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Implementation of a Single Effect Absorption LiBr-H_2O Refrigeration Chiller by using Thermodynamic Modeling and Steady State Simulation

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Abstract: ***The objective of this research paper is to present steady state simulation model and EES program for design and thermodynamic analysis is used to predict the performance of single effect vapor absorption chiller. The working condition of steam is entering and exit to the generator. At that point, the program gives the thermodynamic properties of all purposes of the state, for example, design information each heat exchangers in the cycle and the overall performance of the cycle. The outcome is from EES program is utilized to contemplate the impact of structure parameters on cycle performance. In the conventional absorption refrigeration system dilute solution of LiBr is directly goes to the generator at inlet of generator in this type high heat source is required and increasing the area of the generator. In this paper is to present incorporation of heat reclaimer in the solution heat exchanger and the generator. The addition of one heat exchanger with increasing COP as well as reduced heat source and heat transfer area in the generator. This program gives the operating parameter at all state points, design value of all heat exchanger and design performance of the system. The refrigeration capacity of the system is 100TR. To check the performance of system by using changing flow rate of heat source, heat exchanger effectiveness. The output of this program and simulation results use for the sizing of new refrigeration system.***

***Keywords**: theoretical modelling, heat reclaimer, steady state equation, governing equation.*

I. INTRODUCTION

Absorption cooling was invented by the French scientist Ferdinan. This system is becoming more attractive present days, because of their environmental friendliness. The advantage of the system is the use of solar, hot water, a flame of fossil fuels, the company's waste heat and other heat sources. Due to the global warming reasons with less use of CFC and HCFC compression chillers. In the vapour absorption system Libr use as absorbent and water as refrigerant. A computer program and steady state model is used to predict the performance and sizing calculation of refrigeration system.

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In the absorption system steady state at each point of the system is strongly depends on the thermodynamic properties of solution. For vapour absorption system incorporation of heat reclaimer in the cycle between solution heat exchanger and the generator and results predict that reduce generator area.

II. LITERATURE SURVEY

Pichel et al (1996) performed an experimental setup of 3517KW capacity of LiBr absorption system. This system is operate on hot water at 80-120°C.In the absorption system cooling water is supplied to the absorber and then condenser [1]. Pichel found that when the cooling water is supplied to the system in parallel to both absorber and condenser improve the system performance as compare to the cooling water in series both absorber and condenser section. The COP was found between 0.68 and 0.72

Eisa et al (1986) performed a thermodynamic design data for absorption system found out that the operating temperature in the system is limited because of the Gibbs phase rule and the thermodynamic properties of the working fluid. They found experimentally that a possible combination of operating temperature, the flow ratio, concentration flow of strong and dilute solution in the absorption system. The performance of the system depends upon the flow ratio its decrease with an increase in the coefficient of performance of the system [2].

Eisa and Holland et al (1986) experimentally performed operating parameter to satisfy for the operating process condition in the absorption system. To predict results from changing working parameter on the performance of the system [3]. In the vapour absorption system is influenced by the generator temperature. Coefficient of performance of the system decreases due to the increasing heat transfer load in the generator. The performance of the system depends upon the flow ratio its decrease with an increase in the coefficient of performance of the system.

Eisa and Diggory et al (1987) experimentally performed system to determine the effect of temperature in the absorber and condenser [4]. The cooling water is mainly influenced in the inlet of absorber section as compare to the condenser. It was found that decrease COP value due to increased in temperature difference between the absorber and condenser.

The absorber temperature T_{abs} was varied between 33.0 and 43.1°C and the condenser temperature T_{con} between 33.0 and 50.0°C.

Joudi and Lafta et al (2001) developed simulation program for absorption heat pumps and heat transformers with

LiBr-H_2O as the working fluid [5]. The experimental results simulate to the developed program values with changing the working condition of temperature, pressure, mass flow rate, etc.

A computer model is performed by Jodi and Lafta (1985) was applied in Mitsubishi-York. This is the actually commercial refrigeration plant. This is the catalogue of vapour absorption refrigeration chiller of MITSUBISHI HEAVY INDUSTRIES LTD [5].

Grossman. G. and Micheslon E. A. et al (1993) developed simulation program for absorption heat pumps and heat transformers with LiBr-H_2O as the working fluid [6]. The experimental results simulate to the developed program values with changing the working condition of temperature, pressure, mass flow rate, etc.

