

2008

Condensation Heat Transfer Coefficients of HFC245fa on a Horizontal Plain Tube

Cheolhee Lee
Inha University

KiJung Park
Inha University

Dongsoo Jung
Inha University

Jongseong Kim
Finetec Century Corp.

Follow this and additional works at: <http://docs.lib.purdue.edu/iracc>

Lee, Cheolhee; Park, KiJung; Jung, Dongsoo; and Kim, Jongseong, "Condensation Heat Transfer Coefficients of HFC245fa on a Horizontal Plain Tube" (2008). *International Refrigeration and Air Conditioning Conference*. Paper 905.
<http://docs.lib.purdue.edu/iracc/905>

This document has been made available through Purdue e-Pubs, a service of the Purdue University Libraries. Please contact epubs@purdue.edu for additional information.

Complete proceedings may be acquired in print and on CD-ROM directly from the Ray W. Herrick Laboratories at <https://engineering.purdue.edu/Herrick/Events/orderlit.html>

Condensation Heat Transfer Coefficients of HFC245fa on a Horizontal Plain Tube

Cheol-Hee Lee¹, Ki-Jung Park¹, Dongsoo Jung^{1*}, Jong-Seong Kim²

¹Department of Mechanical Engineering, Inha University,
Incheon, 402-751, Korea
(Tel.: 82-32-860-7320, Fax: 82-32-868-1716, E-mail: dsjung@inha.ac.kr)

²Finetec Century Corp., Tangjung-myun, Asan-shi,
Chungnam, Korea

ABSTRACT

In this study, condensation heat transfer coefficients (HTCs) of HCFC22, HCFC123, HFC134a and HFC245fa are measured on a horizontal plain tube 19.0 mm outside diameter. All data are taken at the vapor temperature of 39°C with a wall subcooling temperature 3-8°C. Test results show the HTCs of newly developed alternative low vapor pressure refrigerant, HFC245fa, on a smooth tube are 9.5% higher than those of HCFC123 while they are 3.3% and 5.6% lower than those of HFC134a and HCFC22 respectively. Nusselt's prediction equation for a smooth tube underpredicts the measured data by 13.7% for all refrigerants while a modified equation yielded 5.9% deviation against all measured data. From the view point of environmental safety and condensation heat transfer, HFC245fa is a long term good candidate to replace HCFC123 used in centrifugal chillers.

1. INTRODUCTION

Chlorofluorocarbon (CFCs) have been used as working fluids for residential and commercial refrigeration and air-conditioning equipment for more than 50 years since their introduction in 1930s. These useful fluids, however, have been regulated and eventually phased out since Molina and Rowland (1974) discovered that chlorine atoms in CFCs destroy the stratospheric ozone layer in 1974. In 1997, Kyoto protocol was proposed to reduce the green house warming, which calls for the energy efficiency improvement in all energy conversion devices including refrigeration equipment (GEER, 1997). In order to comply with the global environmental issues effectively, conventional refrigerants have to be changed to environmentally safe ones. At the same time, the performance of heat exchangers in refrigeration and air-conditioning equipment has to be improved to reduce the indirect green house warming caused by the use of electricity generated mainly by the combustion of fossil fuels. In fact, for most of the refrigerating equipment, the indirect warming effect is more than 95% of the total warming. To increase the heat exchanger performance, research has to be carried out with new alternative refrigerants (Marto and Nunn, 1981; Bergles, 1985).

As the living standard gets escalated in many countries, people demand more comfortable indoor environment and thus central air-conditioning has become essential component in modern society. For this application, centrifugal chillers are employed in most of the large commercial buildings.

