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DEVELOPMENT OF HIGH-TEMPERATURE HEAT PUMP USING ALTERNATIVE MIXTURES

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ABSTRACT

Four kinds of refrigerant mixtures R22/R134a, R22/R152a, R22/R142b and R22/R123, which contain some new halocarbons which are considered to be the alternatives for CFCs, were evaluated in order to realize higher condensing temperature than that using R22 at high temperature operation, and larger heating capacity than that using R22/R114 at normal temperature operation. These mixtures were applied to a newly-developed composition changeable rectifying circuit in which the higher-boiling-point refrigerant was separated and stored. As a result, the composition changeable high-temperature heat pump indicated the most effective characteristics when using R22/R142b as the refrigerant.

1. INTRODUCTION

Technologies that employ refrigerant mixtures are attracting attention from the aspects of energy saving as well as expansion of the employed temperature range. Refrigerant R22 is widely used for heat pump, but R22 is not suitable for high-temperature heat pump due to the high pressure. Refrigerant mixture of R22/R114 is one of R12-substitutes and has been partially used for high-temperature heat pump. But R114 is now under the regulation and its heating capacity is much smaller than that of R22, so the alternative refrigerant and the new heat pump for high temperature operation are needed.

In this paper we examine in detail the characteristics of the basic cycle using non-azeotropic refrigerant mixtures which consist of non-regulated halocarbons (4 types). We also examine a new composition changeable rectifying circuit with mixed refrigerants. The heat pump composed of the composition changeable rectifying circuit can be used for both high temperature and normal temperature operation. We introduce that both the high temperature operation with higher condensing temperature than that using R22 and the normal temperature operation with larger heating capacity than that using R22/R114 can be realized in the composition changeable rectifying circuit with the separation.

2. REFRIGERANTS AND CHARGED COMPOSITIONS

In this study the characteristics of the refrigeration cycle both at normal temperature operation and at high temperature operation using refrigerant mixtures having different boiling points were carefully considered. Then R22 was selected as the lower-boiling-point refrigerant of the mixtures. Four kinds of mixtures R22/R134a, R22/R152a, R22/R142b, and R22/R123 which include the alternative halocarbons, were selected as the refrigerant mixtures. R22/R114 was selected as the reference. The charged compositions of the mixtures, as indicated in Table 1, were determined so that the saturated vapor could condense at a temperature of 75°C and at a pressure of approximately 2.6 MPa.

Table 1. Refrigerant Mixtures and Charged Composition

Refrigerant Mixtures	R22/ R134a	R22/ R152a	R22/ R142b	R22/ R123	(References) R22/ R114	(References) R22
Composition (wt%)	50/50	62/38	75/25	87/13	70/30	100

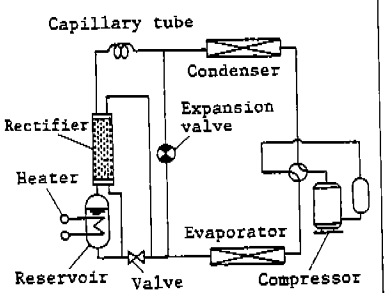
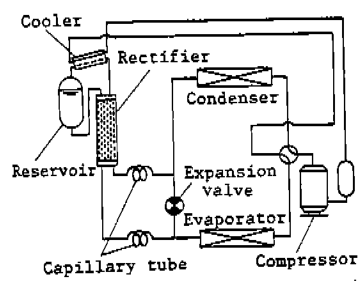
For the evaluation of the separation characteristics, phase equilibria of R22/R114, R22/R134a and R22/R142b were measured by the static method, and the measurement of R22/R123 was omitted. Phase equilibrium data of R22/R152a were cited from Kuwahara et al.[1] and evaluated by the aid of the thermodynamic estimation method[2].

