A Study on the Characteristics an Azeotropic Mixture Combined with CF_3I and a Refrigerant for Air-Conditioner HFC-152a and HFC-152a

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ABSTRACT: In these days, environmental concerns have been increased throughout the industry and community worldwide. To prevent the ozone depletion, ozone depletion potential of a refrigerant must be zero. Simultaneously, a refrigerant with low GWP (global warming potential) is very demanding to reduce green house effect. Chlorine-free HFC-134a is a refrigerant widely used for automotive air-conditioning system because its destruction potential is ecologically zero. Although HFC-134a has no ozone depletion potential, its global warming potential is so high that it is not considered as a perfect alternative refrigerant that is acceptable for long-term use. In this paper, experimental measurement has been carried out to analyze the performance characteristics of automotive air-conditioning system using HFC-152a, which has low GWP and zero ODP. Also mixed refrigerant that is composed of HFC-152a and CF_3I was applied to investigate an alternative possibility for the automotive air-conditioning system. As a result of this study, we could draw following conclusions; With respect to the variation of the rotational speed of compressor, outside air temperature and flow rate, the heat amount of evaporator and compressor and performance coefficient was varied.

1. Introduction

In the early stage of automobiles a refrigerant CFC-12 was used for, however, which becomes a significant environmental matter currently when it has been revealed a fact that it is a insoluble material in the atmospheric space and it destructs the ozone layer by making a chemical reaction with ozone passing through a long time. Consequently it is under stage to provide a countermeasure against the matter internationally for protection of the environment in the earth and the industries using for CFC have been facing with a new problem when the Montreal protocol was signed in 1987 to regulate production, trade, and usage of CFC. From that time on the object materials to regulate have been expanded from 5 kinds to 15 kinds, and those were expanded to even further in the second Amendment in 1992. And as a schedule of regulation was fixed to that it will be abolished wholly in the advanced countries in 1996 and in the developing countries in 2010, a counter refrigerant HFC-134a has been commercialized in automobiles whose Ozone Depletion Potential is zero ecologically and has a similar thermo hydrogen characteristic with the refrigerant CFC-12 since hydrogen is combined together instead of chloride. But in spite of the fact that the ODP of HFC-134a is zero, it has some problems that the value of Global Warming Potential 0.26 is somewhat high as a basis of the refrigerant CFC-11 and it produces acids and poisonous materials when it is resolved by

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the sunlight in the atmospheric space.[1]

And also since it induces a reduction of integrated heat efficiency in an automobile due to the fact that the compressor pressure is higher compared with the CFC-12 and it has a higher value of Global Warming Potential compared with other HFCs, it is required to develop another alternative refrigerant to prevent from the phenomenon of global warming. Therefore many researches have been doing to alternate HFC-134a used in the air-conditioning system in automobile, and even that OS-12 mixed with propane and iso-butane is produced and commercialized in Korea, it is under a stage of examination now to apply it in the air-conditioning system in an automobile since it is an inflammable refrigerant.

Refrigerants of FIC series whose ODP is zero are developed and produced in USA and in Japan and some parts of the researches on a mixed refrigerant CF_3I are doing to alternate HFC-134a in Korea as well. An experiment was carried out in this study to alternate HFC-134a used for a refrigerant in the air-conditioning system in an automobile at present.[2,3,4]

The basic characteristics, optimal operation conditions, and the performance characteristics of air-conditioner for a mixed refrigerant combined HFC-152a, which can be the best material in an aspect of environmental friendship except for the inflammability, with CF_3I (70% HFC-152a/30%CF_3I) using CF_3I, which the ODP is zero, the value of GWP is very low, and can alternate CFC-12 and HFC-134a as a mixed refrigerant component, have analyzed to survey the possibility applying for a refrigerant of the air-conditioning in an automobile in the future in this study as well.

