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Original Research Paper

Engineering

EFFECTS OF SUB-COOLING ON THE PERFORMANCE OF R152a AND RE170 AS POSSIBLE ALTERNATIVES IN A DOMESTIC REFRIGERATION SYSTEM

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ABSTRACT This paper presents the theoretical investigation of effects of sub-cooling on the performance of eco-friendly alternative refrigerants (R152a, RE170 (Dimethyl ether) in a domestic refrigeration system. The study was performed using a vapour compression system with the aim of finding a drop-in replacement for R134a. An increase in sub-cooling effectiveness reduces the compressors power and increases the system refrigeration effect. Also, an increase in the degree of sub-cooling, reduces the refrigerant mass flow rate, compressor power and increases both the refrigerating effect and coefficient of performance (COP) of the system. The comparison of the performance of R134a and the investigated alternative refrigerants showed that R152a and Dimethylether (DME) have the most similar performance characteristics to R134a with DME having better performance. These two refrigerants are the best replacements for R134a in a domestic refrigeration system.

KEYWORDS : R152a, DME, Alternative refrigerants, sub-cooling, R134a.

1.0 INTRODUCTION

R134a has been developed and adopted in domestic refrigerators due to the phase out of CFCs which have high ODP [1]. The Global warming potential of R134a is 1430 as compared to that of CO2 [2]. As per Kyoto Protocol 1997, it is considered as greenhouse gas and hence the production and use of same will be completed in few years. Hence it is to be replaced by eco-friendly refrigerants [3, 4]. Now it is imperative to identify the alternative refrigerant with low GWP in accordance with the limit fixed by EU Regulations [5]. R152a is the only HFC refrigerant that still can be considered as an alternative for R134a in refrigeration systems. While its GWP is about 130, its chemical properties are like those of R134a, thus it could be used in existing production system with just some small changes. R152a has 10% of GWP compared to R134a with lesser amount of refrigerant charge compared to R134a. In the other words with R152a as working fluid, refrigerant charge is about 35% lower than that of R134a. Due to its larger molecules in comparison with R134a, R152a has less refrigerant leakage. It has been proposed as a "drop-in" replacement for R-134a. (Mathur , 2003). The properties of selected refrigerants used in domestic refrigerators and freezers are shown in Table 1.1

TABLE 1. Properties of Selected Refrigerants

Physical properties	R134a	R152a	RE170
Molar mass (kg/kmole)	102.03	66.051	46.07
Triple temperature °C	-103.3	-118.59	-141.5
Boiling point °C	-26.07	-24.023	-24.84
Critical temperature °C	101.06	113.26	126.95
Critical pressure MPa	4.06	4.52	5.37
Critical density kg/m^3	511.9	368	270.99
LHV (KJ/kgK)	216.7	329.5	459.27
ODP	0	0	0
GWP	1430	124	10

A. Baskaran et al analyzed the performance of a vapour compression refrigeration system with various eco-friendly refrigerants of HFC152a, HFC32, HC290, HC1270, HC600a and RE170 and their results were compared with R134a as possible alternative replacement. The results showed that the refrigerant R152a have higher COP of 4.65% than that of R134a. [6]

A. Baskaran et al analyzed the energy and Exergy performance of a vapour compression refrigeration system with various eco-friendly refrigerants of HFC152a, and RE170 and their results were compared with R134a as possible alternative replacement. The results showed that the refrigerant R152a have higher average COP of 4.65% than that of R134a. The exergetic efficiency of the system using R152a is 5.02% higher than that of R134a at -10°C evaporating temperature. The average exergy loss for R152a is 8.2% lower than that of R134a.[7]

B.O. Bolaji et al. comparatively analyzed the characteristics of three ozone friendly refrigerants R32, R134a, R152a. Comparison among the investigated refrigerants confirmed that R152a and R134a have approximately the same performance, but the best performance was obtained from the use of R152a in the system. The average COP of R152a is higher than those of R134a and R32 by 2.6 and 17.6%, respectively. R152a refrigerant has approximately the same performance with R134a, therefore, R152a is considered as a good drop-in substitute for R134a in vapour compression refrigeration system [8].

A. Baskaran et al analyzed the performance of a vapour compression refrigeration system with various eco-friendly refrigerants including HFC152a and their mixtures. The results were compared with R134a as possible alternative replacement [9-16].

