2002

Flow Mal-Distribution In Micro-channel Evaporator

H. Cho
Sungkyunkwan University

K. Cho
Sungkyunkwan University

B. Youn
Samsung Electronics

Y. S. Kim
Samsung Electronics

R6-5

FLOW MAL-DISTRIBUTION IN MICRO-CHANNEL EVAPORATOR

Honggi Cho, Graduate student, Sungkyunkwan University, School of Mechanical Engineering,
300, Chunchun-dong, Changan-ku, Suwon, 440-746, South Korea; Tel.: +82-31-290-7483; Fax: +82-31-290-5849
E-Mail: hgcho@mail.skku.ac.kr
*Keumnam Cho, Ph.D, Professor, Sungkyunkwan University, School of Mechanical Engineering,
300 Chunchun-dong, Changan-ku, Suwon, 440-746, South Korea; Phone: +82-31-290-7445; Fax: +82-31-290-5849
E-Mail: keumnam@yurim.skku.ac.kr *Author for Correspondence

Baek Youn, Ph.D, Principal Engineer, System Appliance Division, Samsung Electronics, 416 Maetan-3Dong,
Paldal-Gu, Suwon, 442-742, South Korea; Phone: +82-31-200-6276; Fax: +82-31-200-6392
E-Mail: baekyoun@samsung.co.kr
Young-Saeng Kim, Senior Engineer, System Appliance Division, Samsung Electronics, 416 Maetan-3Dong,
Paldal-Gu, Suwon, 442-742, South Korea; Phone: +82-31-200-6042; Fax: +82-31-200-6392
E-Mail: h18244@samsung.co.kr

ABSTRACT

The present study experimentally investigated flow mal-distribution and phase separation in micro-channel tubes. The experimental apparatus consisted of a test section with micro-channel tubes, a refrigerant pump, a mass flow meter, a pre-heater, 15 gas-liquid separators, 5 sets of liquid and gas flow meters, and a plate heat exchanger. The test section made of a header pipe and 15 micro-channel tubes. Each micro-channel tube brazed to the header pipe had 8 rectangular ports with the hydraulic diameter of 1.24mm.

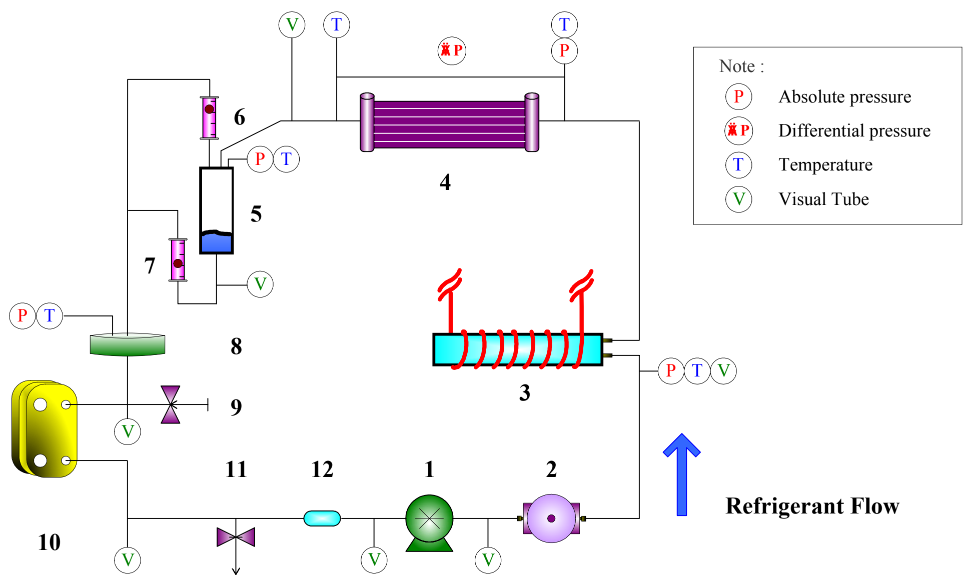
Flow mal-distribution for 15 micro-channel tubes got improved by changing the flow direction to the inlet header from parallel to in-line flow condition. Mass flow rate fraction showed the maximum at channel number 1 under both parallel and in-line flow conditions. The inlet quality didn't affect much on the flow distribution under the parallel and in-line flow conditions. Phase separations under the in-line flow condition differed less than those under the parallel flow condition. The difference of phase separation ratios for 15 micro-channel tubes decreased as the inlet quality increased.

