ТЕПЛООБМІН У КОНВЕКТИВНИХ ТРУБКАХ З ТУРБУЛІЗАТОРОМ

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Анотація. Котлобудування — стратегічна галузь. Її розвиток дає можливість державі самостійно вирішувати питання економного використання палива у всіх галузях промисловості. Надійність і економічність теплогенерувального обладнання, його експлуатація без шкоди для навколишнього середовища є основними показниками ефективного енергозабезпечення країни. Основною тенденцією світового прогресу в комунальній теплоенергетиці є зниження витрат палива при виробленні теплоти за рахунок підвищення коефіцієнта корисної дії (ККД) котлоагрегатів. Одним із способів підвищення ККД є установка турбулізаторів в трубки конвективного пакета. Метою роботи є визначення впливу турбулізатора потоку на інтенсивність теплообміну в конвективної частини жаротрубного котлоагрегату вітчизняного виробництва. У статті наводяться експериментальні дані роботи такого котлоагрегату, а також теоретичні дослідження з визначення характеристик, які впливають на теплообмін, в залежності від ступеня перекриття перерізу каналу трубок турбулізатором у вигляді ламаної стрічки.

Ключові слова: теплообмін, конвективная трубка, турбулізатор, ступінь перекриття, температура, турбулентна в'язкість, коефіцієнт тепловіддачі.

ТЕПЛООБМЕН В КОНВЕКТИВНЫХ ТРУБКАХ С ТУРБУЛИЗАТОРОМ

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Аннотация. Котлостроение — стратегическая отрасль. Ее развитие дает возможность государству самостоятельно решать вопрос экономного использования топлива во всех отраслях промышленности. Надежность и экономичность теплогенерирующего оборудования, его эксплуатация без вреда для окружающей среды являются основными показателями эффективного энергообеспечения страны. Основной тенденцией мирового прогресса в коммунальной теплоэнергетике является снижение расходов топлива при выработке теплоты за счет повышения коэффициента полезного действия (КПД) котлоагрегатов. Одним из способов повышения КПД является установка турбулизаторов в трубки конвективного пакета. Целью работы является определение влияния турбулизатора потока на интенсивность теплообмена в конвективной части жаротрубного котлоагрегата отечественного производства. В статье приводятся экспериментальные данные работы такого котлоагрегата, а также теоретические исследования по определению характеристик, влияющих на теплообмен, в зависимости от степени перекрытия сечения канала трубок турбулизатором в виде ломаной ленты.

Ключевые слова: теплообмен, конвективная трубка, турбулизатор, степень перекрытия, температура, турбулентная вязкость, коэффициент теплоотдачи.

CONVECTIVE HEAT TRANSFER IN THE BOILER TUBE WITH TURBOLATORS

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Abstract. Boiler making is a strategic industry. Its development allows the state to solve the issue of economical use of fuel in all industries. Reliability and efficiency of the heat generating equipment, its operation without harm to the environment are key indicators of effective energy supply of the country. The main trend in the world progress in the municipal power system is to reduce the cost of fuel for generation of heat by increasing the coefficient of performance (COP) of boilers. One way to improve efficiency is to install the tubes turbulators in convective package. The aim is to determine the effect of the turbulator on the intensity of heat transfer in the convective part of the fire-tube heat source of domestic production. The paper presents the experimental data of such a boiler, as well as theoretical studies to determine the characteristics that influence the heat transfer, depending on the degree of overlap of the channel cross section tubes with a turbulator in the form of a broken belt.

Keywords: heat transfer, convective tube, turbulator, the degree of overlap, temperature, turbulent viscosity, the heat transfer coefficient.

Formulation of the problem

Heat transfer from the combustion products in the fire-tube tubes of boiler is carried out by convection. However, the temperature of exhaust gases after the tube is relatively high, which reduces the efficiency of the heat source and there is a need to install additional equipment of heat utilization that allows utilization of the outgoing heat.

Analysis of recent research

Since the price of additional equipment of heat utilization is high, some manufacturers mount flow baffles to increase convective tubes heat transfer [1—5]. Design of these inserts is very diverse, which gives a different final effect [1—4].

Aim and objectives

The aim is to assess the impact of a turbulator on heat transfer in the convective part of the boiler.

