1994

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New Application of R502 Substitute Refrigerant into Freezer-Refrigeretor

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1. Abstract

In Japan, refrigerant R502 is widely used mainly for large refrigerators as well as for merchandisers and automatic vending machines. Especially when it is applied to large household refrigerators, it provides such advantages as downsizing of compressor ranges compared with CFC12, possibility of increased cooling speed during a rapid freezing operation and improvement of reliability with low discharge gas temperature compared with HCFC22. Moreover, a mixed refrigerant R502+CFC12 containing approximately 10% of R12 has so far been adopted from a view point to improve the solubility with lubricating oil. In response to the declaration of control on chlorofluorocarbon by the Montreal Protocol, attention has been given to HCFC22 and its mixtures as substitute refrigerant for R502 and a lot of studies have been made on many substitutes. However, those materials have so far been positioned simply as transit refrigerants because of such defects as high discharge gas temperature, dissatifactory solubility with lubrication oil, ODP not equal to zero. For those reasons, we would like to report the results of the listing up of a new substitute refrigerant for R502 free from the said defects and the studies on its application to refrigeration system.

2. Screenig of refrigerant

Many kinds of mixed refrigerant containing HCFC22 are proposed as refrigerant substituted for R502. [1) 2)] However, our studies at this time were concentrated on HFC mixture refrigerants because we thought it better to apply HFC in a long perspective considering the reinforced control on HCFC implemented in recent years. HFC134a, HFC125, HFC32 and HFC143a are conceivable as HFC mixture candidate refrigerants but none of them can be used independently as a substitute refrigerant for R502. We therefore made various studies on mixtures of 2 to 3 kinds of HFC by using refrigerant property simulations developed by Matsushita Electric. For the details of the simulations, refer to other reports. [3) 4)] Table. 1 indicates the results of calculation of capacity, coefficient of performance (COP), condensing pressure, evaporating pressure, discharge temperature and sliding temperature under the condition of the condensing temperature at 313K(104°F) and the evaporating temperature at 238K(-31°F). In the actual screenig, ODP was excluded from the evaluation because it is 0 and the evaluation was made on GWP, inflammability, oil solubility, and so on. From total rating of those factors, we selected the combination of HFC143a/HFC125/HFC134a= 50/40/10 wt% as a suitable refrigerant to drop-in and the combination of HFC32/HFC125/HFC134a= 20/40/40 wt% as a refrigerant with high efficiency. For HFC143a mixture, we are currently continuing studies by changing the mixing ratio. The HFC32 mixture refrigerant selected among the said refrigerants was announced as Klea 60 by ICI Chemicals with same mixing ratio during our studies. In addition, as for the mixing ratio of the 143a mixture refrigerant, we thought that Suva® HP62 by DuPont is advantageous in availability and suppliability. We conducted the experimental studies to apply two types of refrigerants to our refrigeration system.

3. Calorimetry of compressor

Fig. 1 indicates the results of measurement by calorimeter of compresser using the said HFC32 mixture refrigerant and the HFC143a mixture refrigerant made on a rotary compressor. Comparing to refrigerator application, the HFC143a mixture refrigerant indicates a higher capacity and a higher efficiency compared with R502 + CFC12 because the cooling in the superheating area is not taken into account. The HFC32 mixture refrigerant deteriorates in both coefficient of performance and refrigerating capacity as the evaporating temperature drops. This is because, with a non-azeotropic refrigerant, the calorimeter conditions are decided mixture on the pressure and this makes the superheating area larger as the evaporating temperature drops.

4. Measurement of refrigerator performances

Table. 2 indicates the results of performance measurement of the drop-in performance of the respective mixed refrigerants made on the No.1 refrigerator of 460L class (16cu-ft) provided with rapid freezing function and automatic ice making function. With HFC143a mixture refrigerant,. the charged quantity of refrigerant can be reduced by 20g compared with the mixed refrigerant of R502 +CFC12 if the quantity of each component refrigerant is rationalized in a way to ensure high efficiency of the evaporator. In generally speaking, in one same refrigeration system, the optimal charged quantity of the refrigerant tends to come smaller with refrigerants of a larger latent heat of evaporation. As refrigeration oil, we used a mineral oil for R502+CFC12 and for the HFC32 mixture refrigerant and the HFC143a mixture refrigerant, an ester oil which is more soluble with those refrigerants.

