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Performance of Air Conditioner System by Using Various Refrigerants

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Abstract

Air conditioning is the process of removing heat and moisture from the interior of an occupied space, to improve the comfort of occupants. This process is most commonly used to achieve a more comfortable interior environment, cool/dehumidify rooms filled with heat-producing electronic devices such as computers, servers. Our project main objective is to observe the functioning of air conditioning system by the usage of different commercial refrigerants such as R22, R134a, and R410a. As a result, we are obtaining COP, humidity, theoretical COP, actual COP, relative COP, sensible cooling, energy transfer DBT and WBT at inlet and outlet of duct.

Keywords: R22, R134a, R410

1. INTRODUCTION

The Heating, Ventilation and Air Conditioning (HVAC) and refrigeration system transfers the heat energy from or to the products, or building environment. Energy in form of electricity or heat is used to power mechanical equipment designed to transfer heat from a colder, low-energy level to a warmer, high energy level[1].Refrigeration deals with the transfer of heat from a low temperature level at the heat source to a high temperature level at the heat sink by using a low boiling refrigerant[2].

There are several heat transfer loops in refrigeration system as described below:

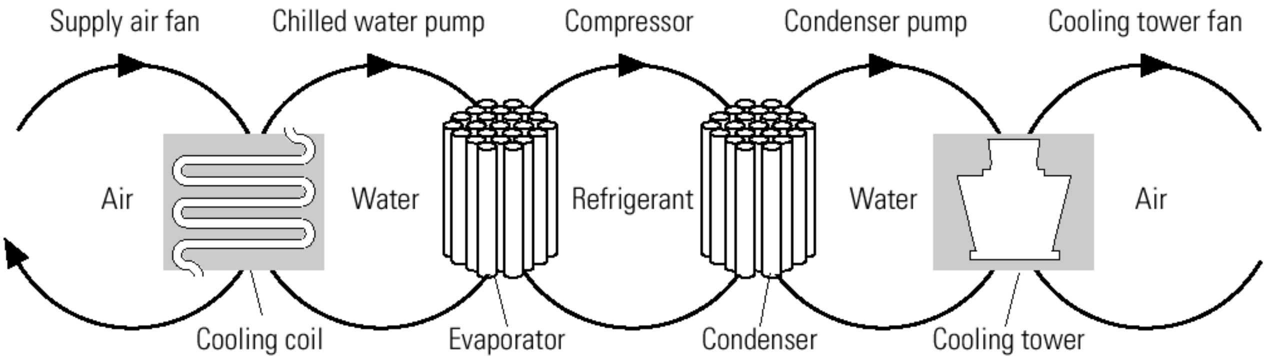

Figure 1. Heat transfer loops in refrigeration system.

In the above figure, thermal energy moves from left to right as it is extracted from the space and expelled into the outdoors through five loops of heat transfer:

- **Indoor air loop**: In the leftmost loop, indoor air is driven by the supply air fan through a cooling coil, where it transfers its heat to chilled water. The cool air then cools the building space.
- **Chilled water loop**: Driven by the chilled water pump, water returns from the cooling coil to the chiller's evaporator to be re-cooled.
- **Refrigerant loop**: Using a phase-change refrigerant, the chiller's compressor pumps heat from the chilled water to the condenser water.
- **Condenser water loop**: Water absorbs heat from the chiller's condenser, and the condenser water pump sends it to the cooling tower.
- **Cooling tower loop**: The cooling tower's fan drives air across an open flow of the hot condenser water, transferring the heat to the outdoors.

2. LITERATURE REVIEW

Richard C.Jordan[1] gives information about understanding of the cooling load to be met is the first and most important part of designing / selecting the components of a refrigeration system. Important factors to be considered in quantifying the load are the actual cooling need, heat (cool) leaks, and internal heat sources (from all heat generating equipment). Consideration should also be given to process changes and /

or changes in ambient conditions that might affect the load in the future. Reducing the load, e.g. through better insulation, maintaining as high a cooling temperature as practical, etc. is the first step toward minimizing electrical power required to meet refrigeration needs.

