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Analysis of theoretical cycle of thermal engines and improvement of diesel mixing process

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Abstract. This article provides a theoretical analysis of the diesel cycle, the device and principle of operation of the proposed atomizer with a replaceable mesh turbulator. This ensures the formation of a homogeneous fuel mixture in the vortex chamber and the completeness of its combustion without toxic emissions. The importance of the scientific work provides for the need to improve the toxicity of the exhaust gases of thermal diesel engines and their fuel efficiency.

1. Introduction

The relevance of the work envisages the need to improve the toxicity of the exhaust gases of thermal diesel engines and their fuel efficiency. The solution to the problem of improving these indicators is possible with the use of an atomizer with replaceable mesh turbulators, which provides the most efficient atomization of fuel and mixture formation, ensuring uniform distribution of the evaporated fuel throughout the cylinder volume and the most complete combustion of fuel with the highest efficiency of the working cycle [1,2].

Improving the quality of these processes can be achieved by developing the design of the fuel supply system and, in particular, the design of injectors and their nozzles, which predetermine the parameters of these processes, the rapid disintegration of fuel jets in the combustion chamber of a diesel engine. At the same time, it reduces the maximum combustion temperatures, which provides turbulization of the fuel flame and as a result of intensive crushing and evaporation of the supplied fuel mixture without the formation of toxic emissions [3,4].

2. Materials and methods

The set goal in the work is achieved by a combination of theoretical and experimental methods. With the help of theoretical methods, computational studies of the parameters of the fuel flow in the flow path of the injector nozzles have been carried out. The experimental part of the work consisted in determining the performance of a diesel engine operating with the proposed sprayer with replaceable mesh turbulators.

It has long been known that a heat engine-machine serves to convert heat into work. Some scientists mistakenly believed that heat is a caloric substance that does not arise and is not destroyed between bodies. The falsity of the material theory was discovered by M.V. Lomonosov. Other scientists, who adhered to the mechanical theory of heat, erroneously argued that heat is the movement of the smallest particles of a body. Later, science confirmed that such a movement exists, but it determines not heat, but the thermal energy of a substance.

3. Results and discussion

Through the efforts of many scientists, it has been shown that heat and work like it is a function of processes. At the same time, every body has a certain internal energy that depends only on its state. Internal energy is the sum of many components, including intra-atomic and intranuclear energy. However, in the thermodynamics of heat engines [1], only the types of internal energy that change in thermodynamic processes are taken into account. These include internal kinetic energy (that is, the energy of translational, rotational and vibrational motion of atoms and molecules) and internal potential energy (that is, the energy that depends on the mutual position of particles and is associated with the forces of intermolecular attraction and repulsion).

It is known that the thermodynamic state of a body is completely determined by any two of the three parameters – pressure (P), temperature (T), and specific volume (V) – the ratio of the body's volume to its mass. These quantities are interconnected by the so-called equations of state. The most familiar to us is the equation of state of a real gas (Clapeyron – Mendeleev equation):

$$PV = RT, \tag{1}$$

here: R – gas constant.

The heat Q received or removed from a given body, the work L performed by it or on it and the change in its internal energy ΔU are related by the equation:

$$Q = L + \Delta U, \tag{2}$$

which is a mathematical expression of the first law of thermodynamics [2]. It means that the heat imparted to the body is spent on increasing internal energy and on performing work. The first law of thermodynamics is a special case of the general law of conservation of energy [5,6].

Heat engine cycle. One of the main elements of any heat engine – the so-called expansion machine – is the output of mechanical work. Expansion machine designs are endlessly varied. Below we will consider the operation of one of the most widely used - a piston machine, its simplest version. Such a machine (Fig. 1) consists of a cylinder and a piston with a rod, which is connected directly or through a transmission mechanism to the consumer, the work-drive unit. At the initial moment of the working stroke, when the piston is located in the extreme left position, there is a compressed and heated working fluid in the working chamber of the cylinder, for example, air or other gas with parameters P, T, V. The gas pressure creates a force pS on the piston (where S is the area piston). Under the action of this force, the piston begins to move to the right. As the piston moves, the gas expands, which continues until the piston stops at the extreme right position. The state of the gas at each moment of the expansion process is determined by the parameters P and V, that is, it can be indicated by a point on the P-V diagram. Thus, the expansion process itself is a sequential transition of gas from one state to another, will be depicted on the P-V diagram in the following form:

Line 1 connecting point 1 (the initial state of the gas) and point 2 is its final state. However, the state of any finite mass of gas can be indicated by a point on the P-V diagram only under one condition: if the value of these parameters is the same throughout the volume occupied by the gas. This state of the gas is called equilibrium. Preservation of this condition during the transition of gas from one state to another (from one point of the process to the next) is possible only when this transition occurs infinitely slowly. Such idealized conditional processes, which represent an infinitely slow change in equilibrium states, are called reversible in thermodynamics [7,8].

