Comparative Performance study of Low Temperature Refrigeration System Using Refrigerant R134a instead to R22

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Abstract : The global sustainability of HFCs like R-134A requires a focus by the HVAC industry on the real environmental issues of refrigerant containment and energy efficiency. By committing to the design of more energy-efficient systems using these refrigerants, the industry will significantly improve the environmental impact of refrigeration and air conditioning products. Cold room is refrigerated space where low temperatures maintain for preservation of dairy products & Food. The cold room is designed with refrigeration capacity 1.3 TR. During retrofit refrigerant procedure, design these system various design parameter like cooling load calculation, selection of compressor, thermostatic expansion valve, condenser capacity and piping design are considered. as well as the change of lubricant in the compressor also considered.

Keywords: low GWP, zero ODP, retrofits, glycol solution.

1. Introduction

The success of the CFC phase-out, along with increasing environmental concerns from regulators and policymakers, continues to drive new, stricter mandates regarding use of refrigerants. The next mandate the heating, ventilating and air conditioning (HVAC) industry now faces is a phase-out of all hydrochlorofluorocarbons (HCFC refrigerants) in new equipment by 2010, including the popular air conditioning refrigerant, R-22. With the phase-out of R-22 system manufacturers are forced to choose new HFC refrigerants that eliminate the harmful chlorine, while offering the best system efficiency possible. All of the HFCs that have been evaluated are nonozone- depleting, nonflammable, recyclable and energy-efficient refrigerants of low toxicity that are safe and cost-effective New refrigerant choices must also be safe to humans, environmentally friendly and provide excellent performance benefits. Hydrofluorocarbons (HFCs), like R-134A, are global warming gases, but due to insignificantly low emissions in air conditioning systems, the indirect global warming impact, which relates to the amount of carbon dioxide produced to power the system, is much more important than the direct global warming potential of the refrigerant itself.

2. Introduction and background

With the phase-out of CFCs and HCFCs, existing refrigeration and air-conditioning equipment operating with CFCs and HCFCs will ultimately need to be either replaced with new equipment or retrofitted with alternative refrigerants. Some service technicians and equipment owners have elected to retrofit to hydro fluorocarbon (HFC) refrigerants such as 134a, 404A or 507. Using these procedures, R-12, R-502, and R-22 equipment can be safely and efficiently retrofitted with HFC-based refrigerants, allowing the equipment to continue in service for the remainder of its useful life. These retrofit guidelines are intended for equipment containing positive displacement compressors. Scientific data support the hypothesis that chlorine from refrigerants is involved in the depletion of the Earth’s ozone layer. The air conditioning industry has supported global efforts to protect the environment by introducing non-chlorine-containing refrigerants. The Montreal Protocol, established in 1987 and revised subsequently, provides guidelines for individual country legislation, setting appropriate timetables for the phase-out of chlorine-containing refrigerants. At present, 191 nations have become party to the Montreal Protocol. In 1997, the Kyoto Protocol, signed and ratified by many nations around the world, focused attention on the impact of human activity on climate change. As a result, there is now increased attention on global warming. While the Kyoto Protocol does not apply to the United States, our industry has worked to reduce the impact of refrigerants on climate change through the use of higher-efficiency refrigerants and system designs.

3. Why is R-22 being replaced?

3.1 Classic Refrigerants Deplete Ozone

In the 1980s, the depletion of stratospheric ozone, a compound which absorbs harmful UV-B radiation was discovered, the root cause of the problem was determined to be atmospheric halogen gases. Atmospheric ozone (O3) is created when oxygen molecules (O2) collide with free oxygen atoms(O), however, upon exposure to solar radiation, halogen gases create compounds that are highly reactive with ozone molecules, breaking them apart, and
leaving oxygen (O2). One of the halogen atoms principally responsible for depleting ozone in this manner is chlorine (Cl), commonly used in so called chlorofluorocarbon (CFC) and hydro chlorofluorocarbon (HCFC) refrigerants.

