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PRESSURE DROP STUDY OF POLYMERIC HOLLOW FIBER HEAT EXCHANGERS

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Abstract: *Polymeric hollow fiber heat exchangers are an alternative to common metal heat exchangers in low-temperature applications. Their advantages are low cost, low weight, and corrosion resistance. The heat transfer surface consists of hundreds or even thousands of fibers of small diameter. The PHFHE for gas-liquid application has a regular structure, which prevents the fibers from blocking the heat transfer surface and allow the gas to flow through the heat exchanger. This arrangement, known as the bank of tubes, is common for the multipass shell and tube heat exchangers. There are relations used to estimate the pressure drop of flow passing the bank of tubes. Those are based on extensive experimental research with steel tubes. Unfortunately, it seems that those relations do not apply to flexible fibers. This paper shows the discrepancy between the theory for non-flexible bank of tubes and measured data of PHFHE.*

Keywords: Polymeric hollow fiber, Heat exchanger, Bank of tubes, Pressure drop.

1. Introduction

Polymeric hollow fiber heat exchangers (PHFHE) are heat exchangers consisted of hundreds of tiny tubes, so-called hollow fibers. The typical outer diameter of hollow fibers is in range 0.6 - 1.6 mm. The thermal conductivity of polymers is low, but this can be overcome by using hollow fibers with a wall thickness of less than 100 µm (Chen et al., 2016). Polymeric hollow fiber heat exchangers appear firstly in (Zarkadas, 2004) and were tested for water-water and ethanol-water systems. Then studies focusing on application in desalination appeared. Study (Song et al., 2010) tested three different kinds of polymeric hollow fibers in hot brine-water and steam-tap water systems and proved that those devices are suitable for desalination. Another study (Song et al., 2018) studied polymer hollow fiber heat exchanger from PVDF. In addition to corrosion resistance, polymer hollow fiber exchangers allow easy shaping and machining. They have a low weight and their cost is lower than metal units. They are also environmentally friendly since the energy required to produce a unit of mass of plastic is about 2 times less than a unit of metal (Zarkadas, 2004).

To have a large active heat transfer surface the separation of fibers is needed. Otherwise, fibers can block each other, and the heat transfer surface would be inefficient. The method of separation was presented (Raudensky et al., 2017). Each fiber is formed by stretching and thermal fixation, then each fiber has its own shape. This process is called chaotization. The chaotized bundles can achieve twice as much heat transfer rate for the same parameters of flows and fibers. Those bundles are still very flexible and can bend in various shapes. The chaotized PHFHE can be used easily for natural convection, for example as an immersed heat exchanger (Weiß et al., 2018).

In 2016 rectangular shape PHFHE for the gas-liquid application was presented in two studies (Astrouski, 2014 and Krasny et al., 2016). Those PHFHE have the heat transfer surface separated by textile interweaving. In the study (Krásný et al., 2016) two PHFHE were compared to the conventional aluminium car radiator. The values of the heat transfer coefficient were similar, but the pressure drop was higher in case of PHFHE.

The pressure drop is an important part of the designing of a heat exchanger. The previous studies focus on the heat transfer rate and its prediction. Unfortunately, there is a very few studies on the topic of pressure drop and none on the gas side in case of gas-liquid application.

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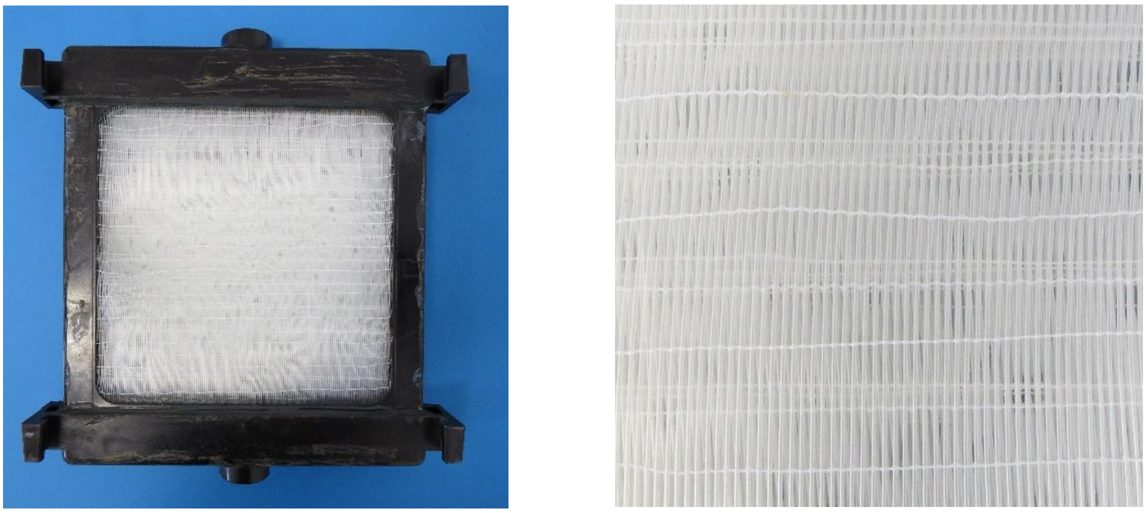

