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Thermodynamic Analysis of Two Stage Cascade Refrigeration System using Natural Refrigerants

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ABSTRACT

A comparative study of thermodynamic analysis of a two-stage cascade refrigeration system using eco friendly/natural refrigerant pairs (R170-R290, R170-R600a, R170-R717, and R170-R1270) is carried out to assess the effects of various operating parameters i.e. evaporator temperature, condenser temperature and temperature difference in cascade condenser on performance parameters viz. COP, ratio of mass flow rates and work done. Thermodynamic analysis shows that out of these refrigerant pairs the COP of R170-R717 refrigerant pair is highest. It also focuses on how the parameters viz. COP, ratio of mass flow rates and work done varies when a suction gas heat exchanger is introduced in the H.T cycle and the variation is compared to the output results of without suction gas heat exchanger.

Keywords:—*Alternate refrigerants, R170 - R717, L.T./H.T cycle, Work done and COP.*

I. INTRODUCTION

For low temperature ranges around -50ºC to -30ºC cascade refrigeration system is used. Cascade system employs two different refrigerants operating in two individual cycles. They are thermally coupled in the cascade condenser. Since each cascade uses a different refrigerant, it is possible to s elect a refrigerant that is best suited for that temperature range. Each cycle uses different refrigerant for better performance of the system and works between very large temperature ranges . The evaporating temperature (TE), the condensing temperature (TC), and the temperature difference (ΔTcc) in the cascade condenser are three important design parameters of a cascade refrigeration system. Very high or very low pressures can be avoided. Migration of lubricating oil fro m one compressor to the other is prevented. The refrigerants to be s elected for the use in cascade refrigeration system should satisfy most of the thermodynamic and thermo-physical properties, which are eco-friendly and has zero ozone depletion potential. Ethane (R170), for low temperature cycle and Propane (R290), iso-butane (R600a), Ammonia (R717) and Propylene (R1270) for high temperature cycle are selected depending on their properties and their availability in Cool Pack software. Variation of mass flow rate, C.O.P and work done are studied for a range of TE (-50ºC to -30ºC), TC (32ºC to 48ºC), ΔTcc (2ºC to 6ºC).

Table 1: Comparison Work of Various Researchers on Subcritical Simulation Study

Authors	Title	Refrigerants		Temperature			C.O.Pmax
		L.T	H.T	TE	AT	TC	
SatyanandaTripathy	Thermodynamic Analysis of a Cascade Refrigeration Sys tem Based On Carbon Dioxide and Ammonia	R 744	R 717	-45 -50 -55	3 4 5	35 40 45	2.01
A. D. Parekh	Thermodynamic Analysis of Cascade Refrigeration System Using R12-R13, R290-R23 and R404A -R23	R12 R 290 R404A	R13 R23 R 23	-80 to -60	2 to 6	25 to 45	1.779 (for R290-R23)
Antonio Messineo	Performance evaluation of cascade refrigeration systems using different refrigerants	R744	R717 R290 R600 R404A, R410A R134a	- 35	5	35	1.71 (R 744- R 717)
Gajendrasinh	Thermodynamic Analysis of Cascade Refrigeration System using a Natural Refrigerants for Supermarket Application	R744	R717 R134a R290 R404A	-55 to -30	2.5	30 to 45	2.08
Getu & Bansal	Thermodynamic analysis of a low R744 – R717 cascade system	R744	R717	-50	5	40	1.4
Simarpreet Singh	Thermodynamic analysis of a lowtewi (r1234yf-r744) cascade system	R744	R1234Y F	-40 To -20	5	30 To 50	1.6
Mrs.J. S. Jadhav	Review of Cascade Refrigeration System With Different Refrigerant Pairs	R744	R717 R134a R290 R404a	-30 To -55	3 To 15	30 To 45	2.08 (R717)
Antonio Messineo	R744-R717 Cascade Refrigeration System: Performance Evaluation compared with a HFC Two-Stage System	R744	R717	-50 To -30	5	35 To 40	1.82

