28 International Journal of Air-Conditioning and Refrigeration Vol. 14, No. 1 (2006)/pp. 28-39

Two-Phase Flow through a T-Junction

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Key words: Two-phase flow, T-junction, Prediction model, Refrigerant

ABSTRACT: Two-phase flow through a T-junction has been studied by numerous researchers so far. The dividing characteristics of the gas and liquid phases at the T-junction are very complicated due to a lot of related variables. The prediction models have been suggested by using experimental data for a specific condition or working fluid. But, they showed the application limitation for the most of the other conditions or fluids. Since most of them are applicable for their own experimental range, the generalized model for the wide range of conditions and fluids is needed. Even though it's not available now, some of the models developed for air-water flow at a T-junction might be applicable for the part of refrigerants with some modifications. Especially, for the two-phase flow of refrigerants at the T-junction, very few studies have been performed. Further experimental study is required to be performed for the wide range of test conditions and fluids to predict properly the two-phase flow distribution and phase separation through the T-junction.

Nomenclature

A : cross-sectional flow area [m^2]
a : distance of dividing streamline [m]
C : coefficient of two-phase multiplier for T-junction
D : tube diameter [m]
F : mass flow rate ratio, M_3/M_1
G : mass flux [kg/m^{2}s]
K : single phase loss coefficient
M : mass flow rate [kg/s]
P : pressure [MPa]
R : radius of curvature [m]
u : velocity [m/s]
X : Lockart-Martinelli parameter
x : quality

Greek symbols

α : void fraction
Θ : angle of branch tube [degree]
θ : center angle of flow area [degree]
ρ : density [kg/m^3]
Ω : angle of inlet tube [degree]

Subscripts

1 : inlet tube
2 : outlet tube
3 : branch tube
G : gas phase
J : junction
L : liquid phase

1. Introduction

Dividing branch-junction is commonly used as a component in industrial piping system.

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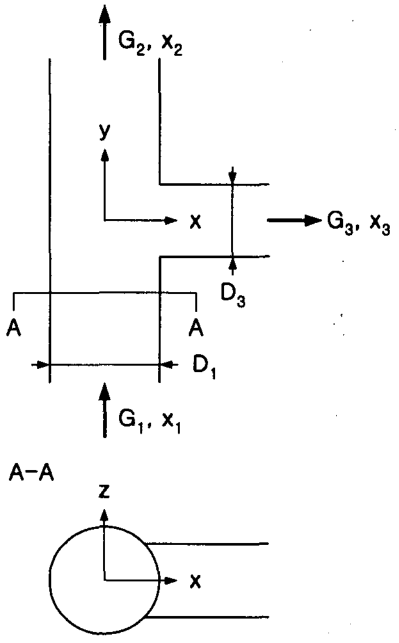
When gas and liquid flowing in a pipe encounter a branch-junction, the two phases very rarely split in the same ratio. The fraction of gas diverted into the branch can be very different from that of the liquid. These unpredictable dividing characteristics of the gas and liquid phases between branch and outlet tubes are complicated due to the large number of variables that influence it. Geometry of the junction, flow pattern and velocities of each phase upstream of the junction, the flow directions of inlet and branch tubes and the pressure gradients in the junction are the important variables that determine the dividing flow characteristics of two-phase flow in the junction. During the past two decades, relevance of this problem to various industrial applications and better understanding of two-phase flow have resulted in a significant amount of experimental work and analytical studies in this area. But, due to its complexity, most of the studies were limited within their experimental ranges or conditions. Especially, the working fluids were selected as air-water or steam-water mixtures, which were most commonly used in industrial piping networks and were easy to treat in experimental studies.

In recent years, dividing junction has been used as a device to distribute refrigerant in air-conditioning systems. In air-conditioning systems, dividing junctions are used as a device for distributing refrigerant into several subsections, for example, each path in an multi-pass evaporator and each indoor unit of a multi-zone VRF (Variable Refrigerant Flow) air conditioning system. The dividing behavior of two-phase refrigerant in a dividing junction is critical in the design of these air conditioning systems and components. As mentioned before, maldistribution of two-phase flow in a dividing junction occurs and it causes non-uniform heat transfer in each pass of a multi-pass heat exchanger or decreasing cooling capacities of some indoor units of a multi-zone VRF system. All of these result in decreasing efficiencies of the entire air-conditioning systems.

