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Experimental analysis of refrigerator by replacing conventional HFC refrigerants with hydrocarbons

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ABSTRACT: *This paper presents an experimental study of isobutene (R-600a), an environment friendly refrigerants with zero ozone depletion potential (ODP) and very low global warming potential (GWP), to replace R-134a in domestic refrigerators. A refrigerator designed to work with R-134a was tested, and its performance using R-600a was evaluated and compared its performance with R-134a. The average COP using R-600a was 27% higher than R-134a respectively. The power consumption by compressor reduced by 3.7% with R-600a refrigerant. The compressor ON time ratio was lowered by 6.98% with R-600a compared with R-134a. The experimental results showed that R-600a can be used as replacement for R-134a in domestic refrigerator.*

Keywords: *Pull down time, ON time ratio, Total Equivalent Warming Impact.*

I. INTRODUCTION

Earlier, the refrigeration systems were mostly used for large cooling applications in which ammonia and carbon dioxide were used as refrigerant. These refrigerants were not found suitable for small cooling applications. With the development of the small refrigeration applications for domestic and commercial purposes, new refrigerants such as sulfur dioxide and methyl chloride were discovered [1, 2]. Methylene chloride and carbon dioxide were used extensively in the large air conditioning applications.

In the later years, the use of almost all the above mentioned refrigerants was stopped because of the invention of the newer group of refrigerants named halocarbons in 1931 [3]. The development of halocarbons was a great breakthrough in the field of refrigeration and air conditioning. However, ammonia is still being used as the refrigerant due to its highly suitable thermal properties. It is still being used in the large cold storages and ice plants. At present, the halocarbons are used extensively as the refrigerants due to a number of desirable properties that they possess. The CFCs and HCFCs have many suitable properties, such as stability, non-toxicity, non-flammable, good material compatibility and good thermodynamic properties, which have led to their common wide spread use by both consumers and industries around the world [4], especially as refrigerants in air conditioning and refrigerating systems.

As HCFCs (hydro-chlorofluorocarbons) which have been used as refrigerants in a vapor compression refrigeration system were known to provide a principal cause to ozone depletion and global warming, production and use of these refrigerants have been restricted [5]. Therefore, new alternative refrigerants should be searched for, which fit to the requirements in an air-conditioner or a heat pump, and refrigerant mixtures which are composed of HFCs (hydrofluorocarbons) having zero ODP (ozone depletion potential) are now being suggested as drop-in or mid-term replacement [6–14].

Due to their higher ozone depletion potential (ODP) and / or global warming potential (GWP), they are to be phased out in the near future. The researchers are attracted to find out some new environmental friendly refrigerants. Hydrocarbons have good potential to replace to HFCs.

Hydrocarbons are considered as alternative fluids for refrigeration, air-conditioning and heat pump applications. Pure butane, propane or their mixtures can be adopted, but due to their flammable properties, the systems have to be designed in such a way that the refrigerant charge is minimized. Therefore, compact heat exchangers and enhanced geometries are adopted in such systems [4]. In general, a refrigerant may be required to satisfy requirements which may be classified as thermodynamic, chemical and physical. The selection of a refrigerant, therefore, depends on satisfying its essential requirements [15]. The choice of a refrigerant for a given application is governed mainly by the refrigerating capacity (very small, small, medium or large), and refrigeration temperature required. The most important thermodynamic property of a refrigerant is its normal boiling point. Most of the other thermodynamic characteristics very much depend on it. The thermodynamic requirements of refrigerants pertain to the condensing and evaporating pressure, critical temperature and pressure, freezing point, volume of the suction vapour per ton, COP, power consumption per ton, etc [15].

