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MODEL AND EXPERIMENTAL RESEARCH OF THE PRESSURE COOLING SYSTEM FOR THE INTERNAL COMBUSTION ENGINE

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Abstract

In this paper, the existing methods to reduce the heat discharged by the engine were characterized and the efficiency of combustion piston engine was analysed, where it was shown the need and the potential for reducing the heat dissipated directly or indirectly to the surrounding atmosphere. The model of the engine cooling system for high coolant temperature developed through AMESim software was presented in this paper. The model of the cooling system was made based on test stand solution designed and built using original components and units diesel engine 4CT90. The simulation researches results of temperature course and pressure course were shown. In this paper was demonstrated that it is possible to maintain the assumed constant pressure of 0.3 MPa in the system and obtain it at the elevated liquid temperature leading to an increase in overall engine efficiency. These researches were carried out also on the experimental model stand, which confirmed the results obtained in simulation researches. Then 4CT90 engine test stand was described, where speed characteristics as a function of torque, power and specific fuel consumption and load characteristics as a function of the fractions of hydrocarbons, carbon monoxide and carbon dioxide, as well as specific and hourly fuel consumption were performed. Comparison of parameters and efficiency assessment of engine interacts with a traditional and pressure cooling system. The efficiency of the engine with the pressure and a traditional cooling system was evaluated.

Keywords: *combustion engines, cooling system, energy balance, engine efficiency, environmental protection*

1. Introduction

One way to improve the efficiency of the currently used internal combustion engines is a more precise control of individual engine units, reducing losses of the heat lost to the cooling and heat escaping from the exhaust gases (turbine drive air compressor) [1].

To date known methods of heat loses reducing in cooling and irradiating was applying the ceramic coating of the combustion chamber walls, called “adiabatization”. So far, this way is expensive, and used in piston engines are unreliable and inefficient [3, 11].

Efficiency of the liquid cooling systems as an ensemble comprehensive energy management in vehicles, can be increased by the use of electronic controls, as well as the less intense cooling of the engine and thus reduce heat losses. For systems that use a coolant containing water, increasing the boiling point of the coolant requires increasing pressure in the cooling system.

Preliminary studies such a system suggest the possibility of increasing the overall efficiency and reduce the amount of toxic components in the exhaust gas at low engine load, when the temperature of the engine exhaust with the classic system is too low for efficient operation of the catalytic converter [2, 4].

2. The efficiency of an internal combustion engine

Thermal efficiency is the ratio of heat transformed into indicated expansion L_i in the real circuit operation to heat Q_d supplied to the system at the circuit [1]:

$$\eta_c = \frac{L_i}{Q_d}, \tag{1}$$

L_i – indicated expansion obtained from the real circulation of heat in the cylinder,
Q_d – the amount of heat obtained from combustion of fuel during one system circuit.

Energy supplied to the piston engine through fuel and air is only partly converted to useful engine work [6-8]. An analysis of the heat balance of various engine solutions show that effective work can be directly converted to about 25%-45% of the supplied energy (Fig. 1). The remaining resources of energy are dissipated directly or indirectly into the surrounding atmosphere, which is caused by thermodynamic efficiency and the need to reduce the temperature of the materials of the engine components [5, 7]. These results in a large number of different streams of heat, which flows inside and outside the engine and therefore is often presented in the form of simplified or detailed Sankey's charts [4, 5]. An example of the measured heat flow for the engine 4CT90 as a function of its speed is shown in Fig. 1 [4].

