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Algorithm for calculating finned plate radiators for the cooling system of automobile and tractor engines

N Umirov[1], **Sh Abdurokhmonov**[2]

[1] Tashkent Institute of Irrigation and Agricultural Mechanization Engineers, 39 K. Niyazov Str., Tashkent 100000, Uzbekistan

E-mail: abduroxmonov.shavkatjon@bk.ru

Abstract. The article describes the role of the radiator of the engine cooling system of automobiles and tractors, and disadvantages of the copper-soldered radiators design. In the creation of modern automobiles and tractors, it is necessary to develop radiator with optimal parameters in which the heat transfer process satisfies the existent condition. Main parameters of the radiator are: size, power consumption to overcome resistances, energy coefficient, and amount of heat released to the atmosphere. Equations to use in the development of an algorithm for water radiator calculation made from finned plates are suggested. The block diagram used to the development of the algorithm for calculating water radiator made from finned plates and calculation results compared with experimental data.

1. Introduction

For the efficient use of automobiles and tractors in operation, it is necessary to maintain the temperature at a certain value in a number of functional systems, in which an important role belongs to the radiator.Due to the constantly increasing energy saturation of automobiles and tractors, the problem of cooling is becoming more and more urgent from year to year.

To improve the efficiency of existing cooling surfaces, to identify new types of cooling surfaces, and to intensify heat transfer, it is necessary to use a computational method.

New directions in the creation of modern automobiles and tractors are the development of optimal radiators, in which heat transfer process satisfied the condition of the existence of an extremum of a certain optimality criterion. Main parameters of the radiator are: size, power consumption to overcome resistances, energy coefficient and an amount of heat released to the atmosphere. In these conditions, due to the need to calculate a large number of engineering calculations, the use of an electronic computer is required.

In the past the calculation of radiators made manually, now the machine method is used, the use of which provides for a thorough algorithmization of the calculation and the introduction of a number of additional elements.

The core heat-releasing element of the radiator includes the tubular-plate and tubular-belt types cooling surface. There brass tubes and copper plates are used. The connection of tubes and plates in copper radiators is carried out by soldering sintering with tin-lead solder. This leads to an increase in the length of the joint and increases the probability of leaks during operation. To eliminate these disadvantages, it is better to use a cooling surface called finned aluminum plates. In this design of the cooling surface, high thermal efficiency is provided by continuously flows out of plate wall material, thereby avoiding the use of soldering elements.

The algorithm for calculating water radiators made of finned plates is developed on the basis of the generalized equations of heat transfer and aerodynamic drag obtained in [1, 2, 3, 4, 5].

The generalized heat transfer coefficient equations have the form:

a) in the laminar flow mode ($R_e < R_{ekr1}$):

$$К = A\lambda(\gamma\beta\upsilon d_e l)^{-0,33}(\gamma V_L)^{0,33}V_w^{0,15}\eta_0, \tag{1}$$

where A is the coefficient characteristic of the collector, A=2.16; λ - coefficient of thermal conductivity; γ - air density; β - coefficient of living cross-section; y - viscosity; d_e - equivalent diameter; l - radiator depth; γV_L - mass velocity of air; V_w - water velocity; η_o - efficiency of the cooling surface; R_e - Reynolds number;

b) in the transient flow mode ($R_{ekr1} \leq R_e \leq R_{ekr2}$):

$$К = A\lambda\left(\frac{l_1}{d_e}\right)^{0,57} \frac{d_e^{1,07\left(\frac{l_1}{d_e}\right)^{-0,1}-1}}{(\gamma\beta\upsilon)^{1,07\left(\frac{l_1}{d_e}\right)^{-0,1}}}\left((\gamma V_L)^{1,07\left(\frac{l_1}{d_e}\right)^{-0,1}}\right)V_w^{0,15}\eta_0, \tag{2}$$

where A=0.0046; $\frac{l_1}{d_e}$ – geometric parameter; l_1- edge length;

c) in the turbulent flow regime $R_e > R_{ekr2}$::

$$К = \frac{A\lambda d_e^{0,68(\frac{l_1}{d_e})^{0,04}-1}}{(\frac{l_1}{d_e})^{0,04}(\gamma\beta\upsilon)^{0,68(\frac{l_1}{d_e})^{0,04}}}(\gamma V_L)^{0,68\left(\frac{l_1}{d_e}\right)^{0б04}} V_w^{0,15}\eta_0. \tag{3}$$

The generalized equations of aerodynamic drag have the following form:

d) in the transient flow mode $R_{ekr1} \leq R_e \leq 6000$:

$$\Delta P_L = A_1\gamma\upsilon^{0,01\left(\frac{l_1}{d_e}\right)^{1б35}} \frac{l_1^{0,3}l(\beta\gamma)^{0,01\left(\frac{l_1}{d_e}\right)^{1,35}-2}}{d_e^{0,01\left(\frac{l_1}{d_e}\right)^{1,35}+1,3}}(\gamma V_l)^{2-0,01\left(\frac{l_1}{d_e}\right)^{1,35}}, \tag{4}$$

where A_1 is the coefficient, A=0.0873;

e) in the turbulent flow regime:

$$P_L = \left[\frac{A_1 l}{(d_e\gamma)\beta^2}\right](\gamma V_L)^2 \tag{5}$$

where A_1=0.16.

