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Performance Evaluation of Triple Effect Vapour Absorption Cooling System

Alka Solanki[1], S.K.Singh[2], Yash Pal[3]
[1,3]*NIT, Kurukshetra, Haryana, India*
[2]*NISE, Gurgaon, Haryana, India*
[1]alkasolanki10@gmail.com, [2]sk.singh.mnre@nic.in, [3]yashpal@nitkkr.ac.in

***Abstract*— The environmental pollution along with global warming has forced us to adopt an alternative approach for the cooling system and the vapour absorption cooling system is a good alternative. The vapour absorption cooling system is not only environment friendly but also energy efficient, effective as well as economic. In this paper effect of seasonal conditions on the performance of triple effect vapour absorption cooling system is carried out experimentally during summer season i.e the month of April, May, June and July. In this sytem LiBr+water has been used as absorbent and refrigerant solution, which is non toxic, non flammable and can work with low grade heat. It is observed from the results that maximum effectiveness of the cooling system is 0.29 in the month of April and maximum Cofficient of Performance (COP) is 1.56 in the month of June.**

***Keywords*—Tripple effect vapour absorption system, COP, Li+Br, cooling system**

I. Introduction

In summer, the demand for air-conditioning increases, hence demand of electricity increases by many folds. Due to higher comfort standards of the community world wise, the 30% of energy consumption is used for cooling / heating of domestic and commercial buildings [1]. At present vapour compression air conditioning systems are generally used for the cooling purpose which results in environmental pollution and global warming. These systems have an impact on stratospheric ozone depletion because of the Chloro Fluoro Carbons (CFC) and the Hydro Fluoro Carbon (HCFC) refrigerants [7-9]. At present, mostly available cooling systems use mechanical compression system, which are driven by conventional electrical power. Due to conventional energy shortage people are moving towards clean energy [14]. Absorption chiller provides an alternative attractive approach of cooling, because they can be driven by non conventional energy sources for which cost of supply is negligible in many cases.

Moreover, absorption cooling system use natural substances and do not cause ozone depletion as working fluid [2-6]. Basically, absorption cooling system for air conditioning applications operates with lithium bromide+ water and use steam or hot water as heat source. In market, two types of cooling chillers are available, single and double effect and now a day's to increase system performance more emphasis is given on the triple effect [2]. This system is environment friendly, safe, efficient, effective and having high COP. In these systems CFC are not used and the absorbent used are non-volatile. The absorbent used in these technologies have high latent heat of vaporization and operates at low grade energy.

In this paper, to evaluate the seasonal effect on the performance of triple effect vapour absorption cooling system an experimental setup of 100 kW capacity was installed at NISE, Gurgoan, Haryan, India. The pictorial view of this system is shown in Fig.1. For getting higher value of COP of the system parabolic trough collector has been used because with suitable direct radiations, the parabolic trough collector obtains more solar heat energy and causes effective solar cooling. In this work, to evaluate the performance analysis of the triple effect vapour absorption cooling system, the meteorological data in the form of daily (hourly mean) values of solar radiation, ambient temperature, daily temperature range and relatively humidity are measured, which are given in Table II.

II. Literature Review

The absorption chiller was first developed in 1850 and first absorption chiller with Lithium Bromide (LiBr) +water was developed in 1970 with its cooling capacity from 5 kW to 12 MW [10]. Prior to this world's first double-effect gas absorption chiller was developed in 1968 [11]. The world's]. first triple effect absorption system using (LiBr+water) was developed on October 5, 1977 [27].

