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Performance Analysis of Lithium-Bromide Water Absorption Refrigeration System Using Waste Heat of Boiler Flue Gases

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***Abstract*— Vapor absorption refrigeration is a low grade thermal input device, which is mostly used along side with industries, which have high thermal waste and also simultaneously requires cooling parts of the plant. For air-conditioning in which refrigeration below 0^0c are not needed, an absorption refrigeration using lithium-bromide and water, has been successfully developed and has achieved great commercial success.**

Owing to the threat of global warming due to high thermal disposal and to compensate the energy crisis, VAR is likely to gain immense prominence in near future. Main theme is to utilize the waste heat of the flue gases generated in thermal power stations. Before leaving these gases to the atmosphere through the chimney necessary mass of flue gases is by passed and is made to deliver it generator so as to run the vapour absorption refrigeration system there by conserving the energy.

The aim of the project is to perform analysis on absorption refrigeration system using lithium-bromide and water as refrigerant and to find out the influence of operating temperatures on the thermal loads of components and their co-efficient of performance. Finally come up with the operating conditions where it can run by effectively utilizing the waste heat of the flue gases.

***Index Terms*— Waste heat recovery, absorption refrigeration, COP of refrigeration**

I. INTRODUCTION

Most of industrial process uses a lot of thermal energy by burning fossil fuel to produce steam or heat for the purpose. After the processes, heat is rejected to the surrounding as waste. This waste heat can be converted to useful refrigeration by using a heat operated refrigeration system, such as an absorption refrigeration cycle. Electricity purchased from utility companies for conventional vapor compression refrigerators can be reduced. The use of heat operated refrigeration systems help 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.

Another difference between absorption systems and conventional vapor compression systems is the working fluid used. Most vapor compression systems commonly use chlorofluorocarbon refrigerants (CFCs), because of their thermo physical properties. It is through the restricted use of CFCs, due to depletion of the ozone layer that will make absorption systems more prominent.

However, although absorption systems seem to provide many advantages, vapor compression systems still dominate all market sectors. In order to promote the use of absorption systems, further development is required to improve their performance and reduce cost.

The absorption system differs fundamentally from VCR system in the method employed for compressing the refrigeration. In the absorption system, the compressor is replaced by the combination of an absorber, a generator, and a pump.

LiBr/water absorption refrigeration system

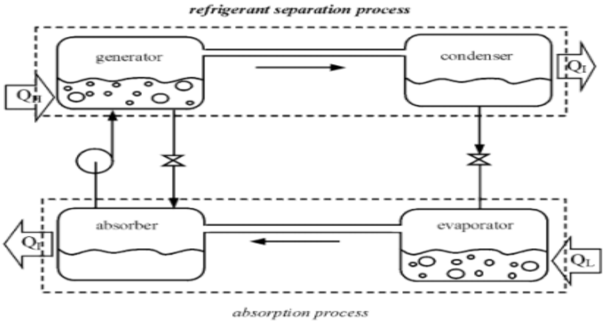

*Fig.1:. Processes of absorption refrigeration cycle***.**

The combination called aqua ammonia was used in absorption systems years before LiBr-water combination become popular. The absorption systems have experienced many ups and downs. The absorption was the predecessor of the vapour compression system in 19th century and aqua- ammonia system enjoyed wide applications In domestic refrigerators and large industrial installations in the chemical and process industries. The LiBr-water system was commercialized in the middle of the 20th century as water chillers for large buildings air-conditioning.

In the LiBr-water system water is the refrigerant. This imposes restriction on its use for applications requiring temperatures below 0^oc.And the LiBr being a salt has a re-crystallization zone when it becomes solid and hence imposes flow restrictions .The vapour absorption system practically LiBr-water system has bounced back with the use of solar energy and the recent emphasis on co-generation which makes available, the otherwise waste heat , for external direct heating source in vapour absorption system

The analysis of this system is relatively easy as the vapour generated in the generator is almost pure refrigerant (water), unlike ammonia-water systems where both ammonia and

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water vapour are generated in the generator.

