Thermodynamic Performance Analysis and Test of Refrigerator Using R152a as Refrigerant

T. Liancheng
Xi'an Jiaotong University

G. Yunting
Xi'an Jiaotong University

THERMODYNAMIC PERFORMANCE ANALYSIS AND TEST OF REFRIGERATOR USING R152a AS REFRIGERANT

Tan Liancheng* Ge Yunting*
(L.C. Tan) (Y.T. Ge)
Xi'an Jiaotong University
Xi'an, China

ABSTRACT

The paper presents the first report of our work on the selection of substitutes for domestic refrigerator working fluid R12. A modified Patel-Teja equation of state is used to calculate the refrigerants thermodynamic properties. A simulating calculation model for refrigeration cycle of domestic refrigerator is proposed and the thermodynamic performance using R12, R134a, R152a was calculated and compared. R152a was selected as an alternative of experimental working fluid of refrigerator. 3% energy saving was measured by use of R152a to substitute for R12 in the primary test of a refrigerator. R152a is recommanded as alternative for R12 in further research.

INTRODUCTION

R12 (CFC12, CCl_2F_2) has been used as a refrigerant in domestic refrigerator more than 60 years, because of its suitable thermodynamic properties, chemical stability, non-toxicity, non-flammability and low cost. In the last 15 years there has been increasing concern about the enviromental problems of CFCs, namely the possible depletion of the ozone layer of the earth in the stratophere and an additive "greenhouse-effect" by preventing the infra-red radiation from the earth into space.

These environmental effect led to the signing of the Montreal Protocal in 1987 requesting to reduce the consumption of fully halogenated CFCs including CFC12. Therefore, new working fluids substituting for CFC12 and other CFCs are under development.

After having made an extensive inventory analysis, R134a (HFC134a, CH_2FCF_3) has been suggested as one of realistic substitute of R12[1]. The character of the R134a is that the value of ODP (Ozone Depletion Potential) equals zero, non-flammability and stability, the temperatures of boiling point and critical point are very near to that of R12. However, the toxicity of this substitute has not been fully investigated.

R152a (HFC152a, CH_3CHF_2) is one of recently available refrigerants on the market and also has the same advantages as R134a but flammability.

In this paper, thermodynamic performance analysis and comparison of refrigerator using R12, R134a, R152a as refrigerant, and a primary result of refrigerator testing using R152a as alternative working fluid of R12 are presented.

SIMULATING CALCULATION MODEL

Considering the real structure of domestic refrigerator, a simulating calculation model for the thermodynamic performance analysis is shown in the pressure-enthalpy diagram as 1-2-3-4-4'-5-5'-6-7-1 depicted in Figure 1. Where 1-2 shows the compression process, affection of efficiency of compressor volume, indication efficiency, friction efficiency of compressor and electric motor have been considered in power consumption calculating of hermetic compressor. 2-3-4 shows the condensation process of pure refrigerant in the condensor, 4-4' the subcooling process in the tube for warming the door sealing. 4'-5-5'-6-7 is the refrigerant throttle process while passing through the capillary tube. From the inlet to exit, the capillary

* L.C. Tan is professor and Y.T. Ge is graduate student of Dept. of Power Machinery Engineering, Xi'an Jiaotong University, Xi'an, China.

contains (Figure 1.) adiabatic single-phase flow 4'-5, diabatic single-phase flow 5-5', diabatic two phase flow 5'-6, adiabatic two phase flow 6-7. The middle part of the capillary tube is always soldered to the suction tube of the compressor, around them covered with heat insulation material, and form a counter flow heat exchanger. Process 5-6 shows the heat emit (h_5-h_6) of refrigerant in the throttle process while 1'-1 shows the heat absorb ($h_1-h_{1'}$) in the suction tube of the compressor. It is seen that the enthalpy of the refrigerant in throttle process decreases from $h_{4'}$ to h_7. At the same time, superheat vapor suction of the compressor is guaranteed. The refrigeration capacity per kilogram of the refrigerator equals $h_{1'}-h_7$, since $h_5-h_6 \simeq h_1-h_{1'}$ and $h_{4'}=h_5$, $h_6=h_7$, so the capacity can be calculated by $h_1-h_{4'}$.

