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AN EXPERIMENTAL INVESTIGATION OF A REFRIGERATION COMPRESSOR USING HFC 134a AS A WORKING SUBSTANCE

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ABSTRACT

A proto type compressor using HFC 134a as a working substance is designed. As the specific volume of HFC 134a is larger than that of CFC 12, the mass flow rate and capacity are decreased. Reduction of residual gas and suction gas temperature and improvement of suction gas passage, motor efficiency, use of low viscocity oil are considered to improve the performance of a HFC 134a compressor. By these modifications, the COP of (Coefficient of Performance) HFC 134a compressor could be improved by 20 %. The results of compressor life tests and compatibility tests practiced with 4 kinds of ester oil are reported.

NOMENCLATURE

A	area of suction muffler inlet
c	speed of sound
fc	cut off frequency of suction muffler
L	length of suction muffler inlet
Ls	Attenuation
m	mass flow rate
m_{leak}	leakage
Q	capacity
Δh_{eva}	difference of enthalpy between evaporator outlet and inlet
V	suction muffler volume
Vd	displacement
v_s	specific volume
W_{eff}	isentropic work
W_{loss}	energy loss during gas compression
W_{32}	energy consumption using 32 cst oil
W_{15}	energy consumption using 15 cst oil
N	rpm
η_v	volumetric efficiency

INTRODUCTION

After the publication of the critical effect of the CFCs on the earth's atmosphere, extensive works have been done to search for new refrigerant to substitute for CFCs. CFC 12 has been widely used as a refrigerant in the refrigeration field due to its excellent thermodynamic properties, chemical stability, non-toxicity, non-flammability.

HFC 134a, although it does not possess all the necessary and sufficient conditions, is currently being studied to replace the CFC 12 as it has relatively similar thermody-namic properties with CFC 12.

The problems to be solved to use HFC 134a as a new refrigerant may be listed as follows.
(1) Performance
(2) Development of new lubricant
(3) Material compatibility

It can be said that one of difficult problems of HFC 134a is a capacity drop resulted from its relatively large specific volume. (Table 1) Although this capacity drop may be easily compensated for by the simple increase of displacement volume, it is more effective to find ways to increase mass flow rate with current displacement volume as it is not always possible to increase displacement volume and it does not imply improvement of efficiency.

Table 1.

	HFC 134a	CFC 12
m	0.7	1
Δh_{eva}	1.24	1
Q	0.87	1

As HFC 134a shows very poor miscibility with mineral oil, it is necessary to develop new lubricant miscible with HFC 134a. Although much work has been done with PAG, polyol ester shows more possibility than PAG in view of hygroscopicity and lubricity. However thermal stability, hydrological stability, still need to be estimated for the compressor reliability. This study is to review measures to improve a compressor performance, to discuss lubricant problem and materials compatibility using HFC 134a as a working fluid.

PERFORMANCE

(1) Model Compressor

Ball joint type reciprocating compressor is used for this study. This model is widely applicated in the domestic refrigeration market. Specification is summarized in Table 2.

Table 2

Specification

Capacity *	200 kcal/h
Bore	23.5 mm
Displacement	7.02 cc/rev
motor output	175 watt
Dimension	ϕ159 x H 170

* with CFC 12

(2) Method of approach

General losses in a reciprocating compressor are shown in Fig.1 for the purpose of brief overview. The mass flow rate, capacity, and COP may be written as equations (1),(2),(3).

