A NOVEL METHOD FOR CALCULATING CORRELATION OF FLOW CONDENSATION PRESSURE DROP IN MICRO-FIN TUBE

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In this paper, the two-phase flow condensation heat transfer experiment of R134a, inside the micro-fin tube, was carried out on the test bench. The influence of working conditions and micro-fin tube structural parameters, on the pressure drop, was investigated, while correlations were also used, to predict the pressure drop inside the tube. The experimental results show that, the pressure drop is positively correlated with mass flux and fin helical angle, while negatively correlated with condensation temperature and cooling water Re. Furthermore, correlations of Cavallini et al., Haraguchi et al., and Pierre have a good predictive effect on the pressure drop, with an average prediction error of less than 17%, while Goto et al correlation overestimates the pressure drop. Based on the pressure drop experimental data of R134a, the function relationship, between Φv/Φl and Xtt, was fitted again, using the computing mechanism of Goto et al correlation. Next, new correlation of predicting the pressure drop, inside the tube, is proposed, while the statistic test shows: the prediction error of new correlation is within ±30% and the average prediction error is less than 10%.

Keywords: two-phase flow; flow condensation; gas/liquid conversion coefficient; correlation; phase separation model.

1. Introduction

In all kinds of heat transfer enhancement tubes, used in refrigeration and air conditioning field, the wall structure of micro-ribbed tubes can not only

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enhance the effect of turbulence, inside the tubes, but also increase the flow resistance of fluid, by dragging, resulting in additional flow power consumption [1]. In order to clarify the deteriorating mechanism of wall structure, while pressure drop occurs within pipes, many scholars have carried out a lot of experimental research and theoretical analysis.

Wu Xiaoming [2-3] analyzed the influence of structure parameters and experimental conditions of micro-finned tubes, on heat transfer and pressure drop, through experiments of R22 flow condensation heat transfer, in tubes; Wang Xuedong [4], based on experimental data, studied the role of pressure drop correlation to internal pressure drop. The theoretical principles of pressure drop in pipes have been relatively more extensively investigated by several scholars. Soliman [5], Chisholm [6], Friedel [7] and Zhang et al. [8] proposed a correlation, for predicting pressure drop in smooth tubes, while Kedzierski [9] and Miyara [10] made reasonable assumptions about the flow mechanism of two-phase flow in smooth tubes, while at the same time, based on experimental data, proposed a new correlation, for predicting pressure drop in micro-ribbed tubes.

In this paper, besides analyzing the influence of mass rate, condensation temperature, cooling water Re and structural parameters of intensified pipe, on pressure drop in pipe, the correlation formulas of phase separation model and homogeneous model are used to predict the pressure drop in pipe, while the accuracy of the correlation formulas is analyzed, using the fitting mechanism of theoretical model. Finally, based on real working conditions, correlation formulas are used to predict the pressure drop in pipe. Based on the experimental data, a new correlation is established, to provide experimental support and a theoretical basis, to the research and development of high efficiency condensation heat exchangers.

2. Experimental bench for flow condensation heat transfer in tube

The experiment of flow condensation heat transfer in tube is mainly carried out on a single tube heat transfer test bench. The schematic diagram is shown in Fig. 1.