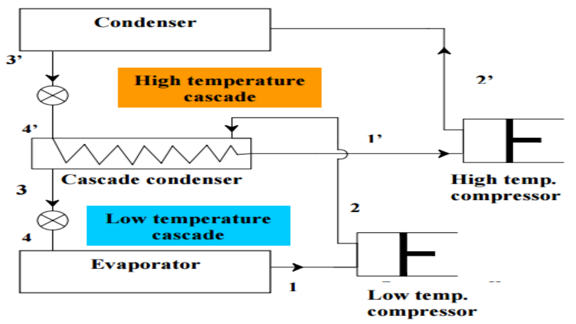

Figure 1.1 Two stage cascade refrigeration system

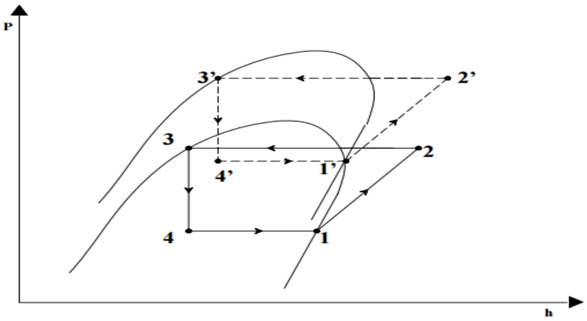

Figure 1.2 P-h diagram of two stage cascade system

II. Literature Review

2.1 Observations made from the literature

The literature review shows that with different refrigerant pairs, evaporating temperature, condensing temperature, cascade condenser temperature difference and coefficient of performance. The important conclusions which are drawn from the literature survey for some of the cascade refrigerant pairs such as R744 - R717, R744- R290, R744-R600a are

- With increase in Te, there is an increase in COP.
- With decrease in Tc there is an increase in COP.
- With decrease in ΔTcc there is an increase in COP.

III. Methodology

A simulation tool (Cool Pack) is used to simulate the various s elected refrigerants .

The thermodynamic analysis of the two-stage cascade refrigeration system was performed based on the following general assumptions :

- All components are assumed to be in a steady-state. The changes in the potential and the kinetic energy of the components are negligible .
- Adiabatic compression with an is entropic efficiency (ηisen) of 80% for both high and low temperature compressors .
- The expansion process is isenthalpic and Compressor heat loss is taken as 10%.
- Pressure and heat losses/gains in the pipe networks or system components are negligible.
- All the heat released by the low-temperature circuit condenser is rejected to the high temperature circuit evaporator.
- Heat transfer processes in cascade condenser, evaporator and condenser are isobaric.
- Heat transfer in cascade condenser, evaporator with the ambient is negligible.
- Efficiency of suction gas heat exchanger is 30%
- The temperature range of evaporator is given from -50°C to -30°C in steps of 5°C.
- The temperature range of condenser is given fro m 32°C to 48°C in steps of 4°C.
- The temperature difference in cascade condenser is maintained fro m 2°C to 6°C in steps of 1°C.
- Refrigeration capacity: HT cycle =20 KW, LT cycle = 15KW
- A superheat of 6°C and sub cooling

of 4oC.

- To evaluate the performance of cascade refrigeration system it's selected that one of the natural refrigerant pairs and fixed two of the three temperature parameters : T E=-40°C, Tc=44°C and ΔTcc=5°C, as constant and varied the third parameter.

