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Performance improvement in integrated refrigeration system

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Abstract

The integrated refrigeration system (IRS) is proposed for waste heat recovery from superheat horn of vapour compression refrigeration cycle. The waste heat rejected by the vapour compression system is recovered through heat exchanger is utilized to run the generator of absorption refrigeration system. The heat rejected by the condenser is recovered to heat the water because recovery of waste heat is contributing in conservation of energy which would help in the reduction of global warming. In this system, the waste heat is being utilized to run vapour absorption system (VARS) therefore there will be increase in overall cooling capacity of the system and increase in coefficient of performance (COP).

Key words: Refrigeration systems, integrated refrigeration system, Thermodynamic Analysis systems

1. Introduction

Refrigeration and air conditioning systems have a major impact on energy demand with roughly 30% of total energy consumption in the world. A rough estimate of waste heat available from refrigeration and air conditioning system indicates that about 3-5 kW of waste energy is rejected to the environment for every kilowatt of energy expended by the compressor. The use of heat operated refrigeration systems help to reduce problems related to global environmental, such as the so called greenhouse effect from CO2 emission from the combustion of fossil fuels in utility power plants. The objective of this paper is to perform first law analysis of Integrated Refrigeration System (IRS). It shall include the computation of the following

- Selection of proper refrigerant for VCR system.
- Cooling capacity enhancement of IRS.
- Increase in overall COP.

Effect of variation in parameters such as absorber temperature, generator temperature, condenser temperature, evaporator temperature, effectiveness and efficiency of compressor etc. This paper mainly deals with the collection of waste heat from refrigeration and air conditioning plants and to utilization of that waste heat as the heat source in the generator of vapour absorption refrigeration system considering the requirement of Cooling.

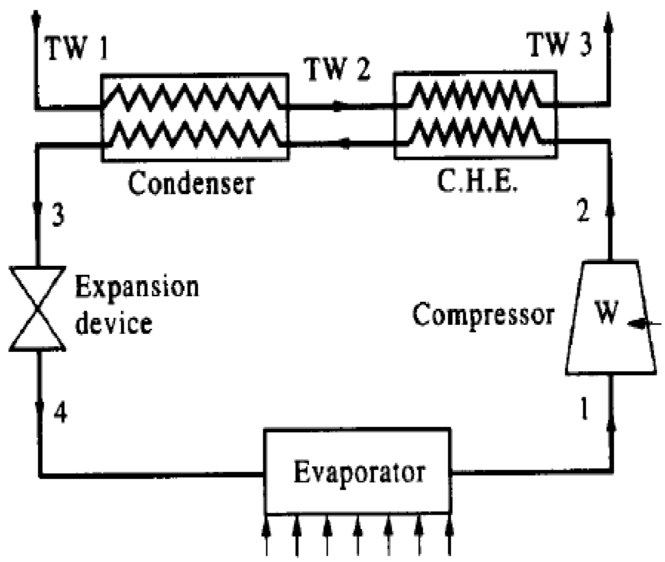

Figure 1: Vapour Compression refrigeration system

2. Literature Review

Hwang [1] presented and analyzed the performance potential of a refrigeration system that was integrated with a micro-

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turbine and an absorption chiller (RMA). The waste heat from the micro-turbine operates the absorption chiller, which provides additional cooling. This additional cooling capacity can be utilized either to subcool the liquid exiting the condenser of the refrigeration system or to precool the air entering the condenser in the refrigeration system. Sarah Kim,[2] carried out the theoretical performance of ionic-liquid based working fluids in an absorption refrigeration system The IL 1-butyl-3-methylimidazolium hexa-fluoro-phosphate and five hydrofluorocarbons (HFCs) were selected as the absorbent and refrigerant, respectively. Using Redlich–Kwong equation of state and two-phase pressure-drop model were used for computing the thermodynamic conditions and performance of the working-fluid pairs. The effects of the disorder and absorber temperatures, solution heat exchanger, and accessibility of waste heat on the system performance were evaluated. R152a found the highest coefficient of performance, 57.3, when the disrober operated on waste heat only and the disrober and absorber were operated at 373.15 and 300.65 K, respectively. The friction-loss component of the total pumping work was observed below 2.5% of the pumping work for all refrigerants Upendra Kumar [3] analyzed configuration of combined refrigeration system consisting of a compression chiller and an absorption chiller that is driven by a micro turbine to generate cooling at low temperatures. The compression chiller is operated directly by the micro turbine at the low temperature stage and the waste heat from the micro turbine is used to drive the absorption chiller that operates at the high temperature stage and helps to the compression chiller performance and concluded that the use of this configuration of integrated refrigeration system is more efficient and less energy consuming than the system without absorption chiller.

