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Performances Assessment of Natural Refrigerants as Substitutes to CFC and HCFC in Hot Climate

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Abstract

Due to the environmental concerns ozone depletion potential (ODP) and global warming potential (GWP) of the existing refrigerants, industry and researchers in this field are investigating long-term solutions. With extensive work on alternatives to chlorofluorocarbons (CFCs) and hydro chlorofluorocarbons (HCFCs), initially hydro fluorocarbons were considered to be long-term solutions. The global warming of HFCs has become a hurdle to accept them as long-term solutions. Now, the focus is on the use of natural refrigerants like hydrocarbons (HCs) such R290, R600, ammonia, carbon dioxide and water. These natural substances have very low GWP, and a zero ODP. This paper presents simulation results through a thermodynamic analysis of R22 and three of its alternatives natural refrigerants (R290, R600a and R717) for A/C and refrigeration purposes operating under various outdoor temperatures, represented by the condenser temperatures. The examined new refrigerants show varying performance, depending on the evaporator temperatures, but in every case, the condenser temperature seems to have an important impact on the performance of the cycle.

Keywords: *refrigerants, substitutes, environment, ozone, performances.*

1. Introduction

Worldwide attempts are being made to phase out the production and consumption of chloro fluorocarbons, as these chemicals are responsible for depletion of stratospheric ozone layer. Refrigeration, A/C and heat pumps sectors are one of the principal users of these chemicals. During the last decade, the number of refrigerants likely to be used in refrigerating machines has dramatically increased as a consequence of the elimination of the CFC's and HCFC's

R22 (HCFC 22) is one of the important refrigerant used in air conditioning all over the world. R22 is controlled substance under the Montreal Protocol. It has to be totally phased out by 2017.. In Europe, HCFCs have already been phased out in new equipment in 2002, and the total phase out of HCFCs is scheduled in 2015. HCF 22 replacements options for A/C, heat pumps and refrigeration systems can be grouped in three categories, Fluorocarbons that are used in conventional vapor compression cycles such as R134a, R410a, R407C, alternatives fluids which include propane R290 and R717 and are also used in vapor compression cycles, and finally alternatives cycles that include absorption systems, and use Tran critical fluids (CO_2 and R744) and air cycle. In general these alternative technologies do not currently offer the same energy efficiency as the vapor compression cycle. Several investigations have been carried out in order to determine the efficiency of potential substitutes to R22.Muerer et al [1] compared the performances of R22 and R 410A working at elevated condensing temperatures up to 60.Chin and Spatz [2] explored some of the advantages and disadvantages of R 410A, and other substitutes to R22. Benamer et al [3] have provided working characteristics to optimize the components of the refrigerating machines, while some reported research [4-7] concerned specific outdoor temperatures, as well modifications of the refrigeration compression cycle. Devotta et al [9] as well other researchers [10-12] has presented a performance evaluation of R290 and other natural refrigerants as a drop substitute to R22 in a air conditioning applications..

This paper presents comparative thermodynamic analyses of R22 and three of its alternatives natural refrigerants (R290, R600, and R717) for A/C and refrigeration purposes operating under high and low outdoor temperatures. These natural substances have the dual advantage of very low global warming, nearly zero and zero depletion. Table 1 presents the environmental data of selected refrigerants. The study enables to determine the effect of the condenser and evaporator temperatures on the coefficient of performance, the volumetric refrigerating capacity, as well as the compressor discharge temperature.

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Table 1. Experimental data of some refrigerants

Refrigerants	ODP	GWP (time horizons of 100 years)
CFC11	1	4600
CFC12	0.82	10600
HCFC22	0.034	1700
HCFC123	0.012	120
HFC134a	0	1300
HFC152a	0	120
R407C	0	1700
R410A	0	2000
HC290	0	20
HC600a	0	20
R717	0	<1
Water	0	<1
CO2	0	1

2. Refrigeration cycle

The refrigeration cycle studied is a vapor compression cycle composed of four main equipments: Evaporator, Compressor, Condenser and a throttling valve as illustrated in figure1, while figure 2 shows the corresponding P-h diagram. The following assumptions are made:

- An evaporation at constant pressure, in the evaporator with an evaporator temperature, T_{ev}, from h_4 to h_1.
- An adiabatic isentropic compression process in the compressor, corresponding from (1) to (2) (h1 to h2).
- A de superheating followed by a condensation at ($T=T_c$) and pressure in the condenser, from (2) to (3). (h_2 to h_3).
- An expansion at constant enthalpy in the throttling valve, corresponding from point 3 to point 4 ($h_3= h_4$).
- The vapour leaving the evaporator as well as the liquid leaving the condenser are supposed to be at saturated states.