IV. Results and Discussion

4.1 Cascade refrigeration system without suction gas heat exchanger

4.1.1 Variation of mass flow (ratio) rates

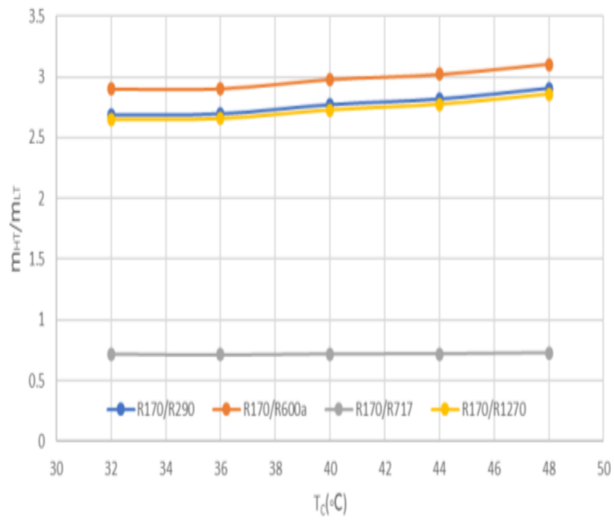

Figure 4.1.1a: mHT/LT vs TE

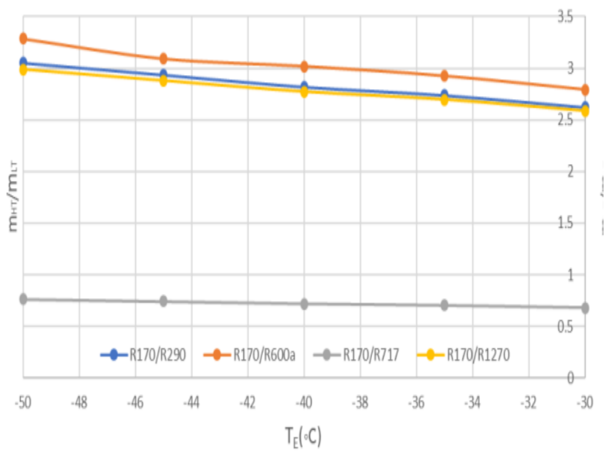

Figure 4.1.1b:mHT/LT vs TC

From Figure 4.1.1a with increase in temperature of 20°C in the evaporator, there is a decrease in 16.52%, 17.69%, 12.41%, 15.35% of mass flow ratio for the refrigerant pairs R170/ R290, R170/ R600a, R170/ R717, R170/ R1270 respectively. It's also observed that the ratio of mass flow rate of R170/ R717 is very small, which is a desirable characteristic. When compared to other pairs R170/ R600a shows a good decrease of 17.69%. Similarly, from Figure 4.1.1b with increase in temperature of 16°C in the condenser, there is an increase in 7.45%, 6.48%, 1.16%, 7.34%, of mass flow ratio for the refrigerant pairs R170/R290 R170/ R600a, R170/ R717, R170/ R1270 respectively. It's also observed that from Figure 4.1.1c the ratio of mass flow rate of R170/R717 is very small, which is a desirable characteristic and shows a s mall increase of 1.16% .With increase in temperature difference from 2°C to 6°C in the cascade condenser, there is a decrease in 3.21 %.3.16%, 3.20%, 3.18% of mass flow ratio for the refrigerant pairs R170/ R290, R170/R600a, R170/ R717 R170/ R1270 respectively, which is nearly same for all refrigerants. It's also observed that the ratio of mass flow rate of R170/ R717 is very small, which is a desirable characteristic.