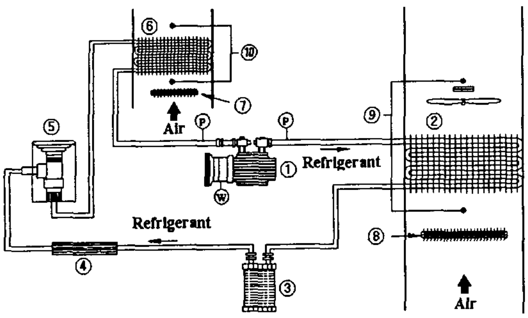
2. Experimenting apparatus and method

2.1 Experimenting apparatus

An air-conditioning system in an automobile has been prepared for this study by remaking an air-conditioning system in a small automobile at minimum order to analyze the operation conditions and the performance characteristics most similar with a real vehicle. An air flow in the inlet of evaporator has been made to regulate with 4 stages by connecting an adjustable resistance with 1.78 Ω, 1.11 Ω, and 0.33 Ω by step into a fan of DC 12 V 220 W. And a air flow in the inlet of condenser has been made to regulate with 2 stages by connecting an adjustable resistance with 0.5 Ω. And also rectangular ducts made from a transparent acryl 140 mm × 145 mm, 680 mm × 380 mm have been mounted in the air inlets in the condenser and in the evaporator to adjust and measure the exterior air temperature and air flow in those parts correctly and a pin coil with 2 kW and a temperature regulator with 4 kW have been mounted in the inlets of evaporator and condenser respectively to regulate the temperatures. The compressor has been made to transform rotation speed by 3 stages, low, medium, and high, according to the driving speed of an automobile by changing the rotation speed accurately and a 5 PS 3-phase driven motor has been mounted to control the corresponding rotation speed accurately as well. And the rotation speed in motor has made to be adjusted by the rotation speed in compressor according to a frequency regulation by establishing an inverter.

A receiver dryer has mounted to remove a moisture contained in the air-conditioning system totally.

A schematic diagram used in the study is shown in Fig. 1. The 4 thermocouple have mounted to measure the air temperatures in the inlets and outlets in the evaporator and condenser correctly and a pressure in the refrigerant was measured by using a pressure meter with 0 to 3400 kPa mounted in the high pressure part and in the low pressure part, whose measured pressure values were compared in each other by using a triple pressure



① Compressor ② Condenser ③ Receiver-dryer
④ Flow meter ⑤ Expansion device
⑥ Evaporator ⑦ Fin coil for evaporator
⑧ Fin coil for condenser
⑨ Thermocouples for cooling air at condenser inlet and outlet
⑩ Thermocouples for cooling air at evaporator inlet and outlet
Ⓟ Pressure gauge for refrigerant at compressor inlet and outlet
Ⓦ Power meter for compression power

Fig. 1 Schematic diagram of the experimental apparatus.

switch used in a real automobile. Preventing the emerging air with high temperature from the condenser and the emerging air with low temperature from the evaporator from influencing the experimental apparatus, a duct has established to exhaust them completely, and the pipes used in the system has isolated from heat not to influence the ambient heat sources.

The required power in the compressor was measured by a digital power meter, the temperature and relative humidity indoors were measured by a digital dry and wet temperature meter, and the measured data were analyzed in a computer through a data acquisition system.

2.2 Experimenting method

One of the major variables influencing the performances of the air-conditioning system is a charging quantity of refrigerant. Even that a charging quantity of refrigerant of R-134a in the real automobile used in this experiment was 730±20 g, the proper quantity was determined by an experiment of charging quantity since it had been difficult to determine the quantities of two refrigerants to replace by changing refrigerant pipes in the experimental apparatus suitable to the experimental environment.

An experiment for charging quantity was done as follows; firstly it was evacuated up to 10^{-7} torr using a vacuum pump to exhaust air and moisture contained in the system completely, and we were observing bubble generation and change of sub cooling displayed on the liquid mirror in the receiver dryer by changing the quantities of HFC-152a with 600, 650, 700, 750, 800, and 850 g successively when a proper charging quantity of 800 g was determined at the point that a sub-cooling became 5℃, at that time it was charged maintaining the outer atmospheric temperature to be 25℃ since a charging quantity of refrigerant varies as a function of an outer atmospheric temperature.