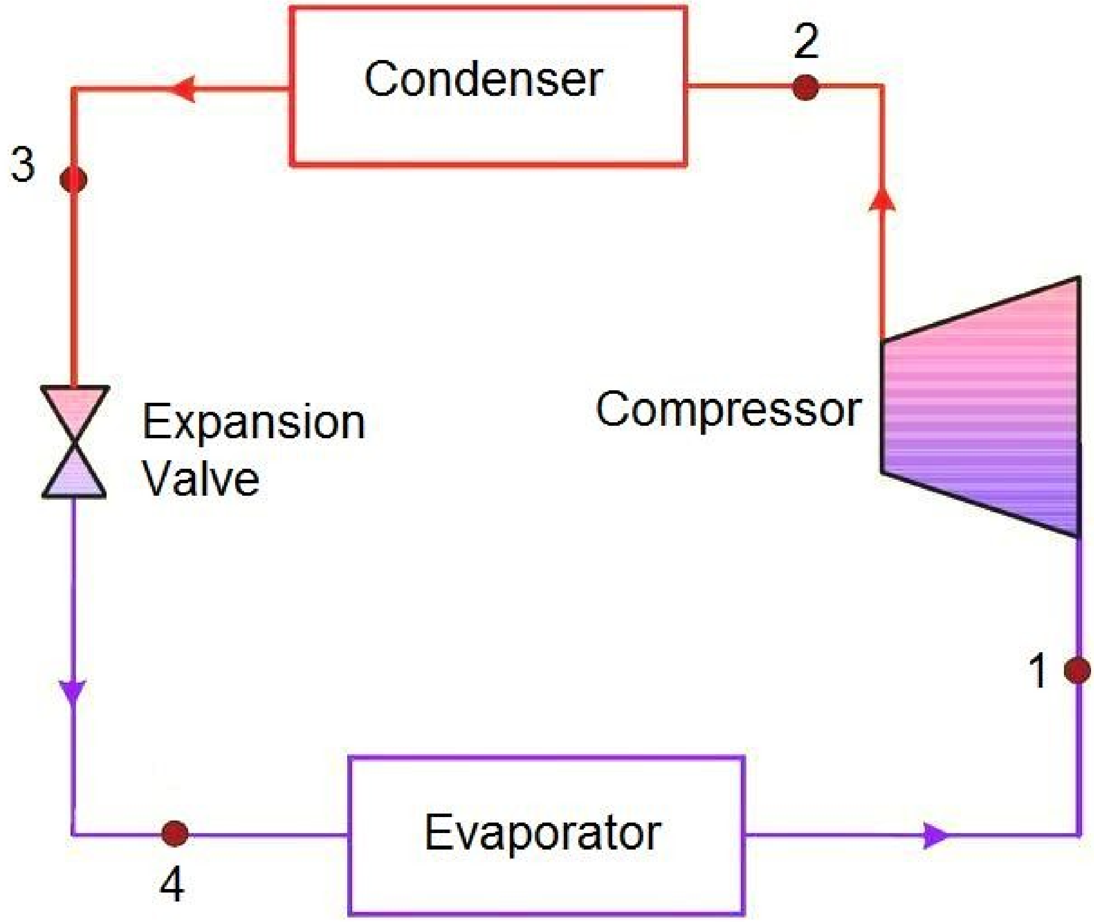

Figure1: Standard Vapor Compression Cycle

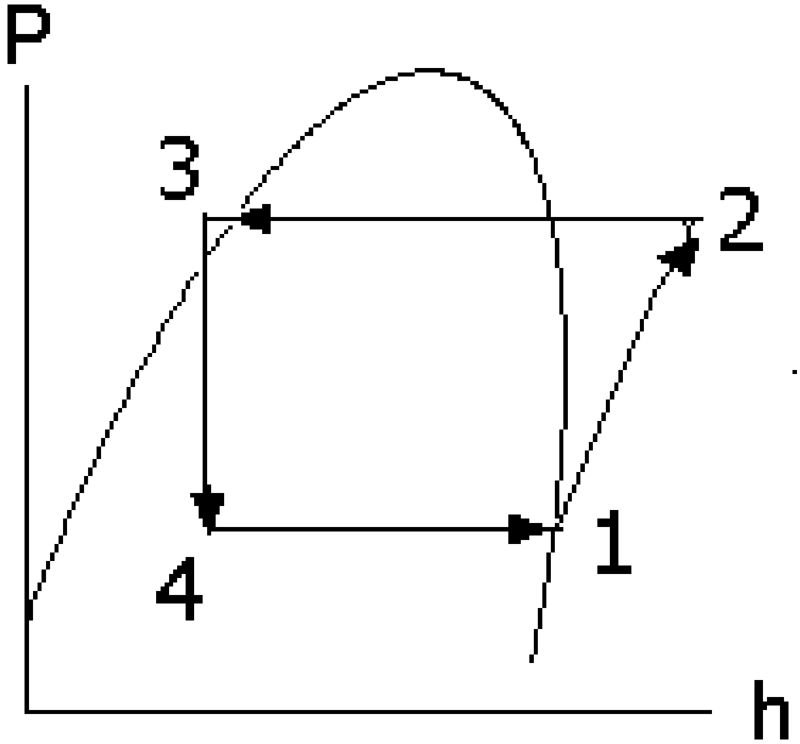

Figure 2 Thermodynamic P-h Diagram

3. Modelling basis

A Simulation model was developed in order to investigate the effect of the evaporator and condenser temperatures (representing the ambient temperatures) on the coefficient of the performance of the cycle (COP), the volumetric refrigerating capacity (VRC), the compressor discharge temperature (T_c), and the compressor load capacity.

The required data for the model are:

- Specifying the nature of the refrigerant by fixing the physical and thermodynamics properties.
- Fixing T_{ev} and T_c.
- Fixing either the mass flow rate of the refrigerant or the refrigeration capacity.

The model enables to estimates the evaporator and condenser pressures (P_{ev} and P_c), the compressor discharge temperature (T_c), as well as the different enthalpies involved in the cycle.
The thermodynamic and transport properties of the refrigerant are determined through chemical thermodynamics relations. Mass balances and energy balances are used to derive expression for the Coefficient of Performance and the refrigeration capacity.
For the cycle studied, the main mechanical power supplied to the system is supposed to be the power supplied to the compressor, P_{cp}.

Mass flow rate of the refrigerant**;** is ,

$$Mr = \frac{Qr}{h_2 - h_1} \tag{1}$$

$$h_1 = h_4 \tag{2}$$

Energy required in the compressor (load)

