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Modelling the Injection of Spark-Ignition Fuel into Combustion Chamber in the Gas and Diesel Operating Process

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Abstract – This article studies the questions of reducing the consumption of diesel fuel via the gas and diesel operating process in small-sized internal combustions engines as well as lowering the amount of noxious substances in exhaust gases. Internal combustion engines (ICE) are the main consumers of petroleum product fuels, the reserves of which are significantly limited in some regions of the world. One of the most promising ways of decreasing the consumption of diesel fuel, diminishing the harmful emissions while reaching the goal of increasing the engine life and using the gas seems transforming diesel engines into gas ones. The most popular method of modifying the diesel engine is the introduction of the gas and diesel operating process, i.e. replacing some part of liquid fuel with gas, most often compressed natural gas. The injection of fuel into the cylinder has been modelled. This simulation has been run with the help of a specially made experimental facility which is based on the diesel 2CH,5/11.

Keywords – ICE; gas diesel; spark-ignition fuel; nozzle; combustion chamber; cylinder.

I. INTRODUCTION

The trend to increase the price of conventional liquid petroleum fuels affects in a negative way the operating costs of power plants with internal combustion engines (ICE), including ship ones. The oil reserves as the major and most popular energy source dramatically decrease, and it is evident that the decline of the petroleum era is coming. In addition, there is the rising issue with protecting the environment from harmful effects of noxious agents in exhaust gases and other wastes from power stations which gets more and more critical, gaining the top priority [1, 2, 3]. The proportion of ICE, compared to other pollutants of the environment, exceeds 70%.

This fact, when taking into account that 80% of mechanical energy, which people use in their activities, is produced by internal combustion engines, makes urgently look for the alternative energy sources, of non-petroleum origin.

The most feasible solution to the problem of lacking diesel fuels seems applying alternative kinds of fuel, and the natural gas comes the first in line. Prices for gas are half of those for liquid petroleum fuels, and this difference is growing. The viability of using gas as fuel for engines in the regions, where it is extracted and transported, has been proved in several research papers as well as technical operations of diesel engines [4, 5].

The current stage of economy development has only brought a few corrections to this problem. In terms of labour intensity, gas is considerably more economical than coal and petroleum fuels, the environmental issues when using gaseous fuel are easier to solve as well.

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II. Methods and Materials

The effective ignition dose of air and fuel mixture as well as remaining in the cylinder exhaust gases represents the essential factor for the efficiency of operating processes in the diesel engines. The key part in mixing of fuel with air is the thermophysical process of fuel droplet evaporation, injected inside the combustion chamber of the nozzle via the perforated injector under the pressure starting from 17,5 MPa. The combination of higher pressure of fuel injection (up to 200 MPa) and small and extra-small diameters of injection nozzle holes (from 0,28 to 0,03 mm) enables to provide the air-fuel ratio (through a single nozzle hole) of over 50 % of droplets with the diameter 5–10 μm. Such ratio of the mixture allows quick evaporation of its biggest part in the hot and flowing air medium. This results in the destruction of intermolecular bonds and formation of free radicals which quickly get oxidized. This enables to minimize the ignition-delay period, thus reducing heat losses in the cooling system and of exhaust gases which provides higher indicator values.

For diesel engines with the cylinder diameter of up to 100 mm and the wall-spray and liquid film mixture in the combustion chamber of semi-separate type in the piston (type-size CH9,5/11), the most typical parameters of fuel injection equipment are the following – injection pressure 17,3–17,5 MPa; diameter of injection nozzle hole 0,28–0,32 mm; number of holes 3–4. Beside that these engines have nozzles installed with the tilt of 35° to the piston centerline, with the eccentric (relative to the piston centerline) combustion chamber of toroidal-conical shape, figure 1.

