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Theoritical Analysis of Nh_3-H_2o Refrigeration System Coupled With Diesel Engine: A Thermodynamic Study

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Abstract: *In this paper theoretical investigation of NH_3-H_2O refrigeration system running on waste heat extracted from diesel engine has been carried out. Thermodynamic property at each point of the proposed system has been calculated using related equations at that state. Heat transfer rate of various components and various performance parameters are also calculated using first law analysis and applying mass and energy balance. Here variations in generator temperature, condenser temperature, absorber temperature and evaporator temperature are examined and its effect on coefficient of performance and circulation ratio is observed. From the results obtained with the help of EES software and enthalpy concentration diagram of NH_3-H_2O it is observed that with increase in generator temperature coefficient of performance of the system increases and it also increases with increase in evaporator temperature but with increase in condenser and evaporator temperature its starts decreasing. Effect of circulation ratio is also analysed it observed that circulation ratio decreases with increase in generator temperature, evaporator temperature and absorber temperature while it increases with increase in generator temperature.*

Keywords: *generator temperature, evaporator temperature, absorber temperature, diesel engine, exhaust temperature, coefficient of performance, refrigerating effect, first law of thermodynamics, ammonia water absorption system.*

Nomenclature
ARS: Absorption refrigeration system
VCR: Vapour compression refrigeration system
COP: Coefficient of performance
X: Concentration
h : Enthalpy
T_g: Generator temperature
T_e : Evaporator temperature
T_a : Absorber temperature
T_c : Condenser temperature
f : Circulation ratio
m: Mass of refrigerant/absorbent/solution

I. Introduction

Energy is nature's gift to mankind in various forms like conventional and non-conventional forms of energy and we know conventional form of energy like energy obtained from fossil fuels are depleting day by day at a very rapid rate resulting in fuel prices soar as a result diesel engine manufactures are beginning to scout for more energy efficiency solutions. This step will also lead to the energy conservation and sustainable development of the country and for energy conservation best way is to shift towards using more energy efficient technology so this can be achieved by increasing the engine efficiency and developing technologies with low pollution emissions. The increase in diesel engine efficiency can be achieved by vaporizing the waste thermal energy in buses and heavy vehicles, a considerable amount of primary energy may be saved by the valuing the waste heat rejected during the operation of system using absorption refrigeration system, which can be driven by low-potential thermal power, for example, solar energy, geothermal energy and wasted heat, shows potentials of saving energy

Conventionally, vapour compression systems are the common refrigeration systems now days. These systems are powered using electric energy produced through burning of increasingly more expensive fuel like diesel or petro and vapour compression system use ozone-depleting refrigerants such as CFCs and HCFCs. The challenges of environment protection and energy economy have led to a growing interest in non-conventional refrigeration systems such as absorption refrigeration. In fact, in an absorption refrigeration system, the refrigeration effect is produced through the use of two fluids and a heat source rather than electrical input as in the more familiar vapour compression system. Therefore, energy recovered from waste heat streams can provide a considerable part of refrigeration and air conditioning needs at no additional cost. As a result, the use of surplus heat rejected by the main propulsion engine provides substantial fuel savings, involving the reduction of pollutants. The performance of this system affects the attainable amount of energy savings. Improving their performance can be only performed using thermodynamic analysis.

However, approximately 55-65%of the primary energy consumed by the vehicle engine is discharged to the environment as waste heat. Finding out how to effectively employ the waste heat from the vehicle engines thus becomes one of the key projects for vehicle energy saving and environmental protection and we know Absorption systems are heat-operated, so they can greatly contribute to reduce primary energy consumption and environmental pollution if powered by waste heat or renewable energies. They can complete the chain of optimum utilisation of fuel energy pointed out the great advantages of linking absorption systems to waste heat recovery from diesel engines Absorption cycles have been used more and more in recent years because they do not operate with ozone-depleting refrigerants such as CFCs and HCFCs.

Now a day's most popular refrigeration system is vapour absorption and adsorption system as these systems can operate on very low temperature to produce desire refrigeration effect without causing any adverse effect on environment [1]. Because pairs of refrigerant used here are free from CFCs [2]. A suitable working fluid is also very important so many researchers have worked and are still investigating to enhance the performance of ARS [3].

Here in this paper first law analysis has been carried out for the proposed system. Till date several investigations have been done on ARS [1-18] very less researchers have utilized or focused on operating ARS using waste heat of automobiles or I.C engines.