THERMODYNAMIC PROPERTIES CALCULATION

For thermodynamic cycle calculating, the first question is how to select the equation of state. Using Petel-Teja equation of state[2] to calculate thermodynamic properties of refrigerants is better than the other cubic volume EOS was demonstrated in reference [3]. A modified Petel-Teja EOS was done in our research group[4], in which we proposed the constant values of two key parameters $\S_c$ and m in the EOS of 20 kinds of refrigerants based on regression method with the objective function $D = Dv^l + Df$, it means to increase the prediction accuracy of specific liquid volume v^l and meet the condition of equal liquid fugacity and vapor fugacity $f^l=f^v$ in the two phase region.

In this work, in order to reach more better prediction accuracy of thermodynamic properties of R12, R152a and R134a, the two parameters $\S_c$ and m is considered as function of temperature, and more better calculation precision is obtained. Table 1 gives the deviation of calculation results with reference data[5,6] of saturated thermodynamic properties for R12, R134a and R152a with this further modified.

Table 1 Deviation of saturated thermodynamic properties for R12, R134a and R152a

fluid	number of points	T_r	Δvv%	Δvl%	ΔPs%	Δhl%	Δhv%	ΔSl%	ΔSv%
R12	35	0.449–0.901	0.7453	0.6616	0.4142	2.4335	0.7201	2.8527	0.2375
R134a	25	0.623–0.979	1.8733	0.6061	0.2291	4.2786	1.5267	6.1234	1.7104
R152a	25	0.577–0.9	0.6662	0.5422	0.3634	2.1416	0.8447	1.1603	0.7123

here, T_r is reduce temperature, $T_r=T/T_c$, T_c refers to critical temperature $\Delta Z\% = |Zcal-Zref|/Zref \times 100\%$, Z refers to saturated state of vapor specific volume vv, liquid specific volume vl, vapor pressure Ps, liquid specific enthaply hl, vapor specific enthaply hv, liquid specific entropy Sl, and vapor specific entropy Sv, and Zref refers to the reference value of Z.

Hence, the further modified Petel-Teja EOS was selected to calculate the thermodynamic properties with which the computer program of cycle calculation and analysis was made.

Figure 2 is a diagrammatic sketch of theoretical refrigeration cycle of R12, R134a and R152a in the lgp-h diagram. The saturated curves of these refrigerants in the Figure were calculated by use of the further modified Petel-Teja EOS. It is seen the refrigeration capacity per kilogram of R152a is much larger than that of R134a and R12 under the condition of the same evaporation temperature.

THERMODYNAMIC PERFORMANCE OF R12, R134a, R152a

In order to analyse and compare the thermodynamic performance using different refrigerant in the same work condition, according to the refrigerator experimental condition and the previous test data of one kind of refrigerator which will be used for testing, the key parameters are selected as follows: the ambient temperature is 32°C, condensation temperature t_k is 42°C, subcooling temperature is 3°C ($t_4-t_{4'}$ in Figure 1), inlet temperature t_1 of compressor (point 1 in Figure 1) is 22°C, and the same type of compressor is used.

Figure 3 to Figure 10 respectively shows, the refrigeration capacity Q_o(W), volumetric capacity Q_v(kJ/m³), heat transfer from the condensor Q_k(W), power comsumption of the hermetic compressor W(W) and the coefficient of performance COP, evaporation pressure P_e(kPa), pressure ratio of the compressor π, and the outlet temperature of the compressor t_2(°C) of refrigerant R12, R134a, R152a vary with different evaporation temperature, at the same condensation temperature t_k=42°C.