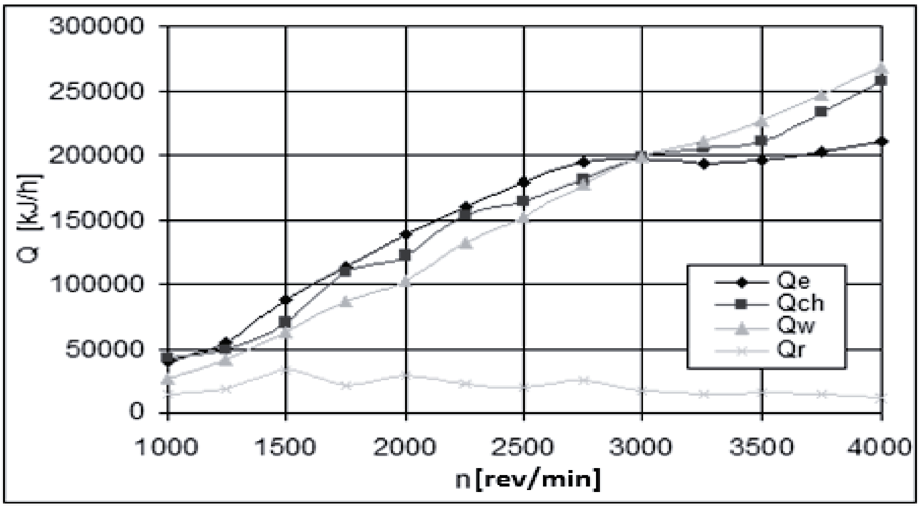

Fig. 1. Comparison of heat engine 4CT90 streams derived from the fuel combustion [4]

Since even 35% of heat can be lost by the same cooling system, studies have been opened on how to improve the existing cooling system by introducing effective thermal management in the vehicles to increase total engine efficiency. One of the ways to do this is to use an electronic work group, as well as less intense cooling of the engine resulting in an increase in coolant temperature and thus reducing heat loss.

Therefore, research in this direction is continued, so that it will be possible to increase the efficiency and reduce the toxic components. This is particularly important, because now it is working on the introduction of alternative propulsion, which can slowly replace the transport vehicles drive of combustion engine [10].

3. Model research of the pressure cooling system

3.1. The model test stand of the internal combustion engine cooling system

Scheme of the test stand expressed through flowcharts was developed in AMESim software. It also performed calculations and simulations showing the courses of pressure, temperature and flow water pump for the assumed pressure parameters (Fig. 2) [12].

Model of the cooling system was made based on test stand solution designed and built using original components and units diesel engine 4CT90. The segments representing the piston internal-combustion engine was changed in this model accord the laboratory test stand. A block of piston-crank system was eliminated, and instead of this, elements were used block of the electric heaters of various powers as a model of heat transferring through the walls and exchanging the heat to the cooling liquid [9].

