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S. H. Kim
Korea University

Y. H. Sim
Kyungmin College

Y. Youn
Korea University

M. K. Min
Korea University

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An Experimental Study on Internal Temperature Distribution and Performance Characteristics in a Reciprocating Compressor for a Domestic Refrigerator

Sang-Ho Kim[1], Yun-Hee Sim[2], Young Youn[1], and Man-Ki Min[3]

[1]HVAV & R Laboratory, Graduate School of Korea University
[2]Department of Building Services & Control System, Kyungmin College
[3]Department of Mechanical Engineering, Korea University

ABSTRACT

The study on performance characteristic of domestic refrigerators is an important issue for energy saving because of its long running time and wide usage. In this study, experiment was conducted to analyze temperature distribution of a reciprocating compressor and performance of a refrigerator under actual operating condition. And effect of heat property inside compressor is implicated in performance of a refrigerator. The temperature distribution in the compressor and performance of the system were measured with temperature in a refrigerating compartment and a freezer, ambient temperature, and fan velocity during steady-state of the system of the refrigerator. Continuous running of the compressor causes temperature in refrigerating compartment to fall far from actual operating temperature. For running the system as actual operating temperature, an electric heater was installed in the freezer. And special temperature sensors were installed inside the compressor to obtain internal temperatures distribution. Ambient temperature and temperature in refrigerating compartment cause evaporating pressure of the system to vary. And it causes mass flow rate of refrigerant to vary. Also velocity of the fan outside compressor causes temperature of refrigerant inside the compressor to vary, and it causes superheat degree of refrigerant in compressor to vary. Therefore evaporating pressure of the system and superheat of suction refrigerant in compressor cause mass flow rate of refrigerant in the compressor to vary. It influences on refrigerating capacity of the system and volumetric efficiency of the compressor. As a conclusion, it is clear that the refrigerating capacity of a refrigerator varies evaporating pressure of the system and superheat of suction refrigerant in the compressor under actual operating condition.

INTRODUCTION

Recently, it has been studied that the substitute energies and the performance improvement of systems because of international needs of energy saving and protection of natural environment. Considering running time and wide usage of a domestic refrigerator, study on a refrigerator is an important issue. Performance of a refrigerator may be improved as cycle characteristics of a refrigerator and performance characteristics of a compressor are clearly understood. And the performance of a compressor may be improved as the characteristics of heat transfer in the compressor are clearly understood. For this reason it has been made much studies, but studies to define reciprocal relationship between performance characteristics of a refrigerator and thermodynamic characteristics of a compressor are rare.

Accordingly in this study, we intend to find out interrelationship of a refrigerator and thermodynamic characteristics of a compressor and performance characteristics with temperature of freezer, ambient temperature, and fan velocity.

BASIC THEORY

Coefficient of performance of a refrigerator, volumetric and isentropic efficiency of a compressor, and etc are expressed as

$$COP = \frac{\dot{Q}_{eva}}{P_{comp}} \quad \cdots(1)$$

$$\dot{Q}_{eva} = \dot{m}_{ref} \cdot (h_{eva,o} - h_{eva,i}) \quad \cdots(2)$$

$$\dot{Q}_{isen} = \dot{m}_{ref} \cdot (h_{comp,isen,o} - h_{comp,i}) \quad \cdots(3)$$

$$\dot{m}_{idea} = \rho_{suc} \cdot V_{cyl} \cdot \omega \quad \cdots(4)$$

$$\eta_v = \frac{\dot{m}_{act}}{\dot{m}_{idea}} \quad \cdots(5)$$

$$\eta_{isen} = \frac{\dot{Q}_{isen}}{P_{comp}} \quad \cdots(6)$$

where $\dot{Q}_{eva}$ is refrigerating capacity, P_{comp} is compressor input work, $\dot{m}_{ref}$ is mass flow rate of refrigerant to be measured by a mass flow meter, $\dot{m}_{idea}$ is ideal mass flow rate to be calculated by thermodynamic property of refrigerant in a suction plenum, ρ_{suc} is density of refrigerant in a suction plenum, V_{cyl} is effective volume of cylinder in a compressor, h is enthalpy.

