Efficiency Enhancement of a Vacuum Absorption Machine in Chilled Water Plant

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Abstract: ***The existing chiller plant in Visakhapatnam steel plant which is based on vapour absorption system is integrated with steam control that is operated on drain control system with pneumatically controlled valve, one heat exchanger, vacuum without purge tank and two solution pumps. This system has the capacity of 1000TR (each chiller) that requires 1050Cu.M/Hr/Chiller service water and uses 22KW power continuous rating. This project is focused on enhancement of efficiency of the existing vacuum absorption machine by re designing the chiller with certain modifications, fabricating and comparing the results of old and new chillers. From industrial point of view the requirement of service water and consumption of power is to be reduced. For achieving the above requirement modifications include addition of heat reclaimer, vacuum system with purge tank for removal of dissolved gases, removal of a solution pump, drain (steam) control is changed to inlet control system with Auto controlled valve and auto level controllers.***

Keywords: chiller plant, heat reclaimer, purge tank, Vishakhapatnam steel plant.

1. Introduction

Visakhapatnam Steel Plant is the largest single location shore based steel plant in India is located 16km south west of city of destiny i.e., Visakhapatnam. Bestowed with modern technologies, VSP has capacity of 3.4 to 6.3 million tons per annum of liquid steel and 2.6 million tons of saleable steel. It has wide areas where ventilation and air-conditioning is required. For satisfying the requirement chiller plants are made as a part of the plant. Presently they are using both vapour compression system and vapour absorption system according to the requirement.

Refrigeration and air conditioning plays a vital role in present industrial applications. Compared to vapour compression system vapour absorption systems are more reliable as since they are relatively In expensive and well established. Therefore enhancing the efficiency of VAM is receiving repeated emphasis. Along with cop major areas in which industrial researches are concentrating is on decrease in power consumption and service water requirement. Since vapour absorption system run on low grade energy they are preferred when there is availability of waste heat and solar energy those comes under low grade heat sources.

2. Existing System

2.1 Introduction for Old Chiller Plant

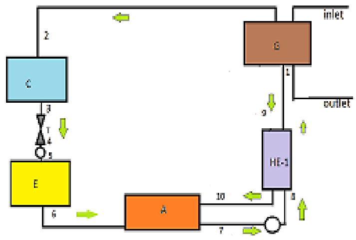
The existing absorption chillers are designed in such a way that a single shell is divided into two sections upper section and lower section. Evaporator and absorber are fitted as two tube bundles in lower section which are operating at pressures in order of 7mmHg (1/100 atmosphere) and the upper section also contains two tube bundles the generator and the condenser operating at pressures in the order of 70 mmHg absolute (1/10 atmosphere). Each tube bundle has its own set of pass heads. In addition, there are two solution pumps, one refrigerant pump, and a heat exchanger. A purge system and control panel completes the unit.

The operation is based on two factors- a refrigerant ie water that boils at low temperature below that of the liquid being chilled, and an absorbent (Li-Br) having greater affinity for refrigerant (water). Liquid to be cooled is allowed to pass through the evaporator tubes which give its latent heat to the refrigerant flowing over the tubes. This heat causes the refrigerant to evaporate since it is at a pressure with a corresponding boiling temperature lower than the departing chilled water temperature.

Refrigerant vapour from the evaporator is attracted and absorbed by an intermediate concentration of Li-Br solution flowing over the outside of the absorber tubes. The dilute solution from the bottom of the absorber is pumped by the solution pump, through the heat exchanger where it is regeneratively heated by the hot concentrated solution- to the generator. The dilute solution flows over the outside of the generator tubes. A portion of the refrigerant in the solution is vaporized by the steam or hot water in the generator tubes, thus concentrating the solution.

Concentrated solution flows by gravity and pressure differential through heat exchanger- where it is cooled re-generatively by cold dilute solution to the mixing pipe. The heat exchanger has thus improved efficiency of the cycle by reducing the steam or hot water required to the dilute solution.