This paper shows a thermodynamic analysis of NH_3–H_2O refrigeration system driven from waste heat of diesel engine or automobile running on CNG like DTC buses for the analysis a model has been developed and useful set of equations are used to calculate property at various points to calculate coefficient of performance and other parameters of the system.

Thus we can say ARS is very advantageous as it runs on waste heat or low grade energy without using environment unfriendly refrigerants but one drawback is that VAS has very low coefficient of performance. Thus in order to achieve high COP thermodynamic analysis have been done in this paper to optimize the various operating conditions as well as we can integrate this refrigeration system with other system where lot of waste heat is available and we are releasing that heat in environment so integrating ARS to fulfill the cooling need of system like automobiles or other system by integrating ARS will obviously increase the overall efficiency of the system despite of its low COP.

II. Approximate Analysis Of Energy Balance Of Diesel Engine

We know that despite of several latest development in the field of I.C engine/Automobiles still the maximum efficiency of I.C. engine is less than 40-45% alternately we can say system is rejecting 55-60% of heat into the atmosphere through exhaust of engine, radiation losses, looses through coolants etc .This clearly indicates amount of energy present in the fuel utilizes and how much is lost. We know during injection of fuel inside combustion chamber a large amount of heat is released at the end of compression to produce power stroke indeed only small fraction of energy is utilize to produce mechanical work so rest of the residual energy discharges at many place during his stay in the cylinder.

For a diesel engine according to first law of thermodynamics

Net heat input = Net heat output

$Q_{input} = \dot{Q}_{radiation} + \dot{Q}_{coolant} + \dot{Q}_{exhaust} + \dot{W}$

Where , Q_{input} = heat supplied to the engine during power stroke.

$\dot{Q}_{radiation}$ = heat transferred to the atmosphere by means of radiation mode of heat transfer.

$\dot{Q}_{exhaust}$ = heat rejected by exhaust gases.

$\dot{W}$ = mechanical work output produce by engine.

A block diagram has been drawn to show energy balance of diesel engine it shows that out of 100% energy input only 45-48% is utilized to produce power rest 52-55% goes in environment as a waste i.e 1-2 % through radiation losses, 23-25% heat goes to coolants while 28-30% goes to environment through exhaust gases. Analysis of heat flows shows that these streams has potential to recovered heat at various temperature levels like through radiation (60-110^{0}C); jacket water temperature (70-90^{0}C); exhaust temperature(200-500^{0}C) etc. This waste heat can be utilized to run absorption refrigeration system.

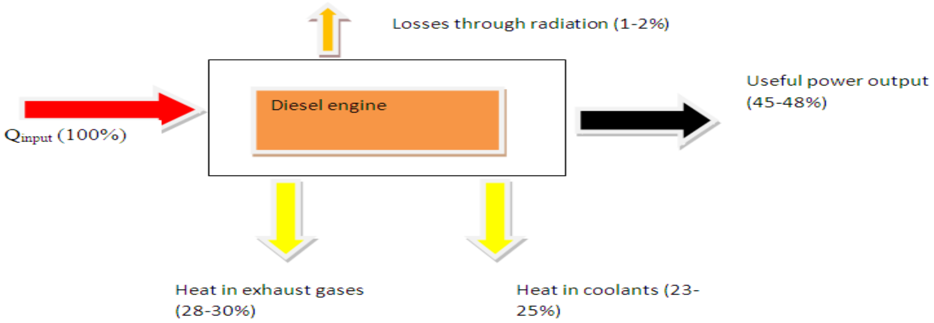


Fig 1 showing heat balance of diesel engine

III. System Description And Its Working

In the system shown in figure 2 Model of NH_3-H_2O single effect refrigeration is shown. In this system evaporator and absorber is maintained at lower pressure level and generator and condenser at higher pressure level. Let's start from absorber, saturated vapour of pure NH_3 at state 5 enters into absorber where ammonia which is working as refrigerant absorbed by solution and refrigerant releases the heat absorbed inside evaporator which is removed by continuous circulation of cooling water and comes out at state 7 then strong solution at state 7 is passed through pump and pumped to generator pressure at state 9 through liquid-liquid heat exchanger. Inside generator solution absorb heat from the waste heat coming out of diesel engine's exhaust, causing refrigerant to vaporise and separate refrigerant from absorbent solution and solution having less concentration of refrigerant returns back to absorber through liquid-liquid heat exchanger. As in case of NH_3-H_2O system vaporize refrigerant contains water along with it so it passes through dephlagmator ,After dephlagmator pure ammonia comes out at state 1 and then it enters into condenser where it rejects heat and condenses and comes out at state 2 then through expansion valve it comes to evaporator at state 4 where it absorbs heat i.e. called refrigerating effect then its converts into vapour and exits at state 5 lower pressure and enters into absorber this process repeats again and again in absorption refrigeration cycle .