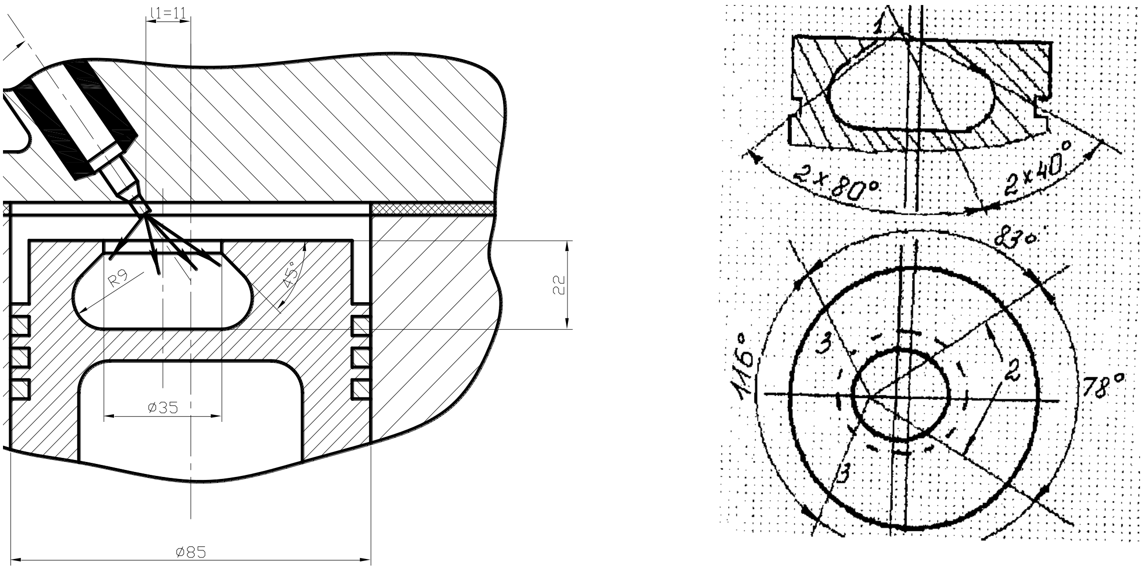


Fig. 1. Diagram of fuel jet distribution in the combustion chamber in the piston
1 – nozzle centerline, 2 – front fuel jets, 3 – back jets

Figure 1 shows that two front fuel jets cover longer distance until they reach the wall of the combustion chamber (CC), while two back jets have shorter flight. This causes unequal conditions for forming fuel jets and evaporation of droplets both in the atmosphere and on the walls of the combustion chamber. Consequently, the process of obtaining good air-fuel ratio will differ in the CC space, as left fuel jets with shorter flight will not evaporate a sufficient amount of fuel droplets to be mixed with air, and processes of ignition, combustion and after-burning of mixture will be somewhat «incomplete».

In other words, some part of fuel will not evaporate, will char as a result of burning the air and fuel mixture and will leave the cylinder with exhaust gases as soot which causes the higher level of smoke in these diesel types and means there is space for improvement in terms of fuel economy. That has led to the idea of providing similar conditions for development of all fuel jets.

Based on the mentioned above and using the geometrics of the injector and CC, the process of injecting fuel into the cylinder has been simulated. Modelling has been carried out with the help of the specially designed experimental facility which is based on the diesel 2CH9,5/11 [7, 8].

III. Results

The initial research of injection has been carried out, using the stains (figure 2) of replacement fuel (coloured acetone) on the flat bottom of plastic foam piston where acetone corrodes to leave a characteristic print, in its various positions from the bottom dead center (BDC), starting from 30° crankshaft rotation angle (CRA) to the top dead center (TDC), taken as the maximum value of fuel injection advance angle (FIAA) and further in every 5° CRA with the reverse pressure in the cylinder, corresponding with the real value of pressure, according to the indicator diagram. The reverse pressure in the cylinder has been made by injecting compressed air from the air tank via the reducer.

Figure 2 demonstrates, as an example, the distribution of fuel jets inside the cylinder in plan view, while the cross section of jets in the elevation of engine torch centerlines has been researched. All this, as a whole, has enabled comparing the CC shape as well as location with the fuel injection conditions via the tilted nozzle with the above given geometrics of nozzle holes and resulted in relevant description of fuel jets.

When applying in a small-sized diesel CH9,5/11 the wall-spray and liquid film mixture with direct fuel injection into the cylinder and located in the piston CC, the consumption of fuel decreases and startability improves. Mixing is done in the CC, located in the piston and having similar structure to the CC of CNIDI.

