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INTERNAL COMBUSTION ENGINE COOLING SYSTEM WITH ELEVATED COOLANT TEMPERATURE RESEARCH ON THE MODEL TEST STAND

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Abstract

In the paper a model test stand designed and built using original components of diesel engine 4CT90 is presented. The stand provides working conditions as close as possible to the exploitation conditions of the engine cooling system. This applies both to the intensity of heat inside the cylinders of the engine, the temperature uniformity along the cylinder axis, as well as variable-speed water pump. Research carried out on the model stand were aimed at checking the operation of the cooling intensity control with varying levels of filling of the cooling system and develop a control method of the cooling system before testing on the dynamometer stand. In addition, system operation at elevated cooling liquid pressure for the possibility of obtaining the elevated coolant temperature were checked. The influence of working conditions on the level of the temperature was also analysed. In this paper, the characteristics selected for two values of pressure, for 0.15 MPa and 0.2 MPa, and for two different values of the degree of filling of the cooling liquid were presented. During the warming-up and continuous heating of the cylinder and the cylinder head by electrical heaters, temperature and overpressure courses before and after the liquid radiator, temperature before the inlet and outlet of the liquid from the engine and the temperature at selected points inside the engine water jacket are designated. The results of measurements of the coolant pump flow at different speed water pump were also presented in this paper.

Keywords: *combustion engines, engine cooling, test stand, coolant temperature*

1. Introduction

Effective management of energy and low level of toxic emission are connected with energy conversion and are the most important challenges of today's civilization. Evolution of civilization as well as conditions of people's life depend on sources of energy and effective exploitation. It includes energy used for propulsion of wheeled vehicles, which are the fundamental means of transport in urban areas.

Internal combustion engines, which are characterized by low efficiency, are still commonly used for vehicle propulsion. Although research are ongoing on the introduction of alternative propulsion, because of technical difficulties, the application of them is a matter of the future. For this reason, research is still carried out on the development of internal combustion engines in the direction of increasing efficiency and reducing toxic components [3].

In the internal combustion engines, the most popular and widely used method of cooling is the cooling liquid that provides more uniform temperature around the combustion chamber than direct cooling air. However, in this first case, the maximum temperature is limited by the properties of the cooling water [1, 4].

In this paper are presented research results the liquid cooling system of the internal combustion engine, performed on the model test stand. First research of the cooling system on the model stand and only later on the dynamometer stand was performed, because a study carried on a running engine could be dangerous for the research object, which could easily leads to overheat and seize.

Damage could happen also during the test devices operating, at elevated temperature of the coolant. In addition, during research of complete engines, fuel is consumed and fumes are emitted.

Therefore, for the research and test of new concepts and solution, favourable is to design and build a test model stand, which lets avoid these problems. To the test cooling system of increased coolant temperature, the test model stand was built, where temperature changes are achieved by means of electric heaters. This test stand also enables easy to control of devices and cooling systems units and facilitates the experimental choice of control parameters of systems with high temperature [5].

2. Model test stand

The research of the cooling system of elevated coolant temperature on the model stand prepared and built using original components and units of diesel engine 4CT90. The test stand ensures working conditions as close as possible to the conditions of normal operation of the engine cooling system. This applies both to the intensity of heat generation inside the cylinders of the engine, the temperature distribution along the axis of the cylinder, as well as variable-speed water pump. The test stand was made using the following motor units: the cylinder block and head with heaters, water pump driven by an electric motor and also radiator with fans. To drive the water pump electric motor with a programmable inverter was used. The scheme of the test stand is shown in Fig. 1.

The basic component of the test stand and the source of heat transferred to the cooling system was cylinder block with head of engine 4CT90. In each cylinder with three cylindrical immersion heater with different electrical power inside the metal cylinders was placed. The heating elements adhered closely to the walls of the engine cylinders (Fig. 3) [6].