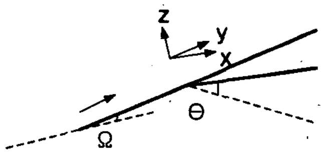
In this paper, we reviewed previous researches for two-phase flow especially in branching T-junction. Most of the researches were performed for air-water or steam-water two-phase flow. Then, we compared them with the experimental data of refrigerants and confirmed the applicability of the models developed by previous researchers for refrigerant systems.

2. Description of branching T-junction

Figure 1 shows a general geometry of a T-junction. The subscripts 1, 2 and 3 indicate the inlet, outlet, and branch tubes, respectively. The



(a) Cross-section A-A



(b) Definition for tube orientation

Fig. 1 Description of T-junction.

directions of inlet and branch tubes are indicated by Ω and Θ, which are the angles between inlet tube and horizontal plane and the angle between branch tube and horizontal plane, respectively. The tube diameter (D) also should be considered. The tube diameter ratio was defined as the ratio of the diameter of branch tube (D_3) to the diameter of inlet tube (D_1).

The mass flow rate ratios of gas and liquid phases are defined as follows:

$$F_G = \frac{M_{G3}}{M_{G1}} \tag{1}$$

$$F_L = \frac{M_{L3}}{M_{L1}} \tag{2}$$

The mass flow rate ratios are the ratios of the mass flow rate of gas or liquid phase at the branch tube to that at the inlet tube. So, according to these definitions, we can get the relations for the mass flux and quality in each tube.

$$G_2 = G_1 \frac{A_1}{A_2} \{(1-F_G)x_1 + (1-F_L)(1-x_1)\} \tag{3}$$

$$G_3 = G_1 \frac{A_1}{A_3} \{F_G x_1 + F_L(1-x_1)\} \tag{4}$$

$$x_2 = \frac{1}{\frac{(1-F_L)}{(1-F_G)} \frac{(1-x_1)}{x_1} + 1} \tag{5}$$

$$x_3 = \frac{1}{\frac{F_L}{F_G} \frac{(1-x_1)}{x_1} + 1} \tag{6}$$

So, in this paper, all of the predicted and measured data were presented with F_G and F_L.

For prediction of the two-phase flow characteristics, the most popular method among the pre-published researches was the dividing streamline model. Figure 2 shows the definition of the dividing streamlines for each phase and the distances of the dividing streamlines, a_G and a_L under the condition of annular flow. As shown in Fig. 2, the mass flow rate ratios for gas and liquid phases can be determined with a_G and a_L. Figure 3 shows the relation between F_G and F_L for same dividing streamline ($a_G = a_L$) assumption. If $a_G = a_L$, the curve

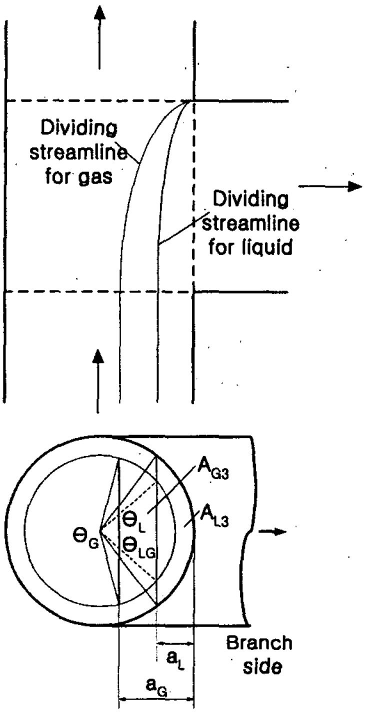


Fig. 2 Dividing streamlines for gas and liquid two-phase flows.