The main part

Heat generator is a complex heat exchanger, in which the interrelated processes of fuel combustion and heat transfer from the flue gas to the system occur. Heat transfer in the heat generator heating surfaces takes place by radiation, convection and conduction. The convective part of the fire-tube heat source is usually carried out from round tubes. To increase the convective component of the heat transfer they put in special inserts of various shapes and configurations — turbulators. During the experiment, the turbulators with different height were used to insert, whereby the channel area of passage changed. The degree of overlap (Ω) amounted to 1/2, 1/3, 1/4, 1/5 and 1/6 of the total passage area. The scheme of the applied turbulator is shown in Figure 1.

Installation of turbulator increases the convective heat transfer component, and increases the air resistance. Figures 2 and 3 show the experimental curves of the flue gas temperature and resistance from the overlapping section of the channel.

Analysis of the graph (Figure 2) shows that the temperature with increasing degree of overlap with the channel cross-section decreases, which means an increase in heat transfer from the combustion products. Dependence in this case, the correlation coefficient being R=0,994, can be described by equation (1):
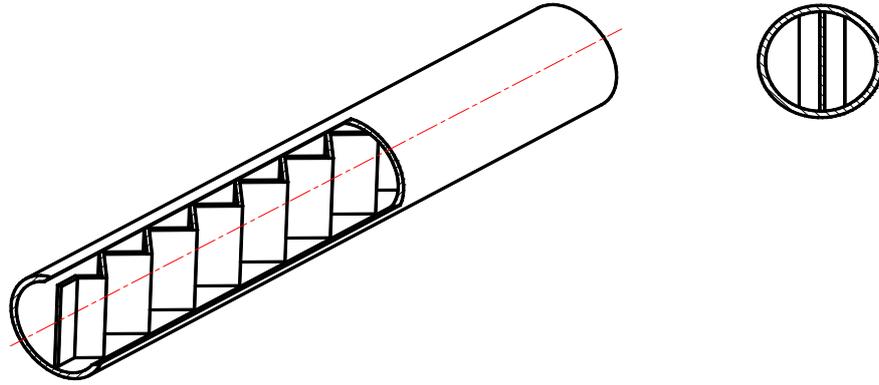
Figure 1. Scheme of convective tube baffle.
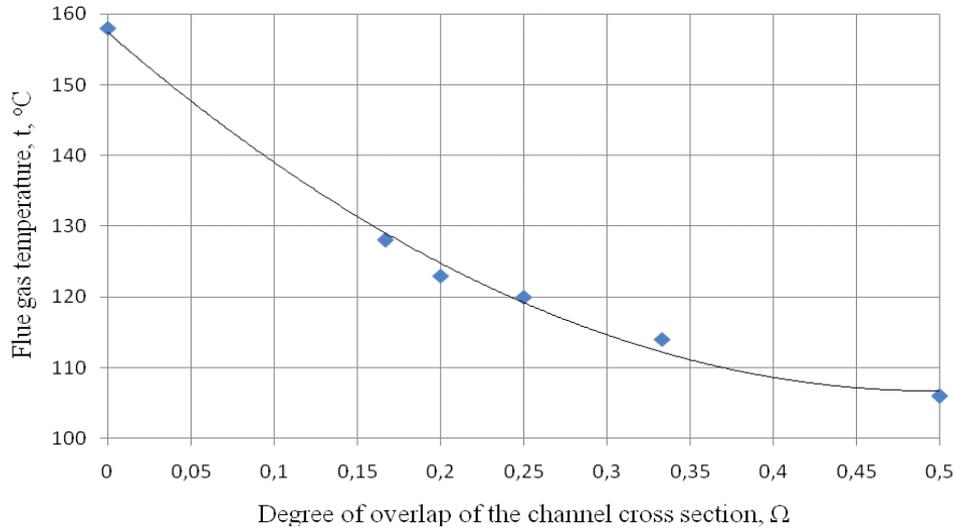
Figure 2. Dependence of the flue gas temperature on the degree of overlap section of the channel.

$$t = 206,05 \cdot \Omega^2 - 204,45 \cdot \Omega + 157,37 . \quad (1)$$

Chart analysis (Figure 3) shows that the pressure loss increases when the degree of overlap section of the channel increases. Dependence in this case, the correlation coefficient being R=0,994, can be described by equation (2):

$$\Delta P = 133,55 \cdot \Omega^2 + 31,459 \cdot \Omega + 44,796 . \quad (2)$$

To determine the optimum it is necessary to construct the above graphs in one coordinate system. The achieved graph is shown in Figure 4.

