

Comparative Analysis of Different Refrigerants in a Water Cooler Test Rig

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ABSTRACT: Refrigeration is the science of producing and maintaining temperatures below that of the surrounding atmosphere. This means of removing of heat from a substance to be cooled. Heat always passes downhill, from a warm body to a cooler one, until both bodies are at the same temperature. Maintaining perishables at their required temperatures is done by refrigeration. Not only perishables but today many humans work spaces in office and factory buildings are air-conditioned and a refrigeration unit is the heart of the system. The main aim of this project is to comparatively analysis of COP using R-134a, R-413A and blend of R-290 and R-600a in Water cooler at a load condition. R-134a and R-413A having zero ODP but High GWP and blend of R-290(Propane) and R-600a (Isobutane) have zero ODP and low GWP. The analysis of variance result showed that 60gm of blend of R-290 and R-600a gives 22.24% higher COP than of R-134a of 160gm and 21.87% higher COP than R-413A of 150gm.

KEYWORDS: ODP, GWP, Kyoto Protocol, Montreal Protocol, p-h chart, COP.

Symbols	Meanings	Symbols	Meanings
ODP	Ozone depleting potential	VOC	Volatile organic compound
GWP	Global warming potential	COP	Coefficient of Performance
CFC	Chloro-fluorocarbon	R-134a	Tetra-fluoroethane
HCFC	Hydro-chlorofluorocarbon	R-290	Propane
HFC	Hydro-fluorocarbon	R-600a	Isobutane
HC	Hydrocarbon	R-413A	MO49

I. INTRODUCTION

The most important characteristics about the refrigerants are Ozone Depleting Potential (ODP) and Global Warming Potential (GWP). Researchers focused on these characteristics at the development of new refrigerant and if this refrigerant has good thermo-physical property then and solely then it is said as environmentally and eco-friendly refrigerant. The development of new refrigerant is extremely important because the refrigerants traditionally used are Chloro-fluorocarbon (CFC) and Hydro-chlorofluorocarbon (HCFC) which have high contribution in GWP and ODP. As per Montreal protocol HCFC refrigerants are phased out and as per Kyoto Protocol HFC refrigerant used in refrigeration system. But after some research on HFC refrigerant EU suggest that HC refrigerant are leading replacement for CFC, HCFC and HFC refrigerants. HC refrigerants have low ODP and low GWP so it is suitable in the refrigeration system. The important issue about of HC refrigerant is their highly flammability property but then also for aerosol propellants, for heating and cooking purpose these refrigerants are used.

1.1) Refrigerant:-

It is a fluid used in refrigeration mechanisms such as air- conditioner, water coolers and refrigerators as the heat carrier which changes from gas to liquid and back to gas in refrigeration cycle.

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 6, June 2016

1.2) Classification of refrigerants based on structure:-

They are again classified into four teams:-

- Chloro-fluorocarbon (CFC) Refrigerants
- Hydro-chlorofluorocarbon (HCFC) Refrigerants
- Hydro-fluorocarbon (HFC) Refrigerants and
- Natural Refrigerants

1.2.1) Chloro-fluorocarbon (CFC) refrigerants:-

The most commonly used Halocarbon (or) Organic refrigerant are the Chloro-fluoro derivatives of methane (CH_4) and ethane (C_2H_6). The fully halogenated refrigerant with chlorine (Cl) atom in their molecules are referred to as Chloro-fluorocarbon (CFC) refrigerant. However in recent years it has been seen that the chlorine molecules released from Chloro-fluorocarbon refrigerant migrates to the stratosphere and that chlorine molecules destroys the earth's stratospheric layer so it causes health hazards problems. It has high ODP and high GWP.

1.2.2) Hydro-chlorofluorocarbon (HCFC) refrigerants:-

The refrigerant which contains hydrogen atoms in their molecule along with chlorine and fluorine atoms are referred to as Hydro-chlorofluorocarbon (HCFC) refrigerant. HCFC refrigerants are a man made created chemical not a natural gas. Commonly used HCFC refrigerant is R-22. It has low ODP but high GWP.

