Design and performance Analysis of Solar Vapour Absorption Cooling System Using parabolic dish Collector

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Abstract— In now a day's use of the conventional energy resources like coal, petroleum etc., it is necessary to utilize renewable energy resources to fill the gap of current energy demand. There is a need to develop more strategies for trapping of all non-conventional energy sources. Out of all resources one of the best and effective sources of energy is the solar energy. Now a days India develop many solar devices are developed and in particular, solar water heating systems with Different solar collector are being used in commercial as well as domestic areas. The usage of solar water heating system is high in winter and Rainy Season. Also the solar energy collection efficiency is more in summer. But a use of solar energy utilization rate is low. Therefore in the present work an attempt has been made to produce the refrigeration effect by obtaining the energy from parabolic dish collector, with the help of vapour absorption refrigeration technique. In this way a commercial parabolic dish collector water heating system can be used for heating purpose in winter and rainy seasons and cooling effect during summer.

Keywords: **Parabolic dish collector, solar heating system, Vapour absorption refrigeration, Ammonia-water, Low cost**

I. INTRODUCTION

Solar energy is a very large free source of energy. The power from the sun intercepted by the earth is approx. 1.8 × 1011 MW, which are many thousands of time larger than the present consumption rate on the earth of all commercial energy sources. Thus in principle solar energy could supply all the present and future energy needs of the world on continuing basis. This makes it one of the most promising of the unconventional energy sources. Solar energy can also be used for cooling buildings (generally known as air-conditioning) or for refrigeration required for preserving food. Solar cooling appears to be an attractive proposition due to the fact that when the cooling demand is more, the sunshine is strongest. This, along with the necessity for providing thermal comfort for people in hot areas of the world and for providing food preservation facilities, may be the motivating factor in continuing research and development in the field of solar cooling systems. Out of the various solar air conditioning alternatives, the absorption system appears to be one of the most promising methods. Chinnappa [1] developed a simplified approximate expression for the theoretical coefficient of performance of the ammonia-water vapour absorption refrigeration system, and also expressions are developed for the theoretical coefficient of performance of the ammonia-lithium nitrate system suitable for use with the corresponding data charts.

Tyagi [2] conducted several experimental studies with a large number of promising binary mixtures, for use in vapour absorption refrigeration and air conditioning systems, and concluded that one of the mixtures Ammonia and Water is suitable where low grade thermal energy such as solar energy and waste heat is available at temperatures between 100 and 120°C. A systematic investigation is made of the two-stage vapour absorption refrigeration system employing the refrigerant absorbent combinations of NH3---H2O and NH3---LiNO3. The effect of operating variables such as generator temperature, evaporator temperature, absorber temperature and condenser temperature on the coefficient of performance (COP), heat transfer rates and relative circulation have been studied for both single-stage and two-stage absorption refrigeration systems [3]. Economic analyses of some sources of energy, such as biogas, liquefied petroleum gas, ordinary flat plate and evacuated tubular collectors, have been carried out for operating absorption cycles with and without heat recovery absorber. For the set of operating conditions under study, the cost is reduced by about 25% in the H2O---NH3 cycle and by about 30% in the NaSCN and LiNO3---ammonia cycles [4].

A solar cooling machine has been built for demonstration purposes [5]. The main part of the device is an absorber/ desorber unit which is mounted inside a concentrating solar collector. The working pair consists of NH3 used as the refrigerant and SrCl2 used as the absorbing medium. Performance of the solar refrigeration unit was measured in a field test. Francisco et al. [6] developed and tested a prototype of a water–ammonia absorption system designed for solar-powered refrigeration in small rural operations. The equipment has been designed to operate with a concentrating solar power system to obtain the required temperatures. Overall, the test results showed unsatisfactory operation of the equipment having low efficiency. The usage possibility of ejector-absorption cooling systems (EACSs) in Turkey using meteorological data has been investigated [7].