INTRODUCTION

The fin-tube heat exchangers were widely applied for the residential air-conditioner. With the increase in the use of micro-channel heat exchangers for industrial and commercial applications because of their small size, weight and refrigerant charge, Bae and Han[1] applied micro-channel heat exchanger for the residential air-conditioner. Residential air-conditioners with micro-channel condenser have been used in the market. Micro-channel evaporator, however, is not to be utilized for residential application. There are two major reasons for its limitation. The first one is the condensate problem inside the louvered fin. It prohibits air from passing through the heat exchanger, and then severely deteriorates thermal performance. The second one is the flow mal-distribution problem in micro-channel tubes. Due to the flow mal-distribution and phase separation in micro-channel tubes, part of the evaporator is filled with superheated vapor and then thermal performance is decreased very much. Even though flow mal-distribution and phase separation problems are important, a few studies have been done for simple T type or Y type junctions by using air-water mixture[2,3] or steam-water mixture[4-6]. To author's knowledge, very few study by using refrigerants has been reported so far. Author's previous study[7] reported the flow distribution and phase separation in T-junction by using R22. Two-phase flow distribution and phase separation depend on lots of geometrical and dynamic parameters. Geometrical parameters are header diameter, header orientation, micro-channel tube diameter, tube pitch, tube length, etc. Dynamic parameters are inlet quality, mass flux, thermal boundary condition, etc. The study on the flow distribution and phase separation contains the complexity of test including selection of geometric and dynamic parameters, pressure control of the system, setting of system balance, proper selection of gas-liquid separator, two-phase flow rate measurement, etc. Asoh et al.[8] and Kariyasaki et al.[9] studied the flow distribution through the multi-pass branch tube with different direction of branch tube. Watanabe et al.[10] and Rong et al.[11] reported the flow distribution in the header of serpentine and stacked plate heat exchanger, respectively. Rong et al.[11] specifically investigated the effects of the header orientation on the flow distribution. Recently visualization in the inlet header of plate type evaporator was investigated by Fei et al.[12]. They reported effect of flow rate and quality on the flow distribution for different flow regimes. Oh and Lee[13] showed the simulation results on the effect of inlet angle, shape and location of refrigerant flow and height of protruding flat tube in the inlet header of parallel flow heat exchanger for single phase flow. Beaver et al.[14] presented experimental results on the effect of flow mal-distribution in micro-channel evaporators using the CO_2 for heat pump application. Even though the flow mal-distribution and phase separation problems in the evaporator are very serious comparing with the condenser application, they were not studied systematically by considering geometry and dynamic parameters for optimal design of the micro-channel evaporator as mentioned before. Thus, they have to be systematically investigated. Some studies on the flow mal-distribution and phase separation for refrigerant system are going on in a couple of research labs. As one of them, the present study investigated the influence of the inlet flow direction and inlet quality on the flow mal-distribution and phase separation in the manifold of the micro-channel evaporator.

