PROVERA TOPLOTNIH KARAKTERISTIKA OREBRENOG GREJNOG TELA

CHECKING OF THERMAL CHARACTERISTICS OF A FINNED RADIATOR

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MOTIVATION

Water that is not well treated and maintained, in addition to all the benefits, it has a devastating effect and negatively affects metals.

Chemically untreated water can have a high PH value.

*In practice, it has been shown that with the increased PH value of water, **corrosion occurs in the interior of aluminum radiators**.*

*In addition to quality water treatment, **one of the solutions in practice is the insertion of a steel pipe insert in the interior of the aluminum heater**.*

*With the insertion of the pipe insert, the **thickness of the material increases**, and thus **the total resistance to heat conduction**.*

Increasing the resistance to heat conduction affects the change in the heat transfer intensity of the radiator.

PRACTICE

The subject of this paper is the research of the influence of a steel pipe insert on the heat transfer intensity of a finned aluminum heater*. The method for stationary heat conduction through fins is used for analytical calculation.*

A methodology for checking the thermal characteristics of the radiator has been developed, starting from the data provided by the manufacturer for the radiator, adapted to engineering practice.

This technical solution comes from the company Aklimat, radiator manufacturer from Slovenia, and it is presented on the figure beside.

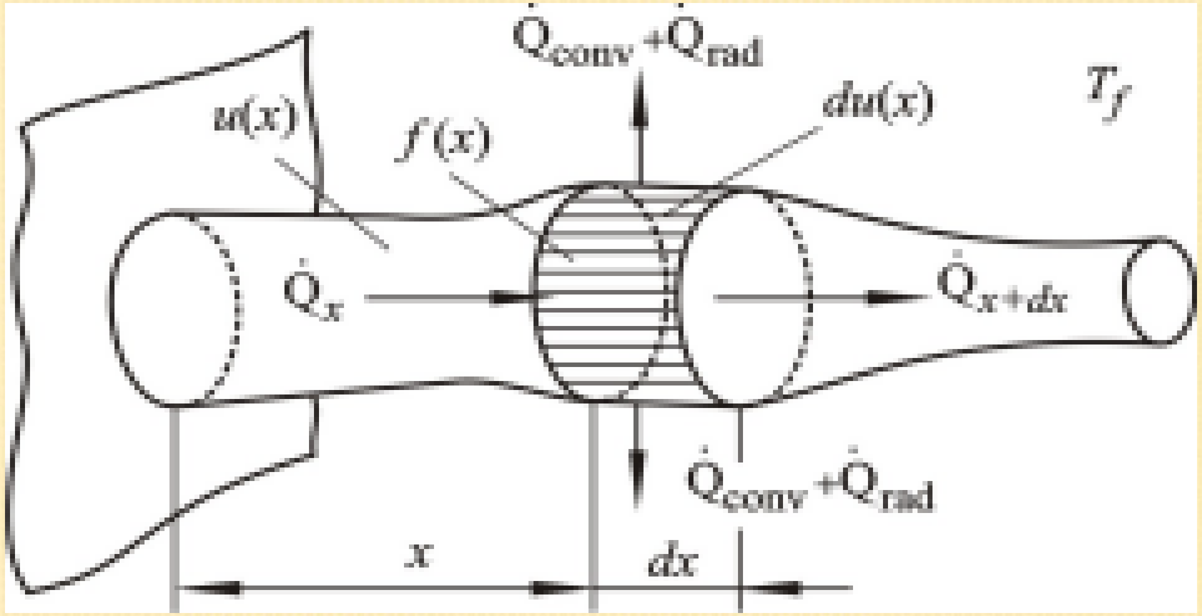
This type of a heating body was investigated in laboratories at the Faculty of Mechanical Engineering in Niš.

ENERGY EQUATION IN GENERAL FORM FOR HEAT TRANSFER BY CONVECTION AND RADIATION FROM THE FINNED SURFACE

Energy equation in general form for 1D heat transfer by convection and radiation from the finned surface is presentend bellow

$$\frac{d^2T}{dx^2} + \left(\frac{1}{f(x)} \cdot \frac{df(x)}{dx}\right) \cdot \frac{dT}{dx} - \left(\frac{1}{f(x)} \cdot \frac{\alpha}{\lambda} \cdot \frac{du(x)}{dx}\right) \cdot \left(T - T_f\right) - \left(\frac{1}{f(x)} \cdot \frac{\varepsilon \cdot \sigma}{\lambda} \cdot \frac{du(x)}{dx}\right)\left(T^4 - T_f{}^4\right) = 0 \qquad (1)$$

This differential equation describes the change in temperature along the length of the fin with convection and radiation.



