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HEAT EXCHANGE INTENSIFICATION IN SMALL CAPACITY GAS-TUBE HOT-WATER BOILER

Modern trends in development of small capacity boiling equipment are considered. New ways of heat exchange intensification in small-capacity hot-water boiler are investigated. The results of the experiments are analyzed. Methods of small capacity hot-water boilers heat calculation are substantiated.

Key words: *heat exchange intensification, boiler, coefficient of convective heat exchange.*

Introduction. Problem set-up

Analysis of recent publications and information at the Internet sites of small capacity hot-water manufactures allows to make a conclusion that modern boiler equipment of small and medium heat capacity is developing in the following directions: increase of energy efficiency by means of reducing thermal losses and complete usage of energy potential of the fuel; reduction of boiler unit dimensions at the expense of intensification of fuel burning process; heat exchange intensification in the furnace and on heating surface; reduction of gaseous emissions (CO, NO_x, SO_x), polluting the atmosphere; increase of boiler operation reliability.

Intensification of heat exchange in boiler elements can be performed in two ways: installing heat exchange intensifiers in the furnace or in the heat-pipe element. As it was noted in [1, 2], the first method gives appreciable results, both regarding heat engineering indices and ecological parameters(efficiency factor increases 1 – 3 %, CO emissions reduce 5 times, NO_x, – 2 times).

As a rule, secondary emitters are installed in cylindrical furnace, this improves heat exchange in the furnace and ecological indices. For small capacity hot-water boilers such method of intensification practically is not used. As the dimensions of the furnace are rather small, the only way to intensify heat exchange is installation of twisted inserts in gas-tube bundle. Nowadays various means of heat exchange intensification in convective elements of hot-water boilers are known: application of perforated surfaces, multilayered convective surfaces, ribbing and inserts of different configuration.

In hot-water boilers, manufactured by Viessamn (Germany), Baltur (Italy)convective surfaces are manufactured in the form of two steel tubes, fitted into one another and pressed in such a way that the shell of the external tube has corrugated form and creates a number of closed air canals [3].

It is noted in [4], that mounting of formed heat exchange surfaces in the form of ring forming and twisted strips allows to decrease the temperature of waste gases to 150 – 170 ºC and increase the efficiency factor to 92 – 93 % at slight increase of the amount of metal.

Application of helical twisted bands in waste recovery gas-pipe hot-water boilers [5], allowed to decrease the temperature of fuel gases by 12%, at increasing of system resistance by 16%. It should be noted, that the research was performed at turbulent motion of heat- transfer agent.

Mounting of intensifiers in the form of hollow, truncated cone (Fig. 1) [6], increased the efficiency factor of the boiler from 85%up to 89 – 93% (depending on the parameters of the intensifiers).

Temperature of flue gases decreased 1.33-2.35 times, and the pressure increased 1.1 – 3.96 times. It should be noted that these investigations were carried out on forced-drought boilers at turbulent motion of flue gases.

Authors [7 – 9] performed the research of the efficiency of the combined intensifiers (twisted band with wire insert, bend around it) in 20 and 200kW boilers. Author shows the considerable effect , obtained as a result of usage of such intensifiers at the expense of radiant heat transfer. Relation between heat flaw at the expense of radiation to total heat flow in gas-pipe element in the range Re equals 1600 – 2100 is 15 – 24 %.

The analysis of the research, performed showed that greater part of research, dealing with the intensification of heat exchange has been carried out for turbulent and partially transient mode. In spite of the fact that nowadays much attention is paid in literature to study of boilers operation efficiency with heat exchange intensification, there is no theoretically ad experimentally substantiated methods of small- capacity, hot-water boilers (SCHWB) calculation with intensified heat exchange, described in literature.

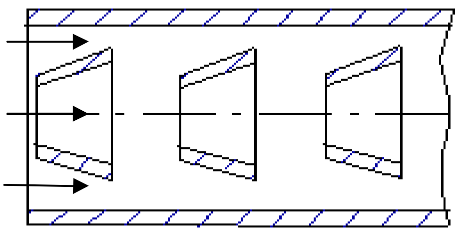

Fig. 1 Insert in the form of hollow truncated cone

The aim of the given paper is study of heat exchange intensity in gas-turbine bank of hot-water boiler with intensification of heat exchange.

