Analysis of Solar Operated Intermittent Vapour Absorption Refrigeration System

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Abstract:

In today's era, two conventional methods for refrigeration are the compression system which uses huge amount of electricity to drive the compressor and other is the absorption system which is bulky and a bit difficult to handle. Hence, for providing a solution to the cooling needs designed a new system which works totally on solar energy using intermittent absorption principle which produces refrigeration effect for cooling and storing in both industry and domestic purposes. Working in the two phases where it absorbs the heat energy from sun during day phase to convert it into refrigeration effect during night phase. The system proves the theoretical cycle of solar intermittent vapor absorption cycle. This system excludes the moving parts in the conventional vapour absorption refrigeration system and has less maintenance. Working on the low heat input, i.e. it requires comparatively lower temperature to the generator is about 96^{o}C which is easy to attain by parabolic trough. The cycle works in two phases producing the effect in 6 hours of operation. The amount of refrigeration effect is based on the maximum temperature of the generator. The maximum drop in the temperature at the evaporator in the present work is estimated to be 4^{o}C.

Keywords: *Solar Energy, Vapour Absorption System, Refrigeration Effect, COP, Ammonia*

I. INTRODUCTION

Refrigeration and air conditioning has become a necessary part of our day to day life which also consumes 18% of worldwide electrical energy. Energy conservation and use of renewable energy sources in an efficient manner has become challenging for engineers in today's era [11]. In recent years, increasing attention is being given to the use of waste heat and solar energy in energizing refrigerating systems. Solar powered refrigeration was very attractive during the last twenty years, since the availability of sunshine and the need for refrigeration increasing day by day. Refrigeration can be achieved by implementing many forms of energy, but the use of solar energy proves beneficial & can be used as an alternative source of energy. The solar energy is available in a very large amount which is inexhaustible and most reliable source of energy.

One of the most effective forms of solar refrigeration is in the production of cooling effect .The major drawback of the vapor compression refrigeration system is that it requires large volume of refrigerant vapor, which requires large mechanical power for its operation. If some methods are used to reduce this volume before compression, there would be considerable reduction in weight of the system and power required for its operation. Heat energy can be used instead of work in producing refrigeration because it gives high COP of the system with machine operated with supply of work energy. The absorption system differs fundamentally from vapor compression system only in the method of employed for compressing the refrigerant. In the absorption system, the compressor is replaced by an absorber, a generator and a pump.

In this present study of the design of solar operated intermittent absorption refrigeration proves beneficial to produce a large refrigeration effect. Since solar energy is available only during the daytime, in order to meet the uninterrupted refrigeration effect production from the solar energy, it is needed to be integrated with a two phase system which works both during sunshine period and also during the evening. The parabolic trough collector collects enough heat from the sun that directly used to operate the refrigeration cycle by circulating refrigerant. The primary refrigerant ammonia has very low boiling point to evaporate from aqueous solution and flow throughout the cycle.

II. LITERATURE REVIEW

Farber [1] has designed the most successful solar refrigeration system to date. It was a compact solar ice maker using a flat-plate collector as the energy source. It was reported that an average of about 42,200 kJ of solar energy was collected by the collector per day and ice produced was about 18.1 kilograms. This gave an overall coefficient of performance of about 0.1 and 12.5 kilograms of ice per m^2 of collector surface per day. Sumathy and Li [2] have analyzed the comparison between ammonia-water and LiBr-H2O systems. Although an ammonia-water system can produce cooling effects below zero temperature, it has certain disadvantages related to its lower (COP); higher generator inlet temperature; higher pumping power; a more complex system and restrictions on its use in-building applications.

Tsoutsos et al. [3] have presented an economic evaluation of solar thermal cooling systems (absorption and adsorption systems). The study showed that the absorption system is 50% cheaper than the adsorption system in terms of capital cost. Solar absorption systems have gained considerable attention among researchers. The major working pairs employed in solar absorption systems are LiBr-H2O and H2O-NH3. Jakob et al. [4] have performed the experimental investigation and simulation of aquaammonia absorption chiller. The experimental results showed that evaporator temperatures of 150 C to 50 C can be achieved at the generator temperatures varying from 650 C to 1150 C. With his investigation he has reached the temperature 1000 C with COP 0.65 and COP is directly proportional to the generator temperature and pressure. Kim and Infante Ferreira [5] have made a comparison between solar electric and solar thermal refrigeration systems, both from the point of view of energy efficiency and economic feasibility. The comparison showed that solar electric refrigeration systems using photovoltaic appear to be more expensive than solar thermal systems. Absorption and adsorption are comparable in terms of performance, but adsorption chillers are more expensive and bulkier than absorption chillers. The total cost of single effect LiBr-water absorption system is estimated to be lowest.