Aphornratana & Sriveerakul [4] presented an experimental investigation of a single-effect absorption using aqueous lithium–bromide as working fluid. A 2 kW cooling capacity experimental refrigerator was tested with various operating temperatures. It was found that the solution circulation ratio (SCR) has a strong effect on the system performance. The measured SCR was 2–5 times greater than the theoretical prediction and found that the low performance of the absorber. The use of solution heat exchanger could increase the COP by up to 60%. Hong guangJin [5] analyzed. the performance of a vapour compression-absorption cascaded refrigeration system (CRS) under fouled conditions by considering main effect of fouling is to decrease the effectiveness of the heat exchanger and found that the overall conductance (UA) of the heat exchanger is decreased due to fouling is to reduce the effective size of the heat exchanger and observed that the percentage decrease in the overall conductance value (UA) of evaporator and condenser due to their fouling is varied from 0 to 50% and its consequences on various aspects of CRS are generated to ascertain any possible patterns. From first law analysis for a clean evaporator and condenser, the electricity consumption is 67.5% less than vapour compression system (VCS) for the same cooling capacity. CRS is able to save only 61.3% of electrical energy when evaporator and condenser conductance is reduced by 50% due to fouling. Evaporator and condenser fouling decreased the COP and rational efficiency of the system by 4.7% and 10.5% respectively and also found that irreversibility in the evaporator and condenser is increased by 42.4% and 62.1% respectively, when their individual performance is degraded by 50% due to fouling. Kaushik and Singh [6] presented an investigation of the feasibility of heat recovery from the condenser of a vapour compression refrigeration (VCR) system through a Canopus heat exchanger (CHE) between the compressor and condenser components as shown in figure. The parametric results obtained for different working fluids, such as R-22, R-12, R-717 and R-500, had been presented. Kaynakli et.al [7] presented a detailed thermodynamic analysis of the water/lithium bromide absorption refrigeration cycle. The influences of operating temperature and effectiveness of heat exchanger on the thermal loads of components, coefficients of performance and efficiency ratio were investigated. Aprea and Renno [8] presented the experimental studies of performances of a vapour compression refrigeration plant using as working fluids R22 and its substitute R417A (R125/R134a/R600, 46.6/50/3.4% in mass). This type of plant is applied to a commercially available cold store, generally adopted for preservation of foodstuff. An integrated refrigeration system (IRS) with a gas engine, a vapour-compression chiller and an absorption chiller was set up and tested by Sun [9]. The vapour-compression refrigeration cycle was operated directly by the gas engine. The waste heat from the gas engine operates the absorption refrigeration cycle, which provides additional cooling. Riffat and Shankland [10] presented the integration of different types of absorption systems with vapour-compression systems. The performances of such systems have been analyzed thermodynamically using various refrigerant/absorbent pairs. The paper concerned with the intermittent absorption system, the intermittent absorption/vapour recompression system and the combined intermittent absorption/vapour compression system. Saskaki et al. [11] have proposed a Cascaded System comprising of Vapor-Compression and Absorption refrigeration cycle. The vapor-compression equipment cools the building space, and the absorption equipment “pumps” the heat rejected from the vapour compression system up to the temperature needed to reject it to the ambient air. In this case, the vapor-compression condenser and the absorption system evaporator are in thermal communication. The temperature lift for both refrigeration systems is reduced. Rinnai Corporation [12] has patented such a concept (2004) of Cascaded System comprising of Absorption and Vapor-Compression refrigeration cycle. The absorption equipment cools the building space, and the vapor-compression equipment “pumps” the rejected heat up to the temperature needed to reject it to the ambient air. In this case, the absorber from the absorption system is in thermal communication with the evaporator of the vapor-compression system.

