Comparative performance analysis of Refrigeration Test RIG for R-12 & R-134a

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Abstract: To tackle the climate change and problem of ozone depletion the United Nation's environmental protection agency proposed a multinational agreement called "Montreal Protocol' for reducing the use of gases threatening the ozone layer. Under this protocol developing countries have to phase out chlorofluorocarbons (CFCs) like R-12 by 2010.For phase out of CFCs the refrigeration industry has accepted the challenge and started working on new refrigerants like hydro fluorocarbons (HFCs) and hydrocarbons (HCs) which being considered as replacements of chlorofluorocarbons in all commercial and industrial applications. Vapor compression refrigeration test rig is an important equipment of thermal engineering lab of mechanical engineering department of any engineering college operated using chlorofluorocarbon 12. Due to its high ozone depleting potential (ODP) it is to be replaced. In this paper, comparative performance analysis of vapor refrigeration test rig for R-12 & R-134a is done using a software NIST CYCLE_ D SOFTWARE for evaluating the performance of these refrigerants.

Keywords: Climate change; ozone depletion; Montreal protocol; eco-friendly refrigerant; hydrocarbon refrigerant; performance analysis.

INTRODUCTION

The Refrigeration and Air Conditioning Lab in the Mechanical Engineering Department of DCRUST, Murthal is equipped with state-of-the-art Refrigeration and Air Conditioning test systems. One of them is the Refrigeration Test Rig which serves the purpose of demonstrating the Vapor Compression Cycle to the students. The Vapor Compression test rig is around 10-15 years old and using R-12 refrigerant as heat carrier. But now according to Montreal protocol R-12 is being phased out and for replacement this test rig is retrofitted with R-134a refrigerant (Agrawal RS(2001); Agarwal and Shrivastva,2010).The Test Rig as shown in fig.1 is an open system in the sense that all the major equipments and parts of the rig that participated in the refrigeration process are visible to the person performing the test. The rig is designed in such way to provide a conducive environment for the study of the Vapor Compression Cycle without concealing any of those parts. This aspect of the rig not only facilitated convenient experimenting but also was of great help for its repair or retrofitting purposes. In this work experimental results for R-12& R-134a from test rig are presented and their comparative performance analysis is done using Cycle-D software (NIST, 2011). Their comparative properties are given in Table1.
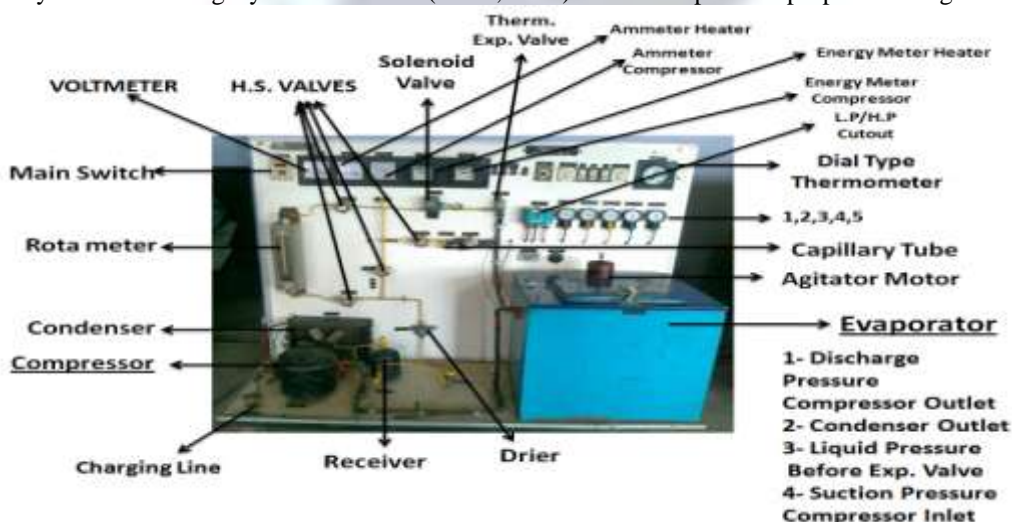

