METHOD OF DESCRIBING THE HEAT EXCHANGER PERFORMANCE

JAN KOLINSKY

Institute of Technology and Business in Ceske Budejovice, Ceske Budejovice, Czech Republic

DOI: 10.17973/MMSJ.2018_12_201869

e-mail: kolinsky@mail.vstecb.cz

The paper deals with the method of description of heat exchanger performance. The power of the heat exchanger is usually dependent on the flow rate of the warmer medium and the flow rate of the colder medium and on the temperature difference of these media at the input. The power of heat exchanger is not a just a value. It is a function of these variables. Different types and designs of heat exchangers have a different power function, but these functions have some common features. The way of characterizing these functions is the subject of this work.

KEYWORDS

heat exchanger, power performance, heat transfer, evaluation

1 INTRODUCTION

Heat exchangers are still one of the most important components of virtually all mechanical systems. All production and other self-propelled machines in some way have to deal with the cooling [Incropera 2003]. If there is insufficient cooling by free or forced convection, another cooling circuit has to be installed. Water-to-water or water-to-air exchangers are the most commonly used types of heat exchangers, as well as condensers and evaporators. Performance of heat exchangers affect significantly the system energy efficiency [An 2017]. It is posiible to make various modifications to improve heat exchangers performance [Boughadia 2017]. Generally, the hot and cold sides can be defined on heat exchanger, with heat transferring from hot to cold.

It is always necessary to ensure sufficient heat transfer for the proper operation of the cooling system, which is characterized by the heat exchanger power performance. The power of the heat exchanger itself is not constant, it depends on many factors that need to be counted in the design. If the heat exchanger is already designed and manufactured, it may be subjected to a test to determine its performance. The so-tested exchanger is usually tested at different media flow rates on one side and the other at the selected temperature difference at the inlet to the heat exchanger [Gasia 2017].

2 POWER CHARACTERISTIC

The heat exchanger has a different power for various combinations of media flow rates. In general, performance with media flow rates increases, but we cannot expect that this increase is linear, nor can it be expected to increase to infinity. The obtained function of power over the coordinates of the flow rates of the individual media is called the performance characteristic. For illustration, one such performance characteristic is shown in Fig. 1.

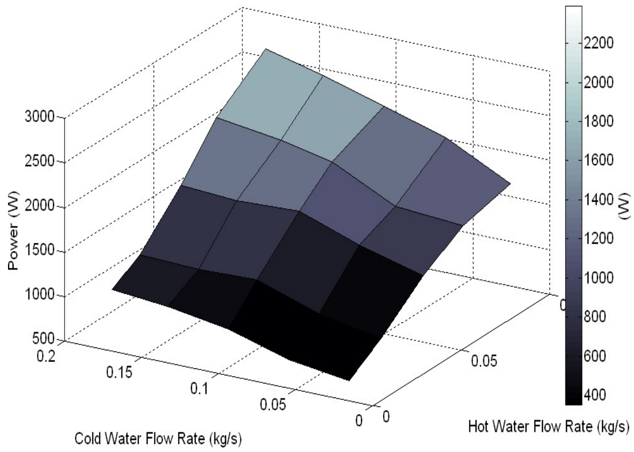

Figure 1. Measured performance characteristic of water-to-water heat exchanger

As can be seen in Figure 1, the performance characteristic has the shape of a hill that rises from the origin of the coordinate system. Typically, power performance measurement is relatively time consuming and energy-intensive, so only a few points, for example a combination of five and five flow rates (a total of 25 modes), are usually measured. The characteristic thus obtained can be relatively safely interpolated, with a lower degree of certainty can be partially extrapolated. The interpolated characteristic is shown in Fig 2. This is a typical shape of power characteristic that resembles a quarter of a hill.

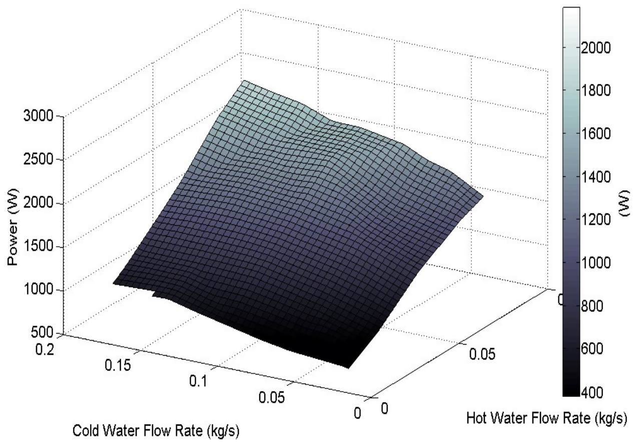

Figure 2. Interpolated performance characteristic of water-to-water heat exchanger

In this way, the performance characteristic for any heat exchanger can be expressed, but the mathematical expression of power as a function of two flow rates is not usually too easy and sufficiently precise to compare the performance characteristics of the various exchangers. The procedure presented in this paper will show how to shift the performance characteristic to a simpler function, preferably the function of just one variable, and to keep as much information as possible of the power performance at different media flow rates. However, the main image remains the performance characteristic as contours on the map with the coordinates of the flow rates of the individual media.