1.2.3) Hydro-fluorocarbons (HFC's) refrigerants:-

The refrigerant which contains no chlorine atoms in their molecule are referred as Hydro-fluorocarbon (HFC) refrigerant such as R-134a, R-143a and R-152a. these refrigerants are the leading replacement for HCFC and CFC refrigerants in refrigeration system. HFC refrigerant have zero ODP and high GWP. Because of high global warming potential most used HFC refrigerant i.e. R-134a is removed by European Union from the refrigeration system. Global warming impact of Hydro-fluorocarbons refrigerant i.e. R-134a is thousands of times stronger than CO_2 . Figure 1 shows Phase- Down schedule of HFC refrigerant regulated by the EU. Phase down schedule of HFC refrigerant begin in 2015 and runs until 2030 during this period availability of Fluorine gas is reduced by 79 %.

EU HFC Phase-Down schedule

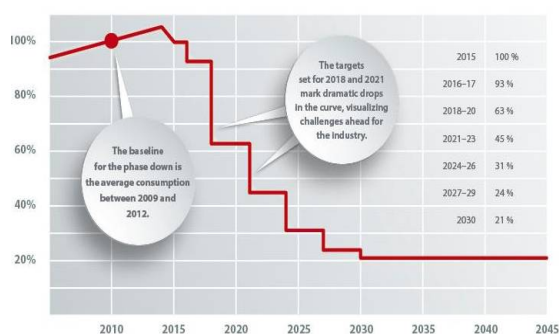


Figure 1:- Phase-Down schedule of HFC regulated by EU

When we focused on the blend of HFC's refrigerant R-413A i.e. MO49 is ternary blend of R-134a of 88%, R-218 of 8% and R-600a of 3%. Ozone depleting potential of R-413A is zero. But global warming potential is high. This refrigerant is used as alternative for R-12 but now this refrigerant is also phased out.

1.3.4) Natural refrigerants:-

These refrigerants are naturally occurring substances like water and air, carbon-dioxide, hydrocarbons, ammonia. These refrigerants are very efficient and cheap. The refrigerant which contains no chlorine no fluorine atoms in their molecule are referred as Hydrocarbon (HC) refrigerant such as R-290, R-600a, R-717, and R-744.

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 6, June 2016

II. LITERATURES REVIEW

[1] Mukesh K Agrawal in this paper it is mentioned that refrigerants the heat from lower to higher temperature reservoir. Each refrigerant has its own thermo-physical property. R-11 and R-12 refrigerants are toxic in nature. In case of ammonia i.e. R-717 they are flammable. So researchers are observed for ecofriendly refrigerant from safety and environmental issues. Along with the ecofriendly refrigerants they focused on effect of working parameters like working temperatures and working pressure, choice of refrigerants, and dimensions of capillary tube which affects on the refrigeration effect, coefficient of performance and compressor work of VCRS.

[2] Gaurav Gupta in this paper it is mentioned that due to high global warming potential HFC refrigerants are phase-down starts from 2015 and runs until 2030. In refrigeration system principally used HFC refrigerant is R-134a but due to its high global warming potential EU begin to cut back the usage of R-134a. Water cooler test rig works on the principle of VCRS. In water cooler test rig they used R-134a and R-152a refrigerant in various blending proportions. And from obtained result they conclude that blend of R-134a and R-152a refrigerant is alternative refrigerant for R-134a.

III. TEST PROCEDURE

Figure 3.1 shows actual test rig setup. Water cooler works on principle of vapour compression refrigeration system. Components of vapour compression refrigeration system are compressor, condenser, filter, expansion device and evaporator.



Figure 3.1:- Test rig setup

Symbols:-

- P_1 = Evaporator Pressure
- P_2 = Condenser Pressure
- T_1 = Evaporator Outlet Temperature
- T_2 = Condenser Inlet Temperature
- T_3 = Condenser Outlet Temperature
- T_4 = Evaporator Inlet Temperature
- T_5 = Water Temperature in Evaporator

3.1 Test Procedure:-

Before giving load on a test rig system was kept under running condition for 3-4 minutes this is doing to ensure that refrigerant can circulate properly among system. After giving a load on a test rig we took the observations at an interval of 5 minutes for full load condition i.e. when the tank is completely filled with water. Test is conducted at high speed of condenser fan at about 1440 rpm.