Fig. 1. Pictorial view solar vapour absorption cooling system at NSI, Gurgon, Haryan,India

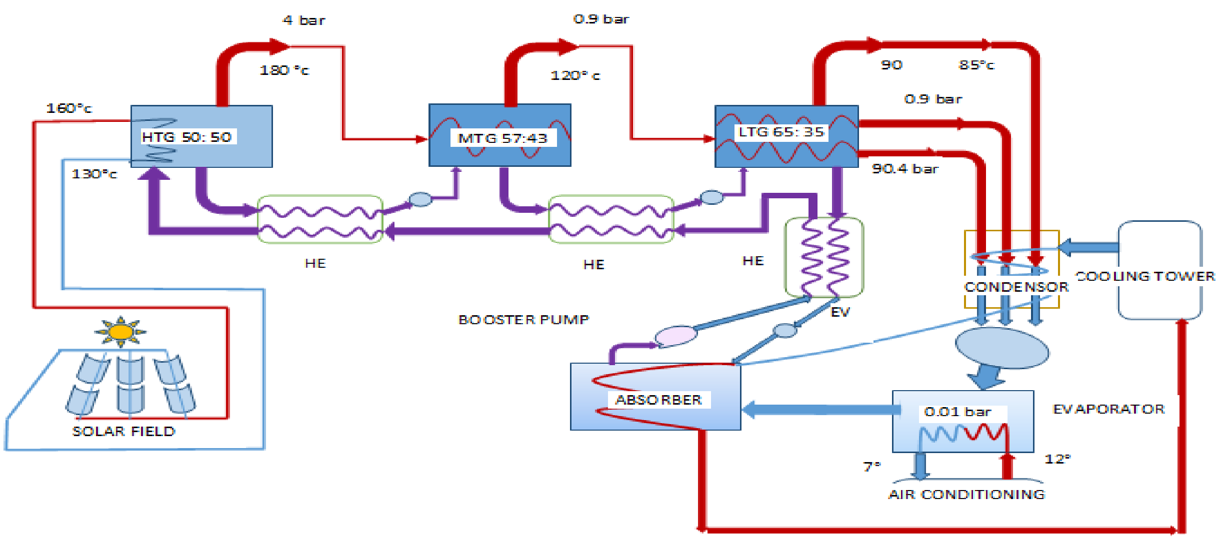

Fig. 2. Schematic diagram of the solar vapour absorption cooling system installed

The use of solar cooling system can be the best alternative especially in tropical regions [12-14]. Between 1960s-70s, many researchers reported the performance of absorption refrigeration process using LiBr+water [10]. By adding a high temperature generator in the existing double effect system, the triple effect system may be realized with higher possibility of actual utilization [15]. To attain higher efficiency, development of triple effect absorption chiller was started in autumn 2001. In Japan, various kinds of solutions/refrigerants combinations are evaluated and their effect on the performance of solar absorption systems were reported [15-21].

In these systems mostly stationary collectors are used for the solar absorption systems [22-26]. Most favorably the solar cooling system works more effectively during high sunshine hours, when the cooling demand is highly required [22-26].

III. System Description And Working Principle

Fig. 2 shows schematic diagram of various components of triple effect vapour absorption cooling system and its technical specifications are given in Table I. This schematic solar cooling diagram represents the proposed conceptual design for the system under investigation.

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The system consists of two important parts; (a) the solar collector system and (b) the absorption cooling system.

In this system LiBr+water has been used as absorbent and refrigerant solution, which are in liquid form. The strong solution (rich in refrigerant) contained in High Temperature Generator (HTG) is heated by solar energy absorbed by parabolic trough collector. The water gets converted in to vapour and moves from HTG to Medium Temperature Generator (MTG). Next, due to high temperature heated water coming from HTG, converts the water of MTG into vapour and moves to Low Temperature Generator (LTG). At the same time LiBr from HTG moves to LTG through the heat exchangers.

Finally all the vapour from all three generators goes to the condenser, where it cools down by the water supplied from cooling tower. In condenser the vapour gets condensed by rejecting heat and converted to liquid form at a high pressure. The refrigerant now passes through the expansion valve and got evaporated in the evaporator by extracting heat from the surroundings. Due to low pressure in the absorber, the LiBr from heat exchanger is collected in the absorber, where it once again mixes with water coming from the evaporator.

