EXPERIMENTAL SCRUTINIZATION OF HEAT TRANSFER CHARACTERISTICS ON TWO-PHASE FLOW IN 1-2 SHELL AND TUBE HEAT EXCHANGER

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Abstract

An experimental work is carried out for air-water system in 1-2 shell and tube heat exchanger with variable configuration for the passage of heating and test fluids with parallel and countercurrent flow. Two-phase parameters such as quality, Lockhart-Martinelli (L-M) parameter and two-phase multiplier were determined. Results showed that the heat transfer coefficient increases with quality for two-phase flow for the range of Reynolds number and quality studied. The L-M parameter is inversely proportional to quality. The two-phase multiplier shows a decreasing trend with increase in L-M parameter as reported in literature, Salcuden et al. [1] From the correlation $h_1 = a\,N_{Re}^{\ m}$, the heat transfer coefficient for two-phase flow can be predicted using the Lockhart-Martinelli parameter - Quality correlation with an error of less than 12%.

Keywords: Heat transfer, Two-Phase multiplier, Tube heat exchanger

I. INTRODUCTION

Simultaneous flow of two or more immiscible phases is termed as multiphase flow. Systems involving multiphase fluid flow occur widely in nature and in industry. The two-phase flow is considered to be the common class of multiphase flow. Heat transfer involving two phases such as liquid-gas is of vital importance especially in petrochemical and allied industries. The presence of a gas phase along with liquid alters not only the fluid dynamic behavior but also the heat transfer characteristics namely, the heat transfer coefficient. Two-phase flow has found wide applications in environmental, chemical and biochemical process in the last decade [2].

The structure of two-phase flow is quite complicated and its flow parameters are described mostly in terms of empirical correlations [3]. A review by Jensen [4] revealed that there are no published data on two-phase flow heat transfer in shell and tube heat exchanger for quality and heat transfer coefficient.

Rani Hemamalini et al. [5] conducted an experimental study on two-phase flow through a pipe and control valve in series for air-palm oil system. They have found that, if data on the single phase flow through the pipe/valve is known for different flow rates it can be used to predict the pressure drop for two-phase flow based on the pure component density, gas and liquid flow rates.

In order to gain fundamental knowledge about the complex nature of two-phase flow behavior more so in heat transfer equipments, experimental work is essential. In the present work on 1-2 shell and tube heat exchanger for air-water system heat transfer characteristics of two-phase and single phase flow for parallel and countercurrent flow for different configurations such P2S, P2T, C2S, C2T, P1S, P1T, C1S and C1T has been studied. The two-phase parameters such as Lockhart-Martinelli parameter [6], quality and two-phase multiplier were determined. A dimensionless correlation is established between two-phase multiplier and Lockhart-Martinelli parameter to predict two-phase heat transfer coefficient based on pure component heat transfer correlation with Reynolds number.

II. EXPERIMENTAL UNIT

The experimental set-up is shown in Figure 1. It has provisions to study parallel and countercurrent flow with device to inject air and cold liquid at varying flow rates. The heating liquid is hot water which can flow either in shell or tube side and its flow rate is kept constant. The test liquid (pure liquid) is pumped from the storage tank (12) using centrifugal pump (14) and its flow rate through the shell and tube side is varied using valves (10). Calibrated rotameters were connected to the air-line (9A), test liquid storage tank (9B) and geyser line (9C) to measure the flow rate of air, test liquid and heating liquid respectively. In the two-phase flow operation, the Ingersoll Rand compressor (11) is used to supply atmospheric air, the _T_joint (21) is used for mixing air and test liquid. Temperatures were noted at inlet and outlet of both tube and shell side using digital temperature indicator (15). The temperature was measured with copper-constantan thermocouples at the inlet and exit flow. The unit also consists of jacketed vessel (20) to cool the test liquid to its original temperature before recycling.