In the past, CFC11 was used predominantly in centrifugal chillers. After the advent of the Montreal protocol in 1987, HCFC123 and HFC134a have been used in newly manufactured chillers replacing CFC11. It is known that HCFC123 is energy efficient and has a similar low operating pressure to the conventional CFC11. Since HCFC123 still contains ozone depleting chlorine, however, it must be replaced by some alternative refrigerants for the protection of the stratospheric ozone layer. On the other hand, HFC134a has a much higher operating pressure and hence the chiller system can be made compact. The entire system, however, has to be redesigned due to a significant change in vapor pressure. At the same time, HFC134a is classified as one of the greenhouse gases by Kyoto protocol of 1997. It is also known that inherently thermodynamic efficiency of HFC134a is lower than those of CFC11 and

HCFC123. Due to these reasons, it is necessary to develop environmentally friendly chillers with low vapor pressure refrigerant of low global warming and no ozone depletion.

Under this situation, Honeywell company introduced HFC245fa to replace HCFC123 and HFC134a in centrifugal chillers. HFC245fa has no ozone depletion potential and its global warming potential and atmospheric life time are 30% and 50% lower than those of HFC134a respectively (Calm and Hourahan, 2001). Because of these good environmental properties, Ebara company in Japan has developed commercial chillers with HFC245a for the past few years and is marketing them in Japan (Furuta, 2006). Also some chiller manufacturers in US have undertaken similar research and development activities to utilize HFC245fa in their new chillers.

For the past decade, some research activities to use HFC245fa in refrigeration and air-conditioning system have been undertaken. Thermal stability tests were performed by Angelino and Invernizzi, 2003 in an attempt to use HFC245fa to replace CFC11 and HCFC123 in low pressure centrifugal chillers.

In the development of new chillers, external condensation heat transfer coefficients (HTCs) are necessary. Most of the condensation heat transfer studies, however, were confined to such fluids as water, n-pentane n-butane, CFCs, HCFCs, and HFCs (Nguyen and Orozco, 1994; Cheng and Tao, 1994; Yilbas and Altuntop, 1990). Recently, Jung *et al.* (1999) and Hwang *et al.* (1999) measured the external condensation HTCs of CFC11, CFC12, and HCFC22 and their alternatives. Also Jung *et al.* (2004; 2005) measured the external condensation HTCs of flammable refrigerants of R1270, R290, R600a, R600, RE170, R32 and their mixtures.

As revealed in the literature survey, there have been no heat transfer data of HFC245fa available in the public domain. In this study, external condensation HTCs of HFC245fa, HCFC22, HCFC123, and HFC134a are measured to provide basic condensation heat transfer data to chiller industry for efficient design of environmentally friendly centrifugal chillers.

2. EXPERIMENTS

2.1 Overall description of experimental apparatus

Figure 1 shows the schematic diagram of the experimental apparatus. The facility is composed of the refrigerant and cooling water loops. The refrigerant vapor supplied to the test section was generated by the immersion heater of 3.5kW in the boiler that was located at the bottom of the apparatus. The vapor generated was fed to the main test section through a connecting pipe and condensed via counter-current heat exchange with the cooling water flowing inside a test tube. The condensate as well as the uncondensed vapor went into a large capacity auxiliary condenser and were cooled there and finally returned to the bottom of the boiler. The cooling water for the test section and for the auxiliary condenser was supplied by two independent external chillers that were capable of controlling the temperature with an accuracy of 0.1 °C as shown in Figure 1.

The main test section was made of a 80mm id stainless steel pipe with a 110mm long sight glass installed in the middle to observe the condensation phenomenon. Both ends of the test section were flanged for easy mounting of the test tube. When the cooling water flows inside the test tube and absorbs heat from the vapor, heat may flow from the water to the flanges at both ends of the test section where they touch the test tube. To prevent this from happening, at both ends of the test section nylon bushings of low thermal conductivity (Monomer cast nylon, 20mm×1.5mm) were tightly fastened on the tube so that heat transfer may occur only on the test tube.