Fig.1: Vapor Compression Refrigeration Test Rig

Status of Montreal Protocol

India acceded to the Montreal Protocol on 17 September 1992. At present India's per capita consumption of ozone-depleting substances is less than 3 g and did not cross 20 g between 1995-97, compared with 300 g permitted under the Protocol(Agrawal, 2001). India commonly produces and uses seven of the 20 substances controlled under the Montreal Protocol. These are CFC-11, CFC-12, CFC-113, Halon-1211, Halon-1301, carbon tetrachloride (CTC) and methyl chloroform.The London Amendment (1990) to the Montreal Protocol mandates to phase out CFCs and Halons by 1.1.2010 with the intermediate reduction schedule of 50% by1.1.2005. The use of CTC is also to be phased out by 1.1.2010 with the intermediate reduction of 85% by 1.1.2005. HFCs have been introduced as transitional substances/immediate substitutes to CFCs and can be used till 2040. India ratified this Amendment on19.6.1992 (Bansal, Aggarwal et. al., 2011).

Table 1: Refrigerants Properties (Ozonecell, 2013)

Refrigerants	Molecular mass (g/mol)	Normal boiling point	Tc	Pc (bar)	Ozone depletion potential(ODP)	Global warming potential(GWP)
CFC12	120.9	-29.8	112	41.15	1	10900
HFC134a	102.03	-26.1	101.1	40.64	0	1300

Table 2: Salient Features Of Vapor Compression Refrigeration Test Rig

Refrigerating Capacity	0.75 Ton
Compressor Make	Shriram
Quantity of refrigerant used	1.4 k.g.
Capacity of evaporator	20lit
Condenser	Air – cooled type
Rated power consumption of fan motor	50W
Rated power consumption of stirrer motor	50W
Voltmeter	0-300V
Ammeter	0-10A

Experimental results of Vapor Compression Refrigeration Test Rig using R-12

Vapor Compression Refrigeration Test Rig`s salient features are presented in Table 2.Experimental results were taken from refrigeration test rig using R-12 refrigerants as given in Table 3. And for the same cooling limits comparative performance analysis is performed using R-134a.

Table 3: Experimental results from refrigeration test rig using R-12 refrigerant

State	Pressure(kg/cm^2)	Temperature(ºC)
Compressor Outlet	7.15	55
Condenser Outlet	7.1	27
After Exp. Valve	0.96	-11.5
Compressor Inlet	0.85	21

Comparative Performance evaluation of R-12 & R-134a

The comparative performance evaluation of R-12 & R-134a refrigerants has been done by using highly rated vapor compression refrigeration design program CYCLE-D of NIST (National Institute of Standard and Technology,2011),

Gaithersburg, USA which is based on simulation technique. The CYCLE-D simulation program is a medium to find better replacements of existing harmful refrigerants which are either phased out or will be phased out in future for all types of refrigeration applications according to Montreal protocol agreement signed by our country .The performance results of simulation, in terms of power consumption, mass flow of refrigerant, refrigerating effect, work done and coefficient of performance of the vapor compression refrigeration test rig when R-134a is used in place of R12 are presented in Table 4.

Table 4: Comparative performance evaluation

Refrigerants	Power consumption in kW	Mass flow in L/sec	Refrigeration effect in Kj/kg.	Work done in kj/kg	COP
R-12	0.280	1.139	133.25	37.37	3.566
R-134a	0.281	1.155	170.71	47.96	3.559

Conclusion

From the study of performance results of R-134a refrigerant when it is used as a refrigerant in place of R12 in the vapor compression refrigeration test rig for the same cooling limits, it is clear that it performs with higher value of power consumption, mass flow of refrigerants, refrigeration effect and work done for the same cooling and there is slight drop in COP. The coefficient of performance (COP) for R-12 calculated is 3.566 and for R-134a is 3.559.Simulation procedure done in Cycle_D software is presented in appendix1 for R-12 and appendix2 for R-134a and their respective p-h and T-s curves are represented. The thermodynamic cycle results for R-12 is represented in TableI.1 and for R-134a is represented in TableII.1.

