up to 15-20 % when operating engines on flat and sloping sections of roads and in traffic jams. Due to the cavitation treatment, the engine power is reduced by only 6÷7 %. The design of the created automobile electromagnetic vibrating cavitator is described. Its application will not only save fuel, but increase the completeness of combustion of water-gasoline fuel mixture, i.e. improve the environment, as well %.

1 Introduction

The defining feature of modernity is intensive research on introduction of the energy-saving technologies and aspects of the renewable energy sources use. It is necessary to note the use of energy-saving technologies in industry [1], the development of thermal modernization in the communal sphere [2], the synthesis of biogas as an efficient energy source [3], the use of energy for the synthesis of aquatic organisms [4], particularly microalgae [5-6]. An important aspect of these problems is introduction of the energy-saving technologies in transport.

The rapid development of electric vehicles, however, does not eliminate the need to improve internal combustion engines. Gasoline engines will be widely used for a long time to drive large vehicles, including military special equipment, as well as for various motorized household devices. Therefore, research aimed at improving the performance of gasoline engines will still be relevant.

Of particular importance today are the studies aimed at preserving the environment, including through the maximum reduction of emissions from the products of incomplete combustion of engine fuel. It is known that the incomplete combustion of fuel in the chambers of engine cylinders is the main reason for the formation of carbon dioxide, harmful to the atmosphere, which contributes to formation of the atmospheric "greenhouse effect".

It is known that the quality of the air-fuel mixture prepared for injection into the working chamber, along with the quality of gasoline, has a decisive influence on the completeness of combustion in the working chamber of the fuel. Mainly the deterioration of fuel combustion conditions and the consequent insufficient completeness of its combustion are caused by insufficient oxygen in the air-fuel mixture. The dispersion of the fuel, i.e. the degree of scattering of its micro-droplets provided by the carburettor or injection nozzles, is important. It is generally accepted that the higher the scattering dispersion of gasoline given in the combustion chamber, the higher the degree of its mixing with air [7]. Accordingly, the best conditions for complete combustion

of fuel are provided. As a result, higher engine power and a lower degree of environmental pollution will be guaranteed [8].

To achieve this effect, scientists from the National University "Kyiv Polytechnic Institute" of Sikorsky created cavitation ultrasonic devices to increase the dispersion of the air-injected mixture injected into the working chambers of the cylinders of engines [9]. The principle of operation of these devices is based on the additional dispersion of fuel jets by vibrating high-frequency ultrasonic dispersants. This is done just before the pre-prepared air-fuel mixture enters the combustion chamber of the engines [10]. The authors note that "… Ultrasonic cavitation treatment of fuel can improve its energy and consumer performance." At the same time, they rightly claim that this is ensured due to the fact that "in the process of flattening cavitation bubbles in micro volumes high temperatures and pressures develop, which create preconditions for appearance of electric charges rich in the energy of dissociated and ionized molecules, as well as atoms and free radicals that improve the process of fuel combustion", [11]. Vibrating ultrasonic dispersants were installed directly in the devices for preparing the air-fuel mixture. Therefore, the authors of this development successfully increased the power of engines by 10-15 % without increasing their size and weight. It has also reduced emissions of harmful carbon dioxide by almost a quarter.

At the end of the last century, scientists at the "Kyiv Polytechnic Institute" made quite successful attempts to use cavitation to improve the quality of diesel and gasoline fuels for internal combustion engines. Under the leadership of Prof. Fedotkina I. M., a study of the effect of cavitation on fuel quality was conducted there. Their theoretical and experimental studies have shown quite good results [12]. In particular, the ability of cavitation to positively affect the improvement of fuel quality was established. Researchers explain this by the destructive effect of cavitation on fuel clots, as well as the degassing of fuel from dissolved non-combustible gases. At the same time, cavitation also contributes to the qualitative mixing of certain fuel fractions [12]. However, it turned out that the improvement of fuel characteristics as a result of its cavitation treatment is quite short-lived. In a few days after the cavitation treatment, the fuel poured into the storage tanks lost the acquired characteristics, which had improved its quality. According to its characteristics, the fuel almost completely returned to its initial state prior to the cavitation treatment [12]. Unfortunately, the researchers then failed to organize the cavitation treatment of fuel just before it is fed into the working chambers of the engines. This is what hindered the widespread production use of cavitation fuel processing.

Different methods have been tried to improve the completeness of fuel combustion in the working chamber of the cylinders of internal combustion engines. In particular, due to the admixture of distilled water in certain proportions to the air-fuel mixture supplied to the working chamber of the engines. This idea was prompted by the fact that under the action of high combustion temperatures of carbon compounds, including gasoline, water molecules decompose, forming a number of gases when interacting with their environment. Along with water vapour, a number of combustible gas compounds are formed here. Among them are combustible compounds of oxygen and hydrogen, as well as their possible combinations. That is why in the case of fires caused by the combustion of carbon compounds, in particular oils, diesel and gasoline, it is never recommended to use water as a fire extinguisher.

However, the problem of clear dosing of the ratios of gasoline, water and air and ensuring their quality mixing with each other is still unresolved and is the main obstacle to the industrial implementation of this progressive idea.

The aim of this study was to create a low-frequency vibration-resonant device for cavitation treatment of water-fuel mixture before its direct supply to the combustion chamber of gasoline engines.

The objectives of the research were as follows:
- study of the influence of the percentage of fuel components in the water-gasoline mixture on the stability of the internal combustion engine;
- creation of an experimental installation for the low-frequency cavitation treatment of water-gasoline fuel mixture;
- development of a technological scheme for preparation of the water-fuel mixture for automobile internal combustion engines.
- development of design of the automobile vibrocavitator for the cavitation treatment of water-fuel mixture or fuel before their supply to the combustion chamber of the engine.