II. OBJECTIVE OF INVESTIGATION

- The aim of the project is to perform analysis on absorption refrigeration system using lithium-bromide and water as refrigerant and to find out the influence of operating temperatures on the thermal loads of components and their co-efficient of performance.
- Finally come up with the operating conditions where it can run by effectively utilizing the waste heat of the flue gases.

III. DESIGN OF ABSORPTION REFRIGERATION CYCLE (SINGLE-EFFECT ABSORPTION SYSTEM)

A single-effect absorption refrigeration system is the simplest and most commonly used design. There are two design configurations depending on the working fluids used. Single-effect system using non-volatility absorbent such as LiBr/water. A single-effect LiBr/water absorption refrigeration system with a solution heat exchanger (HX) that helps decrease heat input at the generator

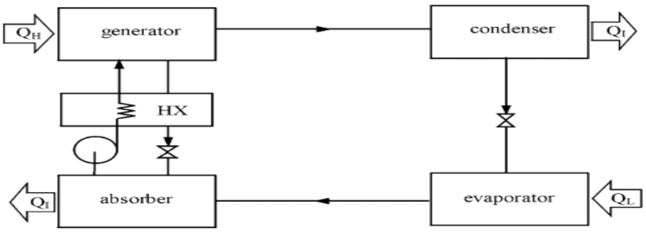


Fig 2:.. A single-effect LiBr/water absorption cycle

High temperature heat supplied to the generator is used to evaporate refrigerant out from the solution (rejected out to the surroundings at the condenser) and is used to heat the solution from the absorber temperature (rejected out to the surroundings at the absorber). Thus, irreversibility is caused as high temperature heat at the generator is wasted out at the absorber and the condenser. In order to reduce this irreversibility, a solution heat exchange is introduced as show in Fig.2.

The heat exchanger allows the solution from the absorber to be preheated before entering the generator by using the heat from the hot solution leaving the generator. Therefore, the COP is improved as the heat input at the generator is reduced. Moreover, the size of the absorber can be reduced as less heat is rejected. Experimental studies shows that COP can be increased up to 60% when a solution heat exchanger is used.
When volatility absorbent such as water/NH3 is used, the system requires an extra component called “a rectifier”, which will purify the refrigerant before entering the condenser. As the absorbent used (water) is highly volatile, it will be evaporated together with ammonia (refrigerant). Without the rectifier, this water will be condensed and accumulate inside the evaporator, causing the performance to drop.
Even if the most common working fluids used are LiBr/water and water/NH3, various researchers have studied performance of a single-effect absorption system using other kinds of working fluids such as LiNO3/NH3,LiBr+ZnBr2/CH3OH, LiNO3+KNO3+NaNO3/water , LiCl/water, Glycerol/water.

IV. IMPROVING OF ABSORPTION PROCESS

An absorber is the most critical component of any absorption refrigeration system. Experimental study shows that the solution circulation ratio (solution circulation rate per unit of refrigerant generated) is found 2 to 5 times greater than the theoretical value. This is due to a non-equilibrium state of solution in the absorber. For given temperature and pressure in the absorber, the solution absorbs fewer refrigerants than that of the theoretical value. Many researches have been conducted in order to understand and to improve an absorption process between the vapor refrigerant and the solution. The most common type of absorber used for LiBr/water system is absorption of vapor refrigerant into a falling film of solution over cooled horizontal tubes. In this type of absorber, during the absorption process, heat is simultaneously removed from the liquid film. Hence, the absorption rate is increased.
However, this design requires a high recirculation rate in order to achieve a good performance. Another notable approach devised is absorption of vapor refrigerant into liquid film on cooled rotating discs. For a given surface area, absorption rate on rotating discs is much greater than that on a convention design.
Thus, size of an absorber used based on this design is much smaller than a convention falling film design. Absorption process within a rotating drum was also studied. For water/NH3, literatures on absorber designs are also provided.

