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Heat Exchangers Comparation

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Abstract: Extended surface heat exchangers are used for water and air as operating mediums, and can be differentiated by the ribs shape. The one has sinuous type ribs, while the other one has flat lamella ribs. In this paper comparison between both types of heat exchangers is made with reference to air velocity in the minimum flow cross - section and Reynolds' number. Better heat transfer can be provide using exchanger with higher values of coefficient α_r and factor j_a. Computer program for mathematical model is made and graphical representation or the results is given.

Keywords: heat exchanger, heat transfer.

1. Mathematical model

Temperature condition for the calculation of heat transfer through ribbed surface of tubes at lamella type heat exchangers, for working mediums water-air and where cooling of the air occurs is visible on Fig. 1. Here, we can see that heat from the fluid surrounding the pipe outside (air) is transferred on the fluid inside the pipe (water).

Heat transfer from the air onto the water is constant since there is neither heat source nor heat sink between both medias.

Total transferred heat is a sum of heat transferred through the outer surface of the pipe [without ribs] A_{cn}, and the heat transferred through ribs area, A_r.

$$Q = \alpha_r \cdot A_r \cdot (t_a - t_{rm}) + \alpha_{cn} \cdot A_{cn} \cdot (t_a - t_{cn}),\ \mathrm{W} \tag{1}$$

α_r and α_{cn} are almost equal,

$$Q = \alpha_r \cdot [A_r \cdot (t_a - t_{rm}) + A_{cn} \cdot (t_a - t_{cn})] \quad ,\mathrm{W} \tag{2}$$

Coefficient of convective heat transfer from the outer side is,

$$\alpha_{an} = \alpha_r \cdot \left(\frac{A_r}{A_n} \cdot \eta_r + \frac{A_{cn}}{A_n} \right) \tag{3}$$

Where,

$$\eta_r = \frac{t_a - t_{rm}}{t_a - t_{cn}} \tag{4}$$

The degree of usefulness is the ratio between heat transferring onto the ribs and heat that would be transferred on the ribs, when all of them would have temperature t_{cn}.

$$\eta_p = \frac{A_r}{A_n} \cdot \eta_r + \frac{A_{cn}}{A_n} \tag{5}$$

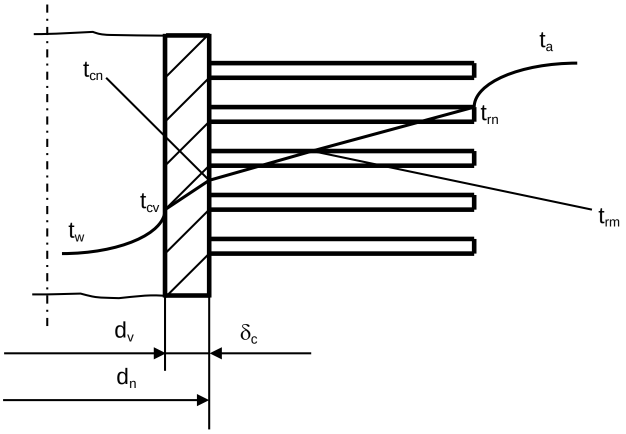

Fig. 1. Temperature variations on ribbed pipe

is heat exchanger's level of utility area,

$$\alpha_r = \frac{1}{L \cdot \eta_p \cdot \left(R - \frac{A_n}{A_v} \cdot \frac{1}{\alpha_v} - \frac{A_n}{A_v} \cdot \frac{\delta_c}{\lambda_c} \right)} \tag{6}$$

coefficient of convective heat transfer of ribs.

Expressions for η_p and α_r form system of two equations with two unknowns that is solved through iteration method. Approximately, for the first iteration η_p=0,8.

Air flows by the length of the rib and upright on the pipe. Cross-section of the fluid between ribs is changed through the current flow. Because of that and sinuous form of lamellas, local coordinates depend on the direction and value of speed.