2   Data and methods

The study of influence of the cavitation treatment on the performance characteristics of the water-gasoline fuel mixture was carried out on a carburettor internal combustion engine model VAZ-21083 car brand VAZ-21099. The study involved two stages. First, in the experimental low-frequency vibration-resonant cavitator, distilled water and A-95 gasoline supplied to its working area were mixed in certain proportions. This mixture was subjected to cavitation treatment for a fixed time. In the second stage of research, the water-gasoline fuel mixture treated in the cavitator was sent to the carburettor of the running engine of the car. According to the readings of the indicator devices on the car panel, certain parameters of the engine operation were recorded.

Since the main difference of the method of preparation of the fuel mixture for internal combustion engines, proposed in this article, is the use at the stage

of preparation of the mixture cavitation treatment of its components, hereinafter describes the nature and mechanisms of formation in the treated fluids cavitation phenomena and their accompanying effects.

Based on the experience of the authors in the field of research of cavitation phenomena and their effects [13-14], it can be argued that three main factors determine the preconditions for the perturbation of cavitation in the fluid thickness or in the liquid flow. These are:

- the presence of cavitation embryos in the liquid. In particular, small mechanical inclusions and most importantly - dissolved in the liquid gases and air, the volumes of which are close to the maximum possible quantities specified by Henry-Dalton' law;

- insignificant, within $(0.9-1.5) \cdot 10^3$ kg/m³, density of liquid or total density of its components;

- providing the fluid with external energy sufficient to break the intermolecular bonds in the fluid thickness or in the fluid streams. In the first case, it may be the supplied kinetic energy, such as magnetic field or ultrasound, in the second - pre-provided to the liquid reserve of potential energy released during the flow of fluid through obstacles, accompanied by a change in the nature of the laminar fluid flow to turbulent.

Accordingly, in the process of experimental research the main attention was paid to control over the presence and intensity of the cavitation process in the water-gasoline mixture, as well as the parameter of the engine of a car powered by cavitation-treated fuel.

The presence of cavitation treatment here was investigated by the kinetics of chemical reactions of the potassium permanganate reduction in the environment of cavitation-treated water. At concentrations of CH_3O_4 equal to 0.5 mol and KM_nO_4, respectively 4×10^{-3} mol, such a reaction occurs at a low rate, which allows monitoring its course and changes in colour shades. Due to the colour changes of the permanganate ion, the reaction can be monitored photometrically using a colorimeter model KFK-2. 1. 1 $\cdot 10^{-6}$ m³ of methanol, $2 \cdot 10^{-6}$ m³ of sulphuric acid (2 molar concentration) and untreated distilled water or water after cavitation treatment were added to a $50 \cdot 10^{-6}$ m³ volumetric flask. Subsequently, $0.2 \cdot 10^{-6}$ m³ of potassium permanganate was added to the volumetric flask and, after vigorous stirring, it was photometered. At the same time, such a liquid mix with usual water not only reacts with insignificant speed, but also practically does not change transparency and colour. In the presence of cavitation-treated water in a volumetric flask, the rate of the oxidation reaction increases significantly by about 3.5 times, the colour of the liquid mixture changes intensely from colourless to deep blue.

According to the test colour tables of the control liquid mixture, comparing it to the reference, where the ultrasonic cavitation treatment was used, one can judge not only about the presence of cavitation treatment of the test batch of water, but also the intensity of the

cavitation field in which this treatment took place. Subsequent experiments showed that the most effective for the combustion of gasoline-fuel mixture was the intensity of the cavitation field of the treatment zone in the range of $(1.0-1.5) \cdot 10^6$ KW/m³.

The volumes of liquids in the storage tanks of the working area of the cavitator, water and gasoline tanks in the cavitator, as well as in the working tanks of the direct supply of gasoline or water-gasoline mixture to the carburettor of the test engine of the car were measured by filling them in volumetric flasks with experimental liquids with the volumes of $50 \cdot 10^{-6}$ m³ and $100 \cdot 10^{-6}$ m³.

The volumes of water and gasoline content in the finished cavitation-treated fuel mixture were determined from calculations of the mass content of the initial ingredients. For example, to provide 10 % water content in the finished mixture with a volume of $2 \cdot 10^{-3}$ m³, the storage tanks of the cavitator were filled by $1.8 \cdot 10^{-3}$ m³ with gasoline and $0.2 \cdot 10^{-3}$ m³ with water.

The parameters of cavitation treatment, which regulate the level of external energy provided to the treated liquids, are important for the quality of the finished cavitation-treated water-gasoline fuel mixture. The main of these parameters are the amplitude and frequency of harmonic oscillations of cavitation perturbators and, of course, the time of cavitation processing. The oscillation frequency of cavitation perturbators on the described devices was set and regulated by a standardized frequency regulator of the supply voltage of the windings of their drives. The model of this AES-120 frequency regulator has a frequency control range from 0 to 150 s^{-1}. The main frequency range of the AC supply voltage used in this experimental study was 40-60 s^{-1}. The measurement of the supply voltage frequency, which determines the oscillation frequency of disk cavitation perturbators in our cavitators, was carried out with an accuracy of 0.5-1.0 s^{-1}.

The amplitude of oscillations of cavitation perturbators was measured in stroboscopic light using a ruler digitized in millimetres. The amplitude was determined as a half of the path that the disk cavitation perturbator will travel during its reciprocating oscillating motion along the geometric axis of the oscillation drive rod. The amplitude of oscillations is regulated by the magnitude of the pulling force of the electromagnetic cavitator's armature with the cavitation perturbators fixed to its electromagnet. The magnitude of this pulling force is determined by the magnitude of the current supplied to the windings of the coil of the electromagnet. The range of studied amplitudes of oscillations of cavitation perturbators was $(0.5-3.5) \cdot 10^{-3}$ m. The amplitude of oscillations was measured in each of the experiments with an accuracy of $(0.10-0.15) \cdot 10^{-3}$ m.

