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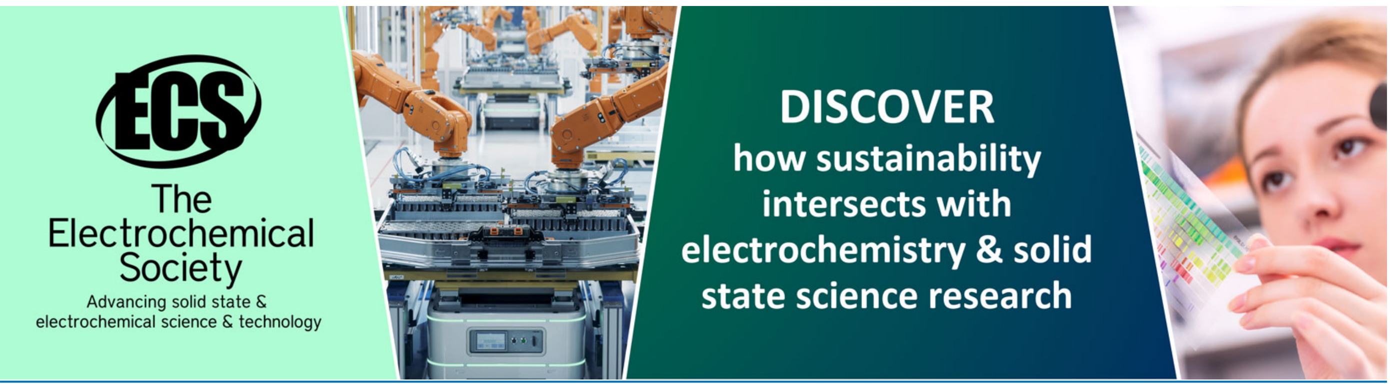

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# Control of mixture formation in the piston internal combustion engine with phased fuel injection

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**Abstract.** The two-phase flow of a fresh charge in the inlet bodies of a commercially available engine accompanied by a heat exchange is investigated. The design changes of the commercially produced internal combustion engine, providing the improvement of the quality of mixture formation and allowing to increase its compression ratio with the subsequent increase of thermal efficiency, are developed, investigated and justified.

## 1. Introduction
For more than a century there has been a constant and systematic increase in the energy and economic performance of internal combustion piston engines (PICE). During this time, high performance of the internal combustion engine was achieved by improving the engine frame, crank and gas distribution mechanisms (CR and GDM) and gas exchange subsystem. To date, the design of modern ICE reached a certain, very high level. Therefore, the problem of further increase of their thermal efficiency is a complex task that requires a large number of complex theoretical and experimental developments aimed at improving the working processes of ICE due to the choice of rational design solutions [1, 2, 3, 4, 5, 6].

## 2. Problem statement
The quality of the thermodynamic processes that make up the working cycle of the internal combustion engine is determined by a set of simultaneously operating mechanisms of the engine – CR, GDM and gas exchange subsystem. Therefore, the performance characteristics of this set of mechanisms should be coordinated with each other, and ensure the rational flow of the processes of removing exhaust gases from the cylinders, filling the cylinders with a fresh charge, mixing, combustion of the combustible mixture, expansion of the working fluid and combustion.

Traditionally, in the practice of domestic engine-building as the main characteristics of the intake its hydraulic resistance is used, exerting a decisive impact on the cyclic mass filling of the cylinders of the ICE with fresh charge. However, in PICE with external mixing, the intake bodies have a significant impact on the formation of the air-fuel mixture. The process of evaporation of the fuel sprayed in the intake is accompanied by the cost of heat for the phase transition. It is obvious that this process should be accompanied by a drop in the temperature of the gas phase and deterioration in the conditions of fuel evaporation. In the course of the study, it is necessary to obtain a quantitative assessment of the described process: to determine the proportion of the evaporated fuel and the temperature of the gas phase along the length of the intake of the PICE.

## 3. Mathematical modeling

A quasi-one-dimensional quasi-stationary model of two continuous interpenetrating media is used as a physical model in the first approximation:
*a*) three-dimensional two-phase flow of the fresh charge is reduced by the conditional straightening of the channel to a quasi-one-dimensional;
*b* the unsteady movement of a fresh charge is represented as a steady-state flow with a conditional average speed proportional to the average speed of the piston in the cylinder of the PICE;
*c*) fuel droplets are considered as a continuous medium with its own imaginary density equal to the ratio of the droplet mass to the volume in which the fresh charge is charged.