Appendix-I: Simulation of R-12

Cycle analysis by CYCLE_D, Version 4.0
Subcritical cycle
Input data: Refrigerant: R12
System cooling capacity (kW)   = 1.00
Compressor isentropic efficiency = 1.000
Compressor volumetric efficiency = 1.000
Electric motor efficiency   = 1.000
Pressure drop (in sat. temp.) (C): in the suction line = 0.0
Evaporator: dew-point temp.   (C) = -11.5   Superheat (C) = 21.0
Condenser: bubble-point temp. (C) = 55.0   Subcooling (C) = 27.0
Effectiveness of the llsl heat exchange = 0.00
Parasitic powers (kW): indoor fan = 0.000,   outdoor fan = 0.000

Table I.1 Thermodynamic Cycle Results for R-12

STATE	T	P	H	V	S	XQ
	(C)	(kPa)	(kJ/kg)	(m^3/kg)	(kJ/kg C)	
1 Compr. shell inlet	9.5	207.3	360.4	8.93E-2	1.61216	1.000
2 Cylinder inlet	9.5	207.3	360.4	8.93E-2	1.61216	1.000
3 Cylinder outlet	85.5	1363.0	397.7	1.52E-2	1.61216	1.000
4 Condenser inlet	85.5	1363.0	397.7	1.52E-2	1.61216	1.000
5 Cond. sat. vapor	55.0	1363.0	373.7	1.27E-2	1.54214	1.000
6 Cond. sat. liquid	55.0	1363.0	255.1	8.40E-4	1.18066	0.000
7 Condenser outlet	28.0	1363.0	227.1	7.67E-4	1.09172	0.000
8 Exp. device inlet	28.0	1363.0	227.1	7.67E-4	1.09172	0.000
9 Evaporator inlet	-11.5	207.3	227.1	2.00E-2	1.10474	0.239
10 Evap. sat. vapor	-11.5	207.3	347.6	8.14E-2	1.56524	1.000
11Evaporator outlet	9.5	207.3	360.4	8.93E-2	1.61216	1.000

Work = 37.37 kJ/kg   Qevap = 133.25 kJ/kg   Qcond = 170.62 kJ/kg
COPc = 3.566   COPh = 4.566
Two-phase glide: evaporator = 0.0 C   condenser = 0.0 C
Condenser superheat = 30.5 C   P(3)/P(2) = 6.57
Liquid line subcooling due to llsl heat transfer = 0.0 C
Suction vapor superheat due to llsl heat transfer = 0.0 C
Volumetric capacity: cooling   heating
@ vol. eff. = 1.00   1492.3 kJ/m^3   1910.8 kJ/m^3