Fig. 1: PHFHE with woven heat transfer surface, on the right detail.

2. Pressure drop of a bank of tubes

The pressure drop is defined as a difference of the total pressure between the two points of the conduit. This difference is caused by the change of mechanical work to heat. The values of pressure drop depend on the geometry of the heat exchanger as well as on the heat transfer fluid and its velocity. Bank of tubes is a very common type of geometry since is widespread in most common heat exchanger type, shell and tube. In the past, several empirical models for pressure drop of bank of tubes was created. In the majority of those models, the pressure drop is stated as a function of velocity of the stream, density of fluid, geometry and arrangement of tubes and pressure drop coefficient, which depends on the tube parameters and Reynolds number. There are two basic tube arrangements, inline and staggered, see Fig. 2. The arrangements are characterized by transversal (S_T), longitudinal (S_L) and diagonal (S_D) pitch.

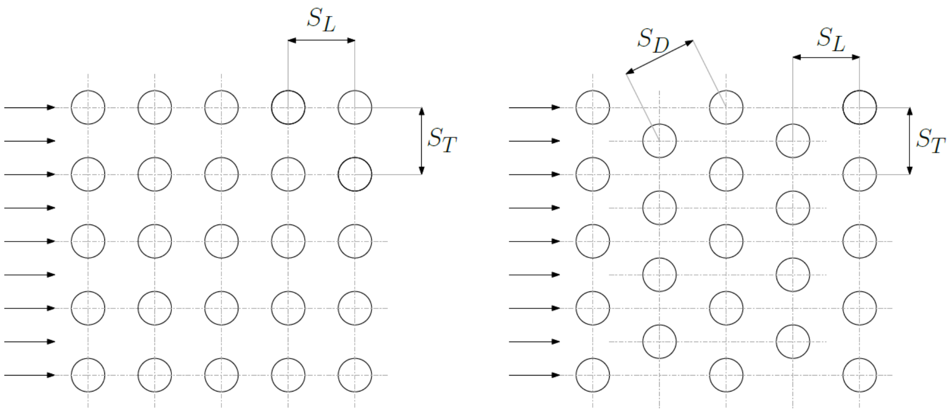

Fig. 2: Inline arrangement (on left) and staggered arrangement (on right).

The first studies on pressure drop appeared at the beginning of the last century. Among the first were Grimison (Grimison, 1937) and Jakob (Jakob, 1938). The next (Gunter and Shaw, 1945), which was criticized shortly after publishing. All those models are not used nowadays.

Kays and London improved Grimison model (Kays and London, 1998). Žukauskas work (Zhukauskas, 1972) was one of the most extensive and we can find his model in many handbooks (Bergman et al., 2011 and Kakac et al., 2002). These two models, unfortunately, have the pressure drop coefficient given in form of tables or graphs only for the most common pitches (1.25, 1.5, 2.0, 2.5). In the case of Zukauskas, the data for typical Reynolds numbers of PHFHE are missing.

In VDI-Heat Atlas (Gaddis, 2010) the model which is based mostly on Gnieliski and does not have these obstacles is published. The pressure drop coefficient is given explicitly as a function of arrangement, pitches, and Reynolds number. This model is used in the presented study.