It is shown that the heat-gain factor (HGF) varies in the range from 1.34 to 2.85 for all the seasons in the selected cities. According to the results obtained, it is sufficient to have a collector surface-area of 4 m2 with high-performance refrigeration all over of Turkey. Velumurugan et al. [8] described a detailed description of a new solar-based refrigeration system using three fluid ammonia-hydrogen/ water (NH3-H2/H2O) vapour absorption system. This technique uses solar energy to produce cold air and does not pollute the environment. The system cooling capacities were found to be between 100 and180 W with a COP between 0.09 and 0.15. Nimai Mukhopadhyay and Someshwar Chowdhury [9] studied theoretical modelling of solar-assisted cascade refrigeration system in cold storage. The system consists of electricity-driven vapour compression refrigeration system and solar-driven vapour absorption refrigeration system. The vapour compression refrigeration system is connected in series with vapour absorption refrigeration system. The results shows higher COP as compared with the conventional vapour compression refrigeration system. COP of this type refrigeration system increases as sunlight becomes intense. Power consumption of the cascade refrigeration system is 50% lower than that of the conventional vapour compression refrigeration (CVCS) in the cooling mode. Although, considerable work on solar cooling systems has been done in the last four decades, due to its complexity, both in concept and in construction, the utilization and commercialization of solar cooling is not as widespread as other solar energy applications like solar water heating and solar space heating. In the present paper, an attempt is made to estimate the cooling effect with solar vapour absorption system using commercial 100 litres solar water heating parabolic dish collector device.

II. FABRICATION AND ASSEMBLY

The parabolic dish collector was fabricated using eight mild steel bars of 21 inch length and a large chromium plated aluminium sheet. The base was created by welding eight strips of curved steel to a central point at the base. Then a circular rim of steel of required diameter was created and welded each to the base. Two arms were welded to the dish for holding the heat source. Steel was used for the stand and a square base was used as a support. Mild steel sheet of length 25 inch and breadth 12 inch was taken and rolled into a cylinder to form the collector box. Two holes were made at the ends and fitted with a pipe extension for fixing half inch tubes. On the top on opposite points two small extensions were welded for fitting on the two arms of the dish. The vessel is fixed on the focal point of the parabolic dish. It is supported at the focal point with the help of cast iron bar. The vessel has a tilting mechanism so that vessel always remains straight. A mini fridge of 40L was used for the experiments. A vapour absorption system which had specifications and size similar to that of the mini fridge was used. Slight modifications were done to the vapor absorption system. An alternate pipe to carry hot water through the generator from the heat source was added. This pipe had an inlet for hot water and an outlet at the top for the colder water. This was placed such that it was in contact with the generator to ensure transfer of heat from the pipe to the generator tube.

