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The results of the experimental research of the heat transfer coefficient during steam condensation in the tubes of the diesel radiator sections

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Summary. The schemes of the stand equipment, testing methods, experiment planning as well as the main calculations of dependence and the obtained results of the tests of serial sections of the radiator of the diesel locomotive in the mode of steam condensers have been presented in this article.
Key words. Experiment, stand equipment, radiator section, heat transfer coefficient, heat transfer ratio.

INTRODUCTION

Many years of international experience in the designing of ICE proved the advantage of using the phase transitions of coolant in the cooling system (CS) of a power plant [Seliverstov, 1973]. The usage of evaporation and condensation of cooling liquid in all the circuits can reduce the power consumption of the coolant flow and convert a part of the steam heat energy into the work in steam turbines, increasing the overall efficiency of the marine ICE by 5 ... 10% [Radchenko, Stahel, Sirota, Konovalov, 2009; Sirota, Bes, Radchenko, Konovalov, 2009].

Earlier the level of technical facilities did not allow to create similar CS of the small size, and phase transitions of the coolant were used only in the CS of the marine ICE. However, modern technologies have solved this problem, and the world's leading manufacturers got interested in this field. For example, BMW has created a car that has an extra coolant circuit with phase transitions [Sintezgaz.org.ua, 2011].

The Department of the railway transport of the East Ukrainian National Dahl University has developed an energy-saving CS of the diesel locomotive engine with coolant phase transitions [Mohyla, Sklifus, 2010]. The proposed cooling system allows to maintain the constant optimum temperatures of the cooling objects (oil diesel 70 ... 86 ° C, charge air 60 ... 75 ° C, water in the diesel jacket 80 ... 105 ° C [Filonov, Gibalov, Nikitin, 1996; Volodin, 1978]) at ambient temperature ± 40 ° C and at any mode of the diesel engine. The application of the phase transition can significantly reduce the average power consumption of the coolant flow, to increase the maximum of heat dissipating ability of the radiator sections [Mohyla, Sklifus, 2011], to accumulate heat for short circle of idle diesel locomotive with the diesel switched off during the cold season of the year with the possibility of further starting a diesel without pre-heating (minimum: 1 hour at - 30°C and 3 hours at 0°C) [Mohyla, Sklifus, 2012]. This significantly reduces the average fuel consumption of the diesel locomotive.

THE MAIN OBJECTIVE OF THE ARTICLE

To design the SO of the locomotive diesel it is necessary to have a series of calculations of the heat balances [Bugaevsky S. B., 2006]. One of the key elements of the CS is a radiator section.

To make a heat calculation of a radiator section operating in the condenser mode, one must have the equations describing this process. At the moment there are no such equations, and that’s why it is necessary to conduct experimental studies of the natural samples of locomotive radiator section, the results of which are presented in this work.

RESEARCH ANALYSIS

When calculating the CS using phase transitions of the coolant, one can use a number of existing formulas that are rather accurate in describing the processes of heat transfer at boiling [Zhukauskas A. A., 1982]. These formulas are widely used for heat exchangers calculation in various fields of industry. They are accurate and verified by numerous investigations and years of experience.

To calculate the heat transfer ratio in the diesel locomotive radiator sections, it is very convenient to use the formula [Kamaev, Apanovich, Kamaev, 1981], which binds the processes inside and outside the tubes irrespective of their physical characteristics:

$$K_t = \left[\left(\frac{1}{\alpha_1} + \frac{\partial_w}{\lambda_w} + \Sigma r_1 \right) \cdot \frac{F_2}{F_1} + \frac{1}{\alpha_2} + \Sigma r_2 \right]^{-1}; \quad (1)$$

where: α – the heat transfer ratio, W / (m^{2}K) - the wall thickness of the tube, m;

λ_w – thermal conductivity of the wall material, W / (mK);

F - heat exchange surface area, m^2;

Σr - coefficient of thermal resistance of pollution, (m^{2}K) / W;

indices 1,2 point out the process inside and outside of the tube respectively (1- a hot coolant, 2 - cooling air).

There are many scientific papers devoted to the investigation of coefficient α_2. For the chosen type of the serial radiator section (BC-0,5) α_2 can be calculated with a high accuracy according to the formulas associated with that type of sections [Kulikov, 1988].

It should be noted that the shape of the cross section pipe of the radiator is not circular. The external dimensions of the pipe are 19.5 x 2.2 mm and the wall thickness is 0.55 mm [Kulikov, 1988]. When having these parameters, the pipe can be called "flat." Such form of the pipe is optimal, and provides the best ratio of the intensity of heat transfer to the air and aerodynamic resistance.

