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Effective Utilization of Flat Plate Collector in Cooling and Heating

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Abstract

Solar energy which is abundantly available can be harnessed effectively by using a solar collector. There are normally two types of solar collector, flat plate (absorption type) & concentrating type (reflecting type). Flat plate collectors have an edge over the concentrating types of collectors, the later one has to be continuously rotated with the changing altitude of the sun and also its collecting area which is formed by a short width along the focal point of the reflecting surface is very small. The flat plate collectors are quite popular and now used for domestic water heating, space heating and all the processes which require temperature less than 100°c. In the present study the performance of a FPC at same shape and size is observed for cooling as well as heating.

Keywords: Flat Plate Collector, Coefficient of Performance, Vapour Absorption Cycle, Solar Heating

List of symbols

FPC	Flat Plate Collector
COP	Coefficient of Performance
VAC	Vapour absorption cycle
TR	Tonnes of refrigeration
CE	Cooling effect
HE	Heating effect
Q	Heat energy (kW)
h	Enthalpy (kJ/kg)
T	Temperature(°C)

Subscripts

g	Generator
c	Condenser

a	Absorber
e	Evaporator
o	Outlet
i	Inlet

Introduction

Solar energy is a non conventional source of energy and it is a result of continuous nuclear fusion reactions. There is a great possibility of utilizing this enormous amount of available energy which is a clean source of energy. But still not much work has been done in this regard because of certain complications. Scientists and engineers are trying to find suitable ways to tap this energy efficiently and effectively. The major complication in utilizing solar energy is its availability in nature. Large areas are required to tap energy which consequently increases the cost as larger solar panels are required. the intensity of the sun is varies according to place, time & season. Therefore, continuous solar energy is not available and need storage system which increase cost and not desired.

Various researchers have tried to contribute in this field. Bajpai [1] designed and studied a cooling method using solar energy. He designed the VAC for cooling effect of 1 TR using ammonia water (NH_3-H_2o) as the working fluid. For this amount of cooling effect, the amount of heat required was found and provided by FPC. Accordingly area of FPC required was calculated and the cop of the cycle was calculated Abu-Ein et al. [2] studied performance analysis of solar power absorption refrigeration system. The VAC was 10 kw capacity and ammonia water (NH_3-H_2o) was the working fluids. A detailed analysis was done for the whole system using first and second laws of thermodynamics. Finally with the help of computer simulation model results was evaluated. Ndegwa et al. [3] performed experimental investigation on the performance of solar air heater with high density polyethylene paper as top cover and brown sand layer as an absorber. For the collector efficiency, heat gain factor and heat loss coefficient were determined. Effects of mass flow rate of air with thermal efficiency were also studied. Budia [4] utilized solar air collectors for space heating and ventilation applications in Romania climatic conditions. With the help of experimental investigations they reported the relationships between the direct solar irradiation, the heat flow, air velocity at outlet, air flow rate, time of input in nominal regime at collector and efficiency of conversion of solar energy into thermal energy. Vettrivel et al. [5] performed the experiment on a flat plate collector. The performance of FPC was found out by calculating the top loss coefficient theoretically and experimentally. They reported emissivity of absorber plate affects the top loss coefficient and finally collector efficiency. Jercan [6] presented a simplified methodology to design FPC. They developed a program in visual basic to evaluate the performance of FPC considering factors such as absorptivity, reflectivity and transmissivity of solar FPC. In this paper utilized solar energy by FPC for cooling and heating purpose..

Theory

In the present work a flat plate collector of particular area is used to produce cooling and heating effect by taking the medium of heat transfer as water and air respectively.

FPC for Cooling

In the present work Solar energy is extracted and used for cooling purposes with the help of flat plate collector. The cycle on which the cooling done is vapour absorption cycle as it requires low grade energy i.e. heat energy which can be fulfilled by solar energy. Fig1, clearly show the solar radiations falling on the flat plate collector and heated the working medium (water). the heated water is heat the generator section of the vapour absorption cycle with the help of heat exchanger.