Nicholas Cox [17] presented to Transforming Technologies Conference, London. In that presentation, it is reported that the Di methyl ether (RE170, DME) makes a better refrigerant than R290 / R600a blends as it has no temperature glide and doesn't separate during leakage. It has been extensively adopted by the aerosol industry as the most cost effective replacement for R134a in propellant applications.

Valentinapostol et al [18] conducted a comparative thermodynamic study considering a single-stage vapour compression refrigeration system (VCRS) using as working fluids DME,R717, R12, R134A, R22 (pure substances) and R404A , R407C (zoetrope mixtures), respectively. The result of this study is that DME could be used as a refrigerant and, more, that DME could be a good substitution alternative for R12 and R134a.

B.M. Adamson [19] reported that the Di methyl ether (DME, C2H6O) possesses a range of desirable properties as a replacement for R-134a. These include better heat transfer characteristics than R-134a, a pressure/temperature relationship very close to R134a, compatibility with mineral oils, low cost and ready availability. It is also highly environmentally friendly. (ODP =0; GWP =1; atmospheric lifetime = 6 days) DME is compatible with most materials commonly found in refrigeration systems.

B.O. Bolaji [20] conducted an experimental evaluation of a liquid-suction heat exchanger applied in a domestic refrigerator using R12 and its alternatives .The results showed that R152a and R134a have the most similar performance characteristics to R12,with R152a having slightly better performance

The performance analysis of the alternative refrigerants in domestic refrigeration system is important in order to find a drop-in replacement for the existing refrigerant in the system. In this paper, the effects of sub-cooling on the performance of eco friendly alternatives (R152a, RE170) to and R-134a using Suction --Liquid heat exchanger are analyzed.

2. MATERIALS AND METHODS

2.1 Refrigeration System with Sub-cooling

The schematic diagram of vapour compression refrigeration system with a sub-cooling heat exchanger is shown in Fig. 1. In this system, the vapour leaving the evaporator is heated up by the condensate, the temperature of condensate decreases from T3 to T3' and the vapour is superheated before suction (the temperature increased from T1 to T1'). The sub-cooling heat exchanger is essentially a concentric type counter-flow heat exchanger which causes the sub-cooling of the liquid refrigerant before throttling.

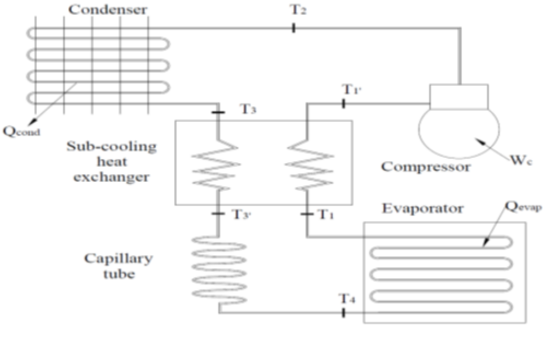

Fig. 1 Schematic of Vapor Compression Refrigeration System with a Liquid Suction Heat Exchanger.

Refrigerating effect without sub-cooling (Qevap, kJ/kg) = $(h_1 - h_4)$ (1)

The refrigerating effect with sub-cooling (*Q'evap*, kJ/kg) = $(h_{1'} - h_4)$ (2)

The compressor work input of the system without heat exchanger (*Wcomp*, kJ/kg) = $(h_2 - h_1)$ (3)

The compressor work input of the system with heat exchanger (*W'comp*, kJ/kg) = $(h_{2'} - h_1)$ (4)

where, h_1 = specific enthalpy of refrigerant at the outlet of evaporator (kJ/kg);

h_2 = specific enthalpy of refrigerant at the outlet of compressor (kJ/kg).

h_4 = specific enthalpy of refrigerant at the inlet of evaporator (kJ/kg).

$h_{1'}$ = specific enthalpy of refrigerant at the inlet to compressor after superheated by the heat exchanger (kJ/kg);

$h_{2'}$ = specific enthalpy of refrigerant at the outlet of compressor of the system with heat exchanger (kJ/kg).

$h_{4'}$ = specific enthalpy of refrigerant at the inlet of evaporator after passing through the heat exchanger and the capillary tube (kJ/kg).

The pressure ratio (*PR*) of the cycle is obtained as:

$$P_R = \frac{P_{cond}}{P_{evap}} \quad (5)$$

where, *Pcond* = absolute condensing pressure (Mpa)

Pevap = absolute evaporating pressure (Mpa).