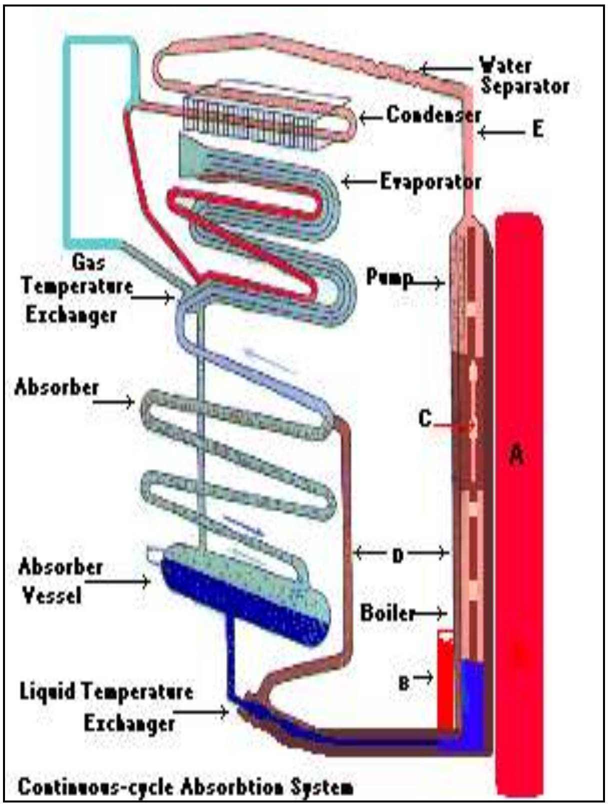

Fig.1 Illustration of a Vapour Absorption System

Fig.2 Experimental set-up of Solar System

Fig.3Experimental set-up of Cooling System

Fig.4Experimental set-up of Solar cooling System

III. DESIGN CALCULATIONS

A. Mass flow rate of ammonia as refrigerant
Mr = 0.18 Kg/min

B. Heat removed in the evaporator
= refrigeration effect
= Mr. × (h4 – h3)
= 1 TR = 210 KJ/min
If cold water flow rate is Mw then Mw Cp ΔT= 210 Ki/min, if ΔT=17 0C then Mw= 3.0 Kg/min

C. Heat removed in condenser
Heat removed in the condenser by the circulated cooling water is given by the equation:
QC = (h4-h3) per kg of ammonia
I.e. QC = Mr × (h2 – h1)= 0.18 × (1630 - 460)
Therefore, heat removedQC = 211.6 KJ/min

D. Design of solar collector
Calculation of collector area Here the collector used is parabolic in shape.
Taking maximum temperature at the generator, TG =90^{0}C
Solar constant (Isc) = 1353W/m2
Extra-terrestrial radiation (Io) = 1398 W/m2
Geographical location of the place where the solar collector was placed:
Latitude =18.6532 N
Longitude = 73.9088 E
Also the month of operation is assumed to be March (δ = 0; t = 0)
Direct radiation reaching the surface at earth is a function of time of the day, latitude location and declination angle
Let
Z-Zenith angle
The zenith angle is calculated thus, Cos z = sin (γ) sin (δ) + cos (γ) cos (δ) cost
Where,
γ- Latitude of location
δ -declination angle
t – Hour angle
I.e., Cos z =sin (γ) sin (δ) + cos (γ) cos (δ) cos (t)
Cos z = sin (18.6532) sin (0) + cos (18.6532) cos (0) cos (0)
Cos z =0.319839 x 0 + 0.947471 x 1 x1
Cos z =0.947471
Z = cos-1(0.0985605)
Z = 18.65320
Intensity of solar radiation,
Iz =Isc e (-c (sec z) s)
Where S and C are climatographically determined constants
Iz =1353 e (-0.357(1/0.947471)0.678)
Iz =1353e (-0.2455)
Iz =1137.825 W/m2
The value of radiation on a horizontal surface (Ih) is
Ih =Iz cos z
Ih =1137.825 x 0.947471 =1078.055 W/ m2
Available radiation intensity =1078.055 W/m2
Assume, 50% efficiency due to:-
1. Variance
2. Collector efficiency
3. Manual tracking system

This implies solar radiation intensity=539.027W/m2 (approx.)
Now,
Reflected intensity
(Ri) = 0.9x539.027 = 485.12 W/m2 (Reflectivity of chromium coated aluminium = 0.9)
Approximately due to lack of Solar radiation (RI) = 450 W/m2
Then,
Heat required at collector box (Qi) = mw x Cp x ΔT
Qi =5 x 4.18 x (90-30)/3600
Qi = 0.348 kW = 348W

Actual Area of parabolic dish (Ad) = 348/485.12
Ad =0.71m2
Area of parabolic dish (Ad) = 348/450
Ad =0.77m2
Take depth (h). h=0.25m
Surface area (As)
As = π/6[r/h2] [(r2+4h2)3/2-r3]
0.77 = π/6[r/0.252] [r3] {[1+ (0.5/r)2]3/2-1}
By trial and error;
r=0.45m, D=0.90m
Focal length (F) =r2/4h = 0.452/4x0.25 =0.2025m
NOTE: Ideal operating temperature required at generator=85^{0}C-90^{0}C