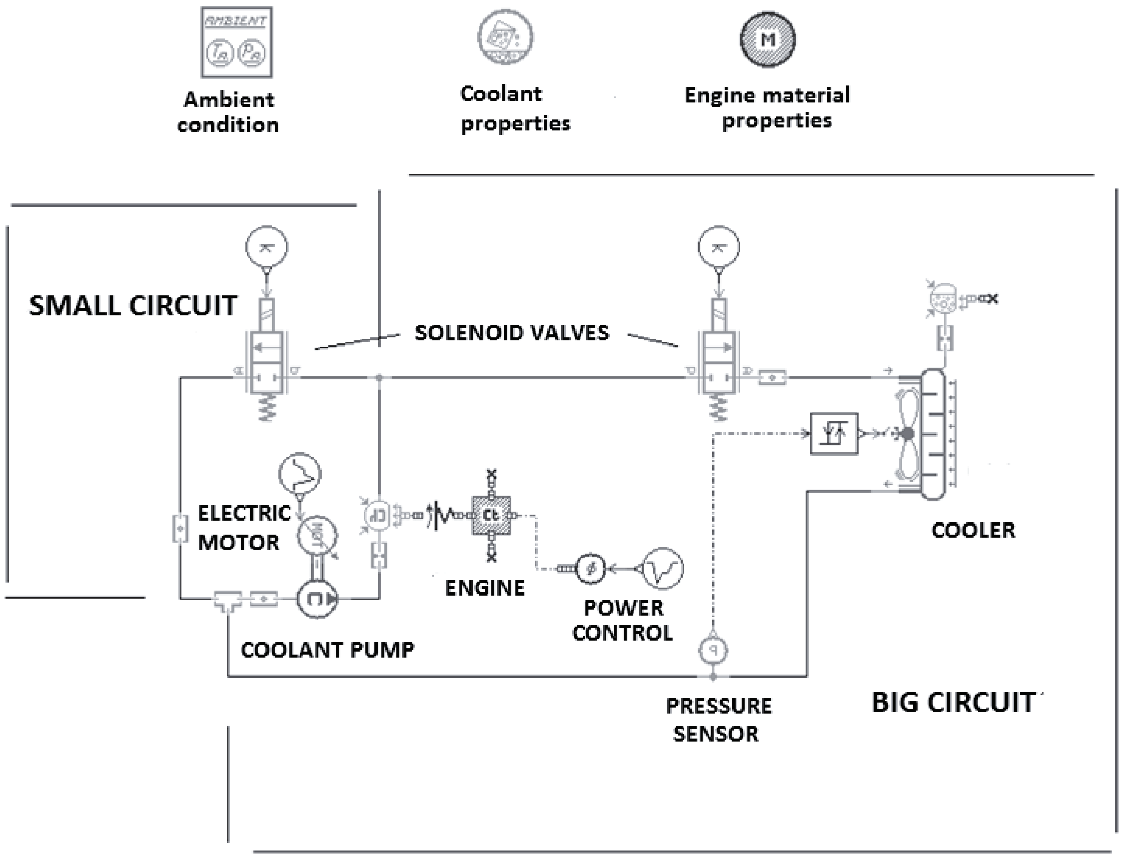

Fig. 2. The scheme of the cooling system model test stand with AMESim software

3.2. The results of the cooling system model

Calculations and simulations for the overpressure of 0.3 MPa at 90% and 85% filling of the liquid, where the volume of the cooling system is 11 dm^3. Fig. 3 shows the pressure and temperature courses for the above values.

During the simulation, at the overpressure of 0.3 MPa and 90% filling of the liquid, pressure was maintained in the range 0.28-0.32 MPa. To achieve the assumed overpressure, around 23 minutes followed its mild growth, but this time the goal was to keep the overpressure of 0.3 MPa.

The overpressure course was characterized by uniformity and could be maintained at a stable level. Temperature courses at the output of the engine block and the entrance to the radiator after achieving the assumed overpressure were formed at 115°C at 90% filling of the cooling system in the coolant. The temperature at the outlet of the radiator was in the range 100°C-105°C.

In these simulations was not considered a small circuit and immediately cooling system was working on a circuit without pump liquid. The pump was turned on only after reaching the assumed overpressure to speed up the engine warming. However, the cooling intensity was controlled on and off the fans. Operation of the engine in a small circuit causes sudden pressure drop and relatively high temperature when switching the system to a large circuit in order to keep the pressure as constant as possible.

4. Experimental research of the pressure cooling system

4.1. Dynamometric test stand with the cooling system pressure

The object of the research was the turbocharged diesel engine 4CT90. It is a four-cylinder engine with indirect injection into swirl chamber made in the cylinder head (Fig. 4).

