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Application of the cooling system with elevated temperature of coolant for the internal combustion engine

Abstract: The paper presents an analysis of the heat balance combustion engine, which was shown that it is possible to increase its efficiency by reducing cooling losses, such as raising the temperature of the coolant. The presented research results show that it was possible to maintain the pressure in the system, and thus the temperature of the liquid on the assumed level for a longer period by changing the intensity of cooling. The increase of coolant temperature to 120°C had an effect an increase of economy of operation and an increase in the maximum engine torque and reduced the share of carbon monoxide and hydrocarbons at low load and low engine speed of its, and therefore outside the scope of the catalytic converter. Increased share of nitrogen oxides, which requires the use of additional and effectively reducing the nitrogen oxides.

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

Zastosowanie układu chłodzenia o podwyższonej temperaturze płynu chłodzącego w tłokowym silniku spalinowym

Streszczenie: W referacie przedstawiono analizę bilansu cieplnego tłokowego silnika spalinowego, w której wykazano, że istnieje możliwość zwiększenia jego sprawności poprzez zmniejszenie strat chłodzenia, np. podwyższajac temperaturę płynu chłodzącego. Przedstawiono wyniki badań, z których wynika, że możliwe było utrzymanie nadciśnienia w układzie, a tym samym temperatury cieczy o założonej wartości przez dłuższy okres zmieniając intensywność chłodzenia. Podwyższenie temperatury cieczy chłodzącej do 120^{o}C wpłynęło na zwiększenie sprawności silnika oraz wzrost maksymalnego momentu obrotowego silnika oraz spowodowało zmniejszenie udziałów tlenku węgla i węglowodorów w spalinach podczas pracy z małym obciążeniem i małą prędkością obrotową. Zwiększyły się udziały tlenków azotu, co wymaga zastosowania dodatkowego i efektywnego układu redukującego tlenki azotu.

Słowa kluczowe: *silniki spalinowe, układ chłodzenia, bilans energii, sprawność ogólna*

1. Introduction

Today more and more important matter is the rational use of energy, especially from non-renewable resources (eg, petroleum) because in the world there is a limited quantity. Due to the depletion of non-renewable resources, the global economy, especially the automotive industry and energy, stand before number of threats, among others increase in fuel prices and energy. It is therefore necessary to look for alternative energy sources and saving of these resources, which are still there. Consequently, commonly used for vehicle propulsion internal combustion engines are continuously improved in terms of increasing their efficiency, as well as new powertrain solutions are developed, which will replace the current engines.

Efficiency of liquid cooling systems as a comprehensive assembly of energy management in vehicles can be improved by the electronic control unit work, the less intense cooling of the engine, or by increasing the temperature of the coolant. For systems that use cooling liquid containing water, increasing the boiling point of the coolant requires pressure increase in the cooling system. Preliminary research indicate the possibility of increasing the overall efficiency and reduce the amount of toxic components in the exhaust at low engine load when the temperature of exhaust gas of the engine with classic system is too low for effective operation of the catalytic converter [2, 4].

2. The efficiency of the internal combustion engine

Heat supplied to the piston engine through fuel and air is only partly converted to useful engine work. 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. 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.

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 [5, 3].

It follows that one way to improve the efficiency of the piston internal combustion engine is to reduce the loss of cooling, which greatly affect the efficiency of the engine [1]. Parameter characterizing the efficiency of conversion of the energy supplied to the engine to work a useful is the effective efficiency of the engine:

$$\eta_e = \frac{\dot{Q}_e}{\dot{Q}_d} \qquad (1)$$

$\dot{Q}_e$ – heat stream transformed into useful work,
$\dot{Q}_d$ – heat stream obtained from combustion of the fuel in one.