Let's define the work L_p, performed by the gas in the reversible expansion process 1-2 (A). Obviously, when the piston moves from one intermediate position to another located at a small distance Δl, the gas will perform work ΔL = pSΔl (Δl – we choose it so small that the pressure p along this path can be considered constant).

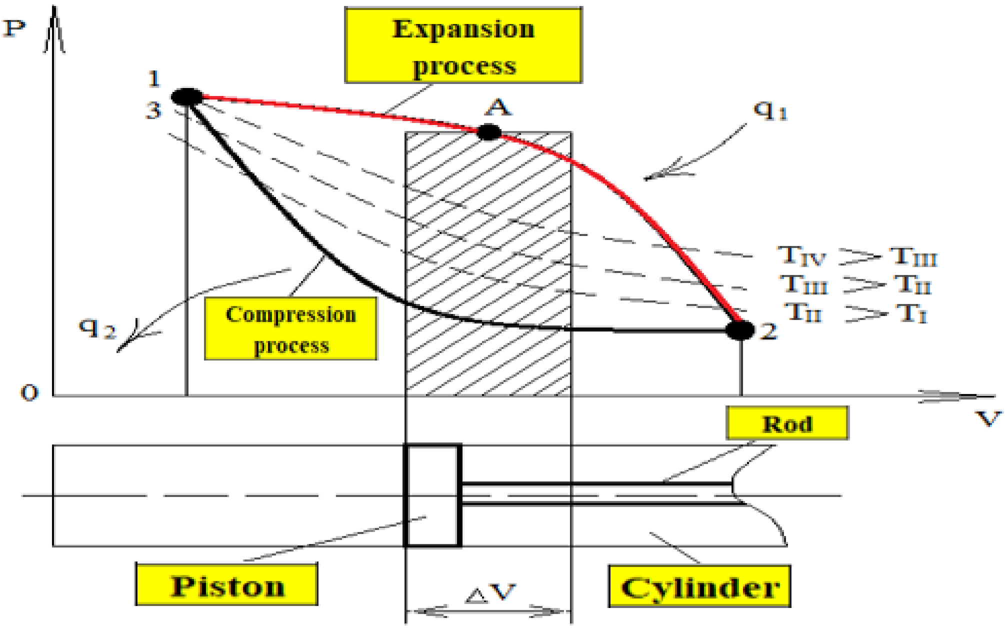

Figure. 1. Heat engine cycle in P-V coordinates.

Since $\Delta S = \Delta V$, then $\Delta L_p = p\Delta V$ (where ΔV is the corresponding change in gas volume). The total work L_p, done by the gas in the process 1-2 is equal to the sum of the elementary work ΔL_p. The work L_p, as it follows from the figure, is equal to 1A22′1′ under the processor 1-2 (A). In order to increase the work of the expansion, it is necessary to "raise" the process 1-2 (A). Constant temperature lines (isotherms) are plotted on the p-V diagram. In accordance with the Clapeyron equation in Fig. 1 it is seen that L_p is the larger, the expansion process occurs at high temperatures. Today, as it will be excellently below, is one of the foundations of the problems over which the creators of heat engines are struggling. To carry out a new working stroke, the gas must be returned to its original state, that is, it must be compressed [9,10].

If, applying force to the piston, move it in the opposite direction, compressing the gas along the same line. And between points 1-2, then, as you might guess, the work of compression will be equal to the work obtained during expansion, that is, as a result, in two strokes of the piston, we will not get work even from an ideal machine. In a working heat engine, the work expended on gas compression is always less than the expansion work. To achieve this, the compression process between points 2-1 must be located below the expansion process (curve B), that is, the compression must be carried out at lower gas temperatures than the expansion process. Thus, before or during expansion, the gas must be heated, and after expansion or during it, it must be cooled. Hence it follows that in addition to the expansion machine, any heat engine must have a heater, a refrigerator and a compression machine - only in this case it is possible to receive work from the engine with a periodic return of the working fluid to its original state. The closed curve consisting of processes 1-2 (A) and 1-2 (B) is called the engine cycle.