The mathematical model of the considered flow in the first approximation is based on the dependencies for the open thermodynamic system using the method of control volumes, as shown in figure 1.

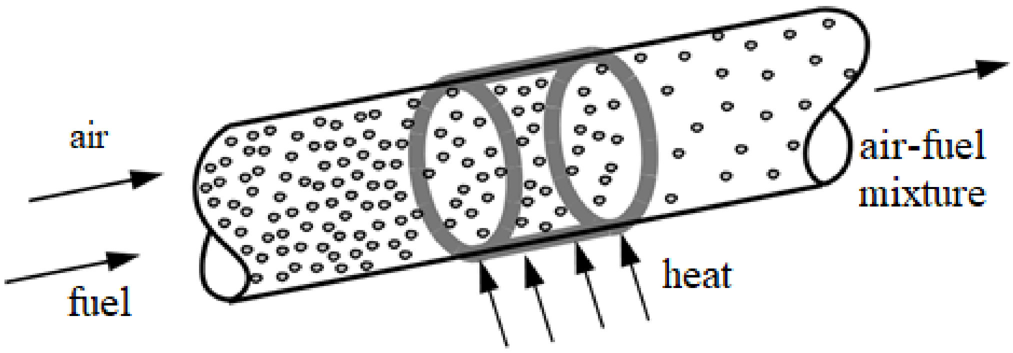


**Figure 1**. Control volume.

When modeling the following is taken into account:
*a*) interphase heat flow inside the control volume;
*b*) heat flow through the walls of the inlet channel;
*c*) phase mass flow through the control boundary.

The heat flow between the fresh charge and the surface of the internal combustion engine intake, as well as the interphase heat flow inside the control volume are determined by the Newton-Richman equation [7, 8, 9]:

$$q_{1-2} = \alpha \cdot (T_1 - T_2) \cdot F_{\kappa.o}.$$

The heat transfer coefficient is chosen taking into account the thermal conductivity coefficient of the gas phase, the average diameter of the fuel droplets, its fractional composition and the gas velocity. The temperature of the gas phase inside the control volume is determined from the equation of the first law of thermodynamics. The share of the evaporated fuel is found from the evaporation process of the conditional average drop taking into account the number of drops in the control volume.

For the numerical experiment, a program compiled for an IBM-compatible personal computer in the C++ programming language was used.

The calculations were performed taking into account different speed and load modes of the PICE. In this case, the influence of many different factors on the evaporation process was simulated: the size of fuel droplets, the flow rate, the surface area of the channel in the intake bodies, the fractional composition of the fuel, the temperature of the channel surface in the intake bodies.

In the course of this study, the necessity and possibility of intensification of the fuel evaporation process in the intake of a serial engine are shown.

## 4. **Experimental modeling**

Thermometry of the four-cylinder in-line internal combustion engine with a working volume of 2,445 liters was carried out according to the scheme shown in figure 2. The convergence of the calculated and experimental data was sufficient.

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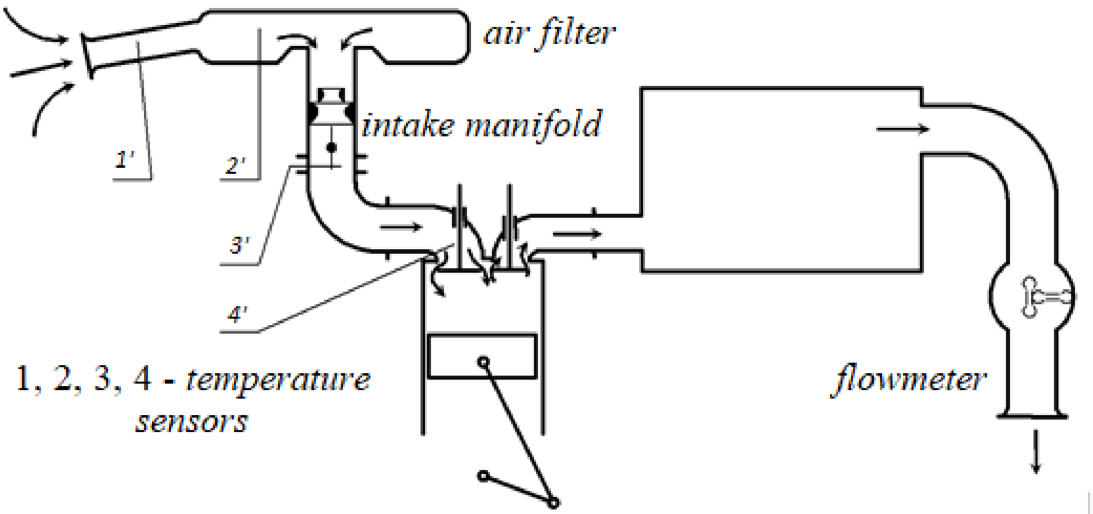


