Int. J. Heat Mass Transfer. Vol. 33, No. 8, pp. 1774–1775, 1990
Printed in Great Britain

0017–9310/90 $3.00 + 0.00

Note on the method of analysis for heat pipe heat exchanger

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(Received 21 July 1989)

INTRODUCTION

IT HAS become a common practice to apply a correction factor to calculate the average heat transfer coefficient for the entire tube bundle of a cross flow tube and shell heat exchanger. Its value is equal to unity when the heat exchanger contains more than ten rows. When there are less than ten rows, tabulated values can be found in standard textbooks, for example, ref. [1]. In most cases the average heat transfer coefficient is sufficient to represent the overall performance of these heat exchangers. However, this approach cannot be used to obtain the heat transfer parameters for each individual row of the bank. Since the heat transfer coefficient of the first row is approximately equal to that for a single row cross tube heat exchanger, it acts as a turbulence generator which increases the heat transfer coefficient for tubes in the following rows. Using an average heat transfer coefficient would exaggerate the heat transfer rate of the first few rows. This was indicated by the comparison of the theoretical and experimental results of Huang and Tsuei [2]. They presented a method of analysis of the performance of heat pipe heat exchangers by using the average convection heat transfer coefficient for all the four rows. Comparing the theoretical and experimental values of hot or cold fluid temperature after their respective first row, it can be noted clearly that the theoretical values of hot fluid are always lower than those of the experimental ones. The reverse is also true for the cold fluid. Both cases indicate that the theoretical temperature calculated was over-estimated by using a constant correction factor for all the rows.

This note presents a method to calculate the heat transfer parameters of each row of tubes of a heat pipe heat exchanger. Comparisons were made with the results of Huang and Tsuei [2]. It was noted that the difference between theoretical and experimental temperatures of both hot and cold fluids in their respective first and second rows were generally improved. However, no significant improvement of the temperature of fluids of the last row was observed.

RESULTS AND DISCUSSION

Huang and Tsuei [2] used a mean convention heat transfer coefficient and calculated the heat transfer rate and temperature distribution of each individual row of a staggered four row heat pipe heat exchanger. The same method was carried out for the present calculation in order to compare with their results, except that the convention heat transfer coefficient for each individual row was used to obtain the present results.

It was assumed that the mean convection heat transfer coefficient of N row tube banks in cross flow is equal to that of their arithmetic mean. It is expressed as

$$\bar{h}_N = f_N \bar{h} = (h_1 + h_2 + \cdots + h_N)/N \quad (1)$$

where $\bar{h}_N$ is the mean convection heat transfer coefficient of an N row tube bundle in cross flow, $h_1, \ldots, h_N$ are the individual convection heat transfer coefficients for row number $1, 2, \ldots, N$, respectively, f_N is the correction factor for the tube bundle which contains less than ten rows. When $N \geqslant 10$, $f_N = 1$, or $\bar{h}_N = \bar{h}$. Using the values of f_N for the staggered arrangement [1] and assuming that the heat transfer areas for each row are equal, the relationships between h_1, $h_2, \ldots, h_N$ and $\bar{h}$ can be calculated. For the first row, it may be considered that the heat exchanger contains only one row of tubes. The value of f_1 is equal to 0.68 [1]. Thus, h_1 can be written as

$$h_1 = 0.68\bar{h}. \quad (2)$$

Considering the first two rows as a single heat exchanger and applying $f_2 = 0.75$, h_2 can be found

$$h_2 = 0.82\bar{h}. \quad (3)$$

Likewise

$$h_3 = 0.99\bar{h} \quad (4)$$

$$h_N = \bar{h}(N > 4). \quad (5)$$

From the calculated results, it can be seen that the numerical constants on the right-hand side of $h_N (N \geqslant 4)$ are slightly larger than unity. Since it is impossible to have a value of h_N larger than $\bar{h}$, it was assumed that $h_N = \bar{h}$ when $N \geqslant 4$. The above results agreed well with Gnielinski's statement that from the first to about the fifth row the heat transfer coefficient increases and then remains constant [3].

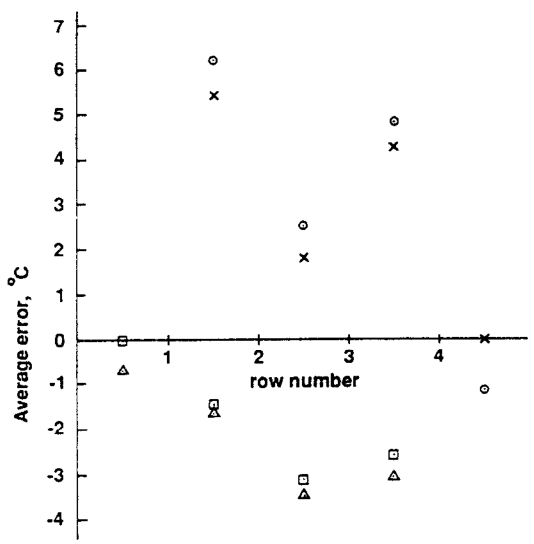

FIG. 1. Average error for all the 12 experiments: ⊙, hot fluid, Huang and Tsuei [2]; △, cold fluid, Huang and Tsuei [2]; ×, hot fluid, present results; ⊡, cold fluid, present results.

NOMENCLATURE

f_i correction factor of the row number i
f_N mean correction factor for N rows of tube bundle
h_i convection heat transfer coefficient of the row number i
$\bar{h}$ mean convection heat transfer coefficient for row number larger than 10
$\bar{h}_N$ mean convection heat transfer coefficient for N rows of tube bundle
N number of rows.

Having obtained the convection heat transfer coefficient for each individual row of a tube bundle in cross flow, the heat transfer parameters of each row of the heat pipe exchanger were calculated using the data given by Huang and Tsuei [2], except the inlet temperatures were used to calculate the mass flow rate instead of at the standard condition. Because the flow rate given by Huang and Tsuei [2] cannot satisfy their results. For all the 12 experiments conducted by Huang and Tsuei [2], six experiments showed that the temperature difference between the experimental and numerical results of the present calculation were improved at all the points. Improvements were also observed in the first few rows for the other six experiments. Figure 1 shows the mean deviation of air temperature between experimental and numerical results for all the 12 experiments. It can be noted that, in general, the present model can predict the air temperature better than using the average heat transfer coefficient for all the rows.

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