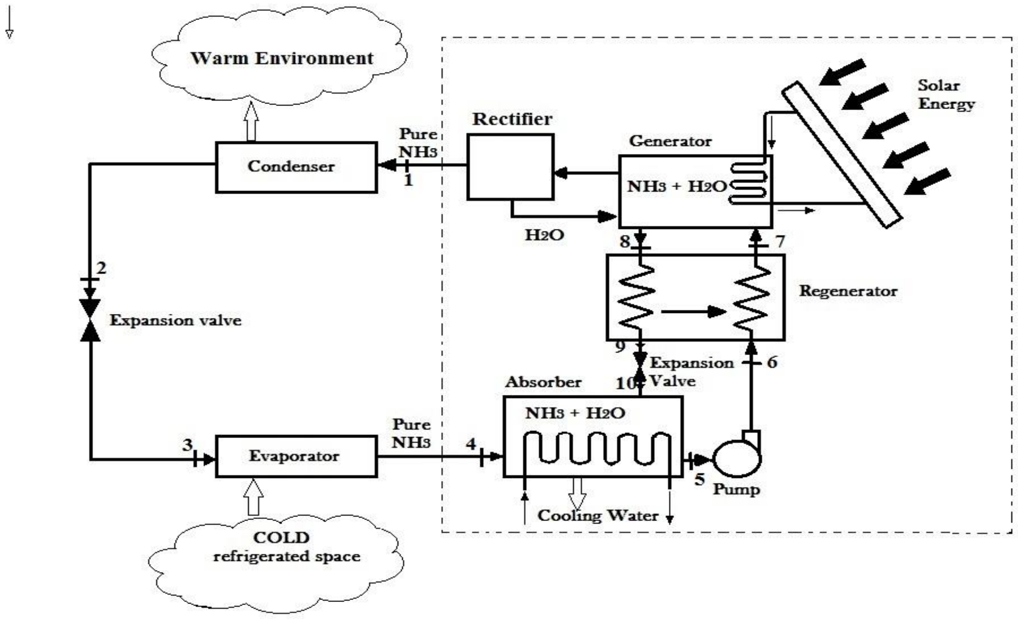


Figure 1: Solar powered vapour absorption cycle

As the generator receives heat, the refrigerant which is ammonia in this case changes its phase from liquid to vapour This vaporized refrigerant is passes through condenser, expansion valve and evaporator..

FPC for Heating

Flat plate collectors can be used to heat water and air for domestic purposes. Here FPC is used as a solar air drier. Fig2. Shows that within the collector air is allowed to pass and due to solar radiations falling on its surface heated This heated air is an essential requirement during winters and for places having very low atmospheric temperatures. The black plate surface absorbs heat through the transparent glass sheet cover and transfers its heat to the carrier fluid and to the surroundings. By taking proper assumptions and relations the amount of temperature rise for the carrier fluid can be found out.

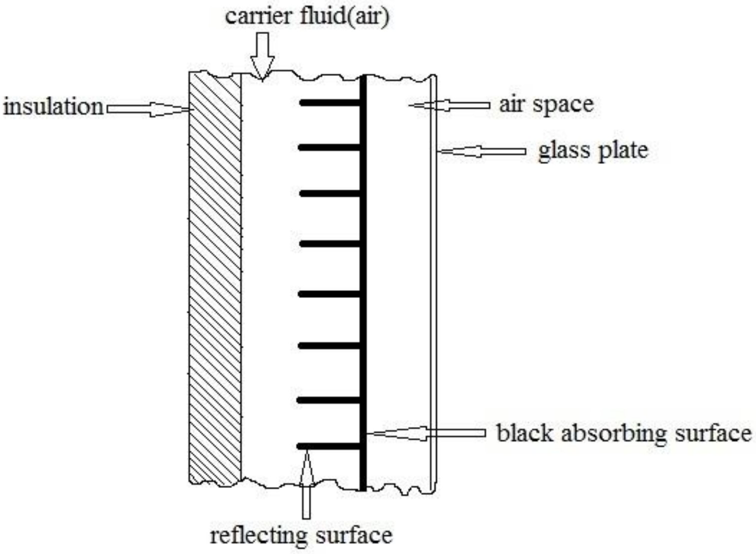


Figure 2: Solar flat plate collector

Calculations

The FPC is facing south east with angle of tilt to vertical as 50°. The radiations are calculated for whole day of 15th January at Ranchi (latitude= 23.34°).

From the above considerations and using suitable relations we can find the various angles and the radiations.[Ref No- 7,8]

Table 1: Direct & Diffused radiations at durations

	8 AM	10 AM	12 PM	2 PM	4 PM
Hour angle(h)	300°	330°	0°	30°	60°
Altitude angle(β)	16.498°	36.66°	45.38°	36.66°	16.498°
solar azimuth angle(α)	-12.313°	9.49°	45°	80.51°	102.312°
Angle of incidence(θ)	34.946°	14.99°	30.17°	57.15°	85.06°
Normal radiation(I_n) (w/m^2)	570.025	797.707	837.875	797.707	570.025
Direct radiation(I_D) (w/m^2)	467.245	770.562	724.37	432.709	49.086
Diffused radiation(I_d) (w/m^2)	29.193	40.854	42.911	40.854	29.193

Cooling calculations

Considerations for flat plate collector

Area of FPC(A)	15m^2
Efficiency of collector plate(K)	80%
Mass flow rate of carrier fluid(m)	1 kg/min
Water inlet temperature(T_i)	20°C