**Figure 2**. The scheme of installation

Figure 3 shows the experimental and calculated dependences of the temperature of the gas phase of the two-phase flow in the inlet of the serial PICE with a working volume of 2,445 liters at full and partial load modes. From figure 3 it follows that the commercially available four-cylinder inline engine with a working volume of 2,445 liters with external mixing is not provided with rational conditions of evaporation of fuel in the intake. The used gas heating, shown in figure 4, does not allow compensating the heat costs for fuel evaporation and the temperature of the gas phase in the rated mode in the area of the inlet falls below 0 degrees Celsius. As a constructive solution that provides intensification of evaporation of the sprayed fuel, it is proposed to fin the walls of the intake and of uneven water heating along their entire length, as shown in figure 4. Since the design changes are performed from the outside of the gas channel, they do not affect the hydraulic characteristics of the intake bodies, selected for special reasons.

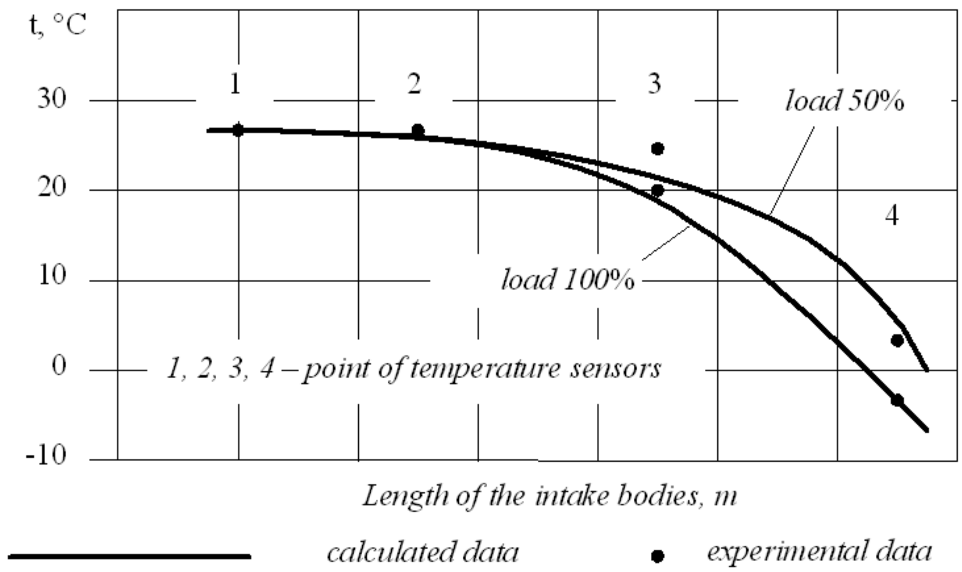


**Figure 3**. The temperature of the two-phase flow in the inlet serial four-cylinder in-line internal combustion engine with a working volume of 2,445 liters