Chidambaram et al. [6] have reviewed research articles in the field of solar cooling techniques, solar collectors, storage methods and their integration, along with performance improvement studies using thermal stratification and cascaded thermal storage systems. The thermal storage system is essential to overcome the disadvantage of the intermittent nature of solar energy and variation in cooling demand. The consequences of the use of the thermal storage integrated system have been clearly distinguished.

V.K. Bajpai [7] has calculated earlier, the heat input required to run the 1 TR vapor refrigeration system, for the operating conditions designed, is about 304.2 KJ/min. This heat in the generator is supplied by the hot water coming from the solar flat plate water heater. For this system the calculated COP of refrigerating unit is 0.69 and COP of the whole system is 0.58.

Syed et al. [8] have done a research in the Kingdom of Saudi Arabia and found that more than 60% of electricity of building sector is consumed by refrigeration and air conditioning system based on the vapor compression refrigeration system. Using solar energy to power such systems will save a large amount of energy (primary or electrical) that can be utilized by the production sectors such as industries. So, they put up their alternate designs for a 24-h operates solar powered absorption refrigeration technology in detail. The analysis indicates that continuously operating solar-powered aqua-ammonia absorption system with refrigerant storage is the most suitable alternative design for an uninterrupted supply of cooling effect. Christine Weber et al. [9] have made concentrating solar collectors using a linear concentrating Fresnel collector that provides the driving heat for two NH3-H2O absorption chillers at temperatures up to 200^{o}C. It provided high efficiency at high driving temperatures favourable for thermally driven chillers and they offer applications for hot climates and industrial process integration. Chilled water temperature is produced in the range between -12^{o}C and 0^{o}C.

J. K. Tangka and N. E. Kamnang [10] have designed a simple solar energy powered intermittent absorption refrigeration system, fabricated and tested. The system uses a generator charged with ammonia and water. The heat source is a solar radiation collector that collects and radiates solar thermal energy onto a black body generator. The generator drives the refrigerant around the system through a condenser and an evaporator. The system was evaluated by leaving it outside under solar radiation and monitoring temperatures at various points inside the collector, the generator, and the evaporator through the use of thermocouple sensors. The average highest and lowest temperatures inside the solar collector were 100°C and 40°C respectively. The average lowest refrigeration temperature was 4°C. The coefficient of performance (COP) of the system was estimated at 0.487.

III. DESIGN OF INTERMITTENT VAPOUR ABSORPTION REFRIGERATION SYSTEM

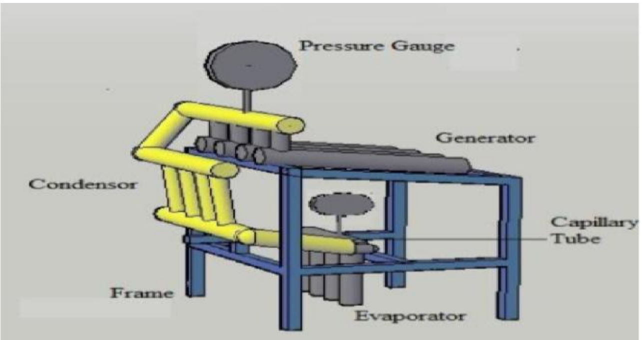

Fig. 1 Solar Intermittent Vapour Absorption Refrigeration System

The basic parts of the solar intermittent vapour absorption refrigeration system are parabolic trough, generator, condenser, expansion tube and the evaporator. The design is based on the basic working principles and few assumptions corresponding to the individual component.

A. Generator

The designed system uses a generator charged with aqua ammonia. The heat source is a solar radiation collector that collects and radiates solar

thermal energy onto a black body generator. The generator is adjusted as the declination angle of 150 corresponding to the angular position of the sun at noon. During the generation cycle, the ammonia becomes vaporized and is driven off. The ammonia vapor at the top of the system is condensed by the air-cooled condenser into a saturated liquid. The basic design of the generator is based on the concept that the heat absorbed by the water at 30^0C to become cooling effect will be same as the heat supplied to the generator.
Hence,

The energy extracted from water

$$E= (m \times Cp \times \Delta T)_{water} + \text{LATENT HEAT} + (m \times Cp \times \Delta T)_{ref..} \quad \text{.. (1)}$$

E = 235.42 KJ
Calculation for water:
C = 0.00314 KW……………………………….Chilled water
TR = 0.00314
Hence, we need 235.42 KJ of heat to be supplied from the generator. Considering losses, while supplying heat to the generator to be 25%.
Then Q becomes 300 KJ
Q = 300 KJ .... Considering losses
Taking water as 1.5 litre ,
From concentration ratio, 0.450 ml of ammonia is taken Total volume of aqua-ammonia required is Volume = 1950 m
Volume 2000 ml of aqua-ammonia

$$Vs = \pi/4 \times dg^2 \times L \quad \text{……………………..................................(2)}$$

Considering length to be 450 mm
dg = 34 mm
This is the diameter of generator tubes with length 450 mm.