By a result of an experiment of charging quantity using the same conditions with the HFC-152a an optimal quantity was determined to be 750 g for the mixed refrigerant as well. In order to survey a pressure ratio and performance characteristics as a function of outer air temperature and rotation speed in the compressor the experiment was carried out by increasing simultaneously the inlet air temperatures in the evaporator and the condenser with 25℃, 30℃, 35℃, 40℃, 45℃ successively, when an allowable error range for the outer atmospheric temperatures was controlled by within ±0.5℃. An air-conditioner is operated in a range of outer atmospheric temperatures from 25℃ to 45℃ when an automobile is driving practically, therefore the temperature was measured by changing the rotation speed of the compressor with three stages of 1000 rpm, 1500 rpm, and 2000 rpm since it is proportional to a speed of engine which is different from that of a general air-conditioner. While maintaining a constant air flow rate in the inlet in the condenser to be 0.414 m^3/s, it was measured by increasing a rotation speed of the fan in the evaporator with 1st stage (0.046 m^3/s), 2nd stage (0.059 m^3/s), 3rd stage (0.10 m^3/s), and 4th stage (0.141 m^3/s).

In this experiment the relative humidity was controlled by 50±5% when the evaporator or condenser was heated or given moisture dependent on an outer atmospheric temperature in the inlet point of the rectangular duct.

3. Results of the experiment and discussion

3.1 Pressures in the evaporator as a function of outer air temperature condition and rotation speed in the compressor

Pressures in the evaporator as a function of outer air temperature and air flow rate when rotation speeds in the compressor of HFC-152a were 1000 rpm, 1500 rpm, and 2000 rpm are shown in Fig. 2, Fig. 3, and Fig. 4 respectively. The pressure in the evaporator was increased as the outer air temperature increased. And the pressure in the evaporator was increased as an air flow rate passing through the evaporator increased as well. But the pressure was decreased since a suction force in the compressor increased when a rotation speed in the compressor was increased.

Pressures in the evaporator as a function of outer air temperature and air flow rate when a rotation speed in the compressor was 1000 rpm is shown in Fig. 2 The pressure in the evaporator was increased as an outer air temperature increased and an air flow rate passing through the inlet in evaporator. But it was shown that an increasing rate of pressure became enlarged as an air flow rate increased in a high outer air temperature of more than 35℃ since an increasing rate of pressure as a function of flow rate was not so much in an outer air temperature of lower than 35℃, which is judged by us that a suction force decreased as a function of outer air temperature since a rotation speed in the compressor was slow and a load in the evaporator increased as an outer air temperature increased.

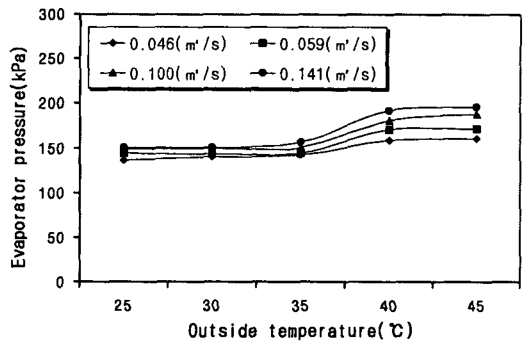


Fig. 2 Evaporator pressure as a function of outside temperature for HFC-152a at 1,000 rpm.

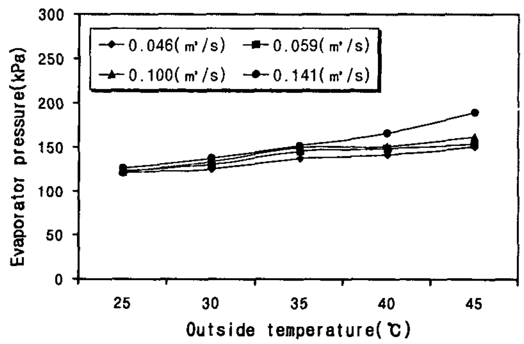


Fig. 3 Evaporator pressure as a function of outside temperature for HFC-152a at 1,500 rpm.

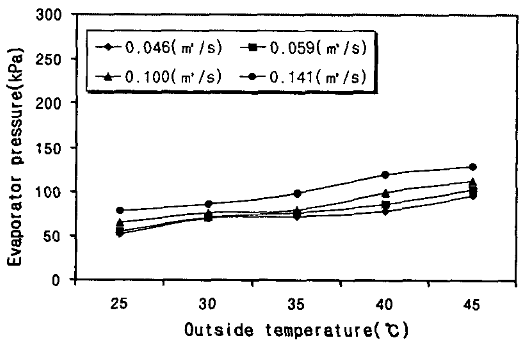


Fig. 4 Evaporator pressure as a function of outside temperature for HFC-152a at 2,000 rpm.