IV. EXPERIMENTATION

4.1 Hot Water Circuit

First the available cold water is filled in the entire circuit of collecting tank, solar panel's riser pipes, header pipes & generator coils. Then the entire system is placed in open atmosphere to receive solar radiation. The radiation received by the absorber plate is transferred to the water in the riser pipes. As a result the water gets heated and the density decreases. As the hot water is less dense than cold water it automatically rises up and enters the collecting tank. The relatively cold water from collecting tank replaces the hot water in the riser pipes and the procedure repeats. The collected hot water then circulates in the coil placed in the generator where the hot water gives off its heat to the refrigerant. So in the hot water circuit the water receives heat in the solar panel and gives off the heat in the generator.

4.2 Refrigerant Circuit

The refrigerant gets separated from the aqua ammonia solution in the generator by absorbing the heat from the hot water in the generator coil. The ammonia after getting vaporized flows through the circuit and enters the condenser. In the condenser the refrigerant Vapour gives off its heat to the surrounding air and gets converted into liquid ammonia. So the refrigerant gives off its latent heat in the condenser. The liquid refrigerant then enters the capillary tube where the pressure drops to the evaporator pressure. The low pressure low temperature liquid refrigerant then enters the evaporator receives heat and produces the refrigerating effecting in the evaporator cabinet. The refrigerant gets converted into Vapour after receiving the heat. The Vapour refrigerant is absorbed by the water present in the absorber. This is due to the chemical affinity of the water towards ammonia. This is the motive force for the refrigerant. In the absorber the ammonia Vapour mixes with water and results in aqua ammonia solution. This solution is pumped to the generator pressure by a fractional HP pump. In the generator the ammonia gets vaporizes and separates from the solution. If any amount of ammonia remains in the solution it is sent back to the absorber through capillary tube. Thus the cycle repeats. After the system is reached to steady state the following readings are taken

1. Collecting tank water outlet temperature

2. Temperature of the refrigerant before evaporator

3. Temperature of the refrigerant after evaporator

4. Results and Discussion

After the total assembly and calculations were complete the setup was tested. The testing was performed from 9:00 am to 4:00 pm and the reading was noted. Every half an hour the parabolic dish was adjusted manually to track the movement of the sun. From the testing done it was noted that the lowest temperature achieved was 8^{0}C. It was noted that the cabin temperature increased for a certain period and then dropped. The C.O.P of the system was obtained from the calculations as 0.1675 for a mini fridge of 40 liters. The tonnage of the system for the test conditions was 0.0168TR and the mass flow rate of the refrigerant obtained was 0.0306 kg/min. It is also observed from the Fig.2 the difference between evaporator temperatures at inlet and outlet marginally increases as the time of operation increases. The temperature drop is found that in the range of 7 to 80C. Almost after two hours of operation there is no further drop is observed and it may be due to there is no change in supply water temperature to the generator. The maximum COP is in the range of 3 to 3.5 and actual COP is found in the range of 0.75 to 0.79.

Table 1Observation Table

Sr no	Local time	Ambient Temp (^oC)	Collator fluid temp (^oC)	Evapo rator Temp (^oC)	COP	Solar radiation (W/m^2)
1	9	27.5	40	32.4	0.02	858.3
2	10	29.8	50	29.4	0.02	894.2
3	11	32.3	62	24.2	0.03	952.1
4	12	32.5	78	18.2	0.21	968.5
5	13	34.5	83	10.2	0.5	1173.82
6	14	35.6	92	6	0.72	1078.66
7	15	35.6	96	5.43	0.75	946.2
8	16	34.5	95	11	0.69	843.2
9	17	33	82	12.6	0.52	723.2
10	18	32	72	15.7	0.5	715.23