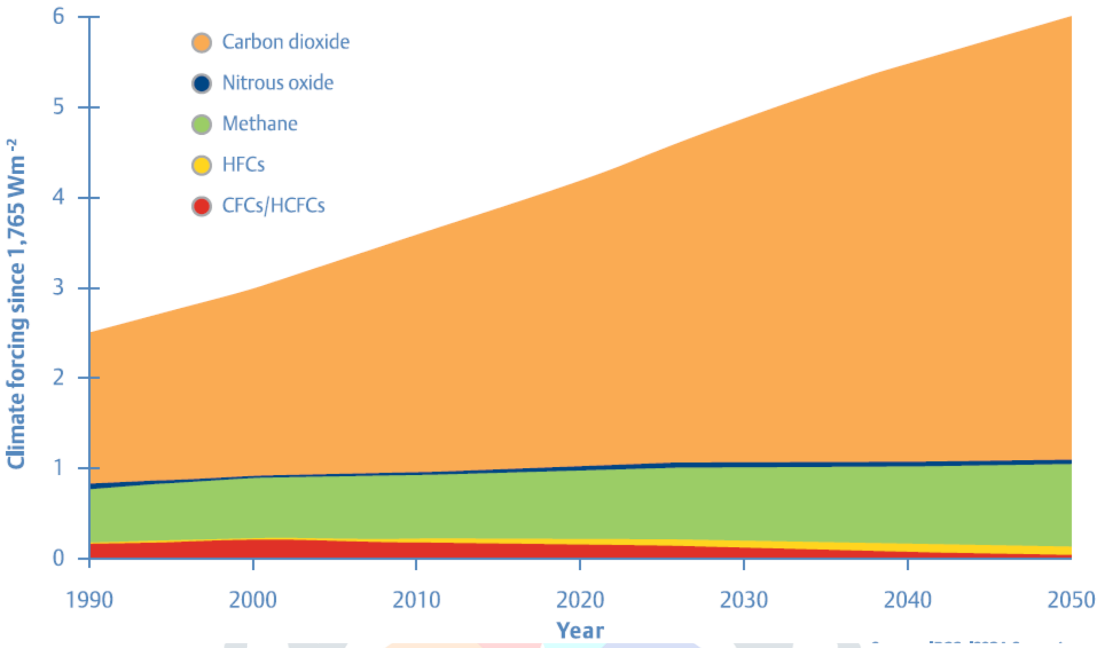
3.2 Regulations

In response to the stratospheric ozone losses, a treaty known as The Montreal Protocol on Substances That Deplete the Ozone Layer was developed. The treaty calls for the discontinuation of the substances with the greatest potential for ozone depletion such as CFC-

12 (R-12) which was phased out in 1996, and gradual phasing out of HCFCs such as HCFC-22 (R-22). As a result, the United States developed ozone protection legislation in the form of the EPA' s US Clean Air Act which will not allow the use of HCFC' s in newly manufactured air conditioning equipment after Jan. 1, 2010.Subsequent production of HCFCs will be for the servicing of existing equipment. Production levels for HCFC-22 (R-22) refrigerant were capped in 1989, and the phase out time line calls for R-22 production levels to be reduced to: 35% of the 1989 cap in 2010, 10% of the 1989 cap in 2015, 0.5% of the 1989 cap in 2020, and complete phase out in 2030.

Figure 4

Relative Projected Contributions of Greenhouse Gases to GWP



Refrigerant Alternatives

The necessity for non-chlorinated refrigerants pursuant to the new regulations resulted in the investigation of HCFC-22 replacements in the 1990s. Several refrigerant alternatives emerged from these studies, with none being a perfect replacement in the sense that it mimics the performance of HCFC-22 in all applications. Those refrigerants that have shown the greatest potential as HCFC-22 replacements are known as hydrofluorocarbons (HFCs), compounds that contain no chlorine atoms, and so have very little or no ozone depletion potential. Of these alternatives, the most commonly considered to be candidates to replace HCFC-22 are HFC refrigerants R-410A, R-134a, and R-407C. R-410A and R-407C are blends, while R-134a is composed of a single constituent.