Study of heat-exchange intensification in gas-turbine bank of the boiler

For the study of heat exchange intensification in high-temperature pipe element of 32 kW hot-water boiler the experimental stand was created according to State Norm (ДСТУ) 3948–2000 [10]. Original method of heat exchange intensification is proposed [11]. Equipment of the stand, technique of investigations and indexes of gas analyzer during tests are described in the paper [12]. Prior the performing basic series of experiments aimed at intensification of heat exchange in high-temperature pipe bank of the boiler numerical calculations of heat exchange in smooth tube canal were performed. In the first approximation we assumed that heat calculation of the furnace was to be carried out according to Normative method (NM), and coefficient of convective heat transfer – by Mikheev formula for laminar mode.

$$Nu = 1.4 \cdot \left(\mathrm{Re} \cdot \frac{d_{\mathrm{int.}}}{L} \right)^{0.4} \mathrm{Pr}_g^{\ 0.33} \cdot \left(\frac{\mathrm{Pr}_g}{\mathrm{Pr}_{wl.}} \right)^{0.25} \qquad (1)$$

Comparison of the results of the given experiment with calculations showed insufficient correspondence of Normative method (NM) of thermal calculations of boiler units to operating conditions of the boiler. The results of calculations showed that calculated temperature at the outlet of the boiler for the experiment without heat exchange intensification, is 100 ºC higher than the temperature, obtained experimentally. Hence, real intensity of heat exchange is higher than the intensity, calculated by NM.

That is why, in the first approximation we suggested to apply flue gases temperature determination correction at the outlet of the furnace. Corresponding results of the research are published in [12].

It should be noted that NM of thermal calculation of boilers [13] contains recommendations regarding the technique of calculation of large capacity boilers with tail surfaces, brief instructions on the design of furnaces and heating surfaces of stationary boilers and necessary reference information. However, the technique of thermal calculation of boiler-units given in the method for heat exchange in the furnace of the boiler, does not take into account the peculiarities of small capacity hot-water boilers construction.

Analysis of the publications of the foreign authors [14, 15] regarding the study of heat engineering indices of 300 kW and 1 MW boilers showed that the discrepancy between calculated temperature at the outlet of the boiler and experimental temperature is up to 25%. Such discrepancy authors connect with the fact that known dependencies for calculation of convective heat exchange do not sufficiently take into account heat exchange in short pipes, namely, initial section of hydrodynamic stabilization of the flow.

Authors [8, 16] have obtained similar results. The investigation showed, that difference between measured and calculated according to known dependences values of Nusselt number in smooth pipe are 20 – 40%. In the given research the necessity of initial section account for short pipes is substantiated. The value of the correction at initial section, suggested by different researches differs greatly.

Correction coefficient at initial section has the form

$$\varepsilon_l = 1 + C/(L/d)^m \tag{2}$$

For determination of average value of Nusselt number, it is necessary to multiply the calculated value of $\overline{Nu}$ by correction (2). According to [14] Khausen suggested the coefficients c = 1, m = 2/3, Grass c = 2,3, m = 1; Mils – c = 2,4, m = 0,68.

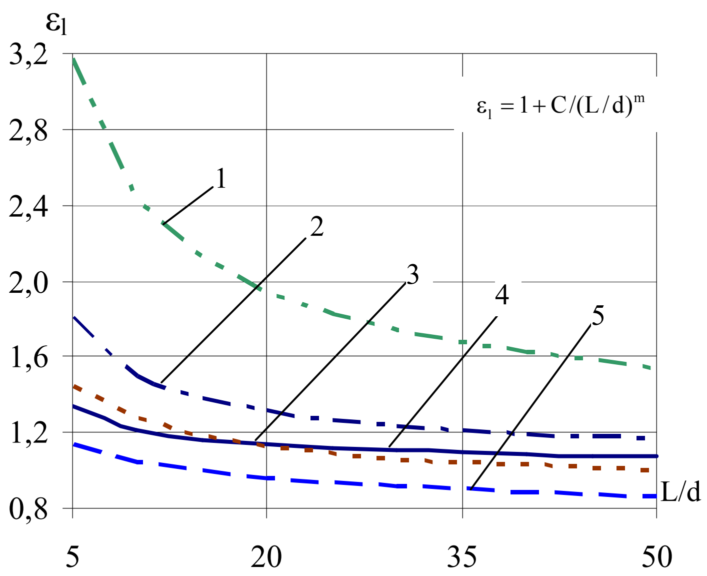

Fig. 2. Dependence of correction coefficient on the relation L/d. 1 – C= 5,7, m=0,6; 2 – C= 2,4, m=0,68; 3 – C= 1, m=2/3; 4 – table data for viscous gravitation mode [17]; 5 – table data for turbulent mode [17].