II. EXPERIMENTAL SETUP

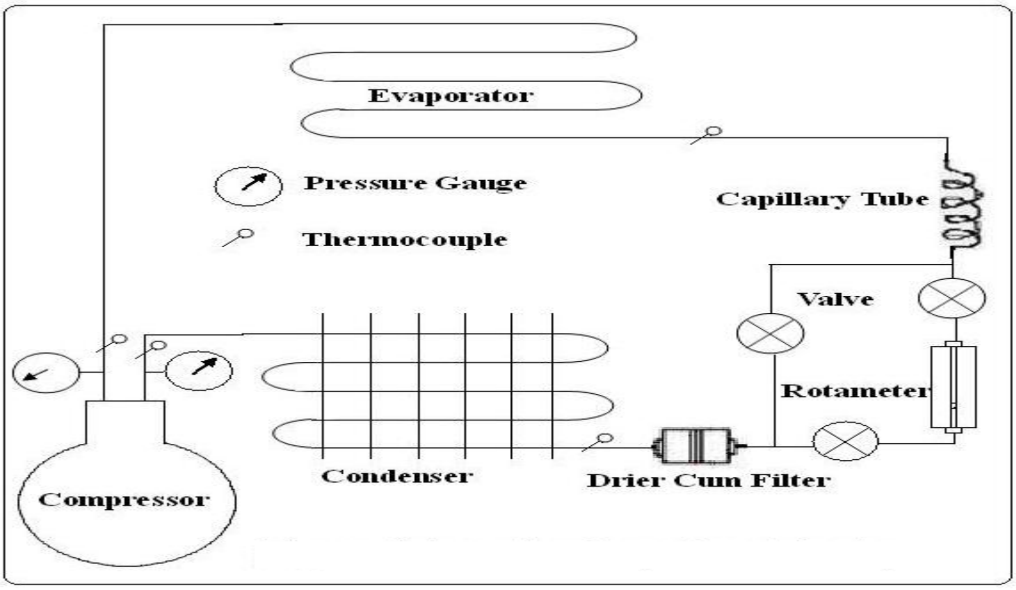

Figure 1: Schematic of experimental setup

Figure 1 shows the schematic of experimental setup which consists of two parts, a 165 liters domestic refrigerator using R-134a as refrigerant and a measurement system consisting of various thermocouples and pressure gauges are also shown in the figure. Experiments were carried out by recording temperatures at different locations.

III. PROPERTIES OF REFRIGERANTS AT 40^{O}C

Table 1: Physical properties of refrigerants

Refrigerant	ASHRAE Number	Chemical Formula	Mo (kg/kmol)	T_{bp} (^{O}C)	T_{tr} (^{O}C)	T_{cr} (^{O}C)	h_{fg} (kJ/kg)	$\square_l$ (kg/m^3)	$\square_v$ (kg/m^3)
Isobutane	R600a	$CH–(CH_3)_3$	58.12	–11.67	–159.59	134.67	311.4	530.0	13.667
Propane	R290	$CH_3–CH_2–CH_3$	44.096	–42.09	–187.67	96.675	306.51	467.07	30.202
Propene	R1270	$CH2{=}CH–CH_3$	42.08	–47.69	–185.2	92.42	303.14	476.66	35.708
R-134a	R-134a	$CF_3–CH_2F$	102.03	–26.074	–103.3	101.06	163.02	1146.7	50.085
R22	R22	$CHClF_2$	86.468	–40.81	–157.42	96.145	166.6	1128.5	66.193
Ammonia	R717	NH_3	17.03	–33.327	–77.655	132.25	1099.31	579.44	12.034

Mo	Molecular weight	T_{cr}	Critical temperature
T_{bp}	Normal boiling point	T_{tr}	Triple point
$\square_l$	Liquid density	$\square_v$	Vapor density
h_{fg}	Latent heat of vaporization		

IV. RESULTS AND DISCUSSIONS

The results show comparisons of various refrigerants such as R-134a, R-600a and blend of R-290 and R-600a (in proportion 1:1) in domestic refrigerator for evaluations of refrigerating effect, compressor work input, COP etc. Experiments were carried out for each refrigerant individually.

4.1 Variation of pull down time with time:

The pull-down time is the time required for changing the evaporator chamber air temperature from ambient condition to the desired final temperature [16]. The experimental refrigerator was designed to operate below $0^{O}C$. Figure 2 shows the comparison of pull-down time of R-134a and R-600a. Figure 2 reveals that the temperature of $0^{O}C$ was obtained in 270 minutes for R-134 and 190 minutes for R-600a. Both the refrigerants show nearly the same refrigerating behavior, also the pull down time for both the refrigerants is identical.