Based on the graph (Figure 4), we can conclude that the optimal value of the degree of overlap of the convective section tube by the baffle is 0,25 or 1/4.

In convective heating surfaces, the heat transfer coefficient determines the heat transfer from the high-temperature combustion products to the heated coolant (water) through the tube wall (k, W/m²·deg), which during burning of natural gas with gas stream emission is determined by the following formula:

$$k = \frac{\zeta \cdot \alpha_c + \alpha_r}{1 + (\zeta \cdot \alpha_c + \alpha_r)} , \quad (3)$$

where ζ — coefficient of the pipes surface washing;

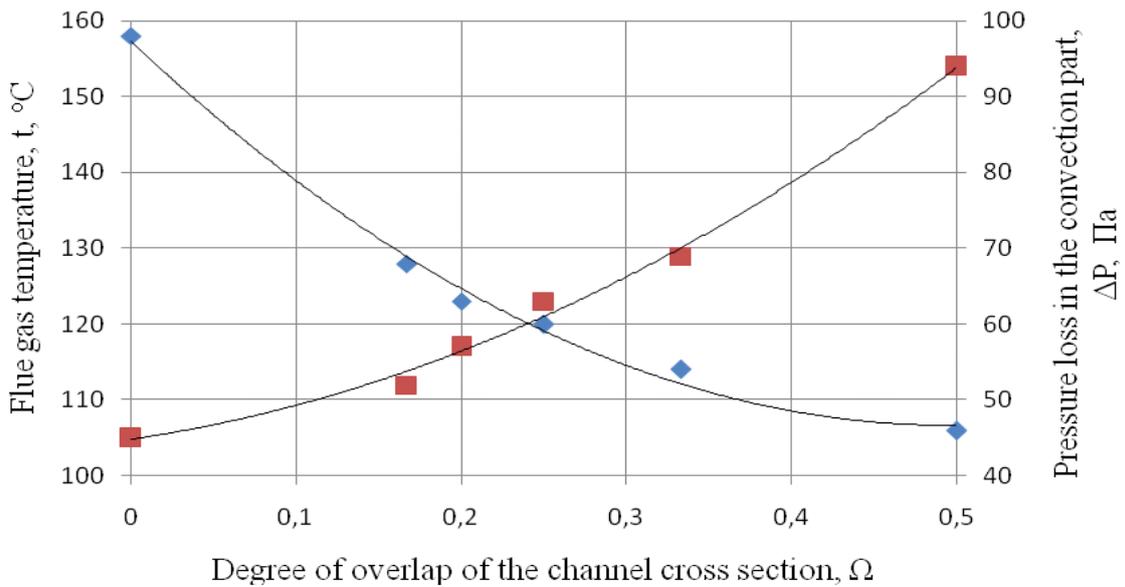α_c — convection heat transfer coefficient of the wall of the combustion, W/m²·deg;

α_r — coefficient of heat transfer from the combustion products to the wall by the radiation, W/m²·deg.

For two-way fire-tube heat generators at the entrance of the combustion products in the convective beam with 180 degrees rotation and local contraction coefficient of washing according to [6] equals to 0,9.

The coefficient of convective heat transfer by radiation to the tubes is determined according to the procedure described in [6].
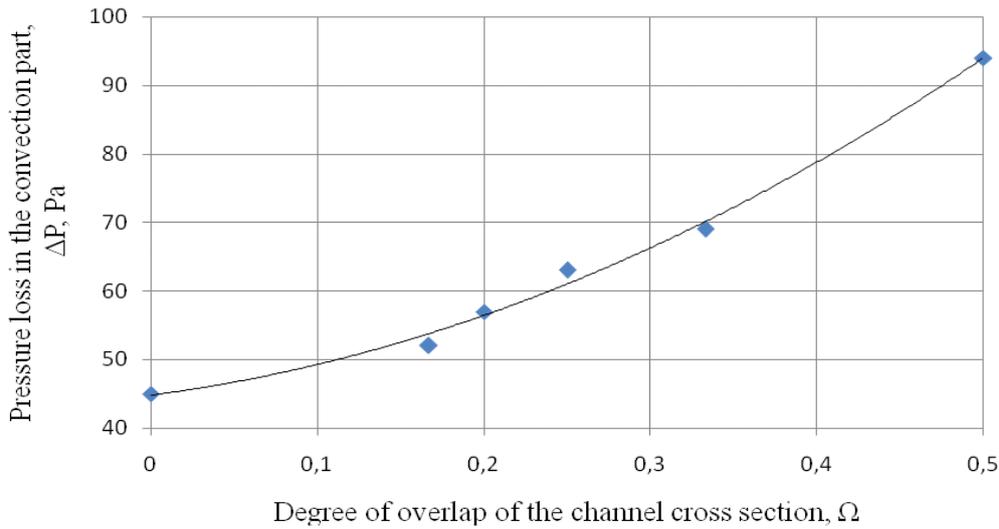
Figure 3. Dependence of pressure losses in the convective tubes on the degree of overlap section of the channel.