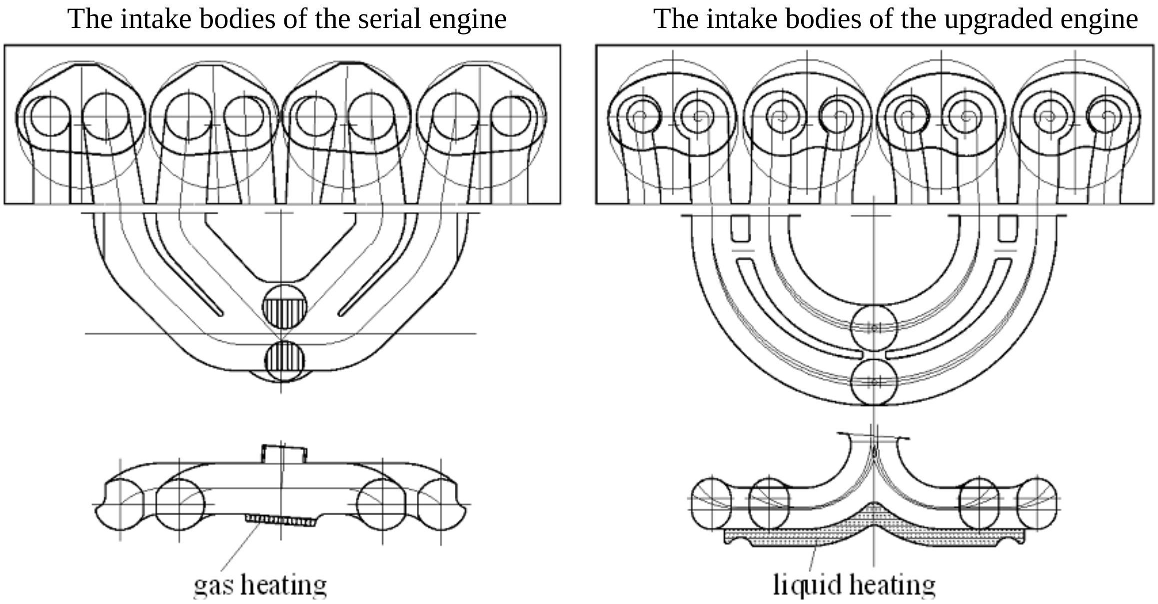


**Figure 4**. Constructive change

## 5. Conclusion.

The performed design changes allowed to significantly improve the technical and economic performance of the engine under consideration, figure 5, and prepared the ground for increasing its compression ratio in the future, followed by an increase in thermal efficiency.

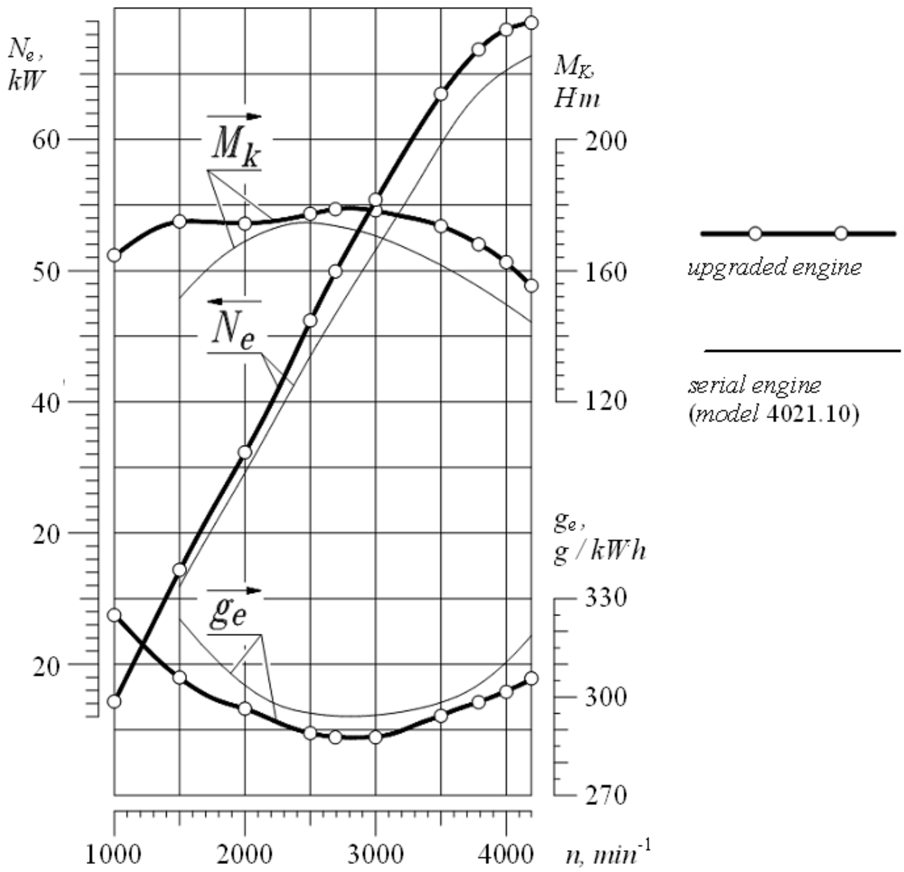


**Figure** 5. Engine performance

One of the results of this work is the conclusion about the fundamental admissibility of using the chosen approach for modeling the processes of heat transfer in the piston engine intake. Selection of design parameters was carried out on the basis of a computational experiment so as to provide the supply of the amount of heat required for the evaporation of the rational fraction of fuel [10].

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