IV. Thermodynamic Analysis And Mathematical Model

A Typical NH_3-H_2O refrigeration system as illustrated in Fig.....comprises of generator, pump, evaporator, condenser, absorber and its thermodynamics analysis is done with the help of mass balance, energy balance and composition balance as:

- Mass balance: $\sum m_i = \sum m_e$
- Concentration or composition : $\sum m_i X_i = \sum m_e X_e$
- Energy conservation: $\sum Q - \sum W = \sum m_e h_e - \sum m_i h_i$

Various assumptions have been considered to simplify the equations while analysis of the system, conservation laws of mass and energy have been applied to each component and each component is considered as control volume exchanging heat, work etc other assumptions are:

- Assuming thermodynamic equilibrium at all points while analysis
- Steady state and steady flow is assumed
- Ammonia at the dephglamator and evaporator outlet is assumed to be in saturated vapour state.
- In the condenser, the refrigerant condenses to a saturated liquid state.
- In the evaporator refrigerant evaporates to a saturated state
- Pressure drop due to friction along the fluid flow through system and heat exchanger is assumed to be negligible
- Heat exchange between system and surroundings, other than that prescribed by heat transfer at the generator, evaporator, condenser, and absorber are assumed negligible.

Let m = mass flow of refrigerant kg/min
m_{SS} = mass flow of strong solution kg /min
m_{ws} = mass of weak solution kg/min