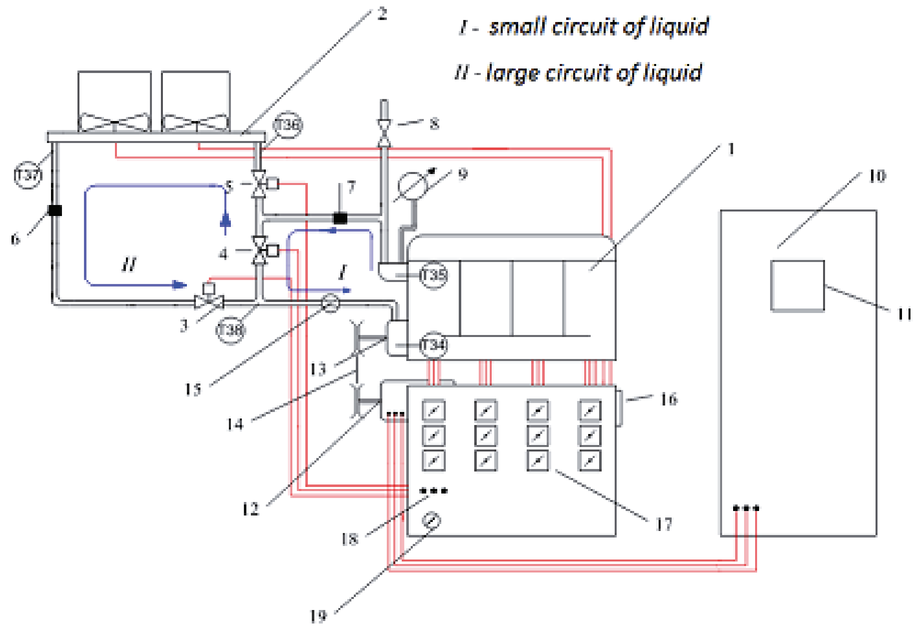

Fig. 1. Scheme of the pressure cooling system: 1 – cylinder block with head, 2 – cooler, 3, 4, 5 – solenoid valves, 6, 7 – electronic manometers, 8 – shutoff valve, 9 – manometer, 10 – inverter, 11 – inverter display and programmer, 12 – electric motor, 13 – water pump, 14 – gear, 15 – flowmeter, 16 – fan power switches, 17 – set of switches, 18 – small and large circuit switches, 19 – main switch

3. Research of the cooling system on the model stand

The research was carried out on the test stand were aimed at verify the operation of the cooling intensity control, with varying degrees of filling the coolant and to develop a method for controlling the cooling system before testing on the dynamometer.