Available energy $(Q_u) = K \times S \times A$

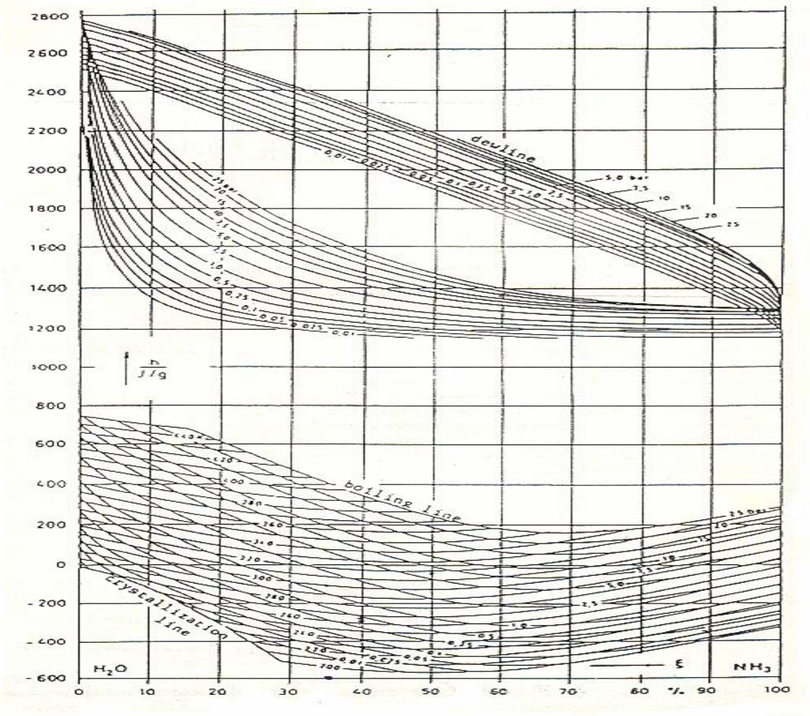
Water outlet temperature $(T_o) = T_i + [Q_u / (m\, c_p)]$

Considerations for vapour absorption cycle

Considered an aqua ammonia (NH_3-H_20) vapour absorption plant working medium under the following considerations.

Concentration of strong solution(C_s)	0.5
Concentration of weak solution(C_w)	0.4
Condenser pressure(P_c)	12 bar
Evaporator pressure(P_e)	1 bar

H-C Chart



From h-c chart, enthalpies at various sections of vapour absorption cycle are

h_1	1630 kJ/kg
$h_2 = h_3$	480 kJ/kg
h_4	1580 kJ/kg
h_a	30 kJ/kg
h_{12}	1720 kJ/kg

Heat supplied to generator (Q_g) = Heat available from solar energy (Q_u)

Solar heat falling on FPC(S) = $I_D + I_d$

Refrigerant flow rate (m_r) can be calculated as , $m_r = Q_g /(h_{12} - h_a)$

Therefore,

$$Q_e = m_r (h_4 - h_3)$$
$$Q_c = m_r (h_1 - h_2)$$
$$Q_a = m_r (h_4 - h_a)$$
$$\text{Cop} = \frac{Qe}{Qg}$$
$$\text{Cooling effect} = \frac{Qe}{3.5}$$

Table 2: Cooling effect and cop at durations

	8 AM	10 AM	12 PM	2 PM	4 PM
S(w/m^2)	496.438	811.416	767.281	473.563	78.279
Q_u(kw)	5.957	9.736	9.207	5.682	0.939
T_0(°C)	105.44	159.644	152.056	101.497	33.468
m_r(kg/s)	0.00352	0.00576	0.00545	0.00336	0.00055
Q_e(kw)	3.872	6.336	5.995	3.696	0.605
Q_c(kw)	4.048	6.624	6.2675	3.864	0.6325
Q_a(kw)	5.456	8.928	8.4475	5.208	0.8525
C.E(TR)	1.106	1.81	1.713	1.056	0.173
COP	0.649	0.6507	0.6511	0.6504	0.644

Heating calculations

Considerations for flat plate collector

Collector surface area(A)	15m^2
Collector surface area receiving direct radiation(A_{sun})	15m^2
Transmissivity of glass for direct radiation(τ_D)	0.8
Transmissivity of glass for diffused radiation(τ_d)	0.8
Absorptivity of plate for radiation(α_s)	0.9
Extended surface area on the side of fluid(A_0)	30m^2
Overall heat transfer coefficient from plate to fluid(U_0)	30w/m^2
Overall heat transfer coefficient from plate to ambient from front(U_F)	5.2w/m^2
Overall heat transfer coefficient from plate to ambient from back(U_B)	0.6w/m^2
Efficiency of collector plate(η_c)	80%
Air inlet temperature = surrounding air temperature	20°C