Now this absorbent and refrigerant solution is once again pumped back to the HTG to complete the cycle through heat exchanger. The liquid solution from the evaporator/absorber (low pressure) goes to generator/condenser (high pressure) due to the pressure difference between them. To maintain the continuity of the system during bad weather conditions, a storage tank with a 30 minute capacity is employed to store the hot water.

TABLE I
EXPERIMENTAL SPECIFICATIONS

Heat source	Hot water from solar collectors
Parabolic Trough Collectors covering area	288m^2
Outlet Temperature	130°C
Inlet	160 °C
Flow	5.4 m^3/ hr
Cooling capacity	100 kW
Chilled water Temperature	12°C /7 °C
Thermal storage	Hot – 30 mins
Chilled	30 mins (PCM for short duration)
Rated COP of cooling system	1.7

IV. DATA COLLECTION AND CALCULATIONS

The data was collected for the month of April, May, June and July during 9:00 AM to 5:00 PM every day. For daily average of the collected data, the analysis of the complete month is carried out and then finally average of each month is calculated. The performance of the system was evaluated using the following key parameters: Direct Normal Irradiation (DNI), Hot Water Inlet Temperature (HW I/L), Hot Water Outlet Temperature (HW O/L), Chilled Water Inlet Temperature (CHW I/L), Chilled Water Outlet Temperature (CHW O/L), Cooling Water Inlet Temperature (CW I/L), Cooling Water Outlet temperature (CW O/L) , U TUBE, COP , Solar Field Inlet Temperature (SF I/L) , Solar Field Outlet Temperature (SF O/L), ambient temperature (T_{amb}), Relative Humidity(RH), Wet Bulb Temperature (WBT) and Effectiveness of cooling tower, etc. These collected data and calculated values are given in Table II.

TABLE II
AVERAGE COLLECTED AND CALCULATED DATA

	APRIL	MAY	JUNE	JULY
DNI	461.59	502.28	521.33	427.33
HW I/L Temp.	137.60°C	145.95°C	149.19°C	133.12°C
HW O/L Temp.	123.08°C	129.12°C	132.90°C	117.15°C
CHW I/L Temp	14.92°C	14.42°C	14.65°C	16.03°C
CHW O/L Temp	9.01°C	8.72°C	8.42°C	9.24°C
CW I/L Temp.	22.60°C	23.93°C	23.36°C	26.93°C
CW O/L Temp.	26.42°C	27.46°C	27.56°C	28.77°C
U Tube Temp	26.00°C	27.15°C	28.71°C	28.27°C
Solar Field I/L Temp.	129.47°C	137.13°C	140.70°C	120.03°C
Solar Field O/L Temp.	137.60°C	145.95°C	149.19°C	133.12°C

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Ambient Temp.	28.18^{0}C	33.87^{0}C	39.02^{0}C	25.77^{0}C
Relative Humadity	33.73	25.17	42.70	64.59
WBT	18.77^{0}C	21.27	29.10	20.42
COP	1.40	1.49	1.56	1.40
Thermal η	0.24	0.22	0.21	0.25
Effectiveness of Cooling Tower	0.29	0.20	0.09	0.21

The performance of the system is calculated as per the formulas given below:

$$COP = \frac{Q_e}{Q_e}$$

where, $Q_e = m \times C_p \times (T_{e\ out} - T_e$

and $Q_g = m \times C_p \times (T_{g\ out} - T_g.$

Effectiveness = 100× (CW O/L - CW I/L)/CW out – WBT, where,

$$WBT = T\,\mathrm{atan}[0.151917\,(RH\% + 8.31365)^{0.5}] + \mathrm{atan}[RH\% - 1.676331] + 0.00391838\,RH^{3/2}\,\mathrm{atan}[0.023101\,RH\%] - 4.686035$$

V. RESULTS AND DISCUSSION

The performance of the triple effect vapour absorption system is evaluated in terms of DNI vs various inlet and out temperatures of different blocks of the system. These are as follows:

A. DNI vs Months

DNI variation during the month of April to June are shown in Fig.3. The DNI increase from 460 kWh / day / m^2 to 521 kWh / day / m^2 to 5 kWh / day / m^2 in month of April to June then reduces to 427 kWh / day / m^2 in month of July. This shows that maximum DNI is available in the month of June.