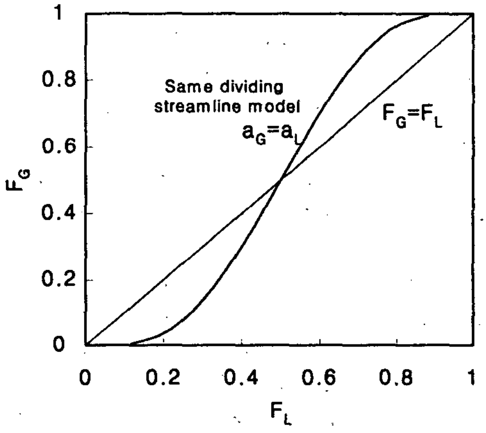


Fig. 3 Phase distribution for the same dividing streamline (R-22, D=8.12 mm, G_1=300 kg/m^{2}s, x_1=0.3).

in Fig. 3 was determined only by the ratio of inlet tube diameter and liquid film thickness of annular flow. But, the condition of $a_G = a_L$ rarely occur in practical condition of dividing two-phase flow in a T-junction. So, many researchers suggested prediction method for relations between F_G and F_L or a_G and a_L.

3. Literature review

The review focuses on the experimental works on T-junction with a horizontal inlet tube using air-water or steam-water flow. They show that the flow distribution, phase separation and pressure changes at the junction are extremely complicated, and affected by inlet flow parameters, fluid properties and junction geometry. Due to lots of parameters involved in the distribution process, studies on the effect of parameters were limited for studying the effect of a few parameters.

Azzopardi and Whalley(1) studied the effect of branch diameter on phase separation in a 32 mm main inlet T-junction with branch diameters of 6.35, 12.7 and 19 mm, giving the diameter ratios of 0.2, 0.4 and 0.6, respectively. Azzopardi(2) extended the study to the diameter ratio of 0.8 and 1. The experiments were performed at the inlet mass flux of 152 kg/m^{2}s and inlet quality of 0.56. The results indicated a systematic influence of branch diameter on phase separation although the trend was not always clear at lower inlet mass flux conditions. It was found that the smaller the branch diameter the higher the quality ratio x_3/x_1. Azzopardi et al.(3) extended the study to stratified flow and obtained the same parametric trend.

Saba and Lahey(4) presented air-water data of both phase redistribution and pressure changes in a horizontal T-junction with the same diameters of 38mm. Three mass fluxes of 1,353, 2,041 and 2,711 kg/m^{2}s were tested. The inlet quality was less than 0.01, which led to bubble flow and slug flow in the inlet tube. It was found that even for these low inlet qualities the degree of phase redistribution was quite pronounced with the gas phase preferentially separating into the branch. In their test conditions, they also found that the inlet mass flux had little effect on phase redistribution.

Seeger et al.(5) published a detailed study on phase redistribution and pressure changes for air-water and steam-water flows in dividing T-junctions with different branch orientations. The experiments were performed in a 50 mm equal diameter T-junction with horizontal, upward and downward branches. The inlet mass flux and quality covered wide ranges of 500~7,500 kg/m^{2}s and 0.002~0.33, which led to the observation of bubbly, slug and annular flow. With a horizontal branch, they found that the degree of phase redistribution x_3/x_1 increased rapidly with increasing branch flow split ratio, peaking near the flow distribution ratio of 0.3, after which total phase separation occurred. The data also indicated that for a fixed inlet superficial liquid velocity, x_3/x_1 decreased as the inlet superficial gas velocity increased. This trend was consistent with the observations of Collier(6) and Henry(7) in the annular flow regime.

Shoham et al.(8) performed air-water experiments in a 51 mm diameter T-junction. The data were collected at fixed inlet superficial gas velocities of 2.5, 6.1 and 26 m/s, while superficial liquid velocity varied from 0.0029 to 0.059 m/s for each gas velocity, thus giving rise to stratified and annular flow. In stratified flow they found that, in all conditions tested, at very low branch flow split, no liquid flowed into the branch. The liquid phase was extracted into the branch only after a higher portion of gas was diverted into the branch. This phenomenon was not reported in the previous researches. The data also showed that, with an increase of inlet superficial liquid velocity, the fraction of liquid extracted into the branch decreased, indicating an increase in the degree of phase separation. This was consistent with the data trend of Collier(6) at the inlet quality below 0.25. In most of the experiments related to annular flow, they observed that the liquid phase tended to be extracted preferentially into the branch at low extraction rate. Furthermore, the annular data showed that, when the inlet superficial liquid velocity increased, the liquid fraction in the branch decreased or the extent of phase separation x_3/x_1 increased.