3.2 Observation Table for R-134a

At load condition the results obtained from the system are tabulated as shown in Table 1.

- a) The tank is completely filled with water (10 liters).

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 6, June 2016

- b) Initial water temperature is 31.4 °C.
- c) The system is filled with 160 gm of HFC-134a refrigerant.

Table 1:- Readings of R-134a at load condition

Observation No	Time (min)	Pressure (psi)		Temperature (°C)				
		P ₁	P ₂	T ₁	T ₂	T ₃	T ₄	T ₅
1	10	22	130	26	47	38	5	11
2	15	21	139	25	52	40	6	9
3	20	23	137	22	53	40	6	8
4	25	24	137	14	53	40	5	7
5	30	23	136	4	51	39	3	7
6	60	20	130	-1	49	40	4	8

3.3) Observation for R-413A

At load condition the results obtain from the system are tabulated as shown in Table 2.

- a) Tank is completely filled with water (10 liters).
- b) Initial water temperature is 31 °C.
- c) The system is filled with 150 gm of HFC-413A refrigerant.

Table 2:- Readings of R-413A at load condition

Observation No	Time (min)	Pressure (psi)		Temperature (°C)				
		P ₁	P ₂	T ₁	T ₂	T ₃	T ₄	T ₅
1	10	24	157	29	51	37	5	11
2	15	25	158	27	50	37	5	8
3	20	26	159	25	54	38	6	7
4	25	26.5	161	20	53	38	6	7
5	30	25	161	11	57	39	6	8
6	60	22	156	0	50	37	1	7

3.4) Observation for blend of R-290 and R-600a refrigerant

At Load condition the results obtain from the system are tabulated as shown in Table 3.

- a) Tank is completely filled with water (10 liters).
- b) Initial water temperature is 31.8 °C.
- c) The system is filled with 60 gm of blend of HC-290 and HC-600a refrigerant.

Table 3:- Readings of blend of R-290 and R-600a at load condition

Observation No	Time (min)	Pressure (psi)		Temperature (°C)				
		P ₁	P ₂	T ₁	T ₂	T ₃	T ₄	T ₅
1	10	26	141	25	43	33	10	11
2	15	27	144	22	51	35	10	10
3	20	28	146	14	51	35	9	8
4	25	27	144	8	50	36	11	9
5	30	25	148	6	50	37	10	9
6	60	24	143	1	44	35	5	8

IV. RESULT AND DISCUSSION

A) For R-134a:- The below Figure 4.1 shows p-h chart for R-134a. By using observations at load condition shown in Table 1 and from p-h chart for R-134a shown in Figure 4.1 refrigeration effect, compressor work and coefficient of performance is calculated.

International Journal of Innovative Research in Science, Engineering and Technology

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Vol. 5, Issue 6, June 2016

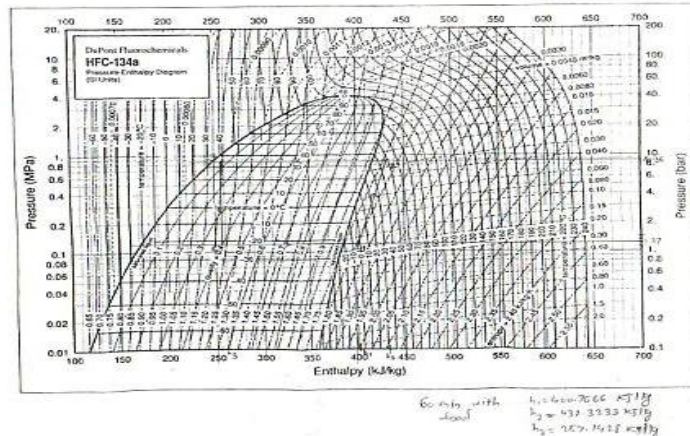


Figure 4.1:- p-h chart for R-134a

Calculation shown at 60minute:-

Property of R-134a is taken from p-h chart as shown in Figure 4.1.