In the vapour absorption system the properties of concentration measured by using calorimetric. Feuerecker et al (2004) developed a new method for measuring vapour liquid equilibrium and properties of Libr solution [7]. In this method they derived enthalpies for LiBr solution from 35-80% and temp up to 180^{o}C.

Park et al (2008) analyzed the performance parameter during operation and calculated the energy consumption amount of Libr-H_2O absorption system with a 210 Tonnage and they found that the performance of absorption system is more significant impact to changing the inlet cooling water temperature rather than the flow rate of cooling water [8].

Kim and Ferreira et al (1985) presented a computer program capable of the behavior of absorption cycle [9]. This model has been applied to single effect absorption system using various working fluids.

Conversion between heat and work in energy systems must be done within the restriction imposed by the laws of thermodynamics. The first law is a statement of conservation of energy: the total change of the energy of a system is equal to the total transfer of energy across the system as heat and work [9].

III. ABSORPTION CHILLER MODELING

The objective of this model is to calculate process parameter at steady state at all points. Also, find out the conductance of each heat exchanger, heat transfer load with using heat balance relation in program. The value of steady state properties at each point program is automatically taken. As shown in fig.1. Shows state points at each entering and leaving through heat exchanger. In the steady state model applying governing equation for each heat exchanger.

The input given to the program is:

1. Steam temperature (T_{12} and T_{13})
2. COW temperature (T_{16} and T_{19})
3. CHW temperature (T_{20} and T_{21})
4. COW and CHW flow rate inlet and outlet.
5. Effectiveness of solution heat exchanger and heat reclaimer.

Some assumption has been made for this program;

- The analysis is made under steady state condition.
- The refrigerant vapour at the outlet of the evaporator is saturated vapour.
- The refrigerant at the outlet of the condenser is saturated liquid.
- Pressure losses in the pipeline and all heat exchangers are negligible.
- The temperature of refrigerant vapour and strong solution from the generator in same.
- The outlet temperature from the absorber and strong solution from the generator is corresponds to equilibrium condition of mixing and separate respectively.

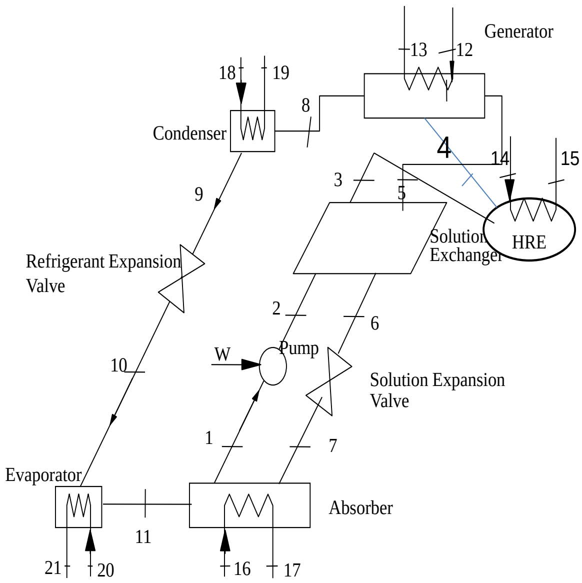

Fig. 1 Block Diagram Of Single Effect Vapour Absorption System

The governing equation for each heat exchanger:

- The generator:

The mass balance equation:

$$m_8 = m_4 - m_5$$

$$= m_4 - (1 - x_4/x_5)$$

Similarly, strong solution flow rate can written as,

$$m_5 = m_4 * x_4/x_5$$

Energy balance on the generator yields:

$$Q = m_8h_8 + m_5h_5 - m_4h_4$$

The energy conservation of energy equation:

$$Q = m_{steam} C_p (t_{12} - t_{13})$$

The heat transfer equation:

$$Q = (UA)_g \, LMTD$$

Where, $(UA)_g$ the overall conductance of heating tube in The generator

- The absorber:

The mass balance equation:

$$m_{11} = m_1 - m_7$$

Concentration balance equation:

$$m_1 x_1 = m_7 x_7$$

Energy balance on the absorber yields:

$$Q = m_7 x_7 + m_1 x_1 - m_{11} x_{11}$$

$$Q = m_{cow} (h_{17} - h_{16})$$

The heat transfer equation:

$$Q = (UA)_{abs} \, LMTD$$

Where, $(UA)_g$ is the overall conductance for heat Transfer surface of absorber

- The evaporator and condenser:

Chilled water is flowing in the evaporator tubes and cooling water is flowing in the condenser tubes.

$$m_8 = m_9 = m_{10} = m_{11} = Q_{evap} / (h_{11} - h_{10})$$

Conservation of energy equation:

$$Q = m_{chw} \, C_p \, (t_{20} - t_{21})$$

The heat transfer equation:

$$Q = (UA)_{evap} \, LMTD$$

Where, $(UA)_{evap}$ is the overall conductance for heat Transfer surface of evaporator

The mass balance equation in the condenser:

$$m_8 = m_9$$

Energy balance on the condenser yields:

$$Q_{con} = m_7 (h_8 - h_9)$$

$$Q = m_{cow} \, C_p \, (t_{18} - t_{19})$$

The heat transfer equation:

$$Q = (UA)_{cond} \, LMTD$$

Where, $(UA)_g$ is the overall conductance for heat Transfer surface of the condenser

- The solution heat exchanger:

Energy balance on the solution heat exchanger yields:

$$Q_{shx} = m_1 (h_3 - h_2)$$

$$Q_{shx} = m_5 (h_5 - h_6)$$

The heat transfer equation:

$$Q = (UA)_{shx} \, LMTD$$

Where, $(UA)_{shx}$ is the overall conductance for heat Transfer surface of the solution heat exchanger.

- The drain heat exchanger:

Effectiveness of heat reclaimer

$$\epsilon_{shr} = (t_{14} - t_{15}) / (t_{14} - t_{13})$$

Energy balance on the heat reclaimer yields:

$$Q_{shr} = m_1 (h_4 - h_3)$$

$$Q_{shr} = m_{12} (h_{14} - h_{15})$$

The heat transfer equation:

$$Q = (UA)_{shr} \, LMTD$$

Where, $(UA)_{shr}$ is the overall conductance for heat Transfer surface of the heat reclaimer.

IV. RESULTS AND DISCUSSION

This paper presents the performance analysis of single effect vapour absorption refrigeration system using EES program and steady state model. The cooling capacity is typically 100 TR steam as heat source. Firstly, input given to the program then follows to the mass and heat balance equation at each point of heat exchanger. To check the performance analysis by using changing individual input parameter. Results are shown below:

1. Varying the steam temperature at the inlet of the generator tube side has a huge impact on the system load.
2. In this system cooling water is supplied to the absorber and condenser. The cooling water at the outlet of condenser tube side changing its effect equally on the performance of the absorber and heat reclaimer.
3. Changing the temperature of chilled water at the exit of the evaporator is also an effect on the evaporator load.
4. Areas of absorber and SHX is also effective due to the changing the outlet temperature of dilute solution.

5. Varying the effectiveness of both heat exchanger also effect on the areas of the exchanger.
6. When the dry saturated refrigerant at the outlet of the evaporator varies changing the evaporator load.
7. When the dilute solution of Libr is the varied effect on the areas of absorber, SHX and heat reclaimer.
8. When the condensate temperature is the varied effect on the areas of generator and heat reclaimer.

Table 1 Input data

T_{12}	T_{13}	T_{14}	T_{15}	T_{16}	T_{19}	T_{20}	T_{21}	(Δt_{9-19})	(Δt_{21-11})	(Δt_{13-5})	(Δt_{17-1})	ϵ_{shx}	ϵ_{shr}
111.4	98	98	74	32	37.5	12	7	2.9	1.2	1.6	2.7	0.52	0.6

Table 2 Array Table

Sr. No.	H (j/g)	M (kg/sec)	P (Kpa)	Q (Fraction)	T (°C)	X (% Libr)
1.	100.8	2.5000000	0.918	0.000	38.995	57.4
2.	100.8	2.5000000	7.567		38.997	57.4
3.	150.4	2.5000000	7.567		63.718	57.4
4.	199.9	2.5000000	7.567		88.410	57.4
5	209.6	2.3446065	7.567	0.000	86.660	62.2
6.	157.0	2.3446065	7.567		59.015	62.2
7.	157.0	2.3446065	0.918	0.008	47.064	62.2
8.	2647.0	0.1553935	7.567		78.793	0.0
9.	169.5	0.1553935	7.567	0.000	40.466	0.0
10.	169.5	0.1553935	0.918	0.060	5.724	0.0
11.	2511.0	0.1553935	0.918	1.000	5.724	0.0
12.	2693.4	0.2250000			111.400	
13.	883.4				98	
14.	918.5	0.2250000			98	
15.	328.7				70	
16.	134.0	27.7700000			32.000	
17.	151.5				34.75	
18.	146.6	27.7700000			35.000	
19.	159.6				38.115	
20.	50.4	16.7700000			12.000	
21.	30.0				7.132	