As shown in Figure 2, a copper tube of 15.9 mm od and 2.0 mm thick was prepared with 0.64mm wide slits located 90° apart at the top, side, and bottom of the tube. These slits were prepared by a milling cutter on the tube in a longitudinal direction from one end to the other. Then, this plain tube was tightly inserted into the test tube with stainless steel wires of 0.6mm diameter placed into the slits across the entire length of the tube. And then, these two tubes were silver soldered together and the wires were pulled out at the final stage. Through this procedure, slits accommodating 0.5mm TCs could be made at locations roughly 1.0 mm beneath the surface as illustrated in Figure 2. If the tubes were not well soldered together, then the temperatures would vary quite significantly in the longitudinal direction resulting in erroneous data. Hence, a consistent way of joining the two tubes was tried many times and thus soldered tubes were cut into many sections to make sure that the silver solder flowed well into every

space in between the tubes. Finally, the best tubes showing good repeatability were selected for the tests. With this procedure, any commercial tube with a smooth inner surface can be tested without altering the surface condition.

2.2 Data reduction

A local condensation HTC was determined by the following equation.

$$h = \frac{Q/A}{(T_{sat} - T_{wall})} \quad (1)$$

where h , Q , A , T_{sat} , T_{wall} are the HTC ($\text{W}/\text{m}^2\cdot\text{K}$), heat transfer rate (W), area (m^2), vapor and surface temperatures ($^{\circ}\text{C}$) respectively. For the plain tube tested, the nominal area based on the outside diameter was used as the area in Equation (1).

Since there would be a temperature drop from the actual surface to the wall thermocouple locations, a 1-D steady-state conduction equation, Equation (2), was applied to determine its magnitude.

$$T_{wall} = T_i + \frac{Q}{2\pi L} \left[\frac{\ln(r/r_i)}{k_{tube}} \right] \quad (2)$$

where T_{wall} , T_i , L , r , r_i , k_{tube} are the actual surface temperature ($^{\circ}\text{C}$), measured temperature by a wall thermocouple ($^{\circ}\text{C}$), length of the tube (m), radius of the tube (m), the distance from the center of the tube to the thermocouple (m), thermal conductivity of the tube ($\text{W}/\text{m}\cdot\text{K}$) respectively.

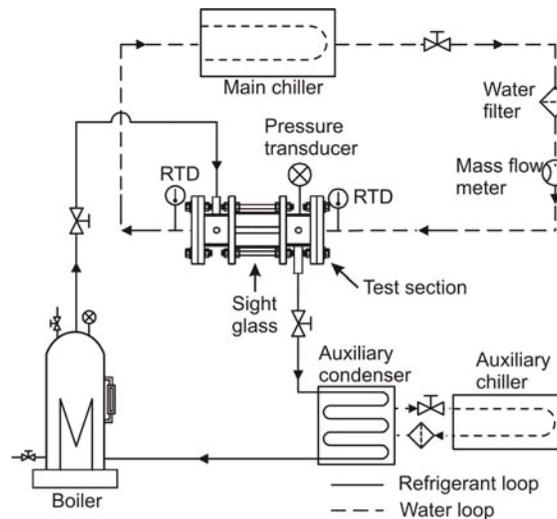


Figure 1: Schematic diagram of the condensation heat transfer experimental apparatus

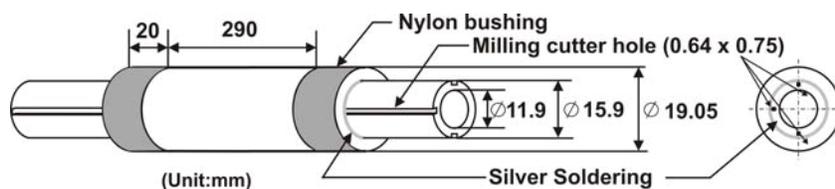


Figure 2: Detailed description of test tube

Table 1: Saturation properties of tested refrigerants at 39°C

Refrigerant	P_{sat} (kPa)	ρ_f (kg/m ³)	ρ_g (kg/m ³)	C_{pf} (kJ/kg·K)	h_{fg} (kJ/kg)	k_f (W/m·K)	μ_f (μ Pa·s)
HCFC22	1497	1133	64.5	1.332	167.76	0.077	140.3
HCFC123	149	1427	9.3	1.037	165.39	0.073	356.3
HFC134a	990	1151	48.7	1.493	164.07	0.075	163.5
HFC245fa	242	1300	13.7	1.355	181.78	0.084	342.0

Since the plain tube was made of copper, the temperature compensation term, $(T_{wall} - T_t)$, in Equation (2) was very small, typically less than 0.1°C. Therefore, this term did not have any significant effect on the HTC and the measured wall temperatures were used directly in the calculation of HTCs.