Ballyk et al.(9) studied steam-water annular flow phase redistribution and pressure changes in a 25 mm diameter horizontal T-junction. These experiments were particularly interesting since the measurements included the void fraction profiles in the three legs of the junction, and the data were collected at a higher range of inlet mass flux of 450~1,200 kg/m^{2}s, not previously tested. The inlet quality covered the range of 0.02~0.15. They reported that the branch quality was higher than the inlet quality over most of the flow split range, and only at low flow split was the branch quality less than that of the inlet. The maximum value of x_3/x_1 occurred at branch flow split ratio around 0.2. It is interesting to note that this result differs from that of Shoham et al.(8) in which liquid tended to be extracted preferentially into the branch for most of the test conditions. These different trends are probably caused by the large difference of inlet mass flux used by the authors (2.9~59 kg/m^{2}s by Shoham et al.(8) and 450~1,200 kg/m^{2}s by Ballyk et al.(9)). High inlet liquid velocity make the axial momentum flux of the liquid phase increase, and furthermore, generates higher entrainment of liquid droplets which have large momentum flux and the large resistance to being diverted to the branch. The data by Ballyk et al.(9) also showed that an increase in inlet quality resulted in reducing the peak and the degree of the phase separation, x_3/x_1, and increasing the flow distribution ratio at which complete vapor extraction took place. The inlet mass flux, however, was found to have little effect on phase separation under their test conditions.

Rubel et al.(10) performed steam-water experiments in a 37.6 mm equal diameter T-junction. The inlet mass flux and quality covered the ranges of 16.1~50.3 kg/m^{2}s and 0.21~0.87 respectively, which resulted mostly in stratified, stratified-wavy and semi-annular flow regime. Their data showed that the inlet mass flux did not have significant effect on the phase redistribution. However, when the inlet quality increased, the degree of phase separation x_3/x_1 decreased in the semi-annular flow and increased in stratified flow. These results are consistent with the observation of Collier.(6) This indicates the complexity of dividing two-phase flow in the junction and also that the parametric trend could be totally reversed depending on the inlet flow pattern.

There was other a number of researches for two-phase flow distribution at a T-junction. They presented their experimental data for air-water or steam-water flow, and some of them suggested empirical prediction models.

Figure 4 shows the comparison between the steam-water data of Rubel et al.(11) (D=0.05 m, gas superficial velocity = 43 m/s, liquid superfi-

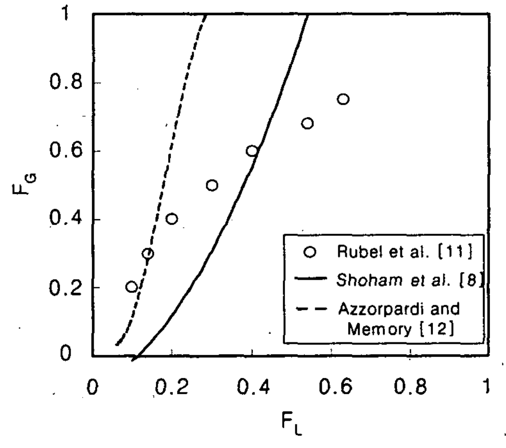


Fig. 4 Comparison between predicted and measured data for steam-water flow in a T-junction (D=0.05 m, P=27.5 MPa).

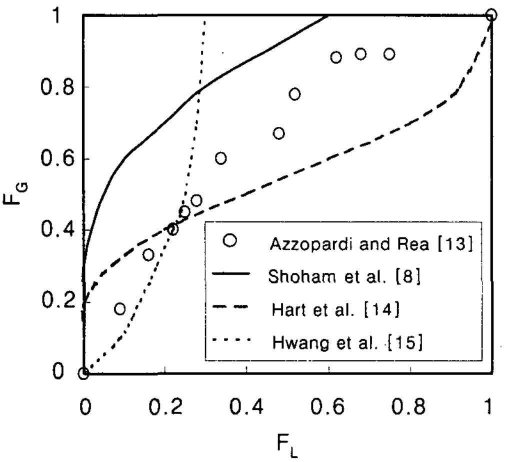


Fig. 5 Comparison between predicted and measured data for air-water flow in a T-junction (D=0.127 m, P=0.1 MPa).