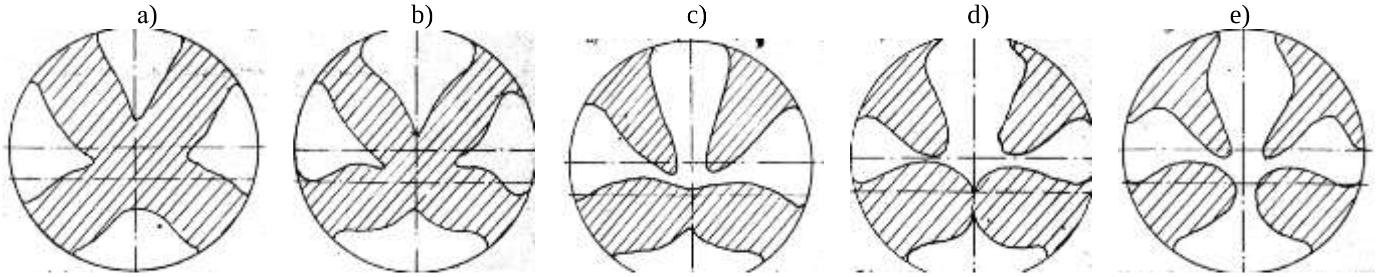


Fig. 2. Injected fuel distribution in the cylinder
a) – 10º to TDC, 1mm, 4,4 MPa; b) – 15º to TDC, 2,3mm, 3,5 MPa; c) – 20º to TDC, 4,1mm, 3,0 MPa;
d) – 25º to TDC, 6,4mm, 2,5 MPa; e) – 30º to TDC, 9,2 mm, 1,5 MPa.

The researched CC differs from the chamber of CNIDI as it has a more developed toroidal surface at the bottom and a smaller conical transition surface at the opening which makes a standard CC similar to a toroidal type of chambers; and the kinetic energy of injected fuel and the energy of air charge provide air and fuel mixing in the CC.

The shape of the combustion chamber creates vortex in it. The nozzle is installed with the tilt of 55° to the plane of the igneous bottom of the cylinder head, shifting the crossing point of the centerline with the plane of igneous bottom (from the cylinder centerline) - 11 mm.

To provide the required ratio between flight distances of injected fuel jets, the CC is shifted by 3mm from the piston centerline towards the nozzle. The fuel is injected into the CC via the nozzle FD22, through the injectors VZTA (4×0,28×120). The optimal adjustment specifications for the diesel type CH9,5/11 – fuel injection advance angle, length of the projected part of the nozzle spray tip relative to the bottom of the cylinder head and primary pressure of fuel injection, have been determined experimentally.

Thus, the optimal length of the projected part of the nozzle spray tip is 1,8–1,9 mm. At these length values the fuel consumption remains virtually unchanged and the characteristic of the operating process, in terms of FIAA, levels off at 23–30º CRA to the TDC, and the accepted pressure of the injection beginning, is 17,2 MPa.

The indicators of the operating process for the diesel types CH9,5/11 are given in Table 1, where T_c and T_{max} – temperatures of final compression and combustion, similarly P_c and P_{max} – pressure of final compression and maximum pressure of combustion; n – rated speed of crankshaft.

The direction of engine torches, and the laws of motion for air charge in the combustion chamber considerably affect the capacity indicators and fuel efficiency of diesels with the CC in the piston. The CC structure of CNIDI type enables to form a toroidal vortex which during compression sends the downcurrent along the CC centerline, while the updraft – peripherally airs the side walls of the CC.

TABLE I. INDICATORS OF OPERATING PROCESS

Indicators	Values	Indicators	Values
g_e, g/kW·h	234–240	p_{max}, MPa	7,39–7,75
g_i, g/kW·h	173–179	$dp/d\varphi$,	0,419
P_{me}, MPa	0,68	MPa/ºCRA	0,332
T_c, K	861	η_e	0,417
T_{max}, K	1859	η_i	0,447
p_c, MPa	3,87	η_m	0,729
n, c^{-1}	25		

Therefore as the fuel injected, the walls of the CC are covered with most of fuel, consequently, the temperature of walls is vital for good quality mixing. According to CNIDI data, the optimal temperature values are 270–320 °C. These data are typical for the chamber in the piston of the type CNIDI when the nozzle is vertical, and its centerline coincides with the cylinder one.