Most of authors, [1] and [2], in their calculations, use maximum velocity of the air in the minimum cross-section,

$$w_{amax} = \frac{m_{sa}}{A_{min}} \tag{7}$$

Hydraulic diameter is taken as a characteristic value when Reynolds' number is calculated [1],

$$d_h = \frac{4 \cdot A_{min}}{A_{cn}} \tag{8}$$

where Reynolds' number,

$$Re_a = \frac{w_{amax} \cdot d_h}{\nu_a} \tag{9}$$

Heat transfer factor, ja, is usually in non-dimensional form [3],

$$j_a = St \cdot Pr_a^n \tag{10}$$

Stanton's-number,

$$St = \frac{Nu}{Re_a \cdot Pr_a} \tag{11}$$

Solution of the previous two terms is,

$$j_a = \frac{\alpha_a \cdot A_{min}}{m_{sa} \cdot c_{pa}} \cdot Pr_a^n \tag{12}$$

A number of authors, in the calculation of convective heat transfer, take the value of exponent of Prantdl's number to be n =0,667. Kotke and Blenke examined the influence of flow on this exponent. They suggest the following function in the expression of convective heat transfer, [4],

$$Pr_a^n = f(\mathrm{Pr}_a) = 1{,}8 \cdot Pr_a^{0,3} - 0{,}8 \tag{13}$$

Now,

$$j_a = \frac{\alpha_r \cdot A_n}{m_{sa} \cdot c_{pa}} \cdot 1{,}8 \cdot Pr^{0,3} - 0{,}8 \tag{14}$$

Factor ja can be found as a function of Reynolds' number,

$$j_a = a \cdot Re_a^b \tag{15}$$

Constants a and b are coefficients of correlation of the values for ja and Reynolds' number.

2. Numerical example

Measurements are taken on two heat exchangers, and their dimensions are visible on Table 1. Heat exchanger number 1 has sinuous lamellas, while heat exchanger number 2 has flat lamellas, [5].

Table 1. Measured dimensions of heat exchangers

Dimensions	No. 1	No. 2
H_t [mm]	468	468
B_t [mm]	500	500
H_r [mm]	465	465
δ_r [mm]	0,15	0,15
B_r [mm]	172,8	172,8
R_r [mm]	2,6	2,6
n_r	192	192
C_h [mm]	33,3	33,3
C_b [mm]	28,8	28,8
d_v [mm]	11	11
d_n [mm]	12,3	12,3
n_{red}	6	6
n_{red1}	14	14
n_{pc}	16	16
n_c	84	84

Calculated surface areas of the heat exchangers are presented on Table 2. Calculations are made according to [6], while surface area is given in m2.

Table 2. Calculated dimensions of heat exchanger

Dimensions	No. 1	No. 2
Frontal surface area of heat exchanger: $A_f = H_t \cdot B_t$	0,234	0,234
Minimum flow cross-section: $A_{min} = \left(H_r - n_{cr} \cdot d_n\right) \cdot n_r \cdot R_r$	0,146	0,146
Ratio: $\sigma = \dfrac{A_{min}}{A_f}$	0,625	0,625
Surface area of non-ribbed pipes: $A_{cn} = d_n \cdot \pi \cdot n_r \cdot R_r \cdot n_c$	1,620	1,620
Surface area of ribs: $A_r = \dfrac{\left(d_r^2 - d_n^2\right) \cdot \pi}{2} \cdot n_r \cdot n_c$	29,812	27,102
Pipe surface area between ribs: $A_g = \left(R_r - \delta_r\right) \cdot d_n \cdot \pi \cdot n_r \cdot n_c$	1,527	1,527
Total area of heat transfer: $A_n = A_r + A_g$	31,339	28,629
Internal pipe area: $A_v = d_v \cdot \pi \cdot n_r \cdot n_c \cdot R_r$	1,449	1,449