3 EFFICIENCY

The exchanger rating can be based on measured power and on the idea of the maximum possible power that the exchanger could transfer at the defined flow rates of both media. The maximum possible power of exchanger under given conditions is defined as the temperature difference at the inlets to the heat exchanger (the temperature at the hot side input minus the temperature at the cold side input) multiplied by the smaller product of the heat capacity and the flow rate on one side or the other.

$$Q\max = C\min(T1in - T2in) \qquad (1)$$

Where *Qmax* is maximal possible heat rate, *Cmin* is lower heat capacity rate (mass flow rate multiplied by specific heat) and T1in and T2in are input temperatures of media (T1 – hot, T2 - cold).

The heat exchanger cannot transfer more heat because it would mean that the temperature of one of the media during the passage through the heat exchanger would change by more than the thermal difference of the inlet temperatures. This does not correspond to the notion that the cold medium may be warmed up maximally to the inlet temperature of the hot medium, and the hot medium may cool maximally to the inlet temperature of the cold medium [Shan 2003].

The maximal possible power thus calculated is shown in Fig. 3.

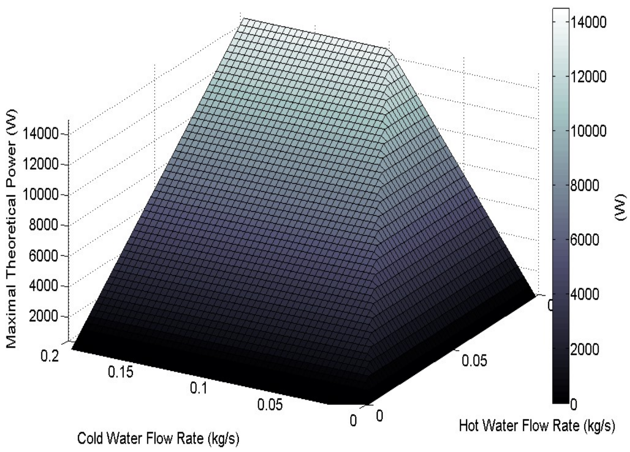

Figure 3. Maximal theoretically possible power

Looking at Fig. 3, it is worth noting that the theoretical maximum power does not have the character of a hill but rather a house roof, that is, a linearly rising function that is fractured in an axis where the flow rates of the two media multiplied by the specific heat capacity are equal to each other. It cannot be expected that the real power performance characteristic would be the same with this theoretical one. The real performance characteristic not only that it has to lie under this theoretical but also obviously will have a different character. Sharp ridge cannot be expected on measured performance characteristic.

If theoretical maximum possible power can be determined at each point of the previously mentioned map, it is possible to divide the real power by this theoretical and thus obtain efficiency of the heat exchanger. This efficiency is again not a single value (a constant), but it's again a function over the map with the same coordinates.

Calculated efficiency is shown in Fig. 4.

It is important to note that there has been no loss of information by calculating the efficiency, since at each point the power of the heat exchanger can be calculated knowing the efficiency. At the same time, there was only a certain simplification of the display, still it is a surface above the flow rates map, but the efficiency takes values only from zero to one. This is especially beneficial if several heat exchangers have to be compared.

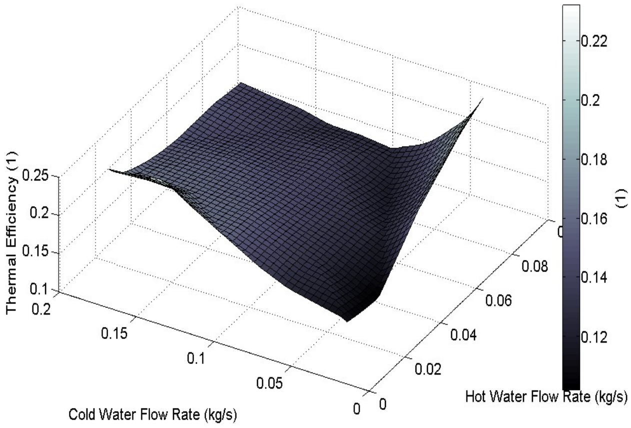

Figure 4. Efficiency as a function of flow rates

The further step of simplification is not easy to define. It is the use of some feature of the efficiency function, which allows to reduce the number of variables on which it depends. Due to the characteristic ridge on the theoretical maximum performance function, some characteristic shape on the surface of efficiency it can be expected that in a similar area. This is the beginning of one of the possible approaches that seeks dependence on efficiency and flow rate ratio. It would be advisable to process the efficiency function by flow rate ratio if it would lead to a definite dependence. This cannot be assumed in general, but if it is assembled such a dependency, Fig. 5 can be obtain for example.