The measurement uncertainties were estimated by the method suggested by Kline and McClintock (1953). In general, the measurement uncertainties increased as the wall subcooling decreased. The uncertainties were estimated to be 1.8-5.5% for the wall subcooling range applied in this study.

3. RESULTS AND DISCUSSION

In this study, external condensation HTCs of four refrigerants of HCFC22, HCFC123, HFC134a and HFC245fa were measured at the vapor temperature of 39°C on a horizontal plain tube of 19.0 mm outside diameter with the wall subcooling of 3-8 °C. Table 1 lists some relevant thermophysical properties of these refrigerants at 39°C, which were obtained by NIST REFPROP program (2007).

3.1 Experiment with horizontal plain tube

First of all, experiments with HCFC22 and HFC134a were carried out to check the reliability of the test method and facility. Figure 3 shows comparison between the present data and the data for HCFC22 and HFC134a taken by Yoo *et al.* (2005). Average deviations between Yoo *et al.* (2005)'s and present data for HCFC22 and HFC134a are 3% and 6% respectively. From this result, the reliability of the present experimental work is indirectly confirmed.

Figure 4 shows the external condensation HTCs of HCFC 22, HCFC123, HFC134a and HFC245fa. For all refrigerants, the external condensation HTCs increased as the vapor pressure increased at the same temperature. Also the external condensation HTCs decreased as the wall subcooling increased. This is a typical trend observed in horizontal condensation heat transfer due to the increase in film thickness with an increase in wall subcooling.

Condensation HTCs of HFC245fa are 9.5% higher than those of HCFC123 while they are 3.3% and 5.6% lower than those of HFC134a and HCFC22 respectively. As seen in Nusselt's correlation (1916), Equation (3), external condensation HTCs are proportional to the heat of condensation and liquid thermal conductivity and they are indirectly proportional to the liquid viscosity.

$$h_{Nusselt} = 0.725 \left[\frac{\rho_f (\rho_f - \rho_g) g k_f^3 h_{fg}}{\mu_f \Delta T D} \right]^{1/4} \quad (3)$$

As can be seen in Table 1, heat of condensation and liquid thermal conductivity of HFC245fa are 10% and 15% higher than those of HCFC123 while the liquid viscosity of HFC245fa is 4% lower than that of HCFC123. Accordingly, one can expect that condensation HTCs of HFC245fa would be higher than those of HCFC123 from the consideration of thermophysical properties alone. As for HCFC22 and HFC134a, their viscosities are half the viscosity of HFC245a with 10% decrease in heat of condensation. Thus, one can expect that condensation HTCs of HCFC22 and HFC134a would be higher than those of HFC245a and Figure 4 reflects this trend. From the view point of condensation heat transfer, even though HCFC123 and HFC134a are presently used in centrifugal chillers, more environmentally friendly refrigerant of HFC245fa may replace them successfully without a significant change in condenser size.