3. Thermodynamic Analysis of Integrated Refrigeration System

The Thermodynamic Analysis of integrated refrigeration system (IRS) is done for vapour compression refrigeration (VCR) system with CHE and vapour absorption refrigeration system (VARS)

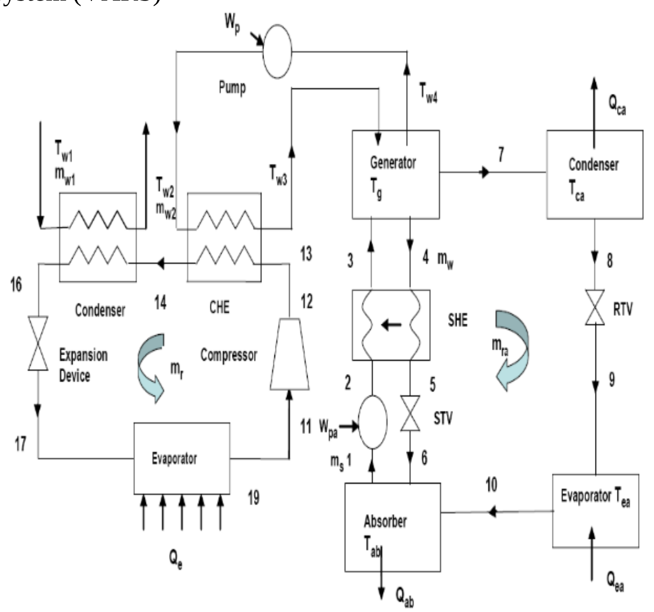

Figure .2.a Schematic diagram of an Integrated Refrigeration System (IRS)

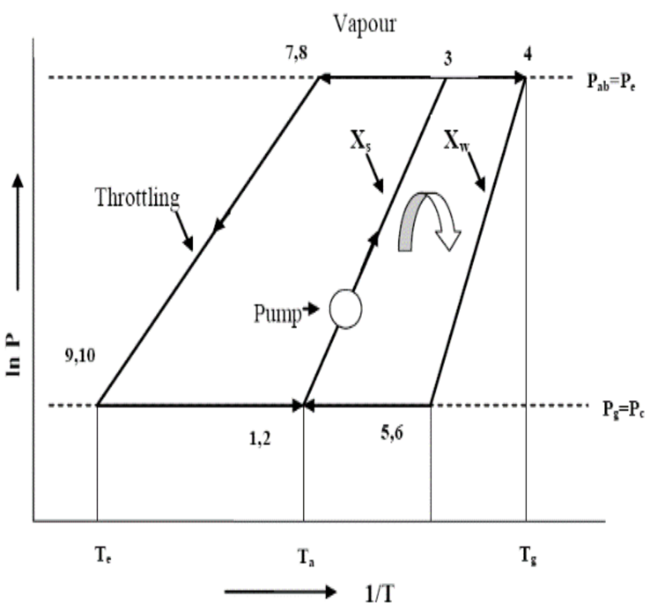

Figure 2.b: Single effect vapour absorption Réfrigération cycle on log p-1/T coordinates.

The following equations are based on mass, energy and concentration balance used in the performance analysis.