For the given conditions f(x)=f=const., and u(x)=U·x , the equation transformed as shown bellow

$$\frac{d^2T}{dx^2} - \frac{U\cdot\alpha}{f\cdot\lambda}\cdot\left(T - T_f\right) - \frac{U\cdot\varepsilon\cdot\sigma}{f\cdot\lambda}\left(T^4 - T_f{}^4\right) = 0 \qquad (2)$$

The boundary conditions that are required to obtain the temperature distribution along the fin are presented and it is as follows

$$T\big|_{x=0} = T_b$$

$$-\lambda\cdot f(L)\cdot\frac{dT}{dx}\Big|_{x=L} = \alpha_L\cdot f(L)\cdot\left(T_L - T_f\right) + \varepsilon\cdot\sigma\cdot f(L)\cdot\left(T_L^4 - T_f{}^4\right) \qquad (3)$$

Heat exchanged per square meter can be expressed through ***an equivalent heat transfer coefficient*** *that will take into account both* ***convective heat exchange (α=α***

$$\dot{q}_{r,tot} = \alpha_{conv} \cdot \left(T - T_f\right) + \alpha_{rad} \cdot \left(T - T_f\right) \ \left[W/m^2\right] \tag{4}$$

$$\dot{q}_{r,tot} = \alpha_{tot} \cdot \left(T - T_f\right) \left[W/m^2\right] \tag{5}$$

$$\alpha_{tot} = \alpha_{conv} + \alpha_{rad} \tag{6}$$

It is under this conditions

$$\dot{q}_{rad} = \alpha_{rad} \cdot \left(T - T_f\right) = \varepsilon \cdot \sigma \left(T^4 - T_f{}^4\right) \tag{7}$$

and the first conservation energy equation tooks form presented bellow

$$\frac{d^2T}{dx^2} - \frac{U \cdot \alpha_{tot}}{f \cdot \lambda} \cdot \left(T - T_f\right) = 0 \tag{8}$$

now boundary conditions are as follows

$$T\big|_{x=0} = T_b$$

$$-\lambda \cdot f(L)\cdot \frac{dT}{dx}\Big|_{x=L} = \alpha_{L,tot}\cdot f(L)\cdot\left(T_L - T_f\right) \qquad (9)$$

where is $\alpha_{L,tot}$ *total heat transfer coefficient from top of fins.*

For a pipe that is finned with straight longitudinal approximately rectangular fins, for $U=2\cdot L+2\cdot\delta$ *and* $f=L\cdot\delta$*, and if it is assumed that the heat transfer coefficient from the top of the fin is* $\alpha_{L,tot}=\alpha_{tot}$*, the temperature distribution is obtained by solving second differential equation with last boundary conditions,and it is below expression*

$$T(x) = T_f + (T_b - T_f)\cdot\frac{\cosh\left[m\cdot(l-x)\right] + \frac{\alpha_{tot}}{\lambda\cdot m}\cdot\sinh\left[m\cdot(l-x)\right]}{\cosh(m\cdot l) + \frac{\alpha_{tot}}{\lambda\cdot m}\cdot\sinh(m\cdot l)} \qquad (10)$$

Heat flux exchanged from the surface of the fin to the air by convection and radiation is equal to the heat flux transfered by conduction through the base of all Nr fins, and it is presented with equations bellow

$$\dot{Q}_{r,tot} = -\lambda \cdot f \cdot \left(\frac{dT}{dx} \right)_{x=0} \cdot Nr = -\lambda \cdot L \cdot \delta \cdot \left(\frac{dT}{dx} \right)_{x=0} \cdot Nr \qquad (11)$$

$$\dot{Q}_{r,tot} = \lambda \cdot m \cdot L \cdot \delta \cdot (T_b - T_f) \cdot \frac{\sinh(m \cdot l) + \frac{\alpha_{tot}}{\lambda \cdot m} \cdot \cosh(m \cdot l)}{\cosh(m \cdot l) + \frac{\alpha_{tot}}{\lambda \cdot m} \cdot \sinh(m \cdot l)} \cdot Nr \; [W] \qquad (12)$$

I want to emphasize that it is experimentally difficult to determine temperature on the base of the fins (Tb).

CALCULATION OF THERMAL CHARACTERISTICS OF A FINNED RADIATOR

In this paper will be performed calculation of the thermal characteristics of the aluminum radiator as a heating body with a steel pipe insert with a wall thickness of 2 mm, which is inserted into the water space of the radiator.

