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Effect of baffle spacing and baffle cut on thermal-hydraulic characteristics of the fluid flow

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Abstract. This article presents the results of investigations of the influence of baffle spacing and baffle cut on the size of dead zone formed near the cross baffles using numerical simulation methods. It is showed the structure of an additional baffle plate which can be used to reduce the dead zone and smoother flow distribution over the cross section.

1. Introduction

This article is devoted to the study of fluid flow in the shell side of shell-and-tube heat exchanger (STHE) and the assessment of the influence of geometric parameters on the thermal-hydraulic characteristics [1, 2]. More intense heat transfer can be achieved by increasing the fluid velocity, but at the same time, it leads to a large increase in pressure drop that reduces the efficiency of heat transfer and increase operating costs [3, 4].

Transfer of certain thermal energy at lower fluid velocity require more heat exchange surface that will increase the cost of the heat exchanger. Thus, it is important to find ways to improve the thermal efficiency of heat exchange equipment by selecting optimal geometric parameters providing the most efficient heat transfer [5, 6].

The efficiency of heat transfer in STHE can be increased by restricting dead zones formed near the cross baffles because of which the pressure drop is increased without a corresponding increase in heat transfer coefficient [7]. The size of the dead zone depends on the baffle spacing and the baffle cut. Thus, the optimal ratio of parameters will reduce pressure drop [8].

This article presents the results of investigations of the influence of baffle spacing and baffle cut on the size of dead zone formed near the cross baffles using numerical simulation methods. It is showed the structure of an additional baffle plate which can be used to reduce the dead zone and smoother flow distribution over the cross section [9].

2. Main part

An important direction of economic development is the economical use of material and energy resources [10, 11]. One aspect of savings is the provision of high thermal efficiency of heat exchange equipment, in particular shell-and-tube heat exchangers (STHE).

STHE is widely used in the oil, gas, oil refining, petrochemical and many other industries. This is due to the reliability of the design and the variety of types and designs for different operating conditions [12]. Common elements for all STHE structures are casing, tubes, distribution chambers, tube plates, dividers and supports. In all designs of the STHE, there are transverse dividers used to increase the velocity of the coolant, to organize the cross current and to maintain the same distance between the tubes.

One of the reasons for the decrease in the efficiency of STHE is the formation of stagnant zones in



the flow around the transverse dividers. The location and magnitude of the stagnant zones depend on the geometric parameters of the flow section, in particular the height of the free segment of the divider wall h_w and the distance between the dividers L_b , since these parameters determine the cross-sectional area of the cross and parallel flows. To minimize the size of stagnant zones, it is necessary to choose the optimal ratio of these parameters [13].

At present, such a ratio is not regulated by normative documents. According to the standards of the Tubular Exchanger Manufacturers Association (TEMA), it is recommended to choose a separation distance from $0.2D$ to D and a free segment height of $0.15D$ to $0.4D$, with the ratio of the height of the window to the distance between the dividers varying widely from 0.15 to 2 [14–16].

A stagnant zone is the region in which the velocity of the fluid is substantially lower than the velocity of the main flow v_B , motions of small velocity are possible. As a rule, stagnant zones are formed behind a streamlined divider and near the casing. Figure 1 shows the longitudinal section of the intertube space of STHE with diameter $D = 400$ mm, blue is the isosurface $v = 0.8 v_B$. It can be seen from the figure that behind the streamlined divider a region is formed in which the velocity of the coolant is lower than in the main stream. The size of this area is not the same for different values of the distance between the dividers and the height of the divider window. With a certain ratio of these geometric parameters, a significant increase in the dimensions of the stagnant zone is observed.

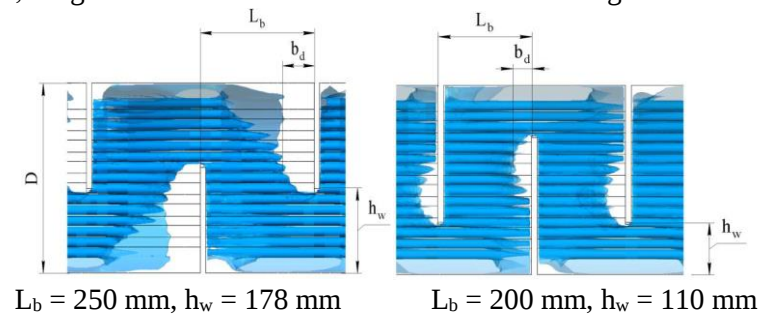


Figure 1. Areas with low velocity of coolant flow.