h_1 = Enthalpy at Evaporator Outlet Temperature (i.e. at -1°C) = 400.76 KJ/Kg

h_2 = Enthalpy at Condenser Inlet Temperature (i.e. at 49°C) = 432.33 KJ/Kg

$hf_3 = h_4$ = Enthalpy at Condenser Outlet Temperature (i.e. at 40°C) = 257.14 KJ/Kg

Refrigeration effect = $h_1 - h_4 = 400.76 - 257.14 = 143.62$ KJ/Kg

Compressor work = $h_2 - h_1 = 432.33 - 400.76 = 31.55$ KJ/Kg

Coefficient of Performance = $\frac{h_1 - h_4}{h_2 - h_1} = \frac{h_1 - hf_3}{h_2 - h_1} = \frac{400.766 - 257.14}{432.333 - 400.766} = 4.54$

Similar calculations are done for other observations and shown in Table 4.

Table 4:- Results for R-134a

Observation No	Time (min)	Enthalpy(KJ/Kg)			Refrigeration effect (KJ/Kg)	Compressor work (KJ/Kg)	COP
		h_1	h_2	$hf_3=h_4$			
1	10	424.13	430.33	254.28	169.84	6.2	27.39
2	15	423.63	436.33	257.14	166.49	12.7	13.10
3	20	420.66	436.63	257.14	163.52	15.96	10.24
4	25	416.66	436.63	257.14	159.52	20	7.97
5	30	406.56	435.33	255.71	150.84	28.76	5.24
6	60	400.76	432.33	257.14	143.62	31.55	4.54

From result for R-134a:- Figure 4.2 shows variation in Refrigeration effect (Vs) Time for R-134a. Figure 4.3 shows variation in Compressor work (Vs) Time for R-134a. Figure 4.4 shows variation in Coefficient of Performance (Vs) Time for R-134a.

