Thermal and hydraulic efficiency of the staggered tube bundle in pulsating flow

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Abstract. Determination of the thermal and hydraulic efficiency $\eta$ is one of the ways to assess the effectiveness of the method used to intensify heat transfer. In this paper, the hydraulic fluid efficiency of diamond-coated tube bundles is determined for a pulsating flow of a heat carrier. The Reynolds number was based on the outer diameter of the pipe and was $Re = 100$, the Prandtl number $Pr$ ranged from 214 to 363. It was shown that an increase in the dimensionless amplitude $\beta$, frequency $f$, and pulsating ratio $\psi$ leads to a decrease in thermal and hydraulic efficiency. The influence of the Prandtl $Pr$ numbers on the thermohydraulic efficiency was also analyzed. It is shown that an increase in thermal and hydraulic efficiency is observed with increasing $Pr$.

1.Introduction

To date, there are many papers devoted to the study of heat transfer and hydrodynamics in bundles of pipes in order to improve the efficiency of heat exchange equipment.

In work [1], an experimental method was used to study heat transfer during transverse flow around a row of plates parallel to each other, which is similar to flow around a bundle of tubes. Air was used as the working fluid. The experiments were performed in the frequency range $10 \leq f \leq 50$ Hz, pulsation amplitudes $13.33 \leq A \leq 15.35$ %, and Reynolds numbers of $250 \leq Re \leq 2000$. The results show that both the frequency and the amplitude of the pulsating flow are influencing the heat transfer. The maximum intensification of heat transfer (enhancement heat transfer) by 136% was observed at $Re = 253, f = 15$ Hz, $A = 13.35\%$.

In work [2], the intensification of heat transfer processes was experimentally studied in the artificial creation of a nonstationary flow regime by imposing low-frequency asymmetrical pulsations on the flow in the intertube space of a corridor bundle of pipes on the flow, and an assessment of the influence of such factors as a change in the frequency and ripple pulsation for the chosen range of Reynolds numbers ($0 \leq f \leq 0.8$ Hz; $0 \leq \psi \leq 1$; $20 \leq Re \leq 100$). The authors show that the imposition of low-frequency pulsations on the liquid flow, with transverse flow around the cylinder located in the center of the corridor bundle of pipes, leads to an intensification of heat exchange in comparison with
the steady-state current, on average, to 10%. At the same time, from the point of view of energy efficiency, the greatest effect is observed in pulsations with a degree of asymmetry $\psi = 0.25$, taking into account additional power inputs for pulsation generation.

In [3-5], an experimental method was used to study the heat transfer in a corridor bundle of tubes under conditions of low-frequency pulsations of the liquid flow. Flow pulsations were asymmetrical. As the working fluid, the water $Pr = 5.5Re$ was used in the range $100 \leq Re \leq 500$, the ripple frequency was $0.125 \leq f \leq 0.5$ Hz, the amplitude of the oscillation was $1.25 \leq A/D \leq 4.5$. The maximum increase in heat transfer by 90% was observed at $Re = 500, f = 0.5$ Hz, $A/D = 4.5$. It is shown that with increasing $Re$ the heat loss decreases, and with increasing $f$ and $A/D$ the heat transfer increases. Also, the positive effect of using low-frequency asymmetric pulsations during heat exchange in a wavy channel was obtained in [6].

The efficiency of the heat exchange equipment depends on the values of the hydraulic resistance and the heat transfer coefficients of the heat exchange elements, which in turn affect the final metal capacity of the heat exchanger and the necessary power of the pumps required for pumping heat carriers. The author [7] studied the thermal-hydraulic efficiency of a discrete-rough channel in a pulsating flow. The evaluation of thermal hydraulic efficiency allows us to conclude that the use of superimposed pulsations in a discrete-rough channel is promising for intensification of heat transfer. The values $I$ and $\eta$ from the Strohal numbers $Sh$ for a discrete-rough channel are given when pulsations are applied to the air flow. The maximum of the coefficient $I = 1.33$ for a discrete-rough channel is observed for $Sh$ about 2.2 and the amplitude $\beta = [0.4; 0.5]$. It is noteworthy that the imposition of pulsations in a discrete-rough channel leads to a large increase in $\eta$. The lowest indices of various coefficients of thermal and hydraulic efficiency were obtained at $Sh = 0.6$, because at this value, the greatest increase in static pressure losses is observed. The obtained results open new possibilities for increasing the thermal and hydraulic efficiency of heat exchangers and cooling systems.