$$Q_{cp} = M_r(h_3 - h_2) = Q_r(\frac{h_3 - h_2}{h_1 - h_4}) \tag{3}$$

Energy liberated in the condenser

$$Q_{cd} = M_r(h_3 - h_4) = Q_r(\frac{h_3 - h_2}{h_1 - h_4}) \tag{4}$$

Volumetric Flow rate (VRC)

$$G = \frac{Q_r}{q_r} = M_r v_a \tag{5}$$

qr= Specific volumetric refrigeration load,

Coefficient of the performance, COP

COP=Refrigeration load / compressor load

$$COP = \frac{Q_R}{Q_{CP}} = \frac{h_2 - h_4}{h_3 - h_4} \tag{6}$$

The COP of the ideal cycle can be defined as follows

$$COP_{ideal} = \frac{T_{ev}}{T_{ev} - T_C} \tag{7}$$

Saturated pressure

The empirical equations proposed by Lee and Kesler [13] is used to estimate the saturated pressures, which is as follows

$$P_{sat}^{+} = f^0(T_r) + w.f^1(T_r) \tag{8}$$

Psat = Reduced Pressure at the saturation liquid vapour

$$P_{sat}^{=} = \frac{P_{sat}}{P_{cr}} \tag{9}$$

f^0 = relative fugacity at zero order (w=0)

Determination of the pressure at the end of compression

For an adiabatic compression and an ideal gas

$$P.V^{\gamma} = constant \tag{10}$$

γ= Cp/Cv ; calculated at one atmosphere and 30C

Using the ideal gas law and the temperature, equation (10) becomes,

$$P..T^{\frac{\gamma}{\gamma-1}} = constant \tag{11}$$

4. Results

The calculations were performed for three potential substitutes to R22, as well as R22, by considering three different condensing temperatures, and investigating the effect of the evaporator temperatures on the coefficient of performance, the volumetric refrigerating capacity the compressor load and the discharge temperature.

