ISSN: 0974-5823 Vol. 7 No. 2 February, 2022

International Journal of Mechanical Engineering

METHOD FOR IMPROVING STARTING OF DIESEL ENGINES IN CONDITIONS OF LOW TEMPERATURES BASED ON THE USE OF ROTARY PULSING DEVICE

A.A. H. Al-MAIDI[1], Yu.V. RODIONOV[2,3], S.I. DANILIN[4], A. E. LOMOVSKIKH[5] and D.V. MITROFANOV[6]

[1]Plant Protection Department.College of Agriculture, University of Misan. Misan, Iraq.

[2]Professor of the Department of Mechanics and Engineering Graphics, Federal State Budgetary Educational Institution of Higher Education "TSTU"

[3]Professor of the Department of Production, Storage and Processing of Plant Growing Products, Michurinsky State Agrarian University

[4]Head of the Department "Technologies of production, storage and processing of crop products", Federal State Budgetary Educational Institution of Higher Education "Michurinsky State Agrarian University"

[5]Associate Professor of the Department "Technologies of Production, Storage and Processing of Plant Growing Products", FSBEI HE "Michurinsky GAU"

[6]Deputy Head of the Research Center Department (Problems of Application, Provision and Management of Air Force Aviation).

ABSTRACT :The analysis of the operation of military vehicles with diesel engines at low temperatures is carried out. A method and a device have been developed to improve the starting of diesel engines by installing a rotary-pulsating apparatus on equipment, directly into the power supply system. Periodic transient hydromechanical processes with the excitation of hydrodynamic, acoustic and impulse cavitation in the working bodies of rotary-pulsating apparatuses are considered, which provide crushing of heavy fractions of hydrocarbon fuel into light ones, which improves the combustion process both in the preheater boiler and in the engine combustion chamber. Mathematical modeling of the fragmentation of a dissolved water drop in the composition of emulsified motor fuel is proposed. The design of a rotary-pulsating apparatus has been developed, which allows to increase the efficiency of starting diesel equipment and reduce the toxicity of exhaust gases. The use of a rotary-pulsating apparatus allows to reduce the start-up time of diesel equipment, as well as to reduce the toxicity of exhaust gases.

Key words: diesel engine, emulsified fuel, rotary-pulsating apparatus, power supply system, diesel fuel

INTRODUCTION. At present, intensive development of the Arctic region is taking place. There are very serious problems associated with the operation of diesel engines, which are now equipped with all trucks. For the operation of such engines, diesel fuel of the Arctic brand is used. Since the minimum temperatures in the Arctic sometimes drop to minus 60 ° C, in such conditions diesel fuel can lose its properties, become cloudy and crystallize.

In this regard, when operating motor vehicles (AT) with diesel engines at low temperatures, difficulties arise with starting a cold engine. Usually, for these purposes, an engine preheater is installed on the AT. But the operating experience of such a preheater with nozzle atomization of fuel allows us to conclude that at a temperature of minus 25 ºC, the following disadvantages arise in its operation.

Spraying fuel with a centrifugal diaphragm nozzle does not ensure its complete evaporation and combustion, which leads to a relatively high smoke and toxicity of exhaust gases (from 3 to 5% for carbon monoxide), leads to soot deposition on the internal hard-to-reach surfaces of the heat exchanger and a decrease in their thermal conductivity.

This predetermines the fire hazard (sparks) and hinders the introduction of highly efficient heat exchangers with a complex heat exchange surface on such heaters. When the internal combustion engines (ICE) AT warms up for 20 ... 30 minutes, white smoke is emitted in large quantities with exhaust gases, which leads to serious environmental pollution and is unacceptable for the Arctic region.

RELEVANCE. In this regard, reducing the engine warm-up time and, accordingly, reducing the amount of white smoke emissions from the exhaust gases of the internal combustion engine is an urgent scientific problem that requires further solution. In this direction, research was carried out by many scientists, among whom we can note A.S. Avseev, A.A. Kardakov, N.I. Akulova. It should be noted that fuel atomization by a centrifugal diaphragm nozzle does not provide the possibility of a significant decrease in the heating capacity of the heater, since the quality of diesel fuel atomization in the engine cylinders depends on the fuel consumption, its type, viscosity, density and is set to the full heating capacity mode. This disadvantage makes it difficult to implement the multifuel property on the "nozzle" heaters, as well as the "standby mode" for long-term maintenance of the AT internal combustion engine in a warm state with the burner operating at low mode (from 20 to 25% of full).