B. Evaporator

The purpose of the evaporator is to remove heat from the water, via the liquid refrigerant. The liquid refrigerant contained within the evaporator is boiling at a low pressure. The level of this pressure is determined by, to enable the transfer of heat, the temperature of the liquid refrigerant must be lower than the temperature of the water being cooled.
When leaving the evaporator coil the liquid refrigerant is in vapor form.
We know that,

$$Q= m \times Cp \times \Delta T \quad \text{…………………………………… (3)}$$

m = 0.5 kg
m= ρ × V
For Calculating Volume,
$V = 87.96 \times 10^3\ m^3$

de=20mm and le= 280mm

C. Condenser

A condenser is a device or unit used to condense a substance from its gaseous to its liquid state, typically by cooling it. In doing so, the latent heat is given up by the substance and will transfer to the coolant. In this proposed ice plant, the condenser consists of tubes of 20 NB pipes.

$$Q = m \times Cp \times \Delta T \quad \text{……………………………….(4)}$$

Q = 75.60 KJ
Hence, the heat rejected is 75.60 KJ

D. Design of Capillary Tube by using CFD Software

The capillary is small diameter tubing that offers the restricted flow of the refrigerant. Its internal diameter ranges from 0.080 to 0.120 inches depending upon the capacity of the refrigerating or air-conditioning system. The pressure drop attained through the capillary depends upon its diameter and length. Capillary tubing made of copper is used most commonly. Capillary tubing is used for small refrigerating and air-conditioning systems like household refrigerators, water coolers, deep freezers, window air-conditioners, split air-conditioners, small packaged air-conditioners etc. For systems in which capillary tubing is fitted, technicians have to be very careful of refrigerant charging as the overcharging can lead excessive high discharge pressures from the compressor, which leads to overloading of the compressor and the chances of refrigerant leakages from the system are also increased. The capillary tube is modelled using GAMBIT (v2.4.6) with appropriate dimension. Then, the model is analysed with the help of FLUENT (v6.3.26) and the expected result was successfully achieved. By using GAMBIT and FLUENT softwares, the length and diameter of capillary tube was decided.

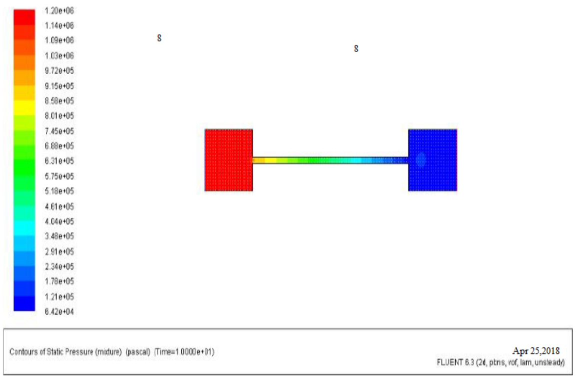

Fig. 2 Capillary Tube Analysis by fluent

E. Parabolic Trough

For Parabolic-trough as per the area of collector dimensions of the aluminium ionized sheet was selected. The depth and the focal length for this particular application were selected by using the parabolic calculator version 2.0. The inputs given were diameter and depth of the sheet and the calculator presents the preferred focal length and a linear diameter of the sheet. The length and diameter were chosen with the help of software called parabolic calculator 2.0 as shown in figure 3.

Area of collector = 492800 mm,

Depth =10mm.

Focal length = 15.63mm.

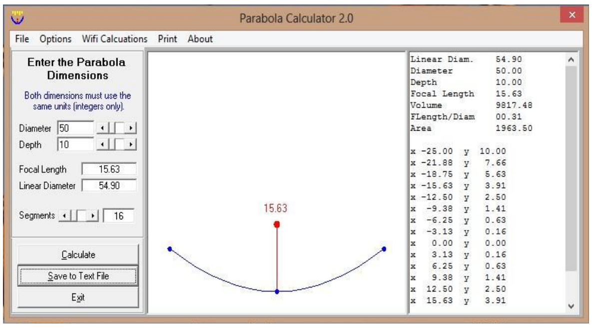

Fig. 3 Parabola Calculator v2.0

IV. RESULTS AND DISCUSSION

The observations are the performance analysis test carried on the set up. The results include the performance during day phase and evening phase. These results are analyzed and discussed.

A. Leakage Testing

After the model was manufactured, leakage testing was performed. The testing was carried first using compressed air and bubble solution was poured on the parts which are suspected to leak.

Table I. Testing of Leakage After the Model has Prepared.