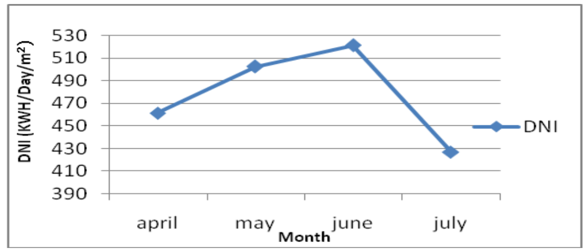

Fig.3. Performance graph of DNI vs Month

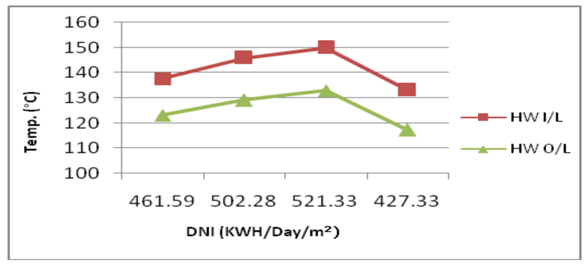

Fig. 4 Performance graph of DNI vs Hot Water Temperature

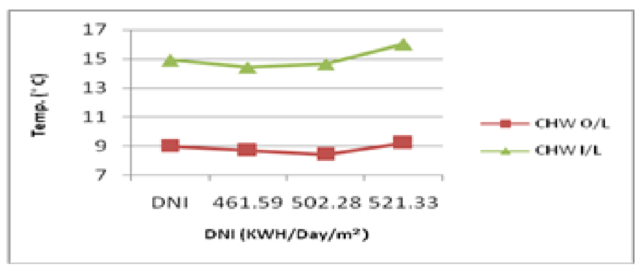

Fig. 5 Performance graph of DNI vs Chilled water temperature

B. DNI vs Hot Water Temperature

The Hot Water temperature inlet and outlet to VAM with respect to DNI is shown in Fig.4. This figure shows that with the increase of DNI, the inlet and outlet hot water temperature to VAM increases. DNI is directly related to the hot water supply to VAM because as DNI increases, the hot water temperature increases and vice versa.

C. DNI vs Chilled Water Temperature

The chilling water temperature inlet and outlet to air conditioning with respect to DNI is shown in Fig. 5. With the increase in DNI, the chilling water temperature inlet and outlet to air conditioning decreases and vice versa. The DNI has indirect relationship with chilled water temperature supply to VAM. The lowest temperature of chilling water is obtained in the month of June, when the DNI is maximum.

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D. DNI vs Chilled Water Temperature

The cooling water temperature inlet and outlet to VAM with respect to DNI is shown in Fig.6. As the cooling water takes away the heat from the condenser and/ absorber and rejects heat outside and hence the temperature get decreased. Fig. 6 shows that when DNI is 521.33 kW/ day/ m^2, the CW I/L temperature is 24^0C and CW O/L temperature is 29 ^{0}C approx.