Pressures in the evaporator as a function of outer air temperature and air flow rate when a rotation speed in the compressor was 1500 rpm is shown in Fig. 3 A pressure in the evaporator was increased as an outer air temperature increased, the increasing rate of pressure was increased even more as the air flow rate increased, and a pressure in the evaporator was reduced as the rotation speed increased. A pressure difference in the evaporator was great as an increase of an air flow quantity in an outer air temperature of 45℃.

Pressures in the evaporator as a function of outer air temperature and air flow rate when a rotation speed in the compressor was 2000 rpm are shown in Fig. 4 which shows us that an increasing rate of pressure was increased but a pressure in the evaporator was decreased as an outer air temperature increased. And it means that the suction force was great since a rotation speed in the compressor was higher that the evaporator capacity.

Pressures in the evaporator as a function of outer air temperature and air flow rate when the rotation speed in the compressor of mixed refrigerant were 1000 rpm, 1500 rpm, and 2000 rpm are shown in Fig. 5, Fig. 6, and Fig. 7 respectively. A pressure in the evaporator was increased as an outer air temperature increased and a pressure in the evaporator was increased as well as an air flow rate increased. In case of HFC-152a an increasing rate of pressure according to an air flow rate was greater when it was used for the mixed refrigerant.

Pressures in the evaporator as a function of outer atmospheric temperature when a rotation speed in the compressor was 1000 rpm are shown in Fig. 5. A pressure in the evaporator was increased when an air flow rate passing through the inlet in the evaporator and the increasing rate was increased as an outer air temperature was high.

There was no difference in pressures when the air flow rates were 0.046 m^3/s and 0.059 m^3/s but there was a great difference in pressures when the air flow rates were 0.100 m^3/s and 0.141 m^3/s since the pressure was increased

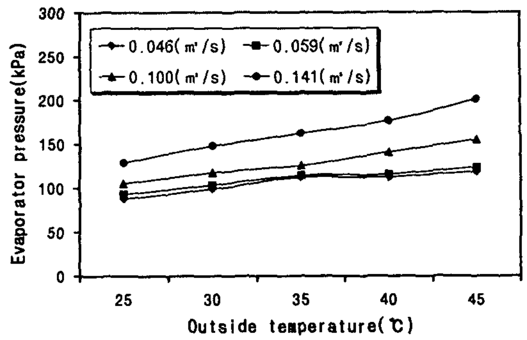


Fig. 5 Evaporator pressure as a function of outside temperature for HFC-152a refrigerant mixed with CF_3I at 1,000 rpm.

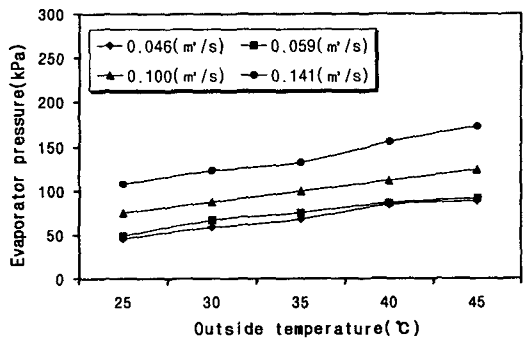


Fig. 6 Evaporator pressure as a function of outside temperature for HFC-152a refrigerant mixed with CF_3I at 1,500 rpm.

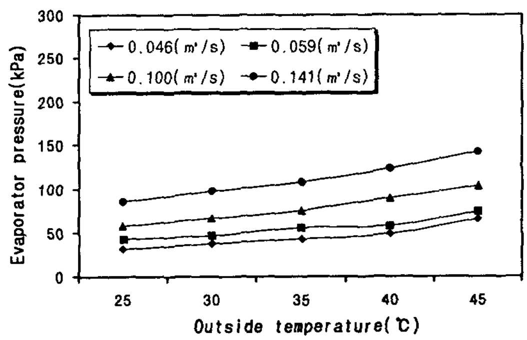


Fig. 7 Evaporator pressure as a function of outside temperature for HFC-152a refrigerant mixed with CF_3I at 2,000 rpm.

by increasing a cooling load in the evaporator as an air flow rate increased.