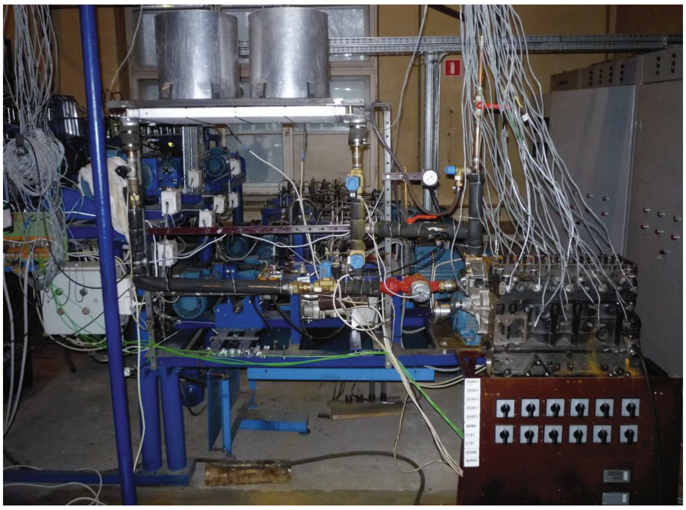

Fig. 2. Pressure cooling system on the model test stand

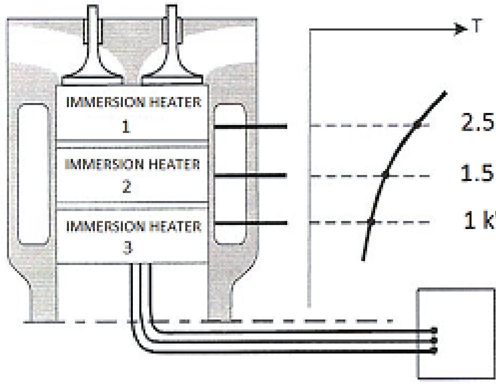

Fig. 3. Arrangement of immersion heaters inside the engine cylinders [5]

The studies were conducted for the overpressure of 0.05 MPa, 0.1 MPa, 0.15 MPa, 0.2 MPa and for variable filling the coolant: 10.5 dm^3, 10 dm^3, 9.5 dm^3 i 9 dm^3, which constitutes approximately value, respectively 95%, 90%, 85% i 80% of liquid filling system in a total volume of 11 dm^3. Remaining capacity of the watertight cooling system was containing air [2].

During the warm-up and continuous heating of the cylinder and the cylinder head using electric heaters, temperature and overpressure courses of liquid in the system before and after the cooler, the temperature the inlet and outlet of the liquid from the engine and the temperature at selected points inside the engine water jacket were appointed. Results of measurements of coolant pump flow at different speed of water pump were also presented.

In this paper, the characteristics selected for two values of overpressure of 0.15 MPa and 0.2 MPa and for two different values of coolant filling degree were presented, because for the lower overpressure value in the system was not possible to increase the temperature of the coolant above 110°C. Therefore, the courses of temperature changes during each test were similar; the courses for one process of warm-up and heating of engine by electric heaters were shown.

The research started with four different volumes at the assumed coolant pressure of 0.05 MPa. Maintaining such a low overpressure at a steady level was very difficult. Practically overpressure within 0.04–0.075 MPa for all degrees of filling of the coolant was maintained, but the highest temperature achieved at the highest filled (95% of the volume of liquid) was temperature 87°C and for the least filling (80%) obtained a temperature of about 112.5°C. At an overpressure of 0.1 MPa reached average temperature values was not too high: for 95% of the liquid filling the average temperature was about 102°C, while for 80% of the filling it was slightly higher – at the level of 112°C. Subsequent tests at an overpressure of 0.15 MPa was carried out. Warming up the system on a small circuit lasted about 25 minutes. After obtaining assumed overpressure, large circuit for about 3 seconds was turn on, that the temperature dropped by about 20°C, while the overpressure of about 0.02 MPa and was maintained in the range 0.135–0.16 MPa (Fig. 4).

For the next cycle exactly the same steps were made until the moment, when after switching on the large system, pressure drop was not noticed. Then the fan No. 1 was turned on, and after a while the fan No. 2. The switching frequency between small and large circuit was on average 3 minutes. Operating time on the large circuit was approximately 3-4 s.

During maintaining a stable heating of the system, the maximum temperature of the liquid at the outlet from the engine at the level 120°C for all the volume of liquid coolant (liquid filling), with a decrease of the temperature to 80°C during the intensive cooling was obtained (Fig. 5).

However, individual characteristics differed significantly course minimum and maximum values of temperatures that resulted from the maintenance of overpressure in the cooling system as