Norman[2] quantitative understanding of the required temperatures and the maximum, minimum, and average expected cooling demands, selection of appropriate refrigeration system (single-stage / multi-stage, economized compression, compound / cascade operation, direct cooling / secondary coolants) and equipment (type of refrigerant, compressor, evaporator, condenser, etc.) can be undertaken.

Priester[3] gives clear information on Refrigerants is substances that can be used in the refrigeration cycle of air conditioning and refrigeration equipment because of their thermodynamic properties. Chloro Fluoro Carbons (CFCs), Hydro Chloro Fluoro Carbons (HCFCs) and Hydro Fluoro Carbons (HFCs) are synthetic substances used as refrigerants. These halogenated refrigerants have to be chemically synthesized as they either do not occur in nature at all or only in trace concentrations. CFCs and HCFCs are being phased out under the Montreal Protocol, an international agreement to protect the ozone layer. They have been controlled by the Montreal Protocol since 1987 because of their ozone depleting potential and high global warming potentials. Consumption of HFCs however is growing dramatically world-wide due to their function as replacement substances for CFCs and HCFCs. Nevertheless HFCs are greenhouse gases. Their use should be avoided in order to slow global warming.

In the past the phase-out of one group of refrigerants that damaged the environment has always led to the increased use of refrigerants that were only less damaging. This happened in the switch from CFCs to HCFCs (though note that HCFCs were regularly used before the phase-out of CFCs as well) and on to HFCs in developed countries and is currently visible in developing countries where HFCs are replacing HCFCs, and to some extent in developed countries where u-HFCs are being introduced. Switching directly from ozone depleting and climate harming fluorinated substances to natural refrigerants in energy-efficient systems and applications is often referred to as “leapfrogging”.

TERI[4]Within the Montreal Protocol, states have always been encouraged to choose alternatives that not only save the ozone layer but that also do not harm the climate. UN Secretary-General Ban Ki-moon urged parties and industries “to seize the opportunity provided by the HCFC phase-out to leapfrog HFCs wherever possible” in his 2011 Ozone Day message. A phase-down of HFCs is also being discussed as an amendment to the Montreal Protocol. With growing concern about future regulations prohibiting the use of HFCs, countries as well as industries have to look for opportunities to leapfrog. This will prevent them from having to phase new sets of fluorinated gases in and out again. We expect this pattern to hold not only in Mexico but around the world. When you look around, there are a lot of hot places where people are getting richer. In our study, we ranked countries in terms of air conditioning potential. We defined potential as the product of population and cooling degree days (CDDs), a unit used to determine the demand for energy to cool buildings.

Table 1: Air Conditioning Potential for Different Countries

Sr. No.	Country	Population (in millions)	Annual CDDs	Annual GDP per capita (in thousands)
1	India	1,242	3,120	1.5
2	China	1,357	1,046	6.8
3	Indonesia	250	3,545	3.5
4	Nigeria	174	3,111	3.0
5	Pakistan	182	2,810	1.3
6	Bangladesh	157	2,820	1.0
7	Brazil	200	2,015	11.2
8	Philippines	98	3,508	2.8
9	United states	316	882	53.0
10	Vietnam	90	3,016	1.9
11	Thailand	67	3,567	5.8
12	Mexico	122	1,560	10.3

What does all this mean for carbon dioxide emissions? It depends on the pace of technological change, both for cooling equipment and for electricity generation. Today’s air conditioners use only about half as much electricity now as in 1990, and continued advances in energy efficiency could reduce the energy consumption impacts substantially. Likewise, continued development of solar, wind and other low-carbon sources of electricity generation could mitigate the increases in carbon dioxide emissions. Pricing carbon would also lead to broader behavioral changes. Our homes and businesses tend to be very energy-intensive. In part, this reflects the fact that carbon emissions are free. Energy would be more expensive with a price on carbon, so more attention would go to building design. Natural shade, orientation, building materials, insulation and other considerations can have a big impact on energy consumption. We need efficient markets if we are going to stay cool without heating up the planet. What Makes Air Conditioners Detrimental to the Environment? Air conditioners have an environmental impact in more ways than one, but the most significant are the inputs and the outputs. These popular cooling machines do not just function on their own and they are powered by electricity. The effects of electricity production alone can be very detrimental to the world in which we live. The hazardous pollutants pumped into the air from traditional fossil fuels are one of the top sources of negative environmental impact. Not only is the energy consumption detrimental, but the gases emitted from air conditioners are also affecting the environment. Many, if not most, of the most harmful CFC gases have been stamped out via the Montreal Protocol, which reduces the emission of pollutants, but the gases that are still being emitted have a huge impact on global warming. It has been said that 27% of all global warming will be due to the gases emitted from air conditioning by the year 2050. This shocking statistic is largely due to the expected increase of use of air conditioning as temperatures continue to rise, thus creating a cycle of damage.