Heat transfer coefficient α_1 for single-phase water flow to the walls of pipes has been much investigated and can be calculated according to the known criteria dependences [Kulikov, 1988]. However, at present there are no any calculated dependences for determining α_1 coefficient for steam condensation in the "flat" tube. To plan the experiment and analyze the obtained data we used the values of α_1 obtained from the known calculated dependences, determining heat transfer coefficient during steam condensation inside a circular pipe of the equivalent diameter [Isachenko, 1977; Wong, 1979].

PROBLEM SOLUTION

To improve the accuracy of the research results and determine Σr, some thermal engineering tests of the chosen water-air section of the BC-0,5 on the universal thermotechnical bench [Kulikov, 1988] by using a method of PJSC "Luganskteplovoz" have been carried out.

The external and internal surfaces of the radiator section were carefully prepared after cleaning by means of the water and air flow, mechanical and chemical treatments.

The conducted tests of the chosen radiator section in the standard mode resulted in the experimental heat transfer ratio having coincided with the theoretical discrepancy in ± 0,4% for all the modes. It allows us to make the conclusion about the high purity of the external and internal surfaces of the presented section of the radiator, and make Σr equal to the zero.

Further the tests were carried out in the radiator section at the steam condensation mode. The experiments were performed on a modified bench for thermal radiator's testing (fig. 1).

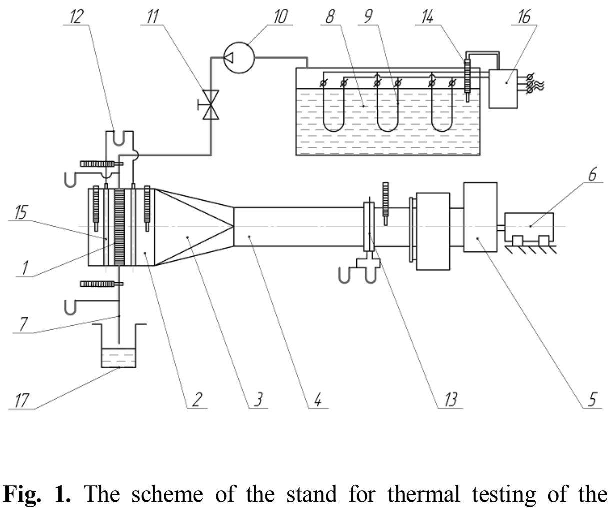

Fig. 1. The scheme of the stand for thermal testing of the radiator sections during condensation of the coolant: 1 – radiator; 2 – branch pipe; 3 – adapter; 4 - air duct; 5 - centrifugal fan; 6 – engine; 7 - condensate duct; 8 – heating tank; 9 – TEH; 10 – compressor; 11 – valve; 12 – micromanometer; 13 - segment diaphragm; 14 – thermometer; 15 - total pressure pipe; 16 - remote control; 17 – condensate measuring unit.

The stand works as follows: a liquid coolant in the heating tank 8 boils under the influence of the tubular electric heaters (TEH) 9 and the obtained steam is fed through the heat-insulated pipe through valve 11 to radiator 1, where it is condensed and transfers the heat to the cooling air. Engine 5 drives a centrifugal pump 6, which sucks the cooling air from the room into pipe 4 through branch pipe 2 with the given consumption, which is controlled by the segment diaphragm 13. The condensate is removed through line 7 into measuring unit 17. The steam is fed by gravity flow at normal pressure, which allows using an open circuit connected to the atmosphere, and prevents the formation of the high redundant pressure, which causes a change in the boiling temperature and condensation. Compressor 10 is an auxiliary device. Micromanometer 12 takes the readings of the total pressure tubes 15 and allows to calculate the aerodynamic resistance. The heat transfer ratio is determined according to the transferred heat, which is calculated by the readings of thermometer 14 and is checked by the obtained mass of condensate in measuring unit 17.

In the experiment the values of three factors ranged as follows: the working length of the pipes *z* (i.e. the working surface of the heat transfer), the linear steam inlet velocity ω_n and mass air velocity when entering the radiator u_2 (directly influences on the temperature of the wall [Vinogradov S. N., Tarantsev K. V., Vinogradov O. S., 2001]). The other factors (radiator pipes shape, physical and chemical properties of the coolant, the pressure in the tank and the radiator, air inlet temperature in the radiator, etc.) were constant.