The cavitation time of the water-gasoline fuel mixture, the duration of the car engine operation at a certain unit of volume of the treated mixture, was measured with a chronometer with an accuracy of 5-10 s.
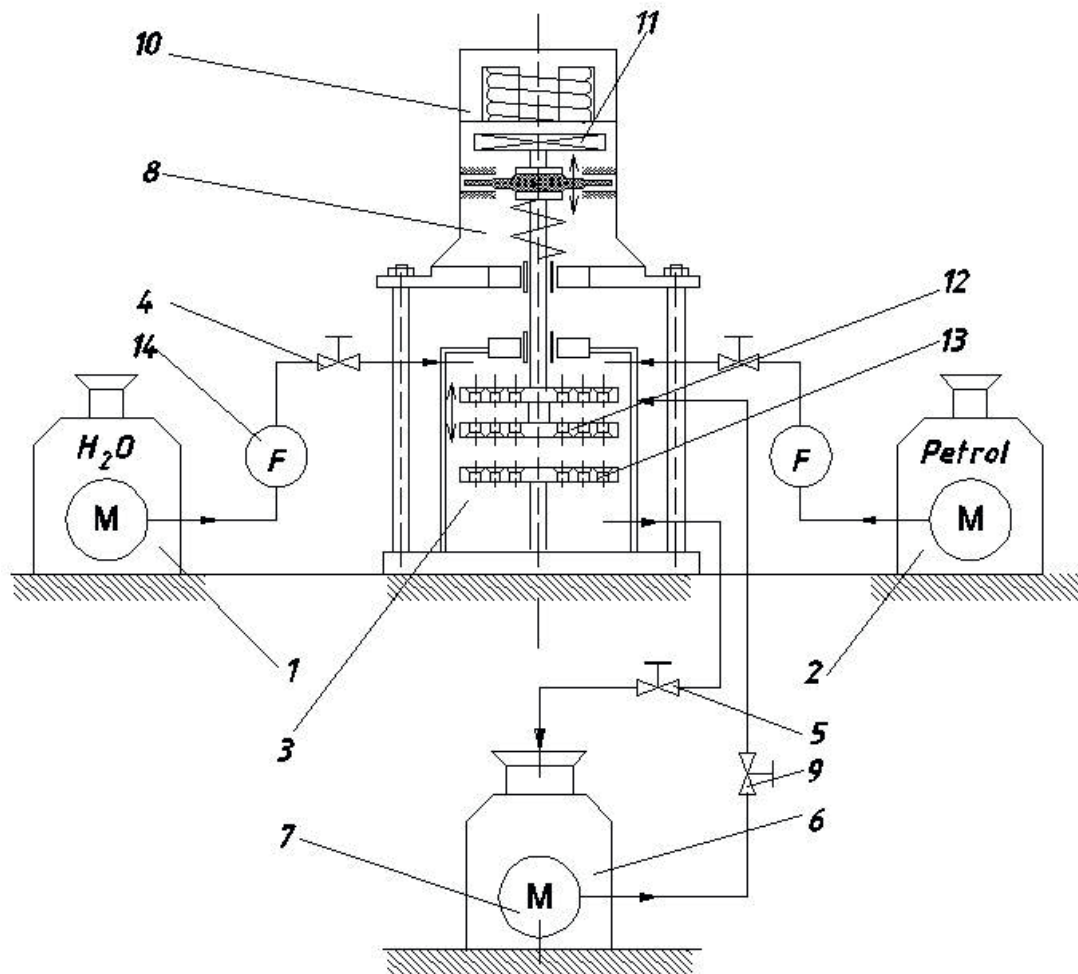
Figure 1 *Technological scheme of laboratory experimental unit for mixing and the cavitation treatment of water-gasoline fuel mixture for internal combustion engines*

The engine crankshaft speed of the experimental car was measured according to the readings of the tachometer installed on the interior panel of the car. Its standard measurement error is (1-1.5) s⁻¹.

The most important of the engine's quality indicators, the level and composition of emissions of the car, were evaluated by comparing the emissions of carbon monoxide, carbon dioxide and hydrocarbons when the engine runs on traditional gasoline A-95 and prepared by the proposed vibratory cavitary water-gasoline. The gas analyzer was used to measure harmful emissions in engine exhaust gases. The main measurements of the emission composition were carried out on an automotive one-component gas analyzer model DOZOR-C (manufacturer - Ukraine). It controlled the volume percentage of CO_2 and carbon dioxide in the emissions of CO. For a more complete analysis of the composition of emissions, a gas analyzer of combustible gases model WINTACT WT8823 was used, which allows the analysis of a wider range of nomenclature of combustible gases, including nitrogen and its oxide, oxygen, water vapour and the like. The measurement accuracy when using both control devices was proportional and was in the range of 0.05-0.1 vol.%.

The data of all the measurements are averaged and indirectly reflected in the text and reference Tables 1, 2 and 3.