An intermediate solution, consisting of a mixture of concentrated solution from the liquid heat exchanger-together with dilute solution from the solution pump- is re circulated over the absorber tubes through the distribution system. Refrigerant vapour released from the dilute solution in the generator is condensed on the condenser tubes by giving up its heat of condensation to cooling water passing through the tubes. This cooling water is the same water that has been previously used to cool the absorber. Condensed refrigerant flows by gravity and pressure differential through a restrictor to the evaporator. This refrigerant and that re-circulated by the refrigerant pump is distributed over the evaporator tubes.Capacity of the unit is simply, accurately and automatically controlled from the temperature of the chilled water leaving the evaporator. A thermostat positions the control valve to meter condensate or hot water flow to the generator.



2.2. Construction

The horizontal shell-and-tube construction of absorption chiller, consists four major components: the evaporator, the absorber, the generator, and the condenser; and these tube bundle components are housed in single shell. The shell is bi-sectioned, in the upper section consists of the tube bundles of the generator and the condenser, and in the lower half section consists of the tube bundles of the evaporator and the absorber.

The solution heat exchanger is of shell-and-tube construction, and housed in a partition in the lower half section of the chiller unit shell.

2.2.1 Evaporator

Refrigerant water, which is led into the evaporator sump tank, is sprayed by a refrigerant pump , through nozzles , over the evaporator tube bundle . as the temperature of incoming chilled water , which passes through evaporator tubes , is higher than that of refrigerant, heat from the chilled water is imparted to refrigerant water covering immediate outside surfaces of the tube bundle causing refrigerant water to transfer heat the refrigerant vapour is led to the absorber by the way of eliminators.

2.2.2 Absorber

Temperature and concentration of LiBr solution are designed to maintain the pressure in absorber a little lower than in the evaporator so that the refrigerant flows continuously from the evaporator to the absorber, where the vapour is absorbed in the LiBr absorbent solution.

When the evaporator is absorbed into the solution, diluting heat and condensing latent heat are imparted to the cooling water flowing through the absorber tubes.

Since the absorbing process takes place on the surface of the tubes, special nozzles are provided to ensure uniform spray of the solution over the tube surfaces.

2.2.3 Solution Heat Exchanger

The solution heat exchanger is a small partition in the lower half of the section of the unit shell, and heat exchanging process takes place between the concentrated solution and the dilute solution.

2.2.4 Generator

Heat energy (steam or hot water) is consumed in the generator to boil refrigerant water out of the dilute solution. The concentrated LiBr solution flows, by gravity and pressure differential, to the absorber from the generator through the solution heat exchanger.

2.2.5 Condensor

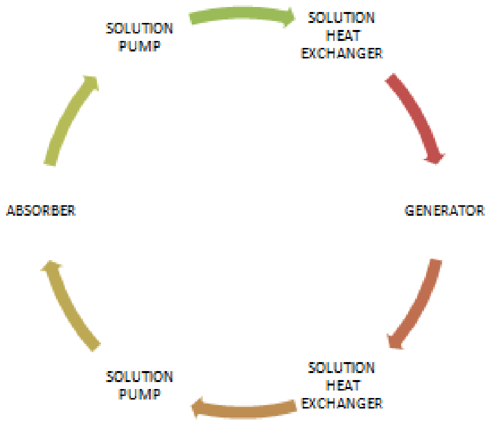
Refrigerant vapour generated in the generator flows to the condenser through the eliminators, and the liquid refrigerant flows into the evaporator sump tank through the adjustment orifice provided at the bottom of the condenser.

