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Thermal and Performance Analysis of R600a in Vapour Compression Cycle

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***Abstract*— The aim of this project is to comparatively analyze of COP using R134a & R600a Refrigerant in Domestic refrigerator at steady state condition. Two different refrigerant are R600a (Isobutene) and R134a (tetrafluoroethae). R134a is zero ozone depletion layer and high global warning and R600a is zero ozone depletion layer and negligible global warning. In domestic refrigerator was selected by the obtained result from R134a and an experiment using 170 g of R600a which indicate the similar result as R134a. Based on outcomes R600a charge amount, condenser evaporator and compressor coefficient of performance were selected for design. The analysis of variance result is indicated that R600a charge amount was the most effective parameter. At optimum condition the amount of charge is required for R600a was 170 g, 66% lower than R134a one, which not only being economic advantages, but also significantly reduces the of flammability of the hydrocarbon refrigerant. Thus in the present work comparatively analyze of COP using R134a & R600a Refrigerant in Domestic refrigerator at steady state condition. All the result were compared. Comparison of performance domestic refrigerator at steady state condition of the system was also studied. The result is indicate that R600a COP is more than R134a.CFD Analysis of condenser & evaporator also shows system effectiveness with respect to the R134a & R600a.**

I. INTRODUCTION

Refrigeration may be defined as the process of achieving and maintaining a temperature below that of the surroundings, the aim being to cool some product or space to the required temperature. One of the most important applications of refrigeration has been the preservation of perishable food products by storing them at low temperatures. Refrigeration systems are also used extensively for providing thermal comfort to human beings by means of air conditioning. Air Conditioning refers to the treatment of air so as to simultaneously control its temperature, moisture content, cleanliness, odour and circulation, as required by occupants, a process, or products in the space. The subject of refrigeration and air conditioning has evolved out of human need for food and comfort, and its history dates back to centuries. The history of refrigeration is very interesting since every aspect of it, the availability of refrigerants, the prime movers and the developments in compressors and the methods of refrigeration all are a part of it. The French scientist Roger ThÝvenot has written an excellent book on the history of refrigeration throughout the world.

II. METHODOLGY

A. Properties of R600a

Its numerical designation is R600a or Isobutane. Its chemical formula (CH3) 3 CH.
Normal boiling point = 260-264 °K at atm pressure
Critical Temperature = 135°C
Critical pressure = 3.65 MPa
Vapour pressure = 204.8 KPa at 21°C
Specific heat of liquid = 2.38 KJ/Kg°C at 25°C
Molar mass = 58.12 g mol−1
Density = 2.51 kg/m3, gas (15 °C, 1atm) 593.4 kg/m3, liquid
Melting point = -159.6 °C, 114 K, -255 °F
Boiling point = -11.7 °C, 261 K, 11 °F
Solubility in water = Insoluble
Ozone depletion potential (ODP) = 0
Global warming potential (GWP) = 3
Flash point = -83 °C, −117 °F; 190 K
Latent heat of evaporation = 362.6 KJ/Kg at atm pressure
Specific Heat Ratio C_p/C_v = 1.091(atm,25.C)
Assigned colour code = Colourless gas