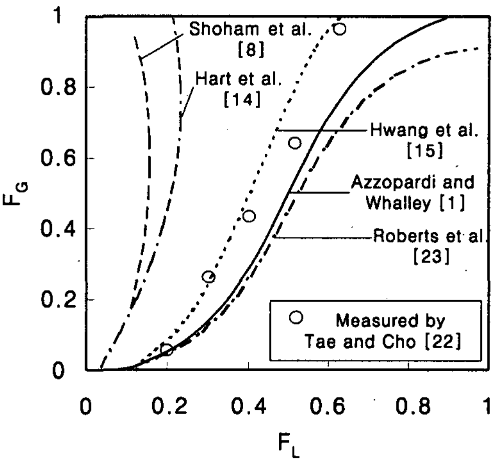


Fig. 6 Comparison of measured data and published values (R-22, D=8.12 mm, G_1= 300 kg/m^{2}s, x_1 =0.3).

cial velocity≒0.11 m/s, P=27.5 MPa) and predictions of the models of Shoham et al.(8) and Azzopardi and Memory.(12) Figure 5 shows the comparison between the air-water data of Azzopardi and Rea(13) (D=0.127 m, gas superficial velocity = 24 m/s, liquid superficial velocity = 0.04 m/s, P=0.1 MPa) and predictions of the models of Shoham et al.,(8) Hart et al.(14) and Hwang et al.(15) According to above-mentioned results, the prediction model developed by using the experimental data for a certain condition and fluid was not applicable for the other condition and fluid. So, the application of these models on the refrigerant cases was not confirmed yet.

Azzopardi(16) reviewed a number of researches for two-phase flow in a T-junction of air-water or steam-water mixture during last two decades. As mentioned in Fig. 4 and Fig. 5, Azzopardi(16) also mentioned that most of the measurements and prediction models had their own limitations to the application for the wide range of parameters and working fluids.

4. Application for refrigerants

Compared with air-water or steam-water flow, dividing two-phase flow characteristics of refrigerants in a T-junction has not been studied for wide ranges of experimental conditions. Watanabe(17) and Kim(18) experimentally investigated two-phase flow distribution characteristics of R-11 in a distribution header with 4 passes. Recently, Tae and Cho(19,20) experimentally investigated the two-phase flow characteristics of R-22 in horizontal and vertical T-junctions. Wider ranges of R-22, R-134a and R-410A were covered by Tae(21) and Tae and Cho.(22) Tae(21) also compared his experimental data for refrigerants with previous prediction models and suggested modified model for dividing two-phase flow of refrigerants at horizontal and vertical T-junctions.

Figure 6 shows the comparison between the measured data for R-22 and the values predicted by several models. Prediction by the other models that were not listed in Fig. 6 was impossible or fairly big different due to the different condition. As shown in Fig. 6, the model by Hwang et al.(15) showed the best agreement with the refrigerant data of Tae and Cho.(22) The models by Azzopardi and Whaley(1) and Roberts et al.(23) were under-predicted the F_G at the fixed F_L. The reason is that both models are based on the assumption of the same dividing streamline for both gas and liquid phases even though the dividing streamline of gas phase is actually located far from the branch side wall than that of liquid for refrigerant. The models by Shoham et al.(8) and Hart et al.(14) over-predicted the experimental data. The reason is as follows; the density ratio of gas and liquid phases for refrigerant is bigger than that for air-water flow. For example, the density ratio (ρ_G/ρ_L) for air-water at 0.1 MPa, 25.0℃ is 0.001, while that for R-22 at the saturated pressure of 0.65 MPa is 0.022. As the density ratio was increased, F_G was decreased for the fixed F_L.

Hwang et al.(15) developed a phenomenological model for horizontal T-junction with the same diameters, which is based on the existence of different dividing streamlines for gas and liquid phases. For the separated two-phase flow such as stratified and annular flows, it was found that the influence of the interfacial drag force is relatively small and may be neglected. The model is then simplified to a balance between centrifugal forces of the two phases as follows:

$$\frac{\rho_G u_G^2}{R_G} = \frac{\rho_L u_L^2}{R_L} \tag{7}$$

where the radii of curvature of gas and liquid phases dividing streamlines are assumed to satisfy the following relation:

$$\frac{R_G}{R_L} = \frac{\left(\frac{a_L}{D_1}\right)^{n_L}}{\left(\frac{a_G}{D_1}\right)^{n_G}} \tag{8}$$