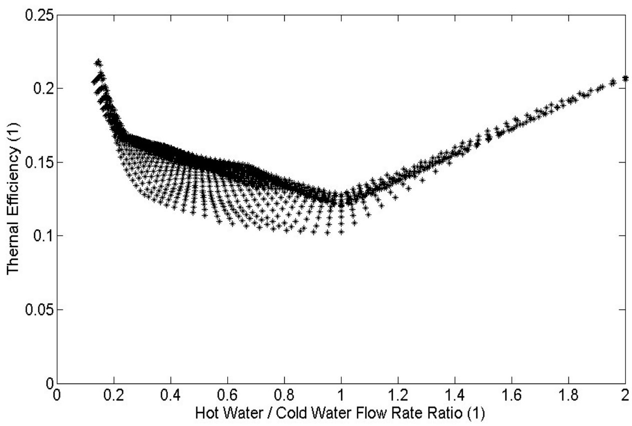

Figure 5. Efficiency as a function of flow rates ratio

Fig. 5 shows that assigning efficiency to the flow rate ratio is not entirely unambiguous; however, for each flow ratio only a certain range of efficiency that can be replaced by a representative value can be seen.

The representation in Fig. 5 is not entirely representative because the expression of the ratio is asymmetric around the value 1. This paper suggests another view where the position on the original map is defined by polar coordinates. Coordinate system is laid in the original plane of hot and cold media flow rates. The angle ϕ corresponds to the flow rate ration and takes values from 0 to 90 degrees. O degrees corresponds to the direction of the axis representing the warm medium flow rate. 45 degrees corresponds to the equal flow rates of both media and 90 degrees corresponds to the flow rate of cold media only. Obviously, values 0 and 90 have no real justification. The second coordinate is *r*, the distance from the beginning, where both flows would be zero. The introduction of the coordinate system is shown in Fig. 6.

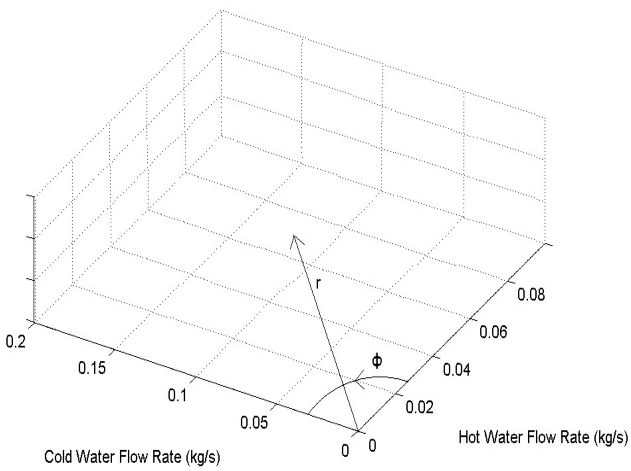

Figure 6. polar coordinate system

Coordinate *r* is further reduced in many processing operations, and virtually loses its significance, however increasing r means that the overall load of the heat exchanger increases. If efficiency is processed as a function of ϕ, it can be displayed as shown in Figure 7.