Pressures in the evaporator as a function of outer atmospheric temperature and air flow rate when a rotation speed in the compressor was 1500 rpm are shown in Fig. 6. A pressure in the evaporator was increased as an outer atmospheric temperature increased, the increasing rate of pressure according to an increase of flow rate was increased more that of 1000 rpm, but a pressure in the evaporator was low.

Pressures in the evaporator as a function of outer atmospheric temperature and air flow rate when a rotation speed in the compressor was 1500 rpm are shown in Fig. 7. A pressure in the evaporator was increased as an outer air temperature increased, a pressure in the evaporator was increased as an air flow rate increased, but a pressure in the evaporator was decreased as a rotation speed in the compressor increased. An increasing rate of pressure in the evaporator used for the mixed refrigerant was greater compared to HFC-152a but the pressure was lower.

3.2 Evaporator capacities as a function of outer air temperature condition and rotation speed in the compressor

Evaporator capacities as a function of outer air temperature and air flow rate when rotation speeds in the compressor of HFC-152a were 1000 rpm, 1500 rpm, and 2000 rpm are shown in Fig. 8, Fig. 9, and Fig. 10 respectively. An evaporator capacity was increased as an outer air temperature increased. And an evaporator capacity was increased as an air flow rate passing through the evaporator increased as well. And an evaporator capacity was increased according to an active heat exchange in the evaporator as a circulating amount of coolant was increased due to an increase of outer load.

Evaporator capacities as a function of outer air temperature and air flow rate when a rotation speed in the compressor was 1000 rpm is

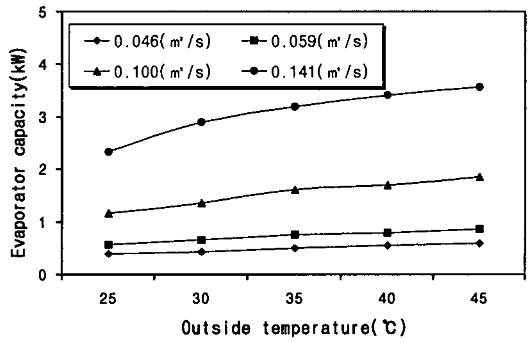


Fig. 8 Evaporator capacity as a function of outside temperature for HFC-152a at 1,000 rpm.

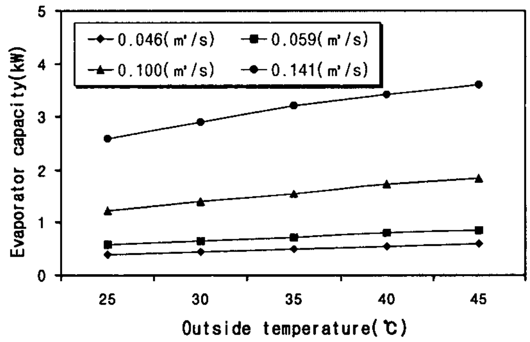


Fig. 9 Evaporator capacity as a function of outside temperature for HFC-152a at 1,500 rpm.

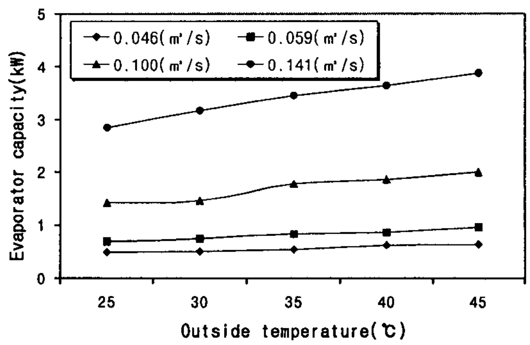


Fig. 10 Evaporator capacity as a function of outside temperature for HFC-152a at 2,000 rpm.

shown in Fig. 8. An evaporator capacity was increased as an outer air temperature increased, the increasing rate of capacity was almost constant when air flow rates were increased to 0.046 m^3/s and 0.059 m^3/s, the increasing rate was increased when air flow rates were increased to 0.100 m^3/s and 0.141 m^3/s, and there was a great difference in the evaporator capacities, since the capacity was decreased when an air flow rate passing through the evaporator was small since it did not make an active heat exchange but it was increased by making an active heat exchange when the air flow rate was increased.