The Coefficient of Performance (COP) is the refrigerating effect produced per unit of work required; therefore,

Without sub-cooling,

$$COP_{ref} = \frac{Q_{evap}}{W_{comp}} \quad (6)$$

With sub-cooling,

$$COP_{ref} = \frac{Q'_{evap}}{W'_{comp}} \quad (7)$$

According to klein and Reindl[21],the effect of sub cooling heat exchanger on refrigeration capacity can be quantified in terms of arelative capacity index as defined in eqn.(8)

$$RCI = \left(\frac{Capacity - Capacity_{nohx}}{Capacity_{nohx}}\right) \times 100\%$$

Where,

Capacity is the refrigeration capacity with a liquid-suction heat exchanger

Capacity nohx is the refrigeration capacity for a system operating at the same condensing and evaporating temperatures without a liquid-suction heat exchanger

The ability of a liquid-suction heat exchanger to transfer energy from the warm liquid to the cool vapor at steady-state conditions is dependent on the size and configuration of the heat transfer device. The liquid-suction heat exchanger performance, expressed in terms of effectiveness, is a parameter in the analysis.

According to klein and Reindl[21], the effectiveness of the liquid-suction heat exchanger is defined in equation (9):

$$\varepsilon = \frac{(T_2 - T_1)}{(T_3 - T_1)} = \frac{(T_{vapor,out} - T_{vapor,in})}{(T_{liquid,in} - T_{vapor,in})}$$

Where the numeric subscripted temperature (T) values correspond to locations depicted in Figure 1. The effectiveness is the ratio of the actual to maximum possible heat transfer rates. It is related to the surface area of the heat exchanger. A zero surface area represents a system without a liquid-suction heat exchanger whereas a system having an infinite heat exchanger area corresponds to an effectiveness of unity.

2.2 Method of Analysis

The software CYCLE_D 4.0 vapour compression cycle design program [22] was used for the analysis to find the performance of the system. The vapour compression refrigeration system with a liquid suction heat exchanger cycle is considered with the following conditions.

System cooling capacity (kW)	= 1.00
Compressor isentropic efficiency	= 1.00
Compressor volumetric efficiency	= 1.00
Electric motor efficiency	= 1.00
Pressure drop in the suction line	= 0.0
Pressure drop in the discharge line	= 0.0
Evaporator: average sat. Temp	= -10°C
Condenser: average sat. Temp	= 50°C
Heat exchanger effectiveness	= 0.1 to 1.0 (in steps of 0.1)
Degree of Sub cooling	= 2°C to 10°C (in steps of 2°C)

The analysis of the variation of performance parameters such as refrigerating effect, isentropic compression work, coefficient of performance, compressor power, and mass flow rate of R134a, R152a, DME are investigated in this theoretical study and they are plotted against the heat exchanger effectiveness as shown in figures from 2 to 5 and degree of sub cooling as shown in figures from 6 to 9.

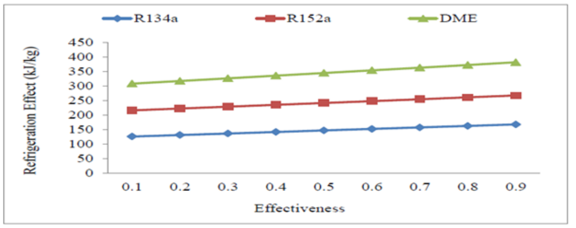

Fig.2 Variation of Refrigerating Effect as a function of the sub-cooling effectiveness

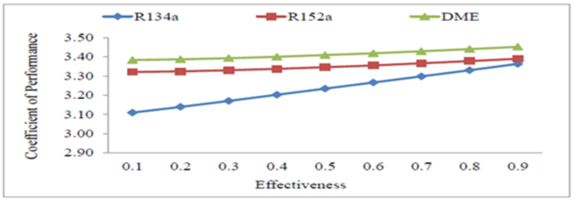

Fig.3 Variation of COP as a function of the sub-cooling effectiveness

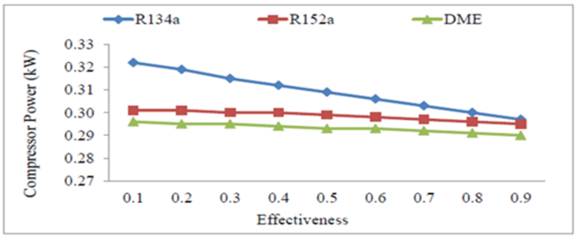

Fig.4 Variation of Compressor power as a function of the sub-cooling effectiveness