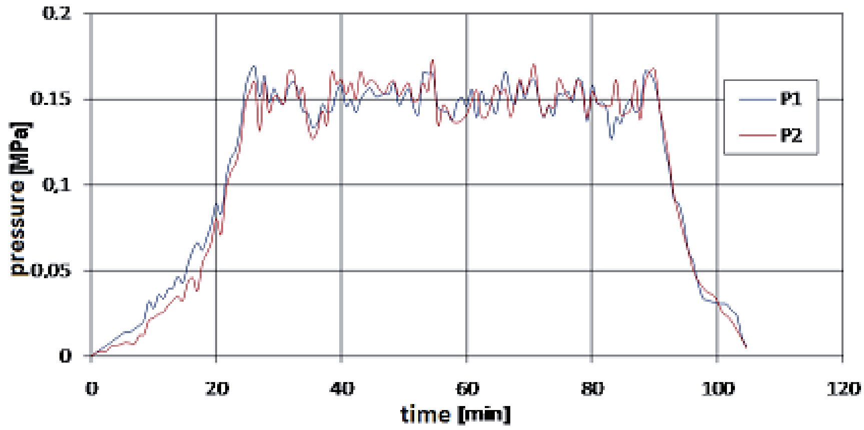

Fig. 4. Course of overpressure coolant in the cooling system during the measurements at a pressure of 0.15 MPa and 90% filling of the liquid. Designations circuits: P1 – small circuit, P2 – large circulation

a)

b)

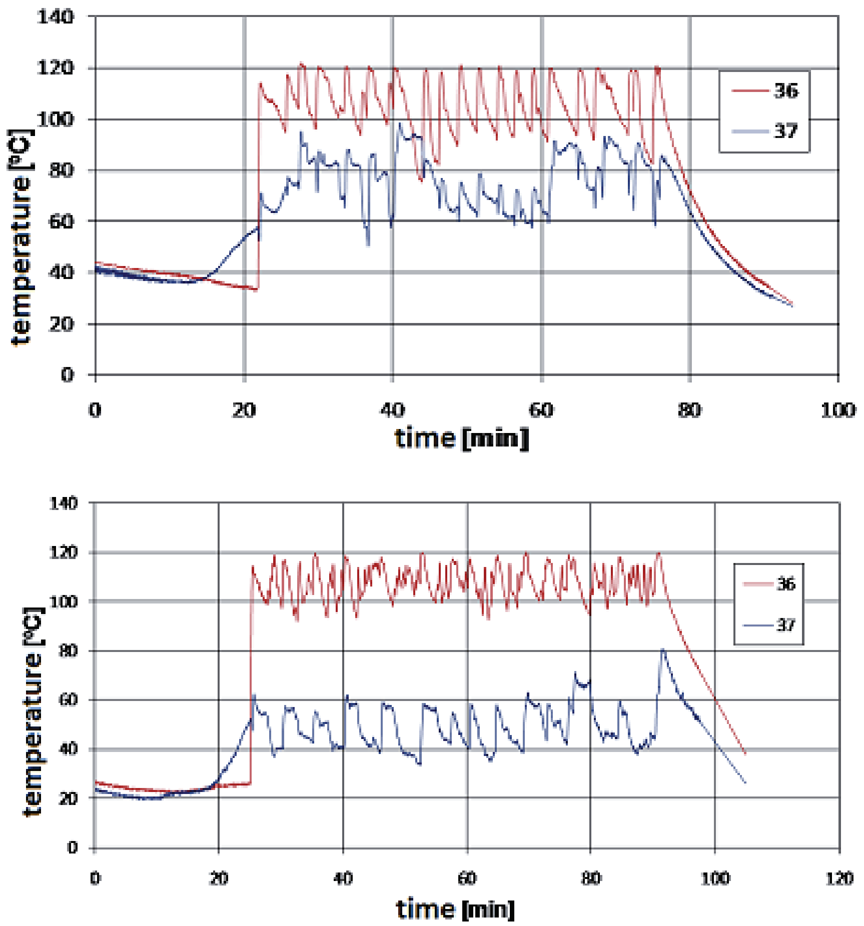

Fig. 5. Course of temperature coolant in the cooling system during the measurements at a pressure of 0.15 MPa and 90% (a) and 80% (b) filling of the liquid. Designations thermocouples: 36 – liquid inlet to the radiator, 37 – liquid outlet of the radiator

constant as possible. When reduced the amount of liquid in the cooling system and increased the air pressure accumulator, these differences were smaller and smaller, at the same time the average temperature of circulation increased, because when temperatures change considerably, achieving the maximum temperature was associated with a simultaneous increase in the intensity of cooling.

