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Influence of pollutions on the thermal characteristics, heat efficiency and optimal dimensions of tubes with londitudinal fins

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Abstract. In this report the results of experimental investigation on the influence of pollution on heat characteristics of tube with longitudinal fins are presented. The thickness of polluting on the finned surface in different time moments is measured. The dynamic of growth for polluted thickness is determined. As follows from experiments, the profile of polluting along the height of fins is near to trapezoidal. The temperature distributions in fins and total heat flux conducted by finned wall at the different time moments are found. The presence of pollution on the finned surface leads to change of temperature distribution in fins which substantially differ from the similar distributions for "clean" fins. The questions connected with the choice of the optimum dimensions of fins being polluted are discussed. It is shown that the optimum dimensions of fins are dependent on the value Biot number of polluting.

Key words: pollution, fin, tube, temperature

INTRODUCTION

In the process of exploitation of finned heat exchanges, which work in polluted environment there is affected their heat efficiency. It is caused by precipitation of pollution on the extended surface. The profile of this pollution along the fin height may be complicated and the influence of pollution on the thermal characteristics of finned surface can be considerable.

By the modelling of heat transfer processes in the fins with pollution or coating which possess a low heat conductivity it was shown [1, 2], that in this case the thermal characteristics of finned surface have a considerable distinction from the characteristics of "clean" surfaces. For example, the temperature distributions in fins with pollution are characterized by great differences from the similar distributions for fins without polluting. Besides, the presence of pollution on the finned surface lead to the necessity of taking into account the influence of pollution on the choice of the optimum dimensions of fins [1,2].

In this report there are presented the results of experimental investigations in which the processes of growth of the pollution on the finned surface and influence of pollution on the temperature distributions, heat efficiency of fins and summary heat flux from tubes with the longitudinal fins were studied. Also, the questions are studied connected with the calculated heat transfer methods and the choice of fin optimum dimensions for conditions of pollution of the extended surface.

EXPERIMENTAL APPARATUS AND PROCEDURES

There was created the experimental set up for investigation of influence the pollution on heat transfer conditions in tubes with longitudinal fins (Fig. 1). As a source for production of the waste gases with the polluted components, a diesel-fed engine was used having the power of 48 kWt, which worked using the fuel-oil. The experimental test section consists of the finned tube, which is contained within the outside tube (system "tube in tube"). The heating surfaces of this section had the next dimensions: outside tube diameter – 89 mm, inside tube diameter – 30 mm, length of tube – 2500 mm; fin height – 20 mm; fin thickness – 1 mm; number fins on the tube – 12.

The experiments were carried out in three directions:

1) Carrying out of balance tests.
2) Measuring the temperature of heat carriers in the channel inside a pipe, and leading into a pipe, in the wall of pipe and along the fin height in the different sections of test section.
3) Determination of the thickness, and thermal and physical properties of pollution.

In balance tests the expenditure of exhaust-gas and water, and output temperatures of gas and water were determined. Also the aerodynamic resistance in gas highway was determined.