Table 2: Ozone depletion, Global warming potentials of CFC's and HCFC's.

Sr. No.	Substance Group	Abbreviation	ODP (Ozone Depletion Potential)	GWP (Global Warming Potential)	Example
1	Saturated Chloro flouro carbons	CFC	0.6-1	4750-14400	R12
2	Saturated Hydro flouro carbons	HCFC	0.02-0.11	77-2310	R22

REFRIGERANTS

R22 Refrigerant

Chlorodi fluoro methane is a hydro chlorofluorocarbon (HCFC). This colourless gas is better known as HCFC-22, or R-22. It is commonly used as a propellant and refrigerant. These applications are being phased out in developed countries due to the compound's ozone depletion potential (ODP) and high global warming potential (GWP), although global use of R-22 continues to increase because of high demand in developing countries R-22 is a versatile intermediate in industrial organ fluorine chemistry, e.g. as a precursor to tetra fluoro ethylene. R-22 cylinders are colour light green.

Table 3: Properties of R22 refrigerant.

Sr. No.	Property	Value
1	Density (ρ) at -69 °C (liquid)	1.49 $g.cm^{-3}$
2	Density(ρ) at -41 °C (liquid)	1.413 $g.cm^{-3}$
3	Density (ρ) at -41 °C (gas)	4.706 $kg.m^{-3}$
4	Density (ρ) at 15 °C (gas)	3.66 $kg.m^{-3}$
5	Specific gravity at 21 °C (gas)	3.08 (air = 1)
6	Specific volume (ν) at 21 °C (gas)	0.275 $m^3.kg^{-1}$
7	Density (ρ) at 15 °C (gas)	3.66 $kg.m^{-3}$
8	Triple point temperature (T_t)	-157.39 °C (115.76 K)
9	Critical temperature (T_c)	96.2 °C (369.3 K)
10	Critical pressure (p_c)	4.936 MPa (49.36 bar)
11	Vapour pressure at 21.1 °C (p_c)	0.9384 MPa (9.384 bar)
12	Critical density (ρ_c)	6.1 $mol.l^{-1}$
13	Latent heat of vaporization (l_v) at boiling point (-40.7 °C)	233.95 $kJ.kg^{-1}$
14	Heat capacity ratio (γ) at 30 °C (86 °F)	1.178253
15	Compressibility factor (Z) at 15 °C	0.9831
16	Viscosity (η) at 0 °C	12.56 µPa.s (0.1256 cP)
17	Ozone depletion potential (ODP)	0.055 (CCl_3F = 1)
18	Global warming potential (GWP)	1810 (CO_2 = 1)

R134a Refrigerant

1,1,1,2-Tetrafluoroethane, R-134a, Freon134a, Forane134a, Genetron134a, Florasol 134a, Suva 134a, or HFC-134a) is a halo alkane refrigerant with thermodynamic properties similar to R-12 (dichlorodifluoromethane) but with insignificant ozone depletion potential and a somewhat lower global warming potential (1,430, compared to R-12's GWP of 10,900).It has the formula CH_2FCF_3 and a boiling point of −26.3 °C (−15.34 °F) at atmospheric pressure. R-134a cylinders are coloured light blue.

Table 4: Properties of R134a refrigerant.