We can confirm the improvement as follows, with the HFC143a mixture refrigerant, the temperature in the freezer compartment dropped by 0.4K (0.72°F) and the temperature in the fresh food compartment dropped by 1K (1.80°F). On the other hand, with the HFC32 mixture refrigerant, the refrigerating capacity became poorer with an increase of 1.1K (1.98°F) in the freezer compartment temperature and an increase of 1.6K (1.83°F) in the fresh food compartment temperature. Furthermore, the electrical input power increased by 3 to 6% with the both mixed refrigerants. The power consumption at a fixed internal temperature deteriorated by approximately 2% with the HFC143a mixture refrigerant and by as much as 13% with the HFC32 mixture refrigerant. It is also noted that, while the temperature difference between the inlet and the outlet of the evaporator is 0.2K (0.36°F) only, this difference is as large as nitride ceramic. As a result, we succeeded in eliminating the wear of the vanes. However, a new wear of approximately 5 μm was produced on the shaft. This is because the sliding condition of the shaft became extremely unfavorable from such reasons that, with the HFC143a mixture refrigerant and the HFC32 mixture refrigerant, the discharge pressure becomes higher compared with HFC134a, the load on the bearing almost doubles and the solubility of refrigerant in the compressor becomes high, causing sharply lowering the viscosity of the refrigeration oil. We studies this problem by changing the contact surface area between the shaft and the bearing, and succeeded in eliminating the wear by increasing the surface of the bearing by 20% only. The results of this improvement are indicated in the latter half of the Table.4. Moreover, we also made similar studies by using a refrigeration oil of non-soluble with the HFC143a mixture refrigerant, but the wear of the vanes and the roller became extremely large. From this fact, we presume that there is a possibility of existence of a certain point at which the lubricating conditions greatly change under high-temperature and high-pressure conditions when a non- soluble refrigeration oil is applied to a high-internal-pressure type compressor such as rotary compressor.

7. Conclusion

We indicated the results of studies conducted by using refrigerator and compressor on the HFC143a and HFC32 mixture refrigerant which use HFC mixture refrigerants only as substitute refrigerants for R502 + CFC12. As far as the application to refrigerators is concerned, not only near-azeotropic HFC143a mixture refrigerants but also non-azeotropic mixed refrigerants with a sliding temperature up to 3K (5.40°F) or so such as HFC32 mixture refrigerant can well be used with an simply improvement to the heat exchanger. Moreover, while the discharge pressure becomes higher with the HFC32 mixture refrigerant compared with HFC134a, its reliability improves through adjustment of the bearing load.

8. References

1)M.B.Shiflett and A.Yokozeki, "Near-azeotropic refrigerants as alternatives for R502", ASHRAE Journal, Vol.35, No2, Feb., p24(1993)

2)R.Oshima, "Mixed refrigernts replacing R500, R502 and R503(in Japanese)", Refrigeration, Vol.69(796), p136(1994)

3)Y.Yoshida et al., "Thermodynamic estimation mathod of ternary refrigerant mixtures using new mixing rules(in japanese)", Trans. of the JAR, vol.8, No3, p195(1991)

4)Y.Yoshida et al., "Utilization of thermopysical properties in refrigeration cycle using HFC-mixtures", Proc.14th Japan Symp.on Thermophys.Prop., p103(1993

5)A.Lorenz and K.Meutzner, "Application of non-azeotropic two-component refrigerants in domestic refrigerators and home freezers", Proc. 14th Int. Cong. Refrig., p1005, IIR(1975)

6)K.Takaichi and H.Sakai, "Lubricants for HFC-134a compatible rotary comp", Proc. International compressor engineering conferance at Purdue, p1035(1992)

3.9K (7.02°F) with the HFC32 mixture refrigerant. This value indicated a high correlation with the results of the simulation. Fig. 2 indicates the results of detailed measurements of temperature made for each path of the heat exchanger of the evaporator under the continuous running conditions of the refrigerator. Usually, a heat exchanger for cooling is designed not to produce any temperature difference due to termination of evaporation of refrigerant by setting the inlet and the outlet at one same point to unify the formation of frost. For that reason, the end point of evaporation may become higher than the air side temperature in application of non-azeotropic refrigerant such as HFC32 mixture refrigerant. As a result, the refrigeration capacity is not utilized effectively and the internal temperature goes up.

5. Improvement of evaporator

To improve the performances with the HFC32 mixture refrigerant, we modified the evaporator and changed the path of flow on the refrigerant side so that the air flow and the refrigerant flow may be opposite to each other.(Refer. to Fig.3)

Table. 3 indicates the results of measurement of performances made on the No.2 refrigerator with modified path. The internal temperature of the freezer compartment improved by as much as 1.6K (2.88°F) in the continuous running operation. Moreover, the electrical input power is also improved by 2% and became about identical to that of the current R502 + CFC12. The energy consumption at a fixed internal temperature sharply improved with 0.4% up against approximately 6% up with the current heat exchanger. The above-mentioned improvements are gained by the effects of formation of Lorenz cycle as it was already pointed out theoretically in the past.[5] We assume that such effects were obtained because of a good agreement between the sliding temperature difference of the HFC32 mixture refrigerant on the inner side and that of the air on the outer side of the heat exchanger tube, especially in the study of this time. Moreover, also regarding frosting, while the fins of the heat exchanger for refrigerator have so far been made uneven to secure the necessary air capacity, the frosting became rather uniform instead with the use of a non-azeotropic mixed refrigerant. Namely, in the case of a refrigeration system having a heat exchanging style in which the air flow and the flow of refrigerant in the tube get in touch with each other over a comparatively long distance as refrigerator, it becomes possible to improve the refrigerating capacity and the coefficient of performance by positively utilizing the sliding temperature of refrigerant.