4.1 Coefficient of the performance (COP)

Figures 3 (f-g) show the variation of the COP with various evaporating temperatures ranging from –30C to 10C, and for three condensing temperatures (30C, 40C, 50C), for the alternatives refrigerants considered, as well for the R22. It can be seen from these figures that the COP varies linearly with the evaporator temperature for all the cases studied..

R 290 seems to be similar to R22, showing similar trends and similar variation for all the cases studied. Ammonia and R600a exhibits smaller COP than R22, when operating under similar conditions.

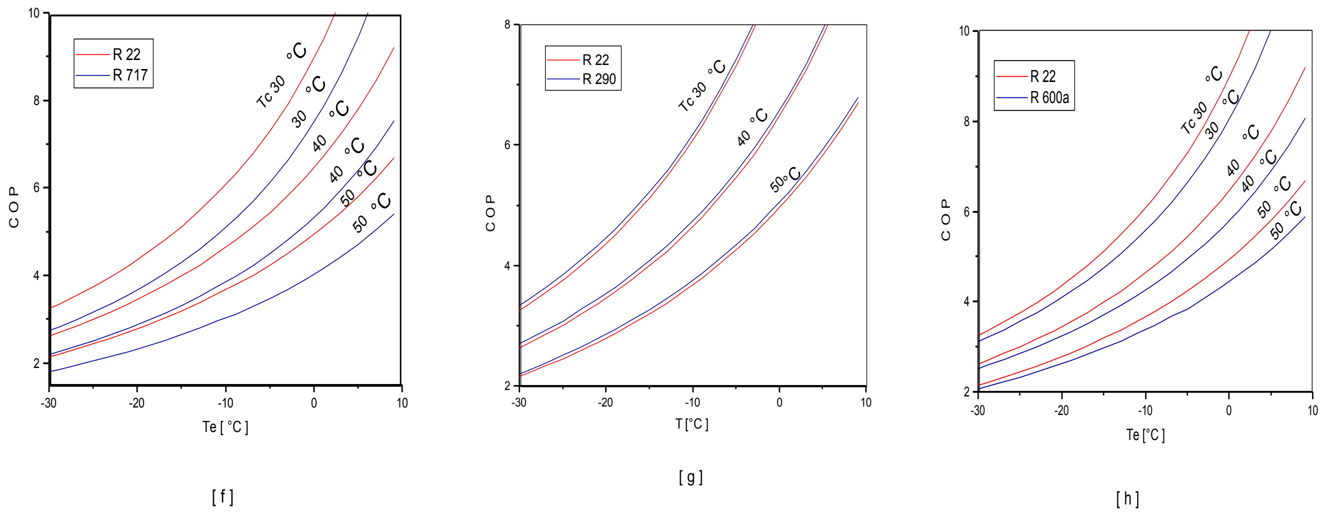

Figure 3: Variation of the Coefficient of performance with respect to Tev and Tcond, for the new refrigerants and R22. (f) R22 / R 717 , (g) R22 / 290, (h) R22 / 600a

4.2 Volumetric refrigerating capacity

Figures 4 (f-g) show the effect of the evaporating temperatures on the volumetric refrigerating capacity (VRC) for three condensing temperatures (30C, 40C and 50C).

It is seen that R290 which has a critical temperature below 10C, exhibits value of VRC close to the R22 values, for the three condensing temperatures considered. R600a gives lower values of VRC, while ammonia on the hand show larger values of VRC, compared to R22, but these values start decreasing the evaporator temperatures decrease

4.3 Variation of the compressor load

Figures 5 (f-g) show the variation of the compressor load with respect to the evaporator temperatures for three different condensing temperatures (30C, 40C, 50C). It is well known that the pressures have a direct impact on the performance of the cycle, moreover, the le lower the pressure ratio, the less energy is required to drive the compressor. It can be seen from these figures that R290 show a slightly lower values than R22, while ammonia and R600a exhibit respectively a higher value of 22% and 10 % than R22.

It can be seen from this analysis, that ammonia possesses very interesting thermodynamic properties, such as its high latent heat but it exhibits dangerous properties such as its flammability, toxicity, and therefore the direct substitution of R22 to ammonia requires important changes to the existing equipment in order to resist ammonia. R290 has physical properties and thermodynamic performances similar to R22, but with lower flow rate, and therefore requiring smaller equipment. This suggests its recommendation as a potential substitute to R22.
R600, which is a flammable refrigerant but less harmful to environment, can also be a potential substitute to R22, despite its lower thermodynamic performance.