2.2.6 Heat Exchanger By-Pass Pipe

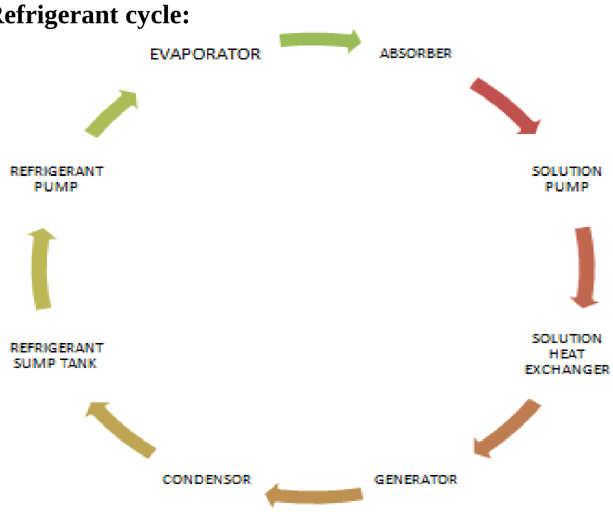
A pipe by-passing the solution heat exchanger is provided connecting generator and the bottom of the absorber. This by- pass pipe is for diverting overflow of the concentrated solution in the generator to the absorber without passing through the solution heat exchanger. While this provision is to maintain pre-determined level of solution in the generator, it is to serve the following important functions:

If and when crystallization, down flow pipe of the concentrated solution in the heat exchanger is clogged up, the concentrated solution is directly led into the absorber by the by-pass pipe with a resultant rise in temperature of the dilute solution going up to the generator through the heat exchanger; and this will help for de- crystallizing the clogged pipe.

LiBr cycle:



Refrigerant cycle:



2.2.7 Coefficient Of Performance(COP):
Tg=90ºC=363K,Tc=60ºC=333K, Te=5ºC=278K
COP = (Th-Tk/Th)*(Tc/Tk-Tc)
= (Tg-Tc/Tg)*(Te/Tc -Te)
= (363-333/363)*(278/333-278)
= 0.42

3. Proposed System

3.1.1 Due to drain control system: Thermal hammering is taking place leading to vibrations in the system. & causing pipe line failures, and then leads to Machine Shut down. Li-Br solution crystallizes when exposed to higher temperature but due to drain control system sometimes high temp steam is coming in contact with Li-Br troubling the system
Present technology is introducing a *control valve at the inlet.*

3.1.2. Introduction of *purge system:* for removal of dissolved gases.

3.1.3. *heat-reclaimer* is added in the cycle in order to enhance the efficiency by pre heat the dilute solution entering into the generator by using waste heat recovery system.(still cycle has to be designed).

3.2. Basic Principles

The boiling point of water is directly proportional to the pressure. At atmospheric pressure water boils at 100c. At lower pressure it boils at lower temperature. At 6mm of Hg absolute pressure the boiling point of water is 3.7c. to change water from liquid to vapour it has to be heated. However it rises until it reaches a point where the temperature stays constant and it starts boiling .ie. the liquid water vaporizes. This point is called boiling point. At this point all heat absorbed by the water doesn't change the temperature of the water but only its phase. This heat required to change the phase of a liquid to vapour, is called the Latent of vaporization. Similarly the heat is rejected by the vapour when it condenses is called latent heat of condensation.

LiBr is a chemical similar to common salt (NaCl). LiBr is soluble in water. It has a property to absorb water due to its chemical affinity. As the concentration of LiBr increase its affinity increases. Also as the temperature of Li-Br decreases its affinity increases. Furthermore there is a large difference between vapour pressure of Li-Br and water. This means if we heat Li-Br water solution, the water will vaporize but Li-Br will stay in the solution and become concentrated.

3.3Modes of Operation

The vapour absorption machine functions in two modes:
1. Cooling mode.
2. Simultaneously heating cooling mode.

3.4 Individual Parts

3.4.1 Evaporator

The evaporator consists of a tube bundle, an outer shell, distribution trays and a refrigerant pan. The chilled water flows inside the tubes. A refrigerant pump circulates the refrigerant pan into distribution trays. From trays the refrigerants falls on the evaporator tubes. The shell pressure is very low(~6mmof Hg).at this pressure the refrigerant evaporates at low temperature (~3.7c) and extracts latent heat of evaporation from the water (Chilled water) being circulated through the evaporated tubes. Thus the water being circulated through the tubes become diluted.