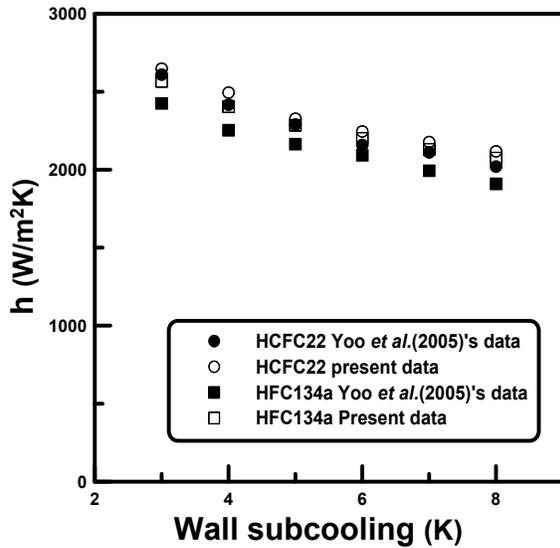


Figure 3: Comparison of HCFC22 and HFC134a with Yoo *et al.* (2005)'s data

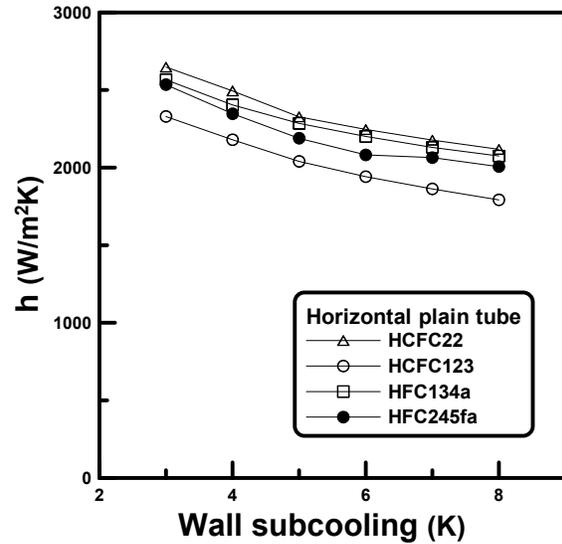


Figure 4: Condensation HTCs as a function wall subcooling on a plain tube

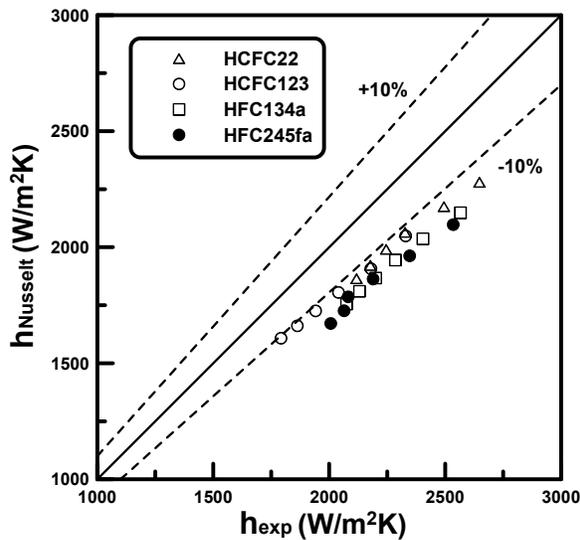


Figure 5: Comparison of the present data with Nusselt's equation

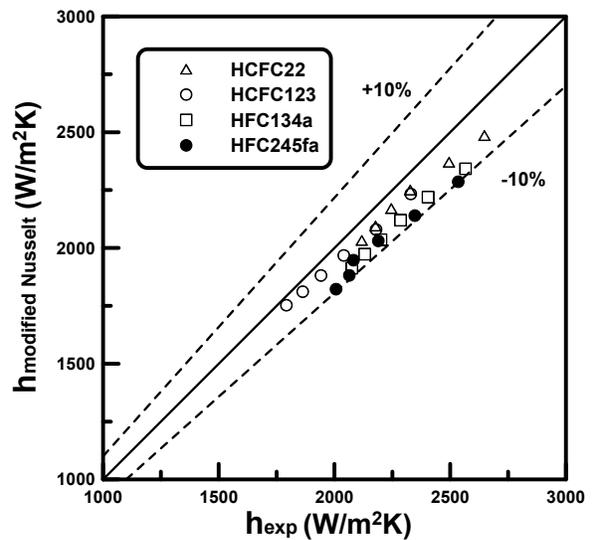


Figure 6: Comparison of the present data with a modified Nusselt's equation

3.2 Comparison with correlations

Figure 5 shows the comparison between the measure data and prediction correlation by Nusselt (1916), Equation (3), for HCFC22, HCFC123, HFC134a and HFC245fa. As seen in Figure 5, the correlation underpredicted the measured data for HCFC22, HCFC123, HFC134a and HFC245fa by 12.2%, 11.4%, 15.3% and 16.0% respectively. Nusselt's correlation was derived based upon an assumption that condensation film is laminar (Collier and Thome, 1994). But in reality, the condensation film formed on the outer tube surface is usually wavy and turbulent. Thus, it is normal that measured HTCs are 10-15% higher than those of the prediction as also seen in Kim *et al.* (1995), Wanniarachchi *et al.* (1986), and Marto *et al.* (1990).

In our laboratory, external condensation HTC's of more than 15 refrigerants have been measured consistently for the past 15 years. In fact, Jung *et al.* (2004) measured condensation HTC's of CFCs, HCFCs, HFCs, and hydrocarbons which can be used in refrigeration and air-conditioning equipment as a pure fluid or as one of the components of mixed refrigerants. Based upon the measured data, Jung *et al.* (2004) increased the constant in Nusselt's correlation by 9.0% to account for the turbulent flow and suggested the following correlation for design engineers.

$$h_{\text{modified Nusselt}} = 0.79 \left[\frac{\rho_f (\rho_f - \rho_g) g k_f^3 h_{fg}}{\mu_f \Delta T D} \right]^{1/4} \quad (4)$$

Figure 6 shows the comparison of the modified correlation and the measured data. The average deviation between the modified correlation and the measured data were less than 6.0% for all refrigerants including a new environmentally friendly refrigerant of HFC245fa.