Sr. No.	Property	Value
1	Chemical formula	CH_2FCF_3
2	Molar mass	102.03 g/mol
3	Appearance	Colourless gas
4	Density	0.00425 g/cm^3, gas
5	Melting point	−103.3 °C (−153.9 °F; 169.8 K)
6	Boiling Point	-14.9°F or -26.1°C
7	Auto Ignition temperature	1418°F or 770°C
8	Ozone Depletion Level	0
9	Solubility in Water	0.11% by weight at 77°F or 25°C
10	Critical Temperature	252°F or 122°C
11	Cylinder Colour Code	Light Blue
12	Global Warming Potential (GWP)	Global Warming Potential (GWP)

R410a Refrigerant

R-410A, sold under the trademarked names AZ-20, EcoFluorR410, Forane410A, Freon 410A, Genetron R410A, Puron, and Suva 410A is a zeotropic, but near-azeotropic mixture of difluoromethane (CH_2F_2, called R-32) and pentafluoroethane (CHF_2CF_3, called R-125), which is used as a refrigerant in air conditioning applications. R-410A cylinders are colored pink.

Table 5: Properties of R410a refrigerant.

Sr. No.	Property	Value
1	Formula	CH_2F_2 (50%) CHF_2CF_3 (50%)
2	Molecular Weight (Da)	72.6
3	Melting point (°C)	−155
4	Boiling point (°C)	−48.5
5	Liquid density (30°C), kg/m^3	1040
6	Vapour density (30°C), air=1.0	3.0
7	Vapour pressure at 21.1°C (MPa)	1.383
8	Critical temperature (°C)	72.8
9	Critical pressure, MPa	4.86
10	Gas heat capacity (kJ/(kg·°C))	0.84
11	Liquid heat capacity @ 1 atm, 30°C, (kJ/(kg·°C))	1.8

3. EXPERIMENTAL WORK

To conduct performnce test on air conditioner (duct type) and to find out C.O.P and relative humidity at different psychrometric processes.

System Components

- Hermetically sealed compressor (1 ton cap)
- Air cooled condenser
- Fan motor with blade
- Expansion device-capillary
- Hand shut off valve-3/8”
- Filter-Drier
- Energy meter (5 - 10)
- Pressure/compound gauges
- Digital Temperature Indicator (-50 to +150)
- Thermocouple
- DP Switch for mains
- Refrigerants
- Evaporator Coil placed inside the duct
- Finned heater for de-humidification process with electronic dimmers
- Boiler for producing steam for humidification process.

Fig1. Air Conditioning Trainer Equipment (duct type)

The standard vapour compression cycle consists of following process,

1. Process -2 represents reversible adiabatic compression from saturated vapour to the condenser pressure or superheated vapour.
2. Process 2 – 3 represents reversible heat rejection at constant pressure, de preheating and condensation.
3. Process 3 – 4 represents irreversible constant enthalpic expansion from saturated liquid to the evaporator pressure.
4. Process 4 – 1 represents reversible heat addition at constant pressure (evaporation to saturated vapour).

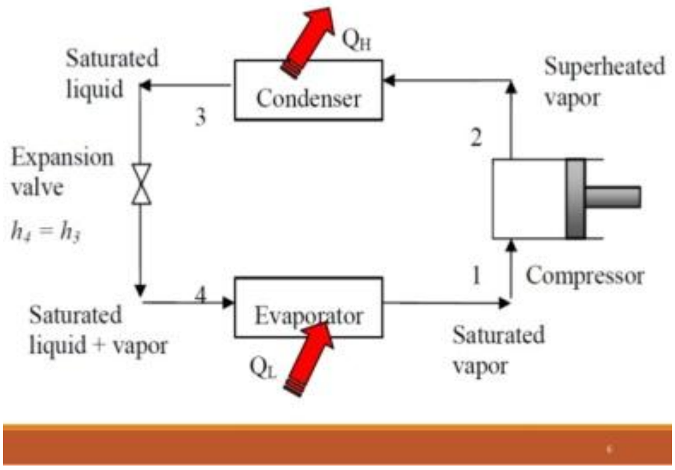

Fig2. Block Diagram of Vapour Compression Refrigeration Cycle.