6. Reliability of compressor

Regarding the reliability of rotary compressors, we have so far been making various improvements against the problem of wear produced on the vanes and the roller with switching to HFC134a.[6] Table.4 indicates the results of a series of reliability tests conducted at this time on the substitute refrigerants for R502 + CFC12. First, we intended to improve the wear resistance and prevent chemical reaction on the sliding face by coating the vane material with a

Table. 1 Simulalation Result

Refrigerant component	Mixture ratio(%)	GWP	COP ratio	Capacity ratio	Discharge temp K (°F)	Sliding temp K (°F) ▲Tc	▲Te
current 502/12	87/13	3.29	100	100	407 (273.2)	0.8 (1.44)	0.8 (1.44)
143a/125/134a	50/40/10	0.91	83	89	389 (240.8)	1.6 (2.88)	2.1 (3.78)
[HP62]	52/44/4	0.94	81	95	388 (239.0)	0.5 (0.90)	0.7 (1.26)
143a/125 [AZ50]	50/50	0.97	79	97	387 (237.2)	0.1 (0.18)	0.1 (0.18)
32/125/134a [Klea60]	20/40/40	0.49	96	94	408 (275.0)	4.6 (8.28)	3.2 (5.76)
[AC9000]	30/10/60	0.28	99	83	419 (294.8)	5.1 (9.18)	6.7 (12.0)
32/125/134	20/50/30	0.51	96	92	403 (266.0)	7.6 (13.7)	6.0 (10.8)
134a	100	0.28	101	55	391 (244.4)	0 (0)	0 (0)

Table. 2 Drop-in performance

Fridge.1	Refrigerant/Oil		143a mix/Ester	32 mix/Ester	502+12/Mineral
	Refrigerant amount	g	240	260	260
AT 303K 60Hz Continous running	Freezer compartment	K (°F)	-0.4 (-0.72)	+1.1 (+1.98)	245.5 (-17.5)
	Fresh food compartment	K (°F)	-1.0 (-1.80)	+1.6 (+2.88)	262.2 (+12.5)
	Compressor discharge	K (°F)	-2.9 (-5.22)	+5.3 (+9.54)	396.2(+253.7)
	Condenser outlet	K (°F)	+0.4 (+0.72)	-1.2 (-2.16)	310.7 (+99.8)
	Evaporator inlet	K (°F)	-0.7 (-1.26)	-1.5 (-2.70)	235.5 (-35.5)
	Evaporator outlet	K (°F)	-0.9 (-1.62)	+2.0 (+3.60)	235.9 (-34.7)
	Input	W	+13(6%)	+7(3%)	219
AT 303K 60Hz Cycling	Running ratio	%	-1.9	+7.1	58.7
	Energy consumption	kwh/day	+0.08(+2.4%)	+0.44(+13.0%)	3.39

Table. 3 Modification performance

Fridge.2	Evaporator Design		Modified	Current	
	Refrigerant/Oil		32 mix/Ester		502+12/Mineral
	Refrigerant amount	g	260		260
AT 303K 60Hz Continous running	Freezer compartment	K (°F)	-0.4 (-0.72)	+1.2 (+2.16)	246.3(-16.06)
	Fresh food compartment	K (°F)	-1.5 (-2.70)	+1.5 (+2.70)	262.6(+13.28)
	Compressor discharge	K (°F)	+2.1 (+3.78)	+4.6 (+8.28)	401.1(+262.5)
	Condenser outlet	K (°F)	-2.1 (-3.78)	-1.6 (-2.88)	311.0(+100.4)
	Evaporator inlet	K (°F)	-1.0 (-1.80)	-0.7 (-1.26)	235.2(-36.04)
	Evaporator outlet	K (°F)	+2.1 (+3.78)	+2.9 (+5.22)	235.9(-34.78)
	Input	W	+5 (+2%)	+9 (+4%)	219
AT 303K 60Hz Cycling	Running ratio	%	-2.4	+1.6	62.6
	Energy consumption	kwh/day	+0.01(+0.4%)	+0.20(+5.7%)	3.57

Table 4 Reliability test result (500h)