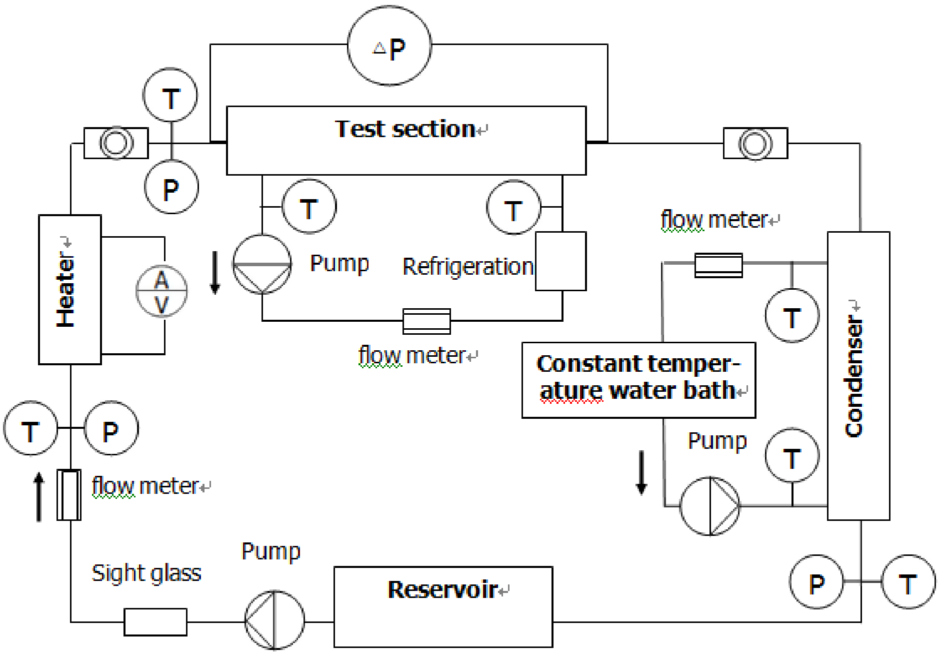


Fig. 1 The schematic diagram of the flow condensation heat transfer inside the tube

The test bench is mainly composed of working fluid test system, cooling water system, low temperature cold source system, heating system, control measurement system, etc. During the experiment, Driven by refrigerant pump, liquid refrigerant flows out of the reservoir and flows to the heater through mass flowmeter. By adjusting the voltage and current of the heater to change the heating quantity of refrigerant in the heater, the state of refrigerant at the inlet of the experimental section is set. Completing the condensation experiment, the refrigerant exchanges heat with cooling water, in the experimental section. The refrigerant state at the inlet and outlet of the experimental section can be observed through a liquid mirror. The refrigerant is sub-cooled in the condenser and enters the reservoir for the next cycle.

Cooling water cycle is mainly composed of pumps, constant temperature water bath, electric heater, electromagnetic flow meter and other components. Heat transfer, in the experimental section, is regulated, by adjusting cooling water temperature and circulating flow rate. In the experiment, Rayleigh number (Re=10000 and Re=14000) of cooling water is selected, to specify the heat transfer characteristics of cooling water. The refrigeration system sub-cools the refrigerant, in the system, taking away the heat dissipation of the refrigerant, in the condenser, maintaining the heat balance of the whole system.

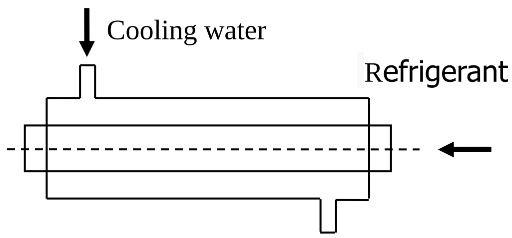


Fig.2 Schematic diagram of the heat transfer in the test section.

The experimental section is a tube heat exchanger. The refrigerant flows in the tube, while the cooling water flows in the annular tube. The two liquids flow in reverse, as shown in Fig. 2. The effective heat transfer area, in the experimental section, is 2.00m. Inner threaded copper tube is selected as the test tube. The specific structural parameters are shown in Table 1.

Table 1

Structural parameters of internally ribbed tube

Tube type	1#	2#
Helical angle	18^o	28^o
Rib height (mm)	0.23	0.23
Rib number	60	60
Tooth apex angle	24.5^o	24.5^o
Pitch (mm)	0.4	0.4
Groove width (mm)	0.2	0.2

PT100 platinum resistance was used, to measure the temperature of refrigerant/cooling water, in the experimental section, at a measuring accuracy of 0.1^{o}C. Drucker GE5072 pressure transmitter, with a measuring range of 0-35bar and a precision level of 0.1, was used to measure the condensation pressure, in the experimental section. RHEONIKE mass flowmeter, composed of RHM03 sensor and RHE14 transmitter, was used to measure the refrigerant flow rate. The measurement accuracy is 0.1 level; The control-display integrated electromagnetic flowmeter is used to measure the cooling water flow, the measurement accuracy level is 0.5. The pressure drop of the experimental section is measured directly, by the pressure drop transmitter. Therefore, the equipment accuracy of the pressure difference transmitter is closely related to the measurement accuracy of the pressure drop. The EJA110A high performance differential pressure transmitter is selected, to measure the pressure drop of the experimental section, directly. Its range is [-100, 100] (kPa), while the measurement accuracy is $\pm$0.05%.