Evaporator capacities as a function of outer air temperature and air flow rate when rotation speeds in the compressor were 1500 rpm and 2000 rpm are shown in Fig. 9 and Fig. 10 respectively.

A evaporator capacity was increased when an outer air temperature was increased equal to a rotation speed 1000 rpm in the compressor and as an air flow rate increased. But an evaporator capacity was not changed almost even when a rotation speed in the compressor was increased. And the reason is judged by us that an expansion valve of temperature type which regulates an amount of refrigerant according to an outer load automatically has been used in this apparatus.

Evaporator capacities as a function of outer air temperature and air flow rate when rotation speeds in the compressor were 1000 rpm, 1500 rpm and 2000 rpm are shown in Fig. 11, Fig. 12, and Fig. 13 respectively. The evaporator capacity of the mixed refrigerant was increased as the outer air temperature and an amount of air flow passing through the evaporator increased which was similar to HFC-152a, however, an amount of the evaporator capacity was inferior than that of HFC-152a, whose reason is judged by us that the evaporator capacity was decreased according to a process of different phase transformation for the mixed refrigerant components.

Evaporator capacities as a function of outer air temperature and air flow rate when the rotation speed in the compressor was 1000 rpm is shown in Fig. 11. An evaporator capacity was increased as an outer air temperature increased

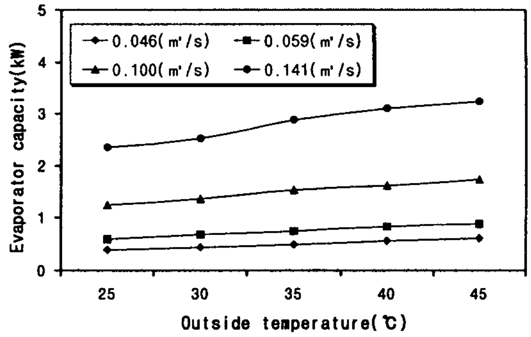


Fig. 11 Evaporator capacity as a function of outside temperature for HFC-152a refrigerant mixed with CF_3I at 1,000 rpm.

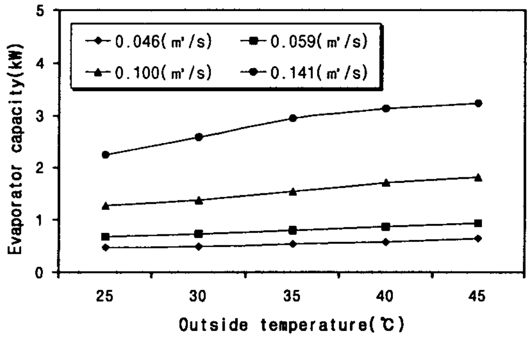


Fig. 12 Evaporator capacity as a function of outside temperature for HFC-152a refrigerant mixed with CF_3I at 1,500 rpm.

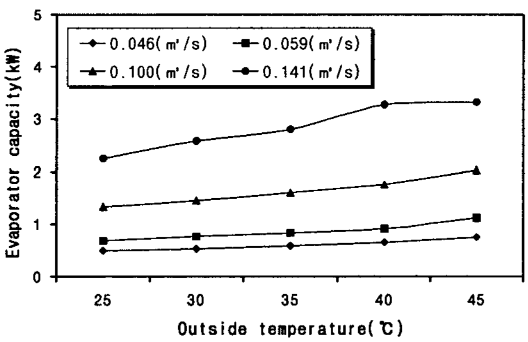


Fig. 13 Evaporator capacity as a function of outside temperature for HFC-152a refrigerant mixed with CF_3I at 2,000 rpm.

and that was increased as an air flow rate increased as well. And the increasing rate of evaporator capacities was constant when the air flow rates were increased to 0.046 m^3/s and 0.059 m^3/s but that was increased when the air flow rates were in creased to 0.100 m^3/s and 0.141 m^3/s and the differences of the evaporator capacities were big.