The exponent n_k in Eq. (8) was determined empirically by Hwang et al.(15) as:

$$n_k = 5 + 20\exp\left[-53\left(\frac{a_k}{D_1}\right)\right] \tag{9}$$

Thus, the relation between the dividing streamlines of gas and liquid phases is:

$$\frac{\left(\frac{a_L}{D_1}\right)^{n_L}}{\left(\frac{a_G}{D_1}\right)^{n_G}} = \frac{\rho_G u_G^2}{\rho_L u_L^2} \tag{10}$$

The model of Hwang et al.(15) can be applied for only horizontal tube orientation. So, Tae(21) suggested modified model for the reduced T-junction ($D_3/D_1 < 1$) or T-junction with vertical inlet or branch tubes based on the experimental data for refrigerants as follows:

$$\frac{\left\{(1+0.52\sin\Theta-0.48\sin\Omega)\frac{a_L}{D_1}\right\}^{n_L}}{\left\{(1-0.65\sin\Theta+0.28\sin\Omega)\frac{a_G}{D_1}\right\}^{n_G}} = \frac{\rho_G u_G^2}{\rho_L u_L^2}\left(\frac{D_3}{D_1}\right)^{1.25} \tag{11}$$

Figure 7 shows the effect of the orientation of the inlet and branch tubes on F's. The mass flow rate ratios of gas at the fixed F_L were

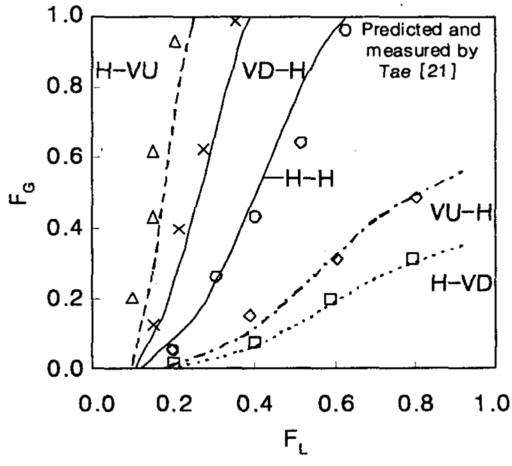


Fig. 7 Effect of the orientation of inlet and branch tubes on F's (R-22, D=8.12 mm, G_1=300 kg/m^{2}s, x_1=0.3).

Table 1 Sensitivity of parameters for refrigerants: measured by Tae and Cho(22)

Parameter		Range	Sensitivity	Baseline case
Inlet flow	Refrigerant	R-22, R-134a, R-410A	2.5%	R-22
	Inlet mass flux (kg/m^2s)	100, 300, 500, 700	23.4%	300
	Inlet quality	0.1~0.9	43.6%	0.3
	Saturated temp. (℃)	3.5, 6.0, 8.5, 11.0	1.8%	8.5
Geometric	Tube diameter (mm)	11.3, 8.12, 4.95	4.4%	8.12
	Diameter ratio	1, 0.72, 0.44	26.5%	1
	Branch direction	H, VU, VD	198%	H
	Inlet direction	H, VU, VD	181%	H

The uncertainty of experimental data of Tae and Cho(22) is maximum 5.1%.

large in the order of vertical upward branch (H-VU) case, vertical downward inlet (VD-H) case, horizontal T-junction (H-H) case, vertical upward inlet (VU-H) case, vertical downward branch (H-VD) case. For the vertical upward branch (H-VU) case, the gravity force acts on the opposite direction to the branch flow direction at the junction area. Due to the difference of the densities between gas and liquid phases, the acting gravity force of liquid is also larger than that of gas. Thus, the mass flow rate ratio of liquid is rapidly decreased for the H-VU case. Similar phenomena were investigated for other directions for R-22, R-134a and R-410A refrigerants. The predicted values were agreed with the measured data by Tae(21) within the maximum 25%.

The sensitivities of the geometric and inlet flow parameters by Tae(21) for refrigerants were presented in Table 1. The sensitivity of parameter was defined as the maximum difference between reference values at the F_L of 0.5 for the baseline cases listed in Table 1 and the value at different condition. As shown in Table 1, the branch tube direction was the most sensitive parameter among the test parameters in the present study. The inlet quality was the most sensitive parameter among the inlet flow parameters of Tae,(21) while the branch tube direction was the most sensitive one among the geometric parameters.

