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THE PERFORMANCE OF COMPACT POLYMER HEAT EXCHANGER USING SPECIALIZED TEST FACILITY

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ABSTRACT

An experimental study was performed to investigate the heat transfer rate of a compact polymer heat exchanger using a refrigerant supply facility as a freezer/refrigerator. This unit was developed to closely simulate an actual freezer/refrigerator, and can control the inlet quality and measure the outlet quality of the testing heat exchanger. The experimental result of the heat transfer rate on the compact polymer heat exchanger was compared to the original aluminum evaporator. The results showed the experimental data are similar to that of the original aluminum evaporator. The heat and mass transfer rate of the compact polymer exchanger was equivalent to that of an aluminum finned tube evaporator. Finally, a unit test was conducted on the domestic freezer/refrigerator. The evaporators of two types were used for testing, designed to have the same volumetric size with a baseline unit. Results of the cooling capacity tests are similar under on/off and continuous running conditions.

INTRODUCTION

Environmental concerns, cost competition and new energy standard levels require continuous improvement in both performance and low manufacturing costs in household refrigerator/freezers. Hence, it is very important to manufacture household refrigerator/freezers with high efficiency performance and acceptable cost. So, the continuous research and development in the refrigeration industry to reduce manufacturing costs, and meeting the required performance and efficiency has led to the development of new types of evaporators in household refrigerator/freezers. One of those results is the compact polymer heat exchanger [4,5,6,7,8]. This new type can supersede the older type of evaporator (typically aluminium fin-tube type) in terms of cost and efficiency. This Study deals with evaporators used in residential freezer/refrigerators. This paper presents the testing details of the compact polymer heat exchanger. The objective was to test and gather performance data on this compact polymer heat exchanger, which was done under different operating conditions using a test apparatus built for the purpose. This involved the development of a cycle simulator, to measure the performance of the evaporator, condenser and compressor as if they ran in a real household freezer/refrigerator cycle.

NOMENCLATURE

A	[m^2]	Heat transfer surface area
U	[W/m^2℃]	Overall heat transfer coefficient
T	[℃]	Temperature
Q	[W]	Heat transfer rate
RH	[%]	Relative humidity
DP	[Pa]	Pressure difference
ID	[mm]	Inner diameter
OD	[mm]	Outer diameter
L	[mm]	Length
H	[mm]	Height
D	[mm]	Depth

Special characters

$\mathcal{PH}$	[-]	Pre Heater
$\mathcal{SC}$	[-]	Sub Cooling unit
$\mathcal{AH}$	[-]	After Heater
$\mathcal{SU}$	[-]	Suction Unit
CG	[-]	PTFE with 25% carbon graphite

Subscripts

max	Maximum
i	inlet
o	outlet

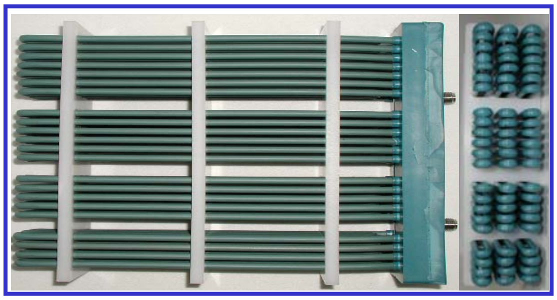
Most currently designed household refrigerators consist of a fresh food compartment and a freezer compartment. Generally, an indirect cooling type of refrigeration system with simple vapour compression cycle is employed. The nominal operating temperature of the fresh food and freezer compartment is 3℃ and -18℃, respectively. It is well known that the thickness of frost on the surface of the evaporator increases as time goes on.

So, we have to defrost periodically using a defrosting heater. From this, it can be stated that if the defrosting efficiency improved, then the power consumption rate may be decreased. Considering the above requirements, we also studied a defrosting system. However, in this paper, we do not deal with defrosting system. Rigorous experiments were performed on the test unit as follows: first, the baseline test was conducted with a 280*L* freezer/refrigerator. Second, the refrigeration cycle was modified to adopt the compact polymer heat exchanger as an evaporator. Finally, system matching and optimization tests were conducted.

COMPACT POLYMER HEAT EXCHANGER

The compact polymer heat exchanger is a new approach model to reduce the material cost and manufacturing cost. The heat exchanger for the evaporator of freezer/refrigerators is provided with a refrigerant tube for the flow of the refrigerant through there, cooling fins attached to the refrigerant tube for obtaining a wider heat transfer area, and a defrosting tube for removing frost on the refrigerant tube and the cooling fins. However, in the back ground art evaporator in a freezer/refrigerator, since the refrigerant tube and the cooling fin are connected as separate components, a cumbersome process for assembling them is required in fabricating the evaporator. Particularly difficult is the attachment of the cooling fins to the refrigerant tube, as the refrigerant tube should be inserted into the cooling fins, which are arranged at fixed intervals, and expanded for fixing the cooling fins thereto. Also, contact resistance between jointed parts of the refrigerant tube and the cooling fin drops heat conductivity, which causes a consequential drop of heat transfer efficiency. That is, the background art evaporator has, not only a complicated fabricating process, but also poor heat exchanging performance, thereby having low productivity and low quality as a product.