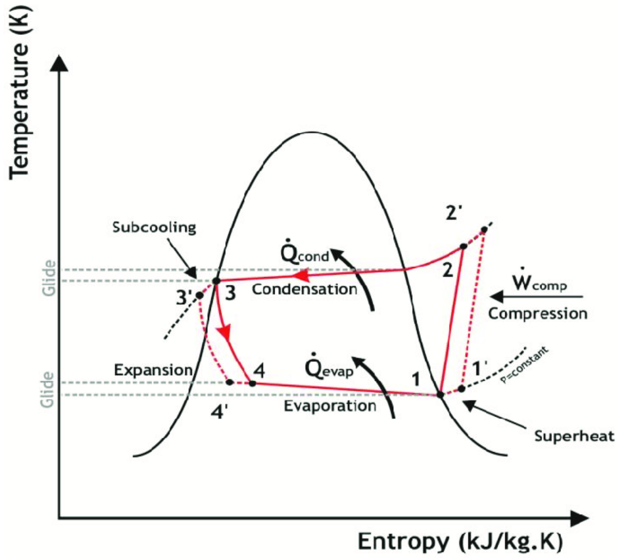

Fig3. T-S of Vapour Compression Rrefrigeration Cycle.

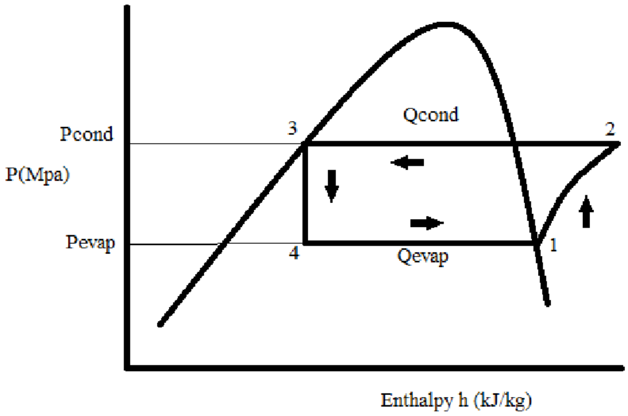

Fig4. P-H of Vapour Compression Refrigeration Cycle.

PSYCHROMETRIC PROCESSES

Sensible Cooling

The process of cooling of air without subtraction of moisture is termed as sensible cooling. This can be achieved by passing the air over cooling coil like evaporating coil of the refrigerant cycle.

Cooling with Dehumidification of air

The removal of water vapour from the air is termed as dehumidification of air. This is only possible if the air is cooled below dew point temperature of air. By heating (heater 1) the inlet air by using electric heaters the quantity of the water vapour presented in the inlet air is reduced. This is essential for dehumidification. We can also remove some more amount of water vapour present in the air after it passing through the cooling coil (evaporator) with the help of heater 2 (if only needed).

Cooling with Humidification

Adding of water vapour to the air is termed as humidification. This can be obtained by adding steam to the air at inlet of the cooling coil then air is passes through a spray chamber, part of the water will be evaporated and is carried with the air, thus increasing the specific humidity. The heat required for the evaporation of water vapour is carried with the air is taken from the air itself by decreasing the temperature of air and the total enthalpy of air remain constant.

Thermocouple Details

T1 – Temperature of refrigerant at inlet of compressor in centigrade.

T2 – Temperature of refrigerant at outlet of compressor in centigrade.

T3 – Temperature of refrigerant at outlet of condenser centigrade.

T4 - Temperature of refrigerant at outlet of expansion device centigrade.

T5 - Ambient temperature centigrade.

WBT_1, DBT_1-Wet and Dry bulb temperature at inlet of duct.

WBT_2, DBT_2- Wet and Dry bulb temperature at outlet of duct.

OPERATIONAL PROCEDURE

1. Plug in the mains card of the system.
2. Switch ON the DP switch so that the digital panel meters indicator corresponding readings.
3. Switch ON the condenser fan and blower.
4. Start the system by switching ON the compressor.
5. Allow air to flow through the air conditioning chamber and let it stabilize for few minutes.
6. Record T1, T2, T3, T4, T5, P1, P2 readings. Also note down the wet and dry bulb temperature inlet and outlet.