The model suggested by Tae(21) for refrigerants was basically modified the model by Hwang et al.(15) Hwang et al.(15) described the key parameter of the momentum flux ratio of gas and liquid phases for two-phase flow distribution in a T-junction. Tae and Cho(22) used R-22, R-134, and R-410A as refrigerants for confirming their model.

5. Pressure change in a T-junction

When two-phase flow was divided at a T-junction, pressure change occurs between inlet and branch, and inlet and outlet tubes as shown in Fig. 8. The pressure gradients in the T-junction affect the phase separation in the T-junction. Saba and Lahey(4) suggested the correlations for the pressure changes in a T-junction and many other researchers(15,24-26) used the similar correlations. For refrigerants, Tae(21) sug-

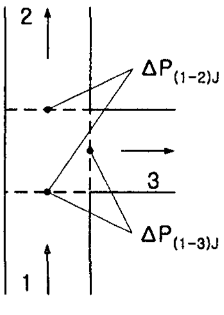


Fig. 8 Pressure change in a T-junction.

gested a model based on Saba and Lahey.(4) But, they didn't use the correlations for single-phase coefficients and two-phase multiplier that Saba and Lahey(4) suggested.

According to the two-phase Bernoulli equation, the pressure gain at the junction between the inlet and outlet tubes occurs due to the decrease of the flow rate. The two-phase Bernoulli equation between inlet and outlet tubes is described as follows:

$$(\Delta P_{1-2})_J = \frac{1}{2}\left\{ G_1^2\left(\frac{x_1^2}{\alpha_1\rho_G} + \frac{(1-x_1)^2}{(1-\alpha_1)\rho_L}\right) - G_2^2\left(\frac{x_2^2}{\alpha_2\rho_G} + \frac{(1-x_2)^2}{(1-\alpha_2)\rho_L}\right)\right\} \tag{12}$$

The void fraction, α, is calculated with Graham et al.(27) for horizontal flow and with Klausner et al.(28) for vertical flow of refrigerants.

The pressure change at the junction between inlet and branch tubes is caused by two terms. The one is the momentum change due to the decrease of flow rate, and this term can be described as the reversible pressure change. And the other one, the irreversible pressure change is due to the change of flow direction (turning into the branch direction) and orifice effect at the entrance of the branch tubes. The pressure change at the junction between inlet and branch tubes is calculated as follows:

$$(\Delta P_{1-3})_J = (\Delta P_{1-3})_{rev.} + (\Delta P_{1-3})_{irr.} \tag{13}$$

$$(\Delta P_{1-3})_{rev.} = \frac{1}{2}\left\{ G_1^2\left(\frac{x_1^2}{\alpha_1\rho_G} + \frac{(1-x_1)^2}{(1-\alpha_1)\rho_L}\right) - G_3^2\left(\frac{x_3^2}{\alpha_3\rho_G} + \frac{(1-x_3)^2}{(1-\alpha_3)\rho_L}\right)\right\} \tag{14}$$

$$(\Delta P_{1-3})_{irr.} = \frac{K_{1-3}}{2}\,\frac{G_1^2(1-x_1)^2}{\rho_L} \times\left(1+\frac{C_{1-3}}{X}+\frac{1}{X^2}\right) \tag{15}$$

$$K_{1-3} = 0.95(1-F_L)^2 + 0.8F_L(1-F_L) + 1.3F_L^2 \tag{16}$$

The single-phase friction loss coefficient, K_{1-3}, was calculated by Gardel's(29) correlation for single-phase flow in a T-junction. The C_{1-3} was suggested by Chisholm and Sutherland(30) for the two-phase T-type branch flow.

$$C_{1-3} = \left[\lambda + (C-\lambda)\left(\frac{\rho_L-\rho_G}{\rho_L}\right)^{0.5}\right] \times\left[\left(\frac{\rho_L}{\rho_G}\right)^{0.5} + \left(\frac{\rho_G}{\rho_L}\right)^{0.5}\right] \tag{17}$$

Chisholm and Sutherland(30) proposed $\lambda=1$ and $C=1.75$ for T-type branch flow.