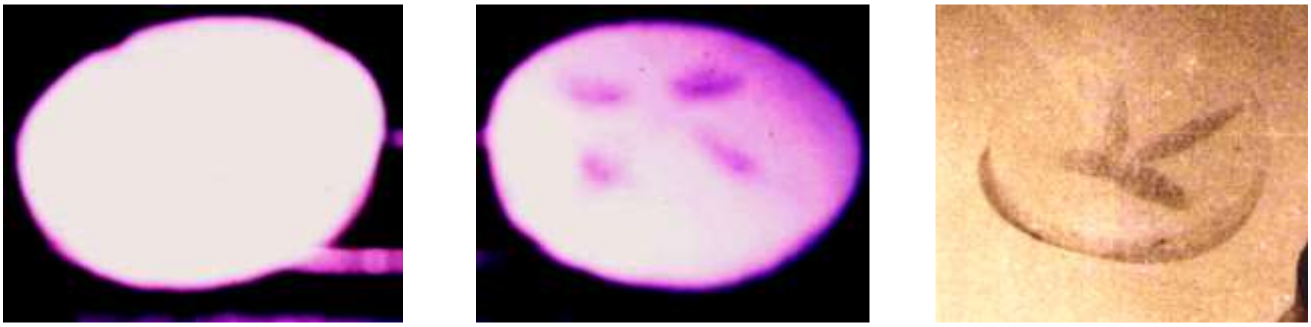
The best adjustment specifications of diesel can also be obtained at the increasing rated speed of crankshaft up to the values from n = 25 $s^{–1}$ to n = 30–40 $s^{–1}$ as is proved by the experiments; and at the rising rated speed of crankshaft, specific fuel consumption gradually grows, while the coefficient of air admission into the cylinder - declines. The maximum pressure of combustion period, as the rated speed of crankshaft goes up, slightly increases (8,35 MPa at n = 37 $s^{–1}$), which is within acceptable values for compression degrees ε = 17–18.

The practice of foreign motor industry takes into account the possibilities of good quality air and fuel mixing not only for the engine torch as a whole, but for every separate jet (in perforated injectors) for, similar in size, engine cylinders. Therefore the diesels of “FIAT”, “DEITZ”, “PERKINS” with D_c ≤ 100–120 mm are produced, using the forms of semi-separated and open CC types where the volume of every jet is individual. These ideas and statements [10, 11] can be summarized as follows, the injected fuel, in the form of a jet made of droplets with the diameter of 10–100 µm, spreads in the CC from the spray valve with the initial speed of 250–280 m/s, which steadily decreases. The volume of inter-droplet space at 90–95% from the volume of a jet is filled with fuel evaporation and air.

The goals of making a highly efficient gas and diesel operating process for standard diesel engines have been set by several writers [5, 6], but the aim of this research is studying the injection process of the spark-ignition dose of liquid fuel in the combustion chamber, development and distribution of fuel jets in the CC space and their interaction with air and gas-air environment. This enables to further advance the solution of such issues as reliable start-up, as well as efficient operating processes of both diesel and gas-and-diesel engines.

According to the hypothesis [8, 9], in the combustion chamber in the piston the combustion process is the most efficient when the jet range is maximum and equal to the length of its flight until it reaches the surface of the combustion chamber. The spray front arrives at the CC surface, at this moment the rate of evaporation falls sharply as a result of the precipitation of fuel on the relatively cold surface of the chamber and the drop structure of the front transforms into the near-wall layer with a smaller evaporating surface area.

Due to the fact that various sources provide different data concerning the amount of ignition fuel (from 5 to 50%), it grows as the cylinder size decreases [2, 5, 6]. As there is no information about the gas and diesel operating process in the engines with the cylinder diameter less than 100 mm, it has led to the necessity to evaluate the distribution of ignition fuel in the cylinder space in order to create maximum possibility for mixing all the injected fuel with gas-air mixture in the cylinder. Based on the mentioned above and using the given geometrics of the injector and the CC, the physical simulation of injecting the ignition fuel into the cylinder has been run (figures 3, 4).



a) b) c)

Fig. 3. Distribution of fuel in the cylinder when injecting the ignition fuel in the gas and diesel operating process
a) no injection; b) injection of ignition fuel 20%; c) injection of ignition fuel 35%