Variation of operating condition of a refrigerator changes temperature distribution of the compressor, and it changes thermodynamic characteristics of suction refrigerant in a compressor. Therefore variation of superheat degree of suction refrigerant in the compressor has influence on performance characteristics of the compressor and the refrigerator.

Fig. 1 illustrates the heat transfer between refrigerant and surrounding of refrigerant. Flow of refrigerant in compressor is consisted of three processes; the suction process that refrigerant inflow from a suction line to a suction plenum, the compression process in a cylinder, and the discharge process that refrigerant outflow from a discharge plenum to a discharge line. Flow refrigerant absorbs heat from surrounding in the compressor during the suction process, but releases heat to surrounding in the compressor during the discharge process.

EXPERIMENTAL APPARATUS AND METHOD

These experiments were conducted under actual operating cycle of a refrigerator with steady-state by continuous running of a compressor. And temperature in a refrigerator is maintained to actual operating temperature by continuous supply of load with a heater installed in a freezer. Under this condition, experimental apparatus was installed to measure temperature of flow refrigerant in the compressor.

Experimental apparatus

This experimental apparatus was installed in the test room that can control temperature and relative humidity.

Refrigerator

R-134a is refrigerant of the refrigerator. A mass flow meter was installed at discharge line of the compressor for measuring mass flow rate of the system, and pressure transducers were installed at suction and discharge lines for measuring evaporating and condensing pressure respectively. Fig. 2 is the schematic diagram of experimental apparatus.

Reciprocating compressor

The compressor was cut off, and flanges for measuring temperature in the compressor was installed on the compressor for easy assembly and overhaul. Fig. 3 illustrates structure of the compressor and location of the temperature sensors in the compressor. For measuring temperature of flow refrigerant in the compressor, temperature sensors were inserted into a muffler, a plenum, and a cylinder. An accelerometer for measuring revolution per minute was adhered to surface of the compressor.

Heater in the freezer

To control temperature and maintain setting temperature of a refrigerator, were electric heat coil type heater(10 m, 500 W) was installed in the freezer. And a PID controller, a thyrister were used.

Experimental method

A Refrigerator control setting temperature in refrigerating compartment and a freezer with on-off control of the compressor. In that case, operating state of a refrigerator was changed rapidly so that it is difficult to analyze performance characteristics.

In this study, steady-state operating cycle of a refrigerator was obtained by continuous running of the compressor. Table 1 illustrates the same experiment condition as the performance experiment condition of refrigerators in KS C 9305. When temperature in refrigerating compartment was maintained to experimental temperature, temperature of flow refrigerant in the compressor, frequency, compressor input power, mass flow rate were measured.

RESULTS AND DISCUSSION

Performance characteristics of a refrigerator and a compressor

Flow refrigerant in the compressor has heat transfer with surrounding of refrigerant during suction, compression, and discharge process. Fig. 4 illustrates temperature and heat transfer ratio distribution of flow refrigerant in the compressor. Heat transfer ratio is defined as

$$\beta = \frac{Local\ heat\ transfer\ rate}{Total\ heat\ transfer\ rate} \quad \cdots\cdots(7)$$

During suction process, temperature of flow refrigerant is lower than that of surrounding in the compressor so that heat flows from surrounding to flow refrigerant in the compressor. Fig. 4

shows heat transfer ratio of suction process(β_{suc}) which are defined as the ratio of heat transfer rate of local to total during suction process and heat transfer ratio of discharge process (β_{dis}).

Heat transfer ratio shows 30% at suction plenum(④), 40% at discharge plenum(⑥) where heat flows from surrounding to flow refrigerant in the compressor, and 70% at discharge muffler(⑦) where heat flows from flow refrigerant to surrounding in the compressor. Like this, the rapid variation of heat transfer ratio between discharge plenum(⑥) and discharge muffler(⑦) results from the structural reason that a cylinder, a plenum, and a discharge muffler are located near frame. Fig. 5(b) illustrates operation cycle of the refrigerator in the Mollier(Pressure-Enthalpy) diagram of R-134a.