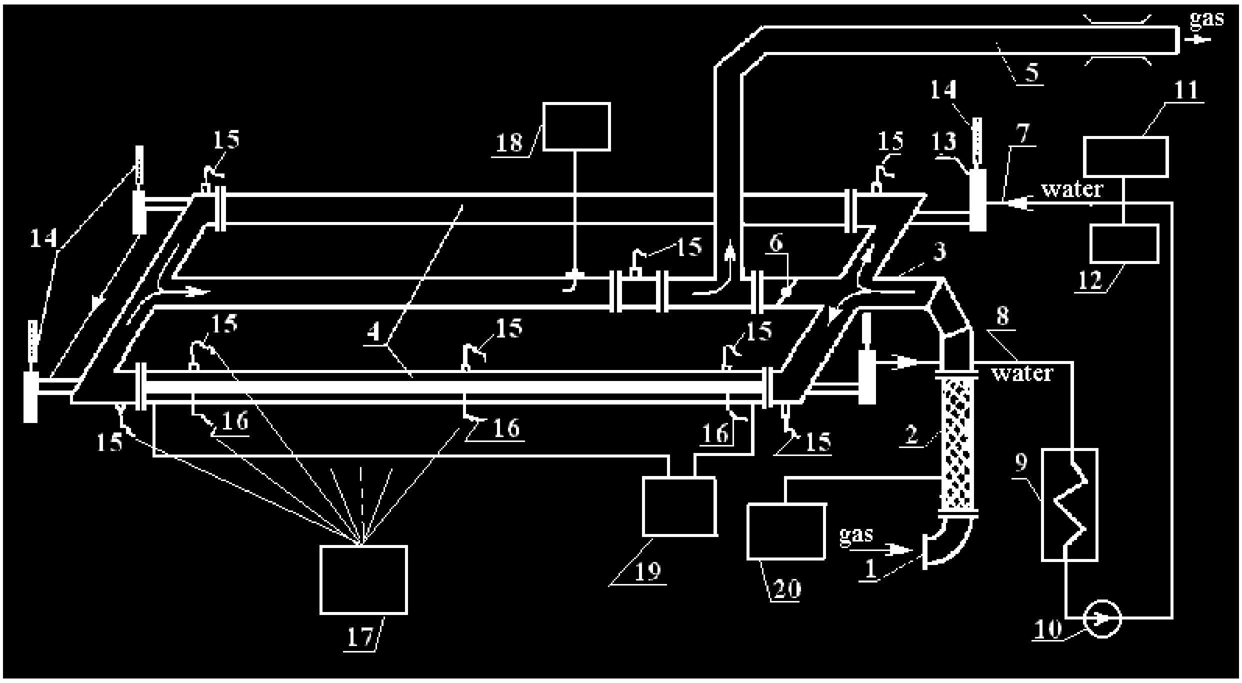

Fig. 1. Scheme of the experimental set up: 1 – inlet tube; 2 – flexible junction; 3 – gas collector; 4 – experimental sections; 5 – outlet tube; 6 – regulation valve; 7 – arrangement for bringing cold water up; 8 – arrangement for the leading of hot water; 9 – system for the cooling of hot water; 10 – circular pump; 11 – device for the measurement of water expenditure; 12 – device for the measurement of the pressure of water; 13 – thermometer for the measurement of the temperature of water; 14 – cartridge-case of thermometer; 15--16 – thermocouples; 17 – device for the measurement of temperatures; 18 – device for the measurement of gas expenditure; 19 – device for the measurement of the change of gas pressure in the experimental section; 20 – device for the measurement of gas pressure

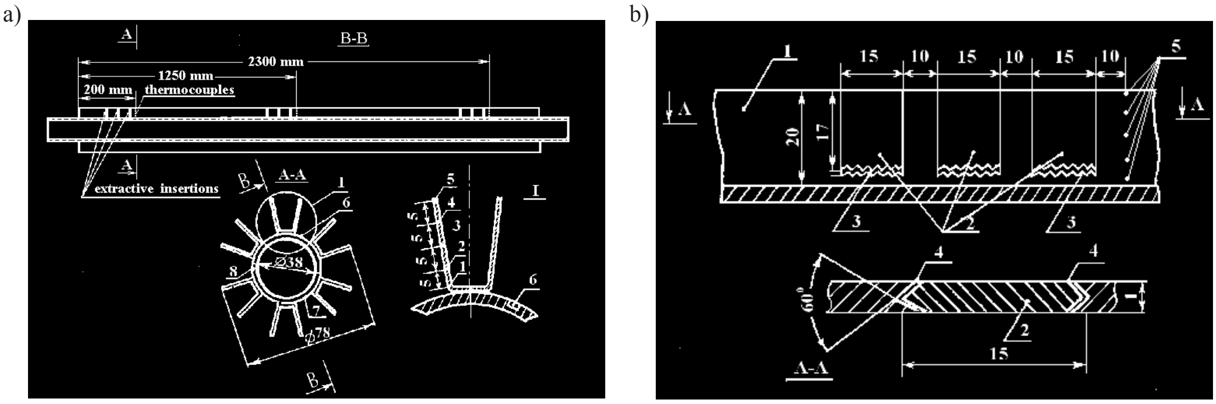

Fig. 2. Experimental section: a) longitudinal and cross section of finned tube, 1-8 – thermocouples along the fin height and on the tube; b) area of fin with insertions for the determination of the thickness and profile of pollution, 1 – fin; 2 – insertions of the type «swallow tail»; 3 – toothed base of insertions; 4 – junction of the insertion with fin; 5 – thermocouples