These Figures demonstrate that, in the evaporation temperature range from -40°C to -20°C which is mostly used in domestic refrigerator, the refrigeration capacity Q_o of R152a is larger than that of R134a but less than that of R12; the volumetric capacity of both R152a and R134a is less than R12; the power consumption of R152a is about 80% that of R12 but a little higher than R134a, and the COP are comparable.

According to the condition indicated in the begining of this paragraph, and the evaporation temperature was chosen as -31°C, -30°C, -30°C respectively for R12, R134a and R152a, cycle calculating with the simulating calculation model has been done, and the results are given in Table 2.

Table 2 Thermodynamic performance calculation of refrigerator in a given condition

Properties	R12	R134a	R152a
W(W)	50.33	40.92	41.35
Q_o(W)	65.10	53.99	55.22
Q_k(W)	115.44	94.91	96.58
COP	1.29	1.32	1.34
Q_v(kJ/m³)	612.48	575.95	562.81
v_1(m³/kg)	0.2072	0.2797	0.4532
t_1(°C)	22	22	22
t_o(°C)	-31	-30	-30
t_k(°C)	42	42	42
P_e(kPa)	96.14	84.57	80.70
P_k(kPa)	1012.48	1071.32	964.09
	10.53	12.67	11.94
M(kg/s)	$5.13\cdot10^{-4}$	$3.35\cdot10^{-4}$	$2.17\cdot10^{-4}$

here, M is the mass flow rate, v_1 is the inlet specific volume of the compressor, P_k notes the condensation pressure, t_o is the evaporation temperature.

Some interesting results shown in Table 2 are given as follows:

For capacity Q_o(W): $Q_{o,12} > Q_{o,152a} > Q_{o,134a}$, $Q_{o,152a}=84.83\%Q_{o,12}$, $Q_{o,134a}=82.93\%Q_{o,12}$

Q_v(kJ/m³): $Q_{v,12} > Q_{v,134a} > Q_{v,152a}$, $Q_{v,152a}=91.89\%Q_{v,12}$, $Q_{v,134}=94.04\%Q_{v,12}$

Power consumption W(W): $W_{12} > W_{152a} > W_{134a}$, $W_{152a}=82.15\%W_{12}$, $W_{134a}=81.3\%W_{12}$

COP: $COP_{152a} > COP_{134a} > COP_{12}$, $COP_{152a}=1.039COP_{12}$, $COP_{134a}=1.023COP_{12}$

It is seen from the calculation results, due to $Q_{o,152a} < Q_{o,12}$, the cooling speed of R152a will be slower than that of R12 in the cooling speed experiment, and will make an increasing effect to the power consumption of the refrigerator. On the other hand, due to $COP_{152a} > COP_{12}$, it will make a decreasing effect to the power consumption of the refrigerator. Consequently, whether saving energy or not is determined to the comprehensive effect.

R12, R152a REFRIGERATOR PERFORMANCE EXPERIMENT

In order to verify the behaviour of the substitute R152a using as working fluid of refrigerator, a primary performance experiment of one type of refrigerator were carried out in Wanbao electrical appliance Industrial Corp., Guang Zhou, China. The refrigerator type is BCD-158A and the compressor type is FN 51Q-10G. The cooling speed and power consumption experiment were carried out at the ambient temperature of 32°C and 25°C respectively. For the testing refrigerator, after experiment using R12, the refrigerant charge quantities and the length of capillary are adjusted while using R152a, the final experimental results is recorded in Table 3.

Table 3 Cooling speed and power consumption experiments using R12 and R152a

Fluid	ti1 (min)	ti2 (min)	te1 (°C)	te2 (°C)	WE (W)	CO	CE (kWh/24h)
R12	58	88	-28.8	-31	90	0.36	1.04
R152a	68	97	-23.3	-27.2	87	0.42	1.011

here, ti1, the necessary time for the freezer temperature reach to -18°C from the begining of the experiment.
ti2, the necessary time for the freezer temperature reach to lower than -18°C and the refrigerator temperature reach to 5°C from the begining.
te1, the lowest temperature that the freezer can be meet.
te2, the lowest temperature that of evaporation.
CO, the working coefficient (hours of motor switch on/operating hours)
CE, the electrical power consumption per 24 hours.