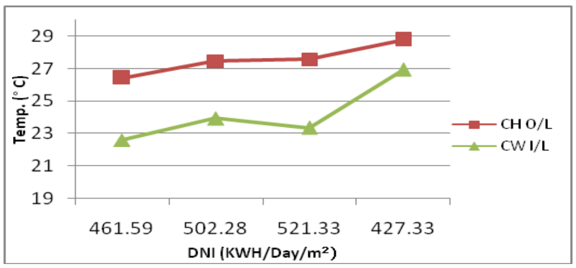

Fig. 6 Performance graph of DNI vs Cooling water Temperature

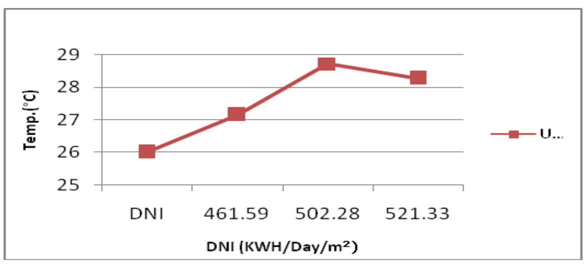

Fig. 7 Performance graph of DNI vs U Tube temperature

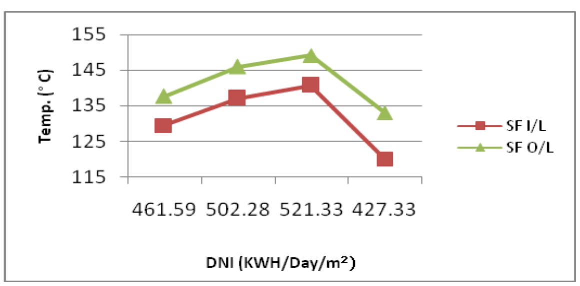

Fig. 8 Performance graph of DNI vs Solar Field temperature.

E. DNI vs U tube Temperature

The U tube temperature with respect to DNI is shown in Fig.7. With the increase in DNI the U Tube temperature increases. The U-Tube temperature increases from April to June because of clear weather conditions, but in the month of July because of the rain and clouds the temperature of U-Tube decreases.

F. DNI vs Solar Field Temperature

The DNI has a direct relationship with solar field water inlet and outlet temperature. Fig.8 shows DNI has directly proportional to the solar field water Inlet and outlet temperature. The hot water outlet from solar field is highest in the month of June.

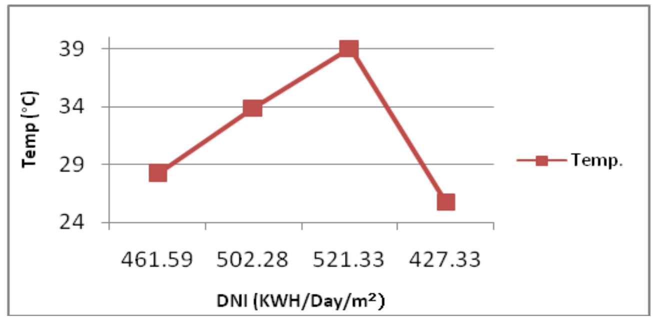

Fig. 9 Performance graph of DNI vs Ambient Temperature.

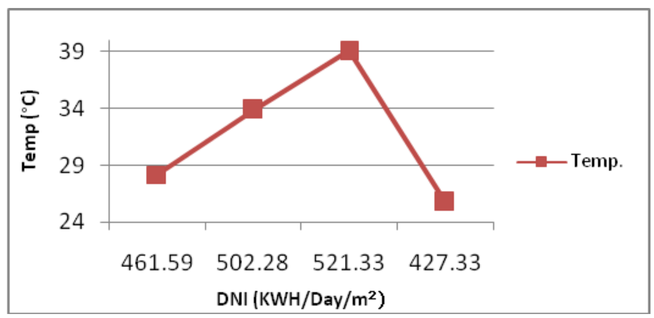

Fig.10 Performance graph of DNI vs Relative Humidity.

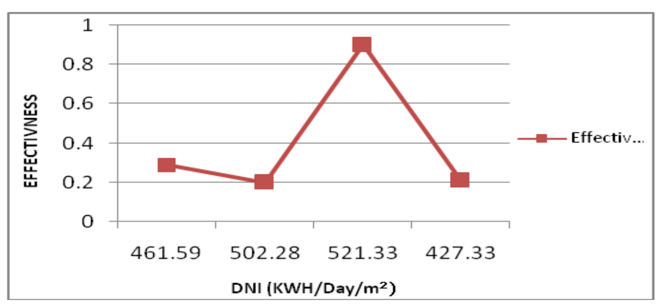

Fig. 11 Performance graph of DNI vs Effectiveness of cooling tower.