Table 1. Expenditure and temperature of heat carriers

Name values	Dimension	Stage I	Stage II	Stage III	Stage IV
Time	hour	4	72	144	216
Gas expenditure	kg/hour	215	207	206	205
Temperature of gas input output	°C	294.9 91.6	294.2 110.3	295.0 124.4	296,5 128,5
Water expenditure	kg/hour	3670	3700	3470	3710
Temperature of water input output	°C	57.6 60.3	56.6 58.6	50.7 53.1	54,0 56,2

For the realisation of works three sections of the finned pipe were prepared for the distances $L_1=200$, $L_2=1250$ and $L_3=2300$ from the beginning of fins (Figure 2). In these sections for the measuring of temperatures in the finned pipe thermocouples were set - in the pipe under the fin, in the middle part of the pipe between the fins and also a few thermocouples along the height of fin with the distance of 5 mm between them (Fig. 2a).

With the purpose of determination of the thickness as well as the thermal and physical properties of pollution on the fin, insertions were made of the type «swallow tail» with toothed base (Fig. 2b). On each of the three sections on the length of pipe three insertions were made. This gave the possibility to take the insertions out in different time moments. To provide a reliable contact between the insertions and the fin, an aluminium foil was used. In different moments of time, the measurement of expenditures, pressures, temperatures was conducted and the collection of insertions was performed. Further, the thickness of pollution was measured for the different heights of the fin, weighing the insertions with pollution, afterwards the coefficient of heat conductivity was calculated for the samples of pollution.

The measurements were conducted for the time period right up to the completion of stabilising of the thickness of polluted layer. Such measurements were conducted in in a few stages:

I. tests with a clean surface period of time),
II. in 72 hours (3 days) the work of setting,
III. in 144 hours (6 days) the work of setting,
IV. in 216 hours (9 days) the work of setting,
V. in 288 hours (12 days) the work of setting.

RESULTS AND DISCUSSION

As the conducted measurements showed, after 216-220 hours (9 days) the thickness of pollution on the surface of the finned pipe was stabilised. The results of the measurement of expenditure for gas and heat carriers, their temperatures on and beyond the experimental section for different time periods are presented in Table 1.

In Table 2 the results of the measurement of the thickness of pollution are presented for different sections along the length of finned pipe and along the height of fin for different distances from the fin base. Besides, in Table 2

Table 2. Thickness of pollution on the surface along the fin height for the different sections

Name values	Dimension	Stage II			Stage III			Stage IV		
		L_1	L_2	L_3	L_4	L_5	L_6	L_7	L_8	L_9
Gas expenditure	kg/hour	207			206			205		
Temperature of gas	°C	288	190	124	290	204	129	291	205	131
Thickness of pollution along the height of fin	mm									
0,15h		0.88	0.60	0.22	1.35	1.12	0.53	1.65	1.45	0.90
0,25h		0.82	0.5	0.22	1.25	1.08		1.60		0.88
0,5h		0.67	0.35	0.18	1.08	0.89	0.35	1.35	1.25	0.78
0,75h		0.54	0.26	0.12	0.95	0.74	0.30	1.25	1.10	0.72
h		0.49	0.23	0.08	0.87	0.60	0.25	1.15	1.00	0.67
Average thickness of pollution along the height of fin	mm	0.75	0.40	0.17	1.13	0.90	0.38	1.40	1.26	0.80
Average increase of pollution	mm	0.75	0.40	0.17	0.38	0.50	0.21	0.27	0.36	0.42