SUMMARY AND CONCLUSION

A simulating calculation model for refrigeration cycle of domestic refrigerator is proposed.

Based on a modified Peta-Taja equation of state, calculating computer program has been made . The thermodynamic performance using R12, R134a, R152a was calculated and compared.

At the same work condition, the refrigeration capacity (Q_o(W)) of R12 is larger than that of R152a or R134a can not verify that the comprehensive thermodynamic cha- racter of refrigerator using R12 is better than that of R152a & R134a, other impor- tant factors, such as COP, power consumption must be considered. This view point has been verified by the refrigerator primary performance experiment. 3% energy saving was observed by use of R152a to substitute R12.We believe, through more careful and detailed adjustment of the charge quantity and capillary length and replacement of compressor, much better behaviour will be expected.

From the results of our study, although only thermodynamic performance we have analysed, and research work both in theory and experiment are still continuing, con- cerning to the thermodynamic properties, ODP=0, and the power consumption of R152a, it is worthy to recommend using R152a as the substitute of refrigerator working fluid in further research.

Flammability still is a problem, however, this requirement does not seem to be absolutely necessary for the refrigerant used in the close circuit of domestic re- frigerator.

ACKNOWLEDGMENTS

The authors want to express thanks to Wanbao electrical appliance Industrial Corp., Guang Zhou, China for the financial support of the experimental test and fellows joint to the experimental test both in Wanbao and in Xi'an Jiaotong Univer- sity.

REFERENCES

[1] Mclinden Mark. O., Didion David. A, P.E., "Quest for alternatives" ASHRAE J. December 1987.

[2] N.C. Patel, and A.S. Teja, "A new cubic equation of state for fluids and fluid

mixtures". Chem. Eng. Sci., Vol.37, pp.463, (1982)

[3] M. Fukushima, N. Ototake, "Estimation of Refrigerant mixture properties using a equation of state". Proc. XVII Int. Cong. Refrig. Vienna, Vol.B, pp.146-151 (1987)

[4] Y.H. Duan, & L.C. Tan "A modified Patel-Teja EOS" Proceedings of Engineering Thermophysics Science Meeting, October, 1989 (in Chinese)

[5] ASHRAE Handbook, 1985 FUNDAM. SI. EDITION, (1985)

[6] David P. Wilson, & Rajat S. Basu, "Thermodynamic Properties of A New Stratospherically Safe Working Fluid-Refrigerant 134a", Paper to be Presented at the ASHRAE Summer Meeting, OTTAWA, ONTARIO, June, (1988)

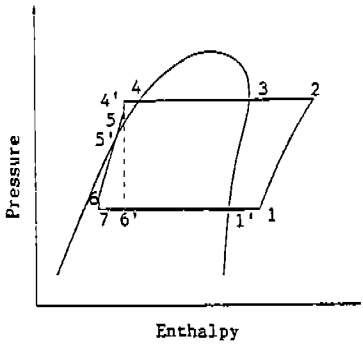


Fig. 1 The refrigeration cycle drawing of refrigerator simulating calculation model in the pressure-enthalpy diagram

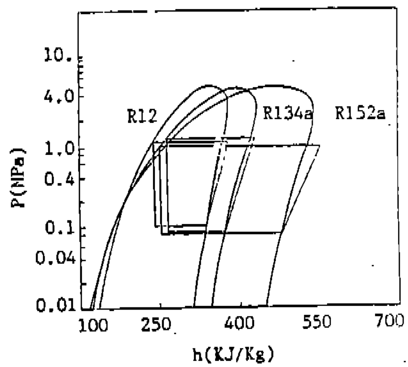


Fig. 2 The pressure-enthalpy diagram and the ideal refrigeration cycle drawing of R12, R134a and R152a