B. Vapour compression cycle

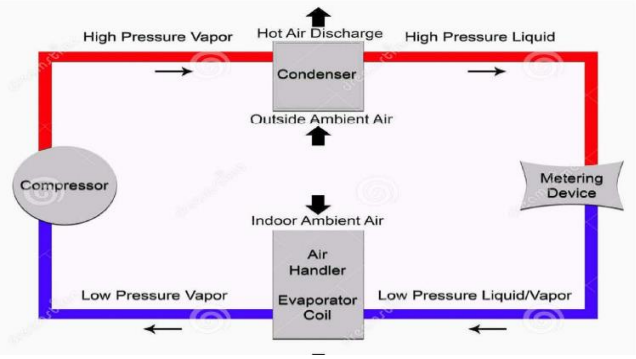

Fig 1. VCC Cycle

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C. Component list

TABLE I
LIST OF COMPONENTS

Sr. No.	Description	Part No.
01	Base stand	SPREFACM0001
02	Pressure gauge: 0 to 500 psi	SPREFACM0002
03	Compound gauge. 0 to -150psi	SPREFACM0003
04	Temperature Indicator.	SPREFACM0004
05	Condensers	SPREFACM0005
06	Evaporators	SPREFACM0006
07	Hermetically Sealed compressor	SPREFACM0007
08	Condenser motor & fan blade	SPREFACM0008
09	Thermostat	SPREFACM0009
10	R134A gas	SPREFACM0010
11	Rotameter	SPREFACM0011
12	Capillary tubes.	SPREFACM0012
13	ON/OFF Switch	SPREFACM0013
14	Pt 100 sensor pencil type & bulb type.	SPREFACM0014
15	Instructional Manual	SPREFACM0015

D. System description

In refrigeration test rig, working medium is liquid; which involves sensible as well as latent heat. And coefficient of performance of refrigeration test rig is more than that of aircompression system. Most of the modern refrigerators work on refrigeration test rig. Therefore it is necessary for engineering students to Study the performance of refrigeration cycle & its different parameter, performance, calculations is focus of this trainer.

Base Stand: This is made up of CRCI square tubes & sheets. This is painted specially with Powder coating. All equipments are mounted on Base stand.
Hermetically Sealed Compressor: This is used to take the refrigerant Vapor at low pressure & low temperature & compress it to a high pressure & high temperature. The capacity of compressor is 0.75 HP
Condenser: The condenser is the forced air-cooled type for which condenser fan and motor has been provided. The function of condenser is to convert high-pressure refrigerant Vapor into high-pressure refrigerant liquid. The outside diameter of condenser is 3/8". Size of condenser as per standard specification is 11" x 10" x 3 Rows

Expansion Devices: (Capillary Tube): Capillary tube is the expansion device
which is used for small units of ½ to 3 tons. The purpose of expansion valve in a refrigeration system is to reduce the high side pressure to the low side pressure so that liquid can evaporate by picking up heat. The length and the small diameter reduce the pressure from condensing pressure to evaporator pressure. Overall Dimension is (Bore x Length) = 0.50" x 5" x 1
Drier: The primary function of the drier is to separate gas and liquid. The secondary
purpose is to remove moisture and filter out dirt.
Pt 100-sensors (Pencil Type & Bulb Type): The temperatures at different points in the system are measured by using RTD (PT – 100) sensors. These are Resistance Temperature Detectors operating on principle of change in Resistance with change in temperature.
Evaporator: This is made up of S.S material having inbuilt coil and heater. It is used as an evaporator in the system.
Rotameter: This is a variable area glass tube liquid flow-measuring device. The glass tube is enclosed in M.S. structure with transparent glass at two sides to read the readings. Calibrated scale is mounted in the enclosure. The float is lifted up as liquid flows through the glass tube and the lift is proportional to the flow rate. Its range is 6.8-68 LPH
Pressure Gauge (0 to 300 PSI.): It is a Bourdon type pressure gauge. This is used to measure pressures at discharge point of compressor.
Compound Gauge. (-30 to 150 PSI.): This Bourdon type pressure gauge measures both negative pressure (Vacuum) as well as positive pressure. This is used to measure pressures at suction point of compressor.
Motor pump: the pump is used as stirrer in the system so as the refrigeration effect should uniformly done.
Energy meter : its main purpose is to indicate the energy consumed by the compressor
Thermostat: it acts as a cut off of the system it switch off the compressor as soon as the temperature of the evaporator drops below set point.
Herter coil: it acts as the load to the refrigeration effect and the heater is placed inside the evaporator.
Volt and Ammeter meter: the volt meter indicates the voltage across the heater coil while the ammeter indicates the current drawn by the heat.