4. CONCLUSIONS

In this study, external condensation heat transfer coefficients of HCFC22, HCFC123, HFC134a and a new alternative refrigerant of HFC245fa are measured on a horizontal smooth tube at 39°C with the wall subcooling of 3-8°C. From the experimental data, following conclusions can be drawn.

- For all refrigerants, external condensation HTC's increased as the vapor pressure increased at the same temperature. Also the external condensation HTC's decreased as the wall subcooling increased.
- The condensation HTC's of HFC245fa are 9.5% higher than those of HCFC123 while they are 3.3% and 5.6% lower than those of HFC134a and HCFC22 respectively.
- For all refrigerants, Nusselt's correlation underpredicted the measured data with an average deviation of 13.7%.
- From the view point of condensation heat transfer, HFC245fa is a good alternative low pressure refrigerant which may replace HCFC123 in centrifugal chillers.

NOMENCLATURE

A	heat transfer area	(m ²)	Subscripts
C	specific heat	(kJ/kg·K)	exp experimental
D	diameter	(m)	f saturated liquid
g	gravitational acceleration	(m/s ²)	g saturated vapor
h	heat transfer coefficient	(W/m ² ·K)	modified Nusselt
h _{fg}	heat of condensation	(kJ/kg)	modified Nusselt Eq.
k	thermal conductivity	(W/m·K)	Nusselt Nusselt
L	length	(m)	p constant pressure
P	pressure	(kPa)	sat saturated
Q	heat transfer rate	(W)	t thermocouple
r	radius	(m)	tube tube
T	temperature	(K)	wall wall
ΔT	wall subcooling	(K)	
ρ	density	(kg/m ³)	
μ	viscosity	(Pa·s)	

REFERENCES

- Bergles, A.E., 1985, Techniques to augment heat transfer, Handbook of heat transfer application, McGraw-Hill, New York, Ch. 3.
- Calm, J.M., Hourahan, G.C., 2001, Refrigerant data summary, *Engineered Systems*, vol. 18, no. 11: p. 74-88.
- Cheng, B., Tao, W.Q., 1994, Experimental study of R-152a film condensation on single horizontal smooth tube and enhanced tubes, *J. Heat Trans.*, vol. 116: p. 266-270.

