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EFFICIENCY EVALUATION CRITERIA OF FLUE FUMES WITH HEAT EXCHANGE INTENSIFICATION FOR BOILER WITH LOW CAPACITY

There had been analyzed the known criteria of evaluation of heat exchange. The new approaches for the evaluation of efficiency of flue fumes of boiler with the low capacity had been suggested. There had been analyzed the results of the numerical researches.

Key words: *flue fumes, boiler, heat exchange intensification, heat exchanger, intensifier, criterion, pressure loss.*

Works on heat exchange intensification had been conducted by different organizations for many years. There had been suggested many different ways for heat exchange intensification during the flow of single phase medium or multiphase medium. Under the conditions of operation of flue boilers, the intensification of heat emission has to be made inside the funnel, where the combustion gas moves. The most efficient are turbulence inserts, which, along with the reduction of section for gas passing, which increases the flow speed and convective constituent of heat emission, ensures the additional heat flow, radiating from the heated insert to the wall of the element.

In spite the great number of equal – deflection methods for heat and hydraulic efficiency of heat exchange intensifiers [1-8], there is no single approach to the evaluation of efficiency of this or that intensification method, which makes it difficult to choose the efficient parameter of heat-exchange intensification.

The objective of the given work is to analyze the known criteria for evaluation of heat exchange evaluation, selection and development of new criteria for evaluation of efficiency of flue fumes.

As a rule, the publications, dedicated to the intensification of heat exchange, compare the received results in the kind of dependence between the relations of criteria values of Nusselt in the funnel with the heat exchange intensification and in the smooth funnel $Nu/Nu_{гл}$, and a resisting factor $\xi/\xi_{гл}$, or evaluate the efficiency of the research method for heat exchange intensification by the parameters $(Nu/Nu_{гл})/(\xi/\xi_{гл})$, or with the help of energy factor of Kyrpichev, $E=Q/N$ – heat power, N – power for heat – transport medium pumping). The later references suggest the method for efficient parameters of G. A. Dreizer. The method is based on using the effective numbers of Reinolds as the condition of equality. For the compared surfaces, the more efficient will be that one, which has the higher value of effective number of Nusselt. There are known works on using thermodynamic methods for evaluation of efficiency of heat exchange intensification [9]. These methods however do not take into consideration the surface mass, volume of the surface, its cost. It is necessary to note, that the works are of theoretical character, and the authors apply typical hydraulic boundary conditions to derive some dependencies [6, 7, 8]: equality of thermal power Q, heat carrier losses G, summed pressure losses on friction ΔP, temperature drops Δt. There are three possible variants of surface comparison:

1. Comparison of the heat exchange capacity surface with the equal capacity of devices, heat carrier losses , pressure losses on heat carrier pumping ($V_i=V_o$, $G_i=G_o$, $\Delta P_i = \Delta P_o$).

2. Comparison of thermal exchange surface square with the equal thermal power , heat carrier losses , pressure losses on heat carrier pumping ($Q_i=Q_o$, $G_i=G_o$, $\Delta P_i = \Delta P_o$).

3. Comparison of pressure losses with the equal thermal power , heat carrier losses , with the equal capacity of devices ($Q_i=Q_o$, $G_i=G_o$, $V_i=V_o$) (hereinafter *i* relates to the intensified surface , and *o* – to the plain-tube).

Methodics of comparison of heat-exchange elements includes[10]: correct setting of comparison, selection of comparison criteria , rational method for criteria calculation , comparison of numerical values of the received criteria.

The high demand to the modern water boiling flue boilers with low capacity requires to ensure the small dimensions and mass during their designing and manufacturing. It is known that by means of heat exchange intensification allows to increase the heat emission factor with the simultaneous increase in pressure losses.

Intensifiers for the flue channels of boilers are suggested to divide into two conditional groups: intensifiers, which cause the small increase in pressure losses with the small increase of heat emission factor (by 1,05 – 1,4 times), and the intensifiers which cause the big increase in pressure losses with the big increase of heat exchange(by 1,4 – 2,1 times). The first group of intensifiers is allowed to use in the boilers with the natural draught, and the second - in boilers with mandatory draught. For the efficient operation of the boilers with the natural draught, the necessary condition of using intensifier, when achieving the necessary capacity of the boiler, is the condition:

$$\Delta P_b=\Delta P_{s.t.b}, \quad (1)$$

where ΔP_b – pressure losses in the boiler elements (ash-pit, fire-chamber, flue fumes) and the funnel, $\Delta P_{s.t.b}$ – flue effect in the elements of the boiler and funnel.