Specification:

TABLE 2. DIMENSIONS OF CONDENSOR PIPE

Parameter	Dimensions
Diameter Of Pipe	0.955 cm
Thickness of pipe	1.5 mm
Total length	1096.3 cm

TABLE 3. DIMESIONS OF FINS

Parameter	Dimension
Number of fins	112
Fin width	5.4-5.5 cm
Fin Height	33 cm

TABLE 4. DIMESIONS OF CONDENSOR SHELLS

Box Height	33 cm
Box Width	15 cm

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Fig. 2 Evaporator

Fig. 3 Evaporator

Emerson Climate Technologies (India) Limited.

PRODUCT SPECIFICATION

MODEL – KCE444HAG-BXXX

SPECIFICATION

A) MODEL DESCRIPTION

Model Name	KCE444HAG-BXXX
Compressor Type	Reciprocating ,Connecting Rod Type
Application Group	High / Medium temperature (HBP / CBP)
Evaporating Temperature Range	-17.8°C To 12.8°C (0° To 55°F)
Refrigerant	R-134a
Rated Voltage	230V, 50Hz, 1Phase
Compressor Cooling	FAN : 350 ft^3 / minute
Typical Application	Water Coolers / Bottle Coolers
Certifications & Approvals	ISI, EN60335-2-34

B) PERFORMANCE SPECIFICATION @ RATED CONDITION

Specification	Unit	HBP	CBP
Cooling Capacity	Btu / h	3675	1880
	kcal / h	926	474
	W	1077	551
	Nominal HP	0.36	0.28
Input Power	W	475	339
Input Current	A	2.2	1.64
EER = Cooling Capacity / Input Power	Btu / W-h	7.74	5.54
	kcal / W-h	1.95	1.4
	W / W	2.27	1.62

Note – Above performance parameters are nominal values & subject to ± 5% variation

C) RATING CONDITIONS

Parameter	Unit	HBP @ ASHRAE-T	CBP @ ASHRAE-T
Evaporating Temperature	°C (°F)	7.2 (45)	-6.7 (20)
Condensing Temperature	°C (°F)	54.4 (130)	54.4 (130)
Ambient Temperature	°C (°F)	35 (95)	35 (95)
Sub cooled Liquid Temp.	°C (°F)	46.1 (115)	46.1 (115)
Return Gas Temperature	°C (°F)	35 (95)	35 (95)
Test voltage	V	230	230

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Emerson Climate Technologies (India) Limited

PRODUCT SPECIFICATION

MODEL – KCE444HAG-B8XX

SPECIFICATION

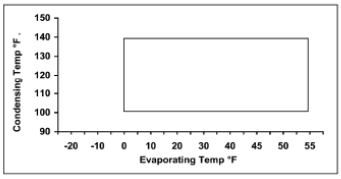
D) MECHANICAL SPECIFICATION

Parameter	Unit	Value
Number of Cylinders	Number (s)	One (1)
Displacement	cm^3 ($inch^3$) / rev	12.05 (0.735)
Net Weight	kg	11.8
Approximate Shipping Weight	kg	12.5
Oil Charge	cm^3 (Oz)	310 (10.5)
Oil Type	Refrigeration Grade	Polyolester (POE)
IPRV (Pressure Differential)	kg / cm^2 (psig)	N / A
Crank Case Heater	W / V	N / A

E) ELECTRICAL SPECIFICATION

Parameter	Unit	Value
Operating Voltage Range	V	180 To 260
Motor Circuit	---	CSCR
Electrical Accessories	---	
➢ Start Capacitor	µF @ V AC	40-60 @ 275
➢ Run Capacitor	µF @ V AC	10 @ 440
➢ Relay	---	KCP14PO
➢ Over Load Protector	---	KAT0072/K3 or T0072/K3
Lock Rotor Ampere (LRA)	A	13
Maximum Continuous Current (MCC)	A	3.0
Motor Insulation	---	B Class
High Potential Test	(kV/second/mA)	1.85 / 1 / 5.5