Evaporator capacities as a function of outer air temperature and air flow rate when a rotation speed in the compressor was 1500 rpm is shown in Fig. 12. Evaporator capacities were equal to those of the rotation speed of the compressor 1000 rpm and the total evaporator capacities were increased by increasing the rotation speed in the compressor.

Evaporator capacities as a function of outer atmospheric temperature and air flow rate when a rotation speed in the compressor was 2000 rpm are shown in Fig. 13. The increasing rate of evaporator capacities was enlarged when an air flow rates were 0.046 m^3/s and 0.059 m^3/s at an outer air temperature of 45℃, which is judged by us that it could be a characteristic of the mixed refrigerant.

3.3 Coefficients of performance as a function of outer air temperature condition and rotation speed in the compressor

Performance coefficients as a function of outer air temperature and air flow rate when rotation speeds in the compressor of HFC-152a were 1000 rpm, 1500 rpm, and 2000 rpm are shown in Fig. 14, Fig. 15, and Fig. 16 respectively. A COP was increased as an outer air temperature and an outer air flow rate increased but the coefficient was decreased as a rotation speed in the compressor increased, since COP was enlarged by increasing the capacitor capacity according to an increase of the outer air temperature.

COPs as a function of outer air temperature and air flow rate when a rotation speed in the compressor was 1000 rpm is shown in Fig. 14. A COP was high at an outer air temperature of 25℃. But it is that COP was decreased since a load factor in the compressor and a required power were decreased by suction a

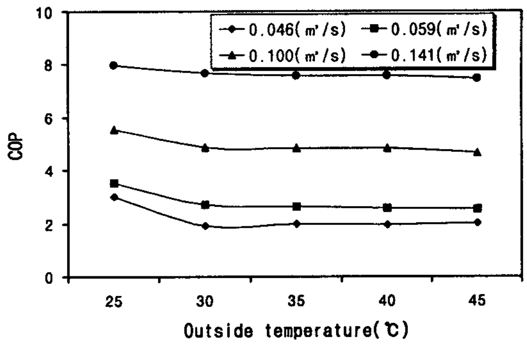


Fig. 14 COP as a function of outside temperature for HFC-152a at 1,000 rpm.

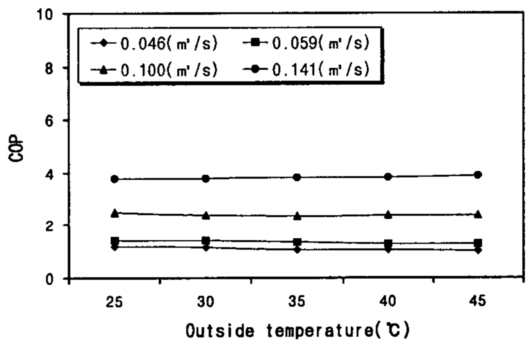


Fig. 15 COP as a function of outside temperature for HFC-152a at 1,500 rpm.

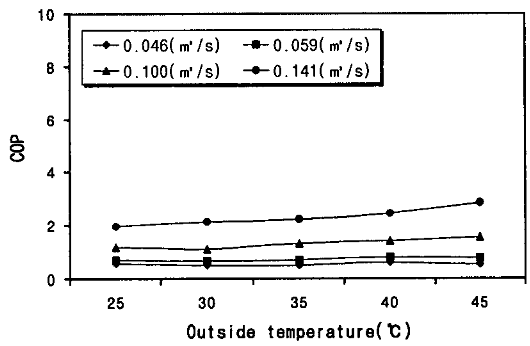


Fig. 16 COP as a function of outside temperature for HFC-152a at 2,000 rpm.

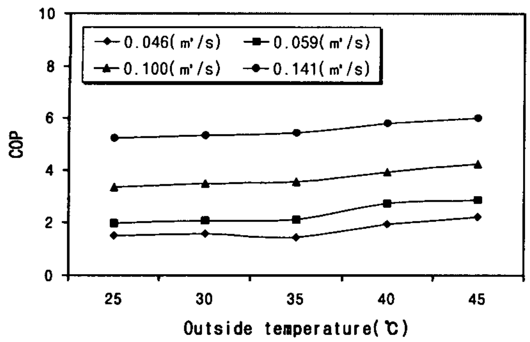


Fig. 17 COP as a function of outside temperature for HFC-152a refrigerant mixed with CF_3I at 1,000 rpm.