The experimental conditions are as follows: the condensation temperature is 35 ºC, 40 ºC and 45ºC, the water Re is 10000 and 14000, the mass rate is 400-900kg/(m^2 • s), the dryness value of refrigerant in import and export are kept at 95%-85%, 15%-5%, in the experimental section. R134a was chosen as the working fluid in the experiment. The physical parameters, under experimental conditions, are shown in Table 2. In order to eliminate the disturbance, from the thermocouple signal line, in the cooling water, the wall temperature of the heat exchanger tube was not measured. In the experiment, the condensation heat transfer process can be regarded as constant heat flow heat transfer.

Table 2

Properties of R134a under working conditions

Temperature (ºC)	35	40	45
Pressure (MPa)	0.887	1.0166	1.1599
Liquid density (kg/m^3)	1167.5	1146.7	1125.1
Gas density (kg/m^3)	43.42	50.09	57.66
Liquid viscosity(10^{-3}Pa.s)	1.72	1.61	1.51
Gas viscosity (10^{-5}Pa.s)	1.21	1.24	1.26

3. Theoretical calculation

In the condensation experiments, the dryness and velocity of the two-phase flow, in the tube, gradually decrease, along the axial direction. In addition, according to the mechanism of pressure drop in the tube, the gravity pressure drop of the two-phase flow, in the tube, can be neglected, meaning that, the total pressure drop in the tube mainly includes friction pressure drop and accelerated pressure drop [11]. The frictional pressure drop is mainly developed in three contact areas: between the gas flow in the pipe and the inner wall of the pipe, between the liquid film and the inner wall of the pipe, and last, between the gas-liquid interface in the pipe.

Because the composition of friction pressure drop is complex, it can not be calculated directly by formula, instead, the relation, described in Eq. (1), is used. Specifically, the friction pressure drop can be calculated by Eq. (1)

$$\Delta P_f = \Delta P_{\exp} - \Delta P_{de} \tag{1}$$

where,

$\triangle P_{exp}$ is the total pressure drop of the fluid, in the experimental section (kPa);

$\triangle P_{de}$ is the accelerated pressure drop of the fluid in the tube (kPa),

$$\Delta P_{de} = \left[\frac{G^2x^2}{\rho_v\varphi} + \frac{G^2(1-x)^2}{\rho_l(1-\varphi)^2}\right]_{x=x_{out}} - \left[\frac{G^2x^2}{\rho_v\varphi} + \frac{G^2(1-x)^2}{\rho_l(1-\varphi)^2}\right]_{x=x_{in}} \quad (2)$$

where,

G is the refrigerant mass flow (kg/s);

ρ_v and ρ_l are the refrigerant gas phase and liquid phase densities, respectively (kg/m^3), as they are the density of two-phase flow;

φ is the void fraction of two-phase flow.

According to Colombo et al [12], friction pressure drop accounts for about 90% of the pressure drop of a two-phase flow in a pipe. Therefore, the influence of experimental variables, on total pressure drop in pipe, can be analyzed mainly through its influence on friction pressure drop.

When calculating frictional pressure drop, using correlation, many scholars often multiply the corresponding single-phase frictional pressure drop gradient by some specially defined coefficients, called "conversion coefficients". The fitting mechanism of pressure drop correlation can be divided into two main categories: phase separation model and homogeneous model. The homogeneous model regards two-phase flow in pipe as a homogeneous mixture medium, while its physical parameters are the average value of the corresponding physical parameters of two-phase flow [11], that is:

$$dP_f / dz = \rho_m j^2 \lambda / (2D) \quad (3)$$

If the pressure drop of pure liquid phase flow is taken, at a constant mass flow, as the calculation criterion, that is:

$$(dP_f / dz)_{lo} = (\lambda_{lo} G^2 v) / (2D) \quad (4)$$

The conversion coefficient Φ_{lo}^2 of the whole liquid phase is as follows:

$$\Phi_{lo}^2 = (dP_f / dz) / (dP_f / dz)_{lo} \quad (5)$$

The split-phase model assumes that [13]: (1) there is no interaction between gas and liquid phases, while the pressure drop of gas phase is equal to that of liquid phase and there is no static pressure difference, along the radial direction; (2) the sum of the volume of liquid phase and the volume of gas phase is equal to the total volume in the pipeline. According to the above hypothesis, the pressure drop of each phase is equal to each other, that is:

$$dP_f / dz = dP_{fl} / dz = dP_{fv} / dz \tag{6}$$

Among them, the frictional pressure drop of liquid, flowing through the same pipeline is as follows:

$$\left(dP_f / dz\right)_l = \left(\lambda_l / D\right)\times\left(G^2(1-x)^2 \nu' / 2\right) \tag{7}$$

