ISSN 2250-3153

Design & Construction of a Solar Driven Ammonia Absorption Refrigeration System

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Abstract-A solar driven ammonia absorption refrigeration system was designed, constructed and tested. It was an intermittent system where ammonia and calcium chloride were used as refrigerant and absorbent respectively. A small capacity vapor absorption system was first analyzed and its characteristics at various points were measured. The main components like evaporator, condenser and generator were designed based on capacity. The necessary heat and mass transfer equations describing the working properties were specified .The experimentally obtained COP was in the range of 0.104-0.126, average 0.118. Information on designing the condenser, evaporator, and generator of the unit has been presented.

Index Terms- Ammonia, Calcium chloride, Intermittent System, Parabolic Solar Collector, Refrigeration system.

I. INTRODUCTION

Energy crisis is the primary concern around the world because world's demands on the limited natural resources those are used to power industrial society are diminishing as the demand is rising gradually [1].Vapor absorption drives without compressor and its refrigerants are C.F.C free so it saves both energy and environment. The best use of vapor refrigeration system is in remote places where acute shortage of electricity is present or only available power source is solar energy. Many agricultural products like fruits, vegetables, meat, fish etc. can be maintained in fresh conditions for significantly longer period of time if they are stored at lower temperature. This situation is even worse in the remote areas like Bangladesh where these fresh food materials are produced. As a result, sharp difference in food supplies exists between the harvest and off harvest periods. High market valued agricultural products are usually abundant and cheap during the harvest season and expensive at other times. Solar refrigeration can assist to change this trend. Besides food products it can play significant role on preserving the immunization vaccines effectiveness by maintaining them at lower temperature in remote places [2].

Absorption refrigeration system depends on the absorption of a refrigerant gas into an absorbent at low pressure and subsequent desorption by heating. The basic cycle of the single effect absorption ion machine consists of the four processes of absorption, evaporation, regeneration and condensation [3].

In the recent years, many research works have been completed on the absorption system as an alternate of vapor compression system. Vapor compression cycle is described as work-operated cycle because it requires work to run the compressor for elevating the pressure of the refrigerant. On the other hand, absorption cycle is referred as heat operated cycle because most of the operating cost is associated with providing the heat that drives off the vapor from the high pressure liquid or solid. In the vapor compression system, energy in the form of work is normally much more valuable and expensive than energy in the form of heat that can be obtained by solar energy, a fossil-fueled flame, waste heat from factories, or district heating [4].

II. ABSORPTION REFRIGERATION SYSTEM

The absorption cycle is similar in certain respects to the vapor compression cycle. In this system, refrigerant is vaporized by absorbing latent heat of vaporization from the materials which have to be cooled at low pressure region; alternately the refrigerant condenses at the condenser by rejecting latent heat of condensation to the adjacent medium at high pressure region. There are three types of absorption systems- intermittent absorption system, continuously absorption system and double intermittent absorption systems. The difference is in the operating period of cycle. In the continuously operating cycle, heat is added in the generator for 24 hours by an external heat source and evaporator maintains it temperature for 24 hours whereas in intermittent system heat is added for a certain period. Intermittent absorption systems are able to use waste heat and solar energy. The intermittent process works with ideal refrigerant and an absorbent. High pressure or heat separates the two elements during the generating phase and cooling/refrigeration takes place through the absorption/adsorption of the pair. Ambient cooling is an intermediate phase which takes place to reduce high pressure gas/vapor into a refrigerant working liquid. Double intermittent absorption systems are the refinement of the intermittent systems that work either in cascade, at a higher pressure and producing refrigeration more than single intermittent absorption process. [5], [6].The coefficient of performance of the absorption cycle (COP $_{abs}$) is calculates as equation (1) [7],

$$COP = \frac{\text{refrigeration rate}}{\text{rate of heat addition at genarator}}$$

$$= \frac{Q_e}{Q_g} \quad \text{.......} (1)$$

III. Design and Experimental Setup

The solar intensity, temperature, generation period was assumed by considering the surrounding environment of experiment (Khulna, Bangladesh). The temperature at day fluctuated between 25^0C to 35^0C where solar intensity was around 700-760 (W/m2) and average generation period was 6-7 hrs. There are various types of refrigerant and absorber pair are being used at present time. Among them NH_3/H_2O is widely used where low temperature is required and NH3/LiBr systems are used where moderate temperature are required like air conditioning [6]. Several refrigerant and absorber pairs were studied and it showed the superiority of solid absorbents over liquid absorbents and calcium chloride was found better, less expensive and available compared to other absorbents [8]. Again the boiling temperature between ammonia and calcium chloride is so distinct that there is no possibility of boiling calcium chloride with the boiling temperature of ammonia. So the design parameter were assumed as follows-

Table 1.0 Design Parameters

Solar Intensity	750 (W/m^2)
Generator temperature	105^0C
Condenser output ammonia temperature	37^0C
Evaporator temperature	2^0C
Pressure at generator	1.3MPa
Pressure at evaporator	0.45MPa
Generation period	6hrs
Mass of water in evaporator	8 kg
Refrigerant /absorber	Ammonia/Calcium chloride