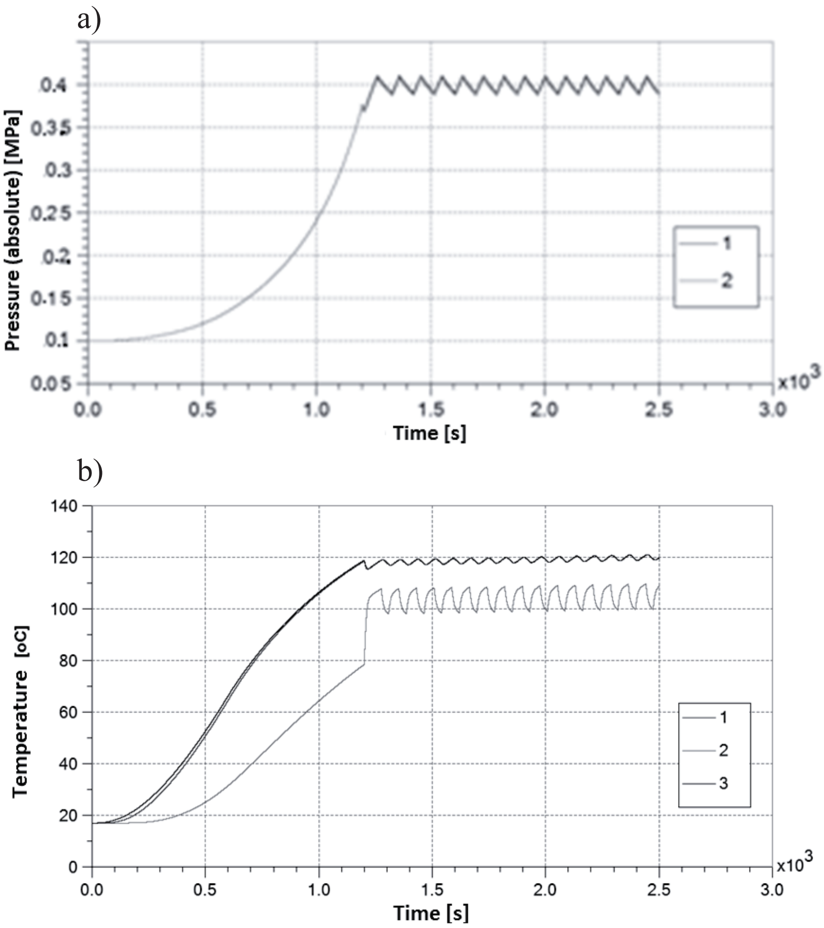

Fig. 3. Course of temperature coolant in the cooling system during the measurements at a overpressure of 0.3 MPa and 90% filling of the liquid: a) pressure: 1 – small circuit, 2 – large circuit, b) temperature: 1 – liquid inlet to the radiator, 2 – liquid outlet of the radiator, 3 – liquid outlet of the cylinder block

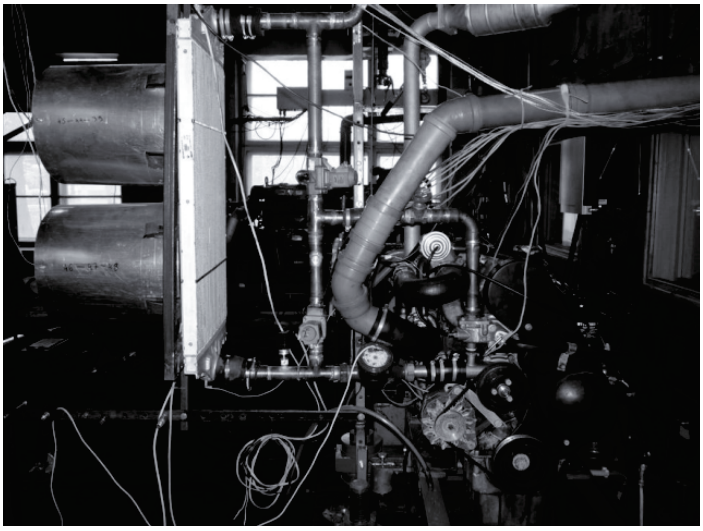

Fig. 4. 4CT90 engine on the dynamometer with a pressurized cooling system

4.2. Comparison of parameters and efficiency assessment of engine operation with a traditional and pressure cooling system

Research, under steady state operating conditions of the engine, was conducted and included the designation speed and load characteristics of standard and pressure cooling system.