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 6, June 2016

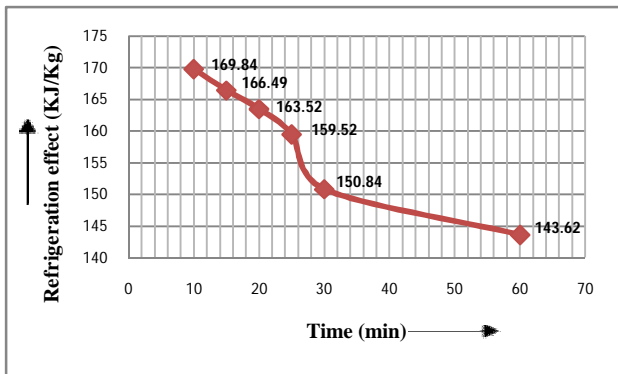


Figure 4.2:- Refrigeration effect (Vs) Time for R-134a

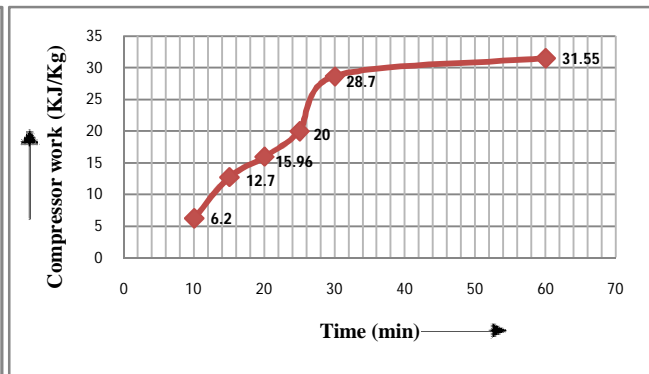


Figure 4.3:- Compressor work (Vs) Time for R-134a

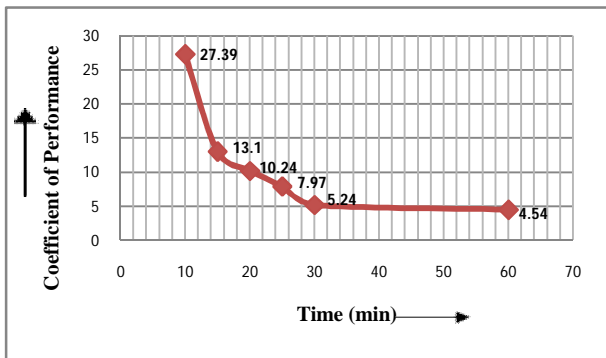


Figure 4.4:- Refrigeration effect (Vs) Time for R-134a

From Figure 4.2 it's discovered that Refrigeration effect decreases with increases in Time for R-134a. From Figure 4.3 it's discovered that Compressor work increases with increases in Time for R-134a. From Figure 4.4 it's discovered that Coefficient of Performance decreases with increases in Time for R-134a.

B) For R-413A:- The below Figure 4.5 shows p-h chart for R-413A. By using observations at load condition shown in Table 2 and from p-h chart for R-413A shown in Figure 4.5 refrigeration effect, compressor work and coefficient of performance is calculated.

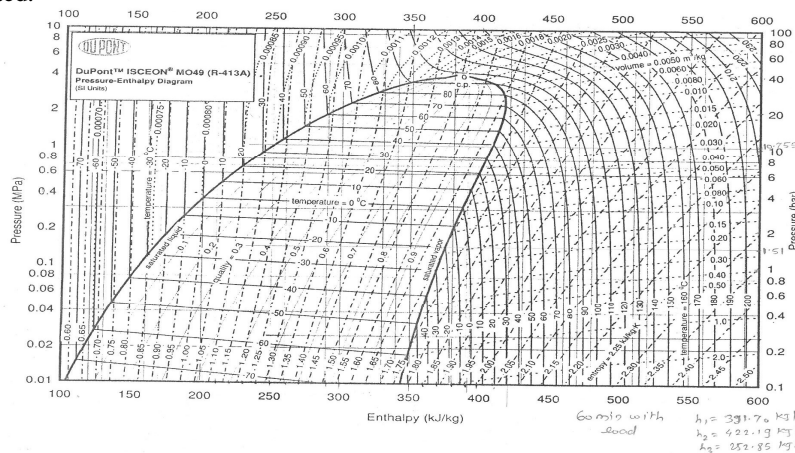


Figure 4.5:- p-h chart for R-413A

Calculation shown at 60minute:-

Property of R-413A is taken from p-h chart as shown in Figure 4.5.

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 6, June 2016

h_1 = Enthalpy at Evaporator Outlet Temperature (i.e. at 0°C) = 391.70 KJ/Kg

h_2 = Enthalpy at Condenser Inlet Temperature (i.e. at 50°C) = 422.19 KJ/Kg

$hf_3 = h_4$ = Enthalpy at Condenser Outlet Temperature (i.e. at 37°C) = 252.85 KJ/Kg

Refrigeration effect = $h_1 - h_4 = 391.70 - 252.85 = 138.85$ KJ/Kg

Compressor work = $h_2 - h_1 = 422.19 - 391.70 = 30.48$ KJ/Kg

Coefficient of Performance = $\frac{h_1 - h_4}{h_2 - h_1} = \frac{h_1 - hf_3}{h_2 - h_1} = \frac{391.70 - 252.85}{422.19 - 391.70} = 4.55$

Similar calculations are done for other observations and shown in Table 5.