The rise in temperature of the carrier fluid according to the above considerations can be given as [Ref no- 8]

$$\Delta t = [K_1 /K_2](1 - e^{-K_3})$$

Where,

$$K_1 = \alpha_s (\tau_D I_D + \tau_d I_d) /(1+(U_F A/U_0 A_0))$$
$$K_2 = U_F (1+(U_F A/U_0 A_0))+U_B$$
$$K_3 = K_2 (A/mC_p)$$

Heating effect = η_c (mC_p Δt)
COP = (outlet air temperature/rise in temperature)

Table 3: Heating effect and cop at durations

	8 AM	10 AM	12 PM	2 PM	4 PM
K_1	328.928	537.625	508.3825	313.772	51.866
K_2	5.3852	5.3852	5.3852	5.3852	5.3852
K_3	1.1482	1.1482	1.1482	1.1482	1.1482
Δt(°C)	41.704	68.166	64.458	39.783	6.576
H.E(TR)	5.06	5.486	5.426	5.03	4.495
COP	1.0635	1.058	1.059	1.064	1.071

Results and Discussions

Table [1] shows the calculation of direct and diffused radiations at selected durations. Table [2] shows the variation of COP and cooling effect with respect to time. Table [3] shows the variation of COP and heating effect with respect to time. Based on the above tables graphs have been plotted between COP, HE and CE.

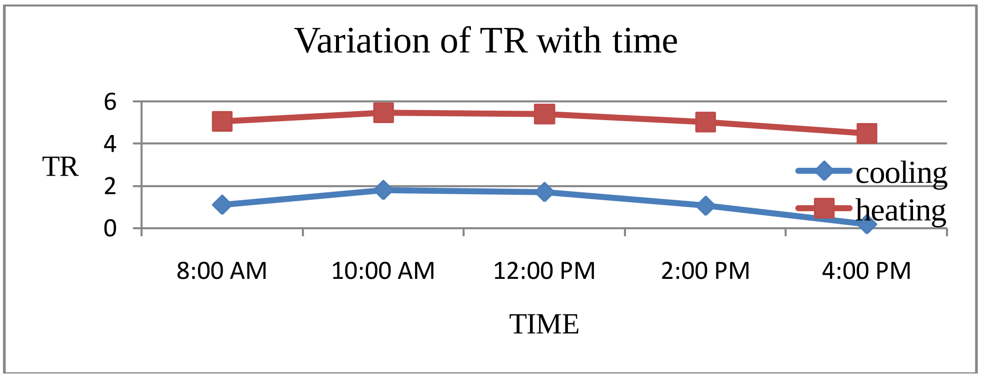


Figure 3: Variation of cooling effect and heating effect with time

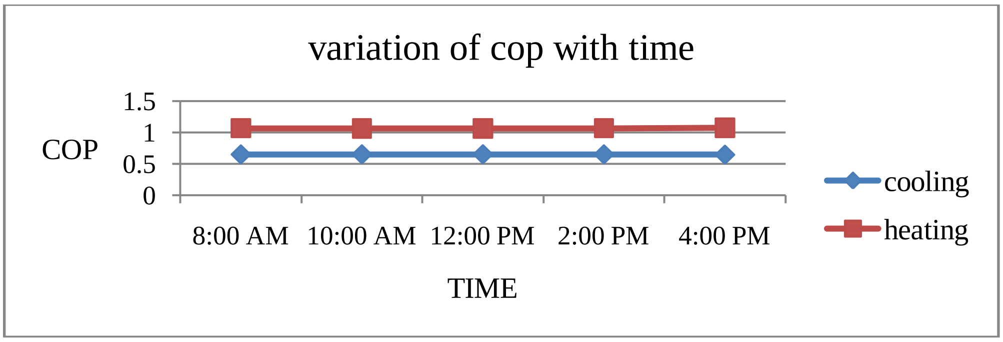


Figure 4: Variation of cop with time for cooling and heating

Fig.3 shows that the heating and cooling effect are increasing in first half of day and decreasing second half. This is due to solar insolation which increases after 10 AM and decrease later. From fig.4 it is clear that for the same shape and size of FPC, COP of heating is almost 50% higher than cooling. This is due to the fact that in cooling an extra cycle (VAC) is carried out which involve losses at the various sections of the cycle i.e. absorber, condenser, evaporator and generator. These losses correspond to lower value of CE and COP in the cooling case. Also for the whole day the value of COP obtained for each case almost remains the same.

Conclusion

For the same FPC, heating effect is 50% higher than cooling effect. Theoretically COP for heating is greater by unity compared to cop for cooling. The curves for heating and cooling with time rise in first half of day and decrease later.

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