In the previous work [8] thermal and hydraulic efficiency of a corridor bundle of pipes was considered for pulsating flows at $Pr = 5.5$. In this paper, the thermal and hydraulic efficiency of a diamond beam in pulsating flows for data obtained in the course of numerical modeling in [9] was considered. The Prandett numbers were located in the range $214 \leq Pr \leq 363$, the Reynolds baizing numbers on the outer diameter of the beam tube were $Re = 100$.

2. Methods
To estimate the thermal hydraulic efficiency of equation (1), the method proposed in [8] was used.

$$\eta = \frac{Nu_p}{Nu_{st}} \frac{\xi_p}{\xi_{st}}$$

Where $Nu_{st}, \xi_p$ – Nusselt number and hydraulic resistance in a steady flow, $Nu_{st}, \xi_{st}$ – Average for the period of pulsations, Nusselt number and equivalent hydraulic resistance during pulsations of the flow. The parameter $\eta$ in equation (1) is also called the Reynolds analogy factor (FAS), and the condition $Re_p = Re_{st}$.

3. Results and discussion
In Fig. 1-3 shows the dependencies $Nu_p/Nu_{st}, \xi_p/\xi_{st}$ and $\eta$ from $Pr, \beta, f$ by which it can be seen that an increase in the regime parameters of pulsations $\beta, f$ leads to a decrease in $\eta$, and an increase of $Pr$ to an increase in $\eta$. With an increase in the number of $Pr$, a decrease occurs $Nu_p/Nu_{st}$ and $\xi_p/\xi_{st}$ (pic. 1). When the nature of the pulsations approaches the symmetric $\psi \to 0.5$ there is a decrease in the telpohydraulic efficiency $\eta$. It is shown that the increase $\beta$ and $f$ leads to an increase $Nu_p/Nu_{st}$ and an increase $Pr$ and $\psi$ to decrease $Nu_p/Nu_{st}$ (Fig.1–3).

On Fig. 4–6 it is shown dependencies $Nu_p/Nu_{st}, \xi_p/\xi_{st}$ and $\eta$ or $\beta Fo$ from different numbers $Pr$ and porosity, which shows that with an increase in the ratio $\beta Fo$, there is an increase in heat transfer and
hydraulic resistance in a non-stationary flow compared with a stationary one. Over the entire range \( \beta/Fo \) and Pr and porosity numbers \( \xi_p/\xi_{st} \) exceeds the \( Nu_p/Nu_{st} \) (Fig. 6). Maximum values of thermal and hydraulic efficiency \( \eta = 0.27 \) (Fig. 6a) and \( \eta = 0.40 \) (Fig. 6b) are observed at a duty ratio \( \psi = 0.25 \) and minimum values of the ratio \( \beta/Fo \).

On Fig. 7–9 it is shown dependencies \( Nu_p/Nu_{st}, \xi_p/\xi_{st} \) and \( \eta \) from \( \beta/(Fo \cdot Pr) \) at different coefficients of porosity, which shows that with an increase in the ratio \( \beta/(Fo \cdot Pr) \), there is an increase in heat transfer and hydraulic resistance. At the minimum values of the duty cycle \( \psi = 0.25 \) and relation \( \beta/(Fo \cdot Pr) = 28 \) thermal hydraulic efficiency has a maximum value \( \eta = 0.40 \) (Fig. 9).
Fig. 4. Dependencies $\frac{Nu_p}{Nu_H}$ from $\beta/Fo$ at $Re = 100$: a) $Pr = 215$; b) $Pr = 363$

Fig. 5. Dependencies $\frac{\xi_p}{\xi_H}$ from $\beta/Fo$ at $Re = 100$: a) $Pr = 215$; b) $Pr = 363$

Fig. 6. Dependencies $\eta$ from $\beta/Fo$ at $Re = 100$: a) $Pr = 215$; b) $Pr = 363$
Fig. 7. Dependencies $Nu_p/Nu_{st}$ from $\beta(Fo \cdot Pr)$ at $Re = 100$

Fig. 8. Dependencies $\xi_p/\xi_{st}$ from $\beta(Fo \cdot Pr)$ at $Re = 100$
Conclusion

The hydraulic efficiency of a chess bundle of pipes is estimated at application of pulsations. It is shown that as the Pr increases, an increase occurs in $\eta$, the maximum values of the thermal hydraulic efficiency $\eta = 0.40$ are observed at $Pr = 363$ and the ripple ripple $\psi = 0.25$.

As the frequency $f$ and the dimensionless amplitude $\beta$ of pulsations, a decrease in $\eta$ occurs.

When the nature of the pulsations approaches a symmetrical $\psi \rightarrow 0.5$, the telophydraulic efficiency decreases $\eta$.

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