Table 5:- Results for R-413A

Observation No	Time (min)	Enthalpy(KJ/Kg)			Refrigeration effect (KJ/Kg)	Compressor work (KJ/Kg)	COP
		h_1	h_2	$hf_3=h_4$			
1	10	417.56	423.90	252.85	164.70	6.341	25.97
2	15	414.87	421.70	252.85	162.02	6.829	23.70
3	20	414.63	426.82	254.28	160.34	12.95	13.14
4	25	410	426.58	254.28	155.71	16.58	9.388
5	30	406.09	427.07	255.71	150.38	20.97	7.169
6	60	391.70	422.19	252.85	138.85	30.48	4.55

From result for R-413A:- Figure 4.6 shows variation in Refrigeration effect (Vs) Time for R-413A. Figure 4.7 shows variation in Compressor work (Vs) Time for R-413A. Figure 4.8 shows variation in Coefficient of Performance (Vs) Time for R-413A.

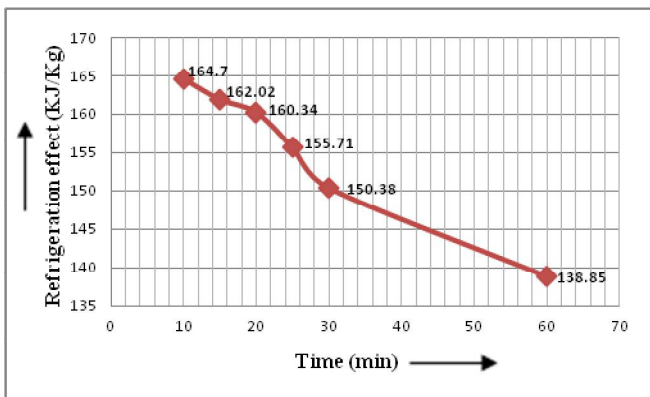


Figure 4.6:- Refrigeration effect (Vs) Time for R-413A.

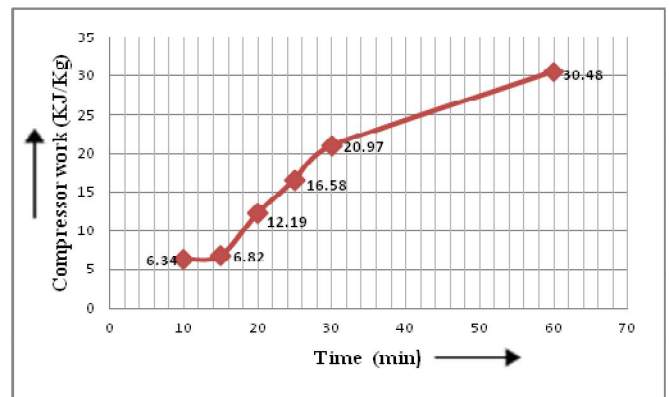


Figure 4.7:- Compressor work (Vs) Time for R- 413A.

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 6, June 2016

From Figure 4.6 it's discovered that Refrigeration effect decreases with increases in Time for R-413A. From Figure 4.7 it's discovered that Compressor work increases with increases in Time for R-413A. From Figure 4.8 it's discovered that Coefficient of Performance decreases with increases in Time for R-413A.

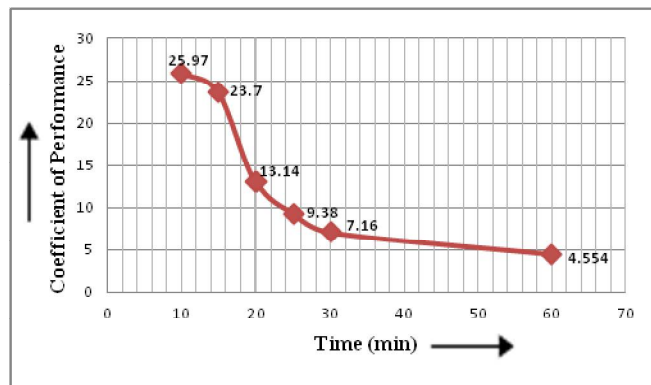


Figure 4.8:- Coefficient of Performance (Vs) Time for R-413A

C) For blend of R-290 (56%) and R-600a (44%):- The below Figure 4.9 shows p-h chart for blend of R-290 and R-600a. By using observations at load condition shown in Table 3 and from p-h chart for R-413A shown in Figure 4.9 refrigeration effect, compressor work and coefficient of performance is calculated.

