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ANALYSIS OF THERMOTECHNICAL CHARACTERISTICS OF RIBBED ECONOMIZERS OF STEAM BOILERS

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It is ascertained that the maximal values of total and unit mass heat-generation with the allocated developed surface of steam boiler economizer are not provided, unlike heat interchange by free convection of ribbed pipes, in a range of really used quantity of ribs, their thicknesses and blow speeds by combustion gases.

Economizers, in which feed (steam boilers) or extraction water (hot-water boilers) is heated, are used for reducing heat loss with end gas of steam and hot-water boilers. As the intensity of heat transfer from combustion gases to water is not high then their pipes are provided with crosscut ribbing withoutside for increasing heat-exchange surface. As a result, economizers become more compact than smooth-wall ones i.e. they have larger heat-exchange surface in a unit of volume [1].

Increasing interest to ribbed pipes in heat-exchange equipment of electric power installations at fossil fuel combustion is conditioned also by a perspective of increasing reliability of heat-exchange device (ribbed pipe length decreases in comparison with the smooth pipes, a number of contact junctions operating under pressure is reduced, a possibility of lowing gas rate appears that results in reducing ash erosion of heat-exchange surface) [2].

For example, water economizer of the system TsKTI is made of round ribbed cast-iron pipes with outer diameter d_1=76 mm. Rib height is h_p=62 mm, their thickness is δ=5 mm. Length of heated part of a pipe is L_t=3 m, 150 ribs were placed on it, i.e. rib spacing is s_p=15 mm [2]. Another economizer construction, developed in the same organization, was made of pipes with diameter d_1=28 mm. Band ribbing (rib height is h_p=10 mm, rib spacing is s_p=10 mm, their thickness is δ_p=1,0 mm, ribbing coefficient is φ=3,8) was used. Application of these rib geometries allowed reducing amount of pipes in 2,4 times in comparison with smooth variant. However, burning high-sulphur residual oil the economizer became dirty and the value of thermal efficiency factor decreased from 0,9 to 0,5. Aerodynamic resistance increased approximately by 30 %. Tests carried out with economizer showed high working capacity and efficiency at natural gas combustion [2].

Economizer of Podolsk engineering plant had the same characteristics of ribbed surface. It was set on a boiler PK-14, burning Ekibastuz coal, ash particles of which possess abrasivity. As a result of exchanging plain-tube economizer by a ribbed one the total length of pipes was reduced from 9800 m to 6700 m; a number of coils decreased respectively from 196 to 134. All deposits formed on ribbed economizer had loose character and were easily damaged from insignificant mechanical action. Ribbed economizer operated more efficient than the equivalent plain-tube economizer [2].

Designing such heat exchangers the questions of determining their rational geometrics are urgent [3]. Depending on the purpose of heat exchanger a number of additional demands are made to them. For example, minimal overall sizes of heat exchanger or minimal weight.

The correctly designed ribbing allows increasing in several times the transferred amount of heat (at preset temperature) in comparison with the smooth-wall surface. Incorrectly designed ribbing may even impair wall heat emission («insulating rib effect») [2].

The aim of thermal design of ribbed surface is to determine the connection of transferred heat flow with heat carrier and wall temperatures, heat-transfer coefficients, rib geometries and thermal conductivity.

In monograph [3] the results of solving the problem on optimization of radiator sizes – horizontal tube with circular ribs at air free convection are given. Dependences E_p, s_p, δ_p and outer rib radius on material specified volume on tube length unit at which the transferred amount of heat is maximum are numerically determined. The designs were carried out for the ribbed copper, aluminum and stainless steel pipes.

As these data were obtained at heat exchange of ribbed surface with air in free convection mode then they give high error for economizer operating conditions.

The aim of the article is to analyze the influence of surface ribbed part geometries and combustion gas rate on economizer thermal characteristics.

The method of thermal design which is based on the equation system of heat flow balance transferred through the ribbed wall became the most widespread in engineering practice [3–5]. The following assumptions: heat carrier temperature and temperature on internal (smooth) side of bearing wall are homothermal, are used. Wall temperature from the ribbing side is the same under ribs and in inter-rib gaps and equals t_s.

Parametric analysis was carried out on the following problem. Water economizer is made of round ribbed cast-iron pipes with outer radius r_1=38 mm. Rib height is h_p=62 mm, their thickness changes in the range from 1 to 5 mm. The length of pipe heated part is L_t=1 m. Quantity of ribs n_p varies on pipe length in the range from 40 to 160 so that $s_p \geq 5$ mm [6]. Temperature on rib base is t_s=180 °C, gas temperature is t_g=400 °C (Fig. 1).