The design of the heater does not exclude the driver's intervention to regulate the pressure of the fuel pump in order to increase it. As a result of excess fuel and its incomplete combustion, the temperature of the heater exhaust gases rises to the fire hazard limit, their smoke and toxicity increase, accelerated coking of the heat exchanger gas ducts occurs, sparks are emitted from the exhaust pipe and the most negative large amount of white smoke (Puzankov, 2007; Oxler,2012).

To avoid these problems, as well as to start a diesel engine that is not equipped with a pre-heater, it is proposed to use a rotary-pulsating apparatus in the power supply system, which allows to process the motor fuel poured into the car's fuel tank and improve the physicochemical properties of the fuel.

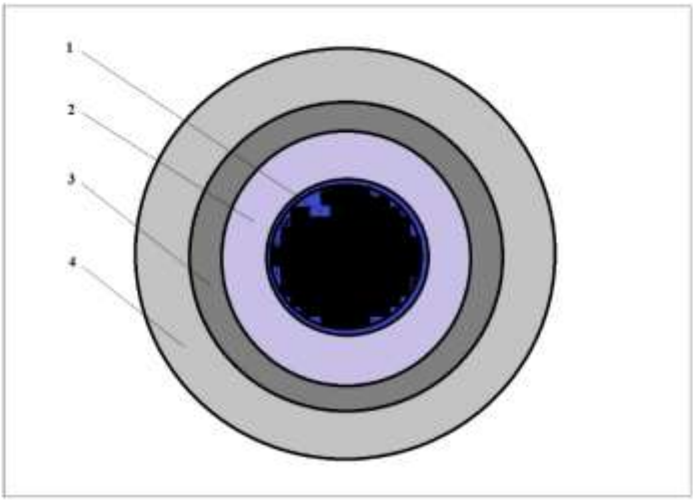
Chemically, diesel is a complex mixture of hydrocarbons. The main problem is the paraffin wax contained in diesel fuel, which tends to crystallize at low temperatures. Diesel fuel becomes clouded (at temperatures below minus 10 ºC), this is the first sign of wax precipitation. At this stage of paraffin crystallization, its crystals are still very small and pass through the fuel filters. Then, when the temperature drops (below minus 25 ºC), paraffin crystals stick together, and finally, the temperature limit comes, at which clots or agglomerates become large and no longer pass through the fine and coarse filter located in the internal combustion engine power system. This state occurs approximately at a temperature of about minus 15 ... 25 ºC and below. With this condition of diesel fuel, all filters are clogged, and therefore the engine loses its performance. Therefore, in order to prevent such a limiting state of diesel fuel, it is proposed to perform cavitation treatment of the fuel while it is still at the initial stage of crystallization, which is poured into the tank of the vehicle. Cavitation treatment is a complex process that consists of two stages. The first is the transition of hydrocarbon liquid fuel into a vapor state, and then the condensation of these vapors.

The analysis of the work in this area allowed us to conclude that the cavitation of motor fuel makes it possible to structure heavy fuel into a highly dispersed and homogeneous mixture. With this treatment, there is no separation of water in a dissolved state, as well as asphalt-resinous substances from the fuel.

Since diesel fuel is a colloidal system (Rosenthal and others,1981; Unger and Andreeva,1995; Unger,1982), that is, a complex mixture of low-boiling hydrocarbons, in this dispersion system multilayer associative combinations are based mainly on exchange and resonance interactions. This fact is important, as it allows you to determine the energy level of the fuel and assess its effect on the physical and chemical properties in the required directions.

It should be noted that the formation of a dispersion phase in heavy fuels is due to the different propensity of the components to intermolecular interaction. Paraffins, as well as aromatic hydrocarbons, tend to form associates. The paraffinic hydrocarbons included in the dispersed phase in diesel fuel can be in both molecular and associative form.

According to the source (Syunyaev,1981), a concept is introduced as a complex structural unit for describing a dispersion system. This structural unit consists of a core and a surrounding solvation shell, as shown in Figure 1.



1 - core; 2 - heavy resins; 3 paraffin fractions; 4 - aromatic fractions

Figure 1 - Model of a complex structural unit of liquid, hydrocarbon fuel

Due to the chaotic movement of vapor droplets, secondary sputtering occurs and, as a rule, the core is an asphaltene associate, which contains stable radicals that have the highest potential for pair interaction among the components that make up the dispersion system. Also, the core can include solid particles, mechanical impurities, as well as droplets (globules) of the aqueous phase dissolved in the fuel.