$$m = \frac{60\ N\ \eta_v\ V_d}{v_s} - m_{leak} \qquad (1)$$

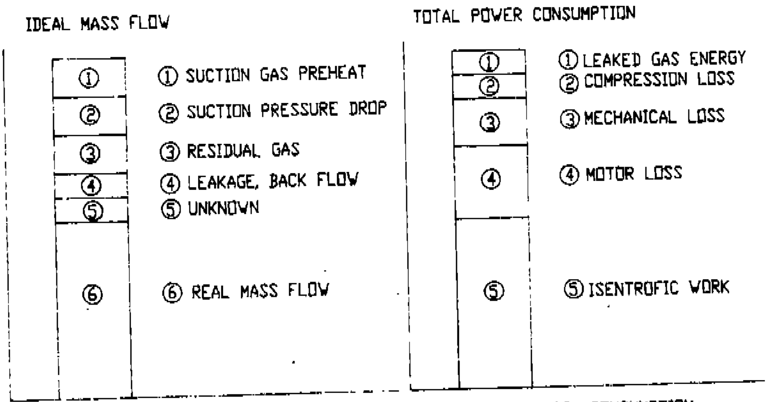
$$Q = m\ \Delta h_{eva} \qquad (2)$$

$$COP = \frac{Q}{W} = \frac{m\ \Delta h_{eva}}{W_{eff} + W_{loss}} \qquad (3)$$

Equation (3) is chosen as a objective function of this study. Each physical factors affecting the objective function will be reviewed. The way of approach is very simple, improvement of volumetric efficiency, reduction of specific volume to increase mass flow rate, and reduction of mechanical and electrical losses. Many previous studies were interested only in the reduction of energy losses to improve compressor efficiency, while this study is rather interested in the increase of mass flow rate as a tool of improving the COP. The degree of compressor design optimization will be measureded by the convergence of real mass flow rate to the ideal mass flow rate. For this purpose, one may define a new parameter coefficient of mass flow rate η_{mf} as follows.

$$\eta_{mf} = \frac{\text{real mass flow rate}}{\text{ideal mass flow rate}} \qquad (4)$$

Ideal mass flow rate is obtainable only when $\eta_v = 1$, $m_{leak} = 0$, $m_{lub} = 0$, suction gas preheat during suction process = 0. Therefore the way to the design modification is evident, $\eta_{mf} = 1$, $W_{loss} = 0$.



(a) MASS FLOW RATE (b) ENERGY CONSUMPTION

FIG. 1 GENERAL LOSSES IN A RECIPROCATING COMPRESSOR

Effect of suction gas temperature

There are many previous studies on the effect of suction gas temperature. Specific volume of suction gas is reduced as the decrease of suction gas temperature to increase the mass flow rate, while the gas compresson work is not so sensitive to the gas temperature./2/ It can be said that the effect of suction gas temperature is straight-forward and the amount of reduction simply depends on the system design. We could reduce 5 C of suction gas temperature to improve 2 % of capacity, 1.5 % of COP with the increased shell surface area (10 %) and nearer semi direct suction, shape improvement of suction inlet to prevent suction gas from being dispersed at the suction pipe.

Effect of suction pressure drop

As the pressure drop during suction process causes increase of specific volume and decrease of capacity, reduction of pressure drop results in improvement of capacity and efficiency. While suction loss can be divided into two parts — suction valve loss and suction passage loss, we simply confined our interest only to the suction passage loss, and reduction of pressure drop by 0.01 kgf/cm G showed 3 % increase of capacity, 2.5 % improvement of COP. The reduction of pressure drop was achieved by the simplification of suction muffler structure.(increase of A and decrease of L) One thing to be mentioned here is that the cut-off frequency of suction muffler is shifted up due to the difference of sonic velocities in CFC 12 and HFC 134a. (C_{134a} / C_{12} = 1.15)

$$f_c = \frac{c}{2\pi}\sqrt{\frac{A}{L\,V}} \qquad (5)$$

As it can be said that compressor noise level is proportional to the cut-off frequency of suction muffler, this shift up may be regarded as one source of rather noisy HFC 134a compressor.

And also the shift up of cut-off frequency accompanied with the muffler structure must be reduced for the even compressor noise level. Table 3 summarizes these procesure.

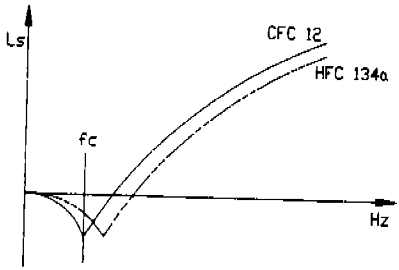


FIG. 2 SHIFT OF CUT-OFF FREQUENCY

Table 3. Shift up of suction muffler cut off frequency due to the difference of sonic velocity

	conventional design with CFC 12	conventional design with HFC 134a	proto-type design with HFC 134a	Improved design with HFC 134a
ratio of cut off frequency noise level capacity C O P	1 reference - -	1.15 + 1 - 2 dB reference reference	1.8 + 3 dB + 3 % + 2.5 %	1.1 less than 1 dB + 3 % + 2.5 %

Effect of residual gas

Many previous studies on the effect of residual gas conclude that clearance volume can be optimised for any given piston and valve plate design. /3/

The residual gas prevent fresh new gas from being sucted during re-expansion process, while too small a clearance volume increases over-compression loss.