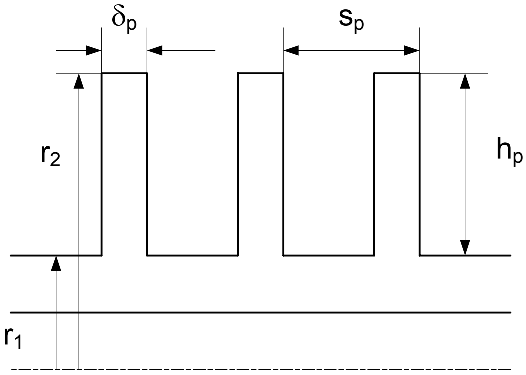

Fig. 1. *Diagram of pipe circular ribbing*

Amount of heat transferred from hot gases to external surface of ribbed pipe was calculated by the formula

$$Q_{pc} = Q_p + Q_c = n_p Q_{p1} + 2\pi r_1 \alpha_k (t_g - t_s)(L_t - n_p \delta_p),$$

where Q_p, Q_c are the amount of heat transferred through the ribbed surface and surface between ribs, respectively, W; α_k is the heat-transfer coefficient from washing medium to ribbed wall.

Dependence of heat-exchange intensity on rib spacing was accepted according to [5]

$$\alpha_k = 0{,}0413(\lambda_g / s_p)(w_g s_p / v_g)^{0{,}72},$$

where w_g, λ_g, v_g are the rate, heat conductivity and kinematic viscosity of combustion gases flowing around the ribbed pipe; s_p is the rib spacing, m, the magnitude of which was determined in the following way

$$s_p = (L_t - n_p \delta_p)/(n_p - 1).$$

Heat emission from rib end was approximately accounted increasing r_2 by a half of rib thickness $r_{2f}=r_2+\delta_p/2$ [3, 4].

Amount of heat withdrawn form one rib is calculated by the formula [4]

$$Q_{p1} = 2\pi r_1 \delta_p m \lambda (t_g - t_s)\psi,$$

$$= \frac{I_1(s_{2f})K_1(s_1) - I_1(s_1)K_1(s_{2f})}{I_0(s_1)K_1(s_{2f}) + I_1(s_{2f})K_0(s_1)},$$

where $m=\sqrt{2\alpha_k/\lambda\delta_p}$ is the complex, 1/m; $s_1=r_1 \cdot m$, $s_{2f}=r_{2f} \cdot m$ are the dimensionless coordinates; δ_p is the rib thickness; λ is its heat conductivity equal 52 W/(m·K); $I_0(s_i)$, $K_0(s_i)$, $I_1(s_i)$, $K_1(s_i)$ are Bessel functions of the first and the second types of zero and first order, respectively, their values were determined by interpolation dependences from reference books [7].

Thermal effectiveness of round rib and pipe ribbed surface were calculated by the expressions [4]:

$$E_p = 2r_1\psi / [m(r_{2f}^2 - r_1^2)],$$

$$E_T = Q_{pc} / Q_{gl} = Q_{pc} / 2\pi r_1 \alpha_t (t_g - t_s) L_t,$$

where Q_{gl} is the amount of heat transferred through the pipe without ribs, W; α_t is the heat-transfer coefficient at crosscut washing of smooth pipe combustion gases was calculated by the formulas [8]:

- at $Re_d=w_g d_1/v_g \le 10^3$ $\alpha_T=0{,}44(d_1/\lambda_g)Re_d^{0{,}5}$;
- at $10^3<Re_d \le 2\cdot 10^5$ $\alpha_T=0{,}22(d_1/\lambda_g)Re_d^{0{,}6}$.

In paper [6] the efficiency of ribbed heat utilizers for boilers was analyzed by heat productivity per rib mass unit

$$Q_M = Q_{pc} / M_p, \quad M_p = \rho_p n_p \pi (r_2^2 - r_1^2)\delta_p.$$

At «manual» calculations, nomograms for determining α_k, E_p [3–5] are used that slows down the procedure of obtaining results and introduces error in them. In order to automate such work the program of computing characteristics of ribbed economizers at given α_k, written in Turbo Pascal environment [9] was modified. The dependence of combustion gas thermal properties on temperature was accounted by Lagrange interpolation polynomial [10].

It is ascertained that at decrease of rib thickness the Q_{pc} decreases, however, specific heat productivity of rib increases (Fig. 2). Numbers above the diagrams denote: variant 1 – δ_p = 5 mm; 2 – δ_p = 1 mm. In this case, rib spacing s_p decreases in such range: variant 1 – from 22 to 5 mm; variant 2 – from 24 to 5 mm combustion gas rate was taken equal 9 m/s. heat-transfer coefficient grows in the following ranges: variant 1 – from 38,6 to 57,2 J/(m²·K), variant 2 – from 36,7 to 56,5 J/(m²·K), and value α_T = 43,3 J/(m²·K).