During cooling, heat is transferred from the gas in the combustion chamber to the surrounding wall, conducted through the cylinder wall and head and absorbed by the liquid:

$$\dot{Q}_{ch} = k \cdot F(\alpha) \cdot (T_g - T_{ch}) \cdot i \qquad (2)$$

where: k [W/m^2 K] – heat transfer coefficient from the gas filling the combustion chamber to the coolant,
F(α) [m^2] – average area of the combustion chamber of a cylinder,
i – number of cylinders,
T_g [K] – temperature of the cylinder wall and head,
T_{ch} [K] – average temperature of the coolant (water).

The engine cycle parameters show that effective engine efficiency can be increased by increasing the heat converted into useful work $\dot{Q}_e$.

This can be done by, for example, reducing heat loss (loss of cooling). Cooling loss reduction can be achieved by:
a) reducing the intensity of the engine cooling,
b) increasing the temperature and pressure of the coolant, using the pressure cooling system.

3. The test stand of the pressure cooling system

Operation of the pressure cooling system was tested first as a model stand, and then the engine dynamometer stand.

The model test stand was built using original elements and units of the diesel engine 4CT90 WSW "ANDORIA" SA. This is a four-cylinder engine with indirect fuel injection into the vortex chamber made in the cylinder head.

The model stand was made using the following units: the cylinder block with heaters, cylinder head, water pump - driven by an independent electric motor and radiator fans. To drive the water pump, the electric motor was used with programmable inverter.
Scheme of the test stand was shown in Fig. 1.

The basic component of the test stand and heat source absorbed by the cooling system was the cylinder block with the engine head 4CT90. In each cylinder, three cylindrical heating elements of different electrical power were placed. The heating elements adhered closely to the walls of the engine cylinders.

The cooling liquid was pumped through the engine 4CT90 by water pump driven by an electric motor through belt drive with belt tensioner. The engine was controlled by inverter with variable speed control.

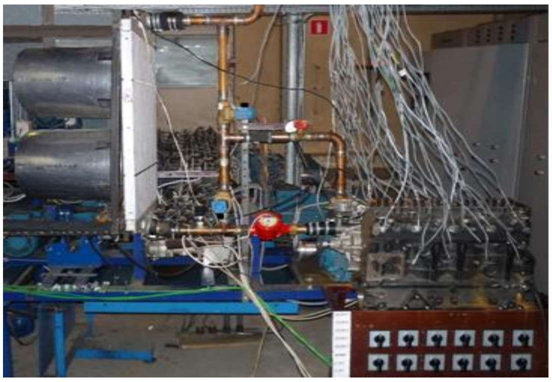


Fig. 1. The model stand with the pressure cooling system
Rys. 1. Stanowisko modelowe z ciśnieniowym układem chłodzenia

Fans, placed on the radiator, were supplied with 12 V voltage car charger Leader 400, the charging current 30 A. This allowed increasing fan speed, which resulted in the possibility of control the intensity of cooling.

As the coolant radiator was used the Renault G9T engine intercooler taken from commercial vehicle. Currently used radiators are made of aluminium and plastic reservoirs and do not have adequate resistance to the increased pressure of the coolant. For this reason charge air cooler was used to research, which is entirely made of steel, and all of its components are connected by welding and resistant to increased pressure.

In the cooling system, were used three Danfoss solenoid valves type EV250B instead of the thermostat and electronic manometers because the primary control parameter in the system was the pressure and the temperature was output parameter.

Coolant flow system was made of standard tubes and copper fittings combined with a cold solder. This provided sufficient integrity and robustness of the system and also easier formation of channel and perform connections to the measuring devices and sensors.

On the engine dynamometer stand were conducted tests to experimental verification of developed cooling systems solutions throughout the speed range. The object of the research was complete turbocharged diesel engine 4CT90 (in research on the model stand was only used the engine block). View of the engine on the dynamometer stand was shown in Fig. 2.