V. HEAT SOURCE UTILIZED FOR ANALYSIS

From the layout it can be observed that the flue gases obtained due to the burning of the fuel which after passing through , air-pre heater , electro-static precipitator , still contains some heat energy , which is left to the atmosphere unused .Instead this heat energy is utilized as an excellent heat source in the generator of the vapour absorption refrigeration system.

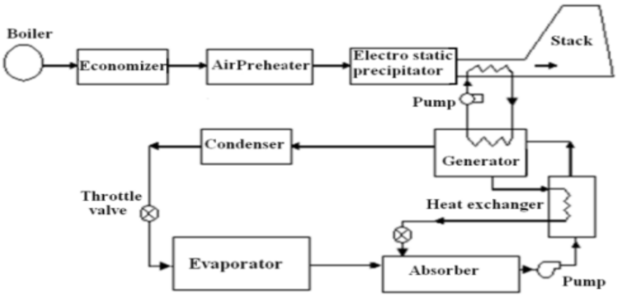


Fig3:..Proposed layout for refrigeration system

The flue gases after passing through the Electrostatic precipitator starts passing towards the stack .Partial heat of this flue gases is apt to the required refrigeration effect is collected using a heat exchanger .

This heated water extracting heat from the flue gases is passed to the generator of the vapour absorption refrigeration system and act as a heat source, and liberates the water vapour from LiBr-water solution which comes into generator .The water vapour evolved in the generator is then passed through the condenser to change the phase and then it is expanded in the expansion valve .Finally it is passed through the evaporator where the refrigerating effect is obtained. The water gains the latent heat of vaporization from the evaporator and changes its state into water vapour. This water vapour is finally absorbed in the absorber to form LiBr-water solution and the cycle is repeated. Thus the energy is conserved.

VI. C.O.P OF THE THEORETICAL ABSORPTION REFRIGERATING SYSTEM

1) Circulation ratio:

Circulation ratio is defined as the ratio of mass flow rate of the solution coming from generator to the absorber to mass flow rate of the working fluid.

Circulation ratio (CR) = $\frac{Xw}{Xs - Xw}$

2) Heat loads (Q)
3) The components Heat loads of the refrigerating system per unit of refrigerant mass are expressed as
4) Heat absorbed in evaporator Qev= h4- h3
5) Heat rejected in the condenser Qco= h1 -h2
6) Heat rejected in the absorber Qab= h4 –h5+CR (h10 –h5)
7) Heat supplied in the generator from the heat source Qge= h1–h7+CR (h8–h7)
8) C.O.P:
9) It is defined as the ratio of the refrigerating effect to the work input to the system.
10) Co-efficient of performance $C.O.P = \frac{Q_{ev}}{Q_{ge} + w_p}$

But Wp =0

Co-efficient of performance

$$C.O.P = \frac{(h_4 - h_3)}{(h_1 - h_7) + CR\ (h_8 - h_7)}$$

From the equation the major parameters which affect the C.O.P are the latent heat of vaporization and the circulation ratio.

When $(h_4 - h_3)$ increases, the C.O.P increases and when the circulation ratio increases, the C.O.P decreases

Here $h_{1, 2, 3....}$ are enthalpies in kJ/kg

X_w is concentration of weak solution

X_s is concentration of strong solution

$Q_{ab, ev, co,ge}$ are the components heat loads per unit mass of refrigerant.