Figure 1 represents the shape of a compact polymer heat exchanger model. Figure 2 represents the shape of the original aluminium evaporator model. The geometric characteristics of the evaporators are given in table 1.



W275×H195(22-step)×D60(6-row)

Figure 1 Compact Polymer Heat Exchanger

W305×H180(6-step)×D60(2-row)

Figure 2 Original Aluminium Fin-tube Evaporator model

Type	**Fin-tube**	**Plastic**
Material	Al (1050)	PBT
Tube I.D/O.D (mm)	7.1 / 8.5	3.0 / 4.0
Tube Pass	Single Pass (1)	Multi Pass (6)
Volumetric size (LXhXD)	510×230×60	510×230×60
Heat transfer area in airside (%)	100	110
Heat transfer rate (%)	100	100

Table 1 Comparison of experimental result for heat transfer rate of two type evaporator

EXPERIMENTAL SETUP AND PROCEDURE FOR THERMAL PERFORMANCE OF EVAPORATOR

Figure 3 shows the schematic diagram of the experimental apparatus which is an open type, small-sized wind tunnel [1]. It consists of a suction fan, flow straightener, first reduction area, a test section, second reduction area, and exit chamber. The air flow rate and velocity are determined by using the measured pressure difference at the nozzle installed inside the exit chamber. The pressures at eight pressure taps are measured by a micro-manometer with a resolution of 0.1Pa and the average pressure difference is determined from these data. The air flow rate is calibrated by a pitot tube downstream of the nozzle and the deviation between these two data is within 0.3%. The air velocity of air passing through the test sector is varied from 0.2 to 1.0m/s using a fan connected to the power regulator. Static pressure is measured using six pressure taps, which are installed at the inlet and the outlet of the test section. The air flow rates are determined by using the measured pressure difference (0-117 mmH2O, uncertainty ±1.5%) at the nozzle (diameter 35mm) of the wind tunnel. The inlet air temperature is measured by using the thermopile consisted 26 type-T thermocouples, and the RTD installed at the inlet of the test section. The exit air temperature follows the thermopile consisted 20 type-T thermocouples and the RTD installed at the

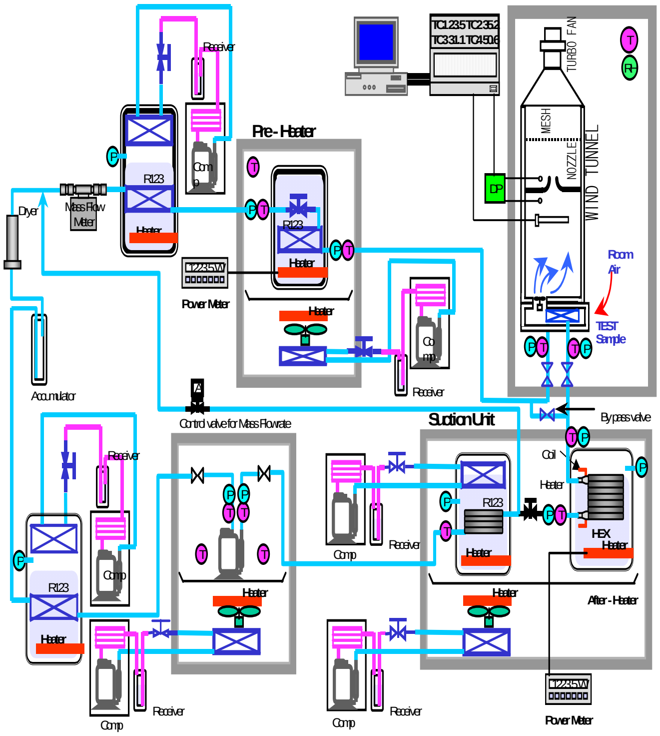


Figure 3 The schematic diagram of the refrigerant supply system

exit of the air mixer in the test section. The uncertainty of the thermopile and RTD on the inlet and exit temperature is, respectively, ±0.02℃ and ±0.05℃ [9]. To control the inlet refrigerant temperature under the same conditions as the actual product, the refrigerant supply system is connected with inlet/outlet pipe line of test sample in a wind tunnel. Styrofoam of 40mm-thickness is used to minimize the heat loss. Figure 3 shows the schematic diagram of the refrigerant supply system, which can measure heat transfer performance in refrigerant side. This system was established to measure the performance of the evaporator, condenser and compressor as if they ran in a real household refrigerator/freezer cycle. The initial condition can be controlled using an after-electric heater and a pre-electric heater. In the case of two phase range, we can't set a value for our initial condition. So, in this case, we can move the measuring point from two phase zone to one phase zone by using an electric heater.