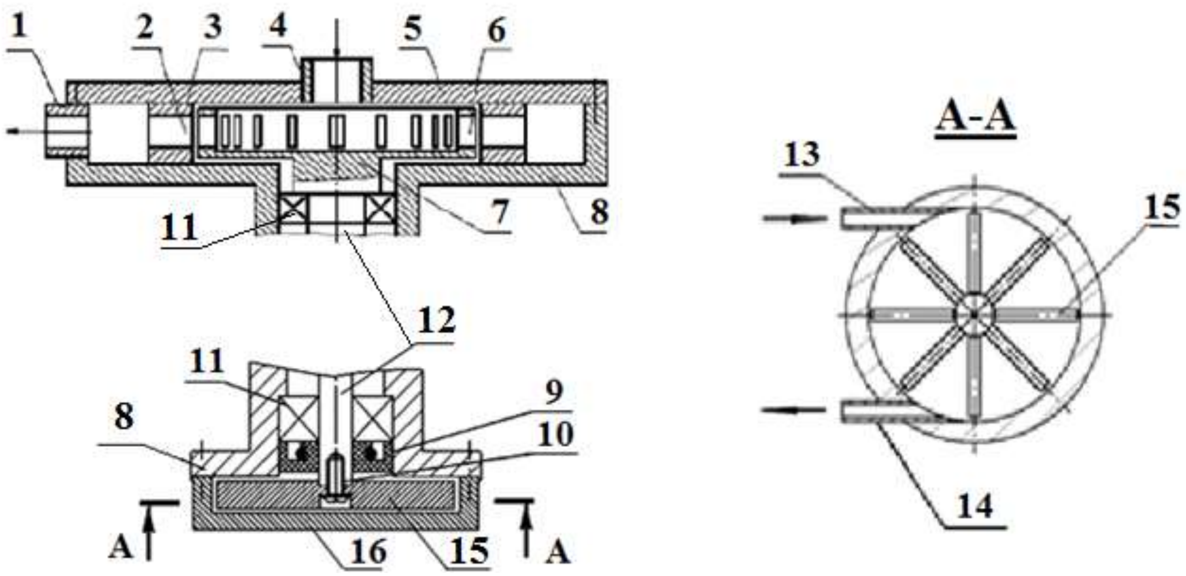
Molecules of heavy resins, aromatic and paraffinic fractions are formed around the core in layers, as shown in Figure 1.

When the concentration of a complex structural unit in the fuel is high, then there is a possibility of their collision and the formation of substantially complex structures with several nuclei. Moreover, these structures have high surface activity. Thus, they will concentrate around water droplets or particles of mechanical impurities at the bottom of the fuel tank. In this case, the formation of very stable water-fuel emulsions in the dispersion medium occurs.

In order to prevent the formation of such a complex structural unit in the fuel, it is proposed to perform cavitation treatment of diesel fuel on board the vehicle using a rotary-pulsating apparatus, which must be installed in the power system (Puzankov, 2007). As can be seen from the analysis performed, the use of homogenizing devices as part of power systems allows saving fuel by effectively affecting its colloidal structure.

The proposed RPA was developed on the basis of an analysis of the design solutions of such devices, described in (Promtov,2021), and can be installed on all types and types of vehicles on which diesel internal combustion engines are installed, as well as where there is a pre-heater power supply in the rupture of the fuel pipe between the unit pump and solenoid valve of the heat exchanger. Such an installation makes it possible to process all diesel fuel that is in a standard fuel tank without high material costs.

A diagram of such an apparatus is shown in Figure 2. Unlike other types, it is capable of producing high-quality cavitation treatment of diesel fuel at relatively low energy costs. The device uses periodic transient hydromechanical processes with the excitation of hydrodynamic, acoustic and impulse cavitation, which provide the rupture of complex molecular bonds and the crushing of heavy fractions of hydrocarbon fuel into lighter ones (Mashinostroenie,2001).