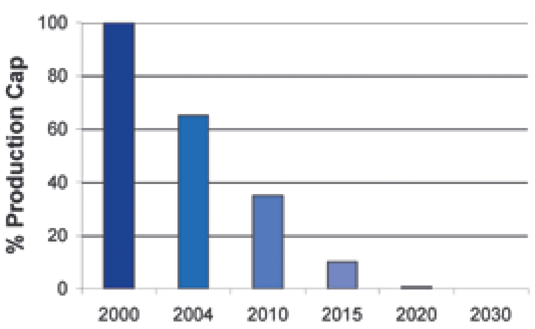
R-410A is composed of a 50/50 mixture of R-32 and R-125, while R-407C is composed of 23% R-32, 25% R-125, and 52% R-134a by weight. When considering alternative refrigerants, the advantages and disadvantages of each (including R-22) must be carefully considered.

What are the potential replacements?

R-22

R-22 has been the industry standard for air conditioning applications. However, as of 2010, the availability of R-22 will diminish significantly, and over the 15 year (or more) lifespan of an air conditioning unit, R-22 will be available only from what is recoverable, which will diminish year over year, likely increasing prices.

R-22 Phase-Out Timeline



R-134a

The advantage to selecting R-134a is that as a single component refrigerant, it is not subject to any of the difficulties that arise with mixtures. However, when compared with R-22, R-134a has a 40% lower refrigeration capacity. In practical applications, using this refrigerant requires larger heat exchanger sizes and bigger compressors to provide the same capacity and efficiency attained with R-22. This requires more sheet metal, a larger equipment footprint, a greater requirement of building space to accommodate equipment, and higher manufacturing costs. This refrigerant cannot be used in existing R-22 systems as a ‘drop-in’ replacement, but requires new, dedicated equipment.

Why is R-134A the best choice?

A Word About Warming Impact

Another environmental issue that is addressed in the evaluation of various refrigerants is their impact on global warming. In the ASHRAE Handbook 2006 – Refrigeration, each refrigerant is assigned a Global Warming Potential (GWP) as they are considered greenhouse gases. The GWP is a measure of the direct effect of the refrigerant on global warming by its release into atmosphere, and as such, does not describe the contribution of greenhouse gases such as carbon dioxide produced by the production of energy required to operate equipment that cycles the refrigerant. To account for the total warming effect (the direct and indirect effects), the Total Equivalent Warming Impact (TEWI) index is used. The direct warming effect associated with a piece of equipment comes from leakage of the refrigerant into the atmosphere, and typically contributes less to the TEWI than does the indirect effect, making the indirect effect the more critical aspect when considering warming potential. Because the indirect effect is related to energy consumption, the most efficient refrigerant will contribute the least to the TEWI. When R-134a, R-410A, R-407C, and R-22 are compared this way, R-134A contributes the least to the TEWI because it is the most efficient and demands the least use of carbon producing fossil fuels in the creation of energy.

R-134A - The Best Choice

On the basis of all these advantages (high efficiency, small footprint, low TEWI), R-134A is the best choice to incorporate into new equipment. It has been used extensively in residential applications for over ten years, has proven itself to be safe and dependable, and is being adopted as the standard to replace R-22 in commercial air conditioning markets. In anticipation of customers needs, AAON began offering commercial products with R-134A in 2001, and subsequently incorporated it into nearly all products. Recently introduced product lines such as HB rooftop units and CB/CC condensing units have been designed to operate with R-134A only. All AAON systems that incorporate R-134A are engineered specifically to work with the refrigerant, independently tested, and certified to guarantee safety and performance. Opponents to adopting R-134A who cite first cost as a reason to continue purchasing equipment featuring R-22 should consider carefully the service costs over the product’s lifetime, as R-22 becomes increasingly scarce. While it is currently possible to continue purchasing new products featuring R-22 it is not necessarily the best option. AAON fully supports R-134A as the refrigerant to succeed R-22 in air conditioning and comfort cooling applications. In 2010, it will be the only refrigerant available in new AAON equipment. To specify R-410A in your next purchase, or for more information about products featuring R-134A, contact your local AAON Sales Representative.