Variation of performance according to operating conditions of a refrigerator

Performance characteristics according to ambient temperature of a refrigerator

Fig. 5 illustrates temperature of flow refrigerant in the compressor and cycle characteristics of a refrigerator according to ambient temperature. In the same condition, efficiency and performance, etc. are shown in Fig. 6 and Table 2. Increase of condensing pressure as increase of ambient temperature results in increase of evaporating pressure. For increase of pressure like this, suction and discharge pressure of the compressor increase so that input power of the compressor and temperature in the compressor increase. Therefore suction refrigerant during suction process was heated up by surrounding in the compressor so that superheat degree of suction refrigerant increases.

The increase of superheat decrease density of refrigerant which is sucked into cylinder for the suction stroke so that volumetric efficiency decreases. But as known from Table 2, volumetric and isentropic efficiency increase due to increase of suction density as increase of evaporating pressure.

As ambient temperature increases, it is known that dominant factor on performance of the compressor and the refrigerator is more increase of evaporating pressure as variation of cycle characteristics than increase of superheat of suction refrigerant as increase of temperature of suction refrigerant in the compressor.

Performance characteristics according to temperature in a freezer

Fig. 7 illustrates temperature of flow refrigerant in the compressor and cycle characteristics of a refrigerator according to temperature in a freezer. In the same condition, efficiency and performance, etc. are shown in Fig. 8 and Table 3. Variation of temperature in a freezer has smaller effect than that of ambient temperature. Thus in this case, variation of temperature in the compressor and cycle characteristics of a refrigerator is small. But in this case, total trend of result is the same. The increase of temperature in a freezer results in the increase of evaporating pressure so that input power of the compressor and temperature in the compressor increase. Therefore suction refrigerant was heated up by surrounding in the compressor. But density of suction refrigerant increases due to the increase of evaporating pressure. Table 3 shows that volumetric efficiency and COP increase as increase of temperature in a freezer.

As temperature in a freezer increases, it is known that the dominant factor on performance of the compressor and the refrigerator is more increase of evaporating pressure as variation of cycle characteristics than increase of superheat of suction refrigerant as increase of temperature of suction refrigerant in the compressor.

Performance characteristics according to fan velocity

The fan in the compressor room of a refrigerator controls the wind velocity to the compressor. And heat transfer rate between shell of the compressor and surrounding of compressor is changed by fan velocity so that temperature in the compressor is varied. Fig. 9 illustrates temperature of flow refrigerant in the compressor and cycle characteristics of a refrigerator according to wind velocity to the compressor.

The fan in the compressor room helps the compressor to emit heat to surrounding. Therefore as fan velocity decreases, temperature in the compressor increases so that suction refrigerant was heated up and superheat degree of suction refrigerant increases. But as known from Fig. 9, fan velocity has little influence on cycle characteristics of a refrigerator except superheat of suction refrigerant in the compressor.

As fan velocity decreases, it is known that volumetric efficiency may decrease due to decrease of suction density as increase of superheat to suction refrigerant.

CONCLUSIONS

(1) It is necessary that a suction plenum be improved because 30% heat transfer ratio of a suction plenum is the highest value during suction process. And it is necessary that a discharge plenum be improved because 70% heat transfer ratio of a discharge plenum is the largest quantity during the discharge process.

(2) The superheat degree of suction refrigerant in the compressor and evaporating pressure of a refrigerator are major factors on mass flow rate of a refrigerator. As ambient temperature and freezer temperature increase, the superheat degree of suction refrigerant increases so that mass flow rate of refrigerant decreases, but evaporating pressure of a refrigerator increases so that mass flow rate of refrigerant increases. But effect of evaporating pressure is larger than that of superheat degree so that mass flow rate of refrigerant increases. As fan velocity decreases, superheat degree of suction refrigerant increases, but evaporating pressure of a refrigerator is nearly constant, so that mass flow rate of refrigerant decreases.