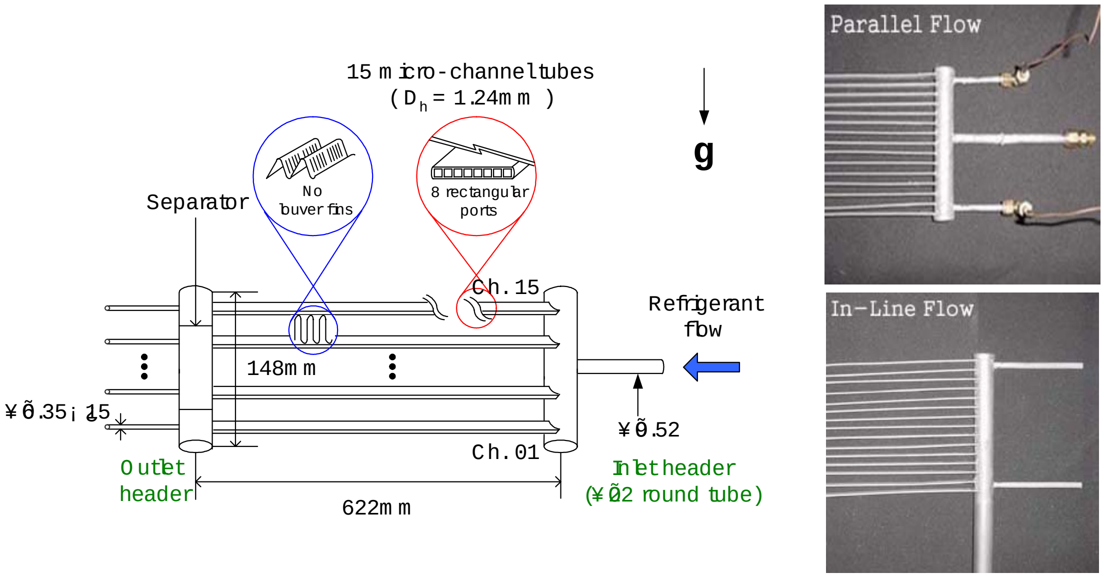
EXPERIMENTAL APPARATUS AND PROCEDURE

Figure 1 shows the schematic diagram of the experimental apparatus for the present study. The experimental apparatus consists of a test section of micro-channel evaporator, a refrigerant pump, a mass flow meter, a pre-heater, 15 gas-liquid separators, 5 sets of liquid and gas volumetric flow meters, and a plate heat exchanger. The test section consisted of an aluminum header pipe with outer diameter of 22mm and inner diameter of 19.4mm and 15 micro-channel tubes. The details and photographs of the test section are shown in Figure 2. Each micro-channel tube had 8 rectangular ports with a hydraulic diameter of 1.24mm, and was brazed to the header. Each micro-channel tube was connected to the copper tube with outer diameter of 6.35mm through the outlet header. The outlet header has separators in it for not mixing two-phase flow in each micro-channel. Then, each tubes were connected to the 15 gas-liquid separators respectively. The volumetric flow rates for the liquid and vapor were measured by rotameters.



1. Refrigerant pump	**2. Mass flow meter**	**3. Pre-heater**
4. Test section	**5. Gas-liquid separator**	**6. Vapor flow meter**
7. Liquid flow meter	**8. Manifold**	**9. Refrigerant inlet**
10. Condenser	**11. Refrigerant outlet**	**12. Filter dryer**

Figure 1. Schematic diagram of the experimental apparatus



(a) Details **(b) Photographs**

Figure 2. Details and photographs of the test section

It was difficult to install 15 sets of rotameters for liquid and vapor. Thus, only 5 sets of rotameters were installed for odd number of micro-channel tubes in order to measure volumetric flow rates. The flow rates for the micro-channel tubes not measured by rotameters were estimated by using the least square equation for flow rate. The least square equation for flow rate was obtained by using the measured flow rate data. After the gas-liquid separator, refrigerant flowed into the manifold, and then condensed by the plate type heat exchanger. The pre-heater was used to control the inlet quality at the inlet header. It was controlled by adjusting the supply voltage to the pre-heater. The speed-controlled refrigerant pump was used to circulate the refrigerant, and the mass flow rate to the inlet header was measured by the coriolis mass flow meter. The working fluid was R-22, and the saturated temperature at the inlet of the test section was set at 7℃ (0.622Mbar). The mass flux at the inlet header was fixed as 60kg/m^2·s, and the inlet qualities were 0.1, 0.2 and 0.3. The absolute pressure was measured by a pressure transducer (10bar range, ± 0.1% resolution) at the inlet of the test section, the pre-heater inlet, inlet of the gas-liquid separator and the manifold. The pressure difference between the inlet and outlet of the test section was measured by a differential pressure gauge (350 mbar range, ±0.1% resolution).