$m_s*X_s=m_w*X_w$

$m_s=m_{ra}+m_w$

Pump work $W_{pa}=m_s*V_g*(P_g-P_{ab})/1000$

$E=(Tg-T5)/(Tg-Tab)$

$W_{pa}=m_s*(h_2-h_1)$

$E1=Qg/DODS$

$m_s*(h_3-h_2)=m_w*(h_4-h_5)$

Energy balance in generator

$m_s*h_3+Q_g=m_w*h_4+m_{ra}*h_7$

3.1 Heat added to Generator

$Q_g=m_{w2}*C_{pw2}*(T_{w3}-T_{w2})+m_{w2}*h_{fg}\_T_{w3}$

Heat transffer Condenser

$Q_{ca}=m_{ra}*(h_7-h_8)$

Energy balance in absorber

$Q_{ab}+m_s*h_1=m_{ra}*h_{10}+m_w*h_6$

Energy balance in Canopus Heat Exchanger

$m_{w2}*C_{pw}*(T_{w3}-T_{w2})+m_{w2}*h_{fg}\_T_{w3}=m_r*(h_{13}-h_{14})$

Compressor work $W_c=m_r*(h_{12}-h_{11})$

3.2 Mass flow rate of refrigerant

$COP=h_{19}-h_{17}/(h_{12}-h_{11})$

$m_r=TR*3.5168/(h_{19}-h_{17})$

$scr=m_s/m_{ra}$

3.3 Degree of de-superheating

$DODS=m_r*(h_{13}-h_{14})$

Heat rejected by condenser+CHE

$Q_c=m_r*(h_{13}-h_{16})$

3.4 Heat Recovered By Canopus Heat Exchanger

$Qe=TR*3.5168$

$CAN=m_{w2}*C_{pw}*(T_{w3}-T_{w2})+m_{w2}*h_{fg}\_T_{w3}$

$QE\%=Q_{ea}*100/Q_e$

$DODS\%=(DODS*100)/Q_c$

$COPa=Q_{ea}/(W_{pa}+Q_g)$

$COP\%=(COPc-COP)*100/COP$

$COPc=(Q_{ea}+Q_e)/(W_{pa}+W_c)$

To evaluate the integrated Refrigeration system with the following assumptions were made.

- The flow through all the components is under steady state.
- The pressure drop due to friction within the absorption refrigeration system can be neglected, except through the expansion valve.
- The fluid streams in the piping between the components and the heat exchangers are adiabatic.
- The strong solution at the outlet of the absorbers and the weak solution at the outlet of the generators are saturated.
- Refrigerant vapour alone leaves the generators, that is, it does not contain any traces of the absorbent.

- The temperature and concentration of LiBr aqueous are in equilibrium at the saturated pressure of LiBr aqueous.
- The LiBr fraction pressure is neglected: i.e. the pressure in the vapour phase is equal to the saturated pressure of water.

4. Results and Discussions

The following input data have been used to validate the proposed thermal model.
Chilling of water: -2°C, Storage of milk: -5°C, Ice silo: -10°C, Ice cream: -20°C,
Fishery item: -25°C, Cold storage & deep freezer: 30°C and simulated results from validates the proposed model table- 1.

Table-1: Simulated Results from developed Program.

Parameters	From program
COP_{VARS}	0.7659
P_{ca} KPa	7.38
P_{ea} KPa	1.2135
P_g KPa	7.38
Q_{ab} KW	4.34
Q_{ca} KW	3.77
Q_{ea} KW	3.517
Q_g KW	4.59
m_{ra} Kg/s	0.0015
Xs %	57.7
Xw %	65.4