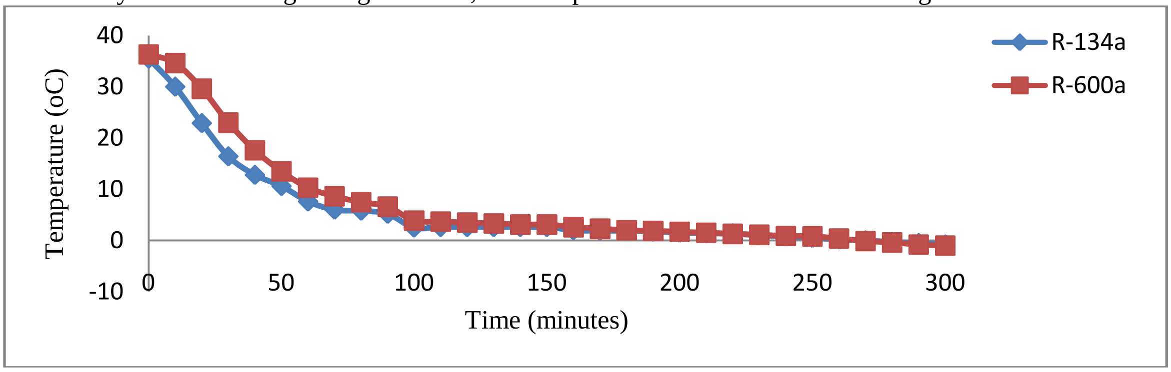

Figure 2: Variation of freezer water temperature with time

4.2 Comparison of COPs for various refrigerants:

Figure 3 and 4 shows the variation of COP for various refrigerants with and without condenser fan. It is clear from the figures that in both the cases, R-134a has the lesser COP as compared to R-600a. It clearly exhibits that COP is improved with hydrocarbon refrigerant. In comparison with R-134a COP is improved by 27% for R-600a in without fan condition. When condenser fan is switched ON, same results are obtained. In this case, improvement in COP is much more than the earlier case and COP of the system improved by 37% for R-600a as compared with R-134a. The specific refrigerating effect in case of all the refrigerants is approximately the same, but the energy input is lower for hydrocarbons, hence the COP of the system with hydrocarbon refrigerants is better than HFC-134a. This shows that hydrocarbons have a great potential to replace R-134a in domestic refrigerator.

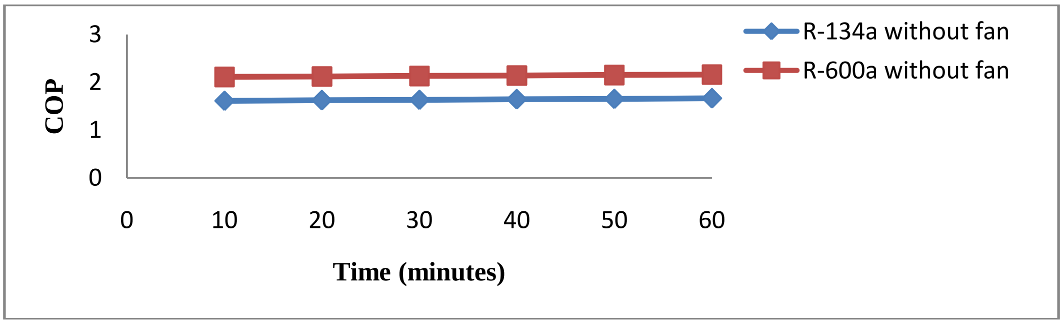

Figure 3: Variation of COP with time for different refrigerants without fan

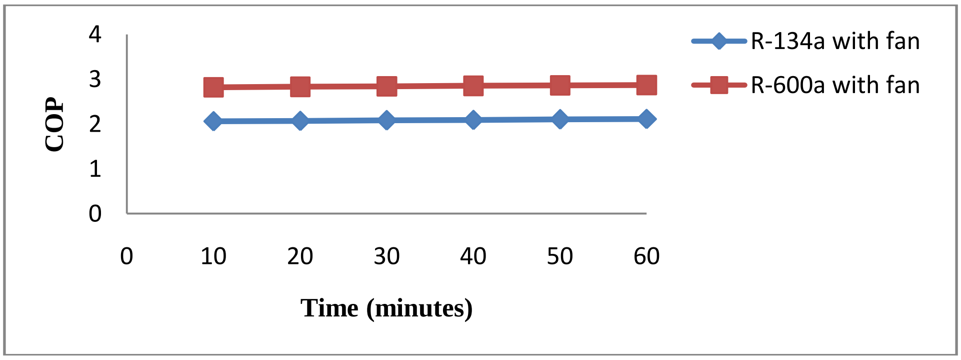

Figure 4: Variation of COP with time for different refrigerants with fan

4.3 Effect of condenser fan on COP of the system:

Figure 5 and 6 show the effect of condenser fan operation on COP of the system. It clearly exhibits that COP improved with forced convection. With condenser fan, the discharge pressure reduced, i.e. the pressure ratio is lowered, and it results in reduction in work input to compressor, hence the COP of the system improved. COP improved by 21% and 34% for R-134a and R-600a respectively with about 10-15% additional power consumption for condenser fan.