3. NEW COMPOSITION CHANGEABLE RECTIFYING CIRCUIT

In order to change mutually efficient high-temperature heating operation and high-capacity normal temperature heating operation, new refrigerating circuit of heat pump was constructed. This circuit used the 'Higher-Boiling Storage' system indicated in Table 2 in which the higher-boiling-point refrigerant was separated and stored, in order to permit rapid composition control at high temperature operation.

In this circuit, the top of a rectifier was connected with a condenser and an evaporator, respectively, in parallel with a main expansion valve. A reservoir with a heater was connected with the bottom of the rectifier, and a check valve was located in a connecting-pipe between the reservoir and the evaporator inlet. When the check valve was opened at high temperature heating, it operated with the charged mixture, resulting in lower condensing pressure than using the lower-boiling-point refrigerant only. When the check valve was closed and the heater was applied at normal temperature heating, the refrigerant flew into the rectifier and the rectification started by the generated vapor. The separated higher-boiling-point refrigerant was stored in the reservoir, and it operated with almost the lower-boiling-point refrigerant only, resulting in larger heating capacity than using the mixture. In this way the main circuit was rich in the lower-boiling-point refrigerant performing the separation at normal temperature operation, and the stored higher-boiling-point refrigerant was mixed into the main circuit at high temperature operation. And separation characteristics were varied due to the regulation of the rectifier pressure.

Table 2. New Rectifying Circuit

System	Higher-boiling Storage	Lower-boiling Storage
Configu-ration		
Main circuit	lower-boiling-point refrigerant flows with separation ↔ Mixed refrigerant flows without separation	higher-boiling-point refrigerant flows with separation ↔ Mixed refrigerant flows without separation
Reservoir	Stores higher-boiling-point refrigerant at the bottom of the rectifier	Stores lower-boiling-point refrigerant at the top of the rectifier
Heater	indispensable	dispensable
Cooler	dispensable	indispensable

Compared with the 'Lower-Boiling Storage' system[3] in Table 2, this system can eliminate a cooler to condense vapors into liquids at the top of the rectifier, although it needs a heater to generate vapors from liquids in the reservoir. And the heater can be substituted by hot pipes in the main circuit.

4. EXPERIMENTAL APPARATUS AND METHOD

4.1 Experimental Apparatus

The apparatus used for the refrigeration cycle experiment is shown in Fig.1. The main circuit for an ordinary refrigeration cycle with an inverter-driven compressor (cylinder volume: approximately 10 cc) etc. was set-up along with a separation circuit composed of a rectifier filled with packings, a lower reservoir with a heater and a reservoir exit valve. In order to control the pressure of the rectifier, from high to low, parallel paths, each of which had an expansion valve and a check valve, were attached both inlet and outlet line at the top of the rectifier. To compare the characteristics of the refrigeration cycle, a high-pressure separation method and a low-pressure separation method were investigated experimentally. Also, so that the characteristics of the main circuit could be measured, check valves were attached to isolate it from the separation circuit. The specification of the separator unit is shown in Table 3. As for the condenser and the evaporator, air-to-air heat-exchangers were used. A gas chromatograph was used to analyze the compositions of the refrigerant mixtures, which were sampled as a liquid from the condenser outlet and from the lower reservoir.

Table 3. Separator Specification

Rectifier	Cu; height 210 mm inner diameter 20 mm
Packings	SUS; coiled packings
Reservoir	Cu; approx. volume 250 cc

