Purdue University
Purdue e-Pubs

International Refrigeration and Air Conditioning Conference | School of Mechanical Engineering

2000

A Study on New Tri-Tube Type Evaporators in Domestic Refrigerator/Freezer

J. S. Lee
LG Electronics Inc.

T. H. Lee
LG Electronics Inc.

S. H. Ham
LG Electronics Inc.

S. Y. Oh
LG Electronics Inc.

K. S. Cho
LG Electronics Inc.

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

Lee, J. S.; Lee, T. H.; Ham, S. H.; Oh, S. Y.; and Cho, K. S., "A Study on New Tri-Tube Type Evaporators in Domestic Refrigerator/Freezer" (2000). *International Refrigeration and Air Conditioning Conference.* Paper 462.
http://docs.lib.purdue.edu/iracc/462

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

A STUDY ON NEW TRI-TUBE TYPE EVAPORATORS IN DOMESTIC REFRIGERATOR/FREEZER

Jang-Seok Lee, Tae-Hee Lee, Seong-Hun Ham, Se-Yoon Oh, Kwan-Shik Cho
HVAC Team, Digital Appliance research laboratory
LG Electronics, Seoul, KOREA

ABSTRACT

This paper presents experimental results of the heat transfer performance of New Tri-tube type evaporators. The Tri-tube type Evaporator is devised to enhance the defrosting efficiency and basic performance of an indirect cooling household refrigerator/freezer. Designers and manufactures of heat exchangers have had to take into account enhanced energy efficiency and cost reduction for many years. The most striking breakthrough is that involving the use of simultaneous extruded fin and tube in order to eliminate thermal contact resistance between fin and tube. As a result, Lighter, more compact heat exchangers have been developed and have led to real gains in terms of cost-performance. In the present investigation, the 590L prototype unit is a modification of a conventional refrigerator/freezer. The cycle matching and performance test is performed at 30℃ ambient temperature. The energy consumption test reveals that compared to the conventional system, the energy consumption of the present refrigeration system is reduced by about 4 %. Moreover, the cooling speed test result shows that with the present refrigeration system, the refrigeration and freezing time become about 10 minute shorter than the conventional system. R-134a was used for this research.

1. INTRODUCTION

Environmental concerns, cost competition and new energy standard level require continuous improvement both performance and low manufacturing cost in household refrigerator/freezer. Hence it is very important to manufacture household refrigerator/freezer with high efficiency performance and acceptable cost. So, the continuous research and development in the refrigeration industry to reduce manufacturing costs and still meet required performance and efficiency has led to the development of New type Evaporators in household refrigerator/freezer. The one of those results is Tri-tube type evaporator. This design supersedes the older type of evaporator in terms of cost and efficiency and typical old type is fin and tube type. This Study deals with evaporator used in commercial household refrigerator/freezer where the flow velocities and geometrical parameters. This paper presents the design and testing details of tri-tube type evaporator. The objective was to test and gather performance data on this evaporator, which was done under different operating conditions using a test apparutus built for the purpose. This involved the development of cycle simulator, to measure the performance of evaporator, condenser and compressor as if it runs in real household refrigerator/freezer cycle.

Most of the currently designed household refrigerator consists of a fresh food compartment and a freezer compartment(hereafter denoted by RF). Generally, an indirect cooling type of refrigeration system with simple vapor compression cycle is employed to a RF. 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 evaporator is increased as time go. So, we have to defrost periodically using defrosting heater. From this, it can be stated that if the defrosting efficiency improve, the power consumtion rate may be decreased. Considering the above requirements, we also studied a defrosting system.

Steady state computer simulation technique was developed for fin and tube type and modified to design the Trituve Evaporator. Rigorous experiments were performed on the test unit as follows: first, the baseline test was conducted with a 590*L* RF unit. Second, the refrigeration cycle was modified to adopt the tri-tube evaporator. Finally, system matching and optimization test were conducted.

