Study and Analysis of VCR System using Different Eco-Friendly Refrigerants

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***Abstract*: According to Montreal Protocol it was decided to initiate the worldwide phase out of CFCs and HCFCs. Moreover in Kyoto Protocol even new developed HFCs refrigerants like R-134a should be gradually phased out due to their high global warming potentials (1430).The present work is to Explore performance evaluation of most promising drop-in replacements of R134a in domestic refrigerator with Zero ODP and low GWP refrigerants. The assessed refrigerants are R290, R600a, R430A, R436A, R1234yf, R1234ze, R744 and DR11.Basic cycle and performance comparison of all alternative refrigerants have been studied and we came to result that the best alternative for CFCs and HCFCs is R744 for VCR cycle. By performing this experiment we will try to the COP of the alternative refrigerant. In this work we have completed theoretical analysis of different refrigerant and we got the following results,**

COP of R134a = 2.732
COP of R600a = 2.786
COP of R290 = 2.676
COP of R744 = 0.7489

***Keywords*: GWP-Global warming potential, ODP- Ozone Depletion Potential, Echo Friendly, Refrigerants.**

1. Introduction

Hydro-chlorofluorocarbons (HCFCs) and Chlorofluorocarbons (CFCs) have been widely used as refrigerants in air conditioning and refrigeration systems from 1930s as a result of their excellent safety properties. However, due to adverse effect on ozone layer, for the year 1987 at Montreal Protocol it was decided to establish requirements that initiated the worldwide elimination of CFCs. By the year 1992, the Montreal Protocol was improved to found a schedule in order to eliminate the HCFCs. Additionally, in year 1997 the Kyoto Protocol stated that the concentration of greenhouse gases in the atmosphere should be set at a level other than intensifying global warming ozone layer. Subsequently it was decided to lower global warming by reduction of greenhouse gases emissions.

As a consequence of this protocol even new developed HFCs refrigerants like R-134a should be gradually eliminated due to their high global warming potentials. Therefore, to meet the global ecological goals, conventional refrigerants should be replaced by more eco-friendly and safest refrigerants in such a way that the energy efficiency also gets improved.

A. Refrigerants and environment

Most refrigerants are known to have a negative effect on the environment as they contribute to global warming and depletion of ozone layer. Greenhouse gases such co2 and emission of some refrigerants contributes to global warming by absorbing infrared radiation and keeping it in the atmosphere. This is called Greenhouse effect.

B. Types of refrigerant

1) Chlorofluorocarbons (CFCs)

They are an excellent non reactive refrigerant that has a low boiling point. They also have low toxicity, are cheap, easy to store and have no risk of fire. Unfortunately, these are greenhouse gases that deplete the ozone layer and it contains fluorine making dangerous to the environment.

2) Hydro-chlorofluorocarbons (HCFCs)

These are currently used as refrigerant as a replacement of CFCs. But soon, even this will be eliminated over time. HCFCs are more ozone friendly than CFCs but still they deplete ozone at a slower rate. But HCFCs are a potent greenhouse gas that is many time more potent than co2. In addition to this HCFCs contribute to chlorine built up in the atmosphere.

3) Hydro-fluorocarbons (HFCs)

Many refrigerator manufacturers choose HFCs because they are good replacement of CFCs and do not deplete ozone as much as CFCs and HCFCs. Unfortunately HFCs are potent source of greenhouse gases and also have high GWP.

4) Natural refrigerants

Natural refrigerants are produced naturally, which means they are not made by man like other refrigerants just mentioned. They can be used as refrigerant for refrigerator and Air-conditioners. Examples of natural refrigerants are Hydrocarbons, Ammonia, Carbon dioxide and Water.

- Comparison of various properties of different types of refrigerants.

C. Advantages of CO2 as a refrigerant

- R-744 operates at a far higher pressure than standard refrigerants. However, this is not excessively high compared to similar engineering applications.
- R-744 systems have a high volumetric refrigeration

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Table 1
Properties of different types of refrigerants

Refrigerant	Molecular weight[g/mol	Critical Temp[°C]	Critical pressure[MPa	Normal boiling	Safety class	ODP	GWP
R134a	102	101.1	4.059	-26	A1	0	1430
Propane(R290)	44.096	134.67	4.23	-42.09	A3	0	3
Iso-butane (R600a)	58.12	134.67	3.65	-11.67	A3	0	3
R-430A	49.08	120.3	3.23	-27.6	A3	0	107
R-436A	54.65	130.1	3.39	-34.3	A3	0	<3
R1234yf	114	95	3.382	-29	A2L	0	4
R1234ze	114.04	79	3.632	-20	A2L	0	6
CO2	44.01	31.10	7.39	-78	A1	0	1

capacity, as a result of their very high vapour density when compared to other refrigerants.

- Refrigeration compressors using R-744 are six to eight times smaller than those of R22 systems.
- Reduction in pipe sizes when using R-744.
- Better heat transfer property than R-404a

D. Disadvantages of co2 as a refrigerant

- The main disadvantage of carbon dioxide as a refrigerant is its high working pressure.
- Special designed components are required.
- R-744 has complex system
- Greater complexity results in possibility of poor performance
- R-744 trans-critical system is not for suitable high ambient area.