The results of the experimental studies have shown that the heat transfer coefficient during condensation α_{1_ex} inside the "flat" pipe of the diesel radiator section is slightly higher than the theoretical value of the coefficient α_{1_t} for condensation inside a circular pipe of the equivalent diameter [Isachenko V. P, 1975]. In this case, the values of the local heat transfer coefficients at the beginning of the pipe α_{1_0} are almost the same for the pipes of various sections. The decrease α_{1_ex} and α_{1_t} regarding α_{1_0} with the enlargement of the pipe is shown in figure 2:

This difference can be easily explained by the physics of the process. When the steam is condensed in the pipe of a circular section, the created condensate makes a liquid film, the thickness of which increases with the length of the pipe. This film of condensate creates additional thermal resistance (∂_c / λ_c) [Miheev, Miheeva, 1977; Hartmann, 1961], which deteriorates the process of heat transfer, hence α_1 is significantly reduced with the enlargement of the pipe.

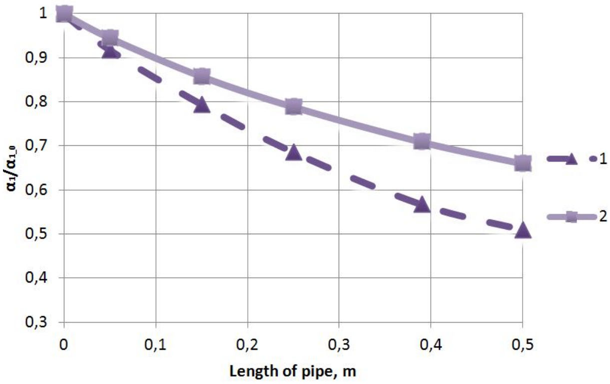

Fig. 2. Reduction of heat transfer coefficient with the enlargement of the pipe: 1 - for a circular pipe; 2 – for a pipe of the "flat" section.

When the steam is condensed inside the pipe of the "flat" section (especially of a small equivalent diameter) the created condensate film moves to the both edges of the cross section under the action of surface tension, freeing up the main flat area of the internal surface of the "flat" pipe [Gerasimov Y.I., Gejderih V.A., 1980].

The results of experimental studies have shown the differences between α_{1_ex} and α_{1_t}, which increases when the Reynolds number (i.e. steam consumption) is increased (fig. 3).

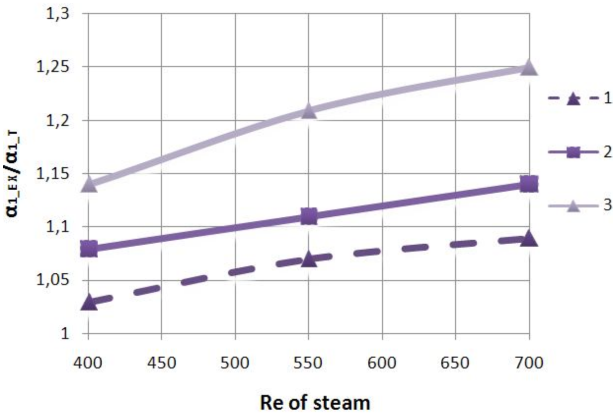

Fig. 3. The increase of average length α_{1_ex} regarding average length α_{1_t} with the increase of the Reynolds number: 1 - for the pipe length L = 0,235 m; 2 - L=0,385 m; 3 - L=0,535 m.

Since the Reynolds number is directly proportional to the speed of the steam, this increase α_{1_ex} can be explained by the displacement of the condensate to the edge of the "flat" section of the pipe under the pressure of the steam flow supplied to the pipe.

CONCLUSIONS

Experimental study of the processes of heat transfer during steam condensation inside the pipes of the diesel radiator sections proved that there is a circulation of the coolant in the cooling system of locomotive diesel without using the pumping equipment (i.e. gravity flow) when the air temperature entering the radiator t_{2_en} is up to 18°C. At t_{2_en} > 18°C it is necessary to apply some energy to the compressor supplying the coolant to the radiator sections.

The advantage of the heat transfer coefficient during steam condensation in the pipes of the "flat" sections over the heat transfer coefficient during steam condensation in the circular pipes has been experimentally confirmed. The difference increases with the length of the pipe and it reached a maximum value of + 30% in the given experiment.

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РЕЗУЛЬТАТЫ ЭКСПЕРИМЕНТАЛЬНЫХ ИССЛЕДОВАНИЙ КОЭФФИЦИЕНТА ТЕПЛООТДАЧИ ПРИ КОНДЕНСАЦИИ ПАРА В ТРУБКАХ ТЕПЛОВОЗНЫХ РАДИАТОРНЫХ СЕКЦИЙ

Ярослав Склифус, Валентин Могила

Аннотация. В статье представлены схемы стендового оборудования, методика испытаний, планирование эксперимента, основные расчетные зависимости, и полученные результаты испытаний серийной радиаторной секции тепловоза в в режиме конденсаторов пара.

Ключевые слова. Эксперимент, стендовое оборудование, радиаторная секция, коэффициент теплопередачи, коэффициент теплоотдачи.