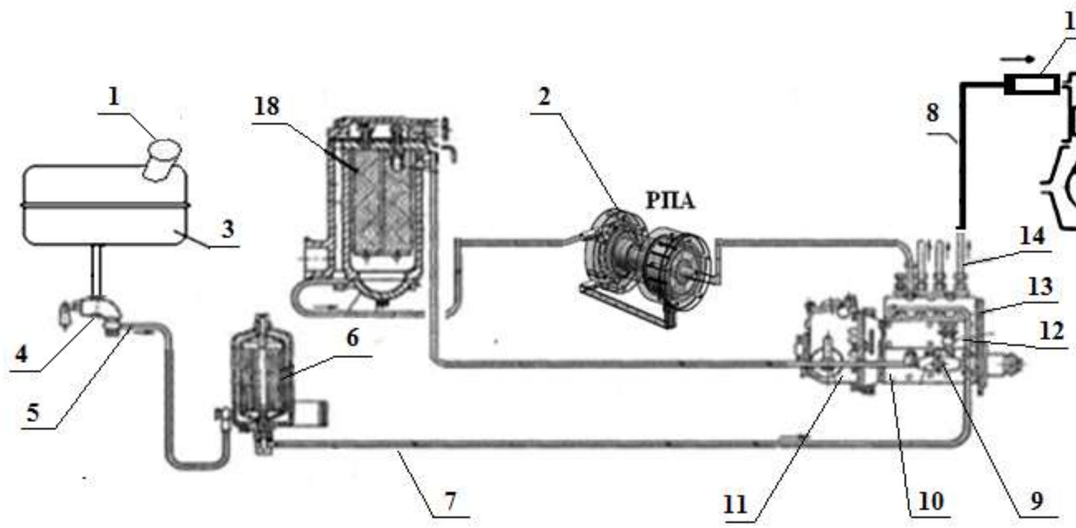
1 - outlet branch pipe; 2 - stator channels; 3 - dubbing camera; 4 - inlet pipe; 5 - cover; 6 - rotor channels; 7 - rotor; 8 - case; 9 - oil seal; 10 - fastening screw; 11 - bearing; 12 - rotor shaft; 13 - fluid supply channel; 14 - liquid discharge channel; 15 - blade impeller; 16 - cover

Figure 2 - Diagram of a rotary-pulsating apparatus

The developed RPA is a highly efficient device, since it uses the energy of the passing fuel jet generated by an external pump to drive the rotor. This design of RPA leads to a decrease in energy consumption by 3 ... 4 times for the volume of processed diesel fuel and a decrease in the time for processing components (Lomovskikh, 2011).

The RPA's work is as follows.

The fuel pump from the fuel tank is fed through the liquid supply channel 13 to the vane impeller 15, then through the liquid discharge channel 14, the fuel enters the inlet pipe and to the rotor 7. In this part of the RPA, due to centrifugal and translational forces, the fuel is directed to the slotted channels of the rotor 6 and stator 2, is pushed through them, and enters the sound chamber 3. It should be noted that during the operation of the RPA, the channels of the rotor 6 and stator 2 quickly overlap, while the fuel under pressure is supplied to the sound chamber 3. The standard motor fuel is then exposed to cavitation phenomena, as well as accompanying quasi-shock, ultrasonic processes formed in the sound chamber, which provides crushing of heavy fractions of hydrocarbon fuel into lighter ones. After that, the processed motor fuel is supplied with kinetic energy and it enters the power system through the outlet pipe 1 and directly into the fine fuel filter 2, as shown in Figure 3, and then into the high-pressure fuel pump (HPP) 4. Such a RPA installation scheme is suitable for all types of diesel internal combustion engines AT.



1 - filler neck; 2 - rotary-pulsating apparatus; 3 - tank; 4 - crane; 5, 7, 8, 13 - fuel hoses; 6 - filter; 9 - pump; 10 - high pressure fuel pump; 11 - speed regulator; 12 - hand pump; 14 - high pressure tube; 15 - combustion chamber of the internal combustion engine; 16 - internal combustion engine; 17 - nozzle; 18 - fine fuel filter

Figure 3 - Installation diagram of RPA in the power supply system of a diesel internal combustion engine

The proposed RPA design for processing motor fuel does not require large material costs for manufacturing, since standard industrially manufactured parts are used.

It should be noted that after the cavitation treatment of the fuel, the temperature of the treated fuel rises to 70 ... 80 ° C at the outlet of the apparatus, which makes it possible to increase the efficiency of its combustion.

According to (Lomovskaya *et al*.,2010), it is the temperature factor that explains the improvement of the diesel fuel combustion process. When diesel fuel is heated to a temperature of up to 80 ° C, its transition to an unstructured state is formed. Under these conditions, its viscosity decreases, and the process of atomization and combustion of diesel fuel is improved.

Cavitation treatment of diesel fuel leads to hydrodynamic disturbance of the dispersed medium, and liquid hydrocarbon fuel acquires new improved physicochemical properties.

When processing hydrocarbon fuel due to the thermal effect of ultrasonic vibrations and changes in the dispersion of the dispersion phase, its viscosity decreases. Then, after a certain time, an increase in viscosity occurs, which lasts more than two hours. After that, there is a slow decrease in viscosity for 2 ... 3 days.

Under the influence of ultrasonic vibrations arising in the sounding chamber of the RPA, the number of active centers increases, which has a positive effect on the intensification of diesel fuel combustion.