2. TRI-TUBE EVAPORATOR

The tri-tube evaporator is a new approach model to enhance the defrosting performance. The evaporator is provided with a refrigerant tube for flow of the refrigerant therethrough, 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. The defrosting tube of bent tube along the refrigerant tube is in contact with the cooling fin and provided with a heater, such as electric heating coil, therein. However, in the back ground art evaporator in a refrigerator, since the refrigerant tube, the cooling fin, and the defrosting tube are connected as separate components, a cumbersome process for assembling them is required in fabrication of the evaporator, particularly, in the attachedment of the cooling fins to the refrigerant tube, the refrigerant tube should be inserted into the cooling fins arranged at fixed intervals and expanded for fixing the cooling fins thereto. And, a contact resistance at jointed parts of the refrigerant tube and the cooling fin drops a heat conductivity, with a consequential drop of a heat transfer efficiency. Moreover, in defrosting, minute gaps and contact resistances between the defrosting tube and the cooling fins causes a heat exchange poor, droping a defrosting efficency[5]. That is, the background art evaporator has, not only a complicated fabricating process, but also poor heat exchange and defrosting efficiencies, thereby causing to have a low productivity and a low quality as a merchandise.
Fig. 1 represents the sectional shape of tri-tube model. Fig. 2 represents the assembly shape of tri-tube model. A defrosting tube disposed between the two refrigerant tubes and fin formed as a unit with, and connecting the refrigerant tubes and the defrosting tube. The geometric characteristics of the evaporators are given in table 1. The evaporator tubes have 8.0mm outside diameter for refrigerant, 6.35mm outer diameter for defrosting heater and 0.7mm wall thickness.

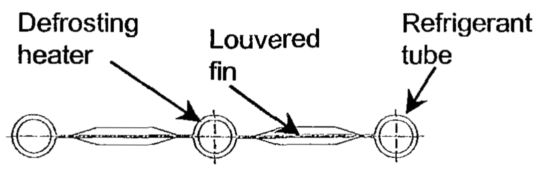

Figure 1. The shape of Tri-tube Sectional area

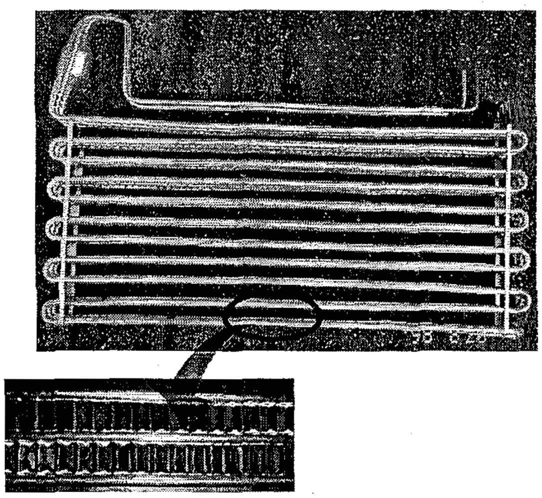

Figure 2. The shape of Tri-tube Evaporator

The refrigerant tubes, fin, and defrosting tube are bent to form a continuous 'S' which can be called serpentine type. Thus the evaporator of this model have no contact resistances, thereby improving a heat exchanger efficiency and a defrosting efficiency.

3. EXPERIMENT

Experimental setup and procedure for thermal performance of evaporators

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 resolution of 0.1Pa and the average pressure difference is determined from these data. The air flow rate is calibrated by a pitot tube at the downstream of 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. Pressure drop is measured using a differential pressure gage. Average air temperature of inlet and outlet section is measured using type T thermocouples installed at the same positions. To control the inlet refrigerant temperature with the same conditions as the actual product, the refrigerant supply system is connected with inlet/oulet pipe line of test sample in wind tunnel. Styrofoam of 40mm-thickness is used to minimize the heat loss.