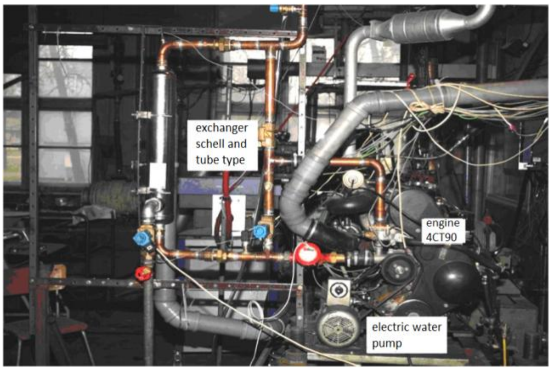


Fig. 2. 4CT90 engine on the dynamometer stand with a pressure cooling system of shell and tube heat exchanger

Rys. 2. Silnik 4CT90 na stanowisku dynamometrycznym z ciśnieniowym układem chłodzenia z wymiennikiem płaszczowo-rurowym

Radiator coolant that was used as a model stand, fully fulfil conditions of the study while the thermal efficiency was too small for the dynamometric stand and it was necessary to rebuild the cooling system. Due to the lack of suitably large steel coolers (coolers used in a higher category cars, or trucks were very large, and two parallel coolers complicated structures of the model stand) for research purposes was decided to use a heat exchanger water/water of greater heat removal capacity on the dynamometric stand which meet the same function as the water cooler/air (Fig. 2).

4. The research results

During the test measurements for the assumed pressure of 0.2 MPa and 90% filling with coolant were made. The filling level of liquid was found after preliminary tests to be optimal, because the greater amount of water in the system caused difficulties in obtaining high temperatures, while the less fluid caused problems with centrifugal pump ribs.

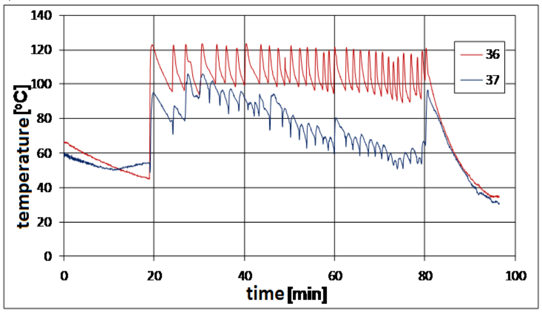
When the overpressure in the system obtained the established value, system was switched to big circuit. With a decline in overpressure of about 0,05 MPa the value included in the range 0.15÷0.2 MPa and was slightly lower than the assumed value for the average level of 0.2 MPa (Fig. 3b).

At the same time the increase in the intensity of cooling of a decline in temperature of about 25°C was occurred but it was possible to reach a maximum temperature of 120°C (Fig. 3a). Increased switching frequency was observed - large circuit switched on for about 2÷3 seconds. At the same time switching on the large circuit, the fans were turned on for about 20÷25 seconds.

As a result of the tests on the model stand, verified the operation of the cooling system of increased coolant pressure for the possibility of obtaining increased coolant temperature and the effects of system conditions on the temperature level.

It was observed that it was possible to maintain the overpressure in the system, and thus the temperature of liquid at assumed level for a long period by changing the cooling intensity by changing the flow rate of the water pump, coolant flow switching between small and big circuit of the cooling system and fans switch on mounted on the radiator.

a)



b)