E. R-744 has 10 noteworthy characteristics

- Non-toxic
- Non-flammable
- Environmentally friendly
- Low triple point
- Low critical point
- High pressure
- High refrigeration volumetric capacity
- High heat transfer characteristics
- Inexpensive
- Readily available

2. Thermodynamic analysis

A vapor compression refrigeration system consists of five components, such as an evaporator, a super heating coil, a compressor, a condenser and an expansion valve. These components are connected in a closed circuit through the pipe that has heat transfer with the environment, as shown in Figure. In state 5, the refrigerant leaves the evaporator at low pressure, low temperature, and saturated steam and enters the super heating coil where it absorbs the heat from the high temperature refrigerant which flows from the condenser.

The refrigerant of the super heating coil enters the compressor through the suction line where both the temperature and the pressure increased in state 1. This process can be shown in figure. In state 2, it leaves the compressor as a high pressure, high temperature, superheated vapor and enters the condenser where it rejects heat to the surrounding medium at constant pressure after being subjected to heat transfer in the discharge line. The refrigerant leaves the condenser in state 3, as high pressure, medium temperature, saturated liquid and enters the super heating coil in state 3. The expansion valve allows the high pressure liquid to flow to a constant high enthalpy pressure at low pressure. In state 4, it leaves the expansion valve as a mixture at low temperature, low pressure and liquid-vapor and enters the evaporator where it absorbs heat at constant pressure, becomes saturated steam and completes the cycle.

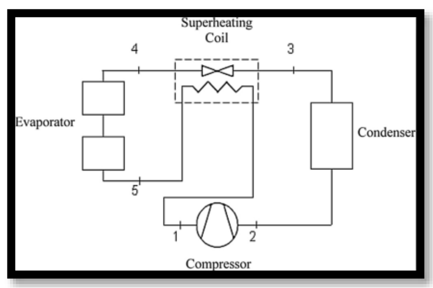

Fig. 1. Schematic representation of VCR

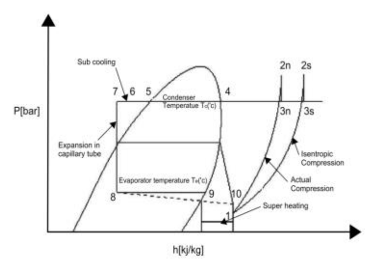

Fig. 1. Pressure-enthalpy diagram of VCR cycle

Thermodynamic analysis is based on the first law of thermodynamics the performance of the vapor compression refrigeration system can be predicted in terms of coefficient of performance (COP), which is defined as the ratio between the net refrigeration effect produced by the refrigerator and the work done by the compressor. It is expressed as

a) coefficient of performance (COP)

$$COP = \frac{\dot{Q}_{Evep}}{\dot{W}_{Comp}}$$

$$COP = \frac{h_9 - h_8}{h_{2s} - h_1} \quad (1)$$

b) *Refrigerating effect* ($\dot{Q}_{Evap}$)

$$\dot{Q}_{Evap} = (h_9 - h_8) kj/kg \quad (2)$$

c) *Mass flow rate*($\dot{m}$)

$$\dot{m} = \left[\frac{\dot{Q}_0}{q_0}\right] kg/s \quad (3)$$

d) *Compressor work* ($\dot{W}$)

$$\dot{W} = \dot{m} w$$

$$\dot{W} = \left(\dot{m}(h_{2s} - h_1)\right) kw \quad (4)$$

e) *Condenser heat rejected*($\dot{Q}_k$)

$$\dot{Q}_k = \dot{m} q_k$$

$$\dot{Q}_k = \left(\dot{m}(h_{3n} - h_6)\right) kw \quad (5)$$

f) *Suction vapour volume*(v_s)

$$v_s = \left(\frac{60 * \dot{m}}{N} v_{10}\right) cc/rev \quad (6)$$

g) *Volumetric efficiency of compressor*(η_v)

$$\eta_v = \frac{v_s}{v_p} \quad (7)$$

h) *Isentropic discharge temperature* (T_{2s})

i) *Actual discharge temperature* (T_{2n})

$$T_{2n} = T_1 \left(\frac{P_2}{P_1}\right)^{\left(\frac{\gamma-1}{\gamma}\right)} k \quad (8)$$

3. Conclusion

From the above analysis, Basic cycle and performance comparison of all alternative refrigerants have been studied and we came to result that the best eco-friendly alternative for CFCs and HCFCs is R744 for VCR cycle. Results of various alternative refrigerants have been analyzed and tabulated as follows.

Table 2
Results of different Refrigerants

S. No.	Parameters	R134a	R600a	R290	R744
1	COP	2.732	2.786	2.676	0.7489
2	Q	89	89	89	89
3	W	0.03257	0.03195	0.03326	0.1188
4	RE	0.089	0.089	0.089	0.089
5	q_0	145	250	272.9	50.42

Where,
COP= Coefficient of performance
Q= Refrigerating Capacity
W= Work done by the compressor
RE= Refrigeration effect (KJ/Kg)
$\mathbf{q_0}$ = Refrigeration effect (KJ/s)

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