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THE COOLING DEVICE OF LOCOMOTIVE WITH VAPORIZING COOLANT

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Summary: The analysis of the intensification methods of heat transfer processes, a comparative analysis of the effectiveness of the radiator sections when they work in the traditional system and using them as a condensing unit in the evaporative cooling system have been presented.

Key words: diesel, radiation section, condensing unit, coolant, heat transfer ratio, pressure.

INTRODUCTION

The cooling devices of modern locomotives are known to be the main consumers of the power transferred from the diesel for the auxiliary engine needs. For instance, for locomotive 2ТЭ116 this power is 225,5 кW [Filonov S. P, Gibalov A. I, Nikitin E. A., 1996] (10,02% of the diesel power), 183,2 кW giving out on the fans and pumps drive of the cooling device of the locomotive. Besides, the heat exchangers of diesel engines are made of expensive scarce non-ferrous metals (mainly copper and its alloys) [Lebedev P. D., 1972], and significant dimensions of the elements of cooling devices are serious obstacles when weighing and setting today's powerful diesel locomotives [Drobinsky V. A., Egunov P. M., 1980]. All these facts indicate a great importance of measures and scientific publications devoted to the improvement of the cooling device of the locomotive.

THE MAIN OBJECTIVE OF THE ARTICLE

To improve the efficiency and to reduce the dimensions and materials of heat exchangers of the locomotive cooling device, it is necessary to analyze and systematize the methods of intensification of heat transfer, and to consider their impact on the flow of heat transfer process and the functioning of the cooling system as a whole. Much attention will be paid to the water-air radiator section (the most expensive element of the cooling system) where locomotive 2ТЭ116 will be taken as an example. In this paper, a comparative analysis of the effectiveness of the radiator sections of the size BC (68 tubes, plates step 2.3 mm, the surface area of 29 m^2, operating height 1206 mm) [Kulikov U. A., 1988] for their work in the traditional system and using them as a condensing unit in evaporative cooling system.

RESEARCH ANALYSIS

There is a great deal of scientific works devoted to the problem of improving the efficiency of the radiator locomotive sections. In this research it was determined that the main factors affecting the intensity of heat transfer are [Isachenko V. P., 1975]:

1) geometrical parameters of the radiator (and the presence of turbulators) [Vinogradov S. N., Tarantsev K. V., Vinogradov O. S., 2001];
2) the velocity of coolant circulation in the tubes;
3) the mass flow rate of cooling air in front of the radiator sections;
4) temperature difference.

The influence of these parameters on the dimensions of the radiator can be represented in the following formula [Kamaev A. A., Apanovich N. G., Kamaev V. A., 1981]:

$$n_s = \frac{Q}{t'_w - t'_a}\left(\frac{1}{KF} + \frac{1}{2u_w c_{pw} S_w} + \frac{1}{2u_a c_{pa} S_a}\right); \tag{1}$$

where: n_s – the required number of radiator sections;
Q – the heat load of the device, W;
t' – the input temperature of the radiator, ^{o}C;
K – the heat radiator section ratio, W/(m^{2}K);
F – the surface area washed by air, for one section, m^2;
u – the mass velocity, kg/(m^{2}s);
c_p – average specific heat capacity, kJ / (kgK);
S – a cross section for heat transfer, m^2.

Indices w and a are used for water and air respectively.

To go back from the mass velocity to linear one can through simple relation: $u = w\rho$ [Wong H., 1979].

Fig. 1 shows the dependence of the heat transfer ratio of pure radiator sections on the factors listed above [Shamshin A. A., Renov A. I., 1971] (Note: the graph also shows the curve corresponding to the mass rate of air 8.6 kg /(m^{2}s), which is of the the same actual value as on locomotive 2ТЭ116 [Bugaevsky S. B., 2006]).