(3) The cycle characteristics of a refrigerator and the performance characteristics of the compressor are dependent on evaporating pressure when ambient temperature and freezer temperature are varied, and superheat degree of suction refrigerant in the compressor when fan velocity is varied.

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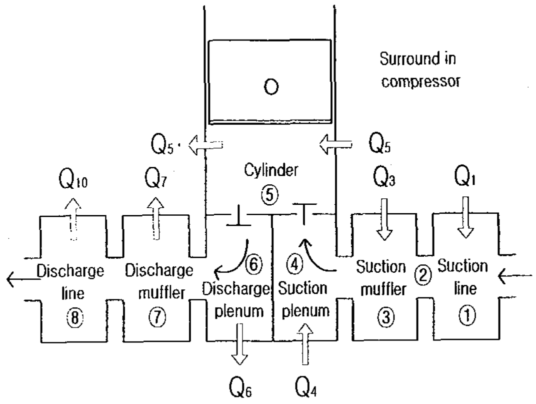


Fig. 1 Heat flow with flow refrigerant in a compressor

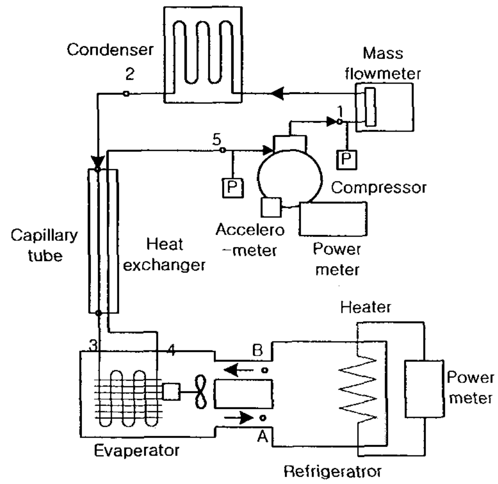
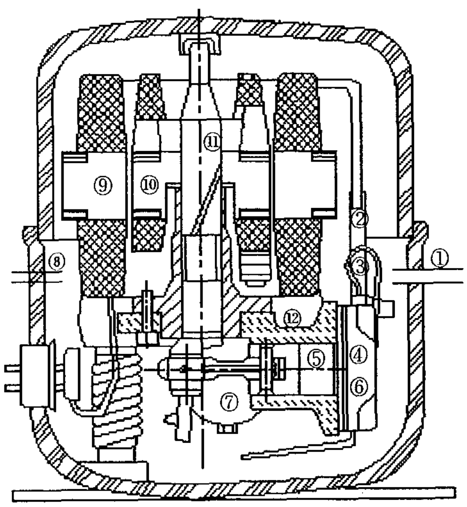


Fig. 2 Schematic of experimental apparatus

Table 1 Experimental condition of a refrigerator

Ambient temp. (℃)	Temp. in a freezer (℃)	Temp. in a refrigerator (℃)	Relative humidity (%)	Fan velocity (m/s)
30	-23	-1	75	4.2
30	-18	3	75	4.2
30	-14	7	75	4.2
43	-18	3	80	4.2
15	-18	3	65	4.2
30	-18	3	75	0



1	Suction line	7	Discharge muffler
2	Muffler inlet	8	Discharge line
3	Muffler	9	Stator
4	Suction plenum	10	Rotor
5	Cylinder	11	Crank shaft
6	Discharge plenum	12	Frame

Fig. 3 Schematic of a compressor

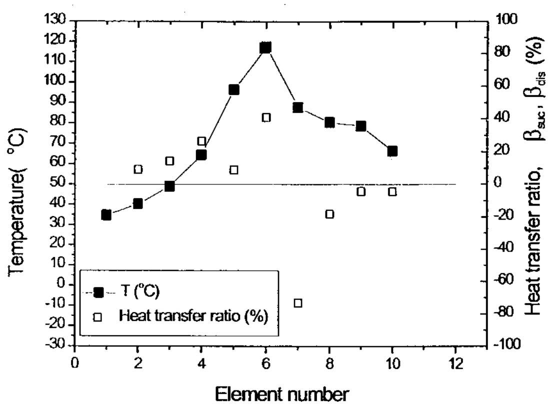


Fig. 4 Temperature and heat transfer ratio distribution according to element number in a compressor