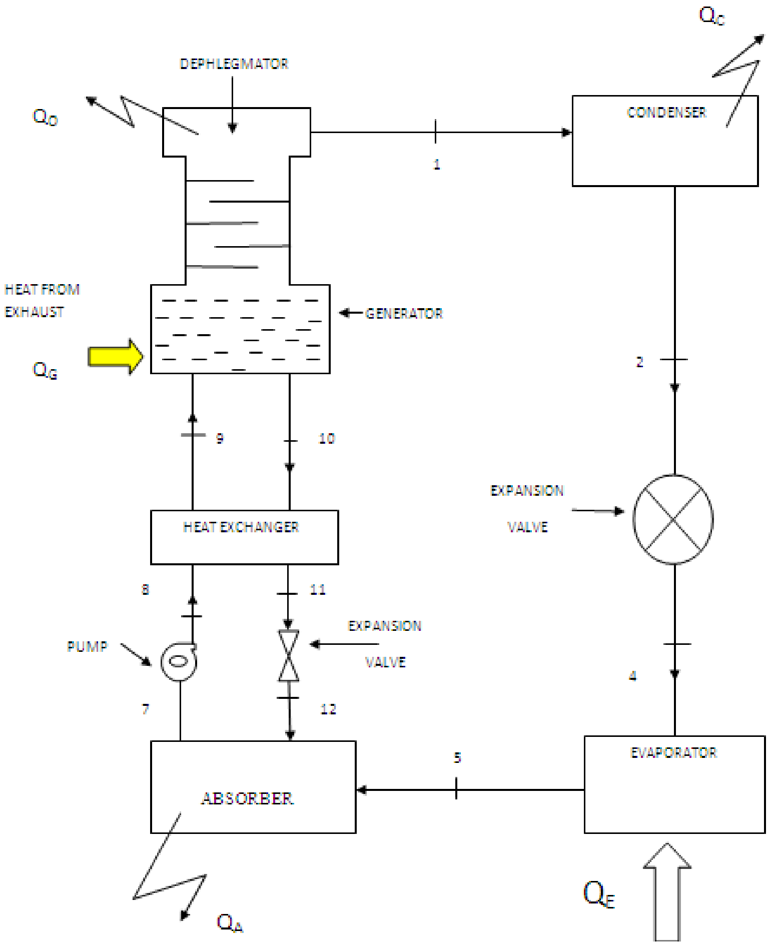


Fig. 1 SCHEMATIC DIAGRAM OF PROPOSED SYSTEM

Condenser

$m_1 = m_2 = m$

$Qc = m (h_7 – h_8)$ kg/min

Expansion value

$m_2 = m_4 = m$

$h_2 = h_4$ (as process is isenthalpic) KJ/kg

Evaporator

$m_4 = m_5 = m$

$Q_e = m(h_5 – h_4)$ KJ/min

Or

$Q_e = (h_5 – h_4)$ KJ/kg vapour

Circulation ratio

$$f = \frac{m_9}{m_1}$$

$m_9 = m_1 + m_{10}$

$m_9X_9 = m_1 + m_{10}X_{10}$

Using above two equations we get

$m_{10} = 1- X_9 / X_9 – X_{10}$

$m_{10} = 1- X_{10} / X_9 – X_{10}$

$m_1 = m_9X_9 – m_{10}X_{10}$

$$f = \frac{m_9}{m_1}$$

Absorber

$Q_a = mh_5 + mfh_{12} – (1+f)mh_7$

Solution pump

$m_7 = m_8 = m_{WS}$

$w_p = (1+f)mV_{solution}(p_c - p_e)$ KJ/min

where $V_{solution} = 7.2 \times 10^{-3}$ m^3/kg

Liquid-liquid solution heat exchanger

$m_2 = m_3$

$m_4 = m_5$

$Q_{HX} = (1 + f)m(h_9 - h_8) = mf(h_{10} - h_{11})$

Generator

$m_9 = m_1 + m_{10}$

Heat input to generator is

$Q_g = m_1 h_1 + m_{10} h_{10} - m_9 h_9$

And finally using the above equations systems performance is measured in terms of coefficient of performance and COP is the ratio of desired effect to the net energy input to the system

Mathematically,

$COP = Q_E / (w_p + Q_g)$

PROCESS SIMULATION

A computer program has been developed using engineering equation solver to solve intensive equations and calculation to calculate value of COP at various operating conditions also enthalpy concentration chart was analysed to get various properties.

Operating parameters used in the analysis summarized in Table 1

Generator temperature	50-130^{0}C
Condenser temperature	20-40^{0}C
Absorber temperature	20-40^{0}C
Heat exchanger effectiveness	0.5-1
Generator pressure=condenser pressure	10 bar
Evaporator pressure = absorber pressure	3.6 bar
Temperature leaving dephlagmator	50^{0}C

Parameters that are fixed in the analysis summarized as Table 2

Generator temperature	90^{0}C
Condenser temperature	25^{0}C
Absorber temperature	25^{0}C
Heat exchanger effectiveness	0.8
Temperature leaving dephlagmator	50^{0}C
Strong solution entering column	75^{0}C
Ton of refrigeration	10

Table 3 Thermodynamic property at each point

State point	Pressure(bar)	Temperature (^{0}C)	Concentration of ammonia per kg of mixture	Enthalpy(KJ/kg)	Flow rate (kg/min)
1	10	50	1	1650	1.76
2	10	25	1	400	1.76
4	3.6	-5	1	400	1.76
5	3.6	10	1	1600	1.76
7	3.6	32	0.39	17	32.32
8	10	32	0.39	17.73	32.32
9	10	75	0.39	230	32.32
10	10	90	0.318	290	30.57
11	10	40	0.318	57.34	30.57
12	3.6	40	0.318	57.34	30.57

V. Result And Discussion

In the paper table 1 shows the range of thermodynamic properties that used in the analysis where table 2 shows the fixed thermodynamic property that is used to calculate the performance of the system whereas table 3 shows Thermodynamic property at each point calculated at various points with the help of software and enthalpy concentration. In this simulation, calculations are performed for 10 ton of cooling load and parameters taken as shown in table 2.

In the table 3 mass flow rate and chemical compositions are provided along with the temperature, concentration, mass flow rate and enthalpy.