RESULTS AND DISCUSSION

Flow mal-distribution in micro-channel tubes

Figure 3 shows the liquid and vapor mass fractions for 15 micro-channel tubes under the parallel flow condition to the inlet header. The mass flux at the inlet header was 60kg/m^2·s. Liquid and vapor mass fraction defined as the ratio of mass flow rate of liquid each channel to the total liquid mass flow rate for 15 channels. Vapor mass fraction was defined was defined as the same way with the liquid mass fraction. Liquid mass fraction was the largest at channel number 1 that corresponds to the bottom channel of the micro-channel test section due to the gravity inside of the header. The second largest liquid mass fraction was observed near the center of the header, located between channel number 8 and 9. It is because the refrigerant inlet was located near the center of the header, and thus the inertia of refrigerant from the refrigerant inlet affected the liquid mass fraction mostly at the micro-channel tube near the center of the header.

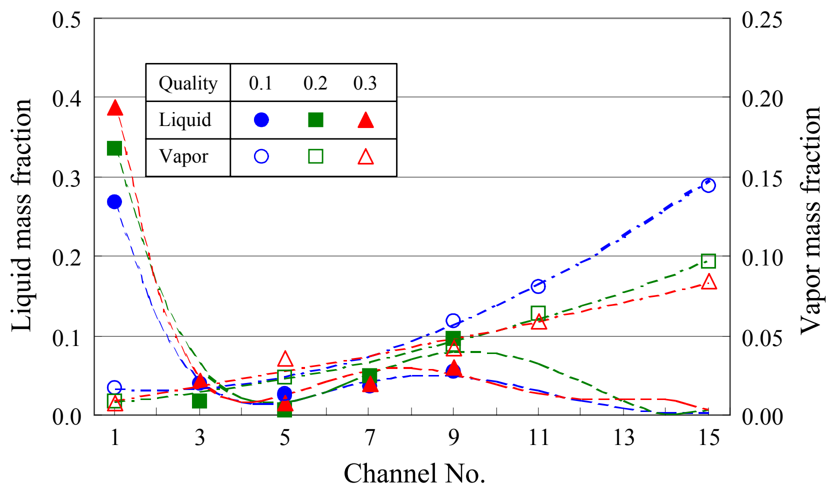


Figure 3. Liquid and vapor mass fractions under the parallel flow condition to the inlet header

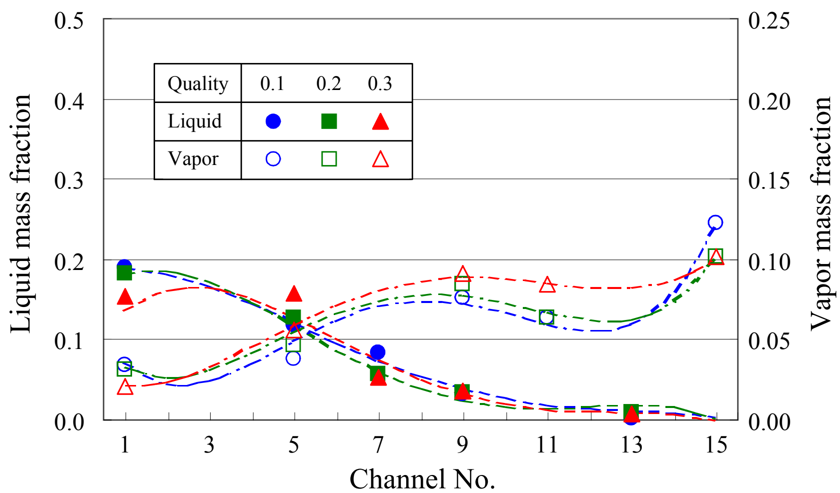


Figure 4. Liquid and vapor mass fractions under the in-line flow condition to the inlet header

In the channel number 15, no liquid flow observed. The liquid mass fraction at channel number 1 was much larger than that of the other channels. Vapor mass fraction increased as channel number increased. It showed the largest for the channel at the top of the header. It may be due that vapor was pushed upward by liquid located mostly at the bottom of the header. As the inlet quality at the header increased from 0.1 to 0.3, liquid mass fraction increased a little bit, while the vapor mass fraction decreased. It means that the position of micro-channel tubes affects on the flow distribution more than the inlet quality at the header.