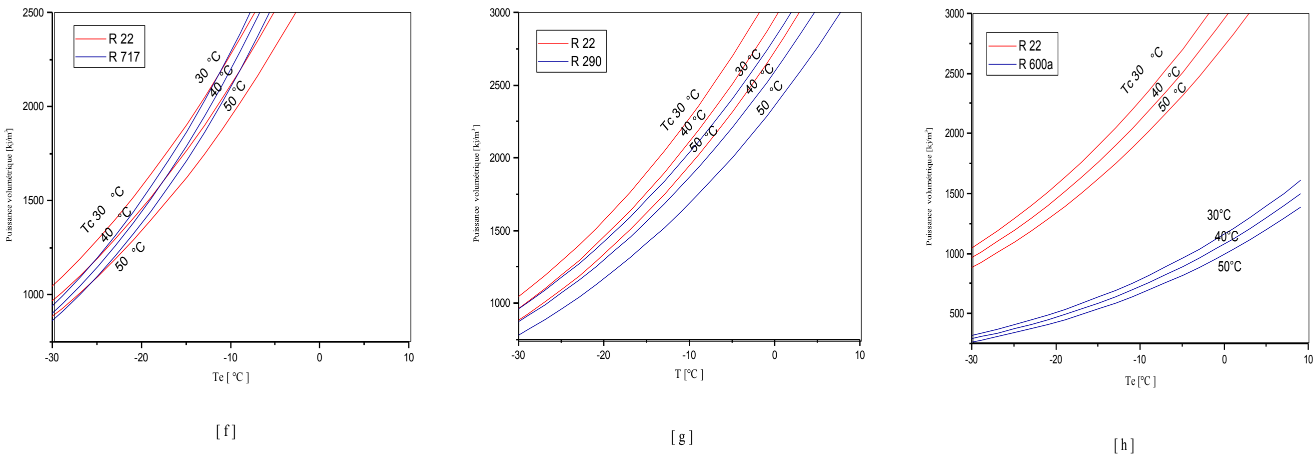

Figure 4 : Variation of the volumetric refrigerating capacity of the new refrigerants studied and R22 with respect to Te and Tc (f) R22 / R 717 , (g) R22 / 290, (h) R22 / 600a

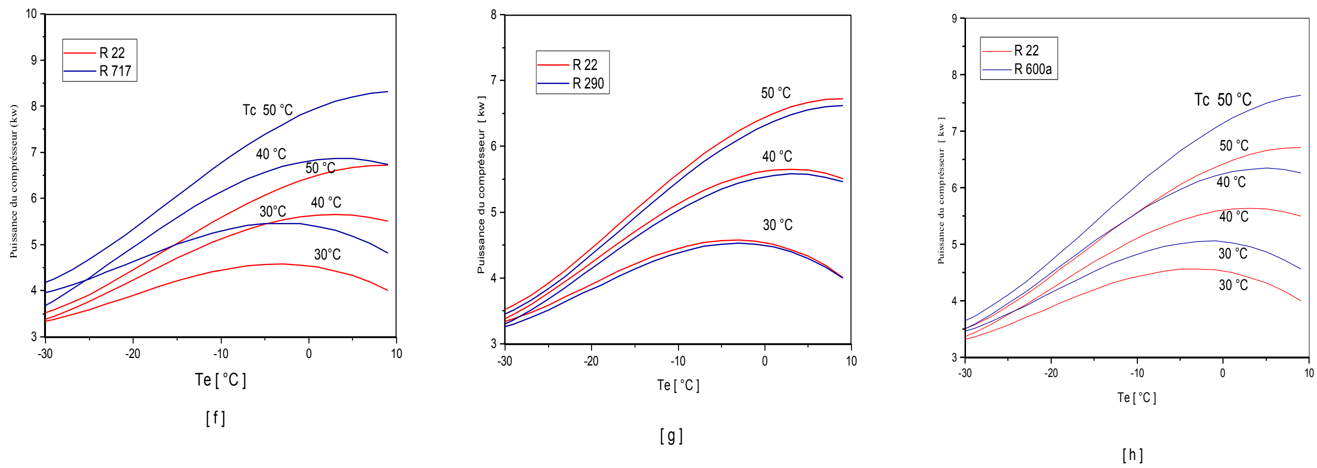

Figure 5: Variation of the compressor load with respect to Tev and Tcond for the new refrigerants and R22 (f) R22 / R 717 , (g) R22 / 290 , (h) R22 / 600a