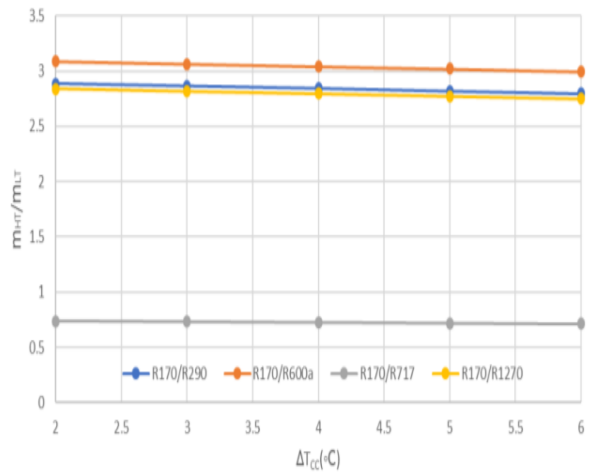

Figure 4.1.1c: mHT/LT vs ΔTCC

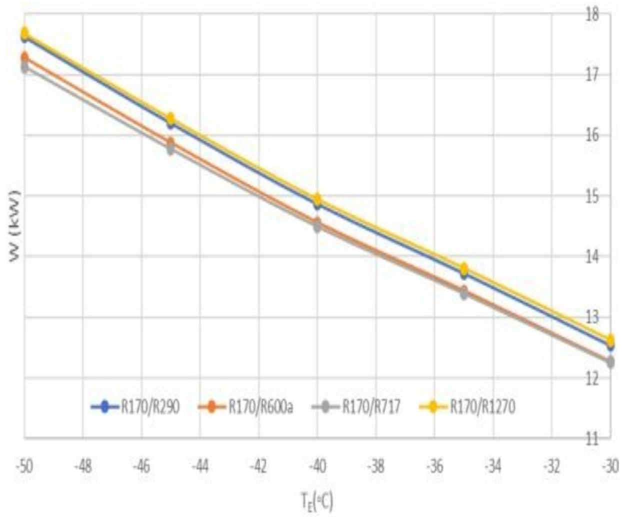

Figure 4.1.2a:TE vs W

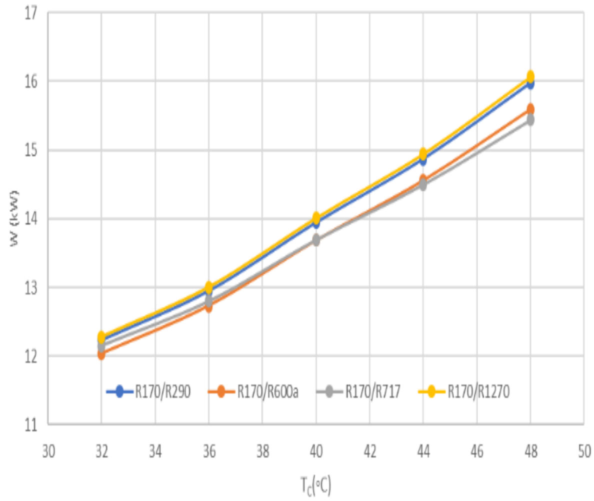

Figure 4.1.2b: TC vs W

4.1.2 Variation of work done (kW)

From figure 4.1.2a with increase in temperature of 20ºC in the evaporator, there is a decrease in 40.56%, 40.87%, 39.74%,40.02% of work done for the refrigerant pairs R170/R290, R170/ R600a, R170/ R717, R170/ R1270 respectively. With increment in evaporator temperature, the refrigerant pair R170/ R600a shows a good decrease of 40.87% when compared to other refrigerant pairs . Similarly, from figure 4.1.2a with increase in temperature of 16 0C in the condenser, there is an increase in 23.39%,22.83%, 21.27%, 23.58% of work done for the refrigerant pairs R170/ R290, R170/R600a, R170/ R717, R170/ R1270 respectively. It's also observed that from figure 4.1.2c the total work done in case of R170/ R717 and R170/ R600a are less among the four pairs . With increase in temperature difference from 20C to 60C in the cascade condenser, there is a decrease in 4.87%, 4.93%, 4.95%, 4.84% of work done for the refrigerant pairs R170/ R290, R170/ R600a, R170/R717, R170/R1270 respectively. It's also observed that the total work done in case of R170/ R717 is less among the four pairs .