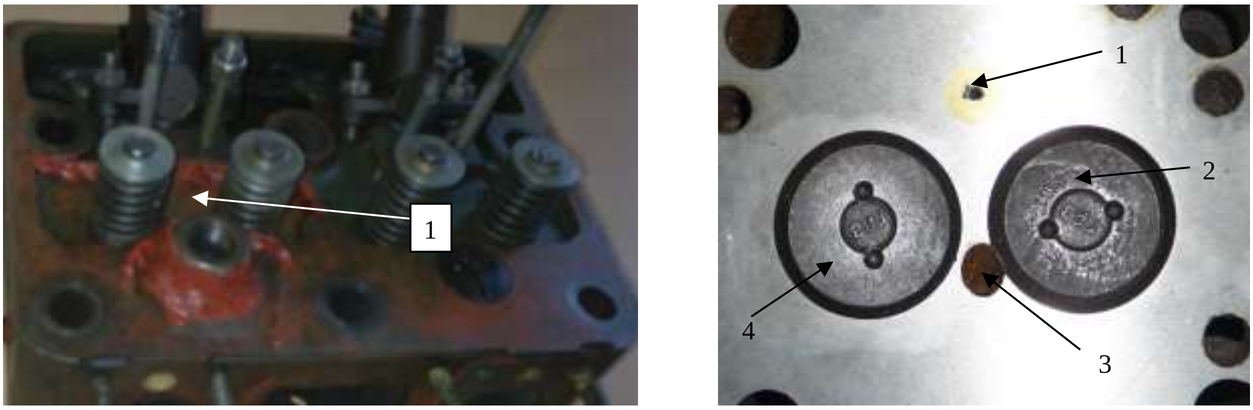


Fig. 4. The cylinder head of ship small-sized diesel of the type CH9,5/11
a) – top view; b) – bottom view: 1 – channel for reverse pressure in the cylinder; 2, 4 – intake and emission valve; 3 – injector nozzle

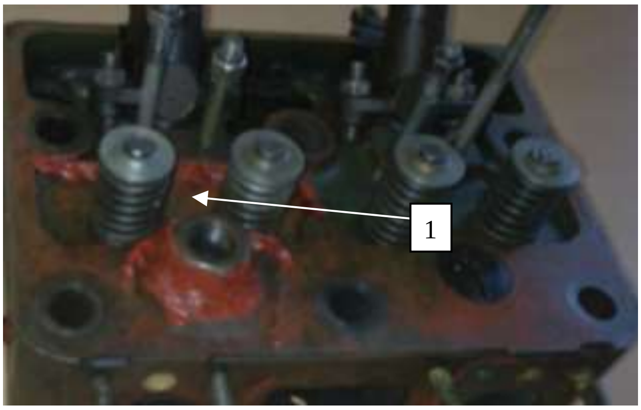
As a prototype, the method of experimental research has been accepted which evaluates the distribution of fuel in the cylinder, as cited in the work of Dzhabrailov A.D. [8]. The experimental facility has been developed, based on the diesel 2CH9,5/11.

The piston has been set at the tilt of 30° CRA, taken as the maximum value of fuel injection advance angle (beginning of injection) to the TDC and characteristic prints of replacement fuel (coloured acetone) on the flat bottom of the piston made of plastic foam, with the reverse pressure of compressed air in the cylinder environment, corresponding with the real value of pressure, according to the indicators diagram, where the acetone leaves characteristic «patterns».

The measurement has been made to evaluate the distribution of fuel in the cylinder space at different injection rate 15, 20, 25, 30, 35%. It has been established, as a result, that the cylinder is filled with diesel fuel the most at 30–35% ignition fuel from the injection rate for the diesel type.

The reverse pressure in the cylinder has been created by injecting the compressed air from the air tank through the reducer into the specially made channel of the cylinder head (figure 4).

The purpose of this research is defining the main physical principles of gas and diesel operating process in the ship small-sized diesel and developing guidelines for practical application. All this, as a whole, has enabled to compare the conditions of fuel injection through the tilted nozzle with the above mentioned geometrics of injector holes and obtain the relevant description of fuel jet shapes.