A) Variation of C.O.P and heat loads with the generator temperature at 2°c evaporator temperature

Evaporator temperature=T_E=2°c

Condenser temperature =TC=30°c

Absorber temperature =TA=30oc

Varying generator temperature TG

From refrigeration tables

PE=5.28mm of Hg= 0.00705 bar

P_C=31.82 mm of Hg=0.04246bar

h_2=125.7 kJ/kg =Enthalpy of saturated water liquid at 30°c

h2=h3 (Throttling process)

h4=2505.2 kJ/kg =Enthalpy of saturated water vapour at 2°c

$h_1= h_{2\ (g)} +1.87(T_G-T_C)$

From Enthalpy- concentration chart

h_5=180 kJ/kg =Point of intersection of evaporator pressure and absorber temperature

$h_5=h_6$ (pump work =0)

$h_6=h_7$

X_5 or X_w= 0.57

$X_5 =X_6= X_7$

h_8=-110 kJ/kg = Point of intersection of condenser pressure and generator temperature

h_9,h_{10}=intersection of h_8 line

X_s or $X_{8, 9, 10}$= 0.58

State points	Pressure in mm of Hg	Temperature in 0c	Concentration c kg Li-br/kg mix	Enthalpy in kJ/kg
1	31.82	55	0	2621.9
2	31.82	30	0	125.7
3	5.28	2	0	125.7
4	5.28	2	0	2505.2
5	5.28	30	0.57	-180
6	31.82	30	0.57	-180
7	31.82	55	0.57	-180
8	31.82	65	0.58	-110
9	31.82	45	0.58	-110
10	5.28	---	0.58	-110

Table.1.Enthalpies for state points with Generator temperature

Heat loads of the components per unit of refrigerant mass:

Heat absorbed in evaporator $Q_{ev}= h_4- h_3$

Q_{ev}=2505.2-125.7

Q_{ev}= 2376.5 kJ/kg

Heat rejected in the condenser $Q_{co}= h_1 -h_2$

Q_{co}=2621.93-125.7

Q_{co}= 2496.23 kJ/kg

Heat rejected in the absorber $Q_{ab}= h_4 –h_5+CR (h_{10} –h_5)$

Q_{ab}=2505.2-(-180)+57(-110-(-180))

Q_{ab}=6672.2 kJ/kg

Heat supplied in the generator from the heat source $Q_{ge}= h_1 –h_7+CR (h_8 –h_7)$

Q_{ge}=2621.93-(-180) +57(-110-(-180))

Q_{ge}=6791.93 kJ/kg

Circulation ratio (CR) = $\frac{Xw}{Xs - Xw}$

$$= \frac{0.57}{0.58 - 0.57} = 57$$

Co-efficient of performance $C.O.P = \frac{Q_{ev}}{Q_{ge} + w_p}$

$$= \frac{2376.5}{6791.3}$$

$$C.O.P = 0.35$$

Generator temperature T_G in °c T_G in °c	C.O.P	CR
65	0.35	57
70	0.55	19
75	0.63	10.4
80	0.66	7.125
85	0.69	5.43
90	0.69	4.4

Table.2.Variation of C.O.P and CR with Generator temperature

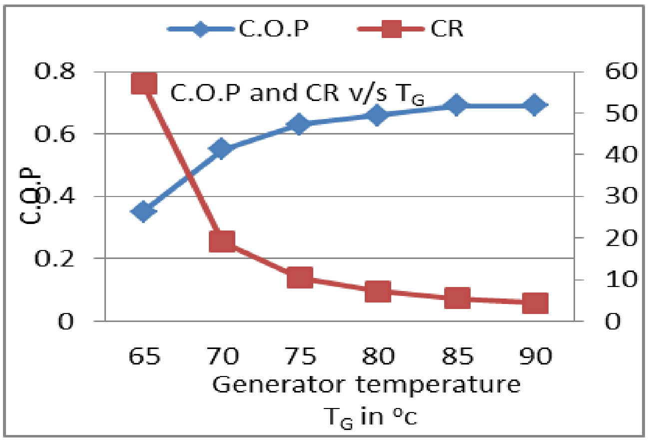
Generator temperature T_G in °c	Heat load in evaporator Q_{ev} in kJ/kg	Heat load in condenser Q_{co} in kJ/kg	Heat load in absorber Q_{ab} in kJ/kg	Heat load in generator Q_{ge} in kJ/kg
65	2376.5	2496.23	6672.2	6791.93
70	2376.5	2505.6	4202.2	4331.3
75	2376.5	2514.9	3649.4	3787.8
80	2376.5	2524.3	3430.32	3578.14
85	2376.5	2533.7	3306.6	3463.8
90	2376.5	2543.04	3298.2	3455.9