Equations (1)-(5) are valid for the following values of geometric parameters: $\frac{l}{d_e} = 11.0 - 18.8$; $\frac{l_1}{d_e} = 1.1 - 7.2$; $d_e = 0.0033 - 0.0049$ (m); δ=0.30-0.35.

Coefficients A and A_1 are given for the SI system of units.

From the above equations, we select those that correspond to the flow modes that take place in the radiators of UAZ automobiles, i.e., transient and turbulent modes. Optimization of the finned cooling surface of the radiator proceeds, first of all, from the possibility of obtaining its minimum cost, and on the energy side – the minimum energy cost for overcoming resistances with the same amount of transmitted heat, i.e., following (1), is determined by the maximum values of the energy coefficient [6, 7, 8, 9].

$$E = \frac{K}{N_{V_0}} \tag{6}$$

where K is the heat transfer coefficient, and the power N_{V_0} is determined by the equation:

$$N_{V_0} = \frac{C_1}{\gamma \varphi_{fr}} (\gamma V_L)^{m+1} \tag{7}$$

where N_{V_0} - power of the air flow passing through the radiator. The coefficient of the cost of materials of the cooling surface of the radiator is calculated by the equation:

$$Ꚍ_{e_i} = \frac{\varphi_0 \varphi_{gi} \bar{M}_i C_0 \left(\frac{\varphi_{fr0}\gamma}{C_{1_0}}\right)^{\frac{n_0}{(m_0+1)}}}{\varphi_i \varphi_{g_0} \bar{M}_0 C_i \left(\frac{\varphi_{fr_i}\gamma}{C_{1_i}}\right)^{\frac{n_i}{(m_i+1)}}} N_{V_0}^{\frac{n_0}{(m_0+1)} - \frac{n_i}{(m_i+1)}} \tag{8}$$

where the subscript "0" refers to the reference surface cooling; *i* - to compare; φ - volumetric compactness; φ_g- ratio mass compactness; φ_{fr} - ratio front of compactness; M̄ - average cost of materials to produce a unit mass of the cooling surface.

Using the above formulas, an algorithm is developed (Fig.1) including the program. As an example, several variants of finned plate radiators for UAZ automobiles are calculated.