3. Experimental details

The data of this study is taken from (Krásný et al., 2016). Two PHFHE with different fiber outer diameter (0.6 and 0.8 mm), but same pitches (S_T = 1.8 mm, S_L = 2 mm) and number of rows (14) were tested in certified calorimetric circuit. The precision of the measurement is in the range of ± 3 %. Inside the fibers flowed 50/50 % water-glycol coolant solution, temperature 60 °C. As a cooling medium, the 20 °C air was used. The measurements were done for 1, 2, 4 and 10 m/s air speed.

Due to the extruding technology and tiny dimension of the fiber, the tolerance of the diameter of hollow fiber was usually ±10 % in both directions. The flexibility of hollow fibers and manufacturing processes cannot guarantee that the arrangement will be precisely in-line as is intended and designed for those heat exchangers. Therefore, the study is done for both arrangements.

4. Results and Discussion

The measured pressure drop for two PHFHE were compared to the computed values, that was calculated for both arrangement, inline and staggered. In both arrangements, the calculation was done with the nominal value of diameter as well as with values that are 10 % higher/lower. The results are plotted in Fig. 3.

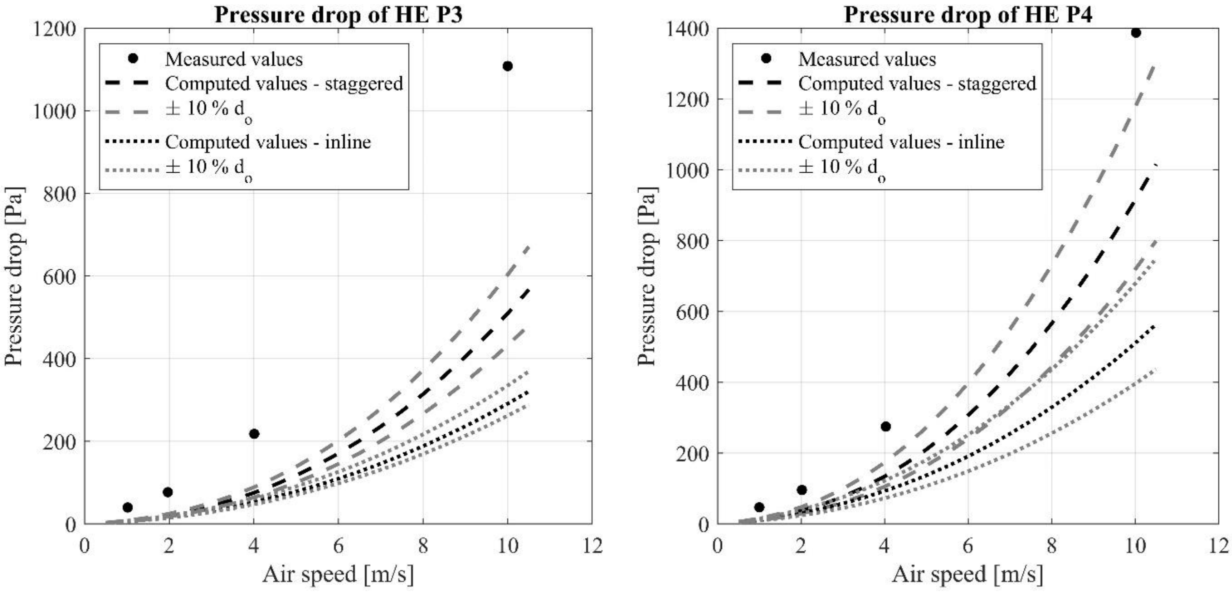

Fig. 3: The results.

It can be seen that the measured values of pressure drop are much higher than those computed. In lower air speed the relative error is even high as 458 % for P3 and 280 % for P4. With increasing air speed the relative error decrease but it is still quite high. For 10 m/s air speed prediction for P3 is having 118 % relative error and P4 51 %.

The variation of diameter causes very significant variation in the pressure drop, namely for P3 it is + 20 % and – 15% and for P4 up to + 32 % and – 23 %. The relative error remains almost the same in all air speed range. Absolutely the difference between the smallest and the largest diameter can be even 200 Pa (in case of air speed 10 m/s).

The discrepancy of the measured and computed results is caused by the flexibility of the polymeric hollow fiber. Firstly, due to the flexibility, the pitches are not the same in the whole heat exchanger and changes with the air flow. The other cause is flow-induced vibrations. The equations used are derived from experiments with metallic tubes, which are more rigid. The flexible fibers are more allowed to vibrate. The pressure drop increase with increasing vibration intensity was studied (Li et al., 2020).