При этом использование интенсификаторов со значительным аэродинамическим сопротивлением требует увеличения длины дымовой трубы.

On condition of unchanged volume of the ire-chamber (V_{ch}=const), unchanged geometrical dimensions of the tube shell, equal losses of the heat carrier ($G_i=G_o$) and temperature drops ($\Delta t_i=\Delta t_o$), as well as when $\Delta P_i \neq \Delta P_o$, it is possible to single out the following variants of optimization of the flue fumes structure:

1) with the unchanged length , diameter, number of funnels, the thermal power of flues in the plain-tube surface is compared to intensification of the heat exchange (the task of increase in boiler capacity);

2) with the equal boiler capacity, the geometrical dimensions of the flue fumes are compared (the task of diminishing the dimensions and mass of the boiler).

For the last case, there are the following variant possible for the optimization of the construction of the flue fumes:

a) with the equal number of funnels n= const and their diameter d=const the intensified surface and plain-tube one have the different length of the funnel l=var;

b) the compared surfaces are composed of different number of funnels with equal diameter and length (l=const, d= const, n=var);

c) the compared surfaces are composed of different number of funnels with different diameter and equal length (l=const, d=var, n=var);

d) the compared surfaces are composed of funnels with different diameter of equal number and length (l=const, d=var, n= const).

Within the frameworks of the given research, the variant a) is being considered.

Selection of criterion for the comparison of flue fumes surfaces

The known criteria for the evaluation of efficiency of thermal exchange intensification [1 – 10] appeared to be inconvenient for engineering calculations and do not correspond with the operation of flue boilers with small capacity (small velocity of smog gases transitional operation modes 2300<Re<10000, the necessity to consider the flue effect of the boiler , thermal stream by the irradiation from the intensifiers to the wall of the funnel of the flue fume). Apart from that the surfaces are usually compared with the equal figures of Rainold, which is impossible to achieve for the real operation conditions of boilers; as after the fixing of tabulator, the velocity of the stream increases. In our opinion the main factors of flue fumes, which take into account its dimensions , mass and square of the thermal exchange surface are coverage – $K_f=\frac{F}{Q}, \frac{m^2}{kW}$;

specific dimensions $-\ K_v = \dfrac{V}{Q},\ \dfrac{m^2}{kW}$; specific mass $-\ K_m = \dfrac{M}{Q},\dfrac{kg}{kW}$; specific pressure loses $-\ K_{\Delta P} = \dfrac{\Delta P}{Q},\ \dfrac{Pa}{kW}$.

On the basis of the above factors, under condition of equity of thermal power there had been suggested the following dimensionless criteria:

$$K_1 = \left(\frac{K_{vi}}{K_{vo}}\right)^c \cdot \left(\frac{K_{mi}}{K_{mo}}\right)^n \cdot \left(\frac{K_{\Delta Pi}}{K_{\Delta Po}}\right)^m, \tag{2}$$

$$K_2 = \left(\frac{K_{fi}}{K_{fo}}\right)^p \cdot \left(\frac{K_{\Delta Pi}}{K_{\Delta Po}}\right)^m, \tag{3}$$

where К1 – criterion which may be used for the correlation of the flue fumes of boilers from the point of view of manufacturing technology, assembling, costs in the detail project report practice; К2 – criterion for the evaluation of efficiency of flue fumes from the thermal and technical point of view.

The most efficient among the range of intensified surfaces of the boiler of the equal thermal capacity will be that one, the value of criterion of which will be the smallest. ($K \rightarrow K_{min}$). In criteria c, n, m, p – degrees factor which emphasize the value of this or that multiplier in criteria.It is necessary to note that the degrees are chosen depending on designing condition on boiler purpose on material the boiler is made of in this work it had been accepted that c=n=m=p=1. For boilers with the natural draught, the multiplier $\left(\dfrac{K_{\Delta Pi}}{K_{\Delta Po}}\right)^m$ is absent and the condition (1) is taken into consideration.