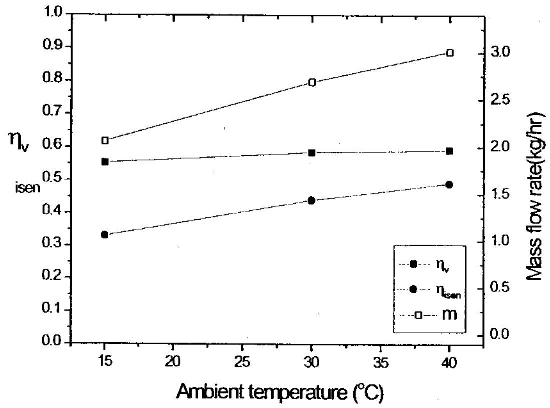
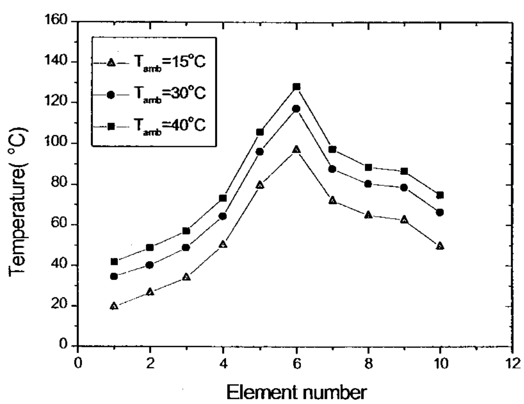
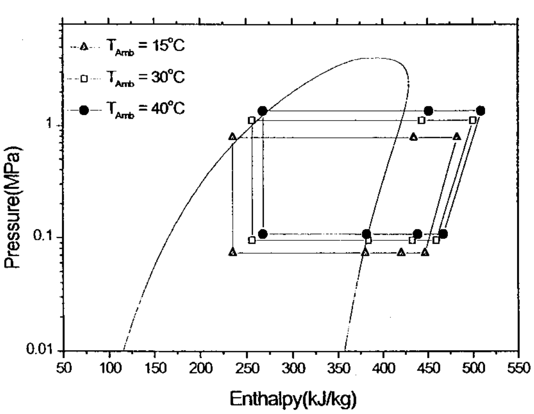


Fig. 6 Efficiency and ideal mass flow rate according to ambient temperature



(a) Temperature distribution with element number at each ambient temperature



(b) Operational cycle of a refrigerator with ambient temperature

Fig. 5 Result according to ambient temperature

Table 2 Performance according to ambient temperature

Ambient temp. (℃)	40	30	15
Mass flow rate (kg/hr)	3.01	2.69	2.06
Compressor input work (W)	134.4	126.3	121.2
Refrigerating effect (kg/kJ)	114.2	128.1	143.2
Refrigerating capacity (W)	95.48	95.72	81.97
C O P	0.71	0.76	0.68
Volumetric efficiency	0.592	0.585	0.553
Isentropic efficiency	0.489	0.444	0.325

Table 3 Performance according to temperature in a freezer

Temp. in a freezer (℃)	-14.5	-18.3	-23
Mass flow rate (kg/hr)	3.23	2.69	2.61
Comp. input power (W)	131.3	126.3	119.1
Refrigerating effect (kg/kJ)	127.1	128.1	127.0
Refrigerating capacity (W)	114.0	95.7	92.1
C O P	0.868	0.758	0.773
Volumetric efficiency	0.683	0.585	0.653
Isentropic efficiency	0.68	0.59	0.63