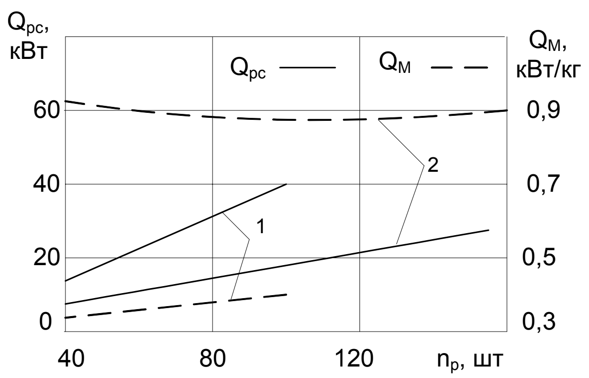

Fig. 2. *Dependence of absolute and specific quantity of heat on rib quantity at their different thickness*

Use of more ribs results in increase of E_T and slight decrease of rib efficiency. For thinner ribs both E_p, and E_T decrease (Fig. 3).

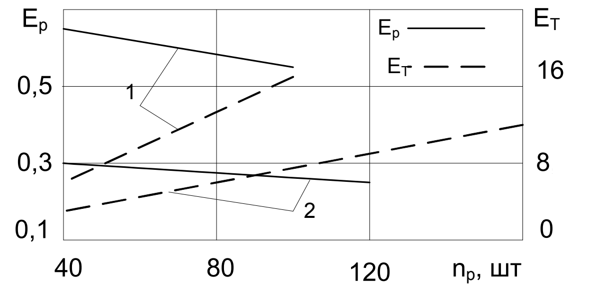

Fig. 3. *Dependence of efficiency of a single rib and ribbed pipe on a quantity of ribs at their different thickness*

Decrease of w_g in three times at δ_p=5 mm resulted in reduction of α_k, α_T (Fig. 4) and E_T to 6,4, however, value E_p increased to 0,82 (Fig. 3). These results correspond qualitatively to literary data [3, 4].

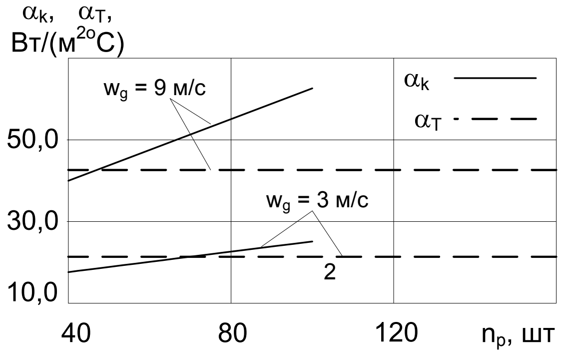

Рис. 4. *Dependence of heat-transfer coefficients of ribbed and smooth pipe on rib quantity*

However, attaching a large number of ribs at short spacing between them complicates the technology of producing and maintenance of this economizer unit.

The results of calculation of thermotechnical characteristics of the above mentioned water economizer of the system TsKTI made of large ribbed cast-iron pipes with outer diameter d_1=28 mm, rib height h_p=10 mm, rib spacing s_p=10 mm, their thickness δ_p=1,0 mm are generalized in the form of interpolation dependences: $Q_M=5{,}021-0{,}0263n_p+0{,}147\cdot10^{-2}n_p^2$, $Q_{pc}=0{,}33+0{,}0267n_p$, $E_p=1{,}015-0{,}55\cdot10^{-2}n_p$.

At n_p=90 pcs. s_p=10 mm, value Q_M=3,87 kJ/kg, Q_{pc}=3,0 kJ, E_p=0,979.

As it is seen, in this case maximal value of Q_M could not be selected.

Thus, using the program written in Turbo Pascal medium of thermal characteristics of economizer area with crosscut ribbed pipe was analyzed. It is ascertained that unlike heat exchange of free convection of such heat exchanger [3] in the range of really used quantity of ribs, their thicknesses, rates of combustion gas blowing, maximal values of total and specific mass heat productivity withdrawn by extended surface of steam boiler economized are not provided.

The developed program of calculation may be used in technique of diagnosing operating conditions of low-temperature heating surfaces, ascertaining deviation of selected diagnostic indicators from the magnitude calculated by mathematical model for concrete working conditions of heat exchangers.

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