Authors [15] having performed experimental research of the 50 kW bio mass fired boiler with L/d = 19,1 obtained the coefficients c = 5,7, m = 0,6. In our literature A. S. Sukhomel for L/d < 15 suggested the correction in the form $\varepsilon_l = 1{,}38 \cdot (L/d)^{-0.12}$. According to [17], if the information, regarding the conditions of the process is not sufficient for evaluation of ε_l the correction can be written in the form $\varepsilon_l \approx 1 + \frac{2}{L/d}$. Corresponding tables for determination of correction coefficient for viscous gravitation mode at L/d < 50 are presented. Authors performed numerical study of parameter L/d impact on the value of ε_l, suggested by different authors (Fig. 2).

It should be noted that in our literature the values of correction coefficients are considerably lower, than the value suggested by foreign authors.

As a result of the experiment (Fig. 3) the temperature of flue gases at the outlet of the boiler without heat exchange intensification was 366 °C, other data in Fig. 3 are calculated data. The closest calculated value of flue gases temperature is 392 °C, it is 7% greater than the experimental value.

Analysis of the results obtained showed (Fig. 3), that usage of the corrections of foreign authors gives minor discrepancy in calculated and measured values of flue gases temperature. This can be explained by the fact that correction coefficients were introduced in conditions close to boiler operation.

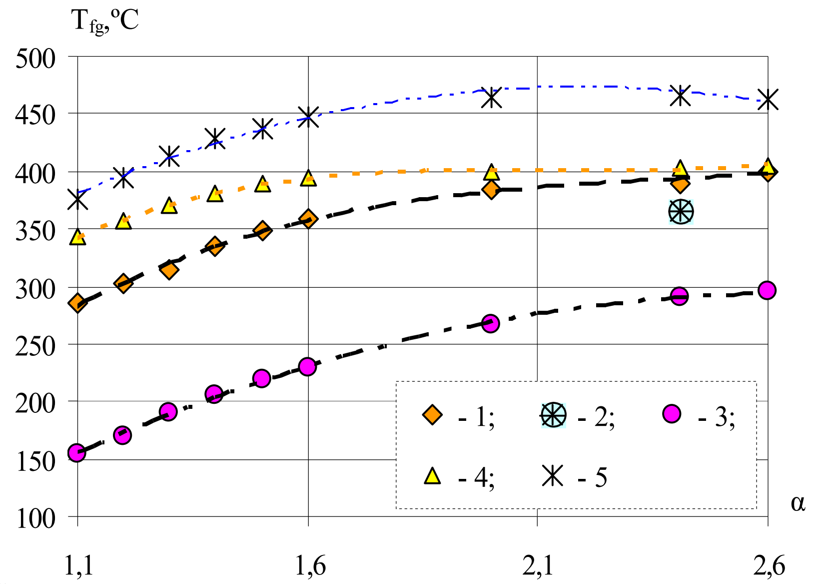

Fig. 3. Comparison of experimental and calculated values of flue gases temperature: 1 – by the formula (1) with the coefficients in the correction (2) c = 2,4, m = 0,68; 2 – experimental data; 3 – by (1) with c = 5,7, m = 0,6; 4 – by the formula, suggested by the authors on the basis of the experiment (3); 5 – by the formula (1) without taking into account the correction.

$$Nu = 0{,}062 \cdot \mathrm{Re}^{0{,}693} \cdot \mathrm{Pr}^{0{,}43} \cdot \left(1 + \frac{2{,}4}{(L/d)^{0{,}68}} \right). \tag{3}$$

As the results showed, taking into account the correction, that takes into consideration heat exchange intensity at the initial section of hydro dynamic stabilization of the flow, allows to determine more accurately temperature of gases at the outlet of the boiler. It is rather important at the design stage of small capacity heat generating equipment, since wrong choice of the dependency for heat exchange calculation will lead to increase of boiler metal content or the boiler will be designed for smaller that necessary, capacity.

In order to reveal the impact of heat exchange intensification on basic engineering indices of the boiler, we performed numerical studies. As intensifiers plate, twisted tape and bent plate, installed at the whole length of heat-pipe bundle (Fig. 4) were taken into account. Dimensions f the boiler, heat of combustion are taken as in experimental research [12]. Variable parameter is excess air coefficient. Fuel expenditures in calculations remain constant B_c=3.8 m^3/hr. The results of numerical experiments are shown in Fig. 5.

The plate reduces the temperature of flue gases by 25 – 43%, increasing efficiency factors of the boiler by 6.52 – 15.7%, this, in its turn, leads to increase of boiler capacity.