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Table 3 Solution table

	Evaporator	Absorber	Condenser	Generator	SHX
Heat Duty(KW)	352	512	385	483	126
LMTD (°C)	3.462	9.32	3.93	10.45	12.02
UA (kW/K)	105	55	98	39	6

Table 4 System performance (SI units) corresponding to input data in Table 1

Q_{evap}	COP	W_p	P_{max}	P_{min}	x_{max}	x_{min}	f
351.6	0.72	0.0104	7.384	0.894	62.6	57.8	12.5

Figures 2-4 present the variations of COP heat load with respect to steam temperature graph plot from EES program.

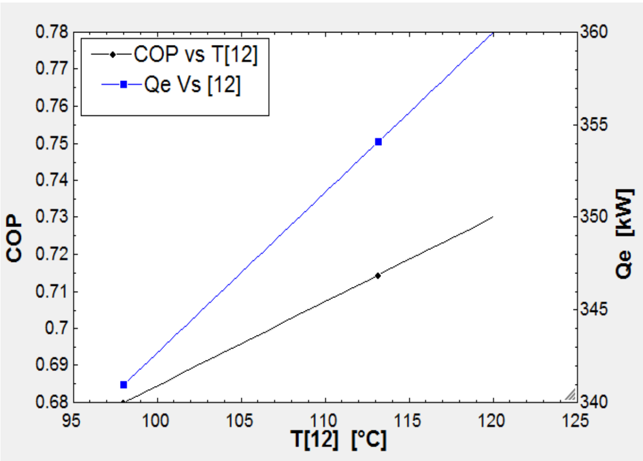

Fig 1. Effect of generator inlet temperature on COP and Cooling capacity

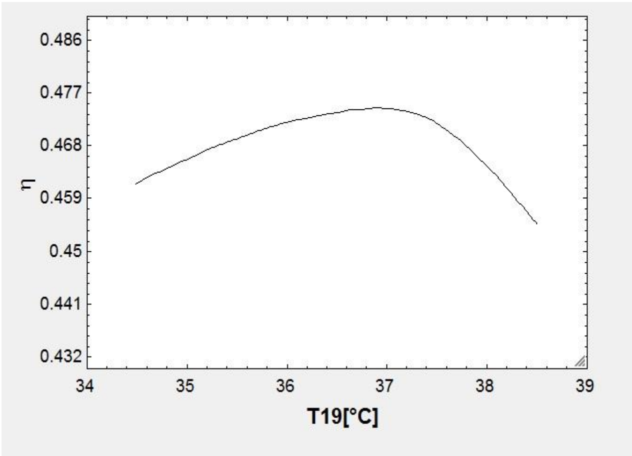

Fig 3. Effect cooling water outlet from condenser vs second law efficiency

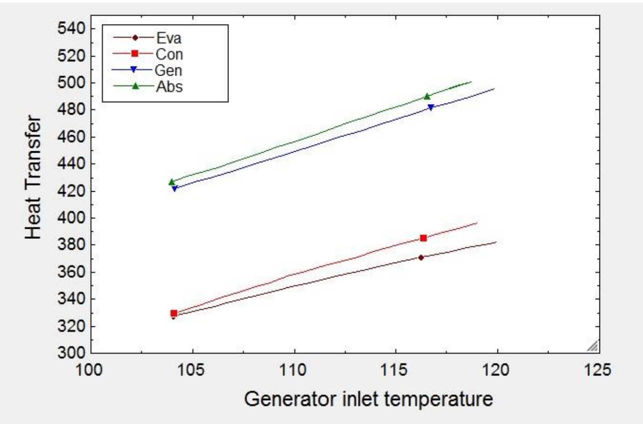

Fig 2. Effect of generator inlet temperature on heat Transfer rates

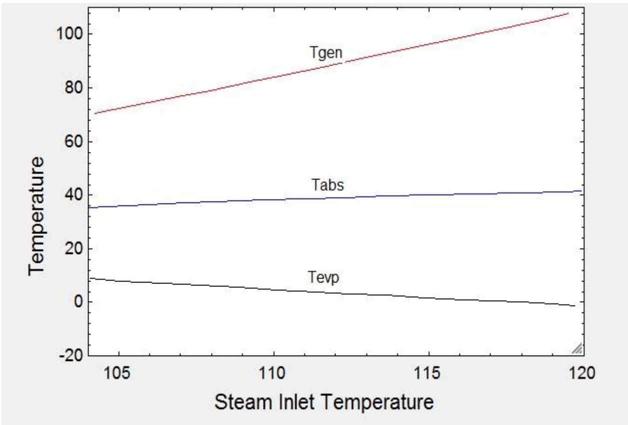

Fig 4. Generator inlet temperature on temperature Of generator, absorber, evaporator