Table.3.Variation of Heat loads with Generator temperature

Similarly repeating the same and analyzed the variation of C.O.P and heat loads with variation of generator temperature, variation of evaporator temperature, variation of condenser temperature and variation of absorber temperature.

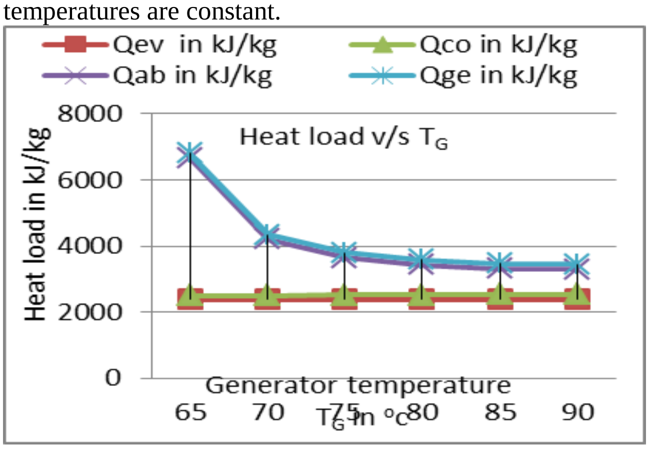
VII. RESULTS AND DISCUSSIONS

The change in the C.O.P with the generator temperature is shown in the graph 1. A considerable decrease of 52 in the circulation ratio is observed due to the increase in the concentration of solution leaving the generator with the increase generator temperature of 35°c. This causes a rise in the C.O.P by 0.34 due to the fact that C.O.P increases with the decrease in circulation ratio.



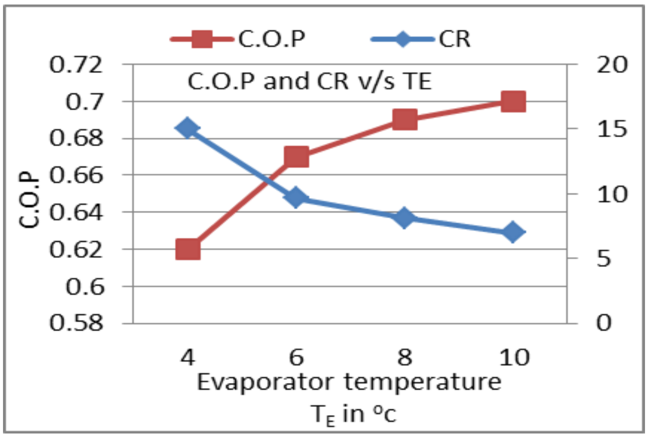
Graph1: C.O.P and CR v/s T_G

A comparison of heat loads of different components with the varying generator temperature is shown in graph 2. The generator temperature rise by 25°c causes a decrease of 3374kJ/kg in absorber and 3336.03kJ/kg in generator heat load. Whereas the evaporator heat load and condenser heat load remains constant since evaporator and condenser temperatures are constant.