Figure 4 shows the liquid and vapor mass fractions for 15 micro-channel tubes under the in-line flow condition to the inlet header. The inlet flow direction to the header was vertical upward. The liquid mass fraction was the largest in the channel number 1 by the same way with the result under the parallel flow condition. But, the absolute value of liquid mass fraction at the channel number 1 was almost half of that for the parallel flow case. The vapor mass fractions under the in-line flow condition showed less difference among channels than those under the parallel flow condition. The effect of the inlet quality at the header on the mass fraction was not big. Flow mal-distribution for 15 micro-channel tubes under in-line flow condition got improved by changing the flow condition to the header from parallel flow to in-line flow. The line shown in Figures 3 and 4 show the least-square-fitted curve by using the measured data.

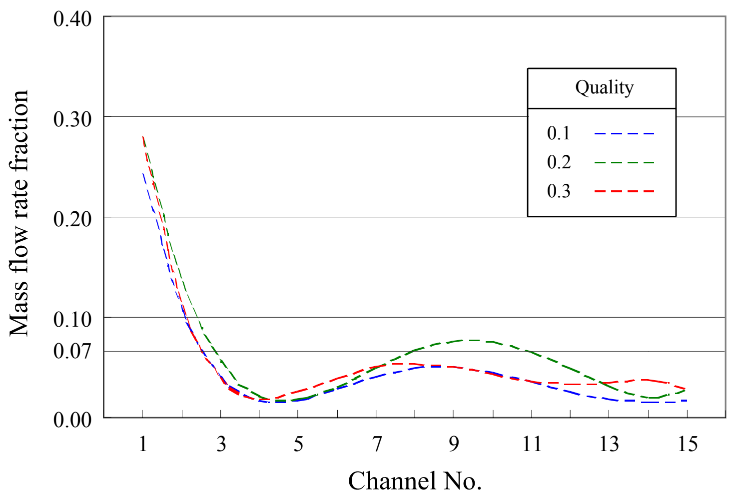


Figure 5. Mass flow rate fraction under the parallel flow condition to the inlet header

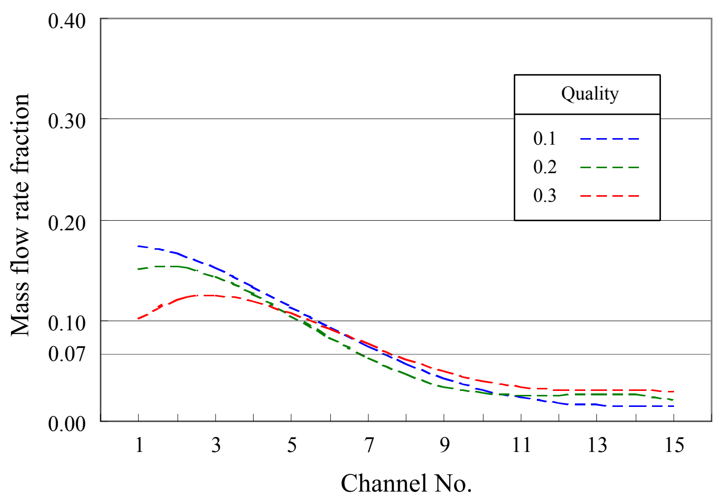


Figure 6. Mass flow rate fraction under the in-line flow condition to the inlet header

Figures 5 and 6 show the mass flow rate fraction for 15 micro-channel tubes under both the parallel and in-line flow conditions at the mass flux of 60kg/m^2·s. Mass flow rate fraction represents the ratio of mass flow rate in each micro-channel tube to total mass flow rate at the inlet header. Mass flow rate fraction was calculated by using the lease square curve obtained by using the experimental data. The average mass flow rate fraction for 15 micro-channel tubes was 0.07. Hence, if there is perfect flow distribution for all of micro-channel tubes, mass flow rate fraction is 0.07 for all of them. The standard deviation can be used to evaluate the degree of distribution. The standard deviation of mass flow rate from fraction for the parallel flow condition was ranged from 0.073 to 0.087, while that for the in-line flow condition was ranged from 0.032 to 0.050. It means that the in-line flow condition has better flow distribution characteristics than the parallel flow condition. Mass flow rate fraction in channel number 1 under both parallel and in-line flow conditions showed the highest value. Parallel flow condition showed the second highest mass flow rate fraction near the refrigerant inlet position. Mass flow rate fraction in Figures 5 and 6 varied similarly with the liquid mass fraction in Figures 3 and 4 since the density of liquid is much larger than the density of vapor. The effect of the inlet quality on the flow mal-distribution was not big except near the refrigerant inlet under the parallel flow condition and the first few channels under the parallel flow in-line flow condition.