Selection criterion for input parameters and their values are depending upon the different applications of the system the evaporator temperature has been varied in the range of -1 to -35°C in step of 1°C and the normal ambient conditions were the deciding factor for the temperature range of condenser and absorber, which is 30°C to 50°C in step of 1°C. The evaporator temperature for the vapour absorption refrigeration system is taken on the basis of various air conditioning applications and it ranges from 2-14°C. The thermodynamic and transport property functions for many fluids including water, dry and moist air. Included in the property database are thermodynamic properties for H_2O-LiBr and NH_3-H_2O mixtures used. Fig-3 shows the variation of heat added with evaporator of vapour absorption system by varying evaporator temperature of vapour compression refrigeration system VCRS for different refrigerants i.e. (R717 and R22) for 30ºC absorber temperature and 35ºC of condenser temperature, with 85ºC of water temperature along with evaporator temperature of T_{eva}=7ºC, by considering 0.80 of heat exchanger effectiveness with compressor efficiency of 0.85 and it was observed that the heat added to absorber increases when evaporator temperature is decreased in both refrigerants. The better thermodynamic performances is observed by using R717 as compared to R22 which produces global warming and depleting ozone layer. Similarly Fig-4 shows the variation of % increase in coefficient of performance with varying evaporator temperature of vapour compression refrigeration system VCRS for different refrigerants i.e. (R717 and R22) for 30ºC absorber temperature and 35ºC of condenser temperature, with 85ºC of water temperature along with evaporator temperature of T_{eva}=7ºC, by considering 0.80 of heat exchanger effectiveness with compressor efficiency of 0.85 and it was observed that the percentage coefficient of performance (% COP)of the system is increases when evaporator temperature is decreased in both refrigerants. The better thermodynamic performances is observed by using R717 as compared to R22 which produces global warming and depleting ozone layer . Fig-5 shows the variation of thermal load on Generator with varying cooling water inlet temperature for CHE for different refrigerants i.e. (R717 and R22) for 30ºC absorber temperature and 35ºC of condenser temperature, with 85ºC of water temperature along with evaporator temperature of T_{eva}=7ºC, by considering 0.80 of heat exchanger effectiveness with compressor efficiency of 0.85 and it was observed that the thermal load variation on Generator with varying cooling water inlet temperature for heat exchanger is slightly increases for different refrigerants when cooling water inlet temperature for heat exchanger is increased in both refrigerants. The better thermodynamic performances is observed by using R717 as compared to R22 which produces global warming and depleting ozone layer. Fig-6 shows the variation in coefficient of performance with varying absorber temperature for different refrigerants i.e. (R717 and R22) for -30ºC 0f evaporator temperature and 35ºC of condenser temperature, with 85ºC of water temperature along with evaporator temperature at T_{eva}=7ºC, by considering 0.80 of heat exchanger effectiveness with compressor efficiency of 0.85 and it was observed that the variation in coefficient of performance with varying absorber temperature for different refrigerants i.e. (R717 and R22) rapidly decreases for different refrigerants when absorber temperature is increases in both refrigerants. The better thermodynamic performances is observed by using R717 as compared to R22 which produces global warming and depleting ozone layer. Fig-7 shows the variation in heat added to evaporator of vapour absorption refrigeration system (VARS) with varying absorber temperature for different refrigerants i.e. (R717 and R22) for -30ºC 0f evaporator temperature and 35ºC of condenser temperature, with 85ºC of water temperature along with evaporator temperature at T_{eva}=7ºC, by considering 0.80 of heat exchanger effectiveness with compressor efficiency of 0.85 and it was observed that the heat added to evaporator of vapour absorption refrigeration system (VARS)is decreases with varying absorber temperature for different refrigerants. The better thermodynamic performances is observed by using R717 as compared to R22 which produces global warming and depleting ozone layer

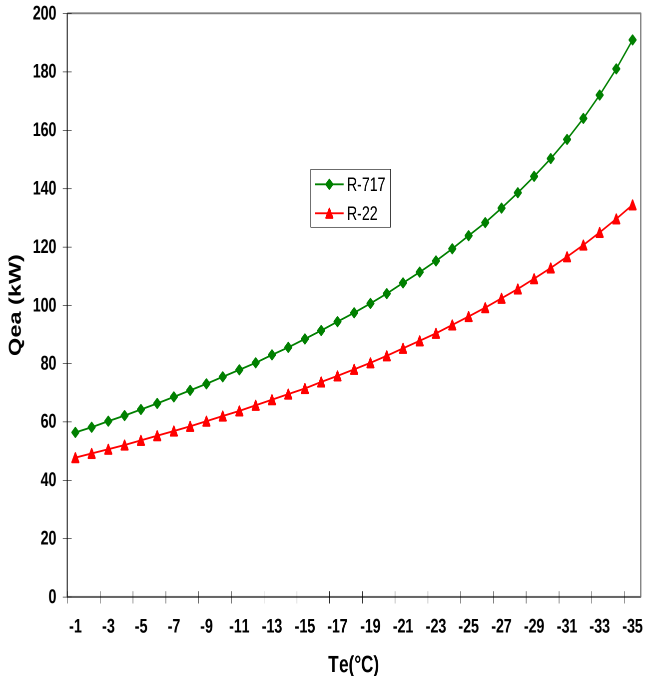

Figure 3: Heat added variations with evaporator of vapour absorption system by varying evaporator temperature of VCR for different refrigerants $T_{absorber}$=30ºC, $T_{condenser}$=35ºC, T_{eva}=7ºC, T_{w2}=85ºC, Effectiveness_HE =0.8, η_c=0.85