Figure 1 shows a flow chart of an experimental laboratory unit for the cavitation treatment of the water-gasoline fuel mixture. In accordance with this scheme, from storage tanks 1 and 2 (Figure 1) gasoline and distilled water in certain percentages were pumped into the working area of the cavitator 3. After filling the working area of the cavitator with water and gasoline control, the valves 4 were closed. Control throttle 5 opened the closed water-gasoline mixture circulation network. Simultaneously, the electromagnetic drive 8 of the vibrating cavitation 3 and the pump 7 located in the storage tank 6 were started. Adjusting throttles 5 and 9 provided uniform circulation of water-gasoline mixture between the storage tank 6 and the working chamber of the cavitator. The technological cycle of the cavitation treatment of the fuel mixture here provided continuous circulation of the mixture between the storage tank 6 and the working area of the vibrocavitator 3. Due to that, gasoline and water were continuously mixed with each other and were subjected to cavitation treatment. The duration of the cavitation treatment of water-

gasoline fuel mixture varied in the range from 3 to 10 minutes.

The main components of a vibration-resonant cavitator (Figure 2) are the electromagnetic actuator 10, which is connected to its elastically mounted oscillating armature 11, as well as the rod with oscillating disk cavitation perturbators 12. The stationary disk cavitation perturbators 13 are installed on the basis of the cavitation coaxially to the oscillating ones. Both oscillating and stationary cavitation perturbators are located in a common cylindrical case 3. That case is equipped with fittings for gasoline and water, as well as for the removal of cavitation-treated fuel mixture. To clean liquids from mechanical contaminants, the supply network to the working chamber of the cavitator of distilled water and gasoline is equipped with filters 14. The main elements of the control panel of the cavitator power supply network are the frequency regulator of the electric supply voltage of its electromagnetic drive model AFC120 and the timer o the duration of processing liquids [13-14].

The uniqueness of the technological capabilities of cavitation is primarily due to the periodic time (up to $1.5 \cdot 10^6$ KW/m^3) energy impact on the treated water-gasoline fuel mixture. This is accompanied by concomitant phenomena of shock microwave formation, phase transitions occurring on the surfaces of cavitation microbubbles and certain chemical transformations. All this does not only accelerate the course of chemical reactions, especially redox, but enables to change the structure of the ingredients of the fuel mixture submitted to the cavitation zone, as well [14]. As a result, in the finished cavitation-treated fuel mixture, water molecules not only change their structure but also partially disintegrate. As a result of a decay, the H_2O_2 molecules are formed from a certain part of its molecules, which are short-lived in time and, in turn, disintegrate into hydrated e^-_{hydro} ions and free H^0 and O^0H radicals. It is these decomposition products and especially radicals, that have increased oxidative capacity, which helps to improve the conditions of complete combustion of the gasoline component of the newly formed fuel mixture.

In addition, which is very important, the cavitation field actively mixes these newly formed components of water with gasoline molecules. This is how cavitation forms the finished fuel mixture. That is, with a certain degree of approximation, one can say that after the cavitation treatment of the components of the fuel mixture of pure water in the traditional perception no longer exists. And this is very positive. After all, the newly formed fuel mixture will not have a detrimental effect on the parts of the fuel system and the combustion chamber of the engines. On the contrary, due to the complete combustion of fuel in the fuel system of the engine, the amount of scale will decrease.

Field studies were performed in the following sequence. A storage tank filled with cavitation treated water-gasoline fuel mixture was fixed above the engine of the car on a special device. The storage tank was connected to the carburettor of the engine by a pipeline and the car engine was started at idle mode. On the dashboard of the car, according to the tachometer, changes in the speed of the engine crankshaft were observed. Using a timer, the duration of the engine to burn a fixed amount of fuel mixture with a volume of 0.001 m^3 was monitored.

3   Results and discussion

Variable parameters in the study of the cavitation treatment of water-gasoline fuel mixture were the percentage of water and gasoline in the fuel mixture, the duration of treatment and vibration parameters of cavitation perturbators, namely their amplitude (A, m) of oscillations and frequency (f, Hz)

The results of the experimental study of the cavitation treatment of water-gasoline fuel mixture are shown in Table 1.

In field studies, the stability of the engine when using cavitation-treated water-gasoline mixture was observed. The results of field studies are shown in Table 2.

Experimental research has shown that in the "idle" modes of operation of the car engine, the presence of up to 15% of distilled water in its fuel does not significantly affect the stability of the engine. At the same time, the crankshaft speed is reduced by only 5÷7%. In addition, it was found that as the water content increases by 6÷8%, the duration of the engine at a fixed 10^{-3} m^3 volume of the fuel mixture is reduced.

Table 1 *Investigation of the cavitation treatment of the water-gasoline fuel mixture*

No.	Percentage of fuel mixture components		Duration of cavitation treatment of fuel mixture, s.	Vibration parameters of cavitation perturbators	
	Gasoline, %	Distilled water, %		Frequency, Hz	Amplitude, 10^{-3} m
1	95	5	5400	48	1.0
2	90	10	5160	45	1.1
3	85	15	4800	50	1.2
4	83	17	4500	52	1.0
5	80	20	4200	47	1.2

Table 2 *The results of the study of the car engine when using cavitation-treated water-gasoline mixture*

No.	Percentage of gasoline and water in the fuel mixture, %	Engine crankshaft speed, s^{-1}	Engine life duration per 10^{-3} m³ fuel mixture, s	Engine stability
1	95/5	18.33	90	stable
2	90/10	17.51	86	stable
3	85/15	16.67	80	stable
4	83/17	16.17	77	unstable
5	80/20	15.83	75	with interruptions

4   Suggestions for using the proposed method

The obtained results of experimental researches give the basis for constructive development of the vibrocavitator built in a fuel supply network. The functions of this vibrocavitator are the task of cavitation treatment of gasoline fuel and the formation of water-gasoline fuel mixture. This vibrator can be installed directly on the engine. To power its electric drive, it is appropriate to use a standard voltage regulator which is electrically connected to the car battery. The vibrating cavitation modes can be adjusted and switched on and off by the car's on-board computer. Schematic structural diagram of such a vibrocavitation is shown in Figure 2.