A stagnant zone is formed when a transverse divider flows around at any ratio of parameters, it is practically impossible to eliminate it. A finite-element modeling of flow past a chess bundle of tubes in a rectangular region is carried out with a non-uniform distribution of the flow across the section. The results of modeling the relative width of the stagnant zone from 0 to 80% have shown that it has a negative effect on the thermohydraulic characteristics: the average value of the heat transfer coefficient for different widths of the stagnant zone varies insignificantly, and the magnitude of the pressure drop significantly increases. It reduces the efficiency of heat transfer. Also in the stagnant zones there is a local increase of temperature, which can cause contamination of the transfer surface, since the polymerization of the deposits depends on the wall temperature of the pipe and can increase at a temperature above the critical temperature. Thus, when designing heat exchangers, it is necessary to select a geometric parameter ratio at which the width of the stagnant zone will be minimal.

Studies of the influence of the distance between the dividers and the height of the one-segment window on the heat transfer in the intertube space of the STHE were carried out by the method of computational hydrodynamics realized in the finite element calculation module ANSYS-CFX [17–19].

The finite-element model represents the flowing part of the STHE intertubular space with a diameter of $B = 400$ mm with a checkerboard of tubes $d = 20$ mm in diameter located in steps of $s_t = 26$ mm. The geometric parameters of single-segment transverse dividers changed in accordance with the values of the investigated parameters: the distance between the baffles $L_b = 150 \dots 325$ mm, the height of the cut-out $h_w = 87.200$ mm. The input of the coolant in this task was not considered, the liquid inlet was set through the cutout of the divider, and the uneven distribution of the flow velocity was taken into account. It is assumed that the flow and heat transfer in the calculated region are stationary, the following uniqueness conditions are given:

physical conditions: liquid – water;

boundary conditions: input with a given velocity distribution and flow temperature; output - with given pressure; the wall is a smooth adiabatic wall with the condition of adherence on the surfaces of the dividers and the cylindrical surface of the casing; the wall is a smooth wall with a predetermined temperature and a sticking condition on the outer surfaces of the heat exchange tubes;

initial conditions: temperature and pressure.

Figure 2 shows the velocity field in the annular space with a separation distance of 250 mm between the dividers and a window height of 133 mm. Figure 3 shows the graphs of the velocity variation in section A-A in the gaps between the tubes at different distances from the axis of the apparatus along the lines indicated in Figure 2. It can be seen from Figures 2 and 3 that the distribution of the flow between the dividers is unequal. In the axial direction, one can distinguish the main flow and the stagnant zone, the velocity in which is much lower. In this case, the width of the stagnant zone is from 50 to 80 mm, which on the average is 29 % of the distance between the dividers. In the transverse direction, the velocity distribution is practically uniform, except for the region located near the inner surface of the casing (Figure 3, line 8) corresponding to the bypass flow path running between the peripheral tubes and the casing.

The bypass flow has a higher speed, which is due to a lower resistance of the bypass path, but it only flushes the outer row of tubes and therefore only slightly participates in the heat exchange process. The proportion of the bypass current, depending on the design of the apparatus, can reach 20–30 % [16].

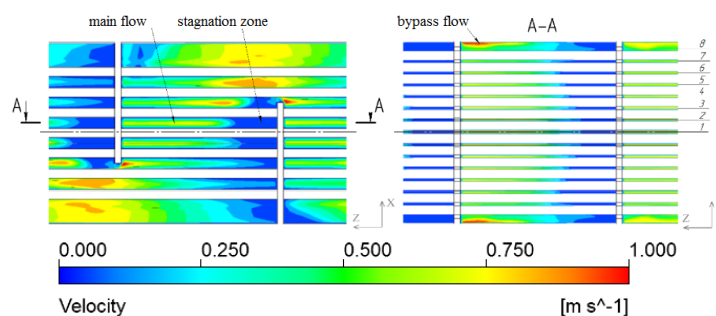


Figure 2. Flow rate distribution

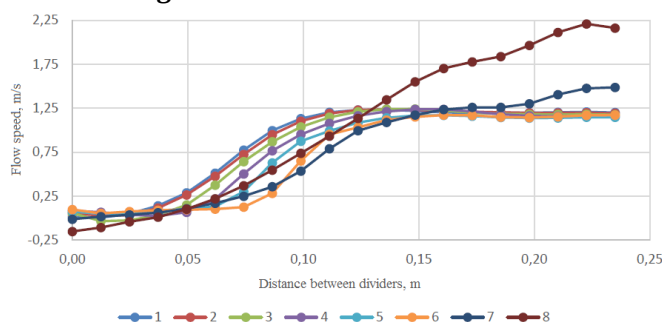


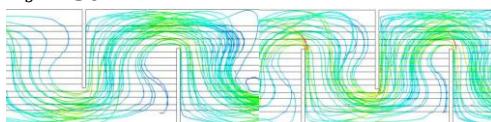
Figure 3. Graphs of velocity change in cross section at different distance from the machine axis along the Y axis.