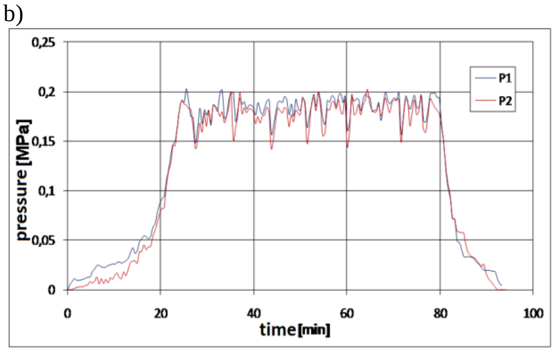


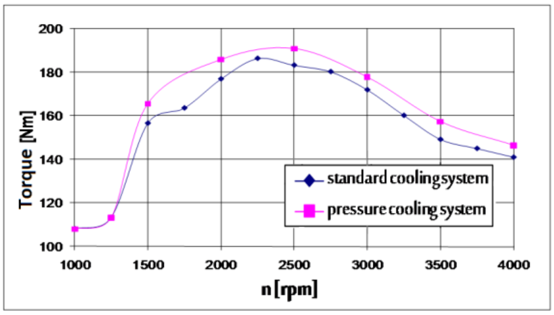
Fig. 3. Coolant courses characteristics during the measurement at the pressure of 0.2 MPa and 95% of the filling with coolant: a) temperature, b) overpressure; circuits designations: P1- small circuit, P2- big circuit; thermoelements designations: 36 – fluid flow to the radiator, 37 – liquid outflow from the radiator

Rys. 3. Przebiegi charakterystyk cieczy chłodzącej podczas pomiarów przy nadciśnieniu 0,2 MPa oraz 95% wypełnieniu układu w ciecz: a) temperatury, b) nadciśnienia; oznaczenia obiegów: P1- mały obieg, P2- duży obieg; oznaczenia termoelementów: 36 – dopływ cieczy do chłodnicy, 37 – odpływ cieczy z chłodnicy

During the test on the dynamometer stand in steady engine operating conditions the velocity characteristics were determined with the standard and pressure cooling system at a pressure of 0.3 MPa.

The courses of the maximum torque as a function of engine speed indicate that the application of the pressure cooling system and increase the temperature of the engine coolant to about 115°C, achieved at a pressure of about 0.3 MPa, resulted in a significant increase in maximum torque across the engine speed range (Fig. 4a). At engine speed of 1500 rev/min and above this speed the averaged increase of torque about 8÷10 Nm corresponds to increase of about 5÷6%. Only at low speed below 1250 rpm/min change in torque was not noticeable. At the same time the increase in torque also increased engine power by about 3÷5 kW (Fig. 4b).

a)



b)

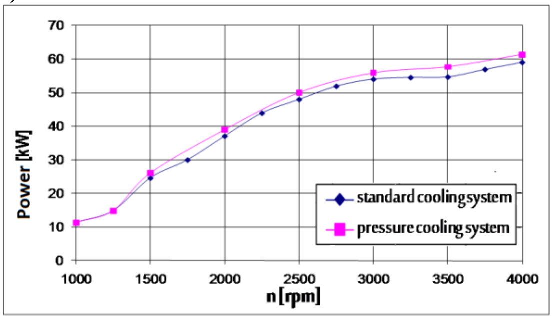


Fig. 4. The speed characteristics of the engine 4CT90 with standard and pressure cooling system: a) – torque, b) – power

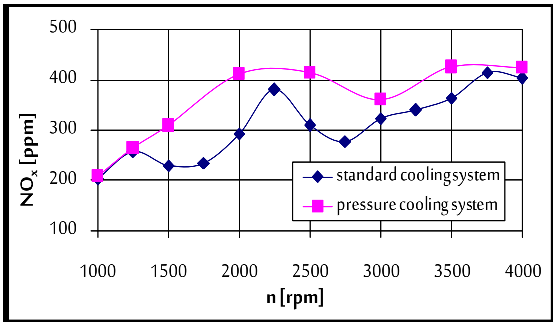
Rys. 4. Charakterystyki prędkościowe silnika 4CT90 ze standardowym i ciśnieniowym układem chłodzenia: a) – moment obrotowy, b) – moc

Torque rise took place at much lower fuel consumption (up to about 1 kg/h in the upper speed range) with comparable fuel consumption in the low engine speed. Therefore, a much improved economy of operation occurred particularly at high engine speeds above 2500 rev/min.