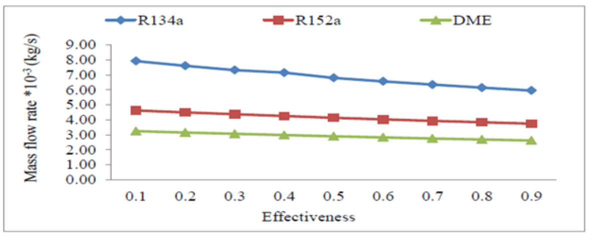

Fig.5 Variation of Mass Flow rate as a function of the sub-cooling effectiveness

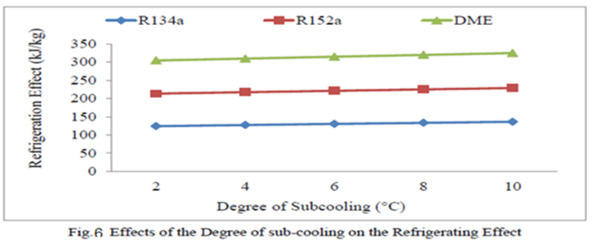

Fig.6 Effects of the Degree of sub-cooling on the Refrigerating Effect

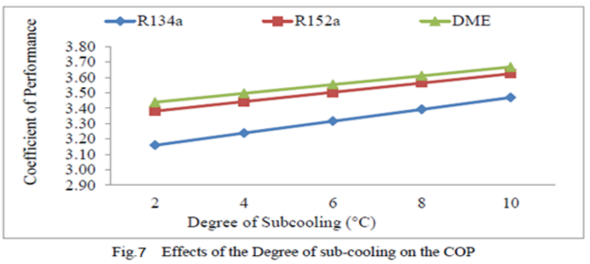

Fig.7 Effects of the Degree of sub-cooling on the COP

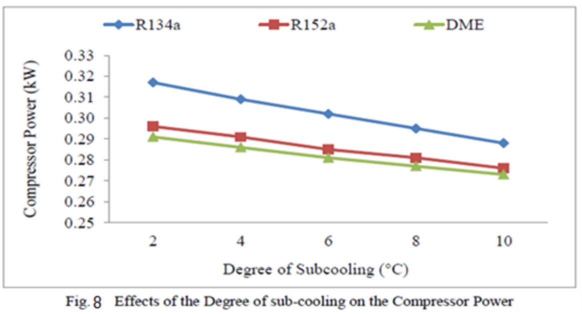

Fig.8 Effects of the Degree of sub-cooling on the Compressor Power

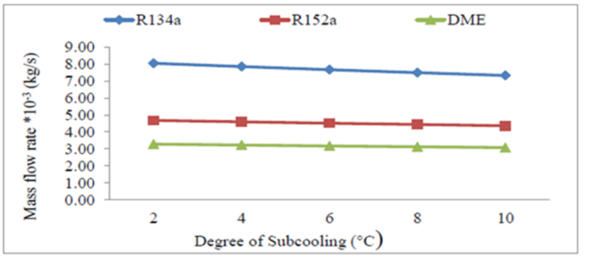

Fig. 9 Effects of the Degree of sub-cooling on the Mass flow rate

4. RESULTS AND DISCUSSION

- The results obtained showed that the compressor power decreases as the sub-cooling effectiveness increases (Fig4). It is also observed that, R134a requires more compressor power than that of R152a and DME. The average compressor power requirement of R152a and DME is lower than that of R134a by about 0.673% and 2.357% respectively.
- As shown in Fig.5, the mass flow rate decreases as the sub-cooling effectiveness increases. The average mass flow rate of R152a and DME are 64.7 % and 135.1% lower than that of R134a. It is observed from the fig 9, the mass flow rate decreases as the sub-cooling temperature increases. Therefore, R152a and DME refrigerants with lower mass flow rates will perform better in the system than R134a.
- The results of COP obtained showed that DME has the highest COP (Fig. 3 &7). The comparison carried out between the COPs of the investigated refrigerants showed that the COP of R152a and DME is higher than that of R134a over the considered range of operating conditions. The average COP of R152a and DME are 3.61% and 5.55% higher than that of R134a.

5. Conclusions

- The results obtained showed that coefficient of performance of the system increases as the degree of sub-cooling increases with decreased refrigerant mass flow rate. The COP of R152a and DME obtained at various degrees of sub-cooling are slightly higher than that of R134a.
- The overall results showed that R152a and DME refrigerants had the most similar performance characteristics to R134a with DME having a slightly better performance.

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