Thus, in the cross section, three regions can be conventionally distinguished: the region of the main stream, the bypass flow and the stagnant zone.

At a constant window height $h_w = 133$ mm and the flow area in the divider window $S_w = 20397$ mm², the size of the stagnation zone and the degree of unevenness of the flow distribution vary depending on the distance between the dividers (Figure 4).

$L_b = 325$ mm

$L_b = 250$ mm



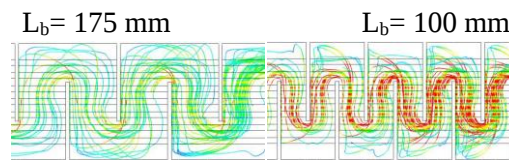


Figure 4. Lines of fluid flow for different locations of dividers.

Figure 5 shows a graph of the flow rate across the flow cross-section between dividers for different distances L_b .

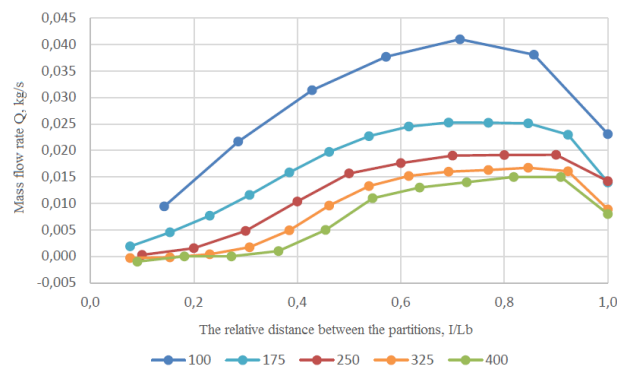


Figure 5. The graph of the flow rate across the flow section.

With a larger distance between the dividers $L_b = 250 \dots 400$ mm and, accordingly, a larger cross-sectional area of the cross flow, $S_c = 23750.38750 \text{ mm}^2$, the low-speed range is much wider, and at a distance of 100 and 175 mm between the baffles, $S_c = 8750$ and 16250 mm^2 , respectively, that is, the distribution of the flow over the section is more uniform.

Thus, in cases where $S_c < S_w$, the relative width of the stagnant zone is smaller and the distribution of the flow between the dividers is more uniform.

The tendency to a more equal distribution of the flow with a smaller distance between the baffles is maintained at a fluid velocity of 0.4 to 2 m/s.

With a constant distance between dividers $L_b = 250$ mm ($S_c = 23750 \text{ mm}^2$), the width of the stagnant zone varies depending on the height of the divider window.

In cases where $S_w > S_c$, with a divider window height of 133 to 178 mm, which corresponds to the area of the flow cross-section in the divider window from 20397 to 33397 mm^2 , the relative width of the stagnant zone does not change significantly. The smaller height of the divider wall $h_w = 87, 110$ mm ($S_w = 12824, 16615 \text{ mm}^2$) contributes to the formation of a wider stagnation zone (Figure 6).

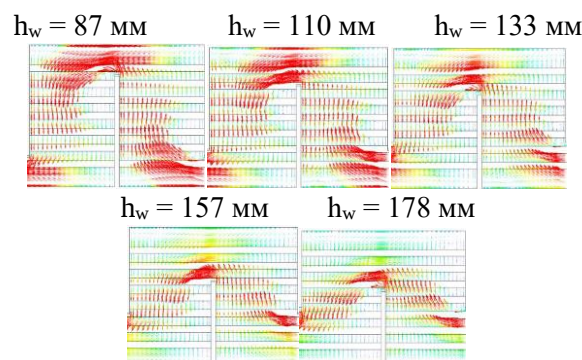


Figure 6. The velocity vector in the longitudinal section of the STHE.

Study of the partial effect of the distance between the dividers and the height of the window on the distribution of the liquid flow showed that both these parameters affect the size of the stagnant zone. An increase in the stagnation zone is observed when the area of the cross-sectional flow cross-section is larger than the cross-sectional area in the divider window.