If we denote the heat supplied to the gas from the heater during the 1-2 (A) process through Q_1, and the heat removed from the gas to the refrigerator during the 1-2 (B) process through Q_2, then the heat received by the gas during the Q_{ts} cycle will be $Q_{ts} = Q_1 - Q_2$. Since the gas in a closed cycle returns to its initial state, the change in its internal energy per cycle is equal to zero. Therefore, in accordance with the first law of thermodynamics:

$$L_{ts} = Q_{ts} = Q_1 - Q_2\,, \tag{3}$$

that is, the work of the gas per cycle is equal to the difference between the values of the supplied and removed heat during the cycle. The efficiency of the cycle is characterized by the thermal efficiency, which is the ratio of the work L_{ts} to the supplied heat:

$$\eta_T = \frac{L_{ts}}{Q_1}\,. \tag{4}$$

The value of Q_1 determines the spent effect, it is proportional to the amount of fuel burned in the engine, the work L_{ts} is a useful effect.

Thus, other things being equal, the more η_T, the more, with the same fuel consumption, work can be obtained during the cycle. As you can see, the piston of a heat engine is like a moving wall of a vessel (cylinder), in which the working fluid (fuel mixture) is enclosed directly, without any intermediate processes, is converted into the work of moving the piston, positive (consumed) during expansion and negative (supplied) during compressions.

Let us recall that in the Gornsby diesel engine [2] liquid fuel (oil) was injected into the cylinders by a jet onto a hot surface and served to evaporate the fuel and of air in the cylinder, due to this, the processes of fuel evaporation and combustion of the mixture, unlike the Trinkler engine, took place faster, as a result of which the pressure in the cylinder increased rapidly, and then when the piston moves to the bottom dead center (BDC), the pressure in the cylinder practically does not drop [11,12,13].

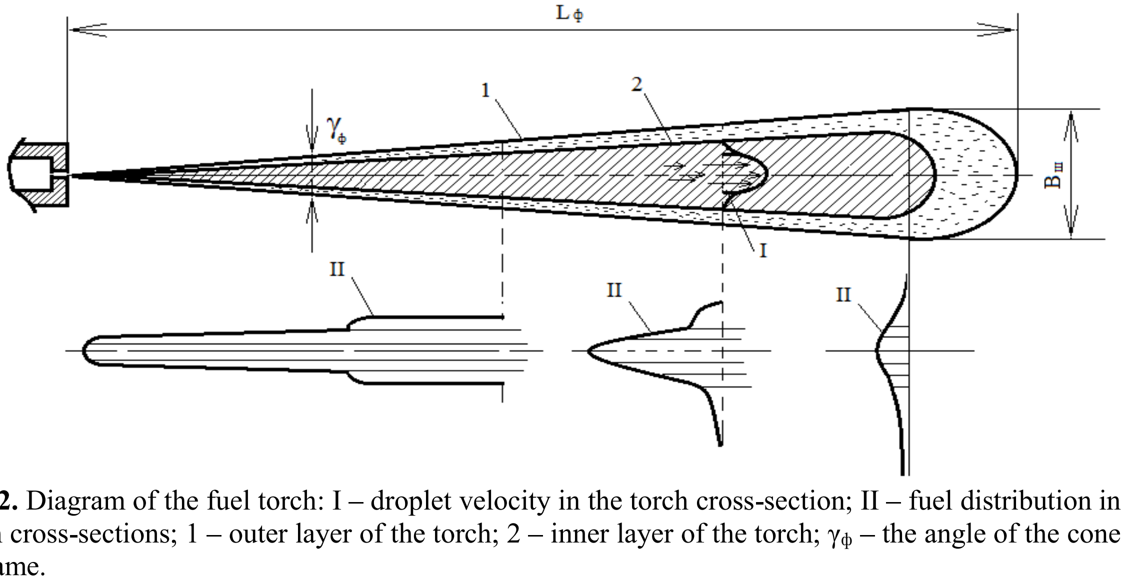

Figure. 2. Diagram of the fuel torch: I – droplet velocity in the torch cross-section; II – fuel distribution in the torch cross-sections; 1 – outer layer of the torch; 2 – inner layer of the torch; $\gamma_ф$ – the angle of the cone of the flame.