3. Component selection criteria:-

3.1 Compressor

Compressor selection of compressor totally depend on the calculated heat load of the system, Evaporating temperature and suction temperature because evaporating temperature of compressor affects the volumetric efficiency of compressor. Evaporating temperature decreases the volumetric efficiency of compressor decreases. It is also depend on types of refrigerant used into the system. For above system as per cooling load 1.5 TR hermetically sealed compressor selected. The specification of compressor is given into the table

Table2. Compressor specifications

No.	Parameter	Unit	Value
1	Capacity	TR	1.528
2	Evaporating Temperature	^{0}c	7.2
3	Condensing Temperature	^{0}c	55
4	Suction Pressure	bar	5.23
5	Discharge Pressure	bar	21

3.2 Condenser

Selection of condenser totally depend on its heat rejection factor, cooling capacity, Temperature difference between refrigerant and atmospheric.

The condenser load is given by formula,

$$\text{Condenser load} = \text{Compressor capacity} \times \text{heat rejection factor} \quad (6)$$

Heat rejection factor obtained by condensing and evaporating temperature of system. The condenser capacity is determine using following formula

$Q = U_o \times A_o \times \Delta T$

Where, U_o = Overall heat transfer coefficient based on outside area (W/m^2 ˚C).
A_o = Outside area of tube (m^2).
ΔT = L.M.T.D for condenser (°C).

3.3 Thermostatic expansion valve

Selection of thermostatic expansion valve and its orifice is completely depends on the pressure drop down. It is also depend on refrigerant type, evaporating temperature, liquid temperature entering the valve, and pressure drop across the valve.

Specification of thermostatic expansion valve
Danfoss TN2 068Z3346 R134a

Characteristic	Value
Type	TN 2
Capillary tube length [mm]	1.500 mm
Equalization connection type	Flare
Inlet connection type	Flare
Inlet size	3/8”
Max. Working Pressure [bar]	34,0 bar
Outlet connection type	Flare
Outlet/Equalization size [in]	1/2"
Refrigerant(s)	R134
Static Superheat (SS) [°C]	5,0

3.4 Evaporator design

During the designing, Evaporator temperature and Condensing temperature is important which give the cooling capacity of the evaporator, the value of evaporator cooling capacity obtained from standard data sheet of compressor. Materials of evaporator, velocity of refrigerant, thickness of wall and contact surface area are some parameters which affect the cooling capacity of evaporator. Evaporator capacity can be calculated as following formula.

$Q = U_o A (T_2 - T_1)$

Where,
U_o = Overall heat transfer coefficient (W/m_2)
A = Area of evaporator surface in (m_2),
T_2 = outside the evaporator Temperature (°C),
T_1= inside the evaporator Saturation temperature (°C)
Following table give the various values for evaporator coil designed for experimental purpose

Table3. Evaporator coil calculation.

Sr.No	Parameter	Unit	Value
1	Mass Flow Rate of refrigerant	kg/min	1.5
2	Velocity of refrigerant	m/sec	0.1586
3	Reynolds Number		18891.7
4	Heat transfer coefficient at refrigerant side	w/m^2k	430.86
5	Overall Heat transfer coefficient	w/m^2k	261.5
6	LMTD for Evaporator	˚C	10.34
7	Length of evaporator coil	meter	34.66

3.5 Retrofit Summary for HFC Refrigerants

Select the **Retrofit Checklist** from the Appendix for the refrigerant you are replacing.

1. Establish baseline performance with CFC/HCFC.

2. Drain mineral oil or alkyl benzene (MO/AB) from the system and measure the volume removed. Leave the CFC/HCFC refrigerant in the system.
3. Add POE lubricant; use the same volume as removed in Step 2. Start up system and operate for at least 24 hours, or more if system has complex piping.
4. Drain POE, and repeat steps 2 and 3 at least two more times. Continue flushing until MO/AB is less than 5% by weight or as recommended by compressor manufacturer.
5. Recover the CFC/HCFC charge into a proper recovery cylinder.
6. Replace the filter/drier & thermostatic expansion valve.
7. Evacuate system and check for leaks.
8. Charge with Suva® refrigerant. Remove liquid only from charging cylinder for Suva® 134Aor Suva® 404A Typical charge is 75–90% by weight of CFC/HCFC charge.
9. Start up system, adjust charge size. Label system for the refrigerant and lubricant used.