The components of the car vibrating cavitation are rigidly fixed in the lower part of the case 3 electromagnet 1 with the winding 2. An anchor 5 of the electromagnet and a rod 6 are fixed on the elastic membrane 4 above the electromagnet 1. On this rod 6, disk cavitation perturbators 7 are mounted. Through the flanges, the cover 8 of the case, located above the membrane 4, is tightly connected to the lower part 3 of the case, for example, with a bolted connection.

In the cover 8 of the case 3 there are two inlet valves 9. For example, spring-loaded 10 petal valves. The inlet openings of the valves are equipped with a fitting 11 for connection to the supply pipe to the cavitator water or gasoline. On the upper part of the cover 8 of the case, namely above the oscillating cavitation perturbators 7, there is a discharge valve 12. This valve is connected through a fitting to the pipe connecting the cavitator with the carburettor or the fuel rail of the car engine.

From theoretical and experimental studies of the cavitation processes is known that the perturbation of cavitation in a liquid flow is possible only under full conditions of energetic influence on the liquid or a rapid change in the nature of the flow. For example, exposure of fluid to ultrasound of a certain intensity or the rapid transition from laminar to turbulent fluid flow. It is generally accepted that the conditions of perturbation in the cavitation fluid are regulated by the Reynolds number. The critical value of this indicator, which relates the characteristics and physical properties of the fluid and the speed of its flow (or movement of solids in it) regulates changes in the nature of fluid flow. Thus, for the water-based liquids at values of the critical Reynolds
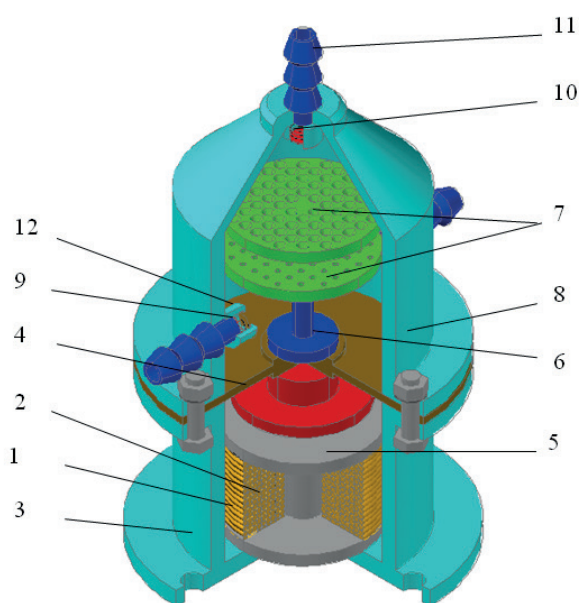

Figure 2 *Schematic structural diagram of the vibrocavitator for preparation of the water-gasoline fuel mixture for the car engine*

number $R_e > 2300$, the laminar regime is transformed into turbulent, which is characterized by manifestations of the cavitation phenomena.

The values of the critical Reynolds number are the main criterion for calculating the energy parameters and velocities of the cavitation perturbators in the proposed devices for the cavitation treatment of water-gasoline fuel mixture.

The classical formula for calculating the value of the critical Reynolds number in this case relates the physical parameters of the treated fluid with the speed of movement of cavitation perturbators in it. Namely

$$R_e = \frac{\rho u l}{\eta} = \frac{u l}{\upsilon} \cdot > 2300, \qquad (1)$$

where $\eta = \upsilon \cdot \rho$ is dynamic viscosity of the treated water-gasoline mixture ;

ρ is the density of the liquid mixture;

υ is the kinematic viscosity of the liquid mixture;

u is the speed of oscillating movements in the liquid mixture of cavitation perturbators;

l is the characteristic total length of the circles of the holes for the flow of liquid in the cavitation perturbators.

When calculating the main design parameters of the cavitator for the treatment of water-gasoline fuel mixture, substituting the numerical values of the physical parameters of the treated liquid mixture in Equation (1), velocity u of oscillatory movements in the liquid mixture of cavitation, required for cavitation perturbation, is determined. The numerical value of the critical Reynolds number is given from the condition $R_{e\,cr.} > 2300$.

The vibrating electromagnetic drive provides cavitation perturbators in our device with oscillating spatial movements. The speed of oscillating movements of cavitation exciters provided by it is defined as so-called "vibration speed" and is equal to $\upsilon = A \cdot f$ where A is the amplitude of oscillations of cavitation perturbators; f is the oscillation frequency of cavitation perturbators.

Equating the required critical velocity for cavitation perturbation with the vibration velocity provided by the vibrocavitation υ and setting the amplitude of oscillations of cavitation perturbators in the range of $A = (0.5-1.5) \cdot 10^{-3}$, m, the oscillation frequency f (H_z) required for cavitation perturbation is determined..

According to the values of the required indicators υ, (m/s) of vibration velocity of cavitation perturbators, their amplitude A, (m) and frequency f, (H_z) of oscillations, the energy parameters of the cavitation vibration drive are calculated. In particular, the traction force of the drive electromagnet P, (H) required to overcome the resistance of the fluid, which is expended on the oscillating movements in the fluid of the cavitation perturbators.

According to the values of the force P, (H), the amplitude A, (m) and the oscillation frequency f, (H_z) of the cavitation perturbators, the power parameters of the electromagnetic drive of the cavitator are chosen.