The generalized criterion for the task of increasing of boil capacity looks like:

$$\overline{K} = \left(\frac{Q_o}{Q_i}\right)^{n+m} \cdot \left(\frac{K_{mi}}{K_{mo}}\right)^n \cdot \left(\frac{K_{\Delta Pi}}{K_{\Delta Po}}\right)^m. \tag{4}$$

Within the frameworks of the given work, the task for diminishing of the mentions mass of the boiler is being considered.

With the objective of obtaining the numerical values of criteria К1 and К2 and their comparison on the basis of the developed mathematical model [11] there had been conducted the numerical researches of thermal exchange intensification in the flue fumes of the boiler [12] with the application of the following thermal exchange intensifiers: plate, cylindrical insert and twisted band. The researches had been conducted for the following conditions of boiler operation: capacity of the boiler - 32 kilowatt, capacity of the fire-chamber 15,6 kilowatt, capacity of the flue fume - 16,4 kilowatt, factor of air surplus α=1,4, temperature of smog gases on the input of the flue fume t1=905,6 ºC, on the output – t2=140 ºC, water temperature mode – 80/60 ºC, funnel diameter $d_т$ fume– 48/41мм, number of funnels – n=24.

The paper conducts the researches of influence of the diameter of the cylinder insert, located along the whole length of the funnel, on the efficiency of thermal exchange, as well as evaluates the parameters with the help of the developed criteria (fig. 1). Variable values in the numerical experiment are the diameter of the cylindrical insert and the length of the funnel.

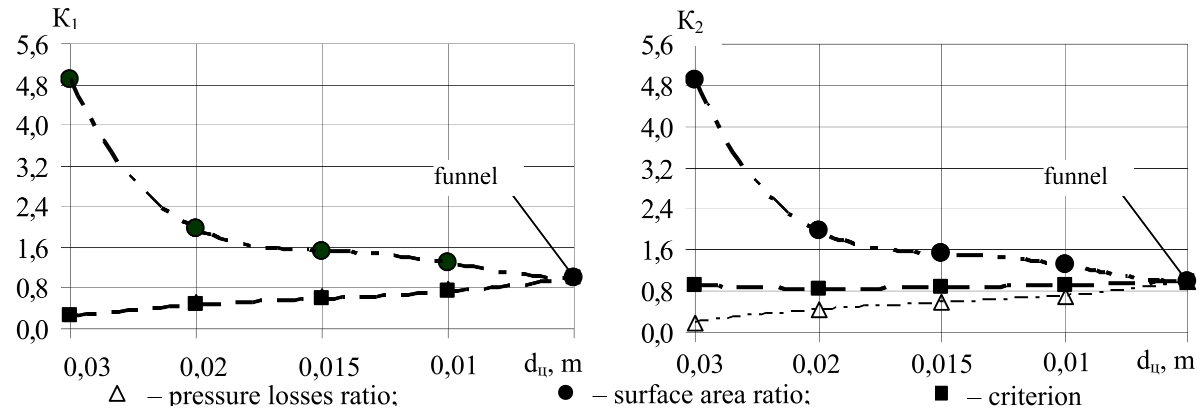

Fig.1. Value of criteria K_1, K_2 depending on the diameter of the cylindrical insert

Diminishing the diameter of cylindrical insert $d_ц$ increases the value of criteria, which is explained by the thermal exchange worsening caused by the decrease in the velocity of smoke gases and the irradiating square of the surface. The above factors cause the increase in length of the funnel which leads to the increase in mass, dimensions, surface square. It had been determined that the rational correlation of the cylinder diameter to the diameter of the funnel is $d_ц/d_т$=0,6...0,36.

For the tube shell of the set dimensions it is possible to only some number of funnels with the diameter d, changing at the same time the length of the funnel for the achievement of the set capacity. Depending on the efficiency of the thermal exchange intensifier, the correlation between the dimensions, mass, surface square, pressure losses will be different. The authors conducted the numerical experiment with the purpose of the research of influence of the funnel diameter on the criteria value. In the researches there had been used the funnels with the inner diameter ranging from 20 to 51 mm. It had been excepted that the width of the plate and of the twisted band equal to the diameter of the funnel, and the correlation $d_ц/d_т$ foe the cylindrical insert has the value 0,6. Thermal exchange intensifiers are located along the whole length of the funnel. Fig. 2 presents the results of the numerical experiments.