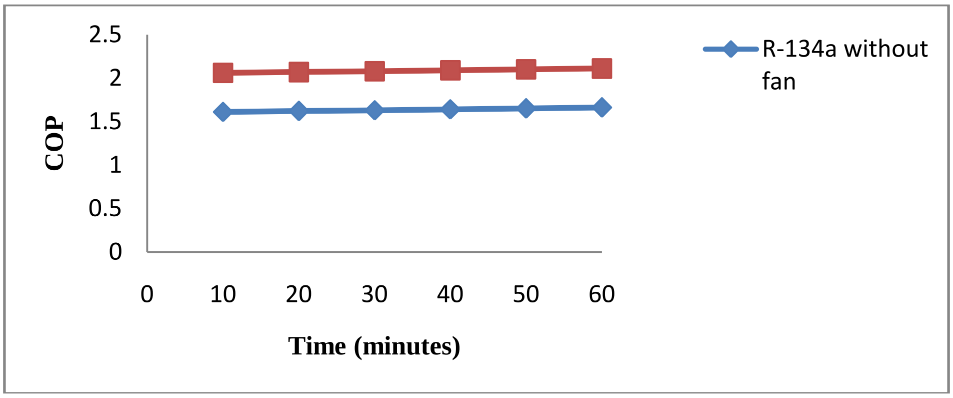

Figure 5: Comparison of COP with time for R-134a with and without fan

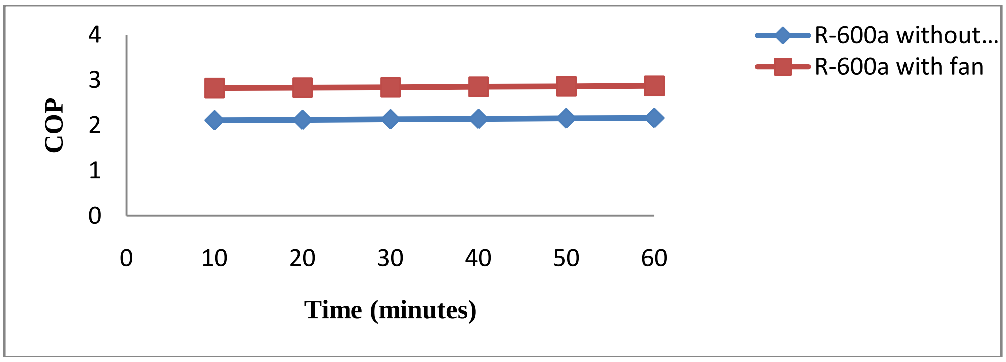

Figure 6: Comparison of COP with time for R-600a with and without fan

4.4 Comparison of refrigerating effect:

Figure 7 shows the variation of refrigerating effect with time. It reveals that R-600a produce refrigerating effect almost twice per kg of refrigerant as compared to R-134a. To achieve the same refrigerating effect, the amount of refrigerant charge reduced to nearly half for R-600a.

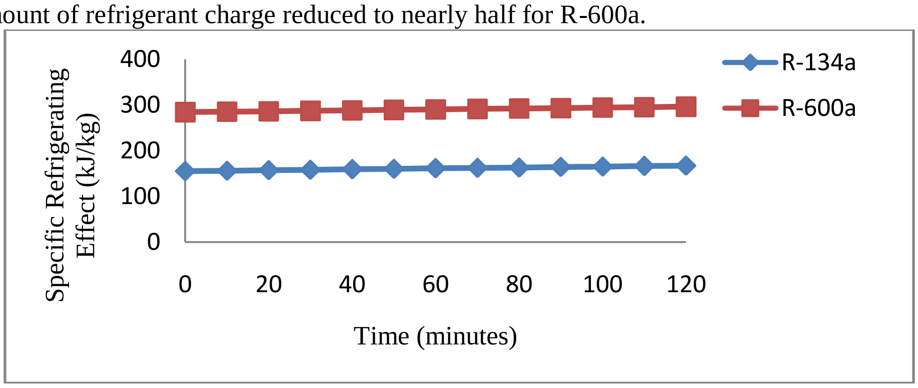

Figure 7: Comparison of specific refrigerating effect

4.5 Comparison of power consumption:

The power consumption for R-134a and R-600a during the trial duration of 1 day was observed as 2.7kW-hr and 2.6kW-hr respectively. This shows a saving of saving of 3.7% for R-600a as compared with R-134a. Thus it can be concluded that hydrocarbons save energy and can prove a better replacement to R-134a in domestic refrigerators. R-600a has about half the leakage, pressure loss and condenser pressure and double the heat transfer coefficient of R134a [17].