5. Conclusions

It is evident that today, several new refrigerants whether pures, mixtures or naturals, are proposed to replace R22. R290 (propane), R600 (iso butane) and R717 (ammonia), which are considered natural refrigerants, seem to be the best potentials candidates to use refrigeration, air conditioning and heat pumps, as new lubricants have also been developed to operate with these refrigerants.

The present analysis has enabled to show that,.

- R 290 may be directly used a substitute to R22, for smaller refrigeration load, while ammonia which possess excellent thermodynamic performance requires specific materials due to its dangerous physical properties.
- Fluids having low critical temperature exhibit an important decrease in cooling capacity.
- Rate of compressor power increase is similar for all fluids.
- The new refrigerants studied have lower compressor discharge temperatures than the R22, and therefore will require compressors operating under less sever conditions.

Nomenclature

h: Enthalpy (kJ/kg)

Mr: Mass flow rate of the refrigerant (kg/sec)

P_c : Condensing Pressure (bar)

P_{ev} : Evaporator Pressure (bar)

P_{sat}= Saturated pressure (atm)

P_{cr} = Critical pressure (atm

T_c : Condensing temperature (C)

T_{ev} : Evaporator temperature (C)

T_{comp}: Compressor discharge temperature (ºC)

V: Volume m^3

γ: Ratio of the specific heat constant (C_p/C_v)

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References

[1]. Meurer.C, Buyle O, Paulus, Comparison of R22 and R410a at elevated condensing temperatures,, PROC 20th International Congress of Refrigeration, Sydney.

[2]. Chin L, Spatz M.w, Issues relating to the adoption of R410 a In air conditioning sysrtes. , PROC 20th International Congress of Refrigeration, Sydney.

[3]. Benamer A, Clodic D, 1999, test bench for comparative measurement of energy efficiency of variable and fixed speed scroll compressor.

[4]. Samuel F.Yana Motta, Domanski.P.A, Performance of R22 and its alternatives working at high outdoor temperatures, 8th International Refrigeration conference, Purdue Universitu, W.lafayetet, USA, 2000.

[5]. Roberts.N.A; Determination of the performance, leak scenario flammability, and oil return characteristics of a novel R22 replacement, Poceedings of the international refrigeration conference, Purdue, 1998.

[6]. Roberts.N.A, Jawad.S.H; Investigation of the vapour-liquid equilibrium behaviour of blends comprising R125, R134a, and R600 or R600a, Poceedings of the international refrigeration conference, Purdue, 2000.

[7]. Baumont.E, Frere.M, Pilatte.A, simulation of refrigerating machines, influences of the heat exchangers design for low refrigerant charges pn the working point, Zero leakage conference, International Institue of refrgeration, Stockolm, 2002.

[8]. Samuel.F Yanna Motta, Domanski.P.A, Performance of R22 and its alternatives, Poceedings of the international refrigeration conference, Purdue, 2000.

[9]. Devotta.S, Padalkar.A.S, Sane.N.K; Performance of HC 290 as a drop –in substitute to HCFC 22 in a window air conditioner, International journal of refrigeration, Vol 28, No 4, 2005. http.dx.doi.org/10.1016/j.ijrefrig.2004.09.013

[10]. Devotta.S, Waghmare.A.V, Sawant.B.M; Alternatives to HCFC -22 for air conditioners, Applied thermal engineering, Vol 21, No6, 2001. http.dx.doi.org/10.1016/S1359-4311(00)00079-X

[11]. Hwang.Y, Gado.A, Radermacher.R; Performance propane in a unitary heat pump, 21st International congress of refrigeration, Washington, USA, 2003.

[12]. Lorentzen.G; The use of of natural refrigerants, a complete solution to CFC/HCFC predicament, International journal of refrigeration, Vol 18, No 3, 1995. http.dx.doi.org/10.1016/0140-7007(94)00001-E

[13]. Smtith, Van Noss, Abott, Introduction to Chemical Engineering Thermodynamics, 7th edition, Ma c Graw Hill.