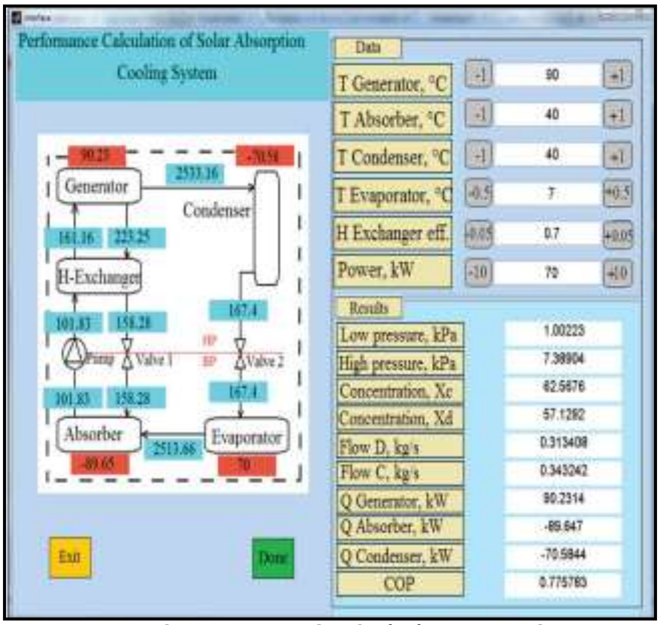

Fig.5Observation in Cool pack of refrigeration cycle

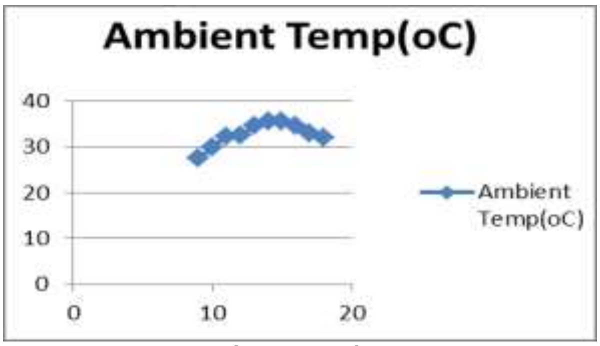

Fig.3Local time Vs. Ambient Temp

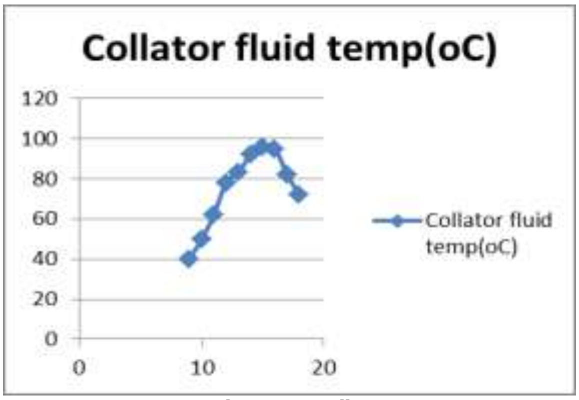

Fig.4Local time Vs. Collator Temp

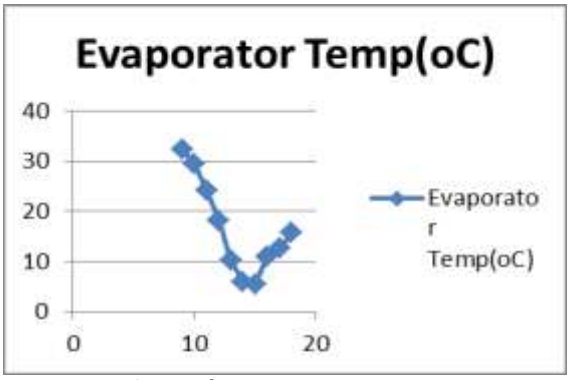

Fig.5 Local time Vs. Evaporator Temp

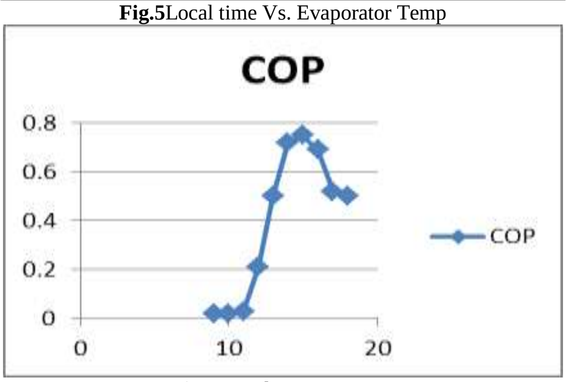

Fig.6 Local time Vs. COP

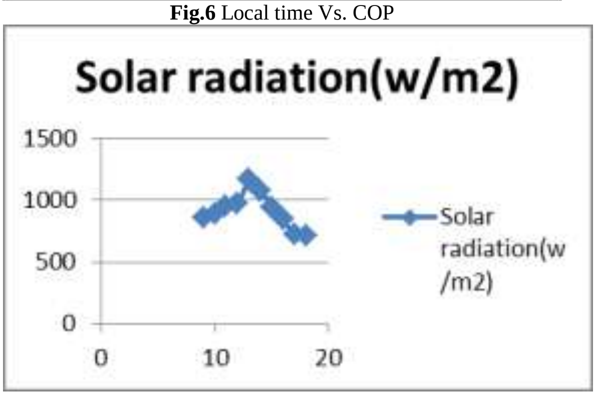

Fig.7 Local time Vs. Solar radiation

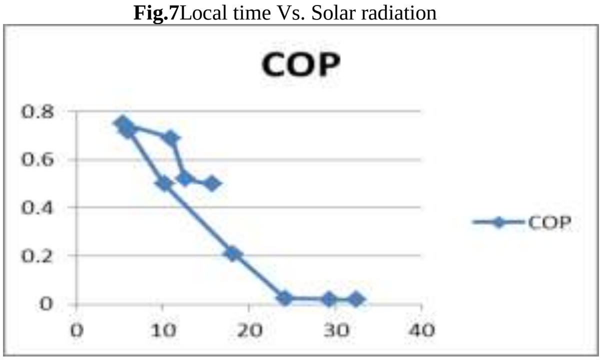

Fig.8. Evaporator Temp Vs COP

V. PAYBACK ANALYSIS

Solar and electrical energy costs intersect at 6th year of operation which is the payback period. From the table shown below, the payback time has been calculated by considering the initial system cost

Table 2Payback analysis

REVENUES AND EXPENSES							
	2015	2016	2017	2018	2019	2020	2021
	Year 0	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6
IC	30,950	Running Cost					
RC		4,818	5,083	5,363	5,658	5,970	6,299
CRC		4,818	9,901	15,264	20,922	26,892	33,191
PC		-26,132	-21,049	-15,686	-10,028	-4,058	2,241

Cost comparison of solar and electrical refrigerator

•The total cost of a selected refrigerator for 10 years is

= Rs.8390 + Rs. 62,052

= Rs.70, 442 /-

•For solar based refrigeration system the total initial cost is = Rs 39,340

•The saving of cost in 10 years is with a difference of

= 70,442 − 39,340

= Rs. 31,102.

•saving per year is = Rs 31102.00

VI. CONCLUSIONS

The following conclusions can be made from the present investigation

1. The Solar parabolic dish collector Water Heater can be effectively used in summer to produce refrigeration effect using Vapour absorption refrigeration cycle.
2. The amount of refrigeration effect is based on the temperature of the hot water supplied to the generator.
3. The maximum drop in the temperature at the evaporator in the present work is estimated to be 7 to 80C.
4. The COP (Coefficient of Performance) of the system is about 0.78 against the maximum COP of the system 3.11.

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