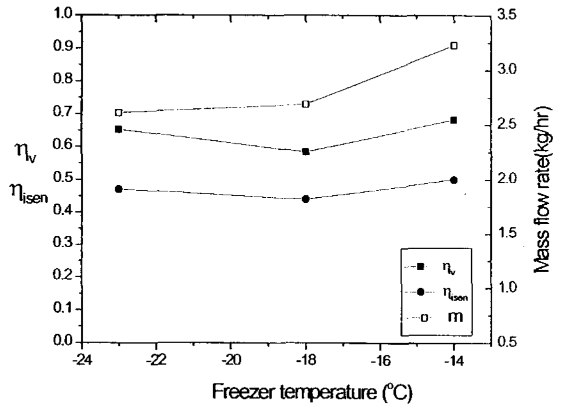
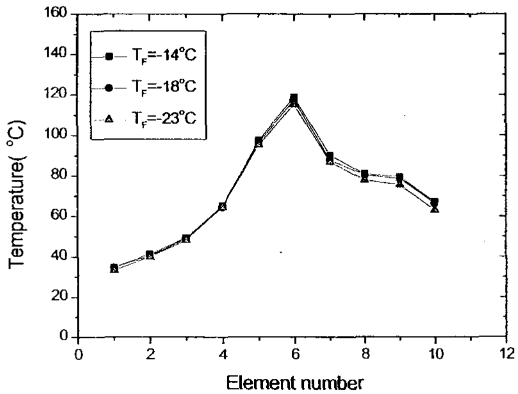
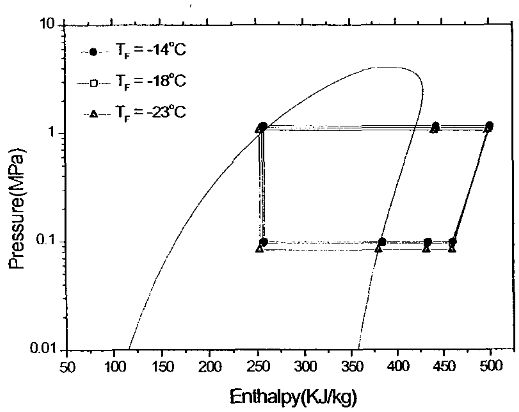


Fig. 8 Efficiency and ideal mass flow rate according to temperature in a freezer

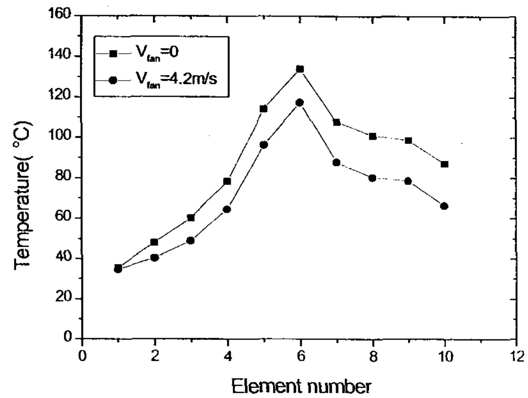


(a) Temperature distribution with element at e temperature in freezer

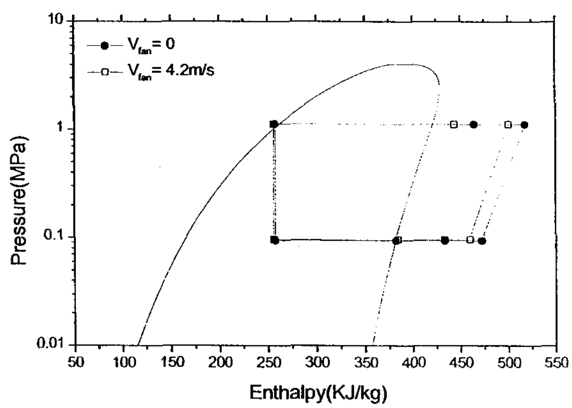


(b) Operational cycle of a refrigerator witł temperature in freezer

Fig. 7 Result according to temperature in a freezer



(a) Temperature distribution with element numl at each fan velocity.



(b) Operational cycle of a refrigerator with fan velocity

Fig. 9 Result according to fan velocity