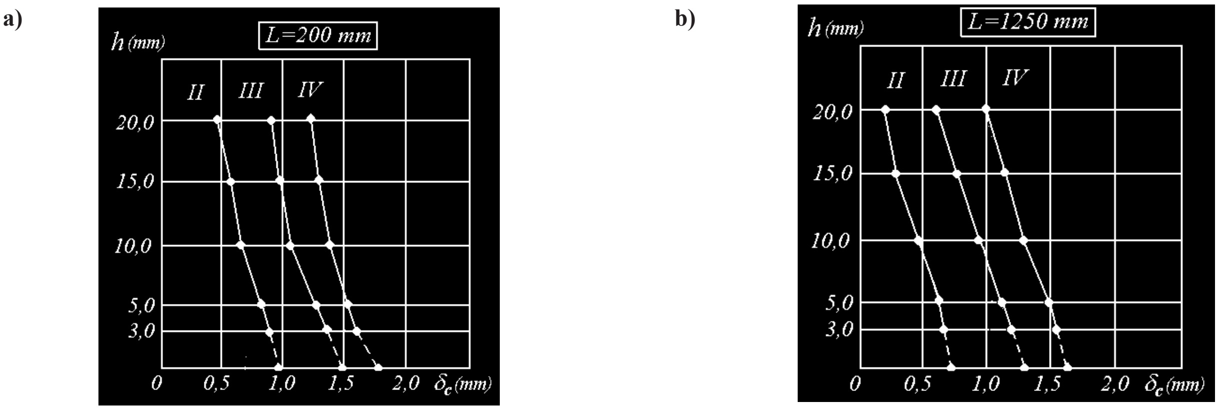

Fig. 3. The distribution of thickness of pollution along the fin height in the different cross-sections of the fin: a) $L=200$ mm; b) $L=1250$ mm

the average thickness and average increase of thickness of pollution along the height of fin are presented for the different sections of a pipe. As follows from the measurement, the thickness of pollution increases on the measure approaching the fin base, and that of pollution along the height of fin for all sections is near to trapezoidal (Fig. 3). The thickness of pollution is decreased along the length of fin (Fig. 4). The dynamics of change of the pollution thickness on the fin in time is presented in Fig. 5. From this figure it follows, that for the initial periods of time the most intensive growth of deposit. With time the speed of increase falls and it is not increased in future, therefore there follows the stabilisation of deposit thickness. This process is typical for all the sections along the length of pipe. However, the processes of stabilisation of pollution have some displacement at times (later in the process) while approaching the areas of finned surface.

Characteristically, on the initial areas of finned pipe the increase of depositsis is substantially greater than on the areas.

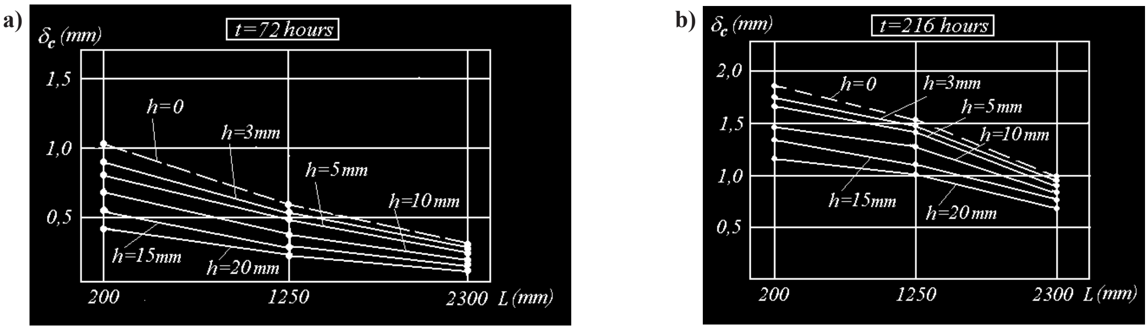

Fig. 4. The distribution of thickness of pollution along the fin length in the different cross-sections on the height of fin: a) $t=72$ hours; b) $t=216$ hours

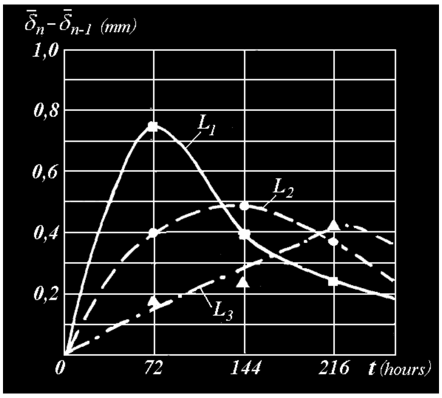

Fig. 5. The dynamics of change of average pollution thickness on a fin (=II, III, IV – number of stage)