To assess the joint effect of the height of the window and the distance between the dividers, models with $L_b = 150 \dots 275$ mm and $h_w = 87 \dots 178$ mm are considered. For the considered options, the ratio of the height of the window to the distance between the dividers lies in the range from 0.31 to 1.18.

For each model, the maximum width of the stagnant zone and its fraction in the distance between the dividers are determined. Figure 7 shows the dependence of the relative width of the stagnant zone b_d/L_b on the ratio h_w/L_b .

With a ratio $h_w/L_b > 0,85$, the width of the stagnation zone is 16,18% of the distance between the dividers. With a reduction in the cutout or an increase in the distance between the dividers, the relative width of the stagnant zone widens, reaching more than 40%. In the opposite case, when $h_w/L_b < 0,85$, the width of the stagnant zone behind the divider practically does not change, but with this ratio of parameters a stagnant zone appears near the casing. Thus, the ratio of the height of the window and the distance between the dividers, equal to 0,85, can be considered optimal for ensuring a minimum size of the stagnant zone behind the baffle wall.

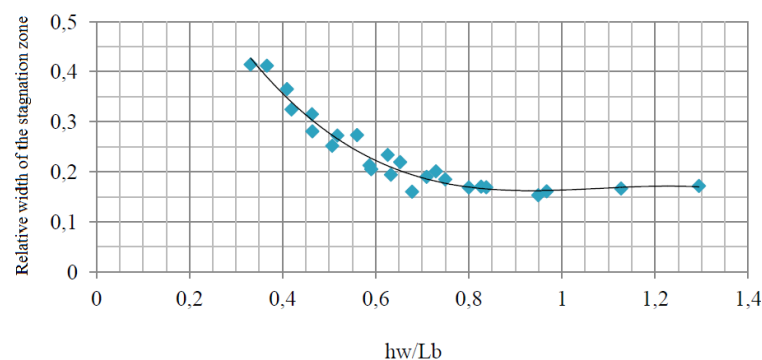


Figure 7. Dependence of the relative width of the stagnant zone on the ratio h_w/L_b .

From the foregoing, it follows that the STHE design, in which the distance between the dividers is smaller than the height of the divider cutout, is optimal insofar as it provides the minimum width of the stagnant zone. The height of the free segment of the divider determines the height of the cross-current region, and an increase in the cut-out of the divider is undesirable. Thus, in order to ensure the highest heat transfer intensity, smaller values of h_w should be taken and, consequently, L_b .

On the other hand, it must be taken into account that the close arrangement of the dividers leads to a more significant increase in the hydraulic resistance than the heat transfer coefficient, i.e. decreasing of the efficiency of heat transfer.

To solve this problem, it is possible by means of additional constructive elements - dividers (figure 8). The additional divider is a rectangular plate with holes for mounting in the tube bundle and is placed between the transverse dividers. Functionally, it acts as a bump, blocking the path of part of the main stream and directing it along the transverse divider to narrow the stagnant zone.

In order to determine the optimal location of the additional divider, several options were considered for placing the bump at different heights and distance from the transverse divider. For STHE diameter of 400 mm with a distance of 325 mm between the dividers, it is optimal to place the bump at $h_o = 89$ mm from the machine axis and at a distance $L_o = 120$ mm from the transverse divider (Figure 9). The velocity fields in the longitudinal section, shown in Fig. 9, show that the bump block contributes to the narrowing of the stagnant zone. The use of an additional divider allowed reducing the pressure drop by 21.2% and increasing the average heat transfer coefficient by 1.3%. This improves the thermal and hydraulic design perfection, characterized by the ratio of the transferred thermal energy to the mechanical energy expended for pumping the coolant.

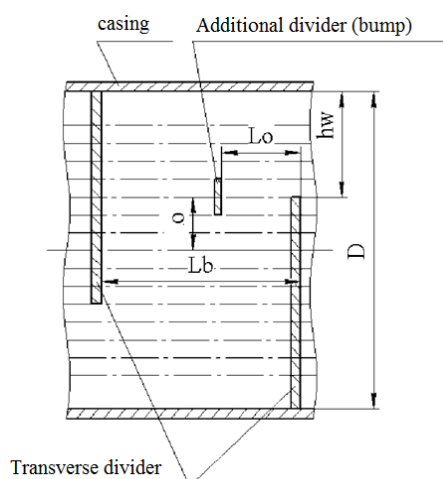


Figure 8. Placing an additional divider.