Figure 4. Dependence of the flue gas temperature and pressure losses in the convective tubes on the overlapping section of the channel.

Convection heat transfer coefficient may be determined from the Nusselt number, Nu:

$$Nu = \frac{\alpha_c \cdot d}{\lambda}, \qquad (4)$$

where d – convection tubes diameter, m;
λ – thermal conductivity, W/(m·deg).
In its turn, turbulator installation increases the turbulence of the flow. The change (increase) of the number Re entails a change (increase) in turbulent viscosity ν_t [7–9], thereby increasing the convection heat transfer coefficient α_c.

To determine the turbulent viscosity the following relationship can be used [10]:

$$\nu_t = 0,93 \cdot u_{av} \cdot \delta \cdot \lambda, \qquad (5)$$

where u_{av} — average flow velocity, m/s;
δ — the boundary layer thickness, mm;
λ — thermal conductivity, W/(m·deg).

$$\delta = \frac{\nu}{u_*} \cdot \exp\left[\frac{1}{5,75} \cdot \left(\frac{u_{cp}}{u_*} - 5,5 \right) \right], \qquad (6)$$

where u_* — dynamic flow rate, m/s.

$$u_* = u_{av} \cdot \sqrt{\frac{\xi}{8}}. \qquad (7)$$

In a turbulent flow ξ can be defined as:

$$\xi = 0,316 \cdot Re^{-\frac{1}{4}}. \qquad (8)$$

The Reynolds number is found from the well-known expression:

$$Re = \frac{u_{av} \cdot d}{\nu}, \qquad (9)$$

where ν — kinematic viscosity coefficient, m²/s.
Also for convection baffle tubes, as a result of the research, the dependence is:

$$Nu = 0,038 \cdot Re^{0,85}. \qquad (10)$$

As a result of substituting 10 and 4 we obtain an expression for the coefficient of convective heat transfer:

$$\alpha_c = 0,038 \cdot Re^{0,85} \cdot \frac{\lambda}{d}. \qquad (11)$$

As a result of the research of convective heat transfer in tubes with a baffle, the following graphs shown in Figures 5, 6, 7, 8 are achieved.

The graph (Figure 5) shows that the velocity of combustion products with the increase in the degree of overlapping section of the channel increases.
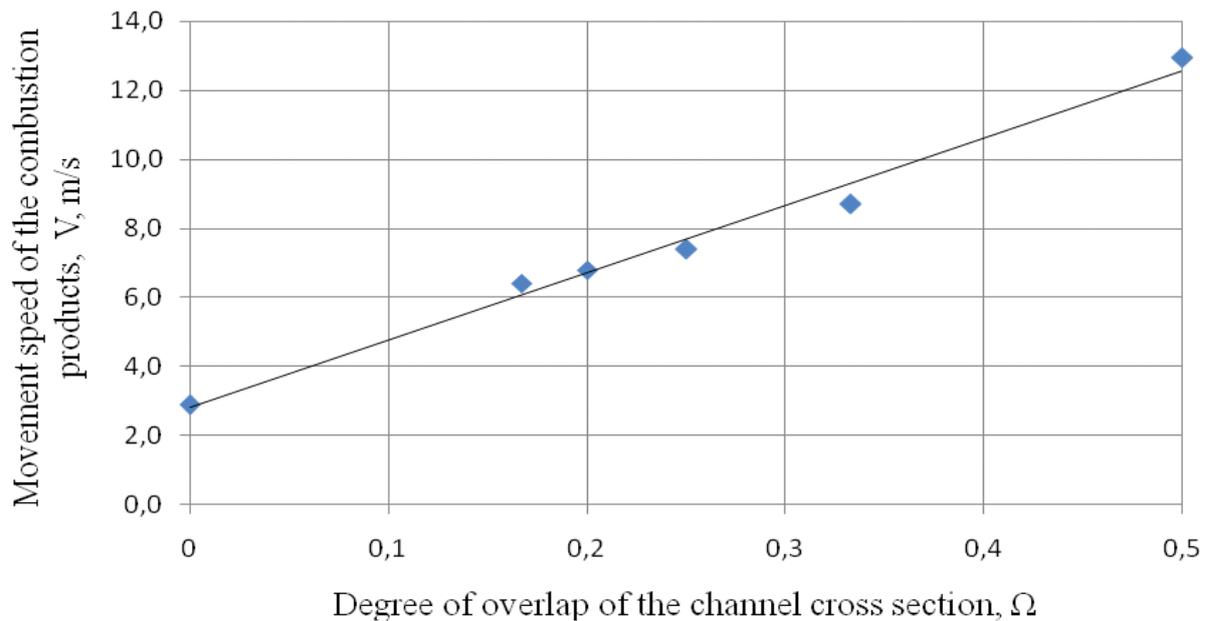
Figure 5. The dependence of the velocity of the combustion products on the degree of overlap section of the channel.