What to Expect Following a Retrofit

These tables show approximate system performance changes following a retrofit. These values are general guidelines for system behavior, and actual performance will vary with each system. Suva® 134a is compared to R-22, Suva® 404A (HP62) and Suva® 507 are compared to R-502.

DuPont™ Suva® Refrig.	**Disch. Press. psi (bar)**	**Suct. Press. psi (bar)**	**Disch. Temp. °F (°C)**	**Refrig. Cap'y. (%)**
134a	+140 (9.65)	25 (1.72)	–10 (38)	–10
404A(HP62)	+130 (8.96)	Same	–10 (–5.6)	Same
507	+140 (9.65)	Same	–15 (+8.3)	Same

4. Selection of secondary refrigerant:-

Antifreeze is a substance added to a solvent, such as water, to lower its freezing point. Antifreeze is typically added to water in the cooling system of an refrigeration system so that it can be cooled below the freezing point of pure water (0^0 C) without freezing. Ethylene glycol is the most widely used refrigeration cooling-system antifreeze, although methanol, ethanol, isopropyl alcohol, and propylene glycol are also used. The brine used in some commercial refrigeration systems is an antifreeze mixture; it is typically a water solution of calcium chloride or propylene glycol.Ethylene glycol is a clear, colorless, odorless, liquid with a sweet taste. It is hygroscopic and completely miscible with many polar solvents such as water, alcohols, glycol ethers, and acetone. Its solubility is low however, in nonpolar solvents, such as benzene, toluene, di-chloro-ethane, and chloroform. Following are some of the thermal properties of ethylene glycol.

Table 5 Thermal properties of ethylene glycol.

Boiling point at 101.3 kPa	197.60 °C
Freezing point	-13.00 °C
Density at 20°C	1.1135 g/cm^3
Refractive index, n_{D20}	1.4318
Heat of vaporization at 101.3 kPa	52.24 kJ/mol
Heat of combustion	19.07 MJ/kg
Critical temperature	372 °C

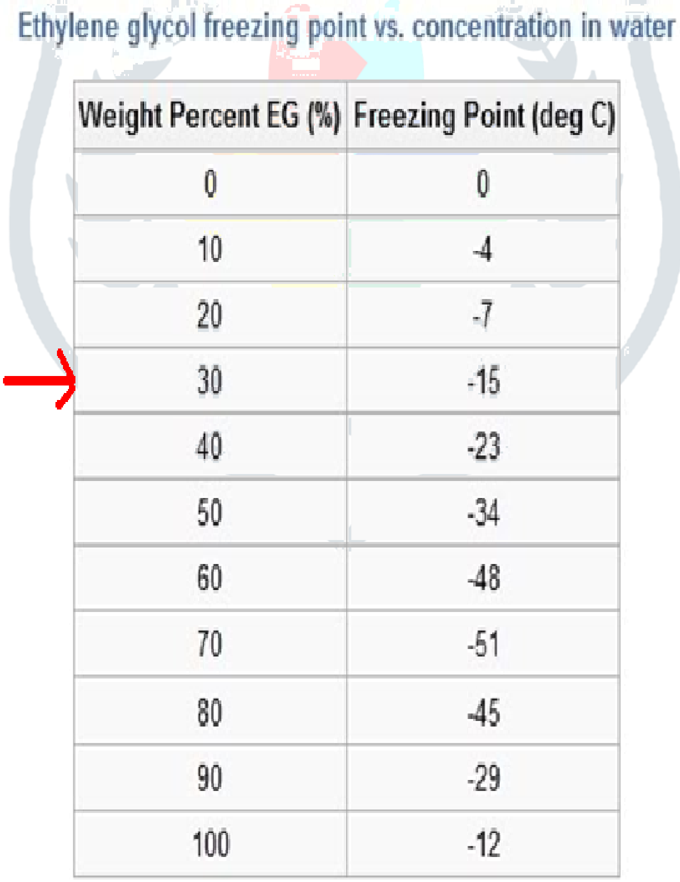
Critical pressure	6515.73 kPa
Critical volume	0.186 L/mol
Flash point	111 °C
Ignition temperature	410 °C
Lower explosive limit	3.20 vol%
Upper explosive limit	53 vol%
Viscosity at 20 °C	19.83 mPa.s
Cubic expansion coefficient at 20 °C	$0.62\times10^{-3}K^{-1}$