The performance was best at the 0.7 % clearance volume ratio, and

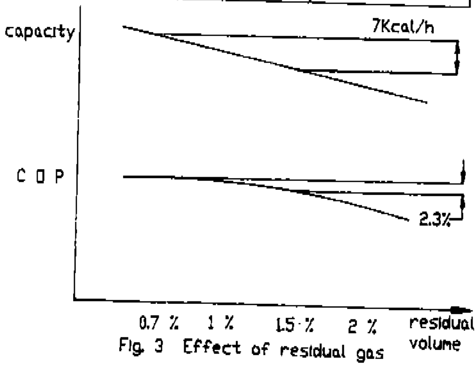


Fig. 3 Effect of residual gas

this was also geometrically possible. 1.4 % increase of capacity and 2.3 % of COP were achieved by the modulation of residual volume.

Effect of low viscosity oil

Frictional loss can be reduced by the use of low viscosity oil. Fig. 4 shows the differences of power consumption between 32 cst and 15 cst lubricants. The effect of low viscosity oil is more remarkable when the shell temperature is low.

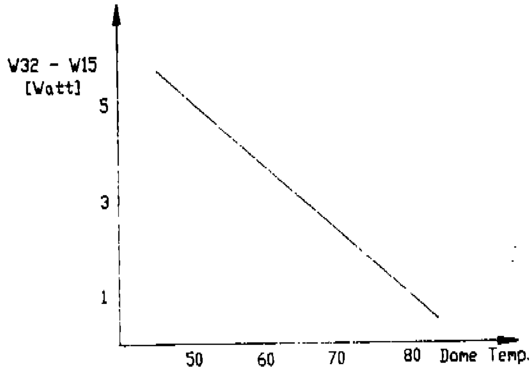


Fig. 4 Effect of low viscosity oil

Improvement of motor efficiency

While motor design of hermetic compressor is restricted by the required starting characteristics, reduction of the coefficient of friction by the surface treatment on the shaft and bearing makes room for the improvement of motor efficiency. Summing up all the effect of improved core material, reduced motor open slot, air gap, we could improve motor efficency from 70 % to 80 % . Table 4 shows the comparison of motor specifications.

Fig.5 shows every effect of compressor design modifications.

Table 4
Motor improvement

core material	3 %
open slot	2 %
air gap	2 %
torque reduction	3 %

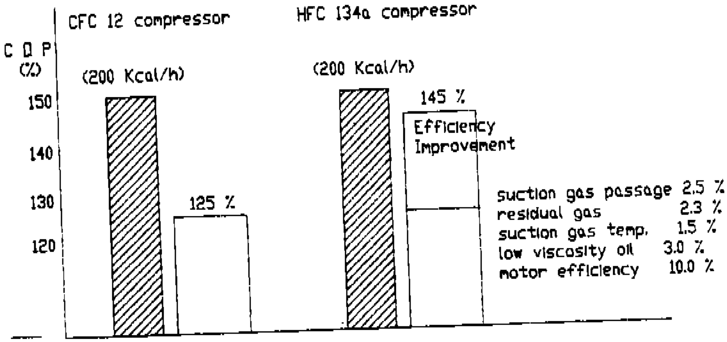


Fig. 5 Performance comparison

LUBRICANT

1 complex type ester and 3 hindered type esters are tested for the HFC 134a compressor (Table 5). The comparison was done by the T.A.N.(Total Acid Number) and metal contents in the life tested lubricants (Table 6). Although conventional method like falex load and wear test are very effective more emphasis was put on the real test.

The hydrolysis of esters may be regarded as one source of future troubles. Our simulative test is accelerating the hydrolysis by heat and intentionally added moisture. The hydrolysis is rated by the change of T.A.N. The test condition and result of lubricants' hydrolysis are described at Table 7. The effect of metal surface treatment on the wear is presented in Table 8. The influence of moisture on the wear is shown in Table 9.