The best indices of efficiency were observed for bent plate. In case of temperature decrease at the outlet of the boiler by 43.75 – 53.68 %, the efficiency factor increases by 7.9 – 24.5%. Such an effect is achieved by means of radiation from inserts to the wall of the pipe. Improvement of heat engineering indices of the boiler takes place on the background of pressure losses increase in gas pipe bundle. But at the expense of smoke chimney effect aerodynamic processes in the boiler do not worsen. In pressure – fired boiler the capacity of smoke exhauster will increase.

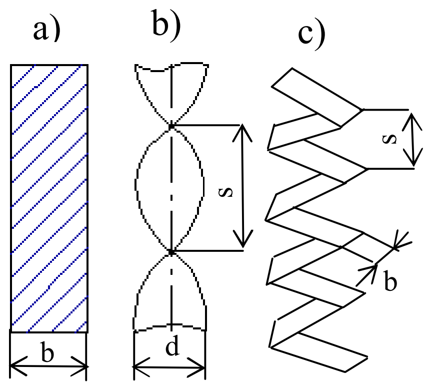

Fig.4. Heat exchange intensifiers : a) plate b = 42 mm; b) – twisted tape s/d = 4,2; c) bent plate b = 20 mm; s = 30 mm;

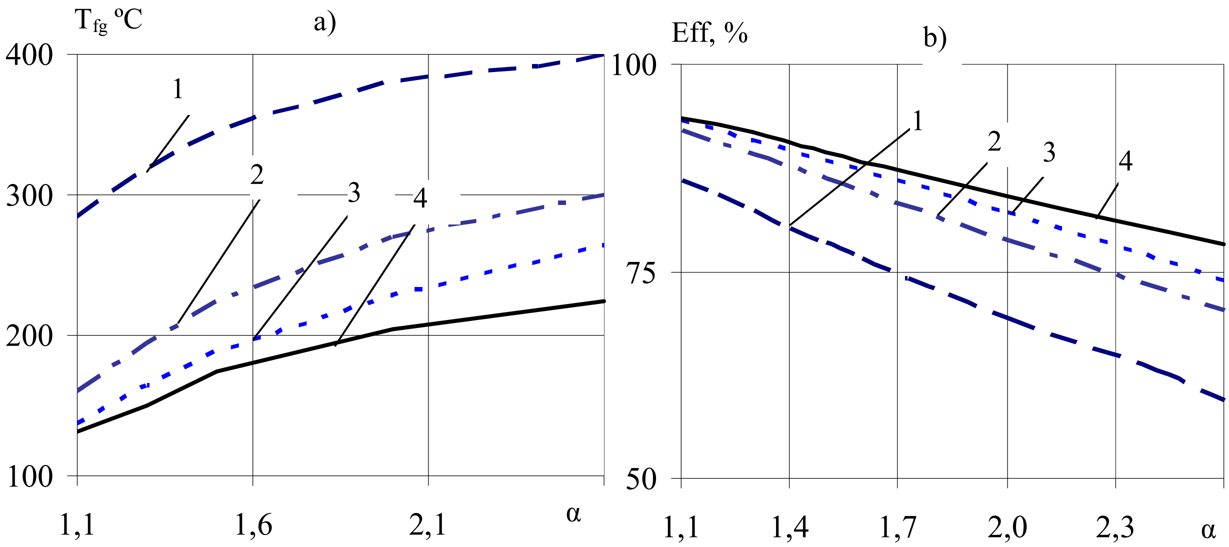

Fig. 5. Dependence of flue gases temperature (a) and efficiency factor of the boiler (b) on the excess air coefficient. 1 – smooth pipe boiler, 2 – boiler with the place, 3 – boiler with twisted tape, 4 – boiler with bent plate.

CONCLUSIONS

Directions of small capacity boiler equipment development have been analyzed. Modern methods of heat exchange intensification in hot-water boiler of small capacity have been considered. Proceeding from own research of the authors and analysis of foreign authors research it is suggested to calculate heat exchange in smooth pipe channels of hot water boilers, taking into account heat exchange intensity correction at the initial section of hydro dynamic stabilization of the flow.

In our opinion, the most adequate correction coefficient is the coefficient proposed by Mills. It is shown that the usage of plates of different configuration improves considerably heat engineering indices of the boiler. The plate reduces the temperature of flue gases by 25 – 43%, at the same time increasing the efficiency factor of the boiler by 6.52 – 15.7 %, and this, in its turn, leads to boiler capacity increase. The best efficiency indices are observed for the bent plate. At the decrease of the temperature at the outlet of the boiler 43.75 – 53.68 %, the efficiency increase by 7.9 – 24.5%. Such an effect is achieved at the expense of radiation from- inserts to the wall of the pipe.

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