Ethylene glycol is also commonly used in chilled water air conditioning systems that place either the chiller or air handlers outside or systems that must cool below the freezing temperature of water.

Benefits:-

- Effective against pipe burst to a minimum temperature of -73°C.
- Helps preventing corrosion of components.
- Improves the heat transfer.
- Safe and easy to use.
- No residual product.
- Ideal also for systems where contact with potable water is possible.
- Chemically stable; it will not have effect on other chemicals already in the systems.

Table 4 Concentration of glycol in water.



Ethylene glycol freezing point vs. concentration in water

Weight Percent EG (%)	Freezing Point (deg C)
0	0
10	-4
20	-7
30	-15
40	-23
50	-34
60	-48
70	-51
80	-45
90	-29
100	-12

5 Comparative of Performance study & Results :-

A simple vapor compressor system is designed for chilled glycol solution which achieve the lowest temperature up to -10^0c at 30% concentration of glycol solution further circulated into the cold room for achieving evaporative cooling. According to the observation and readings obtained from experimental setup of low temperature vapour compression refrigeration system which replacement of R22 by choice of R134a the gives Carnot COP & theoretical COP of the system as per calculation. Actual performance of the evaporative cooling is calculated by keeping product load inside the cold room. Actual COP of system is also of these two refrigerants .Design and adaptation of vapor compressor cycle able to chill 320 liter water in 480 minutes. As mass flow rate of glycol solution is increased evaporative cooling time is decreased. Some readings and observation is given below table.

Table 6 Assessment of Experimental observations for system of (R22)

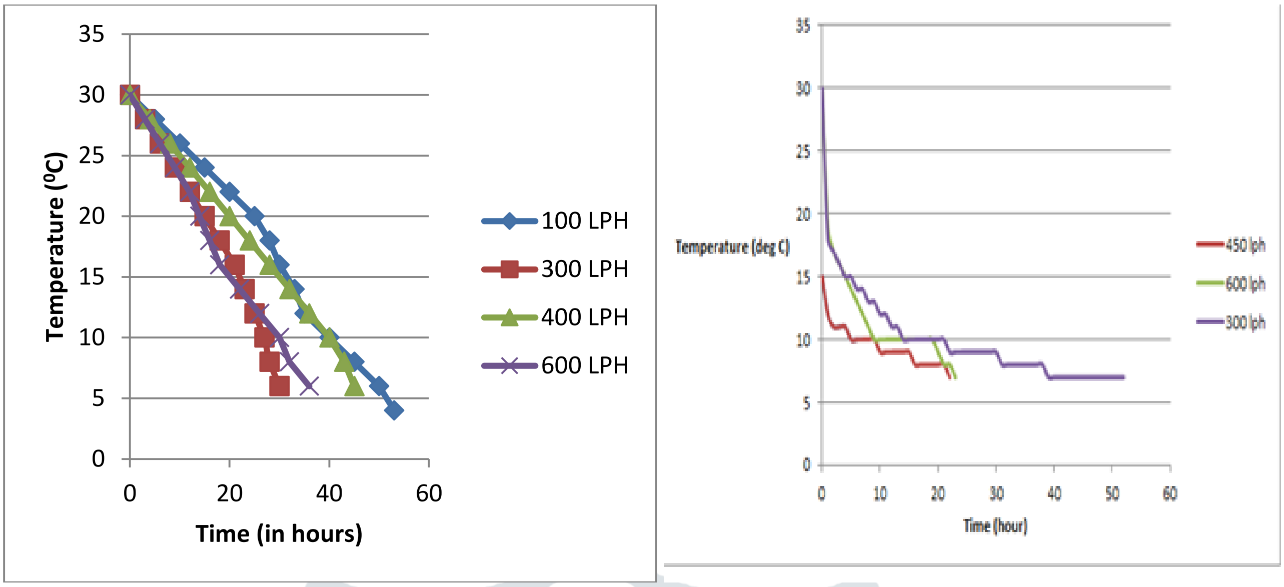
Sr. No.	Parameters	Unit	Reading (R22)			Reading (R134a)		
1	Condenser Pressure	Bar	13.10	12.26	12.06	11.72	10.72	9.65
2	Evaporator Pressure	Bar	1.03	1.58	1.93	1.03	1.28	1.53
3	Condenser Inlet Temp.	^{0}C	67	64	62	66	64	65
4	Condenser Outlet Temp	^{0}C	28	29	31	28	29	27
5	Evaporator Inlet Temp	^{0}C	-13.3	-12.7	-6.9	-14.3	-12	-8
6	Evaporator Outlet Temp	^{0}C	8	17	21	16	21	24
7	Mass Flow Rate Of Refrigerant	LPH	15	30	75	8	8	10
8	Glycol Solution Temperature	^{0}C	-10	-5	0	-10	-5	0
9	Time required for 10 rev. energy meter for compressor	sec	6.7	7	7	8	9	10