Table 5 Typical properties of lubricant

Lubricant	Type	viscosity (cst) 40 C	100 C	VI	T.A.N. (mgKOH/g)
Ester A	complex	31.5	5.8	133	0.01
Ester B	hindered	22.5	4.6	132	0.025
Ester C	hindered	31.49	5.22	102	0.01
Ester D	hindered	32.4	5.25	97	0.01

Table 6 Analysis of used Lub. (500 Hr life test)

Lub.	T.A.N. New	T.A.N. Used	Metal * Element Fe	Cu	Al
Ester A	0.01	0.26	10	1	1
Ester B	0.025	0.17	3	1	1
Ester C	0.01	0.01	5	1	1
Ester D	0.01	0.02	5	1	1
CFC 12 Mineral	0.01	0.30	5	1	1

<u>Test condition</u>
Ps = 0.1 Mpa, Pd = 3.0 Mpa
Dome Temp. = 95 - 105 C
* metal content [ppm]

Table 7 Hydrolysis

Lubricant	moisture (ppm)	T.A.N. (mgKOH/g)	Catalyst
Ester A	1000/170	0.025/3.6	Fe,Cu,Al
Ester B	1000/ 90	0.01/4.8	
Ester C	1000/150	0.01/3.1	
Ester D	1000/260	0.01/2.7	

<u>Test condition</u>
Lub / HFC 134a = 3 / 1 , Duration = 175 C , 14 days

Table 8 Effect of metal surface treatment

Metal element					
with s/t			without s/t		
Fe	Cu	Al	Fe	Cu	Al
5	1	1	10	1	1

MATERIAL COMPATIBILITY

The compatibility with HFC134a/ester mixture of all the construction material are tested by the autoclave test method or bomb test method and the results are compared with the one practiced with CFC 12/mineral oil mixture.

One thing to be appreciated is that it is difficult to draw a general conclusion as the compatibility test result is dependent on the characteristics of locally available materials and lubricant.

<u>Compatibility of PET film</u>

PET film currently being used with CFC 12 is not so compatible with HFC 134a/ester as CFC 12/mineral oil in view of oligomer extraction. But the one being used with HCFC 22 shows good compatibility with HFC 134a/ester. (Table 10)

<u>Compatibility of magnetic wire</u>

Both of polyester nylon and EI/AI wire shows compatibilty with HFC 134a/ester (Table 11).

Table 10 Compatibility of PET film

Material	Mixture	Oligomer wt %	Estimation
PET 1	R12/Mineral	0.28	Reference
PET 2	R12/Mineral	0.10	Better
PET 1	R134a/Ester C	0.53	Worse
PET 2	R134a/Ester B	0.05	Better
PET 2	R134a/Ester C	0.03	Better

<u>Test condition</u> 130 C x 40 Days
PET 1 for CFC 12 , PET 2 for HCFC 22

Table 11 Compatibility of magnetic wire

Material	Mixture	B D V [Kv] Before	After
Polyester	R12/Mineral	12	6
AI/EIW	R12/Mineral	12	11.6
Polyester	R134a/Ester C	12	11
AI/EIW	R134a/Ester C	12	10

<u>Test condition</u> 150 C x 7 Days
* No Blister was found.

CONCLUSION

(1) HFC 134a can be used instead of CFC 12 in the current refrigeration system. But the compressor design modification is needed for the sake of energy efficiency. Total of 20 % improvement of COP was achieved in this study.

(2) Lubricant
Hindered type ester shows better characteristics of lubricant than complex type ester. But a great amount of attention must be paid to the prevention of moisture penetration (less than 40 ppm) during compressor manufacture process as there still remains the possibility of hydrolysis.

(3) Material Compatibility
Both of polyester nylon and EI/AI wire can be used with HFC 134a/ester while it is necessary to review the compatibility of PET film in view of oligomer extraction.

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REFERENCES

(1) J. Kim and W. Soedel, " Performance and gas pulsations when pumping different gases with the same compressor.", 1988 Purdue compressor engineering conference.

(2) Hideki Kawai, " The development of high efficiency compressors by reducing suction gas temperature.", 1982 Purdue compressor engineering conference.

(3) John J. Jacobs, " Analytic and experimental techniques for evaluating compressor performance losses.", 1976 Purdue compressor engineering conference.