Gasketed plate heat exchangers breathing effect

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Abstract. Despite existing issues related to durability and convenience of operation plate heat exchangers are more and more often used in various industries, from the housing and utilities sector to nuclear power. One little-known peculiarity of plate heat exchangers is breathing effect. This effect takes place when pressures of heat exchanging mediums are not equal. Pressure difference between adjacent channels makes channels with lower pressure to narrow and channels with higher pressure to extend. This peculiarity of plate heat exchangers is not advertised and thermal-hydraulic calculations often ignore it. However, this effect can increase the hydraulic resistance of the heat exchanger up to 3.5 times. Given the sufficiently high hydraulic resistance of the plate heat exchangers, its significant increase can affect the functional characteristics of the heat exchanger negatively. Therefore, in thermal-hydraulic calculations it is necessary to take account of breathing effect. In this paper, we consider available experimental data, analyze the factors causing breathing effect and propose measures to minimize it.

1. Introduction
Thermal and hydraulic tests of various gasketed plate heat exchangers (GPHE) were carried out on the JSC «NPO CKTI» (St. Petersburg, Russia) testing facility KS10606 and on the testing facility of Funke GmbH (Gronau/Leine, Germany). The test rig is presented on figure 1, where 1 is the tested GPHE; 2 – flowmeters (Venturi nozzles or electromagnetic flowmeters); P1, P2 – pressure sensors; dP1, dP2 – differential pressure sensors. Water was used as heat exchanging medium for both sides of GPHEs.

During the tests pressure (P1, P2), flow rate (G1, G2), pressure drop (dP1, dP2) were measured and automatically recorded. For these measurements, high-precision calibrated electronic devices were used. The error in measuring did not exceed one kPa for pressure, 0.2 kPa for pressure drop, 2% for flow rate and 1°C for temperature.
Pressure drop can be calculated according to the following equation:

\[ dp = \frac{\xi L L}{2} \rho w^2, \]  

where \( \xi_L = \xi_L + 4f \frac{L}{d_h} \) is drag coefficient. It was assumed that local drag coefficient \( (\xi_L) \) is equal to five. This assumption could not have a noticeable effect on the value of friction factor \( (f) \), because \( \xi_L \) was not more than 9% of \( \xi_L \). \( \rho \) is density of water, kg / m\(^3\), \( w \) is water velocity, m / s; \( f \) is the friction factor; \( L \) is distance along the height between the axes of the plate holes (ports), m; \( d_h \) is hydraulic diameter of channel, m.

The form of equation for friction factor for GPHEs according to [1, 2] is:

\[ f = \frac{A}{Re^n}, \]  

where \( Re = \frac{w d_h}{\nu} \) is Reynolds number for the flow of water; \( \nu \) is the kinematic viscosity of water, m\(^2\)/s; \( A \) and \( n \) are parameters to be determined during the tests.

For all experimental data, \( f \) was determined for both hot (first circuit) and the cold (second circuit) sides of GPHEs.

Only the results of tests of GPHEs where breathing effect was observed are present in this paper. Table 1 presents the main geometric parameters of these GPHEs.

**Table 1. Main geometric parameters of tested GPHEs.**

| Parameter                              | Tested GPHEs |
|----------------------------------------|--------------|
|                                        | #1 | #2 | #3 | #4 | #5 | #6 |
| Heat exchange surface of plate, S\(_p\), m\(^2\) | 0,21 | 0,21 | 0,41 | 0,41 | 0,27 | 0,57 |
| Distance along the height between the axes of the plate holes (ports), L, m | 0,894 | 0,894 | 0,77 | 0,77 | 0,707 | 1,092 |
| Plate width between gaskets, b, m      | 0,195 | 0,195 | 0,616 | 0,616 | 0,396 | 0,497 |
| Average cross sectional area, F\(_c\), m\(^2\) | 4,68·10\(^{-4}\) | 4,68·10\(^{-4}\) | 1,6·10\(^{-3}\) | 1,6·10\(^{-3}\) | 1,872·10\(^{-3}\) | 1,872·10\(^{-3}\) |
| Hydraulic diameter of channel, d\(_h\), m | 0,0048 | 0,0048 | 0,0052 | 0,0052 | 0,006 | 0,006 |
| Number of plates, n\(_p\)              | 9 | 65 | 21 | 31 | 15 | 15 |
2. Results
Two modes of tests were carried out. The first mode is the mode with equal pressures on hot and cold sides of GPHE and the second mode is the mode with different pressures on hot and cold sides of GPHE. Solving equation (1) for $f$ we determine parameters $A$ and $n$ for equation (2). For different GPHEs and different types of plates, the values of $A$ and $n$ are different. In addition, with the increase of Reynolds number, $n$ decreases, and the value of $f$ tends to a constant value. Figure 2 shows the plot of $f$ as a function of the Reynolds number for the mode with equal pressures on hot and cold sides of the tested GPHEs.

![Figure 2](image_url)

**Figure 2.** GPHEs friction factor for equal pressure on hot side and cold side ($P_i = P_j$).

However, due to the breathing effect [3], the hydraulic resistance of GPHEs depends not only on the value of the Reynolds number, but also on the pressure difference in the adjacent channels of hot side and cold side ($P_{i,m} - P_{j,m}$), at i, j = 1, 2; i ≠ j; $P_{i,m} = P_i - 0.5dP_i$; $P_{j,m} = P_j - 0.5dP_j$. Therefore, for the mode with different pressures on hot side and cold side of GPHE, $f$ was plotted as the function of the pressure difference $f = f (P_{i,m} - P_{j,m})$. Results are presented in figure 3 for GPHEs #3 and #4 and in figure 4 for GPHEs #1 and #2.