3.4.2. Absorber

The absorber consists of tube bundle an outer shell(common with the evaporator), distribution trays, and an absorbent collection sump. Concentrated absorbent solution from the low temperature generator is fed into the distribution trays. This solution falls on the absorber tubes. Concentrated absorbent has an affinity to water. Hence the vaporized section from the evaporator is absorbed.Due to this absorption the vacuum in the shell is maintained at low pressure and ensures the correct chilled water temperature. The concentrated absorbent becomes diluted. During this dilution the heat of dilution is generated. This increases the temperature of the absorbent solution. This heat is removed by cooling water circulated in the tubes. As the absorbent solution loses its heat to the cooling water it increases its affinity of absorbing more refrigerant vapour, and gets further diluted. The diluted absorbent collects in the bottom of the shell.

3.4.3Heat Exchanger

The cool and diluted absorbent is pumped to the generator by absorbent pump. It is first passed through the heat exchanger where it absorbs heat from the concentrated absorbent.

3.4.4 Heat Reclaimer

Then the dilute solution enters into the heat reclaimer, where it gets heated by the steam condensate coming from the generator. The solution then enters the generator. These heat exchangers serve to heat up the cool absorbent solution before it enters the generator for re-concentration. This reduces the heat input in generator. This reduction in the energy input required increase the efficiency of cycle.

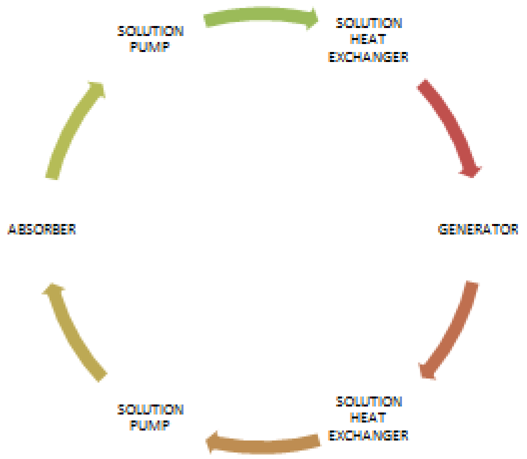
3.4.5. Generator

The generator and condenser tube bundles are enclosed in a shell and are separated by an insulation plate. The generator consists of a shell and tube heat exchanger. Heat is supplied to it by means of steam. The diluted absorbent surrounds these tubes and is heated. The temperature of the solution increases until it reaches its boiling point. The refrigerant boils out of the solution. The solution concentration increases. The concentrated absorbent drains to the absorber to begin a new absorbent cycle. The vaporized refrigerant generated passes to the eliminators and goes to the condenser.

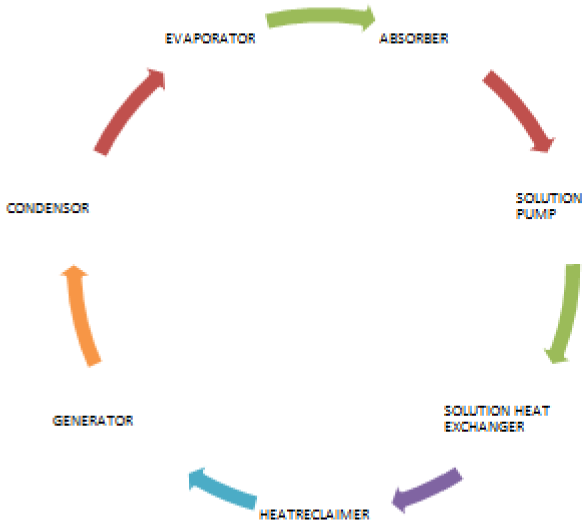
3.4.6. Condenser

Refrigerant vaporized from the absorbent in the generator passes through the eliminators to the condenser. Here the cooling water entering the absorber which flows in the condenser tubes condenses all these refrigerant vapors. The refrigerant vapour condenses on the outside of the condenser tubes, heating the cooling water, and collects in the bottom of the condenser. The condensed refrigerant flows to the evaporator.