Table7 Performance analysis of different temperature of antifreeze solution

		R-134a			R-22			
SR .No.	Temperature	0^{0}C	-5^{0}C	-10^{0}C	5^{0}C	0^{0}C	-5^{0}C	-10^{0}C
1	Carnot C.O.P	4.86	4.08	4.06	5.4	5.375	4.58	4.06
2	Theoretical C.O.P	3.55	3.24	3.1	4.06	3.7667	3.33	2.923
3	Actual C.O.P	2.96	2.07	1.58	1.98	1.9452	1.8657	1.8423
4	Relative C.O.P	0.83	0.63	0.51	0.45	0.51	0.555	0.629
5	Capacity(TR)	0.46	0.53	0.69	0.71	0.63	0.57	0.54

5.1 Graphical presentation of flow rate vs. temp. drop for diff. refrigerants.

Figure 4 shows temperature drop versus required time graph on which x-axis has temperature drop and y-axis with required time. It shows as time is increases temperature drop is goes on increasing. Temperature drop is also depends on mass flow rate of secondary refrigerant that is the glycol solution used into system.



R134a **R-22**

Fig.4 Temperature drop Vs Req. Time graph

Conclusions:-

1) Design vapor compressor chilling plant able to chill glycol solution 310 liters in 480 minutes with temperature difference 40^0C
2) It is found that according to designing the capacity of the chilling plant is 1.15 TR at condensing temperature 66˚C and evaporative temperature -15˚C.
3) With the help of evaporative cooling the load on refrigeration get reduced which is helpful to save power consumption and economical running of the plant.
4) For the dairy products achieve the temperature at 0^0C to -5^0C for preservations we are using antifreeze solution as secondary refrigerant compare to water.
5) In the chiller plant, find the temperature below 0^0C consider the concentration at 30% of glycol solution used as compare 50% concentration used generally in the industry
6) At different temperature of ethylylene glycol solution i.e. $(0,-5,-10)^0$C, calculate the C.O.P. and capacity of plant and analyze that C.O.P. & capacity is decrease and relative C.O.P. is increase.
7) Temperature drop of antifreeze solution is less as compare with water as secondary refrigerant.
8) HFCs are nonflammable, recyclable, energy-efficient refrigerants of low toxicity that are being used safely throughout the world.
9) R-22 is an HCFC that is currently being phased out as part of the Montreal Protocol (1987) & Kyoto Protocol (1997).
10) The advantage to selecting R-134a is that as a single component refrigerant, it is not subject to any of the difficulties that arise with mixtures. However, when compared with R-22, R-134a has a 40% lower Refrigeration capacity.

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