From Fig 3 and 4 we can observe that with increase in generator temperature coefficient of performance increases but after certain range it starts decreasing because of increase of irreversibility on the other hand circulation ratio starts decreases rapidly at first than decreases continuously. In the fig 5 &fig 6 we can observe that with increase in condenser pressure coefficient of performance decreases and circulation ratio increases. From fig 7 & 8 we can say that with increase in evaporator temperature coefficient of performance decreases while circulation ratio increases and at last with increase in absorber temperature COP decreases while circulation ratio increases

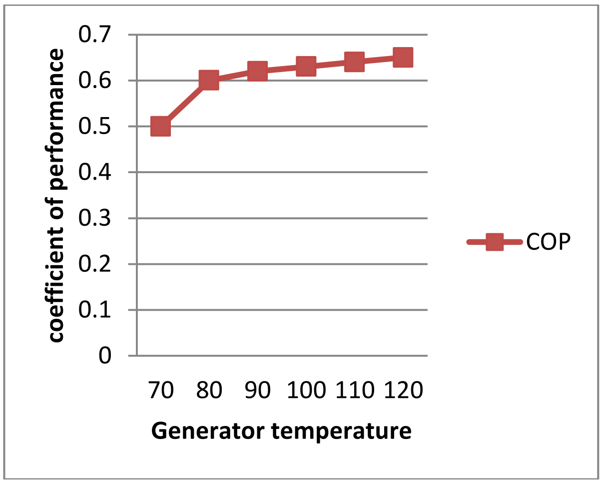


Fig. 3

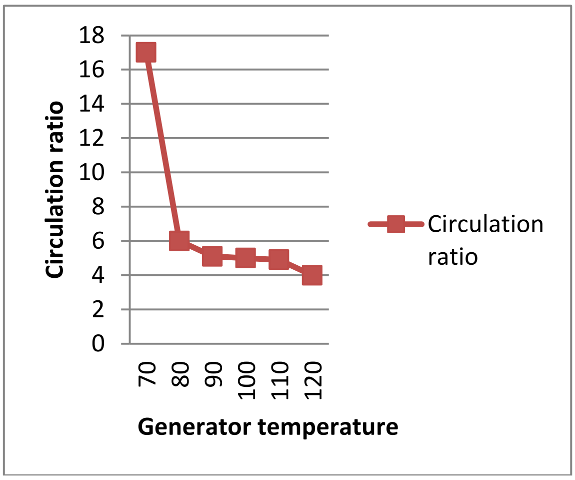


Fig. 4

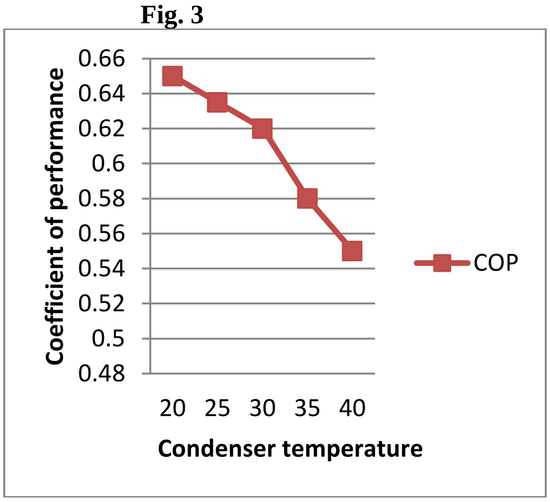
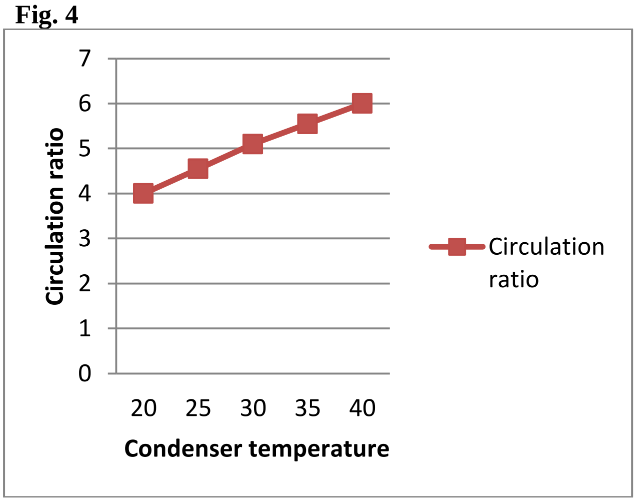