5. Conclusions

Polymeric hollow fiber heat exchangers are alternatives to conventional heat exchangers in applications where chemical resistance or low weight is needed. Along with the heat transfer rate, it is important to know the pressure drop of the heat exchanger, because the pumping power is related to the pressure drop. The optimization of the heat exchanger can save energy and economic cost. The present relations to approximate the pressure drop are in many cases inappropriate since are based on experiments with much bigger tubes and therefore the small Reynolds numbers are missing. The only model which can be used is having a large error. There is a need to revise those relations to the flexible fibers. The diameter of the fiber varies along its length, which can cause the inaccuracy in the pressure drop approximation. This inaccuracy can be even as large as 30 % for common 10 % variation in outer diameter. This has to be taken into account when designing the PHFHE.

Acknowledgement

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References

Astrouski, I. and Raudensky M. (2014) Polymeric Hollow Fiber Heat Exchangers: Liquid-to-Gas Application. ASHRAE Transactions, 120, 2, pp. 95-105.

Bergman, T. L., Incropera F. P., Dewitt D. P. and Lavine A. S. (2011) Fundamentals of Heat and Mass Transfer. John Wiley & Sons, Inc., Noboken.

Chen, X., Su, Y., Reay, D. and Riffat, S. (2016) Recent Research Developments in Polymer Heat Exchangers – A Review. Renewable and Sustainable Energy Reviews, 60, pp. 1367-1386.

Gaddis, E. S. (2010) Pressure Drop of Tube Bundles in Cross Flow in VDI-Heat Atlas. pp. 1079-1091.

Grimison, E. (1937) Correlation and Utilization of New Data on Flow Resistance and Heat Transfer for Cross Flow of Gases over Tube Banks. Transactions of ASME. 59, pp. 583-594.

Gunter, A.Y. and Shaw, W. A. (1946) A General Correlation of Friction Factors of Various Types of Surfaces in Cross Flow. Transaction of ASME. 67, pp. 643-660.

Jakob, M. (1938) Heat Transfer and Flow Resistance in Cross Flow of Gases over Tube Bank. Transactions of ASME. 60, pp. 384.

Kakaç, S., Liu, H. and Pramuanjaroenkij, A. (2002) Heat Exchangers: Selection, Ration, and Thermal Design. CRC Press.

Kays, W.M. and London A.L. (1998) Compact Heat Exchangers. Krieger Pub. Co., Malabar.

Krasny, I., Astrouski, I. and Raudensky, M. (2016) Polymeric Hollow Fiber Heat Exhanger as an Automotive Radiator. Applied Thermal Enfineering. 108, pp. 798-803.

Li, D., Yang, X., Wang, S., Duan, D., Wan, Z., Xia, G., and Liu, W. (2020) Experimntal Research on Vibration-Enhanced Heat Transfer of Fin-Tube Vehicle Radiator. Applied Thermal Engineering. 180, pp. 115836.

Raudensky, M., Astrouski, I., and Dohnal, M. (2017) Intensification of Heat Transfer of Polymeric Hollow Fiber Heat Exchangers by Chaotisation. Applied Thermal Engineering. 113, pp. 632-638.

Song, L., Li, B., Zarkadas, D., Christian, S. and Sirkar K. K. (2010) Polymeric Hollow-Fiber Heat Exchangers for Thermal Desalination Processes. Industrial and Engineering Chemistry Research. 49, 23, pp. 11961-11977.

Song, S., Shan, H., Liu, J., and Li, B. (2018) Heat Transfer Study of PVDF Hollow Fiber Heat Exchanger for Desalination Process. Desalination. 446, pp. 1-11.

Weiß, K., Astrouski, I., Reppich, M. and Raudenský, M. (2018) Polymeric Hollow-Fiber Bundles as Immersed Heat Exchangers. Chemical Engineering & Technology. 41, 7, pp. 1457-1465.

Zarkadas, D. M. and Sirkar K. K. (2004) Polymeric Hollow Fiber Heat Exchangers. Ind. Eng. Chem. Res. 43, 25, pp. 8093-8106.

Zhukauskas, A. (1972) Heat Transfer from Tubes in Crossflow in Advances in Heat Transfer. Academic Press. pp. 93-158.