III. TYPES OF FLOW AND CONFIGURATION

Provisions were made in the experimental set-up to analyze both parallel and countercurrent flow as follows:

Type 1 : Single phase flow (1) : P1S, P1T, C1S, and C1T

Type 2 : Two-phase flow (2) : P1S, P1T, C1S and C1T

Here, P, C, 1, 2, S, T refers to parallel flow, countercurrent flow, single phase liquid, two-phase fluid, shell side and tube side respectively.

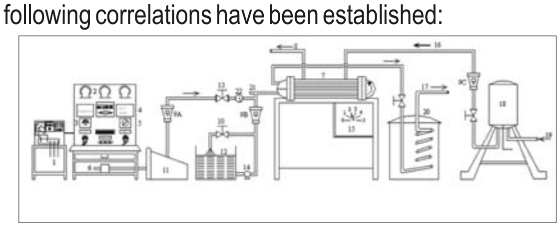
IV. EXPERIMENTAL PROCEDURE

The experiments were carried out in a 1-2 shell and tube heat exchanger for air-water system. For studies on single phase flow, water is circulated and in two-phase flow, air along with test liquid is fed at different flow rates. The flow rate of test liquid (water) and air was varied from of 3.33 x 10^{-5} to 1 x 10^{-4} and 1 x 10^{-4} to 4.18 x 10^{-4} m^3/s respectively. The heating liquid flow rate was kept constant at 2.5 x 10^{-5} m^3/s. The different configurations and their range are given in Table 1.

Table 1. Parameters range of different configurations for air-water system

Confgn.	Two-phase heat transfer coefficient, $h_{2\phi}$ [W/m²K]]	Quality, X	Two-phase multiplier, Φ_L	L-M parameter, x_{tt}^2	LMTD $(\Delta T)_{ln}$
P2ϕS	84-280	0.0024-0.0049	0.3894-0.4545	15.67-6.54	18
P2ϕT	74-162.1	0.0033-0.0065	0.6279-0.6860	18.98-7.37	18.5
C2ϕS	192-373	0.0041-0.0060	0.8533-0.9521	16.76-8.9	18.4
C2ϕT	201-472	0.0050-0.0080	0.7899-0.8616	12.56-9	21.2

The experiments were conducted for parallel and countercurrent flow. The heat transfer coefficients for different flow configurations for single and two-phase system were calculated. For two-phase system the following correlations have been established:



1.	Main supply	12.	Test liquid storage tank
2.	Three phase supply indicator	13.	Non return valve
3.	Temperature indicator	14.	Centrifugal pump
4.	Suction motor speed indicator	15.	Digital temperature indicator
5.	Low speed motor selection	16.	Heating water inlet
6.	Suction hose	17.	Tube side outlet
7.	1-2 Shell and tube heat exchanger	18.	Geyser
8.	Shell side outlet	19.	Water inlet to geyser
9	A,B,C Rotameters	20.	Agitator vessel
10.	Globe valve	21.	T-Joint
11.	Compressor	22.	Magnetic Flow meter

Fig. 1. Schematic diagram of the experimental unit

a) Two-phase heat transfer coefficient, h_2 Vs Quality, X

b) Two-phase multiplier, $_L$ Vs Quality, X

c) Lockhart-Martinelli parameter, x_{tt}^2 Vs Quality, X

d) Two-phase multiplier, $_L$ Vs Lockhart-Martinelli (L-M) parameter, x_{tt}^2

V. RESULTS AND DISCUSSION

Studies on Single Phase Flow:

The test liquid was passed through four different configurations such as P1S, P1T, C1S and C1T. The data on temperature and flow rates of the test and hot fluid were experimentally noted. The heat transfer coefficient for the test fluid was calculated using equations 1 to 8.