This was observed as an initial rapid increase in temperature in the cooling system to about 120°C, while the amount of air at low temperature increase was slower. Simultaneously with increasing the amount of air in the system and reducing the amount of liquid the average temperature of the coolant flowing into the engine substantially decreased. At least filling the liquid of about 80%, it was necessary to cool down the liquid in the radiator to 40-60°C for a temperature inside the engine at a maximum level of about 120°C.

Therefore, it seems appropriate to adopt 90% filling as optimal filling for the system operating conditions and adopted overpressure.

Measurements for the assumed pressure of 0.2 MPa was also carried out at four degrees of filling of the coolant. When the overpressure in the system achieved assumed value, the system was switched to the large circulation and then followed by a decrease overpressure of about 0.05 MPa, and its value ranged 0.15-0.2 MPa, and was slightly lower than the assumed value of the average at 0.2 MPa (Fig. 6).

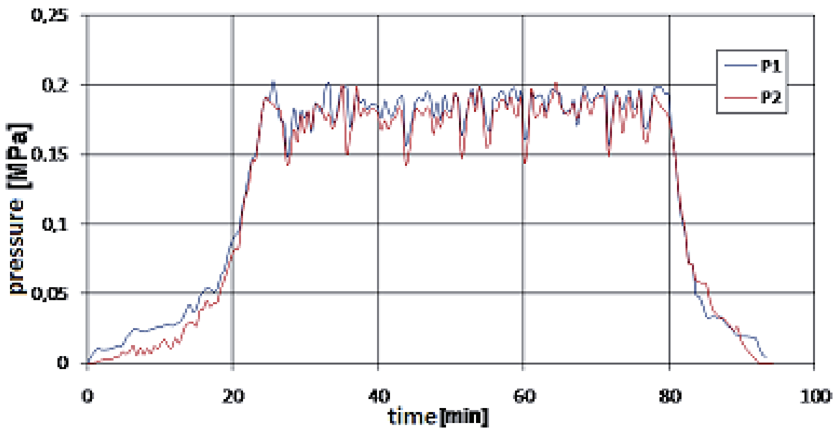

Fig. 6. Course of overpressure coolant in the cooling system during the measurements at a pressure of 0.2 MPa and 90% filling of the liquid

At the same time, an increase in the intensity of cooling followed by a decrease in temperature of about 25°C, but it was possible to achieve a slightly higher maximum temperature 120°C (Fig. 7). Switching frequency increased – a large circulation enrolled for about 2 to 3 seconds. At the same time with switching on large circuit, the fans were turned on for about 20 to 25 seconds. Based on analysis of results of simulation research, it was found that at a fixed overpressure (taking into account deviations) the increase in volume of the cooling system could increase the temperature of the coolant flowing from the engine. The proposal got confirmation during the tests on the model stand, in which the overpressure of 0.15 MPa, the average temperature rise. This was not fully confirmed during the tests on the model stand at the assumed overpressure 0.2 MPa, which can be justified by the unique control of the cooling system, including the too frequent changes in the intensity of cooling, as well as periodic supercooling liquid. Evidence of this low temperature at the outlet of the radiator and the lower than expected overpressure in the system. Probably too suggested a maximum temperature (120°C), and to a lesser extent, increased overpressure, which should be in the range of 0.2 MPa ± 0.02 MPa, as it is achieved at a pressure of 0.15 MPa.

This example shows an important role of control method of the cooling intensity on the cooling system work in the assumed conditions. This problem should be developed in further studies of the pressure cooling system. However, this does not undermine the earlier findings of the adoption of the 90% coolant filling as best suited to the pressure of the cooling system working at an overpressure of 0.2 MPa. Coolant flow rate during the tests was not constant, because the temperature of the boiling point of the liquid, in the pump the water vapour bubbles were formed, which resulted in a decrease of efficiency of liquid discharge.