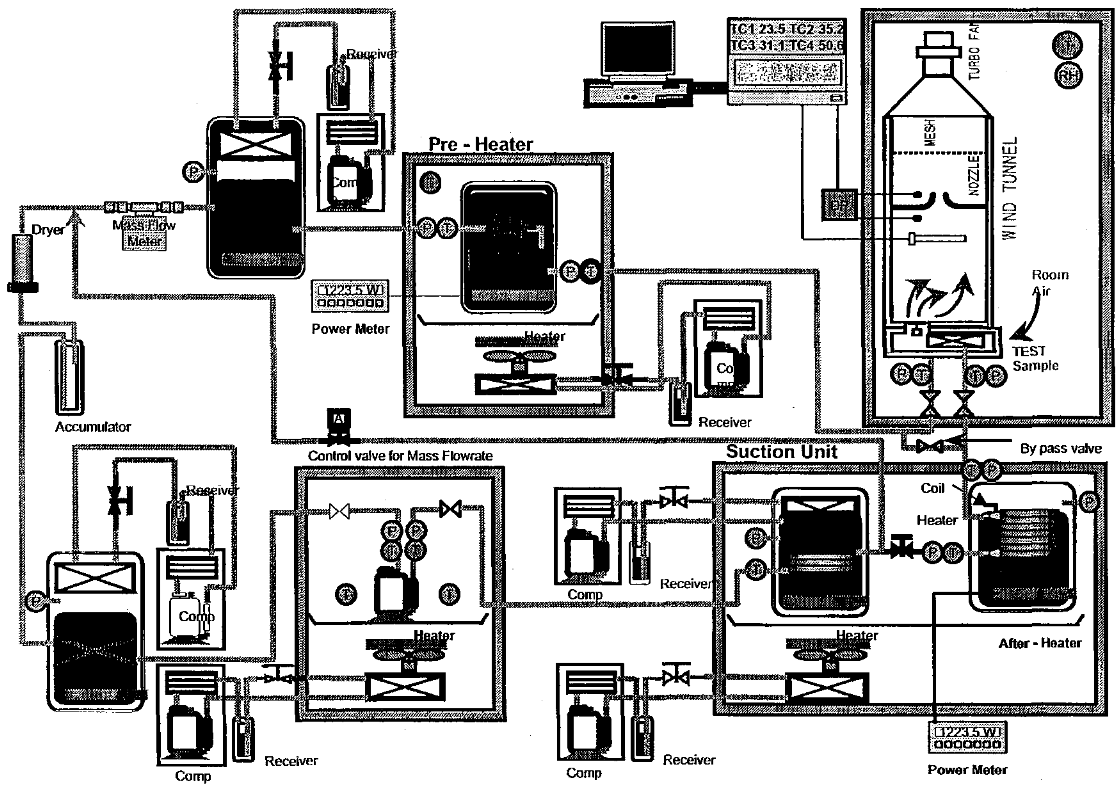

Fig 3. The schematic diagram of thc refrigerant supply syste

Figure 3 shows the schematic diagram of the refrigerant supply system, which can measure heat transfer performance in refrigerant side. It can make to measure the performance of evaporator, condenser and compressor as if it runs in real household refrigerator/freezer cycle. The initial condition can be controlled using after electric heater and pre electric heater. In case of two phase range, we can't set value for our initial condition. So, In case of this, we can move measuring point from two phase zone to one phase zone using electric heater. The energy transferred from the airstream across the evaporator and heat transfer rate can be calculated from the air mass flow rate and temperature. Also, 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. According 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 represent the logarithmic mean temperature difference. All the temperature measurements with the thermocouples are made with an uncertainty of $\pm$ 0.1℃.

Experimental setup and procedure for Baseline test

A baseline test was conducted to the original RF unit. The main purpose of the baseline test was to eventually compare the energy consumption level of the unit to the modified system using tri-tube evaporator. The 590L, automatic defrost, top-mounted RF unit was adopted (it is marketed for the domestic use in Korea in 1999). The unit was equipped with the reciprocating compressor(hereafter denoted by C-1). The condenser was forced-convection cross-flow heat exchanger and has 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 baseline unit was placed inside the environmental chamber maintained at 30℃ and the exact location was marked to ensure 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 on the freezer door.

Experimental setup and procedure for modified system test

After the completion of our baseline test, the RF unit was modified using tri-tube evaporator(hereafter denoted by Tri). At first, The original fin and tube evaporator(hereafter denoted by FTE) was replaced with Tri. The original unit controller was the same previous one. A thermistor to measure the fresh food compartment temperature is mounted on the rear side of inner liner inside the fresh food compartment . A total of twenty thermocouple sensors were attached at the 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 with the refrigerant charge of 150g to check the leakage and the state of the system operation. 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 this optimum refrigerant charge, the tests for the energy consumption, cooling speed, and compressor starting characteristic were performed.

4. RESULTS AND DISCUSSIOIN

The heat transfer rates of evaporators were measured and compared. Evaporators of two types were used for testing, designed same performance capacity, as shown in Table1. They were tested at various different airflow rates, as shown in table 2 and shows heat transfer performance at that test condition.

Figure 4 shows the heat transfer rate under frosting. In these case, the heat transferred from the air to the refrigerant flows in two mode, the first is sensible heat driven by the temperature difference between air and refrigerant and the second is latent heat caused by sublimation of water vapor included in the air stream[2~4]. Because of the growth of frost layer, the heat transfer rate is decresed smoothly with time for both FTE and Tri.