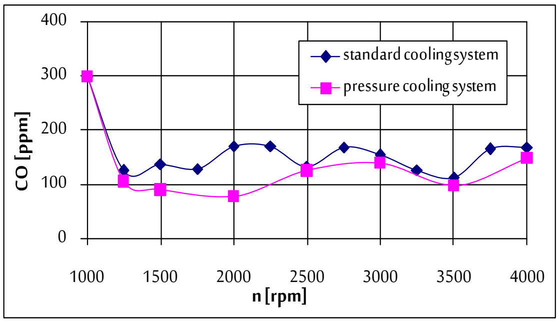
Increased temperature of the coolant results much greater share of nitrogen oxides in the exhaust gases in the entire speed range. In terms of speed 1500÷4000 rev/min is an increase of 50 to 100 ppm compared to the standard cooling system (Fig. 5a). In relation to the shares of measured for the engine with standard cooling system is an average increase of about 15÷30% at a relatively low level of shares of nitrogen oxides in the tested engine with divided combustion chamber. Due to the mixture combustion system, the shares of nitrogen oxides in the exhaust gas are much lower compared to the engine having unshared combustion chamber. However, a relative, a large increase in the share of nitrogen oxides can be justified by the increased air-filled engine (higher concentration of oxygen and higher combustion temperature). The engine worked on the exhaust gas recirculation off and in the exhaust system was not catalytic reactor reducing nitrogen oxides. Application of such a reactor is necessary for engines with cooling systems for elevated coolant temperature.

Shares of carbon monoxide are much smaller for pressure cooling system, and the largest difference occurs at low speed (2000 rev/min) and is a 92 ppm, which means a reduced shares of the gases component by almost half. Above this speed, the shares of this compound are much smaller for the pressure cooling system, although the reduction in the shares of this component is visible throughout the speed range (Fig. 5b).

a)



b)



c)

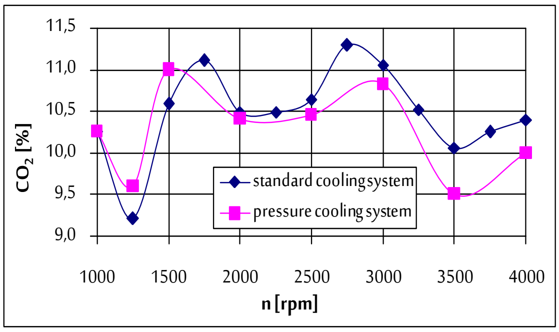


Fig. 5. The speed characteristics of the engine 4CT90 with standard and pressure cooling system: a) – nitrogen oxides shares in exhaust gases, b) – carbon monoxide shares in exhaust gases, c) – carbon dioxide shares in exhaust gases

Rys. 5. Charakterystyki prędkościowe silnika 4CT90 ze standardowym i ciśnieniowym układem chłodzenia: a) – udziały tlenków azotu w spalinach, b) - udziały tlenku węgla w spalinach, c) – udziały dwutlenku węgla

Shares of carbon dioxide for both systems are similar at low speed (Fig. 5c). Noticeable differences sustained in the remaining engine speed range, are approximately correlated with courses of hourly fuel consumption and air. In terms of speed 1500÷4000 rpm/min carbon dioxide shares are lower at pressure cooling system, and below this value are somewhat bigger.

5. Summary

The results of the tests on the model stand showed the possibility of maintaining a stable coolant temperature of the tested object in the long term by controlling the operation of the fans and the water pump rotational speed. Increase of coolant temperature to 120°C had the effect of increasing operating economy and an increase in the maximum torque, also resulted in a reduction of 30÷50% of the carbon monoxide and hydrocarbons shares in the exhaust gases at low load and low speed and therefore outside the scope of the catalytic converter. This should significantly reduce the total emissions of products of incomplete combustion during the certification test and checking. Shares of nitrogen oxides in the pressure cooling system are greater on average by 15÷30% in the limited engine load and speed, which requires the use of additional effective system reducing nitrogen oxides. Currently, the vehicles with compression-ignition engines are equipped with more efficient reactors reducing nitrogen oxides, which should result in the reduction of exhaust components, even if their shares in raw exhaust gases will rise.

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