The process of mixture formation in a diesel engine plays a key role, since the effective performance of a diesel engine significantly depends on the quality of its organization. The most essential elements are the processes of fuel atomization and jet mixture formation.

Spray quality indicators include:

atomization quality, characterized by the average diameter of the fuel droplets;

the homogeneity of the sprayed diesel fuel;

spray parameters, characterized by the total characteristic and the differential spray characteristic.

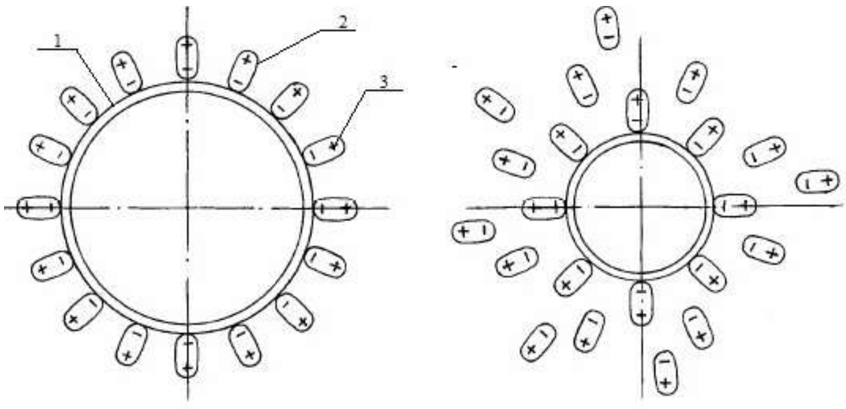
Так как в результате кавитационной обработки дизельного топлива меняются его эксплуатационные свойства ($\mu_т$ – динамическая вязкость; $\rho_т$ – плотность, $\sigma_т$ – коэффициент поверхностного натяжения), а также скорость истечения топлива из сопла форсунки, которая зависит от плотности топлива. При этом средний диаметр капель дизельного топлива будет зависеть от изменения величин $\mu_т$, $\rho_т$, $\sigma_т$ при прочих равных условиях, т.е. можно представить в виде зависимости: $d_{кап.} = f(\mu_т, \rho_т, \sigma_т)$.

Carrying out a theoretical assessment of the influence of fuel indicators on the average diameter of a fuel droplet, it can be concluded that the effect of cavitation treatment on diesel fuel makes it possible to improve the fineness of atomization through the openings of the nozzles of the nozzle up to 20%.

Due to the disappearance of the formed cavitation bubbles when passing through the slotted holes in the rotor and stator, the pressure and temperature of the gas in the fuel increase (about 10,000 K and 100 MPa). This processing of diesel fuel allows crushing almost all heavy fractions, ensuring the output of light fractions during atmospheric distillation through the working bodies of the RPA. Fuel cavitation treatment also accelerates the process of destruction of the paraffin contained in it.

Cavitation action breaks the intermolecular bond between hydrocarbons, that is, there is a temporary rupture of bonds caused by the forces of van der Waals compounds. At the same time, there is a change in the structure and composition of liquid diesel fuel.

The described process is shown in Figure 5, where the molecules located near the wall of a stationary bubble are in an oriented state (Figure 5a).



a) molecules located near the wall of a stationary bubble; b) a cloud of oriented molecules

1 - double electrical layer; 2 - dipole molecules; 3 - the charge of the dipole molecule

Figure 5 - The process of formation of the charge of a "virtual" bubble

Then, at high rates of molecular compression, during cavitation treatment, a reorientation occurs in the vicinity of the bubble and a cloud of oriented molecules is created, as shown in Figure 5b.

For the most effective use of the RPA design, it is necessary to study the existing mathematical models of fluid flow through the stator and rotor of the RPA, which take into account the features of the fluid flow. Therefore, in order to use the existing mathematical models, it is necessary to submit to the RPA a composition that, in terms of its physical properties, is close to a Newtonian fluid. For these purposes, it is necessary to develop a RPA, the design of which will ensure the fulfillment of this condition and will allow obtaining fuel processing to the required (required) quality. To study such a RPA, it is necessary to use a homogenization model that takes into account the peculiarities of the fuel flow in the RPA and the structure of the components that make up the fuel. Therefore, it is necessary to solve the problem of modeling the flow of two components of liquid hydrocarbon fuel through the working bodies of the RPA (Polnova, 1980), without using an emulsifying system.