The measurement of the coefficient of heat conductivity for the material of pollution was conducted. It turned out that this value is near to $\lambda_c = 0.11$ Wt/m^{0}C. Some deviations from this value are caused by the changes in the structure of pollution during its growth on the finned surface at different time moments. In the initial periods of time they have a more dense structure, and with time soot pollution has a more fragile structure, and its thermal and physical properties are changed. The measurement showed that the maximal deviations from the middle value 0.11 Wt/m^{0}C did not exceed 10%.

The results of the measurement of the temperature of pipe and fins, in the different points on the height on the different sections along the length of finned pipe, are presented in Table 3. The typical temperature distributions along the height of fin, in one of sections for different time moments are shown in Fig. 6. As follows from the figure, the temperature distribution in the fins at the presence of pollution substantially differs from the distribution for fins without pollution. The presence of deposits on the finned surface leads to a more uniform

Table 3. The temperature of fin along the height for the different sections along the length of pipe

Name values	Stage I			Stage II			Stage III			Stage IV		
	L_1	L_2	L_3	L_1	L_2	L_3	L_1	L_2	L_3	L_1	L_2	L_3
Gas expenditure, kg/hour	215			207			206			205		
Temperature of gas, °C	282	154	91	288	190	124	290	204	129	291	205	131
Temperature of tube, °C	65	62	60	59	59	58	54	54	52	57	56	55
Temperature of fin along the height, °C												
0,15h	65	62	60	59	59	58	54	54	52	57	56	55
0,25h	102	87	64	67	64	60	65	60	53	67	60	57
0,5h	117	93	65	82	69	62	76	64	57	78	66	60
0,75h	140	98	66	95	77	64	92	74	60	99	75	63
H	187	122	76	126	93	72	118	86	86	120	89	70

distribution of temperature along the height of fins - the more so, the thicker the deposits.

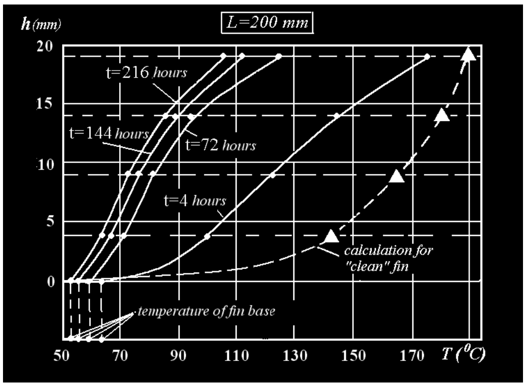

Fig. 6. The temperature distributions along the height of fin for the section $L=200$ mm in the different time periods

Using the balance measurement of the expenditures and temperatures for gas and water heat carriers, the total heat flux leading from finned tube in the different moments of time was calculated. The results of the calculation are presented in Fig. 8. As follows from Figure 7, the presence of pollution on the surface of finned pipe leads to a considerable decrease of the total heat flux, which consists of nearly 30%.

The numeral modelling of heat transfer in pipes with longitudinal fins at the presence of pollution on the external surface was conducted. The results are valid for the temperature distribution and heat efficiency of finned tubes with deposits at using the simplified, two-dimensional and conjugated model. The comparison of results found in these models with experimental data showed their coincidence in a satisfactory way. The maximal errors in the calculations do not exceed 15%.