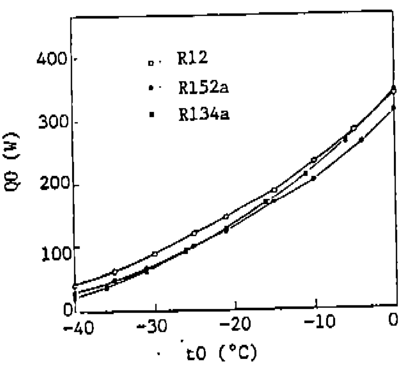


Fig. 3 The refrigerant capacity Q_o(W) — evaporation temperature t0 diagram, condensation temperature t_k=42°C

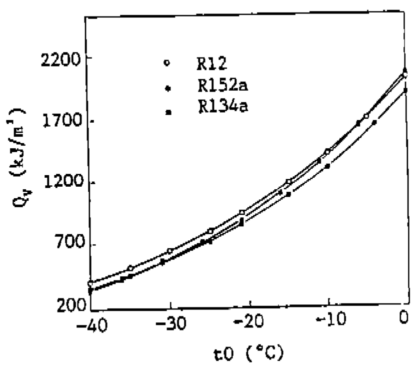


Fig. 4 The volumetric capacity Q_v (kJ/m³) — evaporation temperature t0 (°C) diagram, condensation temperature t_k=42°C

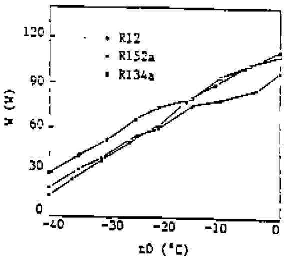


Fig. 5 The heat transfer from condensor Q_k(W) — evaporation temperature t0 (°C) diagram, condensation temperature t_k=42°C

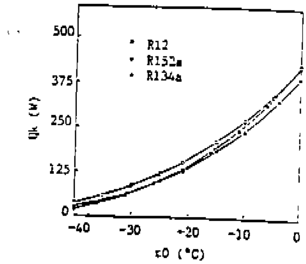


Fig. 6 The power consumption W(W) — evaporator temperature t0 diagram, condensation temperature t_k=42°C

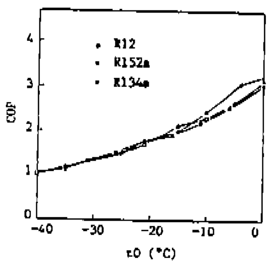


Fig. 7 The coefficient of performance COP — evaporation temperature t0(°C) diagram, condensation temperature t_k=42°C

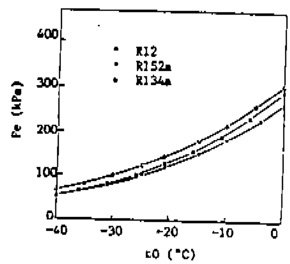


Fig. 8 The evaporation pressure Pe (kPa) — evaporation temperature t0 (°C) diagram, condensation temperature t_k=42°C

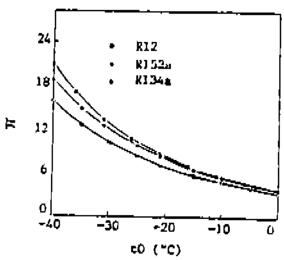
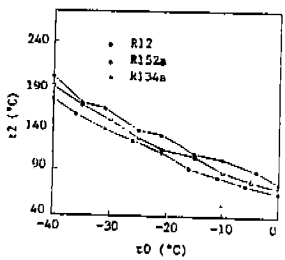


Fig. 9 The ratio of pressure π — evaporation temperature t0(°C) diagram, condensation temperature t_k=42°C



Fif. 10 The outlet temperature of compressor t2(°C) — evaporation temperature t0(°C) diagram, condensation temperature t_k=42°C