Phase separation in micro-channel tubes

Phase separation of two-phase flow into micro-channel tubes through the header is shown in Figures 7 and 8 under parallel flow and in-line flow conditions, respectively. Phase separation ratio, x_n/x_{in}, represents the ratio of the quality in each micro-channel tube to inlet quality at the header. The subscript n of x_n represents the channel number, while the subscript in of x_{in} represents the inlet of the header. Phase separation ratio was estimated by using the least square equation curve for liquid and vapor mass fraction as shown in Figures 3 and 4. The phase separation ratio of one means that micro-channel tube has the same quality with the inlet quality. The phase separation ratio of one was observed for the micro-channel tubes from 4 to 10 under the parallel flow condition, while they were observed for channel number 7 under inlet flow condition. It means that the parallel flow condition showed wider region of equal quality in the micro-channel tubes than the in-line flow condition. The standard deviations of the phase separation ratio were ranged from 0.775 to 3.055 under the parallel flow condition, while they were ranged from 0.635 to 2.235 under the in-line flow condition. Thus, the overall phase separations under the in-line flow condition showed better characteristics than those under the parallel flow condition. As the inlet quality increased, the phase separation ratio differences for 15 micro-channel tubes were reduced.

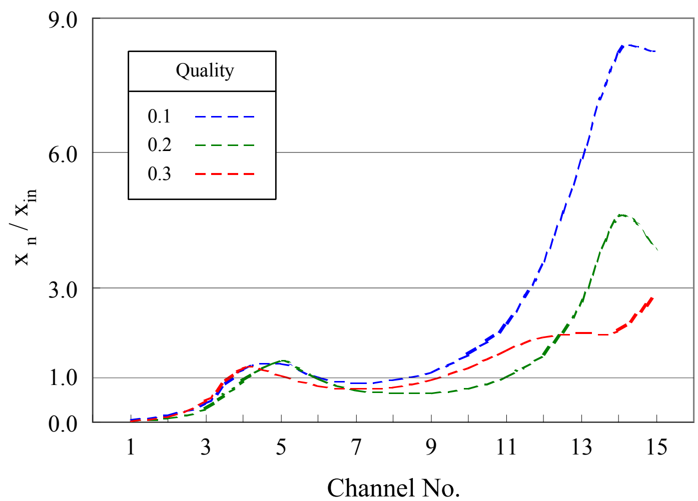


Figure 7. Phase separation ratio under the parallel flow condition to the inlet header

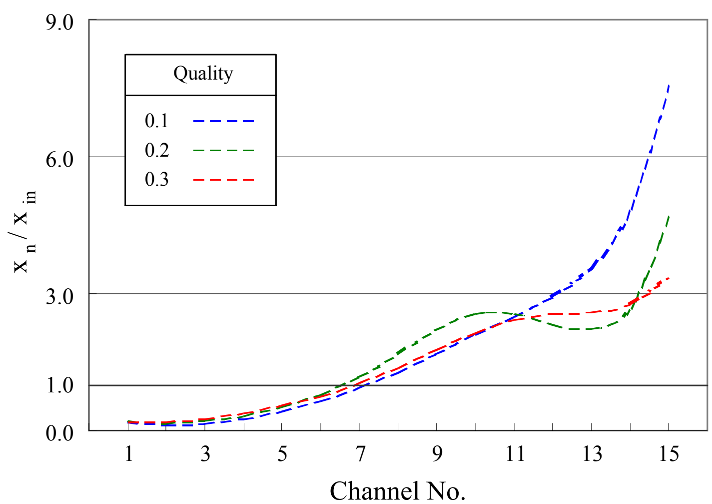


Figure 8. Phase separation ratio under the in-line flow condition to the inlet header

CONCLUSIONS

1. Flow mal-distribution for 15 micro-channel tubes got improved by changing the flow direction to the inlet header from parallel to in-line flow condition.
2. Mass flow rate fraction showed the maximum at channel number 1 under both parallel and in-line flow conditions.
3. The inlet quality didn't affect much on the flow distribution under the parallel and in-line flow conditions.
4. Phase separations under the in-line flow condition differed less than those under the parallel flow condition.
5. The difference of phase separation ratios for 15 micro-channel tubes decreased as the inlet quality increased.