The radiator cell has the following characteristics, according to the manufacturer Aklimat:

- the water temperature at the inlet and outlet of the radia-tor is 90/70 ° C;

- the temperature of ambient is T_f*=20 ° C;*

- the thermal output of the radiator cell is =115 W;

- the height of the radiator cell is L=350 mm;

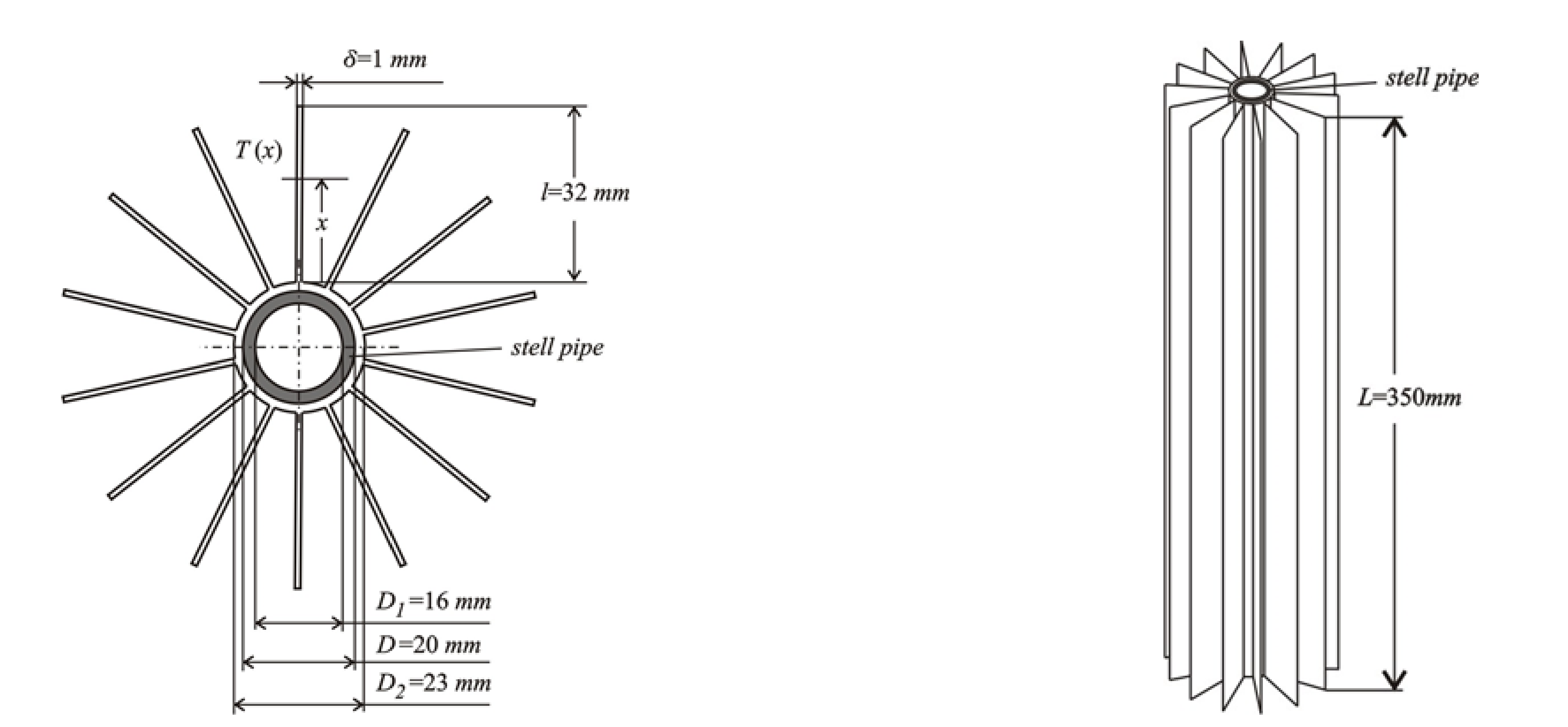
- the total exchange area of the radiator cell is A_{uk}*=0.33 m2;*

- the thickness of the fin is δ *=1 mm;*

- inner diameter of the water side of the radiator cell D_1*=20-4=16 mm; (D=20 mm);*

- outer diameter of the radiator cell D_2*=23 mm.*

Due to the simplification of solving the problem and the complexity of the geometry of the original radiator cell, a finned longitudinal cylinder of the same exchange surfaces with the same fins thickness, the same diameter on the water side, as well as the cylinder wall thickness joint will be used for calculation. In other word it is an approximated version of the given radiator cell with simpler geometry.



Calculation steps:

1. Determination the height and number of fins of the radiator

According to the manufacturer's information the total exchange area of the radiator cell is Auk=0.33 m2.

For the simplified geometry of the radiator joint, the average value of the fin height of 32 mm was adopted, while the thickness of the fin is constant and amounts to 1 mm.

The number of fins is accepted to be Nr=14.

2. Calculation of thermal characteristics of a heating element with a pipe insert

- Determination of thermo-physical properties of water

Thermo-physical properties of water are taken for mean temperature of water flowing through the radiator cell $T_{w,sr} = (90 + 70)/2 = 80\ °C$

- Determination of water flow rate and Reynolds number

Using appropriate equation water flow rate and Reynolds number are calculated.