As it can be seen from the graph, the effect on heat transfer ratio of the radiator coolant circulation speed in the tubes is much lower than the influence of the mass velocity of cooling air. This is explained by the fact that the heat transfer ratio of the air-water section of the radiator can be presented in the following formula [Kamaev A. A., Apanovich N. G., Kamaev V. A., 1981]:

$$K = \frac{1}{\left(\frac{1}{\alpha_1} + \frac{\delta}{\lambda}\right)\frac{F_2}{F_1} + \frac{1}{\alpha_2}} \tag{2}$$

where: K – the heat transfer ratio of the radiator section, W/(m^{2}K);
α – the heat transfer ratio, W/(m^{2}K);
δ – the wall thickness, m;
λ – the ratio of thermal conductivity of wall material, W/(mK);
F – the surface area washed by the coolant, m^2.

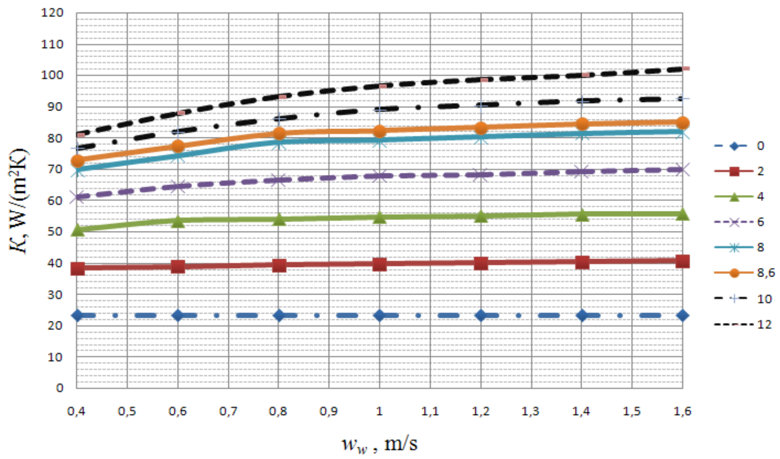

Fig. 1. The dependence of the heat transfer ratio of pure radiator sections on the rate of coolant circulation in the coolant tubes in sections at different values of mass velocity of cooling air

Indices *1* and *2* are used for water and air respectively.

In this case, the heat transfer ratio from the air is 58 ... 175 W / (m^{2}K), while the heat transfer ratio from the water is equal to 4650 ... 6400 W / (m^{2}K) [Kamaev A. A., Apanovich N. G., Kamaev V. A., 1981]. It is quite obvious that the heat transfer ratio of the radiator section depends mainly on the component $1/\alpha_2$. However, when comparing the traditional cooling system and evaporative system, mass flow rate of cooling air is not tied to the processes occurring in the coolant, and depends only on the fans performance [Malinov M. O., Kulikov U. A., Chertok E. B., 1962]. Hence, the further mass velocity of the cooling air will be taken as constant and equal to 8.6 kg/(m^{2}s) [Bugaevsky S. B., 2006].

THE PROBLEM SOLVING

Now taking an example of "cold" circuit (the cooling of the engine's oil), we consider in more detail the influence of the circulation rate of the coolant in the radiator tubes of the sections on the effectiveness and efficiency of the cooling device of the locomotive. As it is seen in Figure 1, the increase in the circulation speed of the coolant leads to an apparent increase in the ratio of heat radiator sections. However, it also increases the value of hydraulic resistance Δp radiator sections (fig. 2), and consequently, the costs of power for pumping the coolant in the cooling system. In addition, the continuity equation of fluid flow [Tchizhyumov S. D., 2007] shows that the increase in fluid circulation rate in the radiator sections results in increase in fluid circulation rate in pipes and water-oil heat exchanger. Hydraulic resistance Δp of water-oil heat exchanger can be calculated by the formula [Kamaev A. A., Apanovich N. G., Kamaev V. A., 1981]:

$$\Delta p_w = z_w (0{,}31 \frac{L_t}{d_{it}} \beta_t + 1{,}4)(w_w^2 \rho_w)/2 \qquad (3)$$

where: Δp_w – hydraulic resistance of water-oil heat exchanger of the water way of water-oil heat exchanger, Pa;
z_w – the number of coolant moves (water), W/(m^{2}K);
L_t –the full length of the tubes, m;
d_{it} – the inner diameter of the tubes, m;
β_t – the ratio depending on temperature and water velocity;
w_w – the speed of water in tubes, m/s;
ρ_w – the water density, kg/m^3.