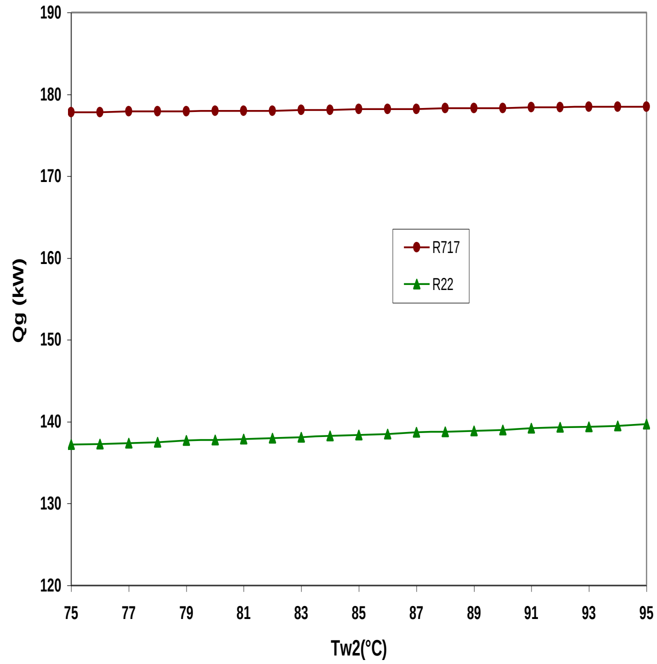

Figure 5: Variation of thermal load on Generator with varying cooling water inlet temperature for CHE for different refrigerants at T_e=30°C, T_{ab}=30°C, T_c=35°C, T_{eva}=7ºC, Effectiveness_HE =0.8, η_c=0.85.

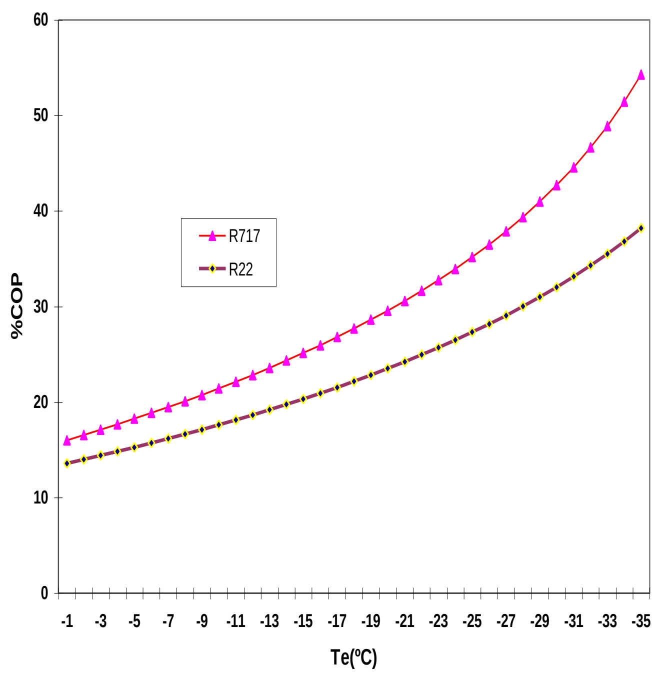

Figure 4: Variation in % increase in coefficient of performance with varying evaporator temperature For different refrigerants at $T_{absorber}$=30ºC, T_{cond}=35ºC, T_{eva}=7ºC,T_{w2}=85ºC, Effectiveness_HE =0.8, η_c=0.85.