F) OPERATING ENVELOP @ 230V, 50Hz, 1Phase



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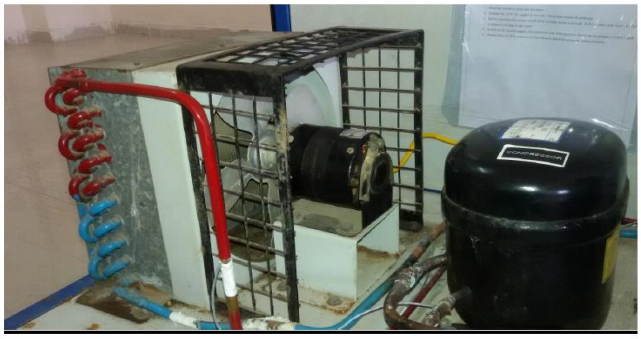

Fig 4. Compressor

Fig 5. Compressor

TABLE 5. Evaporator dimension

Parameter	Dimension
Number of tubes	18
Height of evaporator	33 cm
Circumference of Evaporator	87 cm
Thickness of evaporator	3 mm
Evaporator pipe Dia.	3cm
Total length of tube	1440 cm

Fig 6. Experimental setup

TABLE 6. Components of experimental setup

Components	Quantity
Thermocuples	12
Pressure Gauge	2
Rotameter	1
On/Off Switch	1
Energy Meter	1

E. Experimental procedure

- Fill the evaporator tank up to the end level.
- Ensure that hand valve is in fully closed.
- Apply 230 V supply by inserting the three pin top in socket provided on the distribution board in your laboratory.
- Switch on the mains supply and stirrer on/off switch.
- Switch on electric heater by rotating dimmer in clockwise direction, and if the ambient temp is less Please load the system initially to 35 0 C before starting the compressor.
- Switch on the compressor on/off switch.
- Check that compressor energy meter starts & Rotameter float is lifted up indicating that the compressor is working. The pressure gauge reading is increasing and compound gauge reading is decreasing.
- Observe that Temperature of load tank (T5) decreases showing cooling effect.
- Note down the readings according to observation table
- Switch off the compressor on/off & stirrer on/off switch.
- Switch off the main switch.
- Repeat the above procedure for other experiments.

Installation Procedure:

- Connect the 230-VA.C. Supply to the unit. Use Proper neutral & Earthing.
- Fill the water in the evaporator tank.
- . Switch on the Compressor on/off switch only if the pressure shows on the Gauges are nearly equal.
- Check that temperature indicator shows ambient temperature for all 12 channels.
- The Rotameter shows the flow of refrigerant gas, which is indicated by lift of float in the glass tube. Also check that suction pressure P1 drops and discharge pressure P2 increases.
- Observe with channel 7, the temperature T7 of the Evaporator tank & see that it is reducing. That means the trainer is giving refrigeration effect.

F. Nomenclature

TABLE 7. Nomenclature

Parameter		notification
Condenser inlet temperature	=	T_1
Condenser outlet temperature	=	T_2
Condenser intermediate temperature	=	T_3
Condenser intermediate temperature	=	T_4
Fin temperature at inlet	=	T_5
Fin temperature at corner	=	T_6
Temperature at evaporator inlet	=	T_7
Temperature at evaporator outlet	=	T_8
Temperature at evaporators intermediate pipe	=	T_9
Temperature at evaporators intermediate pipe	=	T_{10}
Evaporator tank temperature	=	T_{11}
Atmospheric temperature	=	T_{12}
Suction pressure	=	P_1
Discharge pressure	=	P_2

G. COP Calculation

Observation table: (R134a)