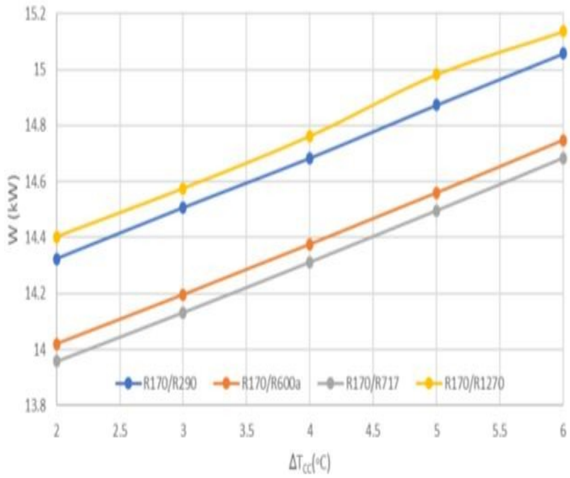

Figure 4.1.2c:ΔTCC vs W

4.1.3 Variation of C.O.P

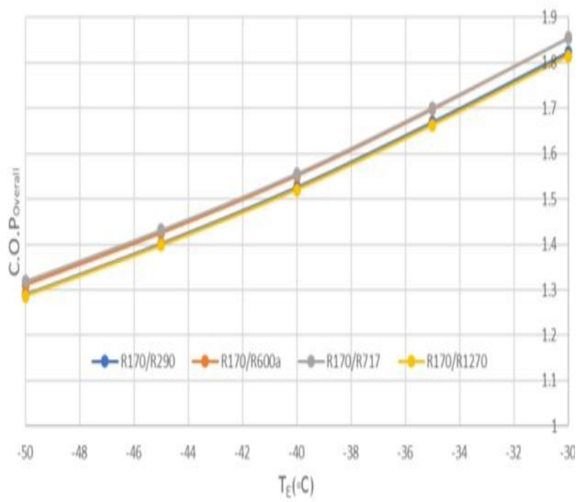

Figure 4.1.3a: C.O.P vs TE

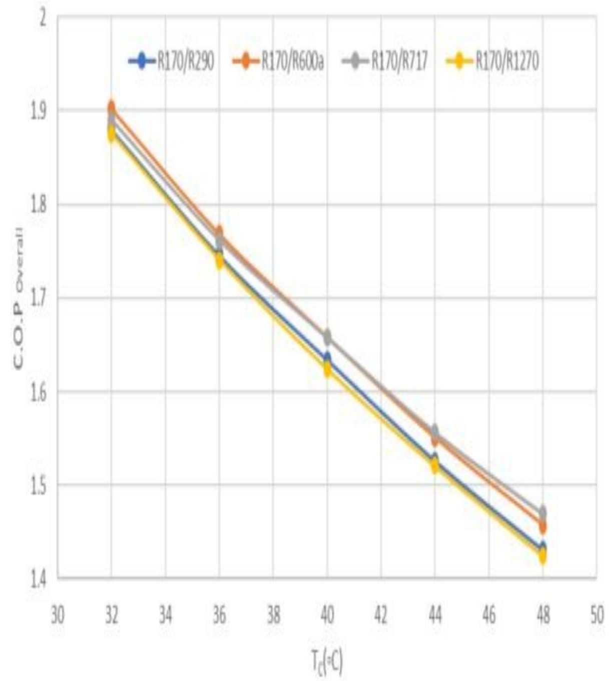

Figure 4.1.3b: C.O.P vs TC

From Figure 4.1.3a with increase in temperature of 20ºC in the evaporator, there is an increase in 29.25%, 29.35%, 28.89%, 29.07% of C.O.P for the refrigerant pairs R170/ R290, R170/ R600a, R170/ R717, R170/ R1270 respectively. It's also observed that the C.O.P in case of R170/ R717 is more among the four pairs. From Figure 4.1.3b with increase in temperature of 16ºC in the condenser, there is a decrease in 31.35%, 30.52%, 28.62%, 31.63% of C.O.P for the refrigerant pairs R170/ R290, R170/ R600a, R170/ R717, R170/ R1270 respectively. It's also observed that from figure 4.1.3c the C.O.P in case of R170/ R717 and R170/ R600a is more among the four pairs. With increase in temperature difference fro m 2ºC to 6ºC in the cascade condenser, there is a decrease in 8.04%, 8.12%, 8.14%, 8.02% of C.O.P for the refrigerant pairs R170/ R290, R170/ R600a, R170/ R717, R170/ R1270 respectively. It's also observed that the C.O.P in case of R170/ R717 is more among the four pairs .