Schedule in this case is approximated by the dependence (12) with a correlation coefficient R=0,977:

$$V = 39,002 \cdot \Omega + 7,1339. \qquad (12)$$

Chart analysis (Figure 6) shows that with increasing Reynolds number turbulent viscosity increases. Dependence in this case, the correlation coefficient being R=0,999, is described by equation (13):

$$v_m = 8 \cdot 10^{-9} \cdot \mathrm{Re} + 0,0002. \qquad (13)$$

The graph (Figure 7) shows that the turbulent viscosity with increasing degree of overlap of the channel cross section increases. Schedule in this case is approximated by the dependence (14) with the correlation coefficient R=0,999:

$$v_m = 6 \cdot 10^{-5} \cdot \Omega^2 + 4 \cdot 10^{-6} \cdot \Omega + 0,0002. \qquad (14)$$
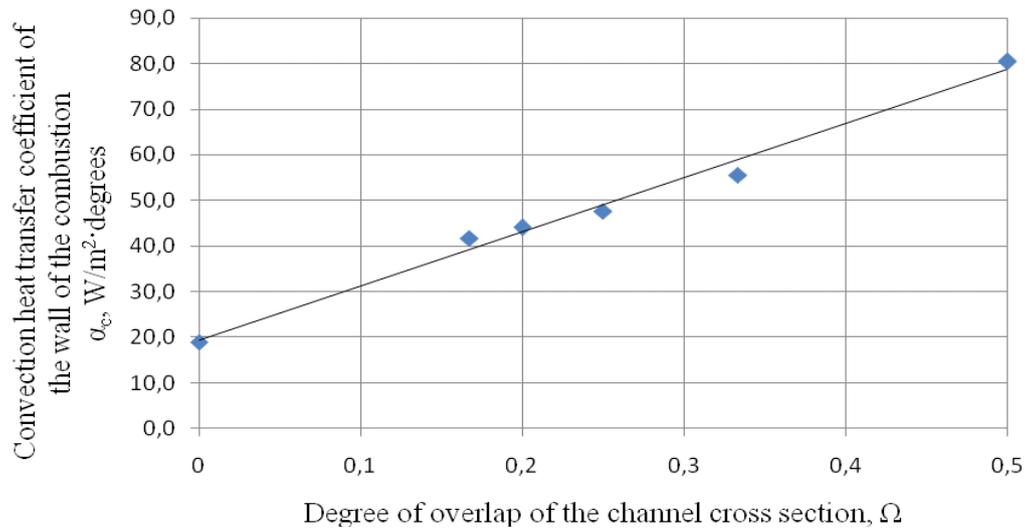
Chart analysis (Figure 8) shows that the convective heat transfer coefficient with increasing
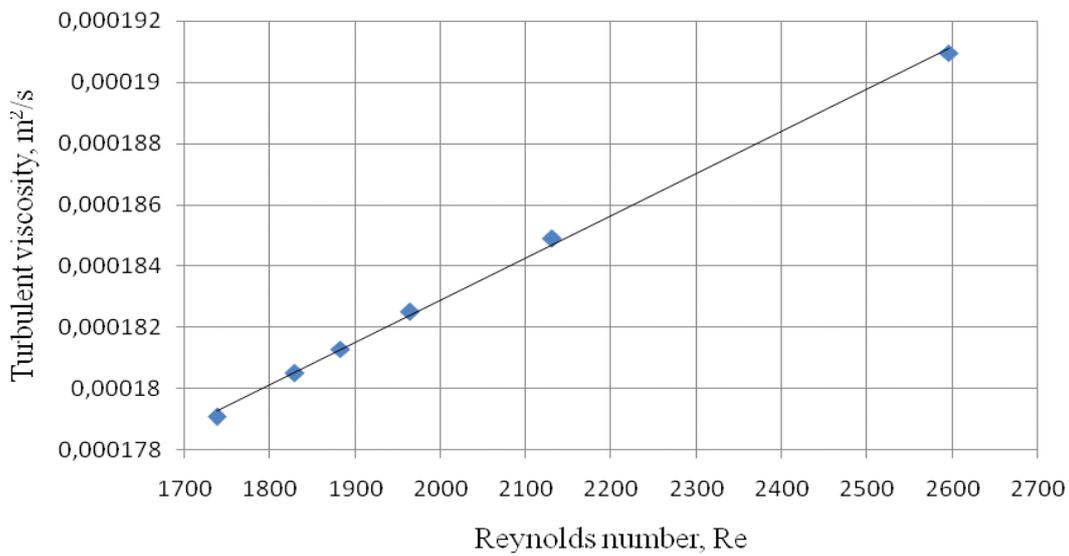
Figure 6. The dependence of the turbulent viscosity on the Reynolds number.
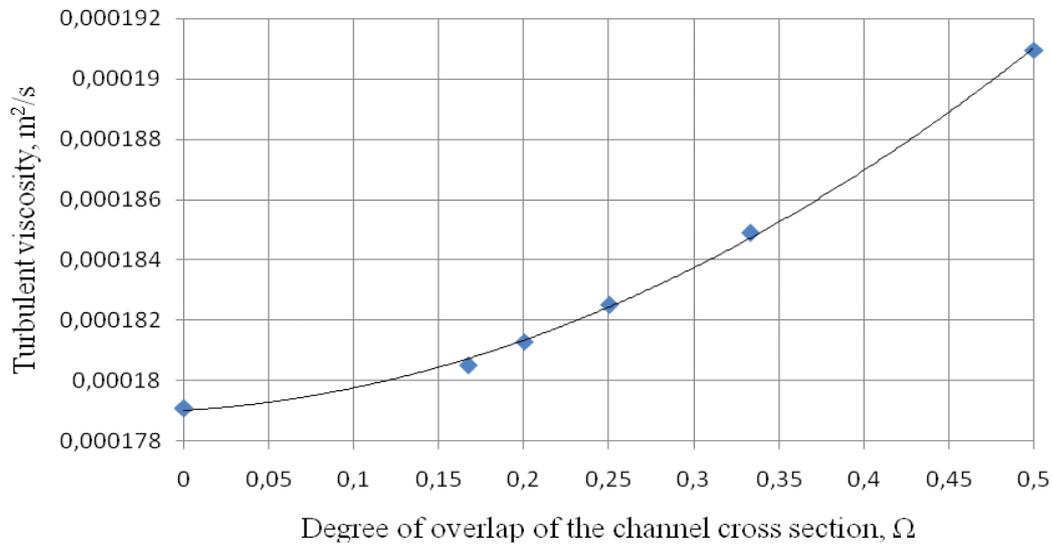
Figure 7. Dependence of the turbulent viscosity on the overlapping section of the channel.

Figure 8. Dependence of the coefficient of heat transfer by convection on the degree of overlap channel.

degree of overlap of the channel cross section increases. Dependence in this case, the correlation coefficient being R = 0,988, is described by equation (15):

$$\alpha_\kappa = 237{,}55 \cdot \Omega + 38{,}154. \qquad (15)$$

Conclusion

When installing turbulators in the convective tubes of the fire-tube boiler unit the velocity of the combustion product increases, which together with the baffle itself leads to an increase of the Reynolds number and the turbulent viscosity flow, thereby increasing the heat transfer coefficient by convection from the combustion products to the wall.

Due to this turbulator design, soot contained in the flue gas accumulates on its surface, the walls of the tubes are clean and there is no reduction of heat transfer efficiency.

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