Time	T_1 °C	T_2 °C	T_3 °C	T_4 °C	T_5 °C	T_6 °C	P_1 Psi	P_2 Psi	Time for 10 blinks
1:35	74.5	38.6	39.5	38.3	39	49.3	17	125	36 sec
1:40	76.5	38.9	39.9	38.6	39.2	49.8	17	130	32
1:45	78.1	39.1	40.4	38.9	39.4	50.5	17	130	34
1:50	82	39.5	41	39.1	39.6	53.3	18	132	33
1:55	83.9	39.7	41.4	38.9	39.7	54.4	18	132	33
2:00	84.9	39.6	41	39.6	39.6	54.4	18	132	33
2:05	86.2	39.9	41.2	39.8	39.8	54.9	18	132.5	33

Time	T_7	T_8	T_9	T_{10}	T_{11}	T_{12}	P_1	P_2	blinks
1:35	1.6	32	27.3	27.6	31.4	33	17	125	36 sec
1:40	1.3	31.4	26.8	27.1	29.7	33	17	130	32
1:45	1.1	31	26.1	26.5	28.2	33	17	130	34
1:50	0.9	29.5	25.5	25.9	27.4	33	18	132	33
1:55	0.8	29	24.9	25.1	26.2	33	18	132	33
2:00	0.7	28.6	24.4	24.6	25.1	33	18	132	33
2:05	0.6	28.2	23.6	24	24.4	33	18	132.5	33

Rotameter reading = 45-47 lph, mass of Fluid = 20 kg
Pressure in bar- P1=1.24 bar
P2=9.13 bar

R600a:

Time	T_1 °C	T_2 °C	T_3 °C	T_4 °C	T_5 °C	T_6 °C	P_1 Psi	P_2 Psi	Blink time
3:55	65.8	45.3	48.6	46.6	49.8	53.9	25	100	37
4:00	65.6	45	47.1	46.9	49.3	53.7	25	100	37
4:05	65.0	44.7	48.7	45.5	48.7	53.9	25	100	36
4:10	64.7	44	47.9	44.8	48.1	52.4	25	100	36
4:15	63.0	43.3	47.0	44.8	47.0	51.0	25	100	36
4:20	61.9	43.1	47.0	44.8	46.9	50.6	22	90	37
4:25	60.4	42.8	46.4	44.3	46.3	49.8	22	90	37

Calculation for R134a:

Suction temp.-28.2oC H1= 428 KJ/Kg
Discharge temp.-86.2 oC H2=485 KJ/Kg
Temp. at condenser outlet-39.9 H3=251 KJ/Kg
Temp. at evaporator inlet-0.6 H4=251 KJ/Kg

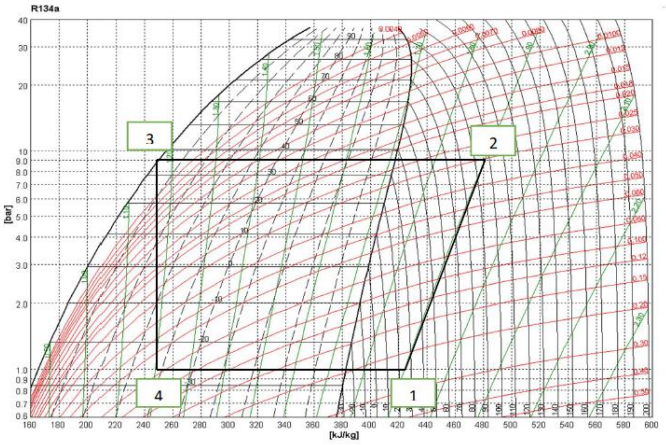

Fig 7. Representation of cycle of R134a on ph chart

Refrigerating Effect= H1- H4
Refrigerating Effect= 428-251
Refrigerating Effect= 171 KJ/Kg
Compressor Work= H2- H1
Compressor Work= 485-428
Compressor Work= 57 KJ/Kg
COPtheoretical = Refrigetating effect/ Compressor work
COPtheoretical = 171/57
COPtheoretical = 3.