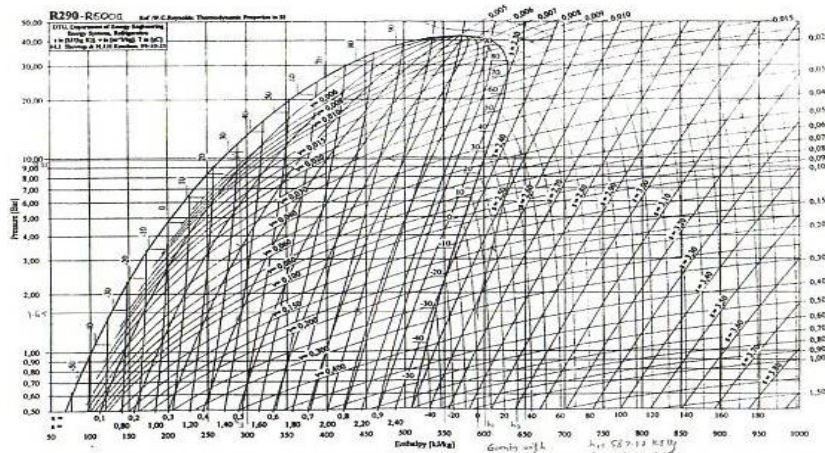


Figure 4.9:- p-h chart for blend of R-290 and R-600a

Calculation shown at 60minute:-

Property of blend of R-290 and R-600a refrigerant is taken from p-h chart as shown in Figure 4.9.

h_1 = Enthalpy at Evaporator Outlet Temperature (i.e. at 1°C) = 587.12 KJ/Kg

h_2 = Enthalpy at Condenser Inlet Temperature (i.e. at 44°C) = 640.26 KJ/Kg

$hf_3 = h_4$ = Enthalpy at Condenser Outlet Temperature (i.e. at 35°C) = 291.66 KJ/Kg

Refrigeration effect = $h_1 - h_4 = 587.12 - 291.66 = 295.45$ KJ/Kg

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 6, June 2016

Compressor work = $h_2 - h_1 = 640.26 - 587.12 = 53.51$ KJ/Kg

Coefficient of Performance = $\frac{h_1 - h_4}{h_2 - h_1} = \frac{h_1 - hf_3}{h_2 - h_1} = \frac{587.12 - 291.66}{640.26 - 587.12} = 5.55$

Similar calculations are done for other observations and shown in Table 6.

Table 6:- Results for blend of R-290 and R-600a refrigerant

Observation No	Time (min)	Enthalpy(KJ/Kg)			Refrigeration effect (KJ/Kg)	Compressor work (KJ/Kg)	COP
		h1	h2	hf ₃ =h ₄			
1	10	632.10	639.01	286.11	345.99	6.90	50.88
2	15	628.52	654.31	291.66	336.85	25.79	13.06
3	20	610.73	654.31	291.66	319.07	43.57	7.32
4	25	600	650	294.44	305.55	50	6.11
5	30	596.52	650	297.22	299.30	53.47	5.59
6	60	587.12	640.26	291.66	295.45	53.51	5.55

From result for blend of R-290 and R-600a refrigerant:-Figure 4.10 shows variation in Refrigeration effect (Vs) Time for blend of R-290 and R-600a. Figure 4.11 shows variation in Compressor work (Vs) Time for blend of R-290 and R-600a. Figure 4.12 shows variation in Coefficient of Performance (Vs) Time for blend of R-290 and R-600a.