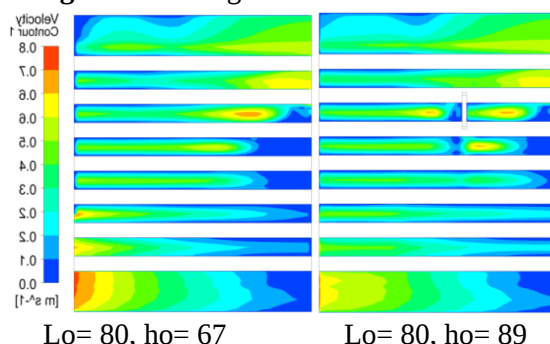


Figure 9. Velocity fields for different location of an additional divider.

Table 1 shows the thermohydraulic characteristics of the section of the annular space STHE, enclosed between adjacent transverse walls.

The coefficient of thermal-hydraulic perfection characterizes the ratio of the amount of heat Q given off by the surface to the power N spent for pumping the coolant relative to the surface [20].

Table 1. Thermohydraulic characteristics.

Characteristics	Without additional Dividers	With additional Dividers	Δ , %
Thermal energy, W	159300	161300	1,3
Mechanical energy, W	2,638	2,083	-21
Coefficient of heat transfer, W/m $\cdot$ K	2648	2678	1,1
Differential pressure, Pa	445,9	351,4	-21,2
Thermohydraulic perfection	60386	77436	28,2

Thus, the use of additional dividers in the STHE construction - bumpers, allows to reduce the hydraulic resistance of the flowing part due to a more even flow distribution and narrowing of the stagnant zones in the cross current region. This contributes to improving the thermal and hydraulic characteristics of the structure and increasing thermal efficiency. The use of bumpers allows to increase the distance between dividers, reducing the cost of the heat exchanger.

3. Conclusions

As a result of the study of the influence of the distance between the transverse dividers L_b and the height of the cutout of the divider wall h_w on the thermal efficiency of the STHE, the dependence of the size of the stagnant zone formed behind the transverse divider on the ratio of the indicated parameters h_w/L_b was revealed.

It is proposed to use additional dividers in the design of the tube bundle STHE, which help reduce the hydraulic resistance due to a more even flow distribution.

References

- [1] Luzzi L, Cammi A, Marcello V D and Fiorina C 2010 *Chemical engineering science* **16** pp 487–488
- [2] Muzychka Y S, Yovanovich M M 2001 *Journal of enhanced heat transfer* **4** pp 243–259
- [3] Chiu Y W, Jang J Y 2009 *Applied thermal engineering* **29** pp 250–258
- [4] Yan X, Xiao Z J, Huang Y P, Wang F 2006 *Hedongli gongcheng* **27** 77–82
- [5] Hamid A H A, Hussam W K, Sheard G J 2016 *Numerical heat transfer* **8** pp 847–869
- [6] Han L, Chang H, Zhang J, Xu T 2015 *Plasma science and technology* **4** pp 347–352
- [7] Guo L, Qin F, Chen J, Chen Z 2008 *Applied thermal engineering* **28** pp 907–914
- [8] Shulman Z P, Khusid B M, Zaltsgendler E A, Ivashkevich E V, Ryklina I L, Erenburg V B *Experimental thermal and fluid science* **1** pp 9–26
- [9] Bakhtizin R N, Pavlova Z H 2015 *Proceedings* **1** pp 35–38
- [10] Konesev S G, Khazieva R T, Kirillov R V 2016 *X International IEEE Scientific and Technical Conference* pp 1–7
- [11] Konesev S G, Khazieva R T, Kirillov R V, Konev A A 2017 *Journal of Physics: Conference Series (JPCS)* **803**
- [12] Konesev S G, Khazieva R T 2015 *Modern problems of science and education. Electronic scientific journal* **1**
- [13] Karetnikov D V, Rizvanov R G, Fairushin A M, Kolokhov K S 2013 *Welding international* **7** pp 557–560
- [14] GOST R 53677-2009 2011 Standartinform 34
- [15] Standards of Tubular Heat Exchanger Manufacturers Association 2007
- [16] Spravochnik po teploobmennikam 1987 p 352
- [17] Chetvertkova O V, Rizvanov R G 2012 *Neftegazovoe delo* **3** pp 109–112
- [18] Chetvertkova O V, Ardashirova E A 2012 *Neft' i gaz* 72
- [19] Chetvertkova O V, Mironov A V, Rizvanov R G, Sharafiev R G 2015 *Neftegazovoe delo* **3** p 452–465
- [20] Antufev V I 1966 *Effektivnost' razlichnyh form konvektivnyh poverhnostei nagreva* p 183