For the calculation of pressure drop in a smooth tube, according to the analysis of Chisholm et al [6], the phase separation conversion coefficient of two-phase flow can be expressed by parameter X_{tt}. The formula of conversion coefficient of liquid phase separation is as follows:

$$\Phi_l^2 = 1 + C / X_{tt} + 1 / X_{tt}^2 \tag{8}$$

The value of parameter C is closely related to the flow pattern of two-phase flow and the structure size of micro-finned tube. Many scholars [14-15] defined the rule of parameter C, based on experimental data, aiming at improving the accuracy of correlation prediction and expanding its scope of application. In the case of micro-finned tube, the existence of fins has a great influence on the fluid flow mechanism, in the tube. Therefore, the influence of fins, on the fluid flow mechanism in the tube, should be taken into account, when determining the formula for calculating the conversion factor.

4. Effect of experimental variables on pressure drop in pipe

The main experimental variables are mass rate, condensation temperature, Rayleigh number Re of test water and spiral angle of fin, limited by the capabilities of the experimental equipment.

The flow condensation pressure drop of R134a, in a 18^o internal screw tube, varies according to the experimental conditions, regarding mass rate within 400-900kg/(m^2·s), condensation temperature at 35 ^{o}C, 40 ^{o}C and 45 ^{o}C and Rayleigh number Re of cooling water at 10000 and 14000 (Fig. 3**)**.

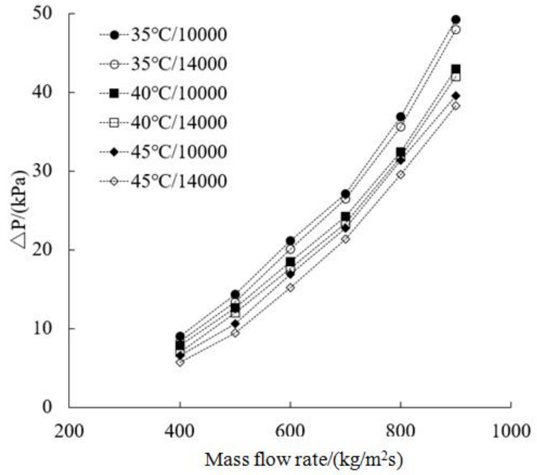


Fig.3 Pressure drop inside the tube, under various test conditions

The graph shows that:

(1) The pressure drop in the tube increases with the increase of mass rate. For every 100 kg / (m^2·s) increase in mass rate, the amount of pressure drop in tube increase ranges between 4.02 kPa and 10.16kPa, which means that, as mass rate increases, the range of pressure drop increase is higher. The velocity difference between inlet and outlet of refrigerant in test tube increases with the increase of mass rate. In other words, the accelerated pressure drop of two-phase flow increases with the increase of mass rate; The difference of gas-liquid density and the difference of liquid-phase velocity increase with the increase of mass rate, they lead to the increase of the friction pressure drop between the inner wall and the liquid film and the gas-liquid interface respectively.

(2) The pressure drop in the tube decreases, as the condensation temperature rises. The condensation temperature mainly affects the pressure drop in the tube, by changing the physical properties of the refrigerant. Table 1 demonstrates that, when the condensation temperature rises, from 35 ºC to 45 ºC, the viscosity of the liquid phase R134a decreases, from 1.72×10^{-4}Pa/s to 1.51×10^{-4} Pa/s, resulting in a decrease in the friction pressure drop, between the liquid film and the inner wall of the tube. In addition, the gas phase density of R134a increases with the increase of temperature, while the liquid phase density decreases with the increase of temperature, that is, the accelerated pressure drop in the tube decreases with the increase of condensation temperature. Both of them lead to the decrease of pressure drop in tube with the increase of condensation temperature.

(3) The pressure drop decreases, as the Re number of test water increases, while the heat transfer coefficient of test water, in annular tube, rises, with the increase of Re number of test water. In order to meet the requirement of heat transfer in tube, the Re number of test water is increased, while the temperature difference of heat transfer is reduced. More specifically, in the tube, the temperature gradient of the liquid film decreases, while, between the liquid film and the inner wall, the frictional pressure drop decreases, with the increase of Re number of the test water. However, the pressure drop in the tube is not significantly affected by the test water Re. For every 4000 increase in the test water Re, the pressure drop in the tube decreases by 0.86-1.37 kPa, otherwise stated, the decrease ranged from 3.06% to 9.8%.