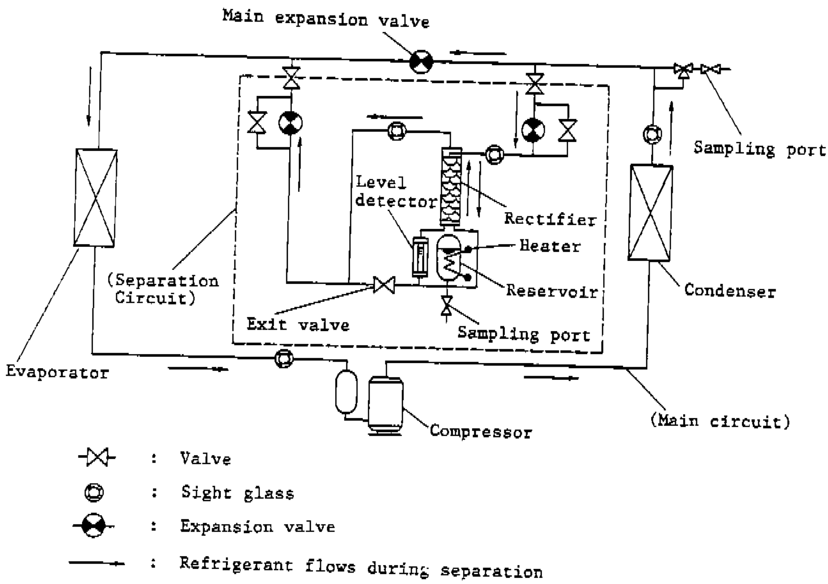


Fig.1. Experimental Apparatus

4.2 Experimental Method

First the characteristics of all the mixtures and R22 only were evaluated both at high temperature operation and at normal temperature operation, under the Japanese Standard Heating conditions. Based on this, refrigerants favorable for testing in the composition changeable rectifying circuit were then chosen. The various tests and experiments were conducted as indicated below.

4.2.1 Cycle Evaluation Experiment

This experiment was conducted for R22/R134a, R22/R152a, R22/R142b, R22/R123, R22/R114 and R22 only. The check valves were closed, and the amount of charged refrigerant and the settings of main expansion valve were varied with only the main circuit. The change of the heating capacity at the condenser and that of the energy efficiency of the apparatus were measured. The peak value was used as the specific value for that kind of refrigerant both at high temperature operation and at normal temperature operation.

4.2.2 Separation Evaluation Experiment

For this experiment, R22/R152a, R22/R142b and R22/R114 as the reference were chosen for the reason described later. The expansion valves of the separation circuit were adjusted to coincide the pressure of the rectifier with high or low pressure of the main circuit. After stable operation using refrigerant mixtures was achieved, the reservoir valve was closed and heating by the heater was applied to begin the separation operation by rectification. Then the higher-boiling-point refrigerant was concentrated and stored in the reservoir. The generated vapor rich in the lower-boiling-point refrigerant (R22) was allowed to flow directly into the evaporator and mix with the two-phase refrigerant passing through the main expansion valve from the condenser outlet, and the refrigerant circulating the main circuit became a rich mixture of R22. Changes of the compositions in both the reservoir and the main circuit were measured over set lengths of time.

5. EXPERIMENTAL RESULTS

5.1 Cycle Evaluation Experiment

5.1.1 High Temperature Operation Characteristics

As indicated in Table 4, the frequency of the compressor was adjusted so that the heating capacity became the same. Table 4 shows the high temperature operation characteristics at a condensing temperature of about 70°C. The energy efficiencies for R22/R152a, R22/R142b and R22/R134a (in that order) except R22/R123 were equal to or better than those shown by R22/R114 at the same heating capacity. Also the

Table 4. Characteristics at high temperature operation

Refrigerant Mixtures	R22/R134a	R22/R152a	R22/R142b	R22/R123	R22/R114	R22
Charged composition (wt%)	50/50	62/38	75/25	87/13	70/30	100
Compressor frequency (Hz)	93	101	95	95	95	79
Heating capacity (kW)	2.41	2.40	2.41	2.39	2.39	2.39
Discharge pressure (MPa)	2.55	2.31	2.45	2.55	2.47	2.94
Suction pressure (MPa)	0.42	0.37	0.40	0.42	0.41	0.53
Compressor input (W)	1130	1120	1130	1180	1140	1180
C.O.P (-) (Ratio to R22/R114)	2.13 (1.01)	2.14 (1.02)	2.13 (1.01)	2.03 (0.97)	2.10 (1)	2.03 (0.97)

pressure at the compressor outlet was 0.4 to 0.6 MPa lower than that for R22, thus showing that the mixtures were suitable for high temperature operation. From these results, using these three mixtures at high temperature operation, we can realize higher condensing temperature than that using R22 at the same high pressure of the main circuit, and better energy efficiency than that of R22/R114.