Fig. 5



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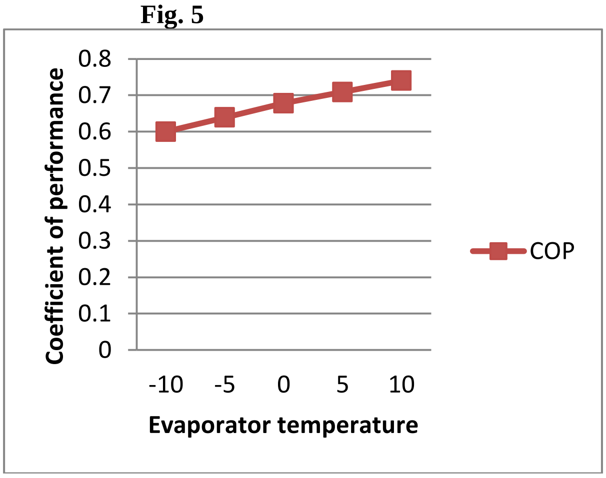

Fig.7

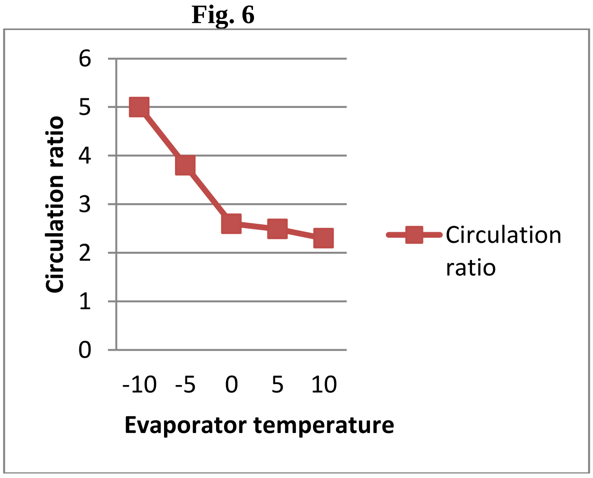

Fig.8

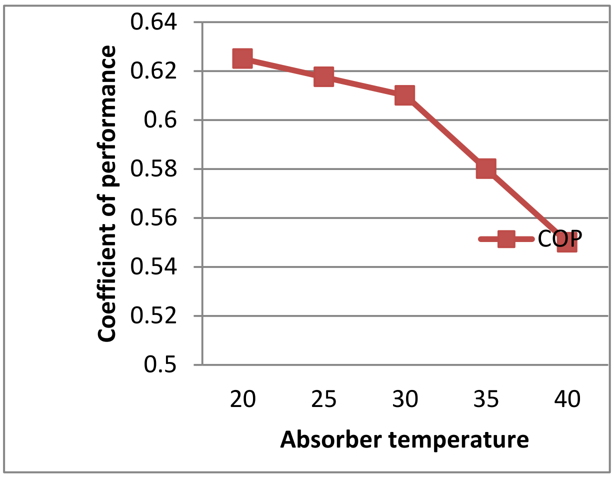

Fig. 9

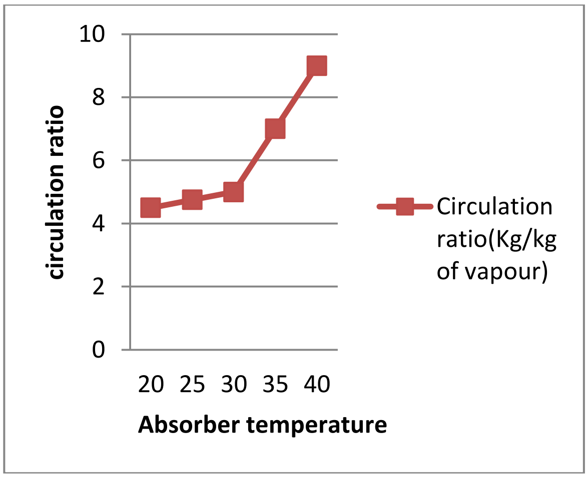

Fig.10

VI. Conclusion

The present study applies first law of thermodynamic using constituted mathematical model to study the performance of single effect ammonia water absorption refrigeration system and we know absorption system's COP is very less but this system seems to be very advantageous when it integrates with diesel engine or CNG engine of DTC buses as that waste heat we can use to produce cooling effect using absorptions system this will definitely increases overall efficiency of engine, On this i will on my next research paper along with second law analysis of system. As COP achieved is very poor so analysis have been done by varying various parameter like generator, evaporator, condenser, absorber temperature and from the above results we can conclude that best performance is at high generator and evaporator temperature whereas circulation will be low at high evaporator and generator temperature and we can conclude parameters optimized for highest performance approximate 0.68 is when generator is maintained at 100^0C,$T_a = 22$,$T_c = 22$ and $T_E = 7^0$C.

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