Under experimental conditions of mass rate 400-900kg/(m^2 • s), condensation temperature 35°C, 40°C and 45°C, and Reynolds number of cooling water 10,000, the variation of flow condensation pressure drop of R134a, with the helix angle of internal thread, is shown in Fig. 4.

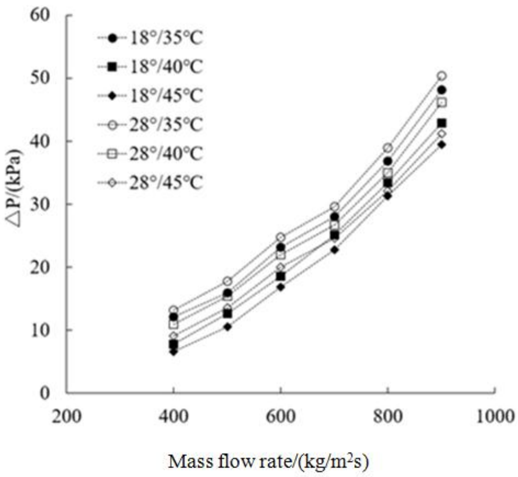


Fig. 4 the influence of the helical angle on the pressure drop inside the tube

The graph shows that: The pressure drop in the tube increases, with the increase of the screw angle of the internal thread. The increase range is 1.05~3.46 kPa, while the increase proportion is less than 5±2.5%. Internal threaded fins affect the pressure drop gradient, mainly by increasing the friction pressure drop between the inner wall and the inner wall of the tube, while the thickness of the liquid film is higher than the height of the fins. There are two main flow modes of condensate in liquid film; one is the axial motion, higher than the fin and the other is the circumferential motion, lower than the fin height. The circumferential flow velocity of the liquid film in the pipe increases, with the increase of the helix angle of the internal thread; that is, the larger the helix angle of the internal thread, the greater the hindrance effect of the internal thread, on the fluid flow power consumption in the pipe.

5. Prediction of pressure drop in pipe by relevance formula

Three phase-splitting model correlations of Cavallini et al., Haraguchi et al. and Goto et al. correlations and a homogeneous model correlation of Pierre correlations were used, to predict the pressure drop characteristics in the pipe. The results show that:

The effect of fin height, fin base diameter and spiral angle of fins, on the fluid flow mechanism in the tube, is characterized by C correlation. First, the concept of equivalent roughness is proposed, to characterize the effect of fins on the inner surface roughness of the tube.

Although correlation of Cavallini et al. is an improved Friedel correlation, based on the experimental data of pressure drop of internal threaded tubes, correlation of Cavallini et al. correlation overestimates 94% of the pressure drop in tubes, especially for 28^{o} micro-ribbed tubes. This means that, the prediction accuracy of Cavallini et al. correlation is greatly affected by the fin structure. The deviation between the predicted value and the experimental value of pressure drop ranges from -12.2% to 39.37%. The average deviation between the predicted value and the experimental value is 12.71%, as shown in Fig. 5.

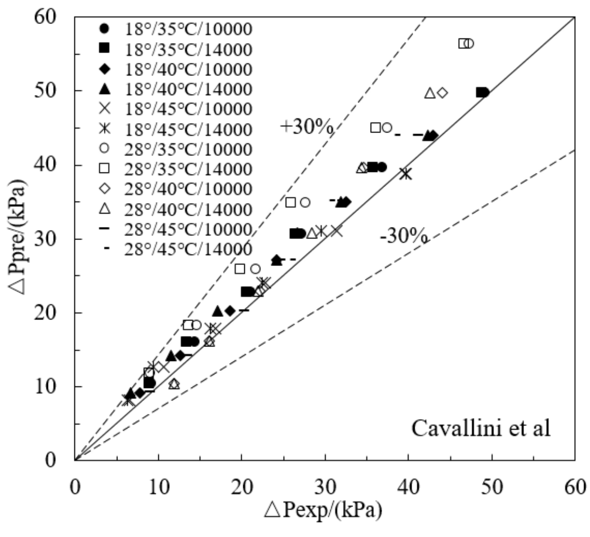


Fig.5 Prediction of the pressure drop inside the tube, by Cavallini et al. correlation

Haraguchi et al. correlation also provides good predictions on pressure drop in tube, while its prediction performance is not affected by experimental variables, such as structural parameters of micro-ribbed tube and experimental conditions. The deviation range between predictive value of correlation and experimental value of pressure drop is -32.41%~21.32%, while the average deviation between them is -1.92%, as shown in Fig. 6.