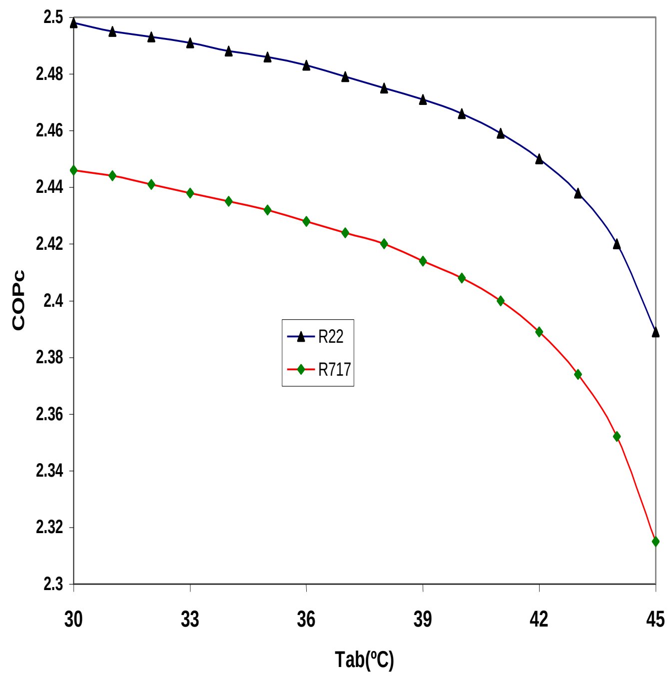

Figure 6: Variation in coefficient of performance with varying absorber temperature for different refrigerants at T_e=- 30°C, T_{w2}=85°C, T_c=35°C, T_{ea}=7ºC, Effectiveness_HE =0.8, η_c=0.85

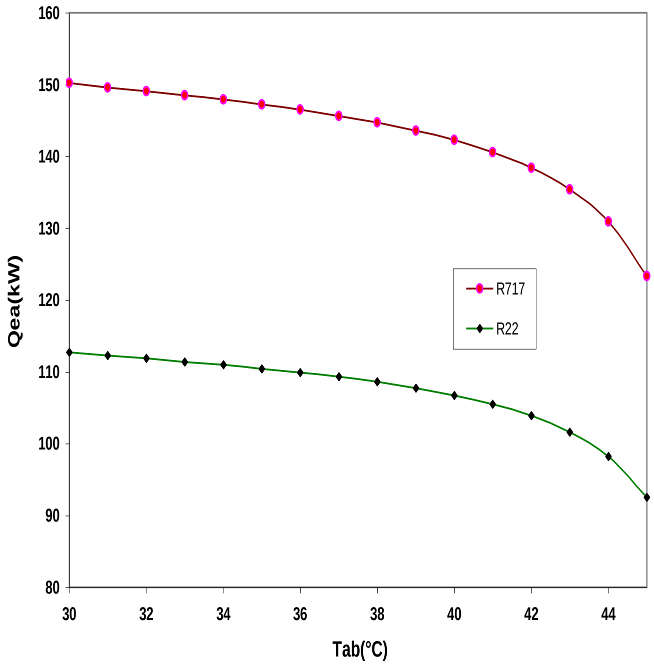

Figure 7: Variation in heat added to evaporator of VAR with varying absorber temperature for different refrigerants at T_{eva} =- 30°C, T_{w2}=85°C, T_{cond}=35°C, T_{ea}=7ºC, Effectiveness_HE =0.8, η_c=0.85.

5. Conclusion

A computer program has been developed and following conclusions were made

(i) Degree of de-superheating (DODS) for different refrigerants like R-717, R-32, R-22, R-600, R-500, R-134A, R-502, R-290, R-114, R-124, R-125 and R-507A, have been computed and the value of first law efficiency in terms of COP of this system is found to be about 2–6

(ii) This increase in COP is about 40% as compared to the vapour compression refrigeration system (VCRS). The cooling capacity (Q_{ea}) is obtained in VARS system is about 150 KW by using the waste heat from superheating horn of a vapour compression refrigeration system (VCRS) system. As inlet water temperature (T_{W2}) to heat exchanger increases, its efficiency also increases slightly. Computed Results from model are better for R-717 (ammonia) as refrigerant as compared to R22.

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