5.1.2 Normal Temperature Operation Characteristics

In Table 5, with the frequency of the compressor at 95 Hz, the characteristics at normal temperature operation at a condensing temperature of about 40°C are shown. Although the heating capacity is not the same at the same compressor frequency, the energy efficiencies for R22/R152a, R22/R142b, and R22/R134a (in that order) except R22/R123 were better than that shown by R22/R114. The correlation between the heating capacity and the energy efficiency is expressed in Fig.2 by using the data shown in Table 5. In different experiments we had confirmed that the relation between the change of the refrigerant composition and the change in characteristics values was almost linear under the condition of a suitable amount of the charged refrigerant. From this, comparing at the same heating capacities, the energy efficiencies of R22/R152a, R22/R142b, and R22/R134a were better than that of R22/R114.

Table 5. Characteristics at normal temperature operation

Refrigerant Mixtures	R22/R134a	R22/R152a	R22/R142b	R22/R123	R22/R114	R22
Charged composition (wt%)	50/50	62/38	75/25	87/13	70/30	100
Compressor frequency (Hz)	95	95	95	95	95	95
Heating capacity (kW) (Ratio to R22/R114)	2.81 (1.02)	2.60 (0.94)	2.66 (0.96)	2.87 (1.04)	2.76 (1)	3.23 (1.17)
Discharge pressure (MPa)	1.31	1.15	1.22	1.40	1.30	1.61
Suction pressure (MPa)	0.39	0.36	0.37	0.42	0.39	0.48
Compressor input (W)	750	660	700	790	740	880
C.O.P (-) (Ratio to R22/R114)	3.75 (1.01)	3.95 (1.06)	3.80 (1.02)	3.64 (0.98)	3.72 (1)	3.67 (0.99)

However, the heating capacity at the charged composition for any of the refrigerant mixtures was much less than that for R22 only. Therefore the composition changeable operation in order to obtain the heating capacities equivalent to R22 is necessary. Taking the data obtained from the above mentioned experiments and the simplicity of realizing the storage operation of the higher-boiling-point refrigerant into consideration, R22/R142b and R22/R152a were chosen to be applied in the composition changeable circuit, in which the portion of the higher-boiling-point refrigerant in the mixtures was less than that of R134a in the mixture R22/R134a.

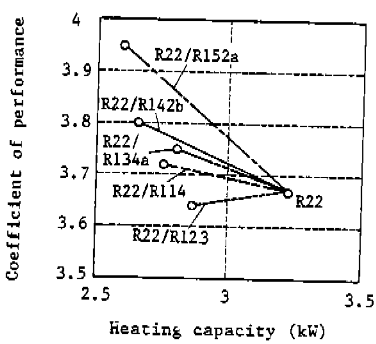
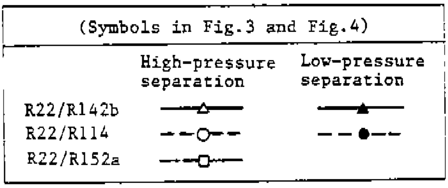


Fig.2. Heating capacity vs. coefficient of performance

5.2 Separation Evaluation Experiment

Fig.3 shows the time evolution of the compositions of both the circulated refrigerant and the stored refrigerant in the composition changeable circuit with 50 watts of the applied heater when the pressure of the rectifier was adjusted to coincide with high or low pressure of the main circuit. The number of theoretical plates (NTP) over time is shown in Fig.4.