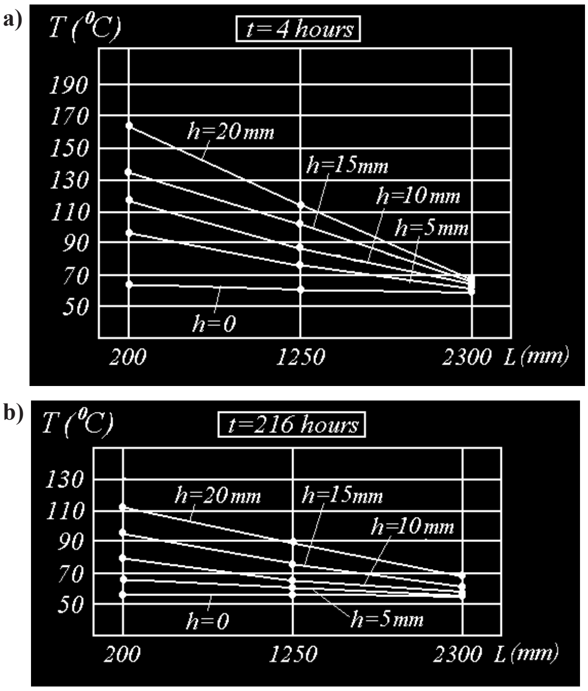

Fig. 7. The temperature distributions along the length of fin for the different sections of the fin height: a) $t=4$ hours; b) $t=216$ hours

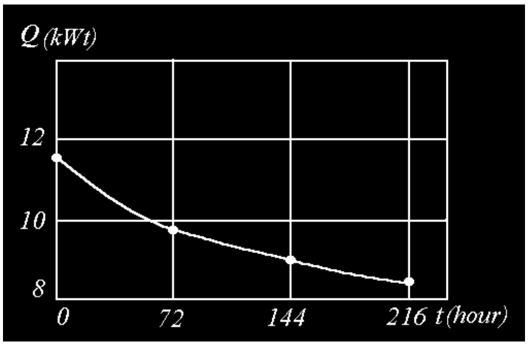

Fig. 8. The total heat flux leading from finned tube in the different periods of time

The important question at the design of heat-exchanges working in a polluted environment is the choice of the optimal fins. The paper [2] provides the formulas for the calculation of the optimum thickness and height of longitudinal fins with pollution or coating:

$$\delta_{f,opt} = 0,632\frac{1+Bi_c}{\alpha\lambda_c}\left(\frac{Q_f}{T_0-T_g}\right)^2, \tag{1}$$

$$h_{f,opt} = 0,7979\frac{1+Bi_c}{\alpha}\left(\frac{Q_f}{T_0-T_g}\right), \tag{2}$$

where: α is heat transfer coefficient, h_f, δ_f - accordingly, height and thickness of fin, δ_c is the thickness of pollution or coating, T_0 is the temperature of fin base, Tg is the temperature of external heat carrier, $B_{ic}=\alpha\delta_c/\lambda_c$ is the Biot number of pollution, Q_f - heat flux of the fin.

As follows from the expressions (1), (2) an optimum height and thickness of fins depends on the Biot number of pollution. These are increased with the growth of Biot number. With such conditon the optimum thickness and height of fins is by1,5 time higher compared with the optimum of «clean» fins. The influence of nonuniformity of pollution along the fin height on the optimum fin dimensions may be taken into account, using the correct coefficients [2].

The crucial issue is the correct choice of the optimum of fins for heat exchanges with extended surfaces which subject to pollution would enable an improvement of the mass and dimensional characteristics of such heat exchanges.

CONCLUSIONS

1) Dynamic of change the thickness of pollution on the surface of finned pipe is determined. It was found out that the maximum speed of the growth the thickness of pollution takes place on the initial section of finned surface. In the course of time the thickness of pollution is stabilised, besides the process of stabilisation is later nearer the end of a finned pipe. Profile of pollution along

the height of fins is close to the trapezoidal profile for all the sections along the length of longitudinal fin.

2) The temperature distributions in a finned tube for the different moments of time are measured. It is found that the presence of pollution on the finned surface leads to a more uniform distribution of temperature along the height of fins, compared with the temperature distribution of a "clean" finned surface. This uniformity of the temperature distribution is the higher, the greater the thickness of pollution. The presence of pollution on the surface of a finned pipe leads to a considerable decrease of the total heat flux.

3) The optimum dimensions of polluted fins depend on the Biot number of pollution and increase with the growth of this value. For the studied condition the optimum height and thickness of longitudinal fins may exceed by 1,5 time the optimum dimensions of "clean" fins.

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