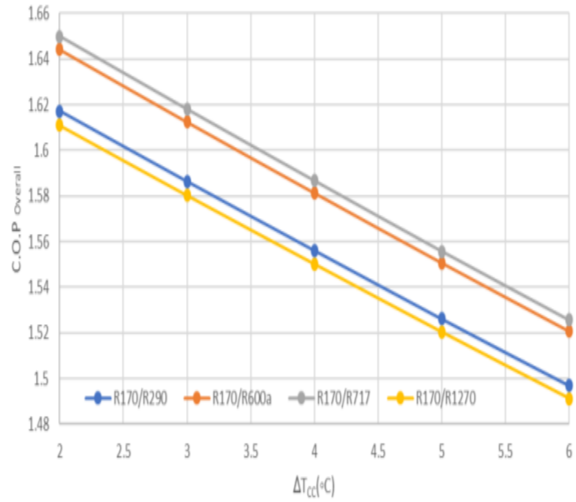

Figure 4.1.3c: C.O.P with ΔTCC

4.2 Cascade refrigeration system with suction gas heat exchanger in H.T cycle

4.2.1 Variation of mass flow (ratio) rates

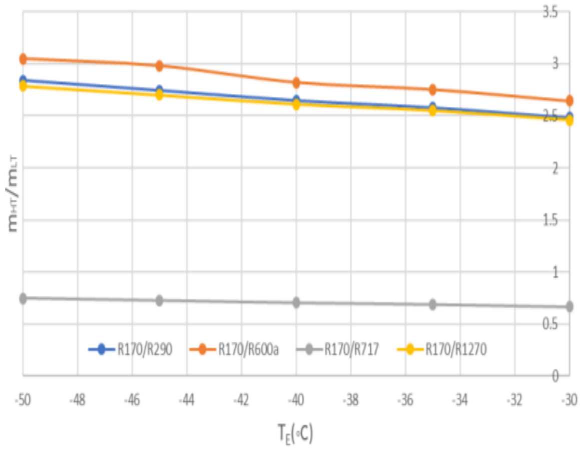

Figure 4.2.1a: mHT/LT vs TE

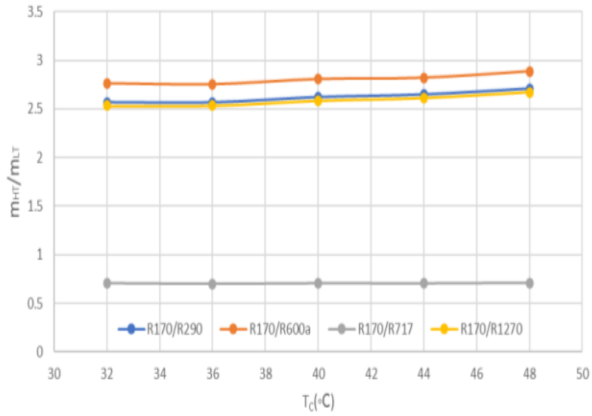

Figure 4.2.1b:mHT/LT vs TC

From figure 4.2.1a with increase in temperature of 20ºC in the evaporator, there is a decrease in 14.26%, 15.28%, 11.7%, 13.4% of mass flow ratio for the refrigerant pairs R170/ R290, R170/ R600a, R170/ R717, R170/ R1270 respectively. From figure 4.2.1b with increase in temperature of 160C in the condenser, there is an increase in 5.13%, 4.11%, 0.42%, 5.16% of mass flow ratio for the refrigerant pairs R170/ R290, R170/ R600a, R170/ R717, R170/R1270 respectively. From figure 4.2.1c with increase in temperature difference fro m 2 0C to 60C in the cascade condenser, there is a decrease in 3.19%, 3.16%, 3.19%, 6.88% of mass flow ratio for the refrigerant pairs R170/ R290, R170/ R600a, R170/ R717, R170/ R1270 respectively.