The content of dissolved water is considered as a component for fuel, which is found in a small amount in diesel fuel, since it has good hygroscopicity. The content of dissolved water in liquid fuels is no more than 0.05%, and in aromatic hydrocarbons it significantly increases 3 ... 4 times. It is known that at temperatures below minus 10 ° C, the solubility of water in liquid hydrocarbon fuel sharply decreases. In this case, part of the dissolved water is released in the form of small droplets, and diesel fuel begins to grow cloudy (Promtov and Aseev,2007 ; Margulis,1984).

It should be noted that over time, moisture accumulates at the bottom of the fuel tank and the fuel is flooded, which in low temperatures can lead to equipment failure by stopping the internal combustion engine when it freezes in the power system. The amount of dissolved moisture is determined by the process of saturation of diesel fuel with atmospheric moisture due to its solubility with increasing fuel temperature. An additional percentage of moisture enters the fuel when the heated fuel is drained into the tank through the drain fuel line 6 (Figure 3), which in the steady-state mode of heat exchange between the tank and the environment (with prolonged operation of the internal combustion engine) characterizes the overheating of the fuel in the tank relative to atmospheric air.

The analysis of the processes of moisture accumulation in the fuel tank of a diesel power supply system revealed the need to improve the fuel system and develop a device (RPA) that allows removing accumulated water from the tank by distributing it in the form of microheterogeneous droplets in the fuel environment. The resulting emulsified fuel with microheterogeneous water droplets, evenly distributed throughout the entire volume of the tank, is fed using a standard power system to the combustion chamber of the internal combustion engine, where it is utilized by combustion. The combustion of such emulsified diesel fuel increases the efficiency of this process.

To determine the size of the dissolved water droplets, it is necessary to perform mathematical modeling of water crushing in the composition of emulsified motor fuel, as a result, the relative speed of the water droplet movement is obtained, at which the process of its crushing in the RPA working bodies is possible:

$$U_{отн}(t_{отн}) = e^{-\beta t_{отн}}\, 2{,}898 + [\frac{1}{\sqrt{z_{кв}}} - \frac{2\mu Y}{\alpha}\frac{\ln|e^{\alpha t_{отн}}+1|}{e^{\beta t_{отн}}} + \frac{\mu Q}{\alpha}\frac{\ln|e^{\alpha t_{отн}}+1|}{e^{\beta t_{отн}}} - \frac{\mu Q}{\alpha}\frac{1}{(e^{\alpha t_{отн}}+1)e^{\beta t_{отн}}}]$$

where, $\alpha = 2H_0\sqrt{z_{кв}}$, $\beta = \frac{9z\rho_2}{(2\rho_1+\rho_2)}$, $\mu = \frac{1}{2\rho_1+\rho_2}$, $Y = 9z\rho_2\frac{1}{\sqrt{z_{кв}}}$, $Q = 8H_0(\rho_2-\rho_1)$, $H_0 = \frac{V_0 t_0}{2L}$, $t_0 = \frac{a_c}{\omega R}$, $V_0 = \sqrt{\frac{2\Delta P}{\rho_2}}$, $Z = \frac{vt_0}{r^2}$, $U_{отн} = \frac{U}{V_0}$.

Here it is indicated ΔP - the pressure drop across the RPA modulator; a_c - width of the stator hole; ω - angular speed of rotation of the rotor; R - rotor radius; L - the length of the modulator; V - flow rate; U - the relative speed of the drop; η is the dynamic viscosity of the dispersion medium; $(\eta = \nu\rho)$ $z_{кв}$?- hydraulic resistance of the modulator (the calculation method is given in (Kardakov, 2011)). According to the obtained equation (1), by varying the design parameters (a_c, R, L) and operating modes of the RPA $(t_0, \omega, \Delta P)$, the parameters and operating modes of the RPA are selected, at which the relative speed of the water drop will be maximum, $U_{отн}$ this will correspond to the minimum size of the dissolved water droplets in diesel fuel.

Let us estimate the maximum values of the relative velocity of a water drop from the point of view of its deformation and fragmentation in an unsteady RPA flow. The criterion for the beginning of fragmentation will be the achievement of the critical Weber number (Kardakov, 2011) :

$$We_{кр} = \frac{rU_{(отн)_{кр}}\Delta\rho}{\sigma_{1,2}}, \qquad (2)$$

where r –is the radius of water droplets in VDS; $U_{отн\ кр}$ - critical relative speed of movement of water droplets; $\Delta\rho = (\rho_2 - \rho_1)$ - the difference between the densities of the dispersed phase and the dispersed medium, $\sigma_{1,2}$ - the interfacial surface tension of the biological membrane of the water-diesel mixture.