Based on the obtained Reynolds number, a laminar flow inside the radiator cell is concluded.

- Determination of Nusselt number and convection coefficient on the water side

Nusselt number for the case of laminar internal flow have following form

$$Nu = 1.86 \cdot \left(\frac{\mathrm{Re} \cdot \mathrm{Pr}}{L / D_1} \right)^{1/3} \cdot \left(\mu / \mu_s \right)^{0,14} \quad - \quad contitons: \quad 0.6 \le \mathrm{Pr} \le 5 \quad and \quad 0.0044 \le \frac{\mu}{\mu_s} \le 9.75$$

Therefore convection coefficient on the water side is obtained

$$\alpha_1 = Nu \cdot \lambda / D_1 = 5.84 \cdot 0.670 / 0.016 = 244.6 \ W / m^2 K$$

- Determination of the heat transfer coefficient as well as the temperature on the outer surface of the cylinder and the root of the fins of the radiator cell

The temperature of the outer surface of the radiator cell and the top surface of the fins is

$$\dot{Q} = L \cdot \left(T_{w,sr} - T_b \right) / R \Rightarrow T_b = T_{w,sr} - \dot{Q} \cdot R / L = 80 - 115 \cdot 0.083 / 0.35 = 53 \ °C$$

The applied methodology is based on the coupling of heat transfer equations from the inside of the pipe and the outside over the wall temperature Tb.

- Determination of thermo-physical properties of fluids on the air side

Thermo-physical properties of air are taken from thermodynamic tables for mean temperature of air flowing through the radiator cell $T_{v,sr} = (53 + 20) / 2 = 36.5 \ °C$

- Determination of convection coefficient on the airside of the radiator cell

The Nusselt number for free convection is determined by using the following formula for appropriate conditions[3]

$$Nu = \varepsilon_R \cdot A \cdot \left(Gr \cdot \Pr\right)^m \cdot \left(\Pr / \Pr_z\right)^n$$

According to previous results, the convection heat transfer coefficient is

$$\alpha_{conv} = \alpha_2 = Nu \cdot \lambda / L = 87 \cdot 0.02682 / 0.35 = 6.7 \ W / m^2 K$$

$$\dot{q}_{rad} = 0.5 \cdot 5.67 \cdot \left[\left(326/100\right)^4 - \left(293/100\right)^4\right] = 111.3 \ W/m^2 \Rightarrow \alpha_{rad} = \frac{\dot{q}_{rad}}{T_b - T_f} = \frac{111.3}{53-20} = 3.4 \ W/m^2$$

$$\alpha_{tot} = \alpha_{conv} + \alpha_{rad} = 6.7 + 3.4 = 10.1 \ W/m^2 K$$

- Heat exchanged by convection and radiation from the outer unfinned and finned surface of a given radiator cell is obtained and total amount presented with bellow expression

$$\dot{Q}_{tot} = \dot{Q}_{r,tot} + \dot{Q}_{z,tot} = 102.5 + 6.8 = 109.3 \ W$$

CONCLUSION

For the same geometry of a finned radiator cell without a steel pipe insert, is calculated the total heat exchanged from the finned surface by convection and radiation, and it is 112.2 W. Thus, inserting a steel pipe insert slightly reduces heat dissipation from the surface of the radiator.

On the water side of the radiator cell, by inserting a steel pipe insert, the flow surface was reduced, which resulted in an increase in the fluid flow rate. Increasing the flow rate of water through the interior of the radiator also increase the value of the Reynolds number, and eventually increase the heat transfer coefficient. By adding a new layer of material, it increases the total resistance to heat conduction. All this eventually cause a decrease in the total heating capacity of the radiator joint by 2.6 % (Table 1). Experimental data showed that the total alpha (α_{tot} *) on the air-side ranged between 10 and 12 W / m2K, which is similar to the calculation.*

Table 1. Calculation results

Case	D_1 [mm]	α_1 [W/m^2K]	T_b [°C]	Nu [/]	α_{tot} [W/m^2K]	$\dot{Q}_{r,tot}$ [W]	$\dot{Q}_{z,tot}$ [W]	$\dot{Q}_{tot}$ [W]
Radiator **without** steel pipe insert	20	195.7	53.3	90,4	10.3	105.2	7.0	112.2
Radiator **with** steel pipe insert	16	244.6	53.0	87,0	10.1	102.5	6.8	109.3
Difference, %	-20	+25	-0.6	-3,8	-1.9	-2.6	-2.9	-2.6

Finally, we want to state that the solution of inserting a steel insert is technically acceptable, because it provides additional protection of the radiator from corrosion that negatively affects the capacity of the radiator, as well as to extend the service life and mechanical resistance of the radiator.