For Humidification Process

a. Fill the water through water inlet valve to the boiler about half to 3/4th and close the valve.
b. Switch on the boiler for about 45 to 60 minutes.
c. c. When steam is formed close the glass tube valve and open steam inlet valve and allow it flow about 10 minutes.
d. Record wet and dry bulb temperature at inlet and outlet.

For Humidification operation

a. Switch on the heater switches.
b. Vary the electronic dimmer up to the corresponding indicator glows.
c. Allow it for few minutes.
d. Record wet and dry bulb temperature at inlet and outlet.

Finally, switch off heaters/boilers, thermostat and after about 5 minutes switch off CF, EF and mains.

4. CALCULATIONS

R22 Refrigerant

Table 6: R22 Readings.

P1	**P2**	**T1**	**T2**	**T3**	**T4**	**T5**	**EMR**	**Wet/Dry Inlet (Centigrade)**	**Wet/Dry Outlet (Centigrade)**
69	280	10.1	46.8	44.5	8.8	30.8	5.41	28/31	18/20

Where,

T1 – Temp.of refrigerant @ inlet of compressor in centigrade.

T2 - Temp.of refrigerant @ outlet of compressor in centigrade.

T3 - Temp.of refrigerant @ outlet of condenser centigrade.

T4 - Temp. of refrigerant @ outlet of expansion device centigrade.

T5 – Ambient temperature centigrade.

P1,P2- Pressure readings in Psi.

EMR- Energy Meter Reading.

From R-22 P-h chart,

h1 = Enthalpy in KJ/kg corresponding to P1 and T1

h4 = Enthalpy in KJ/kg corresponding to P2 and T3

h2 = Enthalpy in KJ/kg corresponding to P2 and T2

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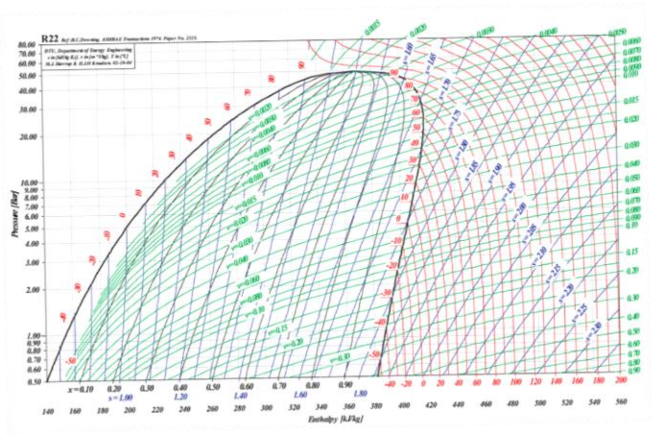

Fig5. R22 P-H chart

$$COP = \frac{h1-h4}{h2-h1}$$

$$= \frac{410-258}{420-410}$$

$$= \frac{152}{10} = 15.2$$

$$\text{Carnot COP} = \frac{T1}{T2-T1} = \frac{283.1}{319.8-283.1} = 7.71$$

$$\text{Compressor output (W)} = \frac{n\times3600}{5.4\times3200} = \frac{5\times3600}{5.4\times3200}$$

$$= 1.041$$

where,

n-number of impulse on energy meter

$$Q = m_a \times C_p(t_1 - t_0)$$

$$= 0.2018\times 1.008(31-20)$$

$$= 2.23$$

where,

t_1-DBT at inlet in degree Celsius.

t_0-DBT at outlet in degree Celsius.

m_a- mass of air=0.2015kg/sec

C_p-Specific heat of air =1.008 KJ/kg

1 Psi = 0.068 bar.

Actual COP $= \frac{Q}{w} = \frac{2.23}{1.041} = 2.14$

Relative COP $= \frac{\text{Actual}}{\text{therithical}} = \frac{2.14}{15.2} = 0.14$

Air conditioning process:

State: 1 Ambient $WBT_1 = 28°C$

$DBT_1 = 31°C$

State: 2 Air out from AC, $WBT_2 = 20°C$

$DBT_2 = 18°C$

Sensible cooling:

$DBT_1 - DBT_2 = 31 - 18 = 13^0C$

DBT_1-Dry Bulb Temperature @ inlet of the duct

DBT_2-Dry Bulb Temperature @ outlet of the duct

From psychrometric chart,

State points 1, 2 on psychometric chart (enclosed) using DBT_1, WBT_1, DBT_2, WBT_2 & thus we can find out corresponding values of specific humidity, enthalpy, relative humidity & specific volume.