G. DNI vs Ambient Temperature

Fig.9 shows the variation of DNI with respect to ambient temperature. In the month of April, DNI is 461.59 kWh/ Day/ m^2 for a ambient temperature of 28.18 ^{0}C.

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From May and June DNI the DNI varies from 502.28 kW/ day/ m^2 to 521.33 kW/day/m^2, while the ambient temperature varies from 33.87 ^{0}C to 39.02 ^{0}C. In July due to rain, clouds and storm, DNI reduces to 427.33 kW /day /m^2 approx. and the ambient temperature decease to 25.77^{O}C

H. DNI vs Relative Humidity

The effect of relative humidity on DNI is shown in Fig.10. With the decrease in relative humidity, the DNI increases. During starting phase of July month the relative humidity starts increasing due to increased water quantity in air that causes the rapid decrease in DNI.

I. DNI vs Effectiveness of Cooling

The variation of DNI on the effectiveness of cooling tower is shown in Fig.11. The effectiveness of cooling tower got decreased in the month of June due to increase in DNI. Hence the effectiveness of cooling tower is maximum in the month of April and minimum in June.

J. DNI vs Thermal Efficiency

Month wise variation of DNI and thermal efficiency of the system is shown in Fig.12. The thermal efficiency has an indirect relationship with DNI. The maximum thermal efficiency is achieved in the month of July where the DNI is minimum, while in the month of June minimum thermal efficiency is achieved having the maximum DNI.

K. DNI vs COP

The effect of DNI on the COP is shown in Fig.13. The COP of VAM has a direct relationship with DNI. The maximum COP of 1.56 is achieved in the month of June. COP increases from April to June and then rapidly decreases in the month of July due to rapid decreases of DNI in the month of July.

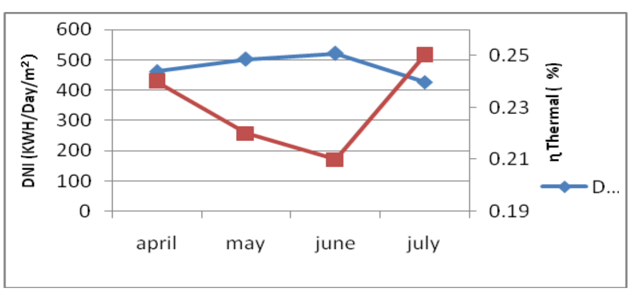

Fig.12 Performance graph of DNI and Thermal Efficiency

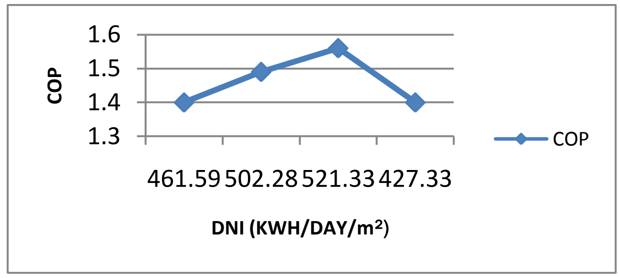

Fig. 13 Performance graph of DNI and coefficient of performance

VI. CONCLUSIONS

To evaluate the performance of triple effect solar vapour absorption refrigeration system due to seasonal effects an experimental setup is installed at NISE, Gurgaon, Haryana, India. The following conclusions are derived from the analysis:

1. The DNI increases from April to June and then rapidly decreases in month of July due to cloudy weather.
2. The atmospheric environmental parameters have a great impact on DNI. DNI increases with increase in ambient temperature and decreases with increase in relative humidity.
3. The thermal Efficiency of system decreases with increase in DNI.
4. The effectiveness of cooling tower decreases with increase in ambient temperature of atmosphere and DNI.
5. The COP increases with increase in the ambient temperature and DNI.
6. The maximum observed COP is 1.56 in the month of June, while theoretical COP is 1.7.
7. The solar vapour absorption air conditioning system may be a good alternative for the conventional air conditioning system in future.

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