At the same time, it was necessary to adjust the speed of the water pump to the degree of filling of the liquid. For a volume of 95% and 90% the most uniform flow was provided at the pump speed of 2000 rev/min, while the filling of 80%, and the water pump speed of 3000 rev/min do not recorded flow of the coolant.

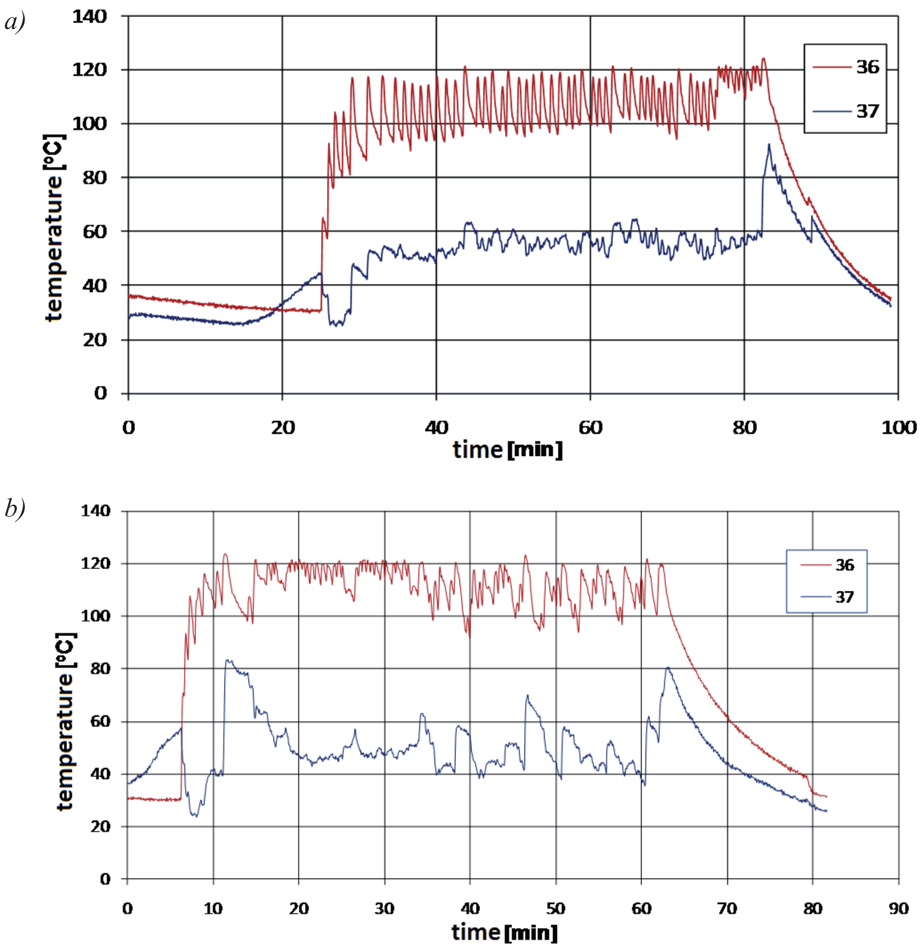

Fig. 7. Course of temperature coolant in the cooling system during the measurements at a pressure of 0.2 MPa and 90% (a) and 80% (b) filling of the liquid

Therefore, at 85% filling of the liquid pump operated at a speed of 3000 rev/min, while at 80% filling the speed of the water pump was increased to 4000 rev/min, which is of course also affect on average flow rate of the coolant. At the same time, it was found that the reduction of the filling liquid flow uniformity deteriorated. This may be due to a greater amount of water vapour and air in the cooling system (Fig. 8).