It is seen from formula 3 that the value of hydraulic resistance Δp of water-oil heat exchanger is also steadily increasing (fig. 2.) with the rate of coolant circulation in the cooling system.

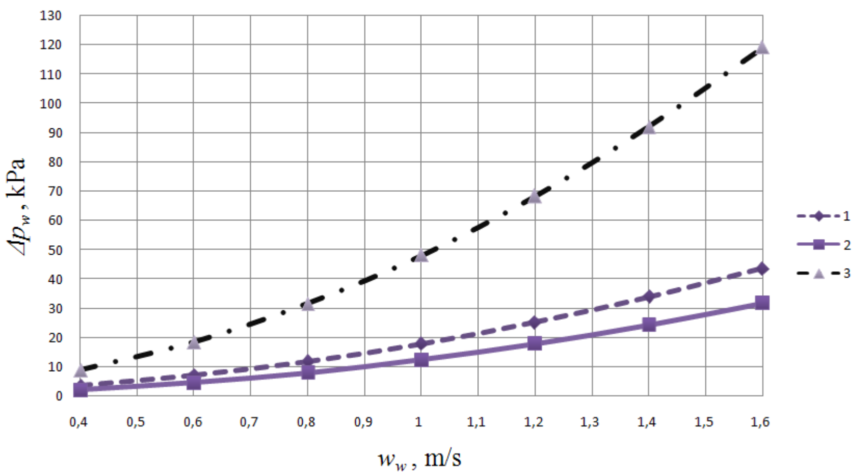

Fig. 2. The dependence of hydraulic resistance on the velocity of circulation of coolant:
1 - hydr. resistance of one section of the radiator, 2 - hydr. resistance of water-oil heat exchanger;
3 - total hydr. resistance of "cold" circuit

Let's consider the work of "cold" circuit of evaporative cooling system [Mohyla V. I., Gorbunov N. I., Sklifus Y. K., Shevchenko R. K., 2010]. The main features of such a system are:

a) the speed of the liquid coolant in the evaporator (water-oil heat exchanger) is zero;

b) the movement of steam from the evaporator to the condenser unit is independent (without any work applied) because of pressure difference in the evaporator and condenser units associated with phase transitions [Isachenko V. P., 1977].

Point *a* indicates the absence of power costs in the evaporator, except for small costs for adding the coolant to maintain a constant liquid level. However, considering the fact that the mass flow of coolant by evaporation is at about 54 times less than when heated (at a temperature drop in heat exchanger 10 ^oC) [Mohyla V. I., Sklifus Y. K., 2010], we can conclude about low power costs power for adding the coolant and can neglect them in future.

Point *b* makes even greater interest. If the heat transfer surface of the capacitor unit is reduced, the amount of exhaust heat won't be enough for the condensation of the incoming steam. Having arranged a compressor before the condensing unit, it is possible to achieve a constant value of mass flow of steam, having applied a certain amount of power. It will result in the steam pumped into a closed volume with high pressure, leading to an increase in its actual temperature [Vukalovich M. P., Novikov I. I., 1968] and the condensation [Mohyla V. I., Sklifus Y. K., 2010]. The consequence of the above given information is that we get the increase in the temperature drop, which leads to the increased intensity of the heat transfer of condensing unit according to the formula [Zhukauskas A. A., 1982]:

$$Q = F \cdot K \cdot \Delta t \tag{4}$$

where: Q – the quantity of the heat output, W;
F – the heat exchange surface area, m^2;
K – the heat transfer ratio, $W/(m^2K)$;
Δt – temperature difference (the difference of average temperatures of the coolant), ^oC.

For water and liquid solutions of [Gerasimov Y. I., Gejderih V. A., 1980] the increase in pressure within the three atmospheres entails the increase in the temperature of condensation (boiling) of about 0.198 ^oC per kPa [Pozin M.E., Grigorov O. N., 1966]. Thus, having applied the same power to the coolant circulation in the radiator sections working in the traditional system and when using them as a condensing unit, we also obtain the increase in temperature drop in the evaporative cooling system.