The significant experimental data dispersion (± 43%) from average line in figure 3 is caused by the dependence of $f$ on the Reynolds number. For GPHEs #1 and #2, the experimental Reynolds number values lie in range from 800 to 26300.

The distance between the cover plates also has its influence on the GPHEs drag coefficient. For example, the stack of plates for GPHEs produced by the Funke GmbH during assembling must be tightened to a certain size [4]. When assembling a package of plates with new gaskets, this size should be maximum. After a period of operation, the gaskets wear and the stack can be tightened till a minimum size.

The dispersion of the experimental data (± 38%) from average lines in figure 4 is less than in figure 3 due to the fact that the experimental data for heat exchangers #3 and #4 are obtained for a narrower range of Reynolds numbers (1100…15700). Experimental data for maximum (Max Sp) and minimum (Min Sp) distances between cover plates are marked separately. For the data with minimum distance between cover plates $f$ is higher, because of the cross sectional area decrease.

Analysis of the experimental data for GPHEs #1 and #2 shows that $f$ on the side with a lower pressure is in 3.0…3.5 times higher than on the side with higher pressure. For GPHEs #3 and #4, this difference does not exceed 1.5 times.
Thus, the drag coefficient in GPHEs depends on three factors: the Reynolds number, the pressure difference between the sides and the distance between the cover plates. The third factor has the least impact on the drag coefficient, because the difference between Max Sp and Min Sp is only 3...5%. To take account of the first two factors, we suggest using method [5]. For \( |P_{i,m} - P_{j,m}| > A \cdot \text{Re}^{-B} \):

\[
f_i = -\arctan\left(\left(C \cdot \ln(\text{Re}) - D\right) \cdot \left(A \cdot \text{Re}^{-B}\right) - 2 \cdot \left(C \cdot \ln(\text{Re}) - D\right) \cdot \left(A \cdot \text{Re}^{-B}\right)^2 + E \cdot \text{Re}^{-F}\right),
\]

and for \( |P_{i,m} - P_{j,m}| \leq A \cdot \text{Re}^{-B} \):

\[
f_i = -\arctan\left(\left(C \cdot \ln(\text{Re}) - D\right) \cdot \left(P_{i,m} - P_{j,m}\right) - 2 \cdot \left(C \cdot \ln(\text{Re}) - D\right) \cdot \left(P_{i,m} - P_{j,m}\right)^2 + E \cdot \text{Re}^{-F}\right),
\]

where A, B, C, D, E, F are numeric parameters determined for each GPHE during tests.
Equation (3) is applicable for large values of $|P_{i,m} - P_{j,m}|$ and takes into account the fact that after a certain threshold value of $|P_{i,m} - P_{j,m}|$ the further increase of pressure difference between the hot side and the cold side of GPHEs does not lead to the increase of friction factor. On the contrary, equation (4) is applicable for $|P_{i,m} - P_{j,m}|$ values below the threshold value [5]. The results for GPHE #5 are shown on figure 5 and for GPHE #6 on figure 5.

For visual clarity the experimental data in these figures are divided into three groups according to the Reynolds numbers. For each group, an average line corresponding to the mean value of the Reynolds numbers for a given group is plotted.

For GPHE #5 $f$ on the side with a lower pressure is in 1.09…1.21 times higher than on the side with higher pressure. For GPHE #6 $f$ on the side with lower pressure is higher in 1.20…1.34 times.

**Figure 5.** GPHE #5 friction factor as the function of pressure difference and Reynolds number, according to equations (3) and (4).

**Figure 6.** GPHE #6 friction factor as the function of pressure difference and Reynolds number, according to equations (3) and (4).
Figure 5 and figure 6 show that evaluating $f$ using equations (3) and (4) has satisfactory results. The discrepancy between the experimental and calculated values of $f$ is less than 8…12%. While evaluating $f$ using equation (2) increase discrepancy to 14…21%. For GPHEs more prone to the breathing effect, this difference is even higher.

A number of tests of GPHEs of various sizes and manufacturers showed that the breathing effect is lesser in GPHEs with flat gasket profile. The main types of gasket profiles for GPHEs are shown in figure 7.

![Gasket Profiles](image)

**Figure 7.** Types of gaskets profiles for GPHEs.

The breathing effect is lesser for C-type gasket profile GPHEs. One side of A-type and B-type gaskets is flat, while the other has a protrusion along its entire length. The both sides of C-type gasket are flat. Apparently, with sufficient manufacturing accuracy, the flat gasket allows the plates to be tightened denser, so their mobility relative to each is reduced. For such GPHEs, the breathing effect changes the value of $f$ in comparison with the mode with equal pressure of heat exchanging mediums by only 3…27%.

In addition, to reduce breathing effect special stops can be created on the surface of the plates. These stops will give additional rigidity to the package of plates and reduce the breathing effect. However, these stops will add disturbances into the flow in the channel and can create small stagnant zones in which deposits will accumulate.

**Conclusion**

In the current study, the breathing effect in GPHEs was experimentally confirmed. Necessity of taking this effect into account in hydraulic calculations was shown. The breathing effect can be significantly different for GPHEs of different sizes.

To create a universal method of estimation of the breathing effect for all types and sizes of GPHEs, it is necessary to obtain a larger volume of experimental data. Proposed equations (3) and (4) can be used as a basis for further studies.

**References**

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