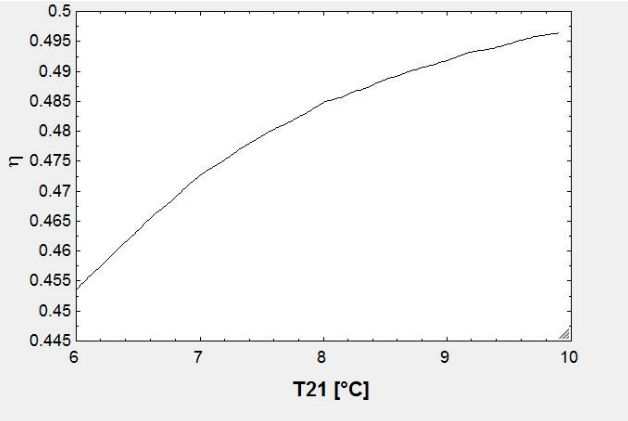

Fig 5. Effect chilled water outlet from evaporator vs. second law efficiency

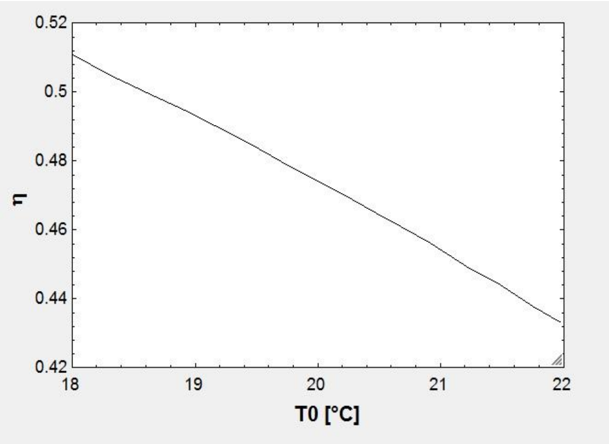

Fig 6. Effect ambient temperature second law efficiency

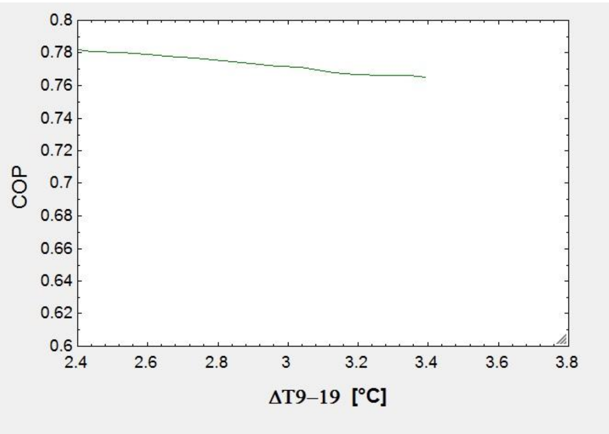

Fig 7. Effect approach temperature in the condenser

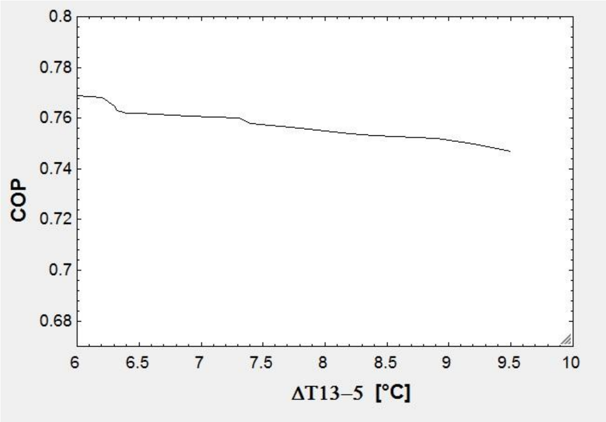

Fig 8. Effect approach temperature in the generator

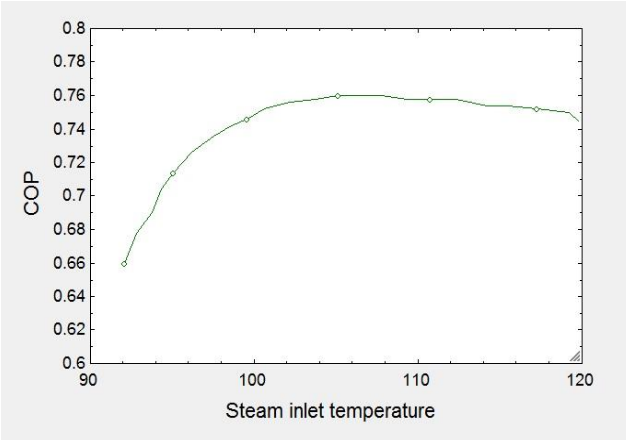

Fig 9. Steam inlet temperature vs. COP

IV.CONCLUSION

A computer and steady state simulation was developed to predict performance, geometry of system and improve performance of system using heat reclaimer. Steam inlet to generator, condensate inlet to the heat reclaimer, COW inlet to absorber also condenser, effectiveness of heat reclaimer these are input data to computer program. This program then provides thermodynamic properties. Design data for all state point in the cycle. Use the available data to calculate design parameters. The program and model give the predicted value of the absorption system. Use a heat reclaimer to improve system performance and reduce heat source. This graph shows the changes in various parameters in the system and improved system performance. Some of the results performed in the following procedures are discussed:

1. The graph above shows the relationship between the change in temperature of the steam inlet on the pipe side and the heat load. As the temperature rises from 100°C to 125°C the heat capacity of each heat exchanger changes. Heat transfer is the initial linear increase from low to high.

2. The input condition for steam temperature is the JIS standard for chillers with single element vapor absorption. The increased heat capacity in each heat exchanger is due to irreversibility.

3. The performance of such a device usually depends on the temperature at the steam inlet. The steam supply pressure in the steam absorption system is higher than in the hot water supply system. Internal circulation mainly depends on three temperature cycles, such as absorber, generator and evaporator. It is noticed that the cycle follows a linear path, and the temperatures of the generator and