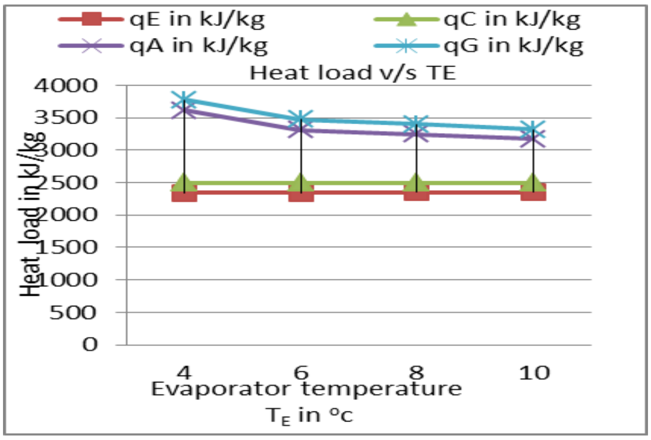
Graph 2: Heat loads v/s T_G

Graph 3 shows the change in the C.O.P with the evaporator temperature. A considerable decrease of 8 in the circulation ratio is observed with the increase in evaporator temperature by 6°c. It causes a rise in the C.O.P 0.08 due to the fact that C.O.P increases with the decrease in circulation ratio.



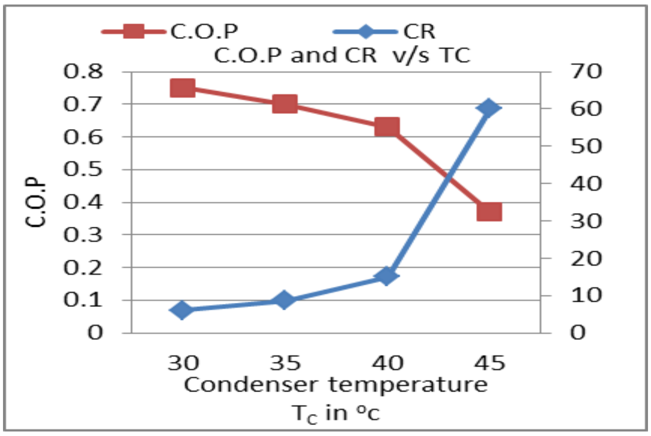
Graph 3: C.O.P and CRv/s T_E

A comparison of heat loads of different components with the varying evaporator temperature is shown in graph 4. The evaporator temperature rise by 6°c causes a decrease of 441kJ/kg in absorber and 452kJ/kg in generator heat load. A small amount of 10 kJ/kg increase in the evaporator heat load is observed, where as Condenser heat load remains constant.



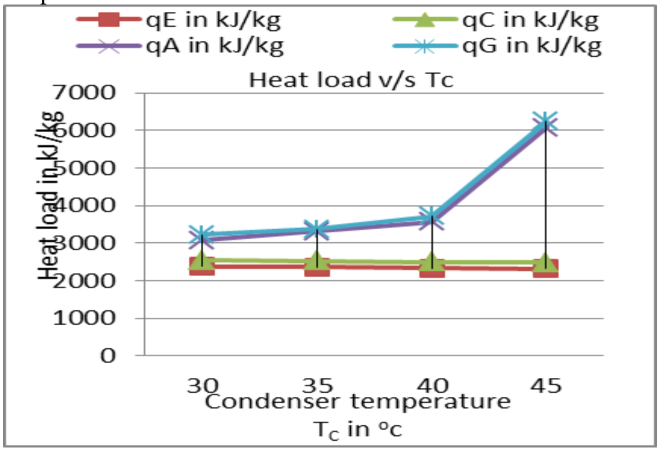
Graph 4: Heat loads v/s T_E

The graph 5 shows the variation of C.O.P and circulation ratio with the condenser temperature .It is observed that the C.O.P value decreases by 0.38 with the increase in condenser temperature 15°c, since there is a increase of 54 in circulation ratio.