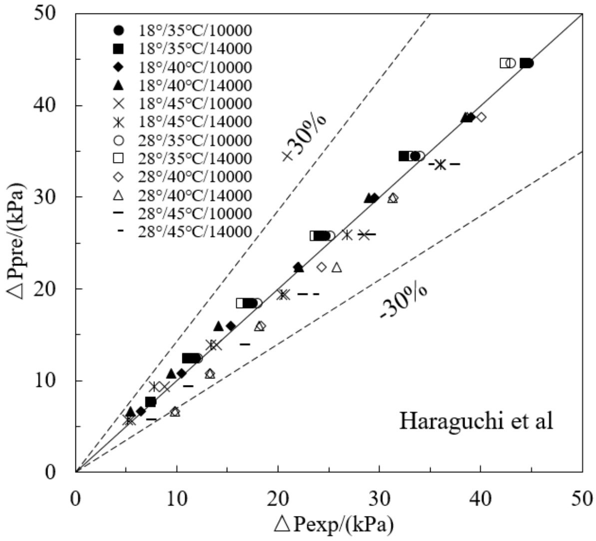


Fig.6 Prediction of the pressure drop inside the tube by Haraguchi et al. correlation

Haraguchi et al. correlation is based on the fitting of the experimental data of the flow condensation pressure drop, of R134a, R123 and R22, in the micro-ribbed tube. The structural parameters of the micro-ribbed tube are similar to those of the experimental tube, while the working fluid, used for the pressure drop test, is R134a. The interference of refrigerant properties on the prediction accuracy of the correlation can be ignored.

Goto et al. correlation is based on the flow condensation pressure drop data of R410A, in herringbone tube. According to the comparison of flow pressure drop experiments, in micro-ribbed tube, it is found that the flow pressure drop in herringbone tube is larger than that in micro-ribbed tube. The G-correlation can be used to predict the pressure drop in inner-ribbed tube, reasonably. That is, the predicted value of Goto et al. correlation is higher than the experimental value of pressure drop.

Goto et al. correlation overestimates the pressure drop in the pipe, while the experimental conditions have little influence on the prediction accuracy. The deviation between the predicted value of the correlation and the experimental value of the pressure drop ranges from 0.95% to 81.17%, while the average deviation, between the predicted value and the experimental value, is 42.64%, as shown in Fig. 7

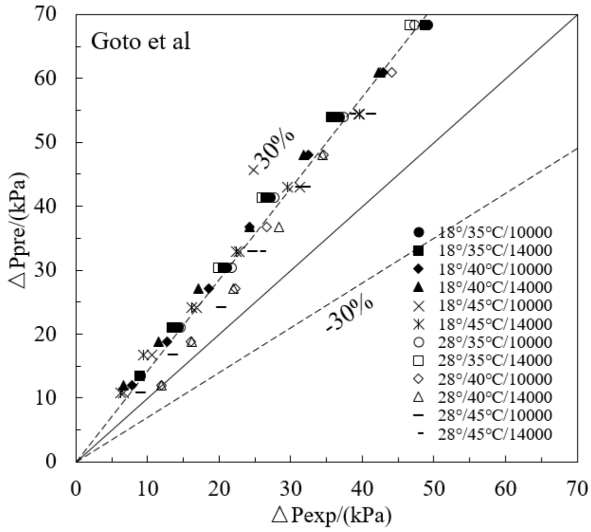


Fig.7 Prediction of the pressure drop inside the tube by Goto et al. correlation

Pierre correlation is based on fitting the pressure drop data of R12, in a horizontal optical tube. It is widely used, because of its simple calculation formula and high prediction accuracy. When predicting the pressure drop in the micro-ribbed tube, the hydraulic diameter of the micro-ribbed tube is used, instead of the inner diameter of the smooth tube. The formula, for calculating the two-phase friction coefficient, is as follows:

$$f_{TP} = 0.053 \times \left(K_f / \mathrm{Re}\right)^{0.25} \tag{9}$$

Pierre correlation overestimates the pressure drop in the tube, as the experimental conditions and the structural parameters of the micro-ribbed tube have a great influence on the prediction accuracy of the correlation, but the prediction error of the correlation is not large. The deviation between the predicted value of correlation and the experimental value of pressure drop ranges from - 10.81% to 60.09%, while the average deviation between them is 16.98%, as shown in Fig. 8.