absorber increase with the temperature of the steam temperature. In these three temperature cycles, the total COP does not change due to changes in two temperatures. However, the efficiency will increase as the level of heat input increases. Consequently, the irreversibility of heat transfer increases due to the high level of heat generated in the system.

4. The figure below shows the increase in chilled water temperature relative to its efficiency. The system load increases due to changes in chilled water inlet temperature. In this case, the COP value changes slightly. However, the cooling capacity increases by 20-30%.When the inlet temperature increases and the pressure on the side of the evaporator increases. This is the effect of increasing pressure on the absorbent part. The overall performance of the chilled water temperature system is increased.

5. When the temperature of the cooling water rises, the heat buildup increases significantly. When more heat is added to the system, the effectiveness of the second law first increases rapidly and then slowly decreases. The evaporator area changes due to temperature changes. In the program, we analyzed the change in temperature at the chilled water inlet, as this temperature increased and the pressure in the evaporator also increased. As the pressure increases, the amount of mass vapor generated in the evaporator in the absorber increases.

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NOMENCLATURE

m = mass flow rate (kg sec^{-1})
x = Concentration of the solution (x/100)
Q = Heat transferred rate (kw)
h = Enthalpy (Kj/kg-1)
C_p =Specific heat
A = Heat transfer area (m^2)
U = Overall heat transfer coefficient (KW/m^2 °C)
COP = Coefficient of performance
ϵ = Heat exchanger effectiveness

Subscripts

Abs	absorber
Con	condenser
COP	coefficient of performance
Gen	generator
Eva	evaporator
LMTD	logarithmic mean temperature difference °C
COW	Cooling water
CHW	Chilled water

AUTHORS PROFILE

Suraj D. Shinde has completed his Bachelor degree in Mechanical Engineering from MIT College Aurangabad Pursuing Master in Heat Power Engineering from MIT-WPU Pune.

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