When the alternating sinusoidal voltage, transformed by the converter of the voltage frequency regulator, is applied to the winding 2 of the electromagnet 1, the iron of the electromagnet is magnetized. Overcoming the elasticity of the membrane 4, the electromagnet attracts the armature 5. Simultaneously with the armature, the rod 6, rigidly connected to it and the cavitation perturbators 7 attached to it, are moved. When the sinusoidal supply voltage of the electromagnet decreases from its maximum value to zero, the elastic force of the elastic membrane 4 returns the armature anchor 5 to its original initial location. At the same time, the rod 6 and the cavitation perturbators 7 move with the armature to the upper initial position. The spatial movements of the membrane 4, the armature 5, the rod 6 and the cavitation perturbators 7 are repeated in a similar order in each subsequent half-cycle of the sinusoidal alternating supply voltage of the electromagnet winding. Eventually, these movements are transformed into a harmonic oscillating motion of the armature 5 of the electromagnet and the associated cavitation perturbators. The frequency of these oscillating movements is twice the frequency of the AC supply voltage of the electromagnet winding. Cavitation perturbators 7 are discs made of stainless steel or other cavitation-resistant material. The surface of the cavitation perturbators 7 of the device is permeated with a large number of conical holes. With oscillating rectilinear sequential movements of these disks, water and gasoline penetrate into their conical holes, which are actively mixed with each other. Penetrating in a confined space into the conical holes of the disks, liquid microjets, due to changes in their shape and speed, form microturbulent flows. In a liquid medium where the water is present, microturbulent flows appear as centres of self-perturbation of the cavitation region.

Cavitation microjets intensively mix liquids available in the working area of the cavitator with each other, forming a homogeneous fuel mixture. In addition, under the action of self-perturbed cavitation, hydrogen peroxide ions $H_2O'_2$ are formed in the water present here. Since hydrogen peroxide is a good oxidant, its presence will contribute to a better combustion of the fuel mixture in the combustion chambers of the engine cylinders. Cavitation also has a positive effect on the gasoline present in the working chamber of the cavitator. Cavitation microbubbles and microjets destroy the fuel clots present in gasoline, thereby improving its complete combustion. Through the outlet valve 12 cavitation-treated in the working chamber of the cavitator, the water-gasoline fuel mixture is pushed into the carburettor of the engine or its fuel distribution rail.

Cavitation-treated in the working chamber of the cavitator water-gasoline fuel mixture through the outlet valve 12 is pushed into the outlet pipe, from which it enters the carburettor of the engine or its distribution fuel bar.

In terms of its design dimensions, the design of the car cavitator is quite small. In terms of weight,
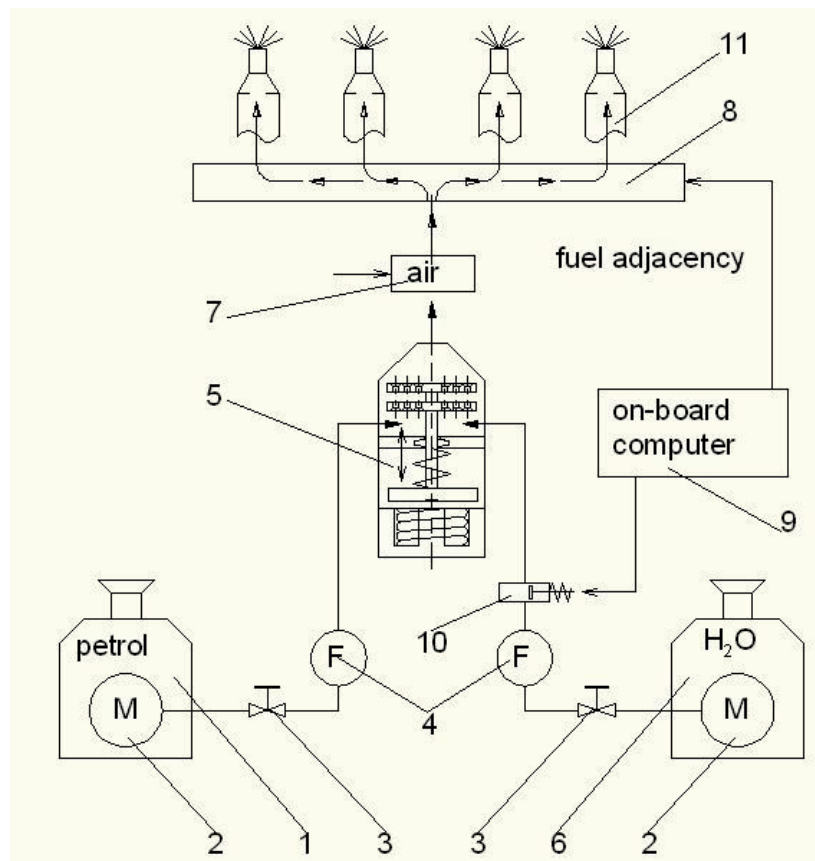
Figure 3 *Technological scheme of the preparation and supply network of the cavitation-treated water-fuel mixture in the combustion chambers of the engine cylinders*

appearance and size, this car cavitator is commensurate with the car electrical distributor. That is why it can be mounted directly on the car engine.

The electrical circuit for converting the 12-volt voltage of the car battery into the alternating 220-volt supply voltage of the cavitator electromagnet can be borrowed from the circuit of the electric converter. Such converters are used to transform accumulated wind or solar 12-volt electricity into alternating 220-volt electricity for domestic power grids.

Figure 3 shows an upgraded technological scheme of the network of preparation and supply of fuel to the combustion chamber of the engine cylinders.