Sr. No.	Method of Leakage Testing	Result
1.	Bubble solution	Leakage was found in the expansion valve.

The Leakage was found near the expansion valve. This portion was well observed and the system was welded at that portion. Again testing was taken using bubble solution, this time there were no bubbles formed. Hence the system was leak proof. Also for once again for conformation the system was tested with phenolphthalein paper. If there might be any leak then the color of the paper changes immediately.

Table II. Testing of model after modification.

Sr.No.	Method of Leakage Testing	Result
1.	Bubble solution	Leakage was not found in the expansion valve.
2.	Phenolphthalein Paper	Leakage was not found in the expansion valve.

B. Performance Analysis

The test of the setup at different places and different environmental conditions was taken and compared with the observations. It is necessary for the purpose of evaluation of the system parameters and time mentioned is in hours and in minutes.

Table III. Observations in Solapur on Day one.

Time (hr)	Intensity (lux)	Upper Temp. T_1(°C)	Lower Temp. T_2(°C)	Upper Pressure P_1(bar)	Lower Pressure P_2(bar)
PHASE I					
10:30	100500	31	30	09.00	1.0
11:00	101200	48	30	10.00	1.0
12:00	102400	68	31	11.00	1.0
13:00	102900	82	31	11.50	1.0
14:00	102600	71	31	11.00	1.5
15:00	101900	58	30	10.50	2.5
16:00	101000	47	30	9	3.5
17:00	99000	38	30	8.50	3.5
PHASE 2					
18:00	-	30	29	8.00	3.50
19:00	-	27	25	7.50	3.00
20:00	-	20	20	7.00	3.00
21:00	-	20	15	6.50	3.00
22:00	-	20	06	6.00	2.50

The initial temperature of the generator was 31°C and static pressure was 9 bar solar intensity was about 100500 Lux. The maximum temperature of the day at generator was 82° C with a pressure of 11.5 bar at 1:00 pm.

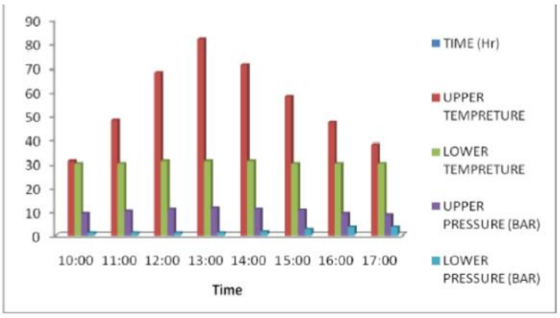

Fig.4 Time Vs Temperature and Pressure

The graph of pressure and temperature is as shown in above table with respect to time during the day phase. The graph shows the maximum values of temperature 82°C and pressure of 11.50 bar at 1:00 pm.

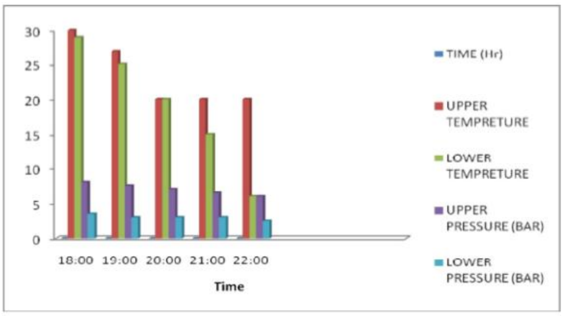

Fig.5 Time Vs Temperature and Pressure

The graph shows the pressure and temperature with respect to time during the evening phase. The graph shows the minimum values of temperature 06 °C and pressure of 2.50 bar at 22:00 pm

V. CONCLUSION

The system proves the theoretical cycle of solar intermittent vapor absorption cycle. This system excludes the moving parts in the conventional ice plants and has less maintenance. Working on the low heat input, i.e. it requires comparatively lower temperature to the generator is about 96^{o}C which is easy to attain by parabolic trough. The cycle works in two phases producing the effect in 6 hours of operation. The amount of refrigeration effect is based on the maximum temperature of the generator. The maximum drop in the temperature at the evaporator in the present work is estimated to be 4^{o}C. The design of the parabolic trough and the capillary tube was calculated and has been verified with the software Parabolic Calculator v2.0 and fluent v6.3.26 software respectively. The results of generator and evaporator temperature variation with respect to time are presented in form of several graphs as shown. The C.O.P obtained was 0.209. The tonnage of the system was computed as 0.00314TR. The additional cost of the refrigeration cycle is very low The system consists of only four components. Hence the design of system is comparatively easy. The system is environment friendly and requires very less maintenance as it contains no moving parts.

Hence from the discussion, ammonia vapor absorption system is suggested for the application. Though the COP of the system is less but since waste heat is given as input, it is not a matter of concern.

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