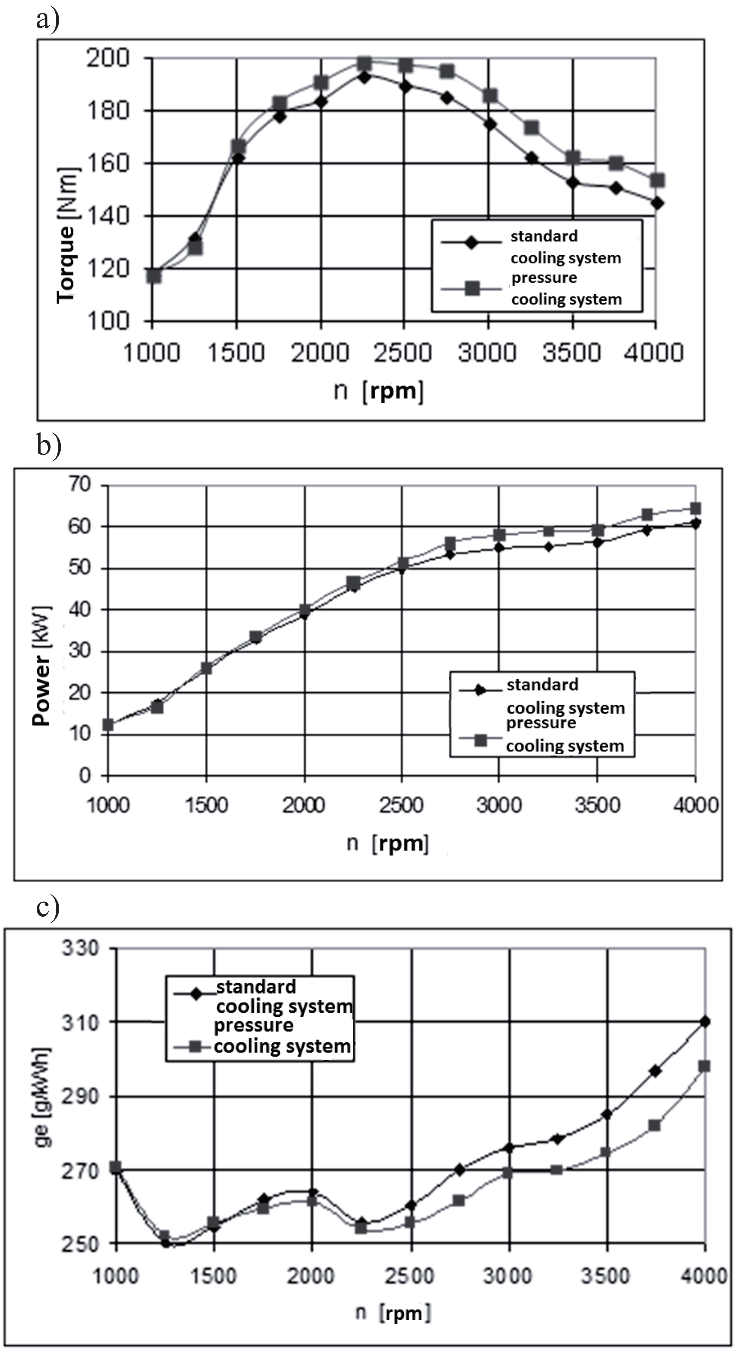

Fig. 5. 4CT90 engine speed characteristics with standard and pressure cooling system: a – torque, b – power, c – specific fuel consumption

The waveform of the maximum torque function of rotational speed can be observed that the application of the pressure cooling system and engine temperature increases significantly impact the growth of the maximum torque at high speed. Results from them that over 3500 rev/min. was followed by approximately 8% increase in torque compared to standard cooling system (Fig. 5a), which represents approximately 10 Nm. It should be noted that, at low engine speed torque showed slight changes. When it comes to power, it runs at low speed are very close to each other, until about 2500 rev/min. is visible slight increase in the pressure of the cooling system (Fig. 5b).

It is also important that the torque increase was accompanied by a similar fuel consumption, reflecting the improving economy of the engine, because the specific fuel consumption decreased about 7-8% at speeds above 3500 rev/min. Fuel consumption by the engine running at low speed, i.e. circa 1000-1500 rev/min was similar for both cooling systems (Fig. 5c).