Taking into account the fact that the heat transfer ratio α_1 during the condensation is equal to α_1 of the traditional system, and is significantly higher than α_2, and ignoring the slight increase in K when the temperature drop is increased, we will make a comparative graph of the dependence of required relative surface area of the heat transfer F' on the pressure of coolant in the radiator sections of p' for "cold" traditional circuit and evaporative cooling systems (fig. 3.). In the graph on the vertical axis the relative heat exchange surface area F', which represents the ratio of the actual surface area of heat transfer surface area F of a radiator section (F_2 = 29 m^2) is shown. The horizontal axis represents the pressure of coolant in the radiator sections p' which is the ratio of the actual pressure taking into account Δp to atmospheric pressure p_{at} .

The graph in fig. 3 shows that when p' = 1,334 (which corresponds to the hydraulic resistance of radiator sections Δp = 33.77 kPa at a coolant circulation rate w = 1,4 m/s [Bugaevsky S. B., 2006] in the traditional cooling system), the required relative area of the heat transfer surface F' of the condensing unit 2.767 (13.766 %) lower than F' of traditional radiator system. With further increase in p' this difference increases.

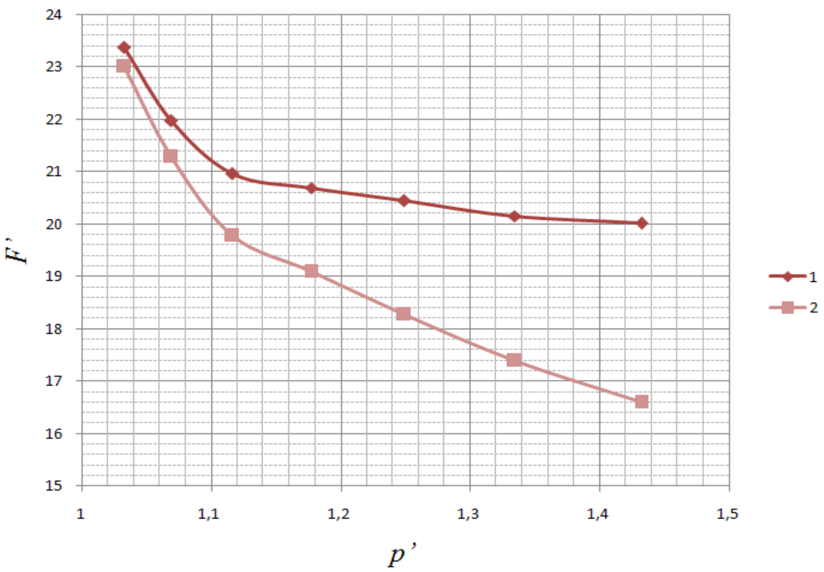

Fig. 3. The dependence of the required relative surface area of the heat transfer on the pressure of coolant in the radiator sections: 1 - traditional cooling system; 2- evaporative cooling system

CONCLUSIONS

When using the radiator sections in the evaporative cooling system of diesel engine it is possible to raise the temperature difference by increasing the coolant pressure by means of a compressor that has a positive effect on the overall size of the refrigerator of the locomotive. Thus, evaporative cooling system is superior to the traditional one, even under the existing costs of power and with the further increase of the section capacity of the locomotive this superiority is becoming more significant.

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ОХЛАЖДАЮЩЕЕ УСТРОЙСТВО ТЕПЛОВОЗА С ИСПАРИТЕЛЬНЫМ КОНТУРОМ ТЕПЛОНОСИТЕЛЯ

Валентин Могила, Николай Горбунов, Ярослав Склифус

Аннотация. В статье представлен анализ методов интенсификации процессов теплообмена, проведен сравнительный анализ эффективности радиаторных секций при работе их в традиционной системе и при использовании их в качестве конденсаторного блока в испарительной системе охлаждения.

Ключевые слова: дизель, радиаторная секция, конденсаторный блок, теплоноситель, коэффициент теплопередачи, давление.