Figure 5 and Figure 6 show the test condition. The humidity and refrigerant mass flow rate were determined to be constant with respect to time after 2 or 3 hours. Photo 1 shows the defrosting process and this can be explained by figure 7. In case of same electric power of defrosting heater, defrosting mechanism is very fast about 40%.

Results of energy consumption tests are summarized in Table 2. It shows that the energy savings, accounting for the improvement of the defrosing efficiency, are 4% under unit running condition which is summarized in Table 3. In case of refrigeration speed test, the RF unit was first left off inside the environmental chamber at 30℃. Once it reached thermal equilibrium state at 30℃, then the unit turns on. For the fresh food and freezer compartment, the elapsed time was measured for the temperature to reach 10℃ and -5℃ respectively. The elapsed time of a modified system using Tri was the same as original one which is used FTE. Results of refrigeration speed test are summarized in Table 4.

5. CONCLUSIONS

This study investigated the heat transfer performance of tri-tube type evaporator comparing of finned 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 refrigerator-freezer conditions.
2. The overall heat transfer coefficient of tri-tube type evaporator is increased about 120% comparing of finned tube type evaporator.
3. The defrosting heater power of tri-tube type evaporator is decreased about 50% comparing of finned tube type evaporator.

It can make decresing energy consumption about 4% for domestic refrigerator-freezer

These are resulted in high heat transfer and offer the main advantage to the manufacturer

6. REFERENCES

1. Rae Jr., W.H. and Pope, A.,1984,Low speed wind tunnel testing, John Wiley & Sons, Inc. 2nd ed.
2. Lee,K.S, Kim,W.S and Lee,T.H.,1997, A One-Dimensional Model for Frost Formation on a cold flat surface, Int.J.Heat Mass Transfe, Vol.40, No.18,pp.4359-4365.
3. Ricard Romero-M?dez, Mihir Sen, K. T. Yang and Rodney L. McClain, 1997, Effect of tube-to-tube conduction on plate-fin and tube heat exchanger performance, *Int. J. of Heat and Mass Transfer*, Vol. 40, No. 16, pp. 3909-3916.
4. Sanders, C. T., 1974, *The Influence of Frost Formation and Defrosting on the Performance of Air Coolers*, Ph. D. Thesis, Delft Technical University.
5. Sheffield, J. W., Abu-Ebid M., and Sauer, H. J., 1987, *Finned tube contact conductance : Empirical Correlation of Thermal conductance*, ASHRAE Transactions, Vol. 91, part 2. pp. 100-117.

Table 1 Geometrical specification of the test evaporator

	FTE	Tri
Overall dimension L × h × D(mm)	*510*× 230× 60	*510*× 230× 60
Number of columns	*8*	*9*
Number of rows	*2*	*2*
Tube ID (mm)	*7.1*	*6.6*
Tube OD (mm)	*8.4*	*8.0*
Fin pitch	*10*	*Louver length 8mm*
Heat transfer area Ratio vs FTE	*1.0*	*0.45*

Table 2. Test Results from wind tunnel test

EVA.	$T_{a,i}$, ℃	$\dot{m}_a$, g/s	$T_{r,i}$, ℃	$x_{r,i}$, ℃	$\dot{m}_r$, kg/h	U, W/m² ℃
TRI	-20.3	7.2	-29.8	0.20	3.7	15.3
	-20.3	9.6	-29.8	0.20	3.7	17.1
	-20.3	12.0	-29.8	0.20	3.7	19.2
	-20.4	14.4	-29.9	0.20	3.8	20.6
FTE	-20.0	7.2	-30.0	0.20	3.8	7.1
	-20.3	10.0	-29.9	0.20	3.8	7.7
	-20.0	12.0	-30.0	0.20	3.7	8.7
	-20.3	14.4	-30.0	0.20	3.7	8.9

(Refrigerant : R-134a)

Table 3. Summary of the design results

	ORIGINAL (FTE)	MODIFIED (Tri)
Compressor	*C-1*	*C-1*
Evaporation temperature	*-27* ℃	*-27* ℃
Condensing temperature	*42* ℃	*42* ℃
Volume flow rate of air	*1CMM*	*1CMM*
%run time	*46.1%*	*46.1%*
Energy Consumption	*55.0kWh/month*	*51.0kWh/month*