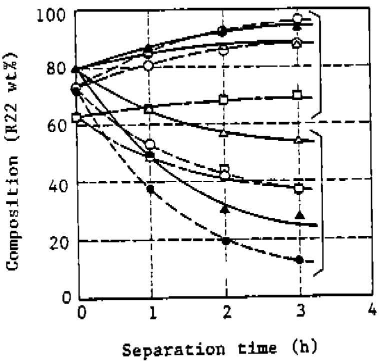


Fig.3. Separation time vs. composition

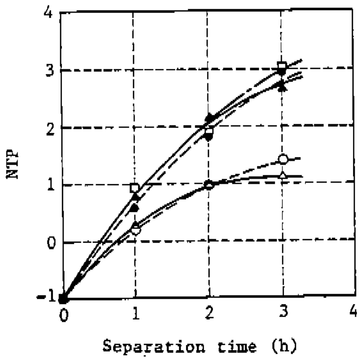


Fig.4. Separation time vs. NTP

At the high pressure separation, the characteristics shown by R22/R142b and R22/R114 closely resembled each other. On the other hand, in spite of having a higher NTP value than other mixtures, the compositional change of the circulated refrigerant demonstrated by R22/R152a was less than the others. This is explained from the fact (as we actually observed) that, over a period of time, the liquid level in the reservoir dropped and the amount of the higher-boiling-point refrigerant (R152a) in the reservoir decreased. The reason behind this is considered that the flooding phenomenon deteriorated the separation characteristics.

Also, at the low pressure separation, the characteristics of R22/R142b and R22/R114 resembled each other. The separation characteristics of both mixtures were improved when the rectifier's pressure was coincided with the low pressure of the main circuit, compared with that at the high pressure separation. This is due to the fact that the specific volume of the generated vapor was increased at the low pressure and the increase of the speed of the vapor through the rectifier caused the better vapor-liquid contact. For the low pressure separation of R22/R152a, the refrigerant amount in the reservoir was more decreasing than that for the high pressure separation, although the data were not plotted in Fig.3 and Fig.4.

Table 6 shows the characteristics of these mixtures after separation. R22/R152a with the high pressure separation showed little change in the composition of the main circuit in which the amount was overcharged and had smaller heating capacity in comparison with R22. For R22/R152a, the specification of the rectifier and the applied heater should be examined further. On the other hand, R22/R142b showed about the same heating capacity as R22 as well as R22/R114 and was suitable for use as the refrigerant in the composition changeable circuit with the low pressure separation. Moreover, the flammable composition of R22/R142b is more limited than that of R22/R152a.

6. CONCLUSIONS

For either high temperature or normal temperature operation, the characteristics of the refrigeration cycle demonstrated by R22/R152a, R22/R142b, and R22/R134a (in that order) except R22/R123 were equal to or better than that of R22/R114.

Table 6. Characteristics after separation

Refrigerant Mixtures		R22/R152a	R22/R142b	R22/R114
Charged Composition	(wt%)	62/38	75/25	70/30
Main circuit composition	(wt%)	69/31	95/5	95/5
Compressor frequency	(Hz)	95	95	95
Heating capacity (Ratio to R22)	(kW)	2.66 (0.82)	3.12 (0.97)	3.17 (0.98)
Compressor input	(watt)	720	840	870
Coefficient of performance (Ratio to R22)	(-)	3.69 (1.01)	3.71 (1.01)	3.66 (1.00)

The separation characteristics of the 'Higher-boiling Storage' system are improved when the rectifier's pressure is coincided with the low pressure of the main circuit. R22/R142b demonstrates equal separation characteristics to those of R22/R114 in the composition changeable circuit.

Alternative Refrigerant Mixture R22/R142b works better than R22/R114 and assures reliability due to the lower pressure than R22 for high temperature operation. And this mixture can be used with the same characteristics as R22 at normal temperature operation in the newly-developed composition changeable circuit with the separation.

7. REFERENCES

1) T. Kuwahara et al.: The 19th Autumn meeting of the Society of Chemical Engineers, Japan 389 (1985)

2) Y. Yoshida et al.: National Technical Report 29 (1) 111 (1983)

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