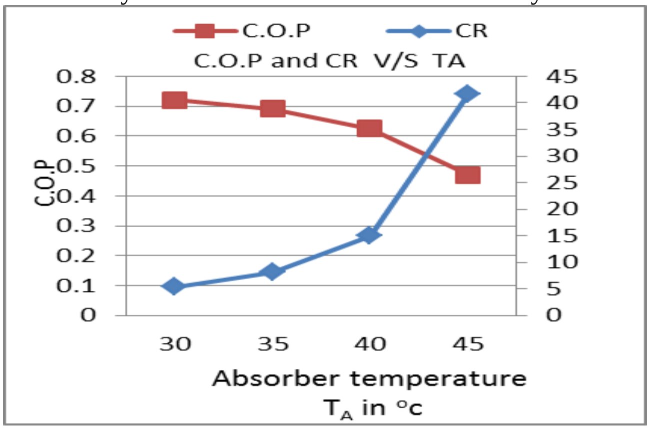
Graph 5: C.O.P and CR v/s T_C

Comparisons of heat loads of different components with the varying condenser temperature is shown in graph 6. When the condenser temperature increases by 15°c causes the increase in circulation ratio by 56, In this case both the generator and absorber heat loads increases by 3002.3kJ/kg and 3003.5kJ/kg. The enthalpy of saturated liquid increases with increase of condenser temperature. Thus it causes a decrease of 63.8kJ/kg and 62.66kJ/kg in the condenser and evaporator heat loads.



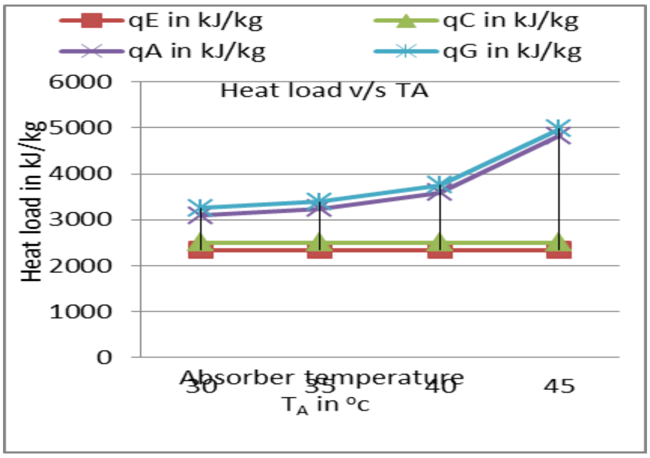
Graph 6: Heat loads v/s T_C

Variation of C.O.P and circulation ratio with absorber temperature is shown in graph 7. It can be seen that C.O.P decereases with theincerease in absorber temperature.The concentration of weak solution increases with incerease in absorber temperature of 15°c and causes circulation ratio to increases by 36 and therfore C.O.P to decerases by 0.23.



Graph 7: C.O.P and CR v/s T_A

Comparison of heat loads of different components with the varying absorber temperature is shown in graph 8. By increasing the absorber temperature to 15 °c, the concentration of strong solution decreases. This causes increase in the generator and absorber heat loads by 1731.3kJ/kg and1729.1kJ/kg respectively. However the heat loads of the condenser and evaporator remains constant. Since the evaporator and condenser temperatures are constant.



Graph 8: Heat loads v/s T_A

CONCLUSIONS

- The heat load on the generator decreases by 3336.03kJ/kg with the increase in generator temperature of 25°c and 452kJ/kg with the increase in evaporator temperature of 6 °c. This decrease in generator heat load causes the increase of C.O.P value by 0.34, when the generator temperature is increased by 35°c and 0.08 with the increase in evaporator temperature of 6 °c.
- The heat load on the generator increases by 3002.3kJ/kg as the condenser temperature increased by 15oc and 1731.3kJ/kg as absorber temperature increased by 15oc. The increase in the generator heat load decreases the C.O.P value by 0.38, when the condenser temperature is increased by 15oc and 0.23 when the absorber temperature is increased by 15oc.
- Thus this analysis provides that the operating temperatures of condenser and absorber has to be maintained less than 40oc, evaporator temperature has

to be more than 10oc and the generator temperature not exceeding 85oc, so as to run the absorption system efficiently during the utilization of heat from the waste flue gases and provide cooling effect in the boiler control room and therefore conserving the energy.

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