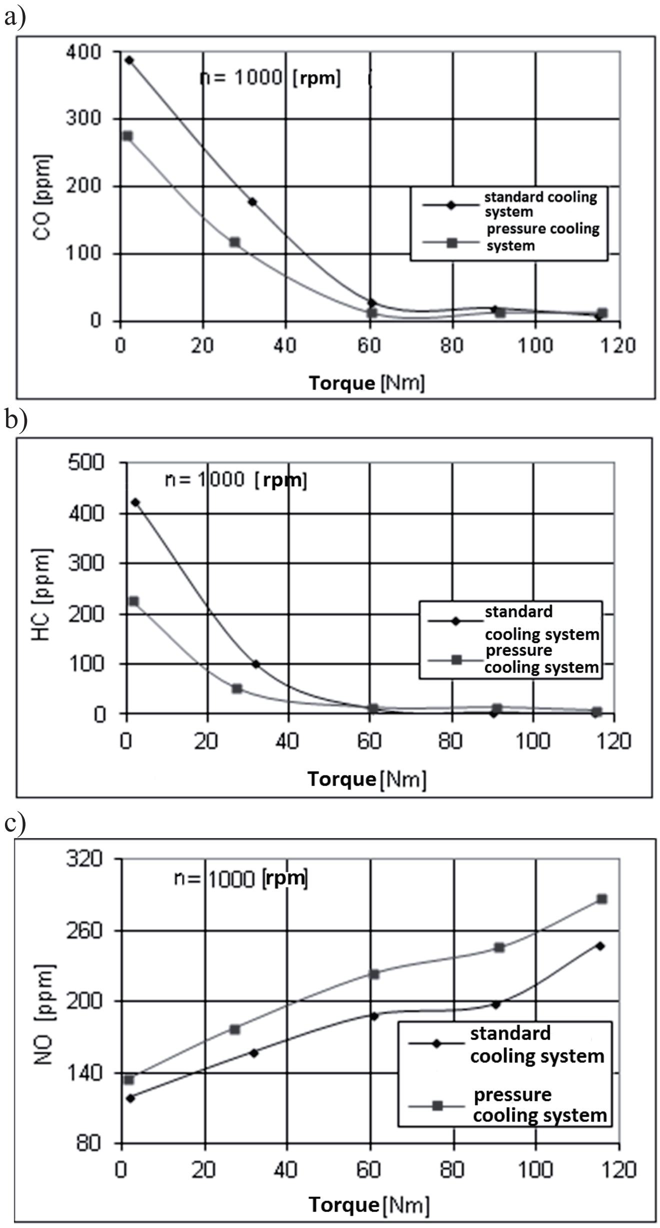

Fig. 6. 4CT90 engine load characteristics with standard and pressure cooling system at n = 1000 rev/min: a – carbon monoxide share, b – hydrocarbons share, c – nitrogen oxides share

Load characteristics show that the share of carbon monoxide and hydrocarbons at low load decreased by 25-50%. Especially significant changes occur at low engine speed, because under these conditions, the shares of these exhaust gas components are greatest. The shares are decreasing with increasing load and the load reaches 60-90 Nm followed stabilization at a level comparable to the two pressure systems (Fig. 6a, 6b). Shares of nitrogen oxides in the exhaust gas for an engine operating with a pressure system are significantly larger, which is independent of load and engine speed. This is an increase of 40-60 ppm, with the highest in the upper range the engine load (Fig. 6c).

Fuel consumption as a function of engine load at a speed of just over 2000 rev/min was significantly lower, because then you will see reduced hourly fuel consumption, resulting in a reduction in unit consumption by a few percent (Fig. 7a, 7b).

The shares of carbon dioxide are similar for both the standard and pressure cooling system in the range of small and medium load and low speed. At a higher speed (3000 r/min) and high load share of this component was lower, due to lower fuel consumption and higher consumption of air (Fig. 7c).