$H_1 = 88$ kJ/kg of dry air

$H_2 = 49$ kJ/kg of dry air

Therefore,

Energy transfer (cooling) = $H_1 - H_2 = 39$ KJ/kg of dry air

Relative humidity = 82 %

Specific volume = 0.885 m^3/kg

Calculations for R134a

Table 7: R134a readings.

P1	**P2**	**T1**	**T2**	**T3**	**T4**	**T5**	**EMR**	**Wet/Dry Inlet (Centigrade)**	**Wet/Dry Outlet (Centigrade)**
50	260	18.1	62.4	54.2	10.5	30.5	5.41	28/32	20/21

T1 – Temp.of refrigerant @ inlet of compressor in centigrade.

T2 - Temp.of refrigerant @ outlet of compressor in centigrade.

T3 - Temp.of refrigerant @ outlet of condenser in centigrade.

T4 - Temp. of refrigerant @ outlet of expansion device in centigrade.

T5 – Ambient temperature centigrade.

P1, P2- Pressure readings in Psi.

EMR- Energy Meter Reading.

From R-134a P-h chart,

h1 = Enthalpy in KJ/kg corresponding to P1 and T1

h4 = Enthalpy in KJ/kg corresponding to P2 and T3

h2 = Enthalpy in KJ/kg corresponding to P2 and T2

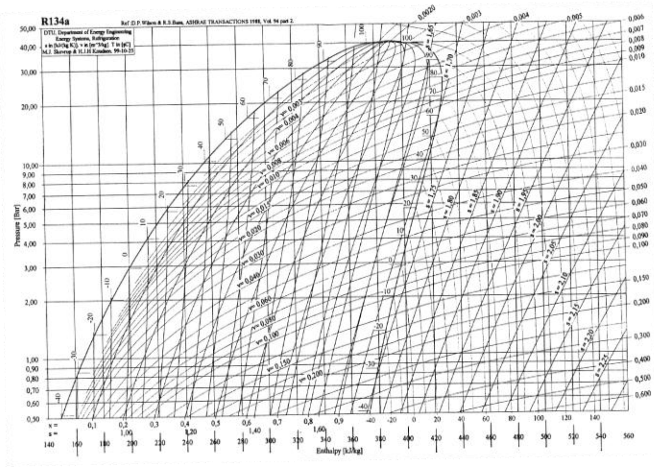

Fig6. R134a P-H chart

Calculations for R410a

Table 8: R410a readings.

P1	P2	T1	T2	T3	T4	T5	EMR	Wet/Dry Inlet (Centigrade)	Wet/Dry Outlet (Centigrade)
84	315	24.2	68.2	36.7	8.2	30.5	5.41	32/29	21/19

T1 – Temp.of refrigerant @ inlet of compressor in centigrade.

T2 - Temp.of refrigerant @ outlet of compressor in centigrade.

T3 - Temp.of refrigerant @ outlet of condenser centigrade.

T4 - Temp. of refrigerant @ outlet of expansion device in centigrade.

T5 – Ambient temperature centigrade .

P1,P2- Pressure readings in Psi.

EMR-Energy Meter Reading.