Test specification	Refrigerant Oil Vane material Shaft design	502+12 Mineral Steel Current	143a mix. Ester Nitride ⇦	⇦ Insoluble ⇦ ⇦	⇦ Ester ⇦ Modified	32 mix. ⇦ ⇦ ⇦
Wear amount	Vane wear [μm] Shaft wear [μm]	15.0 0	5< 5.0	63.0 50.0	5< 0	5< 0
Oil changes	Color [ASTM] TAN [mgKOH/g]	L4.0 0.02	L2.5 0.11	L2.0 0.09	L5.5 0.7	L2.5 0.5

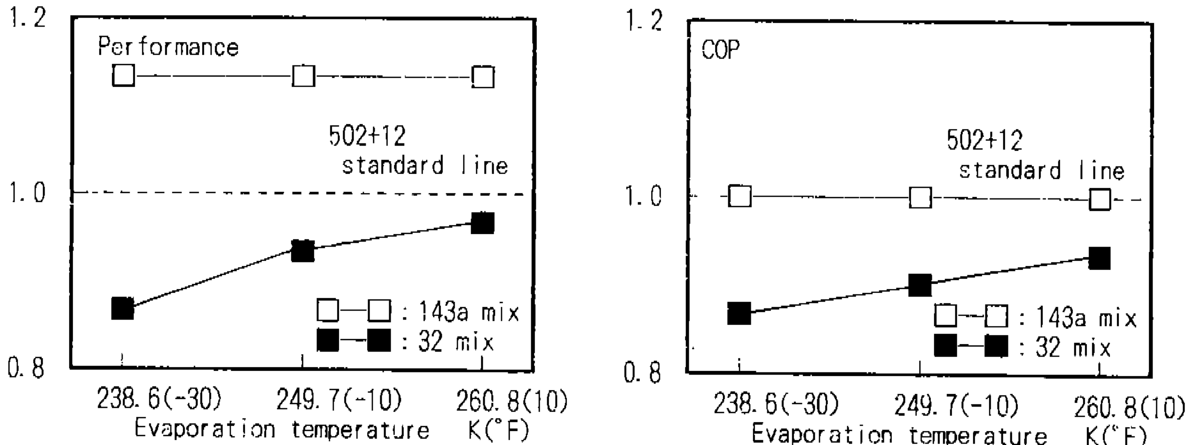

Fig. 1 Measurement of calorimeter

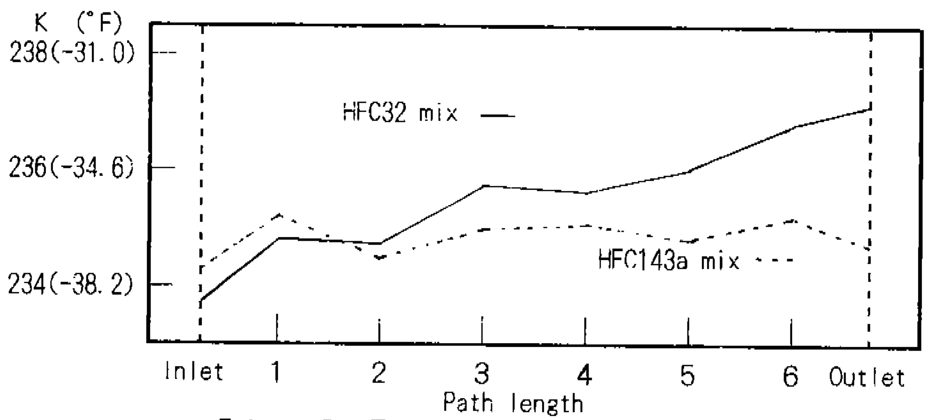

Fig. 2 Temperature sliding

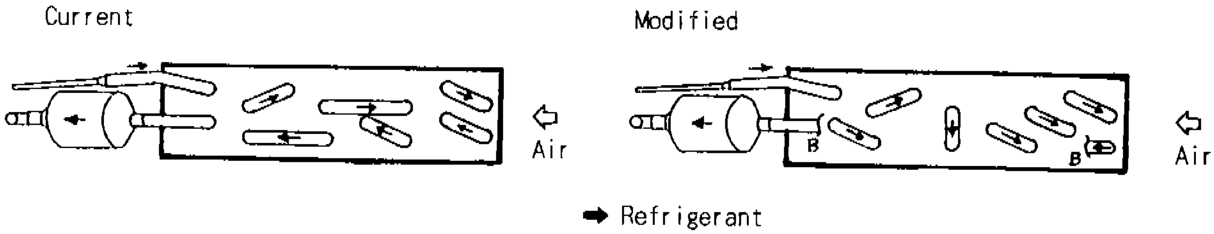

Fig. 3 Improvement of evaporator