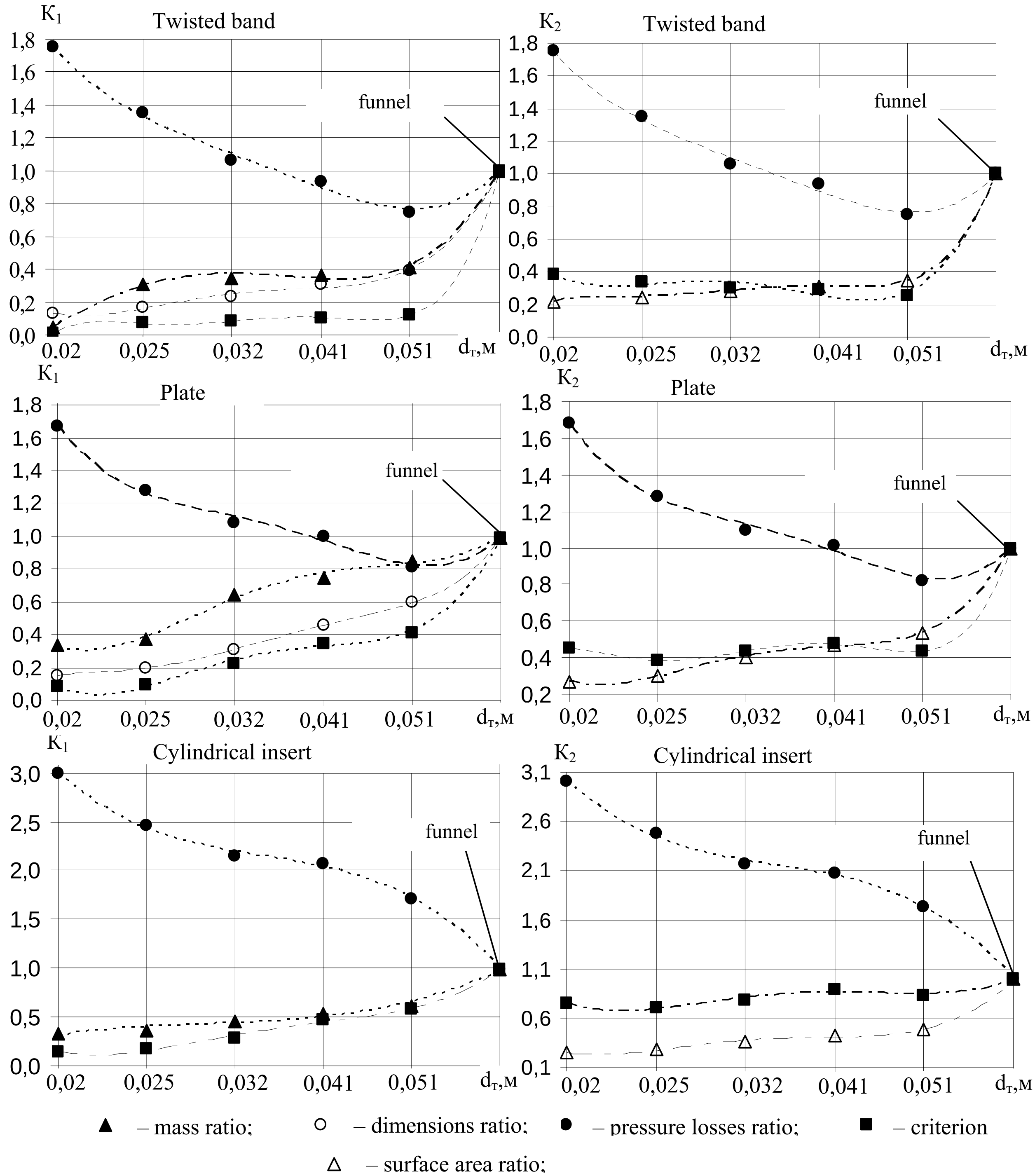

Fig. 2. Influence of the funnel diameter of the flue fume on the values of criteria K_1 and K_2

As is shown on fig. 2 the best values of criteria are observed for the funnels with the small diameter. It is explained by the fact that during the equal loses of heat carriers and temperature drops, the speed of smoke gases will be higher, which positively influences the thermal exchange, but at the same time the air dynamic resistance of the fume increases. For the funnels with the middle diameters the values of criteria are somewhat higher but from the point of view of manufacturing technology of flue fumes (the number of welding decreases, assembling simplifies) their usage appears to be appropriate. The twisted band appears the most efficient among the all intensifiers in the range of funnel diameter change.