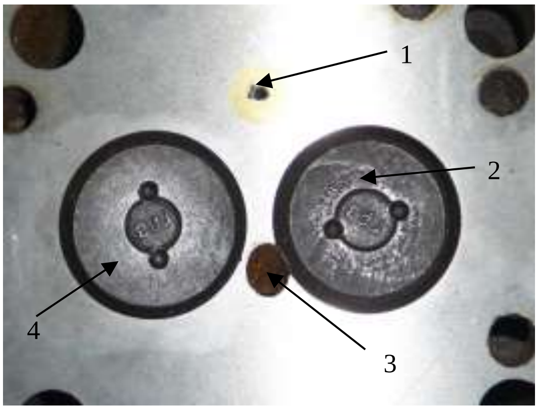


Fig. 5. The cylinder head of ship small-sized diesel of the type CH9,5/11
a) – top view; *b)* – bottom view: 1 – channel for reverse pressure in the cylinder; 2, 4 – intake and emission valve; 3 – injector nozzle

The obtained results prove that the process of formation of engine torches is complicated for the given CC design form and geometrics of the nozzle, the distribution of injected fuel in the cylinder is imperfect which results in areas, overrich in fuel, and areas with the excess of air and gas. This impedes pre-flame reactions when mixing air and fuel at the start of the engine, as well as when working with gas and air mixture in operating conditions.

IV. Conclusion

The key scientific and technical objectives of this work are:

- researching the specific features of diesel and gas-and-diesel operating processes;
- researching the processes of injection and distribution of ignition fuel;
- defining the essential technical solutions and rational limits of using gaseous fuel in the gas and diesel mode of the researched diesel;
- developing and producing the experimental facility for modelling the gas and diesel operating process in the ship engine of the type CH9,5/11;
- researching experimentally the impact of various structural variables on the gas and diesel operating process with the aim of determining the optimal parameters of the researched engine;
- developing practical guidelines for application of the gas and diesel operating process in the ship small-sized diesel of the type CH9,5/11 with the cylindrical combustion chamber in the piston.

Beside the experimental approach, when solving the problem of distributing the ignition dose of liquid fuel in the air and gas-and-air environment, it is necessary to research the theory of the issue [12]. It seems wise to set as an objective the mathematical modelling of the air and fuel mixing process in the engine cylinder.

References

[1] B.V. Budzulyak, “Prospects of using natural gas as a motor fuel”, Gas industry, № 4, pp. 17–19, 2005.

[2] A.F. Dorokhov, I.A. Apkarov, Coang Hoan Luong, “Features of the use of gaseous fuels in marine power plants”, Bulletin of AGTU Ser.: Marine engineering and technology, 2012.

[3] I. A. Abkarov, K.K. Kolosov, “External indicators of different ways of mixture formation in a small-sized marine diesel engines”, Vestnik of ASTU. Ser.: Marine engineering and technology, № 2, 2011.

[4] P.A. Dorokhov, I.A. Apkarov, “Mixing And working process parameters of diesel engine with combustion chamber in piston of complex spatial form "Fifth" European conference on innovations in technical and natural Sciences”, Austria, Vienna, December 23, 2014. (5th European Conference on Innovations in Technical and Natural Sciences).

[5] Yu.V. Galyshev, L.E. Magidovich, “Prospects of application of gas fuels in ice”, Dvigatelestroyeniye, № 3, pp. 31–35. 2001.

[6] V.S. Epifanov, S.V. Kirpichenkov, “Reduction of toxic emissions of exhaust gases of marine diesel engines–an important task for the river fleet”, 7 River transport, no. 2, pp. 57–59, 2004.

[7] A.F. Dorokhov, A.D. Dzhabrailov, “Development and research of combustion chamber parameters in the piston of complex spatial form”, SB. science. Tr. SPb.: Institute of problems of mechanical engineering, RAS. 96 p., 1998.

[8] A.D. Dzhabrailov, "Development and research of design, technological and operational parameters of the combustion chamber in the piston", Diss. kand. Techn. of Sciences Saint-Petersburg, 167 p., 1998.

[9] V.N. Fainleib, V.I. Boran, "Improving the efficiency of mixture formation in diesel engines by acting on the dynamics of the spray of fuel", Dvigatelestroenieno, no. 9, pp. 8–12, 1986.

[10] A.K. Kostin, B.P. Pugachev, Yu. Yu. Kochenev, "The Work of diesel engines under operating conditions", Reference; Under the General, edited by A. K. Kostin, Leningrad: Mashinostroenie, 1989. 284 p.

[11] A.S. Lyshevski, Fuel Atomization in marine diesels, Leningrad: Shipbuilding, 1971, 248 c.

[12] A.F. Dorokhov, "A Mathematical model of formation of the combustion chamber in the piston of the complex space forms", Journal of engineering, no. 4, pp. 15–18, 2000.