A typical fuel supply network here is supplemented by a water-gasoline fuel mixture cavitator, a water supply subsystem and its control equipment. As well as the traditional fuel supply scheme, the proposed one includes a storage tank 1, a gasoline pump 2, a control throttle 3 and a filter 4. However, here the gasoline is not fed into the carburettor, but first into the cavitator 5. A similar portion of distilled water is fed into the cavitator simultaneously from the additionally arranged storage tank 6 via a similarly arranged network with a pump, an adjusting throttle and a filter. To ensure a predetermined percentage of water and gasoline in the fuel mixture, the volume of water supply is regulated at the stage of adjustment by the control throttle 3. In the cavitator, distilled water and gasoline are subjected

to cavitation treatment, mixed with each other and fed through the exhaust pipe to the carburettor of the car or its distribution bar 8. As with the traditional fuel supply scheme, for example, when using an injector scheme of fuel mixture injection, the water-gasoline fuel mixture formed in the cavitator 5 is saturated with air and through the injectors 11 enters the combustion chamber of the engine cylinders.

It is reasonable to assume that with the addition of distilled water to the fuel mixture in difficult modes of engine operation, its torque and certain dynamic characteristics may decrease. Therefore, it is advisable in cases of forced engine operation to temporarily abandon the water supply and return to the classic scheme of gasoline supply. In modern cars, it is advisable to put this function on the on-board computer 9, which at certain moments of load changes will turn on or off the solenoid valve 7 of the water supply network.

5 Analysis of the advantages of using the proposed method

It is clear that the main points of the water-gasoline mixture using would be the so-called light modes of engines operation. These can be periods when the engine is idling, when the engine is warming up, when driving on flat and descending sections on the slopes

and so on. But most often these are periods of the slow movement of the car in the so-called "car traffic jams" inherent in modern cities. It is in such fairly frequent road transport situations that the modes of operation of automobile engines for the development of high power are completely unnecessary and the cost of this expensive fuel is inappropriate. Here it would be appropriate to switch to e use the cheaper fuel mixtures. For example, the proposed water-gasoline. After all, the cost savings of gasoline provided in the range of 10-15% will be guaranteed to cover the cost of equipping cars with the proposed system of cavitation preparation of the water-gasoline mixture. Fuel savings would be even more noticeable if one organically combines the cavitation preparation of water-gasoline fuel mixture with devices of cavitation fuel spraying at the stages of its injection into the working chambers of engine cylinders [15].

It may seem that the simplified modes of operation of car engines, which are characterized by operation at close to "idling" modes, in the general period of operation of the car, take up a small percentage of time. These are the periods of operation of cars in the conditions of driving on flat and descending sections of routes, at their idle time in city traffic jams, etc. However, this is a misconception, although it is quite common. The indisputable experience of the so-called "hybrid" cars, operated on both fuel and electric drives, suggests otherwise. Namely, in urban conditions of car operation in modern cities, the periods of operation of their drive electric motors and internal combustion engine are almost the same. After all, the fuel engine is switched on automatically and only for the heavy-duty modes of operation, i.e. acceleration, uphill, overtaking and poor quality road surfaces.

This gives grounds to conclude that in the so-called "light modes of operation of engines" modern cars are operated up to 50% of their operation duration. Similarly, if one takes into account the statistics, according to which the average annual mileage of a car is about twenty thousand kilometres, one can predict that half of this mileage will fall on "light" engine conditions. Thus, with a certain degree of approximation, one can assume that during the year of operation, the mileage of a car on a water-gasoline fuel mixture can be about 10 thousand kilometres. If one assumes, for an approximate calculation, that the indirect fuel consumption here is about 10 litres per 100 km and take into account that 15% of this fuel can be replaced by water, the annual savings on one car from the installation of its vibrocavitation will reach $ 150. This is at the indirect cost of A-95 gasoline, which is about $ 1 per 1 litre of fuel.

For the practical arrangement on the car engine of the proposed system of preparation of the water-gasoline fuel mixture, first of all, the vibrocavitation device, for cavitation processing and mixing of the mixture components, will be required. To provide power to its drive, one would need a voltage converter from a constant 12-volt to a change of 220-volt. Additional storage capacity would also be required to store distilled water and pipelines with control equipment to supply water and gasoline to the cavitator and transfer the formed fuel mixture to the carburettor or the fuel rail. Component pipelines, their control valves, solenoid valves and a storage tank are manufactured industrially and their total cost, according to the estimates, will not exceed $ 50. Unfortunately, vibrocavitators for preparation of the water-gasoline fuel mixtures are not manufactured by industry. Therefore, at this stage they would have to be made individually. However, given that their production will not require expensive scarce materials, we can assume that the manufacture of one cavitator will cost about $ 150. Thus, the total cost of equipping one car with a system of preparation of the water-gasoline fuel mixture will be approximately $ 200. The same proportional annual savings are provided by use of 15% of water in the water-gasoline fuel mixture to power the car engine when operating the engine in light modes, in particular when working at idle. Therefore, equipping the car with a system of preparation of the water-gasoline fuel mixture will pay off in one year of the car operation. Considering that systems of this type are designed for a 5-year service life, one can assume that during this period, the car owners would be able to save about $ 700 on the cost of partial replacement of gasoline with water. It is taken into account that part of the savings will have to be spent on purchase of the distilled water and maintenance and routine inspections and minor repairs of the system.

It is undeniable that the economic factors of any of the proposed technical solutions are important. However, with regard to the road transport, which has flooded almost all the populated cities and towns around the world, no less important is the problem of reducing the harmful emissions of fuel combustion products into the atmosphere. This environmental problem is multifaceted. First of all, it is a problem of active consumption of atmospheric oxygen by automobile engines for the maintenance of the fuel combustion process. It is known that 2.5 kg of oxygen is absorbed from the atmosphere to burn $1 \cdot 10^{-3}$ m^3 of gasoline in a car engine. To some extent, this means that by equipping the car's engine with the proposed system of preparation of the water-gasoline fuel mixture, one reduces the annual consumption of atmospheric oxygen by such a car by approximately 300 kg.