Table 3. Measured and calculated values for heat exchanger number 1

m_{sa} kg/s	m_{sw} kg/s	t_{av} °C	t_{ai} °C	t_{wv} °C	t_{wi} °C	Q_a W	Q_w W	Q_s W	k W/m²K	α_w W/m²K	w_a m/s	α_r W/m²K	Re_a	j_a	η_r	η_p
0,233	0,231	20,88	12,83	5,32	10,18	5029	4715	1965	17,20	513,19	1,309	27,86	2566	0,0143	0,89	0,88
0,315	0,231	19,90	13,40	5,32	10,27	5059	4802	2138	17,68	513,16	1,768	34,38	3473	0,0130	0,86	0,86
0,413	0,231	19,69	13,66	5,21	10,23	5126	4870	2586	17,81	512,80	2,318	43,97	4553	0,0127	0,83	0,83
0,491	0,231	19,94	13,86	5,22	10,31	5235	4938	3087	17,96	512,83	2,758	55,51	5407	0,0135	0,80	0,79
0,563	0,231	20,57	14,28	5,31	10,57	5341	5103	3652	17,65	513,12	3,168	61,04	6185	0,0129	0,79	0,78
0,665	0,231	18,77	13,42	5,49	10,12	4716	4492	3652	17,94	513,65	3,725	78,11	7349	0,0140	0,74	0,73
0,754	0,231	18,06	13,35	5,91	10,25	4335	4211	3638	17,88	514,95	4,218	84,45	8346	0,0134	0,73	0,72
0,833	0,231	19,66	14,46	5,82	10,78	5040	4812	4436	18,18	514,69	4,682	99,82	9167	0,0143	0,70	0,68
0,925	0,231	22,34	16,46	6,03	12,06	6100	5850	5568	18,61	515,39	5,241	121,37	10071	0,0156	0,66	0,64
1,009	0,231	22,77	17,13	6,04	12,40	6302	6170	5823	18,23	515,44	5,728	108,04	10958	0,0128	0,68	0,67
1,084	0,230	23,25	17,75	5,97	12,70	6395	6501	6097	18,64	514,11	6,165	133,03	11742	0,0146	0,64	0,62
1,138	0,231	25,81	19,16	5,28	13,42	8376	7897	7750	18,91	513,10	6,516	143,12	12214	0,0150	0,63	0,61

Table 4. Measured and calculated values for heat exchanger number 2

m_{sa} kg/s	m_{sw} kg/s	t_{av} °C	t_{ai} °C	t_{wv} °C	t_{wi} °C	Q_a W	Q_w W	Q_s W	k W/m²K	α_w W/m²K	w_a m/s	α_r W/m²K	Re_a	j_a	η_r	η_p
0,235	0,225	24,45	15,42	6,16	12,64	6310	6124	2251	19,82	550,59	1,334	27,96	2552	0,0142	0,89	0,88
0,324	0,225	22,90	15,85	5,91	12,31	6142	6048	2408	19,77	549,71	1,836	30,98	3528	0,0114	0,88	0,87
0,415	0,225	22,25	15,97	5,95	12,11	5850	5821	2727	19,30	549,82	2,349	34,41	4525	0,0099	0,86	0,86
0,477	0,226	21,80	15,67	5,87	11,72	5593	5553	3041	18,87	550,75	2,697	37,77	5209	0,0094	0,85	0,85
0,542	0,226	21,54	15,45	5,74	11,41	5436	5382	3417	18,51	550,30	3,062	41,89	5926	0,0092	0,84	0,83
0,595	0,228	21,61	15,40	5,72	11,31	5359	5353	3812	18,16	552,65	3,361	45,00	6505	0,0090	0,83	0,82
0,717	0,217	20,67	14,88	5,59	11,04	5087	4967	4262	18,43	538,69	4,040	62,00	7865	0,0103	0,78	0,77
0,827	0,218	21,52	15,52	5,04	11,20	5624	5640	5087	18,42	538,13	4,672	68,59	9041	0,0099	0,77	0,75
0,923	0,219	22,83	16,28	3,84	11,07	6679	6650	6194	19,16	535,42	5,233	85,59	10042	0,0111	0,73	0,71
1,025	0,223	18,30	14,27	5,91	10,69	4578	4477	4219	19,45	547,11	5,746	84,78	11318	0,0099	0,73	0,71
1,104	0,226	18,39	14,51	5,84	10,74	4677	4651	4374	19,87	550,54	6,192	93,60	12182	0,0101	0,71	0,70
1,177	0,227	18,88	14,93	5,46	10,76	5071	5053	4747	20,04	550,49	6,612	98,11	12961	0,0099	0,70	0,69
1,200	0,227	20,80	16,37	5,57	11,63	5549	5778	5429	20,39	550,89	6,780	114,14	13115	0,0113	0,67	0,65

Measured values are taken according to [7].

3. Conclusions

Measured and calculated values for both heat exchangers are presented on Tables 3 and 4, respectively. Calculations are made for constant mass flow of water, with the aim of calculating heat transfer from the outer side of heat exchanger. Values for convective heat transfer of the ribs, αr, and heat transfer factor, ja, are also shown.