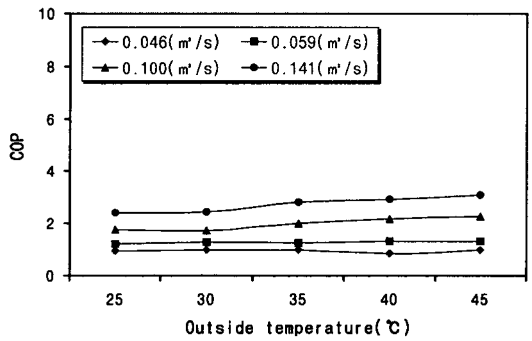


Fig. 18 COP as a function of outside temperature for HFC-152a refrigerant mixed with CF_3I at 1,500 rpm.

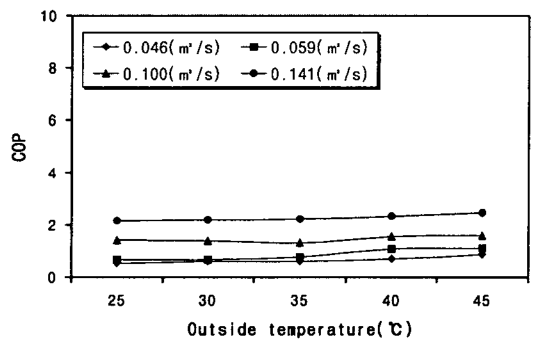


Fig. 19 COP as a function of outside temperature for HFC-152a refrigerant mixed with CF_3I at 2,000 rpm.

refrigerant of wet vapor state, not saturated vapor, in the compressor for that it did not make an active heat exchange in the evaporator according to that a rotation speed in the compressor and an outer air temperature were low in all.

COPs as a function of outer air temperature and air flow rate when rotation speeds in the compressor were 1500 rpm and 2000 rpm are shown in Fig. 15 and Fig. 16 respectively.

A COP was increased since an outer air temperature and an air flow rate passing through the evaporator increased but the coefficient was decreased when a rotation speed in the compressor was increased.

COPs as a function of outer air temperature and air flow rate when rotation speeds in the compressor were 1000 rpm, 1500 rpm and 2000 rpm are shown in Fig. 17, Fig. 18, and Fig. 19 respectively. A COP was increased as an outer air temperature and an air flow rate passing through the evaporator increased in all which was equal to that of HFC-152a, but the coefficient was decreased as a rotation speed in the compressor was increased.

COPs as a function of outer air temperature and air flow rate when rotation speeds in the compressor was 1000 rpm is shown in Fig. 17. The increasing rate was low as an outer air temperature and an air flow rate increased in all but the difference of COPs was high.

COPs as a function of outer air temperature and air flow rate when the rotation speeds in the compressor were 1500 rpm and 2000 rpm are shown in Fig. 18 and Fig. 19 respectively. An COP was increased as an outer air temperature and an air flow rate increased in all but the total COPs were decreased when a rotation speed in the compressor increased.

4. Conclusions

Aiming to alternate a refrigerant of HFC-134a which is used in an air-conditioning system in an automobile at present, a characteristic experiment for performance has been carried out by using a single refrigerant of HFC-152a and a mixed refrigerant combined with HFC-152a and CF_3I in this study. We summarize the results as follows.

(1) The air-conditioning system is influenced much from the changes of evaporator capacity, condenser capacity, and the coefficient of performance as a rotation speed in a compressor, an outer air temperature, and an air flow rate are varied.

(2) Pressures in the evaporator were decreased as a rotation speed in the compressor was increased, and the pressure for HFC-152a was higher by 24% than that for the mixed refrigerant.

(3) Evaporator capacities were higher for HFC-152a at an outer air temperature of 35℃ but a required power was decreased for it. The evaporator capacity and the required power were increased for HFC-152a at an outer air temperature of 40℃.

(4) Coefficients of performance for HFC-152a. were higher than those for the mixed refrigerant at the rotation speeds of 1000 rpm and 1500 rpm, but the COPs of the two refrigerants were almost similar at a rotation speed of 2000 rpm.

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