LiBr cycle:

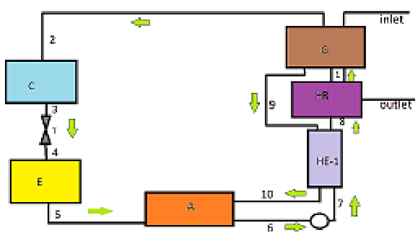


Refrigerant cycle:



3.5 Thermodynamic Analysis of the System

When there is transfer of fluids through four important components of a refrigeration system as shown in fig. ie through evaporator, absorber, generator and condenser. These chillers use either hot water or low pressure steam as input source of heat. As the system is kept at partial vacuum the water obtained the ability to extract heat in the evaporator and evaporate. But the thermal efficiency is stumpy. due to low efficiency even it is a sound technology it is used only where waste heat is available in ample quantities. . Single-effect chillers can be used to generate chilled water for air conditioning and for cooling process water, and are generally accessible in capacities from 7.5 to 1,500 tons.



3.5.1. Theoretical COP

Assumptions:

Only refrigerant boils in the generator.

No pressure drop due to friction.

Steady state and steady flow.

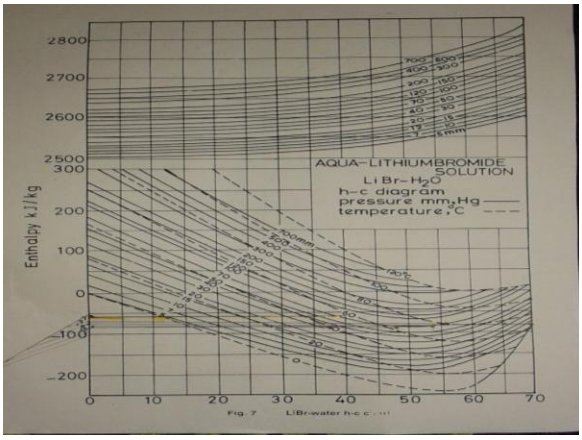
Let m= mass flow rate of refrigerant, Kg/s

mss= mass flow rate of strong solution

mws= mass flow rate of weak solution.

Required output is 1000 tons = 3500kW.

Therefore refrigeration effect = 3500kW.



- **Evaporator:**
  - Qe = Refrigerating effect = 3500 kW
  - 3500 = m(h5-h4) = m(2510.6-293.0)
  - m = (3500/(2510.6-293.0)) = 1.578 kg/s
  - λ = (ξws/(ξss-ξws))
  - cws-concentration of weak solution
  - css- concentration of strong solution = (1.2/(1.6-1.2))
    = (1.2/0.4)
    = 3.
  - mss = λ*m
    = 3* 1.578
    = 4.734 Kg/s
  - mws = (1+λ) m
    = (1+3) (1.578)
    = 6.312

- **Absorber :** applying energy balance
  - Qa = mh5 + mssh10 – mwsh6
    = 1.578(2510.6)+4.73 (-81) –(6.312)(-101)
    = 3961.726 – 383.13 + 637.512
    = 4216.108 kW.

- **Solution heat exchanger :**
  - mwsh7-mwsh8 = mssh9-mssh10
  - h7-h8 = (mss /mws) (h9-h10)
    = (4.734/6.312) (-62+81)
    = 14.25
    h8 = -69.25

- **Generator:**
  - Qg=mh2+mssh9-mwsh8 =1.578(2676.0)+4.734(-62)-6.312(-69.25)
    = 4366.328kW.

- **Condenser:**
  - Qc = m (h3-h2)
    = 1.578 (2676-293)

= 3760.374kW.

- **COP** =(Qe/Qg)
  = (3500/4366)
  = 0.8016.