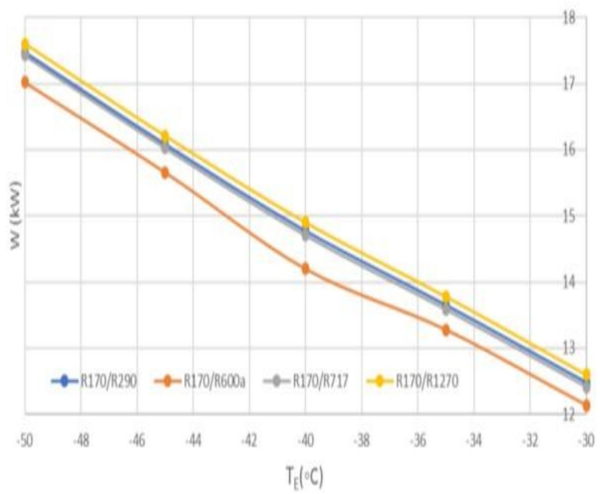

Figure 4.2.1c: mHT/LT vs ΔTCC

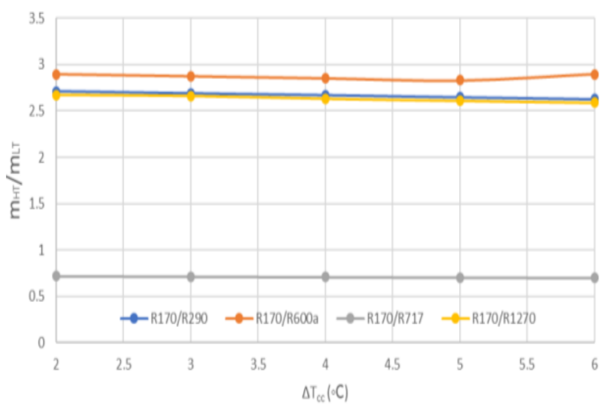

Figure 4.2.2a: TE vs W

4.2.2 Variation of work (kW)

From figure 4.2.2a with increase in temperature of 20ºC in the evaporator, there is a decrease in 31.98%, 40.19%, 40.33%, 39.68% of work done for the refrigerant pairs R170/R290, R170/R600a, R170/ R717, R170/ R1270 respectively. From figure 4.2.2b with increase in temperature of 16ºC in the condenser, there is an increase in 22.93%, 22.13%, 21.54%, 23.20% of work done for the refrigerant pairs R170/ R290, R170/R600a R170/ R717, R170/R1270 respectively. Fro m Figure 4.2.2c with increase in temperature difference from 20C to 60C in the cascade condenser, there is a decrease in 4.37%, 5.01%, 4.89%, 4.83% of work done for the refrigerant pairs R170/ R290, R170/ R600a, R170/ R717, R170/ R1270 respectively.