Actual COP:

$$\text{Refrigerating Effect} = \frac{m*C_p*(T_{11@1:35}-T_{11@2:05})}{\text{Time(sec)}}$$

$$\text{Refrigerating Effect} = \frac{20*4.187*(31.4-24.4)}{30*60}$$

Refrigerating effect= 0.3256 KW

$$\text{Compressor Work} = \frac{10*3600}{\text{Time}*3200}$$

Compressor Work = (10*3600)/(33*3200)
= 0.3409KW

COPActual = Refrigerating effect/Compressor work
=0.3256/0.3409 = 0.9556 = 1

Tonnage Capacity:
Tonnage capacity = Refrigerating effect/3.51
= 0.3256/3.51
= 0.092 tonn

Calculation: (R600a)
Rotameter reading = 35-37 lph :
mass of Fluid = 20 kg
Pressure in bar P1=1.37 bar
P2=6.2 bar
Suction temp-9.4ºC H1=580 KJ/Kg
Discharge temp-60.4ºC H2=640 KJ/Kg
Temp. at condenser outlet-42.8º C H3=360 KJ/Kg
Temp. at evaporator inlet-6.9ºC H4=360 KJ/Kg

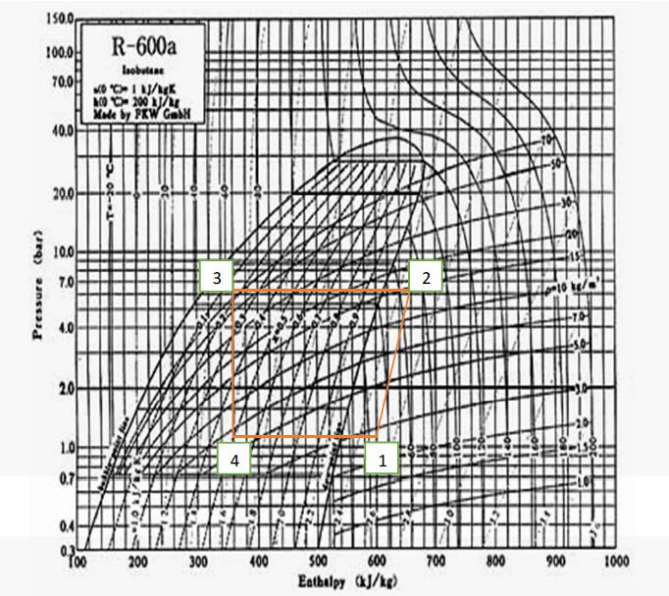

Fig 8. Representation of cycle of R600a on ph chart

Refrigerating Effect= H1- H4
Refrigerating Effect= 580-360
Refrigerating Effect= 220 KJ/Kg
Compressor Work= H2- H1
Compressor Work= 640-580
Compressor Work= 60 KJ/Kg
COPtheoretical = Refrigetating effect/Compressor work
= 220/60 = 3.66

Actual COP:
R. E = m*Cp*(T11@3:55-T11@4:25)/Time(sec)
= 20*4.187*(18.3-10.1)/(30*60)
= 0.3814KW

Compressor Work = (10*3600)/(Time*3200)
= (10*3600)/(36.5*3200)
= 0.3082 KW.

COPActual = Refrigerating effect/Compressor work
= 0.3814/0.3082 = 1.23
Tonnage Capacity:
Tonnage capacity = Refrigerating effect/3.51
= 0.3814/3.51 = 0.108

III. CONCLUSION

- By Changing the Refrigerant from R134a to R600a the system theoretical COP is increased by 22.2% and actual COP by 29.4%.
- Power Consumption is reduced considerably by 9.5%.
- Compressor works controlled temperature under 63 oC which less as compared to R134a i.e. 82 oC.
- We get better cooling effect in less time in evaporator by using R600a.
- Load on the compressor while running on R600a as refrigerant is less as Compared to the compressor running on R134a as refrigerant.

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