The energy transferred from the air stream across the evaporator and the heat transfer rate can be calculated from the air mass flow rate and temperature. Also, the heat transfer rate in refrigerant side can be calculated from the enthalpy difference across the devices. The electrical energy input into the circuit, used by both pre-heater and after-heater, is also known. The steady state is generally obtained in 2 hours, and the test is repeated with increasing or decreasing velocity to identify the reproducibility. As time passed, the frost formation was noticed. So, we'd like to measure the heat transfer performance according to the amount of frost. The overall heat transfer coefficient is obtained as follows.

$$Q = U \times A \times \Delta T \qquad (1)$$

ΔT represents the logarithmic mean temperature difference.

EXPERIMENTAL SETUP AND PROCEDURE FOR UNIT TEST

A unit test was conducted on the original domestic freezer/refrigerator. The main purpose of the baseline test was to eventually compare the pull down cooling capacity level of the unit to the modified system using the compact polymer heat exchanger. The 280 ℓ, automatic defrost, bottom-mounted domestic freezer/refrigerator unit was adopted. The unit was equipped with a reciprocating compressor. The condenser was a forced-convection cross-flow heat exchanger and had a 10W fan. A suction line heat exchanger, with both capillary tubes soldered to the suction line, was also included. The evaporator was placed in the freezer compartment. The compressor and condenser were located under the cabinet. An electronic controller is used to control the operation of system components such as compressor and fan motor. The freezer air temperature and compressor operation was controlled by a thermistor, while the fresh food air temperature was controlled by thermistor and electronic damper installed in the fresh food compartment. The test unit was placed inside an environmental chamber maintained at 30℃ and the exact location was marked to ensure the consistency of the tests over the period of the experiment. In order to measure the energy consumption, the fresh food and freezer compartment temperatures were set to be nominal temperatures using the button placed in the control panel.

After the completion of our baseline test, the domestic freezer/refrigerator unit was modified using the compact polymer heat exchanger (hereafter denoted by Plastic Eva or PE). At first, the original fin-tube evaporator (hereafter denoted by FTE) was replaced with a Plastic Eva. The unit controller was the same as the previous one. A thermistor for measuring the fresh food compartment temperature is mounted on the rear side of the inner liner inside the fresh food compartment. A total of twenty thermocouple sensors were attached at locations along the tubes of the heat exchanger inlets and outlets to measure temperatures. Two pressure transducers were installed at the outlet of the condenser and the compressor suction line. A data acquisition system and Hybrid recorder were used to obtain the real time data. The cycle matching test was conducted. Next, the test to determine the optimum amount of refrigerant charge was performed by increasing the amount of refrigerant charge by 10g at one time. Finally, with the optimum refrigerant charge of 140g, the pull-down test and on-off running test were performed.

RESULTS AND DISCUSSION

The heat transfer rates of the evaporators were measured and compared. Evaporators of two types were used for testing, designed to have the same heat transfer performance as shown in Table 1. They were tested at various airflow rates and Figure 4 shows the heat transfer performance. The heat transfer performance of the plastic evaporator (compact polymer heat exchanger) is similar to that of the fin-tube evaporator. In this study, the frosting behavior characteristics of the thermally conductive plastic were investigated through a series of experiments on specimens of thermally conductive plastic based on PBT (Polybutylene Terephthalate), three types of plastics based on PTFE (Polytetrafluoroethylene), and aluminium.

Figure 5 shows the temporal growth of the frost thickness for each specimen. The frosting behaviors of the test specimens were similar except for the pure PTFE. The similarity in frosting behavior was due to the thickness of the test specimens (1.0mm) which made no difference in the thermal conductivity effects [2,3]. Among the specimens, the PBT recorded a surface temperature of almost the same as that of aluminium. Figure 6 shows the variation of the mass flux with time for each specimen. In the early stages of frost formation, the PTFE specimens with the highest initial surface temperature had the smallest mass flux, whereas both the PBT and aluminium specimens, which had the lowest initial temperature, had the largest mass fluxes. The mass flux of the PBT was similar to that of the aluminium specimen during the early stages of frost formation, but because of the relatively low density of the formed frost, the mass flux changed to values that were similar to the other PTFE composites as time increased. The rate of mass flux decrease for the pure PTFE specimen was less than that of the other specimens because the growth of frost density on the PTFE surface exceeded the increase in frost thickness.