THERMODYNAMIC CALCULATIONS

S.NO	STEP POINTS	TEMP in °C	POSITION	PRESSURE mm of Hg	ENTHALPHY	CONCENTRATION
1	2	100	Cond inlet	70	2676	-
2	3	70	EV inlet/cond outlet	70	293	-
3	4	70	Evap intel/EV outlet	6.525	293	-
4	5	5	Evap outlet/absorber inlet	6.525	2510.6	-
5	6	55	Absorber outlet/solution pump inlet	6.525	-101	1.2
6	7	55	Solution pump outlet/HE inlet	70	-55	1.2
7	8	65	HE outlet/RC inlet	70	-78/-69.3	1.2
8	1	75	RC outlet	70	-69	1.2
9	9	80-85	Generator outlet/ HE inlet	70	-62	1.6
10	10	65	HE outlet/ absorber inlet			

3.5.2 Practical COP:

Tg= generator temperature Tc= condenser temperature Te=evaporator temperature

Tg=84.2ºC =357.2K Tc=40.6ºC= 313.6K Te=5.6ºC = 28.6K

COP =(Tg-Tc/Tg)*(Te/Tc -Te)
= [(357.2-313.6)/357.2]*[28.6/(313.6-28.6)]
= 0.12 *7.96
= 0.796

3.6 Steam Control System

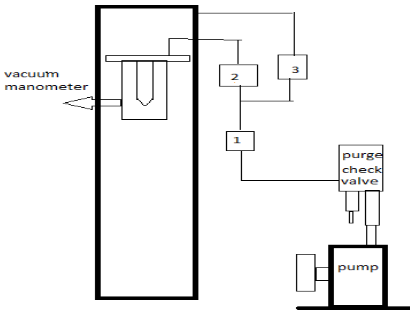
Steam input can be controlled in two ways:

- Steam inlet control system
- Drain control system.

Here in this chiller plant we are using steam inlet control system where in which we are controlling steam at the input unlike in old chiller plant where the control system is at drain control system. Due to control system fixed at outlet (drain) the chance of contact of Li Br with the high temp steam increases as a result of which thermal hammering occurs and also Li Br solution crystallizes when exposed to higher temperature, the chances of crystallization also increased. Steam control system increases the control over the steam inlet by decreasing the above mentioned problems.

3.7 Purge Tank:

Non-condensable gases in the shell are collected in the absorber where the pressure is lowest. The outlet pipe is provided in the absorber at the top of solution level, and the non-condensable gases are led out to the purge receiver and extracted to outside atmosphere by a vacuum pump. The Smart Purge system automatically and continuously removes non-condensable gases from the absorber section and collects them in a cylindrical tank mounted on the outside of the upper shell. The transport of non-condensable to the purge tank is accomplished through the use of an educator along with a gas separator. This process is virtually infallible and continuous during chiller operation. The undissolved gases may be due to the leak from outer atmosphere or due to corrosion of walls. The only moving part required for this process is the use of the solution pump, where a small amount of solution is taken from the discharge line to drive the educator. The quantity of non condensable gases in the purge tank is continuously monitored with the help of manometer fixed on the purge tank and when a specific level is reached these gases are expelled by the automatic activation of an electric motor driven vacuum pump. Kinds of purging: The two types of purging are Purging from the storage tank, and Purging from the shell.



PURGE SYSTEM

3.8 Heat Reclaimer

It acts as an economizer. The input given to the generator is decreased. As LiBr temperature increases the affinity increases. High affinity leads to increase in absorption capacity of the absorber. Therefore heat reclaimer helps in increase the affinity leading to increase in absorption capacity.

3.9. Solution Pump

The removal of a solution pump added for increase in conservation of energy. It decreased the power consumption of almost 6.6 kW.

4. Result

Due to the changes made in the design COP increased by 0.3.The power supply for a plant decreased from 22kW to

8kW and cooling water or service water requirement is decreased from 1050 Cu.M/Hr/Chiller to 900 Cu.M/Hr/Chiller.

References

[1] Refrigeration and air conditioning by CP ARORA, text book.
[2] Thermodynamic Analysis of Vapor Absorption
[3] Refrigeration System and Calculation of COP. International journal for research in applied science and Engineering technology (ijraset)
[4] Thermal Technologies Europe AB | www.thermatec.se | info@thermatec.se
[5] Refrigeration and air conditioning by Domakundwar.

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