After that, from expression (2) we get:

$$U_{(отн)_{кр}} = \left(\frac{We_{кр}\sigma_{1,2}}{r\Delta\rho}\right)^{\frac{1}{2}}, \qquad (3)$$

The critical speed of movement of water droplets in the RPA is determined by the formula:

$$U_{кр} = U_{отн}V_0 = \sqrt{\left(\frac{We_{кр}\sigma_{1,2}}{r\Delta\rho}\right)\frac{2\Delta P}{\rho_2}}, \qquad (4)$$

From formula (4), the minimum diameter of water phase droplets in diesel fuel prepared on RPA is derived:

$$\tilde{d}_{\min\, теор.} = 2\times\frac{We_{кр}\sigma_{1,2}}{U_{кр}^2\Delta\rho}, \qquad (5)$$

With the help of the developed software product, we construct a graphical dependence of the function $U_{отн} = f\left(t_{отн}\right)$ for VDS, prepared on the RPA, shown in Figure 6.

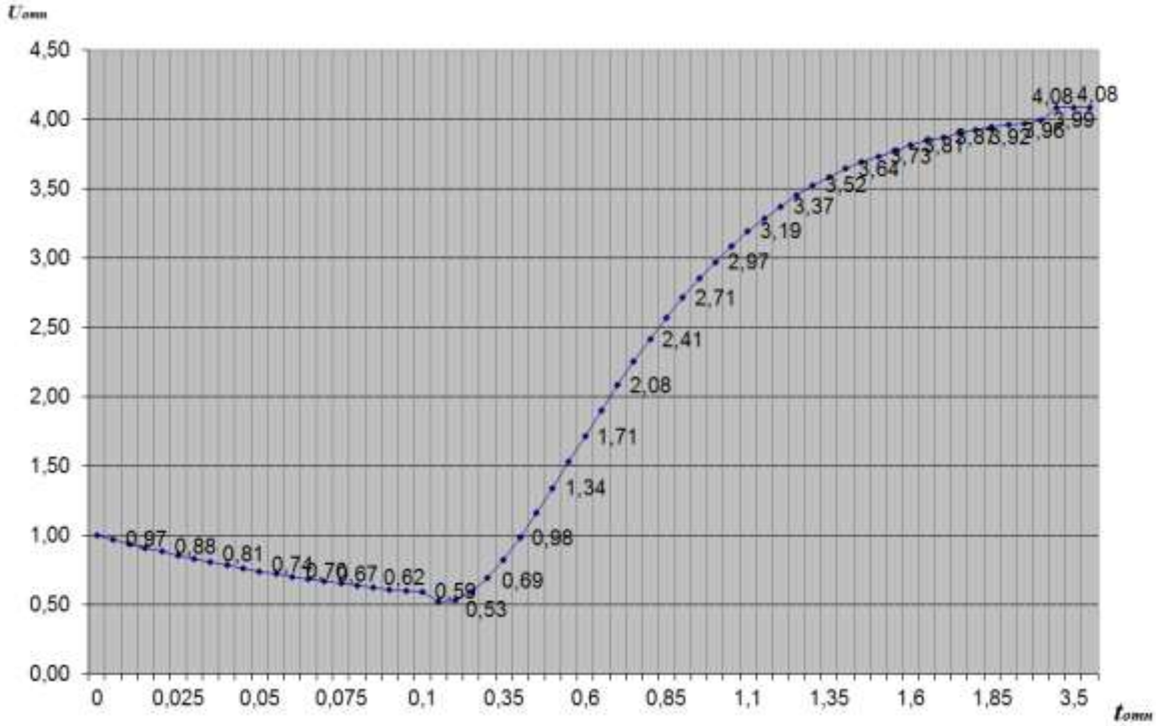


Figure 6 - Dependence Urel = *f* (trel) for emulsified fuel prepared at RPA

In this case, the following values of the investigated quantities were set U_{rel} = 0.53 - the relative speed at which the process of crushing a drop of water becomes possible; $\Delta p = p_2 - p_1$ is the difference between the densities of the dispersed phase and the dispersed medium, where water droplets are distributed in the fuel Δp = 140 ... 280 kg / m^3, p_2 = 998 ... 1003 kg / m^3 is the density of water, p_1 = 830 ... 860 kg / m^3 - fuel density; σ12 = 26.86 * 10-3 N / m - interfacial surface tension of the biological membrane VDS.

The analysis of the calculation results shows that all the studied modes of flow around a water drop in periodic transient hydromechanical processes provide its fragmentation to an average diameter of less than 2 microns. Such a size of water droplets allows it to be evenly distributed over the volume of the fuel tank and to obtain a highly dispersed water-diesel emulsion with the aim of further removing it through the standard power system. Water droplets of this size (less than 2 microns) easily pass through the filter elements of standard fuel filters, which in the winter period of operation will prevent the accumulation of water in the filters, its freezing. Therefore, the use of RPA in the power supply system of a diesel internal combustion engine will significantly reduce the failure of military equipment during operation at low temperatures.