The dependence of both factors [αr and ja] relative to wa and Re is shown on Fig. 2, and Fig. 3., respectively, while analytical dependence is given with the following expressions,

- Heat exchanger number. 1, $\alpha_r = 22{,}104 \cdot w_a - 5{,}1119$ $j_a = 0{,}0086 \cdot \mathrm{Re}_a^{0{,}0531}$
- Heat exchanger number 2, $\alpha_r = 15{,}476 \cdot w_a - 0{,}7355$ $j_a = 0{,}00233 \cdot \mathrm{Re}_a^{-0{,}0912}$

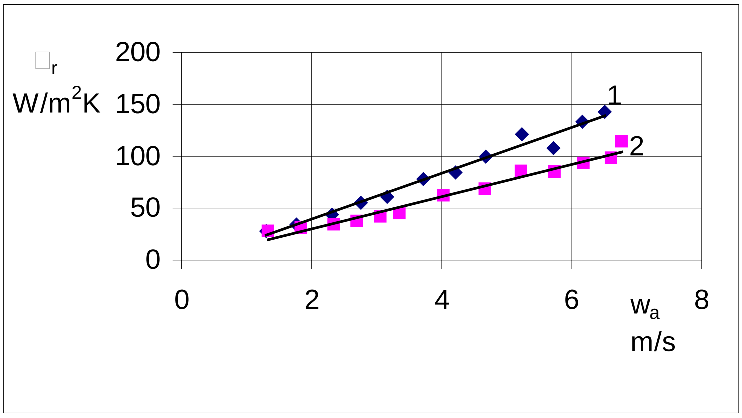

Fig. 2. Dependence of coefficient of convective heat transfer from the air onto pipe with ribs α_r, from air velocity in the minimum flow cross-section w_a

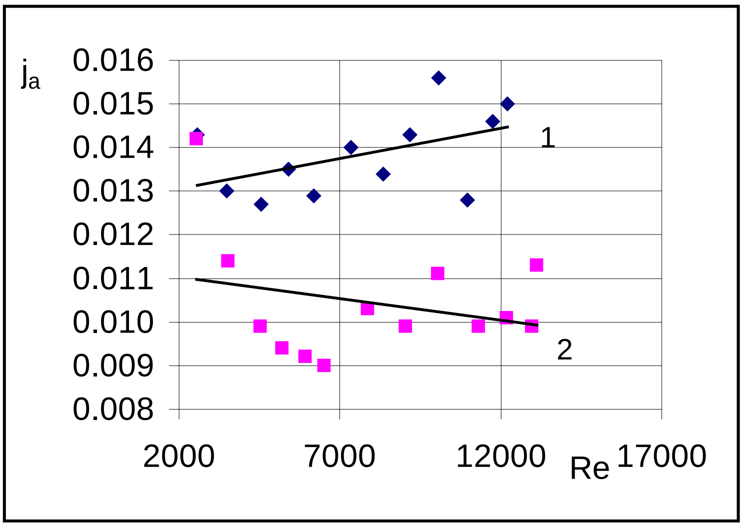

Fig. 3. Dependence of heat transfer coefficient, j_a, from Reynolds' number

Heat exchangers with higher values of coefficient αr and factor ja have better heat transfer. According to this, heat exchanger number 1, with sinuous shaped lamellas has better heat transfer. This is expressed in larger values for wa, or when wa > 4 m/s and with greater Reynolds' number values, Re > 9000.

Nomenclature

B_r - lamella's width [mm]
B_t - heat exchanger's width [mm]
C_b - distance between pipes onto heat exchangers' width [mm]
C_h - distance between pipes onto heat exchangers' height [mm]
d_n - external pipe diameter [mm]
d_v - internal pipe diameter [mm]
f_a - friction coefficient [dimensionless]
H_r - lamella's height [mm]
H_t - heat exchanger's height [mm]
j_a - heat transfer factor [dimensionless]
n_c - number of pipes [dimensionless]
n_r - number of lamellas [dimensionless]
Q - heat energy [W]
R_r - spacing between lamellas [mm]
t_a - temperature of the air [°C]
t_{cn} - temperature on the pipe's external surface [°C]
t_{cv} - temperature on pipe's internal surface [°C]
t_m - mean temperature [°C]
t_{rm} - mean temperature on the rib [°C]
t_w - water temperature [°C]
α_{cn} - coefficient of convective heat transfer from the air onto pipe without ribs [W/m^2K]
α_r - coefficient of convective heat transfer from the air onto ribbed pipe [W/m^2K]
α_w - coefficient of convective heat transfer on the side of the water [W/m^2K]
δ_r - lamella's thickness [mm]

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