- Collier, J.G., Thome, J.R., 1994, Convective boiling and condensation, 3rd ed., Clarendon Press, Oxford, 449 p.
- Furuta, T., 2006, Development of centrifugal refrigeration machine with R245fa, The International Symposium on New Refrigerants and Environmental Technology 2006, Session 7.
- Global Environmental Change Report, 1997, A brief analysis of the Kyoto protocol, vol. IX, no. 24.
- Hwang, S.M., Kim, K.K., Jung, D.S., Kim, C.B., 1999, Condensation heat transfer coefficients of R22 alternative refrigerants on enhanced tubes, *Transactions of the Korean Society of Mechanical Engineers B*, vol. 23, no. 4: p. 459-469.
- Jung, D.S., Kim, C.B., Cho, S.J., Song, K.H., 1999, Condensation heat transfer coefficients of enhanced tubes with alternative refrigerants for CFC11 and CFC12, *Int. J. Refrig.*, vol. 22: p. 548-557.
- Jung, D.S., Chae, S.N., Bae, D.S., Oho, S.J., 2004, Condensation heat transfer coefficients of flammable refrigerants, *Int. J. Refrig.*, vol. 27: p. 314-317.
- Jung, D.S., Chae, S.N., Bae, D.S., Yoo, G.S., 2005, Condensation heat transfer coefficients of binary HFC mixtures on low fin and Turbo-C tubes, *Int. J. Refrig.*, vol. 28: p. 212-217.
- Kim, N.H., Jung, I.K., Kim, K. H., 1995, An experimental study on condensation heat transfer of low-finned tubes, *Korean Journal of Air-Conditioning and Refrigeration Engineering*, vol. 7, no. 2: p. 298-309.
- Kline, S.J., McClintock, F.A., 1953, Describing uncertainties in single-sample experiments, *Mechanical Engineer*, vol. 75: p. 3-8.
- Lemmon, E.W., Huber, M.L., McLinden, M.O., 2007, NIST Reference Fluid Thermodynamics and Transport Properties, REFPROP version 8.0.
- Marto, P.J., Nunn, R.H., 1981, Power condenser heat transfer technology, Hemisphere Washington, pp. 287-372.
- Marto, P.J., Zebrowski, D., Wanniarachchi, A.S., Rose, J.W., 1990, An experimental study of R-113 film condensation on horizontal integral-fin tubes, *J. Heat Trans.*, vol. 112: p. 758-767.
- Molina, M.J., Rowland, F.S., 1974, Stratoapheric sink for chlorofluoromethanes : chlorine atom catalyzed destruction of ozone, *Nature*, vol. 249: p. 810-812
- Nguyen, T.N., Orozco, J.A., 1994, Condensation of R-113 on enhanced surfaces, *ASHRAE Transaction*, vol. 100, part 1: p. 736-743.
- Nusselt, W., 1916, Die oberflächenkondensation des wasserdampfes, *Z. Ver. Deut. Ing.*, Vol. 60: p. 541.
- United Nations Environmental Programme, 1987, Montreal protocol on substances that deplete the ozone layer, Final act, New York; United Nations.
- Wanniarachchi, A.S., Marto, P.J., Rose, J.W., 1986, Film condensation of steam on horizontal finned tubes: Effect of fin spacing, *J. Heat Trans.*, vol. 108: p. 960-966.
- Yilbas, B.S., Altuntop, N., 1990, Condensing heat transfer of freon-21 on plain horizontal tubes, *Indian Journal of Technology*, vol. 28: p. 100-106.
- Yoo, G.S., Hwang, J.H., Park, K.J., Jung, D.S., 2005, External condensation heat transfer coefficients of R22 alternative refrigerants and HFC134a according to the saturated vapor temperature change on a smooth tube, *Korean Journal of Air-Conditioning and Refrigeration Engineering*, vol. 17, no. 8: p. 729-735.

ACKNOWLEDGEMENT

This work was supported by Korean government's research funding for clean environment projects. Finetec Century Corp., main research carrier for this project, actually funded the project.