Thus, the average minimum size of a droplet of the dissolved aqueous phase in a fuel medium during crushing in a dynamic RPA was determined, depending on its structural dimensions (radius of the rotor and stator, width of the stator opening, length of slots, hydraulic resistance of the modulator itself) and operating modes (angular velocity of the rotor , the processing time of the emulsion, the pressure drop in the modulator) of the apparatus (Margulis,1986).

Conclusions. The use of the developed RPA for processing liquid diesel fuel will improve its physicochemical properties and bring it closer to the requirements of the EURO-5 standard (the sulfur content is reduced by up to 2 times and the content of actual resins up to 9 times), regardless of the quality of the initial hydrocarbon fuel. The use of such fuel for ICE AT will also increase the resource by improving the combustion process in the engine cylinders, and will also facilitate its start at temperatures below minus 30 ° C (Akulov, 2005).

Full-scale tests carried out on a KAMAZ-740 diesel internal combustion engine showed that the use of RPA in the fuel system allows in 96% out of 100 cases to start at an air temperature below minus 50 ° C the first time. Thus, the introduction of RPA into the fuel systems of AT diesel engines in Arctic conditions will increase the efficiency of starting equipment at low temperatures, as well as reduce the toxicity of exhaust gases, the content of white smoke when operating in the warm-up mode.

REFERENCES

1. Puzankov A.G. Cars design, theory and calculation. M.: Publishing house of the center "Academy", 2007. 544 p.
2. Oxler G. What is cavitation? / G. Oxler // Science and Design 2012. No. 3. pp. 70–73.
3. Rosenthal YES. and others . Methods of determination and calculation of structural parameters of heavy oil residues. LTI. L.: 1981.
4. Unger F.G., Andreeva L.N. Fundamental aspects of oil chemistry: The nature of resins and asphaltenes. Novosibirsk: Nauka, 1995. 268 p.
5. Unger F.G. The role of paramagnetism in the formation of the structure of oils and oil residues. In the book. Investigation of the composition and structure of heavy petroleum products. -M.: TSNIITE neftekhim, 1982.
6. Syunyaev Z.I. Physico-chemical mechanics of petroleum dispersed systems: Textbook. M.: MINH and GP, 1981. 89 p.
7. Promtov M.A. Rotary type pulsating devices: theory and practice.
8. Moscow: Mashinostroenie-1, 2001. 260 p.
9. Rotary pulsating apparatus: pat. No. 2516146 of the Russian Federation, IPC 7 In 01 F 5/00. dated 03/20/2014. Ivanov V.P., Tomilov A.A., Lomovskikh A.E., etc.; application No. 2011134397; publ. 16.08.2011. 12 p.
10. Lomovskaya A. E., Khabarov S. R., Kapustin D. E. Preparation and filing of VTE in the ice SNO OP as a way of improving the economic and environmental performance of the internal combustion engine // abstracts of reports of the Russian scientific and technical conference, Voronezh, Russia (October 28-29, 2010), Voronezh: Voronezh state technical University, 2010. P. 140–142.
11. Polnova V. Chemistry of macromolecular compounds of oil. L.: Publishing house of Leningrad state University, 1980.
12. Promtov M. A., A. S. Aseev. Pulse technologies of oil and petroleum products processing // Oil refining and petrochemistry. 2007. No. 6. pp. 22–24.
13. Margulis M.A. Fundamentals of sound chemistry (chemical reactions in acoustic fields): Textbook for chemical chemistry. and chemical.-technol. spec. universities. M.: Higher School., 1984. 272 p.
14. Kardakov A. A. Improving the reliability of diesel fuel equipment by cavitation treatment of fuel / A. A. Kardakov // Journal of Water Communications. Issue 2. pp. 43–46.
15. Margulis M.A. Sound chemical reactions and sonoluminescence. M.: "Chemistry", 1986. 288 p.
16. Akulov N.I. Development of processes for obtaining emulsions of water-alcohol solutions in gasoline in rotary devices with flow modulation and their coagulation. M.: Nauka, 2005. 202 p.
17. Lipson A.G., V.A. Kuznetsov, J. Miley. The output of the DD reaction in the process of electric breakdown of cavitation bubbles in dielectric deuterated liquids // Letters in ZhTF. 2004. No. 10. pp. 39–45.