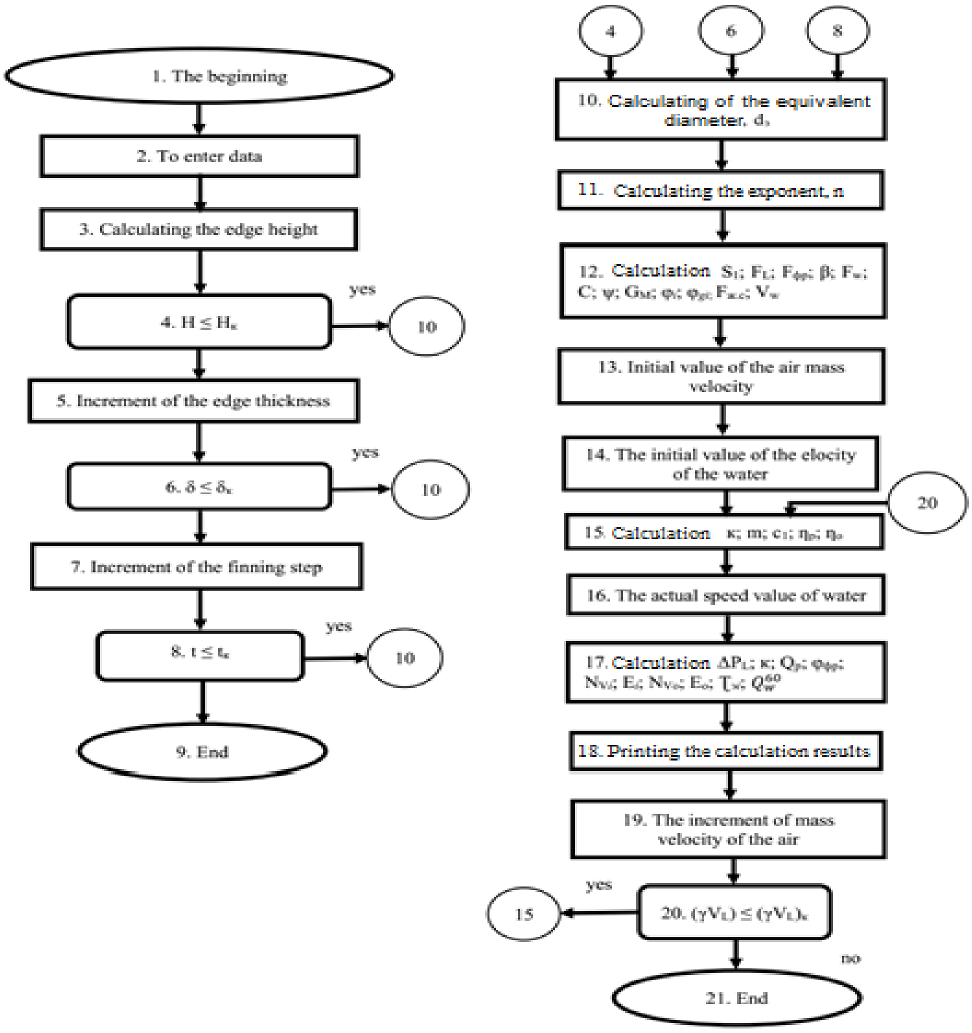

Figure 1. Block diagram of the algorithm for calculating water radiators made of ribbed plates

Initial data for calculation of the radiator ribbed plates are: the number of partitions of n; pitch of fins t; the average fin thickness δ; relation $\frac{l_1}{d_e}$; active depth of the radiator *l*; step increment Δt fins; the increment of the average thickness of the rib Δδ; number of cast sections *i* (in order to increase the height of the ribs at a constant front radiator); radiator height L; radiator width B; wall thickness Δ; water channel height b; air thermal conductivity coefficient λ_L; air temperature t_L; air kinematic viscosity coefficient ω; water flow rate G_w; mass velocity of air γV_L; thermal conductivity coefficient of aluminum alloy λ_p; specific heat capacity of water C_{pw}; initial temperature head Δt_H; final value of fin height N_c; final value of fin pitch t_c; final value of average thickness of fin δ_k; density of aluminum alloy λ_A; the exponent in the formula aerodynamic drag m; the final value of the mass velocity of air $(\gamma V_L)_к$; the characteristic coefficient C_1 in the formula N_{V_i}; the increment of mass air velocity (γV_L); the coefficient of volumetric compactness fo; the average cost of materials to produce a unit mass of a surface $\bar{M}_i$; intrinsic factor; coefficient of compactness front φ_{fr_o}; characteristic coefficient C_{1_o}; characteristic exponent n_o; the characteristic exponent m_o; ratio of mass of compactness φ_{g_o}; the average cost of materials to produce a unit mass of the cooling surface $\bar{M}_o$.

When choosing the value of the coefficient of thermal conductivity, specific heat capacity and air viscosity, it is necessary to take into account the air temperature [10, 11, 12, 13, 14]. After entering the data, the calculation is performed.

The results of the calculation and the experimental data of the control example are summarized in Table 1.

Table 1. Comparison of experimental and calculated data of the control example (with the same finning parameters) for the radiator

№	Parameter name	Experimental data	Estimated data
1.	Heat transfer coefficient K, W/m^2K at γV_L=10 kg/m^2s	136.9	147.464
2.	Heat transfer Q_w^{60}, W at γV_L=10 kg/m^2s	44915.13	46980.08
3.	Aerodynamic drag ΔP_L, Pa at γV_L=10 kg/m^2s	264.7	261.524

The table shows that the differences between the experimental and calculated data are estimated within the accuracy of the experiment (1.2-7%).

To compare the coefficient of the cost of materials, the data of a copper-soldered radiator is used as a reference, i.e. for it $Ꞇ_{e_i} = 1{,}0$. The values of this criterion for a radiator with a cooling surface made of finned plates are significantly lower ($Ꞇ_{e_i} = 0.49$), since for a radiator made of finned plates, the energy coefficient is equal to E=2.35.

These advantages give grounds to use radiators made of ribbed plates

Conclusion

To improve the efficiency of the existing cooling surfaces of internal combustion engine radiators, to identify promising cooling surfaces and to intensify heat transfer, it is necessary to use an algorithm.

The calculation algorithm on an electronic computer allows determining the design parameters, the power consumption for overcoming resistances, the energy coefficient and the amount of heat released by the radiator into the surrounding atmosphere.

The calculation algorithm provides the calculation of the heat transfer of finned plate radiators in various design options and makes it possible to choose the optimal design parameters of the cooling surfaces of the finned plate radiator.

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