Table 4. Test result of refrigeration speed

	ORIGINAL (FTE)	MODIFIED (Tri)
fresh food*(30 ℃ -> 10 ℃)*	*115min*	*112min*
freezer*(30 ℃ -> -5 ℃)*	*77min*	*76min*

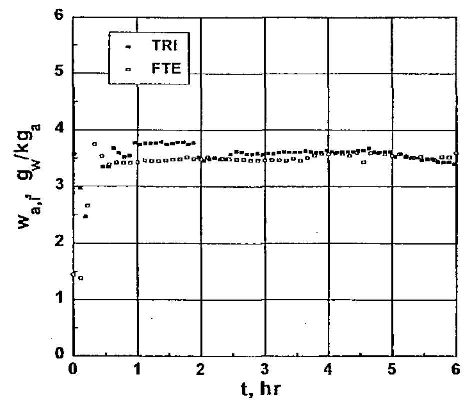

Fig.5 The Humidity condition

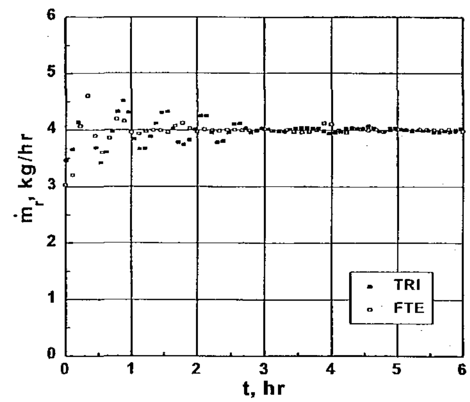

Fig.6 Refrigerant mass flow rate

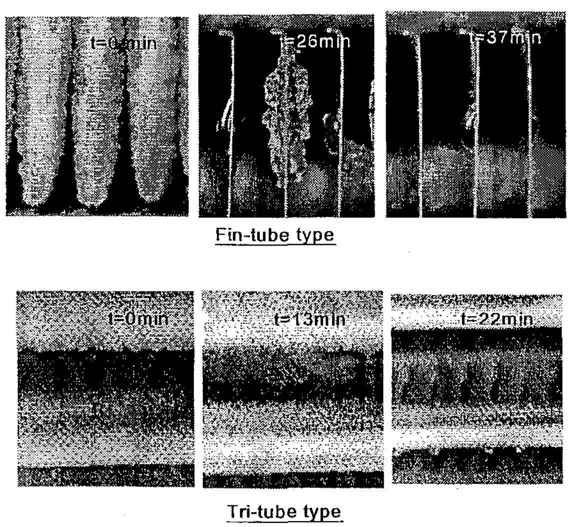

Photo 1 Defrosting Process with time

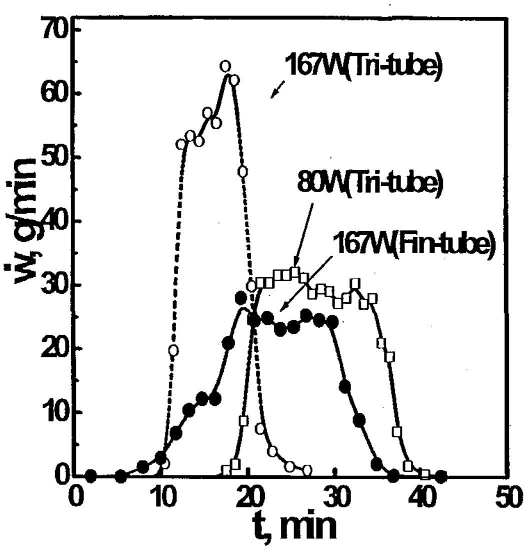

Fig.7 Defrosting process with time

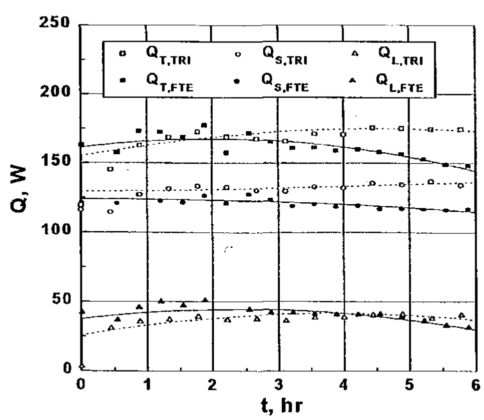

Fig.4 The heat transfer rate under frosting