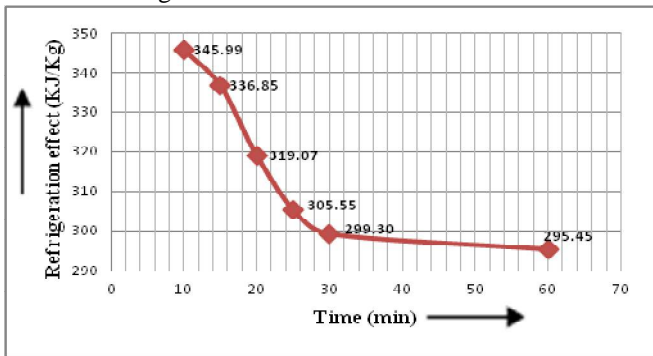


Figure 4.10:- Refrigeration effect (Vs) Time for blend of R-290 and R-600a

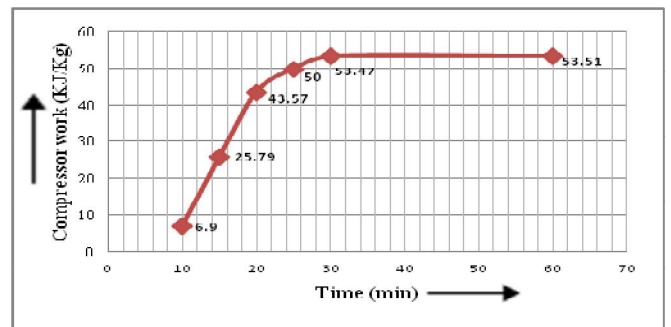


Figure 4.11:- Compressor work (Vs) Time

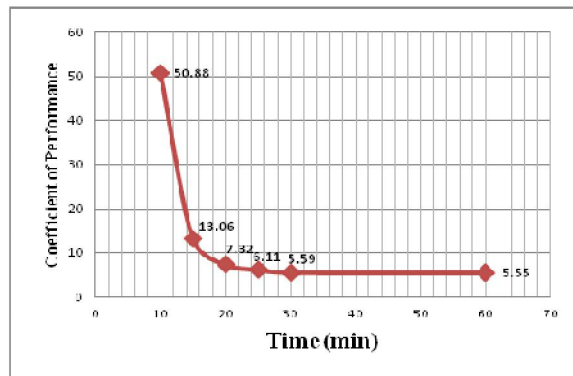


Figure 4.12:- Coefficient of Performance (Vs) Time for blend of R-290 and R-600a

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 6, June 2016

From Figure 4.10 it's discovered that Refrigeration effect decreases with increases in Time for blend of R-290 and R-600a. From Figure 4.11 it's discovered that Compressor work increases with increases in Time for blend of R-290 and R-600a refrigerant. From Figure 4.12 it's discovered that Coefficient of Performance decreases with increases in Time for blend of R-290 and R-600a refrigerant.

V. CONCLUSION

- R-134a and R-413A have a zero ODP and high GWP characteristics and blend of R-290 and R-600a have a zero ODP and negligible GWP characteristics so blend of hydrocarbon refrigerant is appropriate substitute for hydro-fluorocarbon refrigerant in refrigeration system.
- Discharge temperature of compressor is decreased by 10.20% by using blend R-290 and R-600a as compared to R-134a and 12% decreased as compared to R-413A.
- Blend of R-290 and R-600a refrigerant gives more refrigeration effect than R-134a and R-413A.
- Blend of R-290 and R-600a of 60gm requires 62.5% less charge compared to R-134a of 160gm and 60% less charge compared to R-413A of 150gm.
- Blend of R-290 and R-600a of 60gm gives 22.24% higher COP than of R-134a of 160gm and 21.87% higher COP than of R-413A of 150gm.

$$\begin{aligned} \text{\% increment in COP} &= \frac{\text{COP}_{\text{for blend of HC-290 and HC-600a}} - \text{COP}_{\text{for HFC-134a}}}{\text{COP}_{\text{for HFC-134a}}} \\ &= \frac{5.55 - 4.54}{4.54} * 100 \\ &= 22.24\% \end{aligned}$$

$$\begin{aligned} \text{\% increment in COP} &= \frac{\text{COP}_{\text{for blend of HC-290 and HC-600a}} - \text{COP}_{\text{for HFC-413A}}}{\text{COP}_{\text{for HFC-413A}}} \\ &= \frac{5.55 - 4.55}{4.55} * 100 \\ &= 21.87\% \end{aligned}$$

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