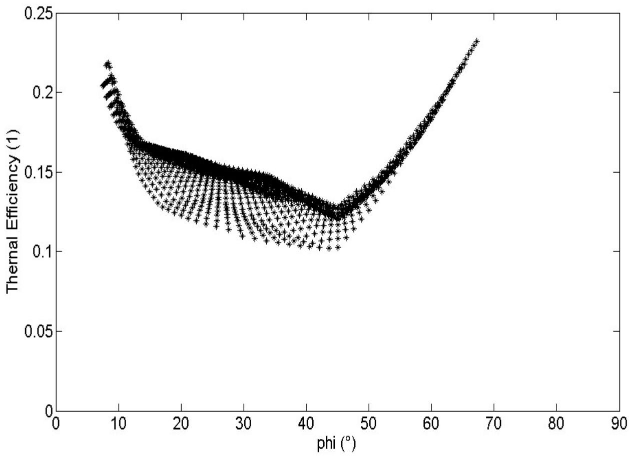

Figure 7. Efficiency as a function of ϕ

This view is now symmetrical about 45 degrees and it gives a better idea of the shape of the efficiency function. Looking at Fig. 7, it can be said that it is not only a function but it is obviously a wider range in which efficiency is moving, however, for example, the lower limit of this range is quite obvious and corresponds to value about 0.1 in the vicinity 45°. Values in areas close to ϕ = 0° and ϕ = 90° are not relevant because the theoretical power of the heat exchanger is zero within these limits and therefore the measured value (with some uncertainty of measurement) divided by this power can take relatively large values.
The resulting efficiency display depends largely on the range where power performance characteristic has been measured. If there is some relatively narrow area that can be replaced by a function after the phi function evaluation, it is beneficial. If the area is wider, it is necessary to analyze the efficiency on the whole original map of flow rates, then it is appropriate to apply the approaches taking into account the actual conditions on the exchanger. Such criteria are, above all, characteristic dimensionless numbers for internal and external heat transfer, such as Nusselt number, Prandtl number, Reynolds number and others. Here it is important to note that the conditions on both sides of the heat exchanger change significantly with the flow rates and the formulas and ranges of validity of the characteristic numbers are limited, so the power performance characteristic of the heat exchanger can be a very complex function in general, and any simplification is a risk of neglecting some partial influence.
Another precondition that is required to meet the condition in Equation 1 is that the heat exchanger is not an evaporator or condenser. In these cases, the heat exchanger does not change the temperature on the side where the phase change occurs. The total maximum possible output of the heat exchanger is then dependent on the latent heat of the individual media and the degree of phase change, in general, one side of the heat exchanger should have a constant temperature. Then, the condition for determining the maximum possible power needs to be adjusted.
In such cases, a side on which the phase change does not occur is suitable for *Cmin* in equation 1, but it is not necessarily a sufficient condition, therefore, it is possible to recommend the procedure defined in this paper only for exchangers that do not change state on either side.
If the flow rate on the phase change side is low and there is a complete phase change, then this must be taken into account. The temperature ceases to be constant when the phase change is complete.

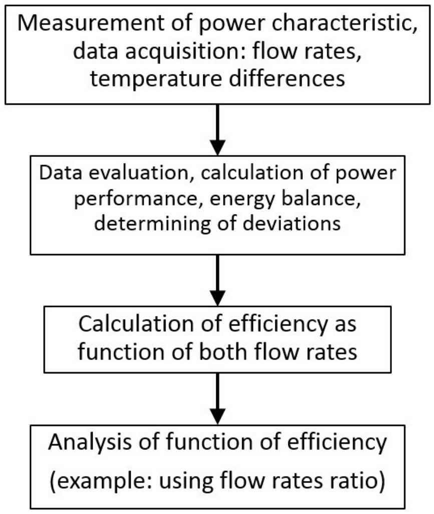

Figure 8. performance characteristic processing scheme

The basic procedure for evaluating and processing the performance characteristics is given in Figure 8. This is a sequence of steps that has proven itself to process data from the measurement of the various exchangers to be compared.

4 CONCLUSION

The paper demonstrated several steps of processing the power performance characteristics of heat exchanger, including the introduction of a new coordinate system based on the probable dependence of the efficiency of the exchanger on the flow rate ratio on each side of the heat exchanger. When processing the experimentally acquired power characteristics of the heat exchanger, emphasis is placed on reducing the number of variables while preserving the possibility of reconstructing the heat exchanger power under the given conditions. The paper states that it is more appropriate to study and describe the function of efficiency than the performance characteristics itself because it offers a better possibility to compare several different heat exchangers.

REFERENCES

[An 2017] An, C. S. et al. Thermo-hydraulic analysis of multi-row cross-flow heat exchangers. International Journal of Heat and Mass Transfer, 2017, Vol. 120, pp. 534-539.

[Boughadia 2017] Boughadia, K. et al. Effect of the perforation design on the fluid flow and heat transfer characteristics of a plate fin heat exchanger. International Journal of Thermal Science, 2017, Vol. 126, pp. 172-180.

[Gasia 2017] Gasia, J. et al. Comparative study of the thermal performance of four different shell-and-tube heat exchangers used as latent heat thermal energy storage systems. Journal of Renewable Energy, December 2007, Vol. 114, pp. 934-944.

[Incropera 2003] Incropera, F. P. Fundamentals of heat and mass transfer, Wiley, New York, 2007.

[Shan 2003] Shah, R. K. and Sekulic, D. P. Fundamentals of heat exchangers design, Wiley, New York, 2003.

CONTACT:

Ing. Jan Kolinsky, PhD.
Institute of Technology and Business in Ceske Budejovice
Faculty of Technology
Department of Mechanical Engineering
Okruzni 517/10, 370 014 Ceske Budejovice, Czech Republic
Tel.: +420 387 842 157
e-mail: kolinsky@mail.vstecb.cz