This study investigated the pull-down cooling performance using a plastic evaporator compared to an original finned tube type evaporator as shown in Figure 7 and Table 2. The evaporators of two types were used for testing, designed to be volumetric the same size, as baseline models.

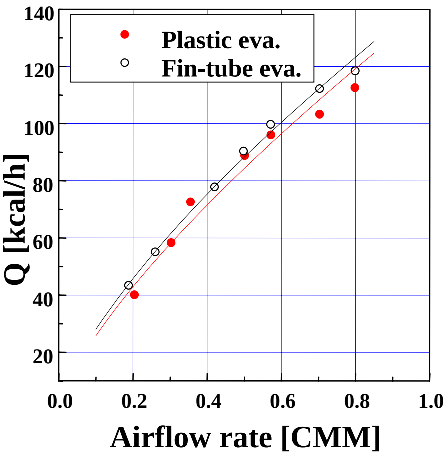


Figure 4 The variation of heat transfer rate with air flow rate on various evaporator model.

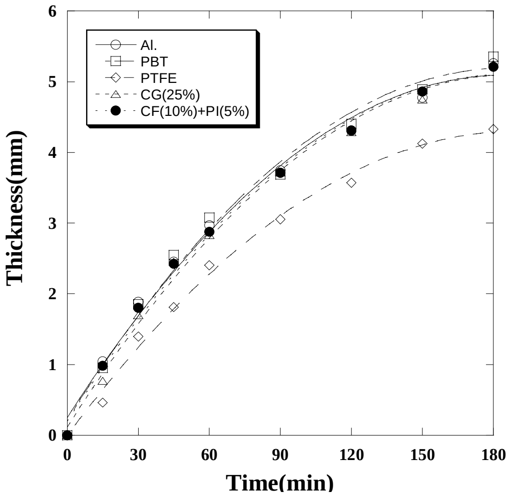


Figure 5 Temporal variations of the frost thickness for different test specimens.

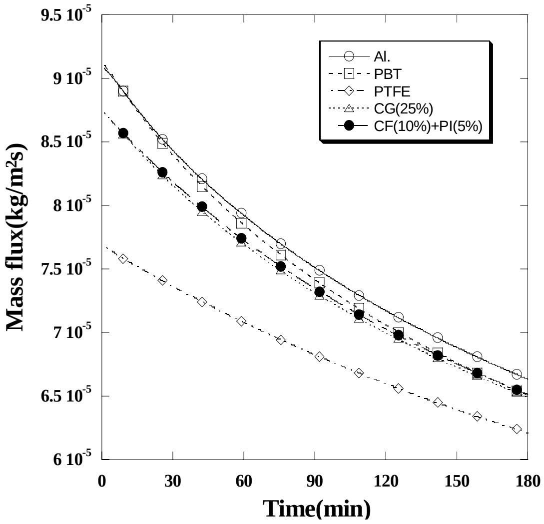


Figure 6 Temporal variations of the mass transfer for different test specimens.

Figure 7 Experimental setup for domestic freezer /refrigerator unit.

Results of the pull-down test and the on-off running test are similar as shown in table 2.

		Plastic	Fin-Tube
F 1/3 (℃)		-19.20	-20.4
R 1/3 (℃)		2.80	2.00
Running time / cycle	ON (min)	19.83	21.21
	OFF(min)	18.83	16.88
Running rate (%)		51.29	55.69
Cycle number / 1 hour		1.55	1.58

(a) On-off running test

	Plastic	Fin -Tube
Evaporator in (℃)	-36.75	-39.64
Evaporator out (℃)	-39.79	-39.87
F 1/3 (℃)	-31.35	-36.00
R 1/3 (℃)	-10.38	-10.71
Suction Pipe (℃)	32.93	29.04
Dryer in (℃)	33.27	33.10
Compressor Dome (℃)	56.15	57.98
Condenser Out (℃)	33.17	33.05

(b) Pull-down test

Table 2 Experimental results of both on/off running and Pull down condition

CONCLUSION

This study investigated the heat transfer performance of a compact polymer heat exchanger compared to an original aluminium fin-tube type evaporator. The following conclusions can be drawn from this experimental study.

1. The low temperature evaporator test facility was developed to closely simulate domestic freezer/refrigerator conditions.
2. The heat and mass transfer rate of the compact polymer heat exchanger was equivalent to that of the aluminium fin-tube evaporator.
3. We obtained a similar cooling capacity with a plastic evaporator as to that of the original aluminium fin-tube evaporator.

And finally, for the purpose of enhancing the heat transfer rate, we have to redesign the pass for solving the refrigerant flow mal distribution.

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