4. Conclusions

1) The original cooling system operating at elevated pressure coolant was developed, built and tested. With an average overpressure 0.3 MPa in the cooling system, due to evaporation of cooling water, the water temperature at the outlet of the cylinder head, was achieved at 120°C.
2) A result of research the cooling system operation, which was increased pressure of the coolant, in terms of the possibility of obtaining an elevated coolant temperature and the effects of the working conditions of the system on this temperature level was verified. It was found that tested cooling system operated correctly, maintaining a sufficiently high pressure and temperature.
3) The pressure was basic control system parameter and the temperature was output parameter. When the pressure limit was exceeded, cooling intensity was increased, and the reduction of the pressure the cooling intensity was reduced. It was observed, that it was possible to maintain the pressure in the system and thus temperature of the liquid at the assumed level for a longer period of time. Cooling intensity was changing by adjusting flow water pump, coolant flow switching between small and large cooling system and fan starting mounted on the radiators.

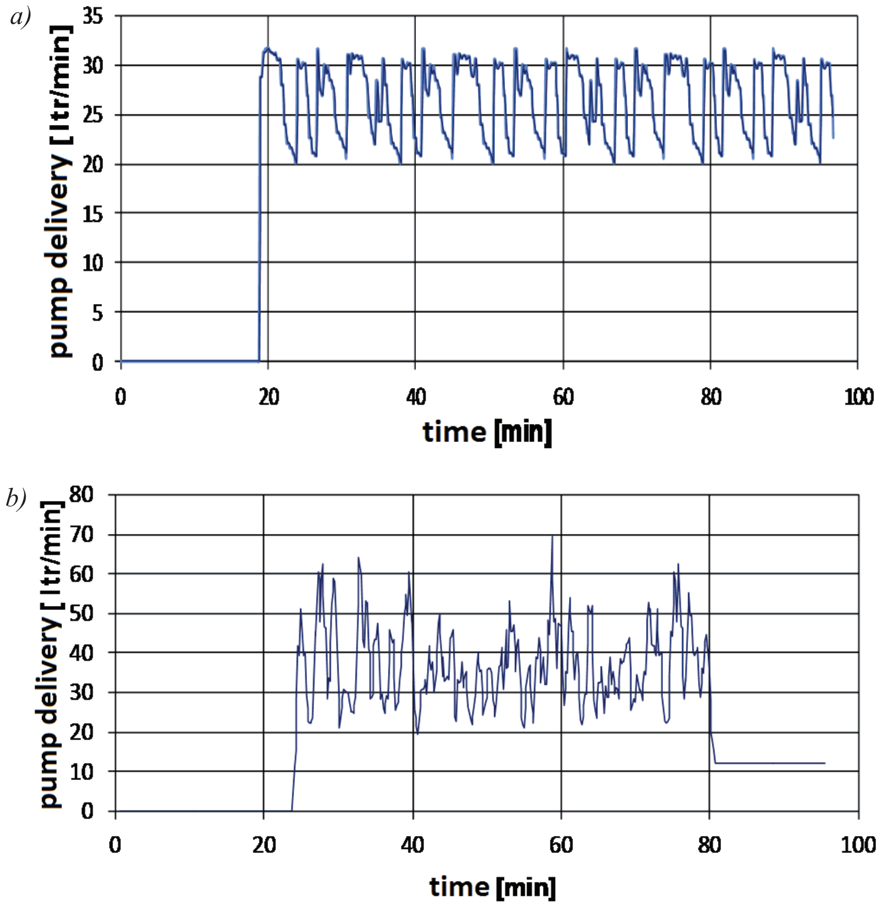

Fig. 8. Course coolant flow during the measurements at a pressure of 0.2 MPa and varying the liquid filling system: a) filling of 95% and a water pump speed n = 2000 rev/min, b) filling of 85% and a water pump speed 3000 rev/min

4) The experimental results on the model stand showed the desirability of limit the coolant fill to 90% so that the rest of the system containing air acted as a pressure accumulator, improving control of system.

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