ACKNOWLEDGEMENTS

This work was supported by SFARC project (Number 20010410-500) funded by Samsung Electronics and Brain Korea 21 project(2001).

REFERENCES

[1] Bae, T. S. and Han, C. S., 1996, A feasibility study on room air conditioner with parallel flow condenser, Proceedings of Summer Annual Meeting of SAREK, pp. 402-407.

[2] Shoham, O., Brill, J. P., and Taitel, Y., 1987, Two-phase flow splitting in a tee junction- Experiment and modelling, Chemical Engineering Science, Vol. 42, No. 11, pp. 2667-2676.

[3] Hwang, S. T., Soliman, H. M., and Lahey Jr., R. T., 1988, Phase separation in dividing two-phase flows, Int. J. Multiphase Flow, Vol. 14, No. 4, pp. 439-458.

[4] Ballyk, J. D., Shoukri, M., and Chan, A. M. C., 1988, Steam-water annular flow in a horizontal dividing T-junction, Int. J. Multiphase Flow, Vol. 14, No. 3, pp. 265-285.

[5] Seeger, W., Reiman, J., and Muller, U., 1986, Two-phase flow in a T-junction with a horizontal inlet Part 1: Phase separation, Int. J. Multiphase Flow, Vol. 12, No. 4, pp. 575-585.

[6] Reiman, J. and Seeger, W., 1986, Two-phase flow in a T-junction with a horizontal inlet Part 2: Pressure Differences, Int. J. Multiphase Flow, Vol. 12, No. 4, pp. 587-608.

[7] Park, J. H., Cho, K., and Cho, H. G., 1999, Characteristics of two-phase flow distribution and pressure drop in a horizontal T-type evaporator tube, Korean Journal of Air-Conditioning and Refrigeration Engineering, Vol. 11, No. 5, pp. 658-668.

[8] Asoh, M., Hirao, Y., Aoki, Y., Watanabe, Y., and Fukano, T., 1991, Phase separation of refrigerant two-phase mixture flowing downward into three thin branches from a horizontal header pipe, Proceedings of ASME/JSME Thermal Engineering Conference: Vol. 2, pp. 159-164.

[9] Kariyasaki, A., Nagashima, T., Fukano, T., and Ousaka, A., 1995, Flow separation characteristics of horizontal two-phase air-water flow into successive horizontal capillary tubes through T-junction, Proceedings of ASME/JSME Thermal Engineering Conference: Vol. 2, pp. 75-82.

[10] Watanabe, M., Katsuta, M., and Nagata, K., 1995, Two-phase flow distribution in multi-pass tube modeling serpentine type evaporator, Proceedings of ASME/JSME Thermal Engineering Conference: Vol. 2, pp. 35-42.

[11] Rong, X., Kawaji, M., and Burgers, J. G., 1995, Two-phase flow distribution in a stacked plate heat exchanger, Gas Liquid Flows, FED-Vol. 225, pp. 115-122.

[12] Fei, P., Cantrak, Dj., and Hrnjak, P., 2002, Refrigerant distribution in the inlet header of plate evaporators, SAE Technical Paper Series. Document No. 2002-01-0948.

[13] Oh, S. J. and Lee, K. S., 2001, Optimal shape of header part in a parallel-flow heat exchanger, Korean Journal of Air-Conditioning and Refrigeration Engineering, Vol. 13, No. 10, pp. 1017-1024.

[14] Beaver, A., Hrnjak, P., Yin, J., and Bullard, C., 2000, Effects of distribution in headers of microchannel evaporators on transcritical CO2 heat pump performance, Proceedings of the ASME Advanced Energy Systems Division, Orlando, FL, pp. 55-64.