-----------------Compressor and System Results----------------------

Compressor power   = 0.280 kW
Compressor COP: COPc = 3.566   COPh = 4.566
m^3/h = 1.139   m^3/h/kW = 1.139
Refrigerant mass flow rate = 7.5045E-03 kg/s Total power = 0.280 kW
Cooling capacity: evaporator= 1.000 kW   system = 1.000 kW
Heating capacity: condenser = 1.280 kW   system = 1.280 kW
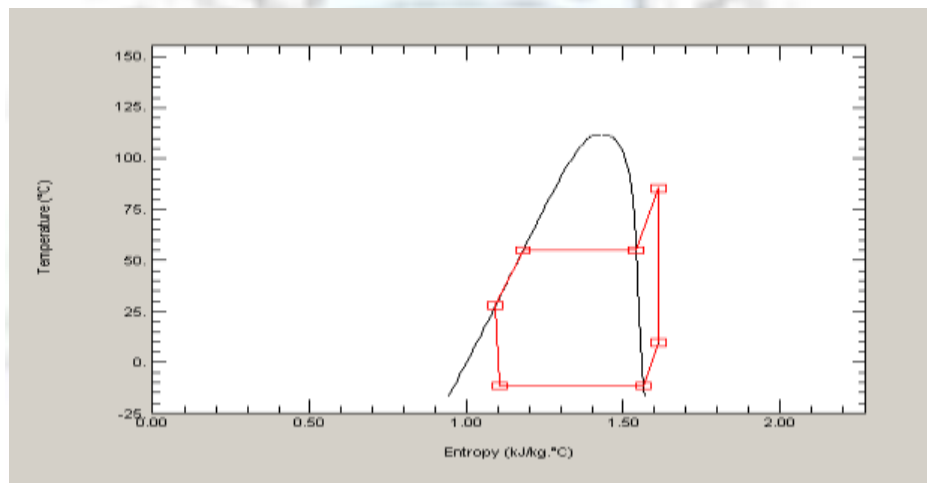System COP: COPc,sys = 3.566   COPh,sys = 4.566
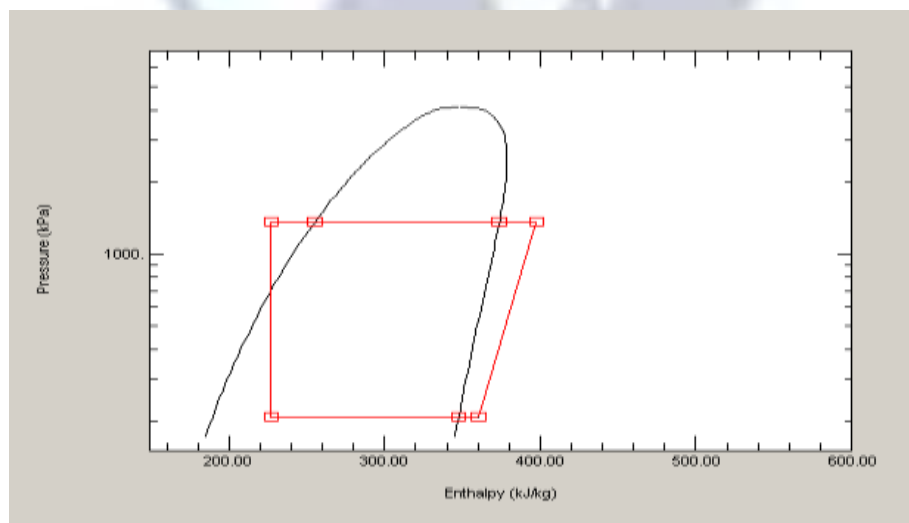

Fig.I.1: T-S curve for R-12 refrigerant

Fig.I.2: P-h curve for R-12 refrigerant

Appendix - II: Simulation of R-134a

Cycle analysis by CYCLE_D, Version 4.0
Subcritical cycle
Input data:Refrigerant: R134a
System cooling capacity (kW)   = 1.00
Compressor isentropic efficiency = 1.000
Compressor volumetric efficiency = 1.000
Electric motor efficiency   = 1.000
Pressure drop (in sat. temp.) (C): in the suction line = 0.0
                                   in the discharge line = 0.0
Evaporator: dew-point temp.   (C) = -11.5   Superheat (C) = 21.0
Condenser: bubble-point temp. (C) = 55.0   Subcooling (C) = 27.0
Effectiveness of the llsl heat exchange = 0.00
Parasitic powers (kW): indoor fan = 0.000   outdoor fan = 0.000
              controls   = 0.000

Table II.1 Thermodynamic Cycle Results for R-134a

STATE	T	P	H	V	S	XQ
	(C)	(kPa)	(kJ/kg)	(m^3/kg)	(kJ/kg C)	
1 Compr. shell inlet	9.5	189.0	409.6	1.16E-1	1.79984	1.000
2 Cylinder inlet	9.5	189.0	409.6	1.16E-1	1.79984	1.000
3 Cylinder outlet	82.2	1491.5	457.5	1.59E-2	1.79984	1.000
4 Condenser inlet	82.2	1491.5	457.5	1.59E-2	1.79984	1.000
5 Cond. sat. vapor	55.0	1491.5	425.2	1.31E-2	1.70501	1.000
6 Cond. sat. liquid	55.0	1491.5	279.5	9.27E-4	1.26106	0.000
7 Condenser outlet	28.0	1491.5	238.8	8.33E-4	1.13197	0.000
8 Exp. device inlet	28.0	1491.5	238.8	8.33E-4	1.13197	0.000
9 Evaporator inlet	-11.5	189.0	238.8	2.81E-2	1.15000	0.261
10 Evap. sat. vapor	-11.5	189.0	391.8	1.05E-1	1.73443	1.000
11 Evaporator outlet	9.5	189.0	409.6	1.16E-1	1.79984	1.000