Table 2: Comparison of power consumption

Sr. No.	Refrigerant	Energy consumption (kW-hr)	% reduction
1.	R-134a	2.7	---
2.	R-600a	2.6	3.70%

V. CONCLUSIONS

Experimental analysis has been carried out to study the effect of various hydrocarbon refrigerants.

1. The COP of the system has been improved with the hydrocarbon refrigerants. The average COP obtained using R-600a 27% higher than that of R-134a.
2. The compressor consumed 3.7% lesser energy with R-600a as compared with R-134a.
3. The compressor ON time ratio was reduced by 6.98% when R-600a was used as compared with R-134a.
4. The mass of refrigerant required to be charged to the system for satisfactory performance was reduced by 46.15% with R-600a when it was compared with R-134a.
5. The system did not require any modification. The system gives the better results with R-600a compared with R-134a. This refrigerant has zero ODP and very low GWP of the order of 3 to 4 as compared to 1300 of R-134a. Hence, it can be concluded that R-600a can be used as a replacement to R-134a with better performance lesser energy consumption, pull down time and ON time ratio.

REFERENCES

Journal Papers:

[1] McMullan JT. Refrigeration and the environment issues and strategies for the future. International Journal of Refrigeration 2002; 25(5):89-99.

[2] Bolaji BO. CFC refrigerants and stratospheric ozone: past, present and future. In: Okoko E, Adekunle VAJ, editors. Environmental Sustainability and
Conservation in Nigeria 2005; 37: 231-239.

[3] B. O. Bolaji, Experimental study of R152a and R32 to replace R134a in a domestic refrigerator, Energy 35 (2010) 3793–3798.

[4] Radermacher R, Kim K. Domestic refrigeration: recent development. International Journal of Refrigeration 1996; 19:61-9.

[5] Z. Jiang, Development of alternative refrigerant to HCFC22, Organo-Fluorine Industry 3 (1997) 8–10 (in Chinese).

[6] K.J. Park, D. Jung, Thermodynamic performance of HCFC22 alternative refrigerants for residential air-conditioning applications, Energy and Buildings 39 (2007) 675–680.

[7] J.Y. Chen, J.L. Yu, Performance of a new refrigeration cycle using refrigerant mixture R32/R134a for residential air-conditioner applications, Energy and Buildings 40 (2008) 2022–2027.

[8] A. Arora, S.C. Kaushik, Theoretical analysis of a vapour compression refrigeration system with R502, R404A and R507A, International Journal of Refrigeration 31 (6) (2008) 998–1005.

[9] R. Doring, H. Buchwald, J. Hellmann, Results of experimental and theoretical studies of the azeotropic refrigerant R507, International Journal of Refrigeration 20 (2) (1997) 78–84.

[10] C. Aprea, R. Mastrullo, Behavior and performances of R502 alternative working fluids in refrigerating plant, International Journal of Refrigeration 19 (4) (1996) 257–263.

[11] G. Eric, Hydrocarbons as refrigerants: an overview, International Journal of Refrigeration 24 (1) (2001) 15–24.

[12] S.B. Riffat, C.F. Afonso, A.C. Oliveira, D.A. Reay, Natural refrigerants for refrigeration and air-conditioning systems, Applied Thermal Engineering 17 (1) (1996) 33–42.

[13] J. Swinney, W.E. Jones, J.A. Wilson, The impact of mixed non-azeotropic working fluids on refrigeration system performance, International Journal of Refrigeration 21 (8) (1998) 607–616.

[14] J.M. Calm, G.C. Hourahan, Refrigerant data summary, Heat/Piping/Air Conditioning Engineering 79 (1) (2007) 50–64.

[15] C. P. Arora, Refrigeration and air conditioning, Third Edition, The McGraw-Hill Companies, 2012.

[16] ISO, International Standard Organization. International Standard-8187, household refrigerating applications (refrigerators/freezers) characteristics and test methods. 1991.

[17] I. L. Maclaine-cross, E. Leonardi, Why Hydrocarbons Save Energy, AIRAH Journal, June 1997, Volume 51 No. 6, pp. 33-37.