Another, even more important problem for mankind, caused by operation of the automobile internal combustion engines, is their harmful emissions into the atmosphere of combustion products of carbon fuel. After all, it is generally accepted that for every 10 thousand kilometres a car on average burns a ton of gasoline, consuming (absorbing from the atmosphere!) 3.5 tons of oxygen and emitting 16 tons of exhaust gases, including very toxic 80 kg of CO, 10 kg of nitrogen oxides, 20 kg

Table 3 *Comparative studies of the content of automotive emissions*

No.	Controlled gases of automobile emissions	The content of harmful emissions in volume percentages, vol. %		The difference in performance, %
		Gasoline A-95	Cavitation-treated water-gasoline fuel mixture	
1	CO	5	4	20
2	CO_2	16	13	19
3	NO_x	0.5	0.4	20

of hydrocarbons. Keep in mind that each $1 \cdot 10^{-3}$ m³ of gasoline burns causes formation of 16 m³ of a mixture of different exhaust gases.

Therefore, the reduction of 15÷17% of gasoline costs for the engine of the car in light modes, which provides the proposed system of cavitation preparation of water-gasoline fuel mixture, guarantees a proportional reduction of approximately the same 15% of emissions in exhaust gases.

At this stage of the active struggle of the world community and especially Europe, for environmental protection and reduction of greenhouse gas emissions, the standard for emissions in fuel combustion products, the so-called "Euro 6" standard, introduced here, reduces the carbon dioxide emissions from $120 \cdot 10^{-6}$ kg/m³ to $90 \cdot 10^{-6}$ kg/m³. At the same time, recognizing the importance of reducing car emissions, the world-renowned SAE study has shown that one of the most effective ways to reduce car emissions is by "injecting water into the combustion chamber." This reduces emissions of nitrogen oxides and other toxic components by up to 90%.

Of course, all these statements need to be tested experimentally. Therefore, a number of experimental studies were conducted aimed at comparative study of the cavitation-treated water-gasoline fuel mixture effect on the volume of harmful emissions during its combustion. For measurements, a single-component gas analyzer model DOZOR-C was used, which measured the content of carbon monoxide in the exhaust gases and a multi-component gas analyzer model WINTACT WT8823, which was used to measure the content of carbon dioxide CO_2 and nitrogen oxide in the exhaust gases. Measurements were performed under the similar operating conditions of the car engine at "idling" at the same temperatures of the engine coolant (90 ± 2) °C and the environment (22 °C). By adjusting the degree of opening of the carburettor throttle, the same numerical values of crankshaft speed were achieved. According to the readings of the car tachometer, they were (20±1) s⁻¹. Comparative measurements of the content of automotive emissions were performed when using gasoline grade A-95 and the cavitation-treated water-gasoline fuel mixture, formed on its basis with the addition of 15% of distilled water The results of comparative studies are shown in Table 3.

Thus, the data of a comparative study of the content of harmful emissions of the engine model VAZ-21083 car VAZ-2199 when burning traditional gasoline brand A-95 or the cavitation-treated water-gasoline mixture with 15% of distilled water in the fuel mixture, show that the presence of water in the cavitation-treated fuel mixture reduces the amount of harmful carcinogenic gases in car emissions by about 19-20%.

Therefore, using the proposed system of cavitation treatment of water-gasoline fuel mixture can have undeniable environmental benefit.

It consists in the fact that a car equipped in this way will not burn about 150 litres of gasoline during the year due to its replacement with water. And for a city with a million inhabitants, where, according to statistics, there is one car for every four inhabitants, the environment will not be polluted by the products of combustion of almost 18 million litres of gasoline. It is conventionally taken into account that the number of cars with gasoline and diesel engines in the city is about the same.

6   Conclusions

1. Experimental research has confirmed the ability to use cavitation treatment for intensive mixing of difficult to mix water and gasoline in certain mass ratios. The water-gasoline fuel mixture formed by cavitation treatment is suitable for ensuring stable operation of automobile engines in the facilitated modes, for example, "idling". The range of stable operation of the engine on the water-gasoline cavitation-treated fuel mixture is in the ratio of 15-17% of water to 85-83% of gasoline in the formed fuel mixture.

2. It is experimentally established that when the mass of water in the water-gasoline cavitation-treated fuel mixture increases, the engine crankshaft speed decreases by 15-20 percent. This will be accompanied by a proportional decrease in its torque and, accordingly, engine power.

3. The working chamber with the disk cavitation perturbators placed in it is the basis of the proposed design of a low-frequency vibration-resonant cavitator for mixing and cavitation treatment of the water-gasoline fuel mixture. The electromagnetic drive healed by the car battery provides oscillating movements to cavitation disturbers. It is established that the optimum modes of oscillatory displacements of cavitation perturbators are the amplitude of oscillations of $(1.0-1.5) \cdot 10^{-3}$ m at the frequency of

their oscillations in the range of 47-52 Hz.

4. The improved technological scheme of a power supply of the automobile internal combustion engine' cylinders with the cavitation-treated water-gasoline fuel supply includes supplementation of a traditional gasoline supply network with an electromagnetic vibrating cavitator for mixing the water-gasoline mixture and an additional water supply network with its accumulation tank.

5. The so-called "facilitated" modes of engine operation, including idling, traffic jams, driving on flat and descending sections of highways, etc. are the main periods of use of the water-gasoline fuel mixture during the operation of cars.

6. The use of the water-gasoline fuel mixture during one-year operation of the car can save up to 150 litres of gasoline worth about $ 150. In addition, along with the economic benefits, there is also an environmental component. It is the reduction of the amount of gasoline burned.

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