$$N_{Re} = \frac{DV\rho}{\mu} \quad (1)$$

$$N_{Pr} = \frac{C_p \mu}{K} \quad (2)$$

$$N_{gz} = N_{pe} \frac{\Pi D}{4L} \quad (3)$$

$$N_{nu} = \frac{h_i D}{K} \quad (4)$$

$$N_{Pe} = N_{re} \times N_{pr} \quad (5)$$

$$Q_i = U_i A_i (T)_{ln} \quad (6)$$

$$1 / U_i = (1/h_i) + (1/h_0) (A_i/A_0) \quad (7)$$

$$N_{Nu} = 2.0 N_{Gz}^{0.3} \quad (8)$$

$$D_e = 4 \times r_H \quad (9)$$

Since the flow was laminar Equation 8 is used to calculate the heat transfer coefficient 'h' of the test fluid on tube and shell side. However for the passage of test fluid through shell side an equivalent diameter given by equation 9 was used to determine velocity. Figure 2 is a plot of heat transfer coefficient of test liquid as a function of Reynolds number for the test liquids studied. A general relation of the form was arrived by regression analysis.

$$h_1 = a N_{Re}^m \quad (10)$$

The relevant relations and values are given in Figure 2 and Table 1 respectively.

From the results it is seen for test liquid that the heat transfer co-efficient is a maximum under countercurrent flow. Water gives higher heat transfer coefficient because of its high thermal conductivity, low viscosity and also the logarithmic mean temperature difference is maximum in countercurrent flow.

Studies on Two-Phase Flow:

For two-phase studies, the properties of the mixture of water and air are taken as weighted average of the test fluid properties at respective temperatures, [7].

$k = k_1x_1 + K_2x_2$ (11)

$= {}_1x_1 + {}_2x_2$ (12)

$= {}_1x_1 + {}_2x_2$ (13)

$Cp = Cp_1x_1 + Cp_2x_2$ (14)

The relations involved in various calculations for two-phase flow are given by equations 15 to 18.

$$\text{Quality, } X = \frac{1}{\left(1+\frac{\rho_L}{\rho_G}\frac{Q_L}{Q_G}\right)} \quad (15)$$

$$\text{Two-phase multiplier, }_L = \frac{h_{2\phi}}{h_{1\phi}} \quad (16)$$

$$= \frac{\text{Two-phase heat transfer coefficien}}{\text{Single phase heat transfer coefficient}}$$

$$\Phi_L = \frac{h_{2\phi}}{h_{1\phi}} = 1 + \frac{C}{x_{tt}} + \frac{1}{x_{tt}^{\ 2}} \quad (17)$$

Lockhart-Martinelli (LM) parameter = x_{tt}^2 = (18)

The flow regime is stratified for the system studied with air flow rate of $1 \times 10^{-4} - 4.18 \times 10^{-4}$ m^3/s and test liquid flow rate of $3.33 \times 10^{-5} - 1 \times 10^{-4}$ m^3/s as found in literature Vlasogiannis et al. [8]. Figure 2 shows the variation of single phase heat transfer coefficient with Reynolds number. The value of slope m is given in Table 2. Figure 3 and 4 present graphically the two-phase heat transfer coefficient with Reynolds number and Quality X. Figure 5 and 6 shows the variation of two phase multiplier with quality and LM parameter. Figure 7 is reconstructed from Fig. 5 and 6. The data was fitted by regression analysis and the constants are shown in the respective figures. The increase of two-phase multiplier with quality is in agreement with literature Salcudean et al. [1]. The increase in two-phase heat transfer coefficient in the range of quality studied may be due to increased turbulence. At higher air rates (higher quality) this may not be the case since a film heat transfer coefficient may predominate. This is the work which is being pursued in this laboratory.