Table 1 presents the results of numerical researches of thermal exchange intensification with the application of the above intensifiers for such variants of their location: along the whole length of the funnel (Li=Ltube), in the upper part of the funnel when Li=0,75Ltube, Li=0,5Ltube,, Li=0,25Ltube, as well in the lower part of the funnel when Li=0,75Ltube, Li=0,5Ltube,, Li=0,25Ltube. It had been determined that intensification of thermal exchange in the lower part of the funnel is more efficient, because the necessary length of the funnel for achievement of necessary capacity of the boiler is significantly lower, then during the location of the of the intensifiers in the upper part, which is proved by the criteria values.

Table 1

Values of criteria for different variants of thermal exchange intensifiers location

Thermal exchange intensifier	Intensifiers parameters							
	$L=L_{tube}$	$L_i=0{,}75L_{tube}$		$L_i=0{,}5L_{tube}$		$L_i=0{,}25L_{tube}$		Criterion
		Lower part of the funnel	Upper part of the funnel	Lower part of the funnel	Upper part of the funnel	Lower part of the funnel	Upper part of the funnel	
Plate	0,31	0,298	0,634	0,473	0,757	0,724	0,784	K_1
Cylindrical insert	0,368	0,476	0,817	0,588	1,165	0,758	1,194	K_1
Twisted band	0,067	0,27	0,313	0,31	0,481	0,432	0,832	K_1
Plate	0,55	0,52	0,581	0,643	0,683	0,767	0,751	K_2
Cylindrical insert	0,869	1,009	1,143	1,076	1,172	1,158	1,183	K_2
Twisted band	0,205	0,607	0,539	0,641	0,667	0,72	0,904	K_2

As is shown in table 1, the twisted band is the most efficient within the whole range of parameters changing among the intensifiers which is explained by the additional stream twisting; the rational parameters of intensifier are: $L_i=L_{tube}$, $L_i=0{,}75L_{tube}$.

It had been determined that during the location of intensifiers in the lower part of the funnel, the thermal stream increases by 43 – 72 % at the cost of irradiation, which is explained by more high temperature of smoke gases. During the location of the intensifier in the upper part of the funnel this factor goes up to 18 – 35%. The analogical results had been received by the authors in [13], who applied the twisted cruciate bands with an aim of thermal exchange of intensification, and the thermal stream increased up to 10 – 80% due to irradiation. Thus the usage of different inserts in the flue boilers of small capacity is an efficient method for thermal exchange intensification.

For practical realization of the developed criteria, with the objective of correlation of intensifiers, it is necessary to conduct the detailed thermal and aerodynamic calculation of the boiler.

Thus the suggested criteria allow to evaluate the efficiency of the thermal exchange intensification in the flue fume of the boiler with the low capacity under the following conditions of correlation: equity of thermal capacity, loses of heat carriers, temperature drop. The geometrical dimensions and pressure loses for the plain-tube surface and the surface with the thermal exchange intensification may be different.

Conclusions

The analysis of reference information shows that today there is no unique approach to evaluation of the efficiency of this or that method of intensification, which makes it difficult to choose the optimal parameters of heat – exchange devices on condition of using the heat exchange intensification. Besides the known criteria do not correspond to the operation conditions of flue fumes boiler with small capacity. The authors had suggested the generalized criterion for evaluation of the efficiency of intensification of the heat exchange. The authors obtained the values of the suggested criteria by the numerical experiment. It had been set, that the optimum correlation of the diameter of the cylindrical insert to the diameter of the funnel is the value $d_ц / d_т$=0,6...0,36. It had also been found that the most efficient intensifier is the twisted band, it is reasonable to locate the intensifier in the lower part of the funnel, and the optimum parameters are of the intensifiers are L_i=L_{of} the funnel, L_i=0,75of the funnel. It is necessary to note that during the manufacturing of boilers it is necessary to use funnels of the average diameter, which simplifies the mounting of flue fumes, as well as causes the decrease in numbers of welding therefore simplifying the technology of boils manufacturing.

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