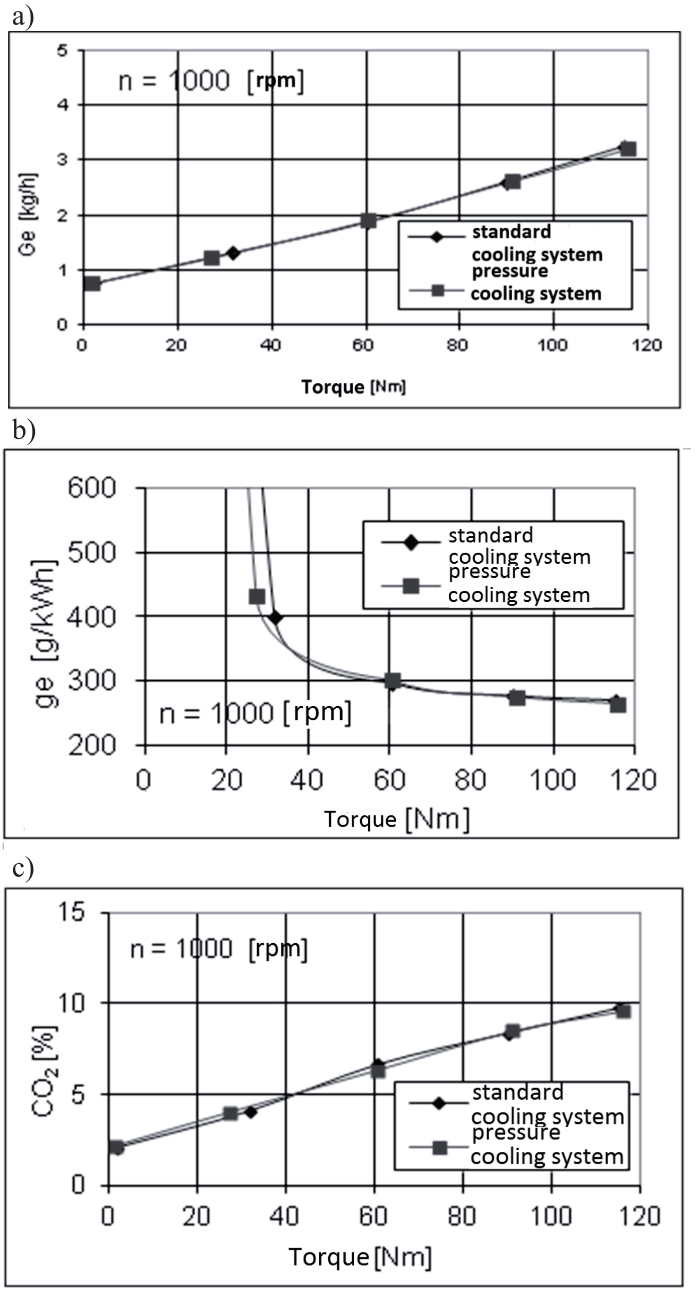

Fig. 7. 4CT90 engine load characteristics with standard and pressure cooling system at n = 1000 rev/min: a – hourly fuel consumption, b – specific fuel consumption*, c – the shares of carbon dioxide*

Fuel consumption as a function of engine load at a speed of just over 2000 rev/min was significantly lower, because then you will see reduced hourly fuel consumption, resulting in a reduction in unit consumption by a few percent (Fig. 7a, 7b).

The shares of carbon dioxide are similar for both the standard and pressure cooling system in the range of small and medium load and low speed. At a higher speed (3000 r/min) and high load share of this component was lower, due to lower fuel consumption and higher consumption of air (Fig. 7c).

4. Conclusions

As a result of simulations, it was found that it is possible to maintain almost constant temperature courses in the cylinder block and head and the input and output of the engine in this range of research. This means that the system can be controlled so that it was possible to maintain the pressure and temperature and at a given level of acceptable limits.

1. The pressure cooling system ensured the stable maintenance of the coolant temperature of the object over a long period of time. Controlled pressure increase also allows an increase in the boiling point of the liquid, which further increased the temperature of the liquid.
2. Experimental research conducted on the dynamometer showed correct operation of the system and satisfactory agreement of results with those obtained on the basis of simulations. For a long time it was possible to maintain the pressure in the system for a given level of test cooling system to work properly and flawlessly, keeping the liquid temperature is high enough walking in the engine.
3. Application of pressure cooling system and the coolant temperature increasing caused the decrease in carbon monoxide and hydrocarbons at low engine loads and especially at low speeds thereof and therefore outside the scope of the catalytic after-burner operation. Preference was also lower fuel consumption, especially at high speed. Larger were, however, shares of nitrogen oxides in the exhaust gas.

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