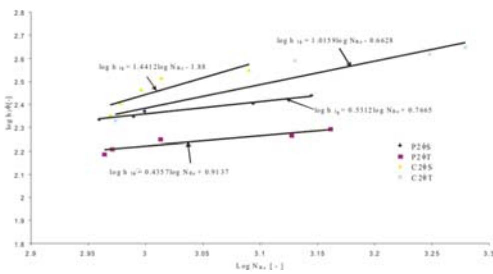


Fig. 2. Log h 1 Vs Log NRe of pure water for different configurations

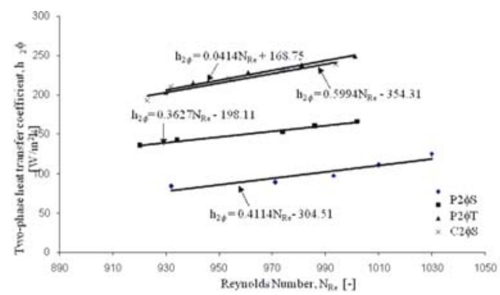


Fig. 3. Two-phase heat transfer coefficient Vs Reynolds number of air-water system for different configurations

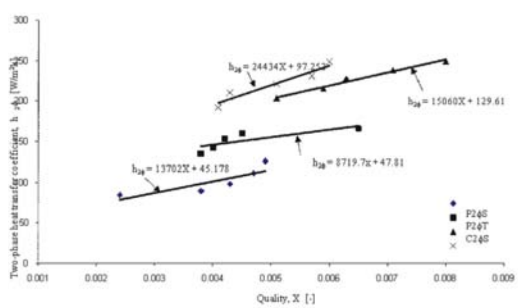


Fig. 4. Two-phase heat transfer coefficient Vs Quality of air-water system for different configurations

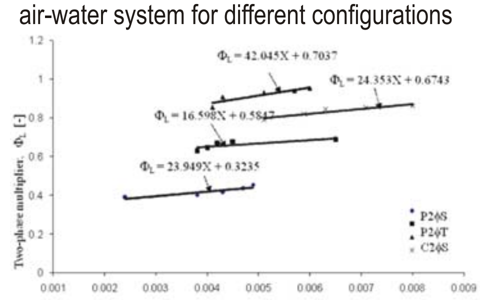


Fig. 5. Two-phase multiplier Vs Quality of air-water system for different configurations

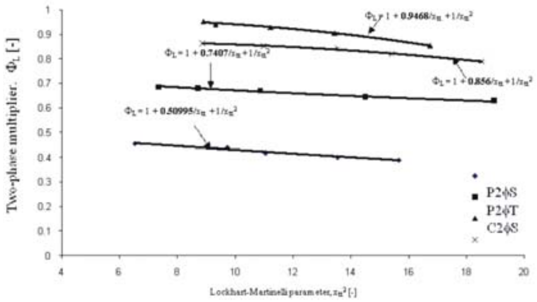


Fig. 6. Two-phase multiplier Vs L-M parameter of air-water system for different configurations

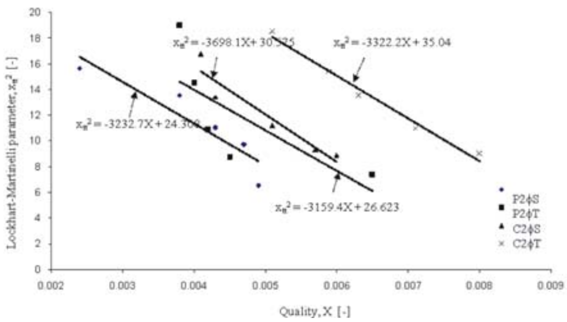


Fig. 7. L-M parameter Vs Quality of air-water system for different configurations

VI. CONCLUSION

1. Two-phase flow through 1-2 shell and tube heat exchanger has been studied for water with air as gas phase. The experimental results showed that two-phase heat transfer coefficient increases with quality.

2. The results of single-phase and two-phase flow heat transfer show that present experimental set-up is reliable.

3. The correlations have been established for Two-phase heat transfer coefficient Vs quality, Two-phase multiplier Vs quality, Two-phase multiplier Vs L-M parameter and Lockhart-Martinelli (L-M) parameter Vs quality.

4. The two-phase multiplier shows a decreasing trend with increase in L-M parameter.

5. If the data on single phase is known for different flow rates it can be used to generate data on heat transfer co-efficient for two phase flow based on the pure component density, gas and liquid flow rates. Error ranges from 0.44 to 12 percent.

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