As for R. Diesel, the grounds for challenging his patents are also controversial. It is known that R. Diesel claimed the following method: first, the air is compressed to such a pressure that the temperature rising from the compression exceeds the ignition temperature of the fuel. And then the fuel is slowly injected, and it is stipulated that the inlet is made when the piston moves to the BDC. The law of admission the fuel is coordinated with the movement of the piston so as to ensure a constant pressure during fuel combustion.

In recent years, various designs of nozzles have been created aimed at increasing the efficiency of heat engines [14].

One of the main disadvantages of the atomizers of these nozzles of the design is the difficulty of obtaining a homogeneous homogeneous fuel mixture in the vortex chamber of the engine. A cone-shaped torch, having a large fuel capacity, $L_ф$ length and $B_ф$ width, is difficult to obtain a homogeneous fuel mixture of intensity due to crushing, decreasing the torch intensity and self-ignition process

The use of heat in an engine is characterized by efficiency, and its economy is characterized by the amount of heat consumed per unit of useful power.

In accordance with the second law of thermodynamics for a theoretical cycle performed by 1 kg of the working fluid, the thermal efficiency is:

$$\eta_t = 1 - \frac{|q_2|}{q_1} = \frac{q_1 - |q_2|}{q_1} = \frac{L_r}{q_1}, \tag{5}$$

here: $|q_2|$ is the absolute value of the amount of heat in a cycle for a cold source, J/kg; q_1 is the amount of heat supplied per cycle, J/kg; L_r is the work done by 1 kg of the working fluid per cycle, J/kg; $L_r = q_1 - |q_2|$.

$$\eta_1 = \frac{q_1 - |q_2|}{q_1} = \frac{AL}{q_1}, \tag{6}$$

here: q_1 and q_2 are expressed in kcal / kg; l - c. kg/m; A – thermal equivalent in kcal/(kg·m).

The presence of losses associated with the irreversibility of the cycle processes leads to a decrease in the cycle work:

$$L_{n(rev)} > L_{n(irrev)}. \tag{7}$$

These losses are taken into account by the so-called internal relative cycle efficiency:

$$\eta_{from} = \frac{L_{n(irrev)}}{L_{n(rev)}}. \tag{8}$$

The generated energy in cycles is not all transferred by the heat engine to the consumer, part of it is spent on friction in the engine units and other losses. In addition, not all of the heat obtained during fuel combustion reaches the working fluid - some of it is lost in the form of heat losses. All these losses are taken into account by the effective efficiency of individual elements of the engine $\eta_{ет}$.

To increase the fuel efficiency of diesel engines, we propose to additionally equip the nozzles with sprays with replaceable mesh turbulators, as shown in Figure 3.

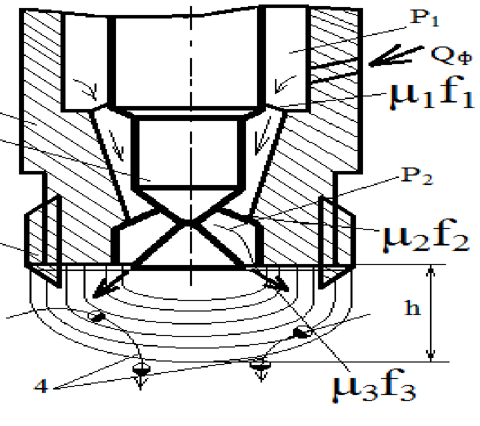

Figure. 3. Construction of the atomizer with the mesh turbulator: 1-body; 2-nozzle hole; 3-needle (pin); 4-mesh turbulator.

It consists of a body 1, a nozzle 2, a needle 3, a replaceable turbulator 4. The fuel mixture is thrown out through the nozzle hole 2 of the sprayer at a speed W towards the mesh turbulator installed at a distance of 20-25 mm relative to the nozzle. The highly heated circular cylinders of the mesh turbulizer ensure the turbulence of the fuel flame and, as a result of intensive crushing and evaporation of the supplied fuel mixture, without the formation of toxic emissions [14,15].

4. Conclusions

- In diesel engines, the expansion cycle takes place under the conditions of a long-range and wide fuel torch, therefore, the self-ignition process occurs with a large toxic release.
- The generated energy due to the cycle in diesel engines is not all transferred to the consumer, part of the work is spent on friction in the engine units, and part of the heat received during fuel combustion is spent in the form of heat losses, the thermal efficiency of a diesel engine is generally determined by the effective efficiency of the engine.
- The proposed atomizer, due to turbulization of the fuel torch at short distances (20-25 mm), creates optimal conditions for the formation of a homogeneous mixture with a complete supplied fuel mixture without toxic emissions.

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