Figure 9 shows the comparison between the predicted pressure profiles and measured pressure data by Tae(21) for R-22 in the test section. As shown in Fig. 9, there were flow disturbance regions within about 100 mm after the junction in the outlet and branch tubes. The predicted absolute pressures agreed with the experimental data within maximum 25% error range. Figures 10 and 11 show the pressure changes at the T-junction between inlet and branch tubes and inlet and outlet tubes, respectively. The experimentally measured data by Tae(21) are compared with predicted values with the correlation by Tae(21) and Saba and Lahey.(4) The correlation of Saba and Lahey(4) over-predicts the refrigerant data in Fig. 10,

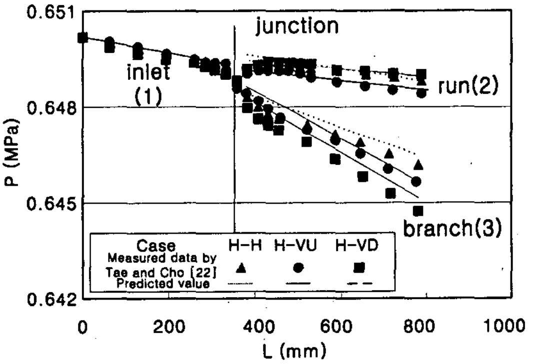


Fig. 9 Pressure profiles in the test section (R-22, horizontal T-junction, D=8.12 mm, G_1=300 kg/m^{2}s, x_1=0.3).

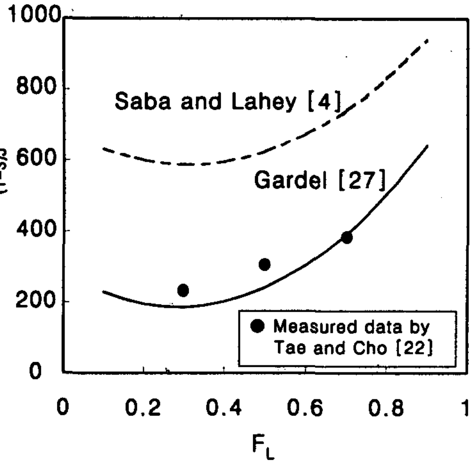


Fig. 10 Pressure change between inlet and branch tubes (R-22, D=8.12 mm, G_1= 300 kg/m^{2}s, x_1=0.3).

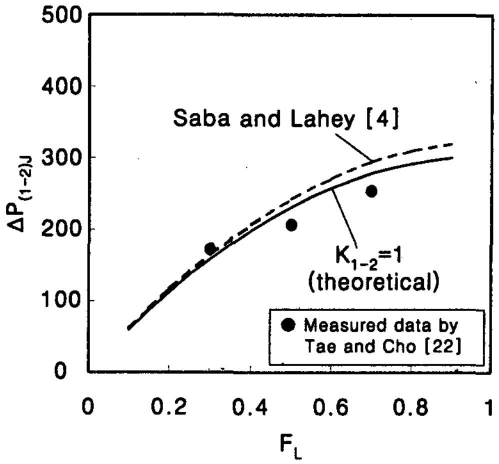


Fig. 11 Pressure change between inlet and outlet tubes (R-22, D=8.12 mm, G_1= 300 kg/m^{2}s, x_1=0.3).

whereas the correlation of Gardel(29) shows good agreements. Also, for the pressure gain between inlet and outlet tubes in Fig. 11, the Saba and Lahey's(4) correlation over-predicts the experimental data, whereas the theoretical equation, Eq. (12), yields better prediction.

6. Conclusions

(1) Dividing two-phase flow at a branching T-junction has been studied by numerous researchers. The predictive models have been suggested by using experimental data for a specific condition or fluid. But, they show the application limitation for the most of the other conditions or fluids.

(2) Few studies have been performed for two-phase flow of refrigerant at a T-junction. Some of the models developed for air-water flow at a T-junction might be applicable for the refrigerants with some modifications.

(3) According to the sensitivity analysis of parameters of Tae,(21) the tube orientation was the most sensitive among the inlet flow conditions, while the quality was the most sensitive among the inlet flow parameters on the two-phase flow distribution characteristics of refrigerants at the T-junction.

(4) Further experimental study for the wider ranges of flow rate, diameter, and fluid should be performed in the future research. Also, interaction and flow disturbance between branches should be considered for more accurate prediction and analysis in practical multi-pass systems.

Acknowledgement

This study was supported by Brain Korea 21 Project in Korea and SFARC in Sungkyunkwan University.

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