Work = 47.96 kJ/kg   Q$_{evap}$ = 170.71 kJ/kg   Q$_{cond}$ = 218.67 kJ/kg
COP$_c$ = 3.559   COP$_h$ = 4.559
Two-phase glide: evaporator = 0.0 C   condenser = 0.0 C
Condenser superheat   = 27.2 C   P(3)/P(2) = 7.89
Liquid line subcooling due to llsl heat transfer   = 0.0 C
Suction vapor superheat due to llsl heat transfer   = 0.0 C
Volumetric capacity: cooling   heating
 @ vol. eff. = 1.00   1471.1 kJ/m^3   1884.4 kJ/m^3

----------------Compressor and System Results-----------------------

Compressor power =   0.281 kW
Compressor COP: COPc = 3.559   COPh = 4.559
m^3/h = 1.155   m^3/h/kW = 1.155
Refrigerant mass flow rate = 5.8580E-03 kg/s Total power =   0.281 kW
Cooling capacity: evaporator= 1.000 kW   system = 1.000 kW
Heating capacity: condenser = 1.281 kW   system = 1.281 kW
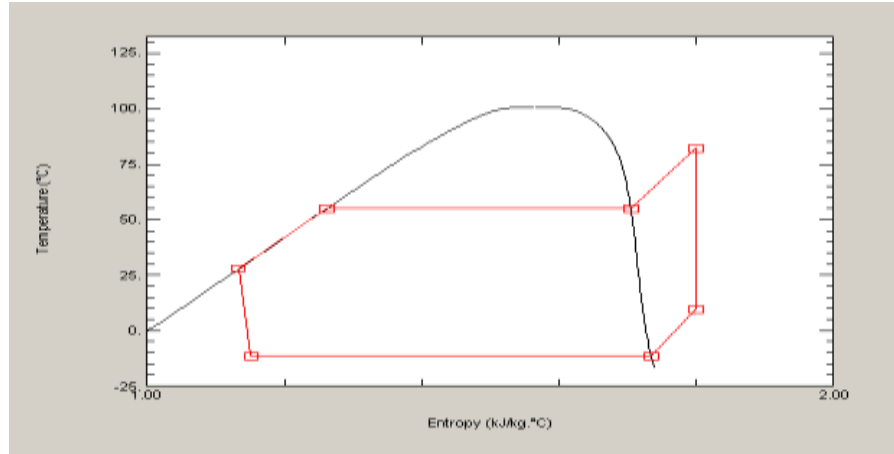System COP: COP$_{c,sys}$ = 3.559   COP$_{h,sys}$ = 4.559

Fig.II.1: T-S curve for R-134a refrigerant

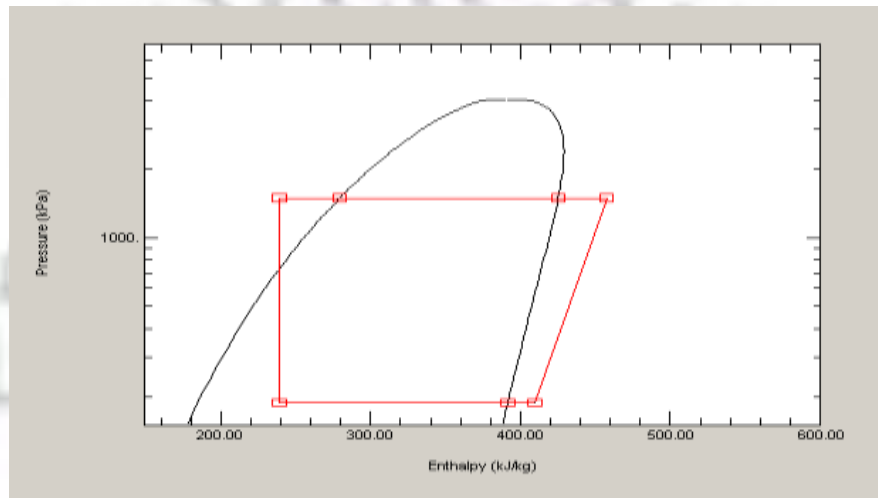

Fig.II.2: P-h curve for R-134a refrigerant

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