From R-410a P-h chart,

h1 = Enthalpy in KJ/kg corresponding to P1 and T1

h4 = Enthalpy in KJ/kg corresponding to P2 and T3

h2 = Enthalpy in KJ/kg corresponding to P2 and T2

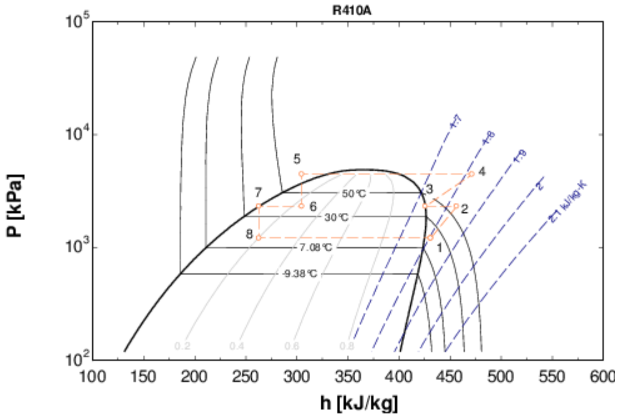

Fig7. R410a P-H chart

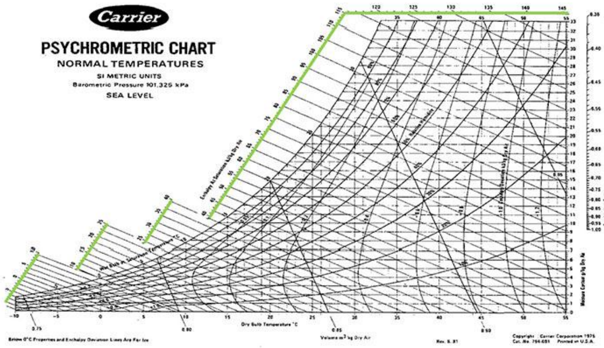

Fig8. Psychrometric chart

$$COP = \frac{h1-h4}{h2-h1}$$
$$= \frac{455-260}{475-455}$$
$$= \frac{195}{20} = 9.75$$

$$\text{Carnot COP} = \frac{T1}{T2-T1}$$
$$= \frac{297.2}{341.2-297.2} = 6.75$$

$$\text{Compressor output (W)} = \frac{n\times3600}{4.2\times3200} = \frac{5\times3600}{4.2\times3200}$$
$$= 1.33$$

Where,

n - number of impulse on energy meter

$$Q = m_a \times C_p(t_1 - t_0)$$
$$= 0.2018\times 1.008(32-21)$$
$$= 2.38$$

Where, t_1 - DBT at inlet in degree celsius

t_0 - DBT at outlet in degree celsius

m_a - mass of air=0.2015kg/sec

C_p-Specific heat of air=1.008 KJ/kg

1 Psi = 0.068 bar.

Actual COP $= \frac{Q}{w} = \frac{2.38}{1.33} = 1.78$

Relative COP $= \frac{\text{Actual}}{\text{theritical}} = \frac{1.78}{9.75} = 0.18$

Air conditioning process:

State: 1 Ambient $WBT_1 = 29°C$

$DBT_1 = 32°C$

State: 2 Air out from AC, $WBT_2 = 19°C$

$DBT_2 = 21°C$

Sensible cooling:

$$DBT_1 - DBT_2 = 32 - 21 = 11^0C$$

DBT_1 - Dry Bulb Temperature @ inlet of the duct

DBT_2 - Dry Bulb Temperature @ outlet of the duct

From psychrometric chart,

State points 1, 2 on psychometric chart (enclosed) using DBT_1, WBT_1, DBT_2, WBT_2 & thus we can find out corresponding values of specific humidity, enthalpy, relative humidity & specific volume.

$H_1 = 93$ kJ/kg of dry air

$H_2 = 53$ kJ/kg of dry air

Energy transfer (cooling) = H_1-H_2 = 30 KJ/kg of dry air

Relative humidity = 82 %

Specific volume = 0.895 m^3/kg

CONCLUSION

- Carnot COP of R22 is equal to half the value of theoretical COP.
- Theoretical COP of R134a is nearly equal to Carnot COP.
- Carnot COP of R410a is nearly 70% of theoretical COP.
- Performance wise R22 is better but it has high Global Warming Potential.
- R410a acts as a better replacement for by R22, since R22 will become extinct by 2020.
- R134a is less preferable when compared to R22 refrigerant.
- Refrigeration effect of R410a is more when compared to R22 & R134a.

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