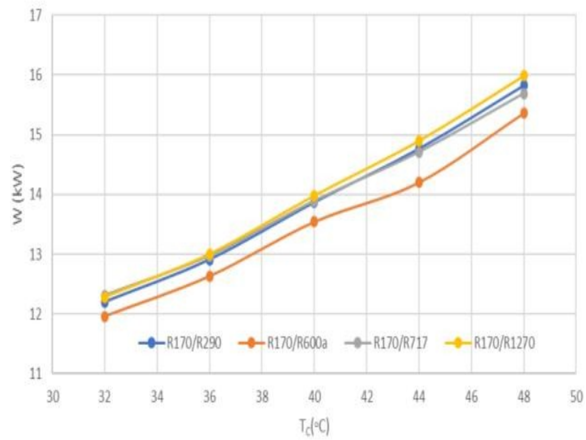

Figure 4.2.2b: TC vs W

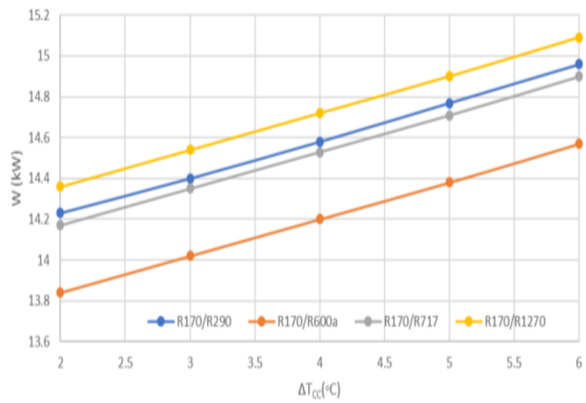

Figure 4.2.2c: ΔTCC vs W

4.2.3 Variation of C.O.P

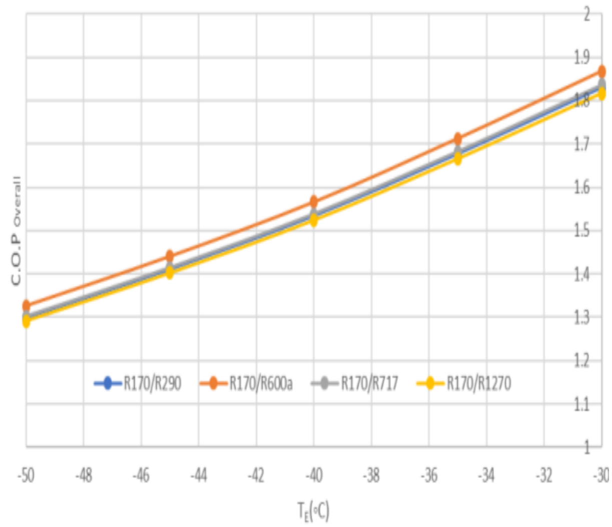

Figure 4.2.3a: C.O.P vs TE

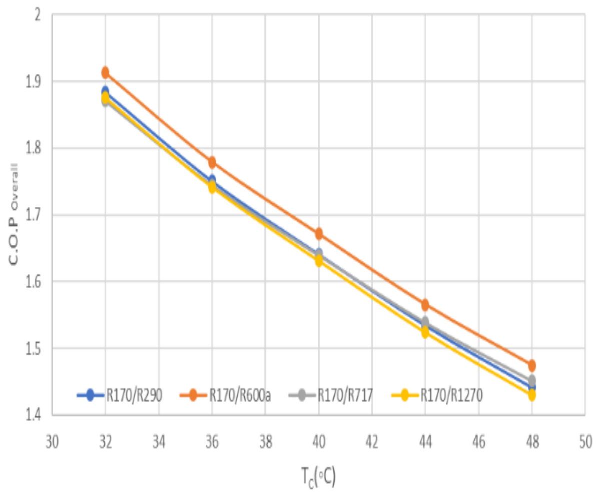

Figure 4.2.3b: C.O.P vs TC

From figure 4.2.3a with increase in temperature of 20ºC in the evaporator, there is an increase in 29.03%, 29.03%, 29.14%, 28.92% of C.O.P for the refrigerant pairs R170/R290, R170/R600a R170/ R717, R170/ R1270 respectively. From figure 4.2.3b with increase in temperature of 16ºC in the condenser, there is a decrease in 30.71%, 29.71%, 28.93%, 31.14% of C.O.P. for the refrigerant pairs R170/ R290, R170/ R600a, R170/R717 R170/ R1270 respectively. From Figure 4.2.3c with increase in temperature difference from 2ºC to 6ºC in the cascade condenser, there is a decrease in 8.06%, 8.17%, 8.07%, 8.03% of C.O.P for the refrigerant pairs R170/ R290, R170/ R600a R170/R717, R170/R1270 respectively.

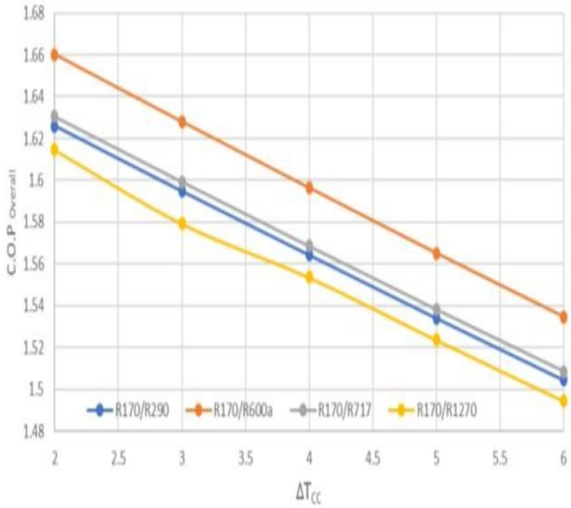

Figure 4.2.3c: C.O.P with ΔTCC

V. CONCLUSIONS

Without suction gas heat exchanger in HT cycle it can be observed that the ratio of mass flow rate for refrigerant pair R170/ R717 is low, which can be attributed to high latent heat of vaporization of ammonia. Also, the total work done in this refrigerant pair is less and the C.O.P. is high. Fro m this it can be concluded that R170/R717 is the best possible refrigerant pair among the four natural refrigerant pairs. With suction gas heat exchanger in HT cycle the C.O.P. and other parameters of R170/ R600a imp rove more compared to other refrigerant pairs.

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