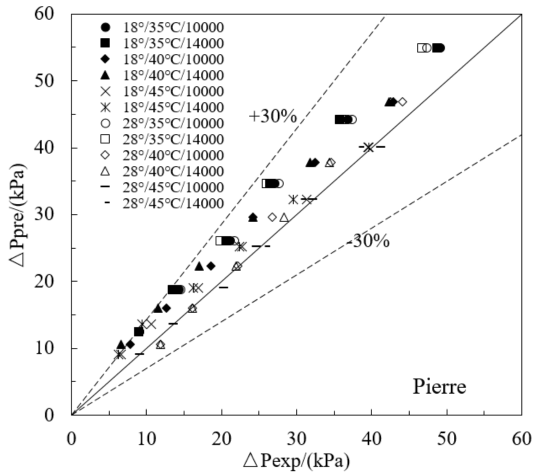


Fig.8 Prediction of the pressure drop inside the tube by the Pierre correlation

The average prediction errors of C correlation, H correlation and P correlation are all less than 17%. The better prediction results, not only confirm the high accuracy of correlation prediction, but also confirm the high accuracy of pressure drop experimental data, while further confirm the reliability of the test results of the experimental platform.

6. A study of novel relevance

Since the gas-liquid flow of two-phase flow in tube is clear and the mixing effect of two-phase flow is poor, the phase separation model is selected, as the theoretical basis for studying the pressure drop correlation of two-phase flow in tube. That is, it is assumed that there is a ratio relationship, between the pressure drop of two-phase flow and the pressure drop of single-phase flow in a pipe, which is defined as the conversion coefficients Φ_v and Φ_l of gas phase and liquid phase, respectively.

Gas phase conversion coefficient Φv:

$$\Phi_v = \sqrt{(dP_f/dz)/(dP_v/dz)} = aX_{tt}^m + bX_{tt}^n + c \tag{10}$$

Liquid phase conversion coefficient Φ_l:

$$\Phi_l = \sqrt{(dP_f/dz)/(dP_l/dz)} = aX_{tt}^m + bX_{tt}^n + c \tag{11}$$

Gas phase friction pressure drop (dP_v/dz):

$$(dP_v/dz) = 2 f_v G^2 x^2 / (\rho_v d) \tag{12}$$

Liquid friction pressure drop (dP_l/dz):

$$\left(dP_l/dz\right)=2f_lG^2(1-x)^2/(\rho_l d) \tag{13}$$

where, f_v and f_l are friction coefficients of pure gas/liquid flow in tubes, respectively.

The guiding principle of the new correlation is as follows: referring to the fitting mechanism of Goto et al. correlation, it is assumed that the gas/liquid phase conversion coefficient Φ_v/Φ_l is only a function of Lockhart-Martinelli parameter X_{tt}.

Based on the experimental data of condensation pressure drop of R134a two-phase flow in an internal threaded tube, the relationship between gas/liquid phase conversion coefficient Φ_v/Φ_l and parameter X_{tt} is fitted, while the liquid/gas phase friction pressure drop, in the two-phase flow in the tube, is taken as the calculation criterion. Finally, the correlation formula, for predicting the pressure drop in an internal threaded tube, with high accuracy, is obtained.

The core of the new correlation is to determine the relationship between the gas/liquid conversion coefficient Φ_v/Φ_l and the parameter X_{tt}, that is, to define the values of the coefficients a, b, c, m and n.

The specific solution process is as follows: the first step is to determine the relationship between the experimental value of two-phase friction pressure drop in tube and the calculated value of single-phase pressure drop in tube, that is, to define the value of gas/liquid phase conversion coefficient v/l. Following, the value of parameter X_{tt} is calculated, under experimental conditions. Finally, the relationship between gas/liquid phase conversion coefficient v/l and parameter X_{tt} is advanced. When the deviation effect is less than 10%, the calculation formula is valid. Finally, the calculation formula is obtained as follows:

New correlation gas phase conversion coefficient Φ_v:

$$\Phi_v^2=3.94X_{tt}^{-1.58}-22.43X_{tt}^{-0.79}+33.23 \tag{14}$$

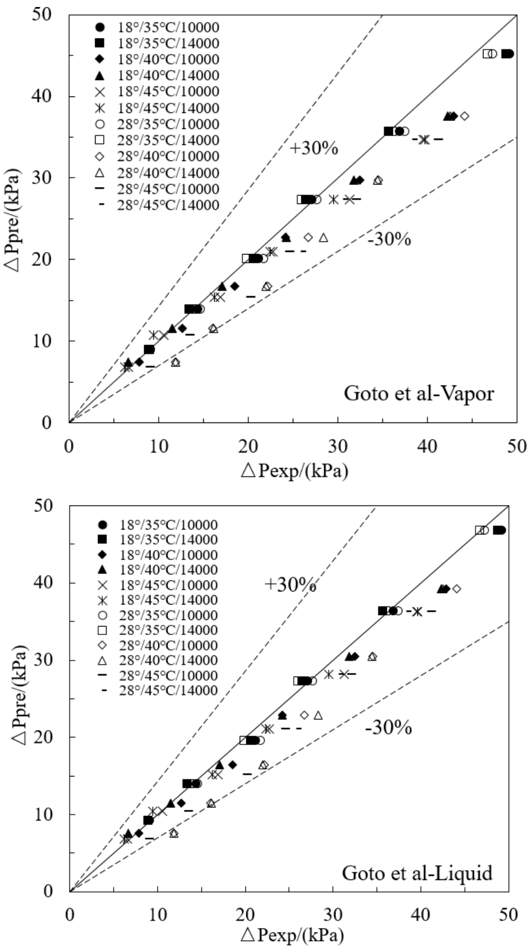
New correlative liquid phase conversion coefficient Φ_l:

$$\Phi_l^2=2.44X_{tt}^{-3.3}-37.42X_{tt}^{-1.65}+175.2 \tag{15}$$

In order to verify the predictive effect of the new correlation, the two-phase condensation pressure drop characteristics of R134a, in internal threaded tubes, are predicted by using Eqs. (14) and (15), respectively. The concrete predictive results are shown in Fig. 9.

For the gas phase prediction model and the liquid phase prediction model, the deviation between the calculated value of the new correlation and the experimental value of pressure drop is not greatly affected by the experimental variables, such as saturation temperature, mass rate and screw angle of the internal thread. The deviation between the calculated value and the experimental value is within ±30%, while the average deviation, between the calculated value and the experimental value, is - 8.79% and - 7.85%, respectively.

The smaller prediction error and better agreement between the calculated value of the new correlation and the experimental value can prove the validity and reliability of the new correlation prediction results.



(a) Gas phase prediction model (b) Liquid phase prediction model

Fig.9 Prediction of the new developed prediction model on the pressure drop (a) gas phase (b) liquid phase.

The experimental data of the new correlation fitting are derived from the condensation heat transfer experiment of two-phase flow in annular flow pattern of internal threaded tube. Therefore, the new correlation is only applicable to the prediction of condensation pressure drop of two-phase flow, under annular flow pattern, in internal threaded tubes. Moreover, the influence of two-phase flow dryness value, on the prediction accuracy of the new correlation, requires further experimental verification

7. Conclusion

The experiments of R134a two-phase flow condensation heat transfer, in micro-finned tubes were carried out, under the experimental conditions of mass rate of 400-900kg/(m2 s), condensation temperature of 35^0C, 40^0C and 45^0C, and Reynolds number of cooling water of 10000 and 14000. At the same time, the prediction accuracy of the pressure drop prediction correlation is validated. Based on the experimental data, the new correlation is studied, leading to the following main conclusions:

(1) When the homogeneous model and the split-phase model are used, to predict the pressure drop in the pipe, it is found that: The prediction accuracy of Cavallini et al. correlation is greatly affected by fin structure, but the prediction accuracy of C correlation is still high. The average deviation between the predicted value and the experimental value of pressure drop is 12.71%. The prediction accuracy of Haraguchi et al. correlation is the highest, while the average error of correlation prediction is -1.92%. Pierre correlation overestimates the pressure drop in pipe, while the average error of correlation prediction is 16.98%. Goto et al. based on fitting of pressure drop in herringbone teeth tube can realize the prediction of pressure drop in tube, but the correlation overestimates the pressure drop in tube. The error span of correlation prediction is large, while the average error of prediction is 42.64%.

(2) Referring to Goto et al. correlation fitting mechanism: The gas/liquid phase conversion coefficient Φ_V/Φ_L is only a function of parameter X_{tt}. Based on the experimental data of condensation pressure drop of R134a two-phase flow in tube, the relationship between Φ_V/Φ_L and parameter X_{tt} is re-fitted. The fitting correlation can accurately predict the pressure drop in the pipe. The error range of correlation prediction is within ±30% and the average error of prediction is less than 10%.

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