A. System Description

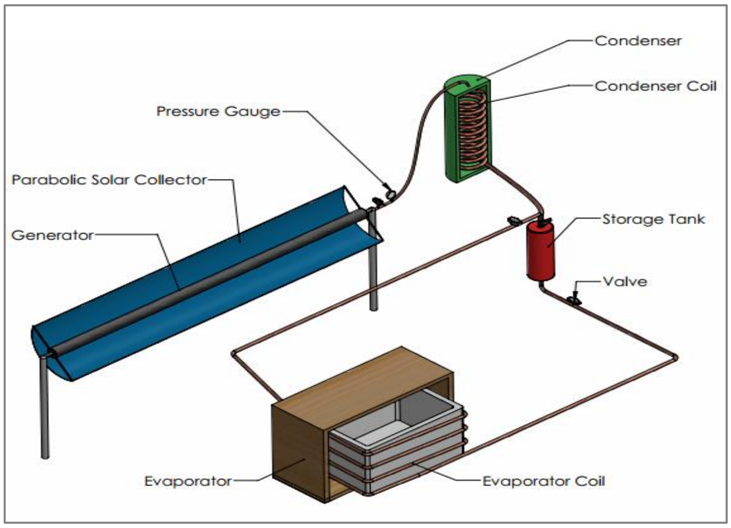

Fig 1.0 Proposed Design of Intermittent vapor absorption system

This system actually was not a true refrigeration system. It was an intermittent refrigeration system because here the mass flow rate was not constant throughout the system. The mass flow rate of the ammonia vapor in system increased when the temperature of the generator increased. The proposed system used-a generator for heating the salt-ammonia mixture, a condenser coil for condensing the vapor ammonia into liquid ammonia, a storage tank for storing the liquid ammonia coming from condenser at day cycle and an evaporator where the materials for cooling were kept. The absorption system operated in a day/night cycle, generating distilled ammonia during the daytime and reabsorbed it at night. During the day cycle the valve on the storage tank was opened, the valves at the bottom of the storage tank and outlet of the evaporator remained closed. Ammonia vapor condensed in the condenser coil and dripped down into the storage tank .About 100 degrees centigrade, six of the eight ammonia molecules bound to each salt molecule were available [9]. At night cycle the valve on the storage tank was kept closed and the valves at the bottom of the storage tank and outlet of the evaporator were kept opened. The liquid ammonia from the storage tank passed through the evaporator coils and got vaporized after taking heat from the evaporator box. As the pressure at the generator remained low at night cycle the ammonia vapor went toward the generator and reabsorbed in the calcium chloride. The total working cycle of the system is shown by the following diagram-

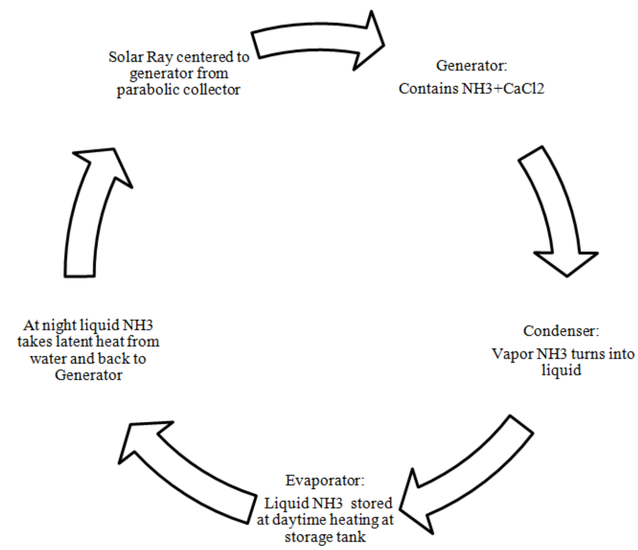

Fig 2.0 Working cycle of vapor absorption system

The ammonia gas is toxic and highly corrosive to brass so the pressure gauge, elbow, valve, T-section, union and the tube for piping were made of stainless steel. Another concerning thing of the project was the sustainability of high pressure. The system was made in such a way that can sustain about 1.7MPa pressure because the ammonia expands greatly. The main components of the system were designed as follows:

The system used a parabolic solar collector. A cylindrical parabolic shape reflector was designed to use as a reflector in this project. Firstly a parabola was drawn in a paper and then drawn parabola was used to construct the structure of the reflector. Reflector had two parts: structure for parabola and reflecting sheet. GI square bar was used for structure of the parabola due to its low weight and high strength to hold the structure. S .S. magnet sheet was used as reflector. PVC sheet was used for supporting the reflector. The structure of the reflector was made by welding. The reflector and PVC sheet were attached with the structure by screws. The reflector size was 2.2 x 1.59 m. The entire reflector was stood by shaft which was nearly passed through the centre of gravity of the reflector and receiver.

The proposed generator was a tube made of stainless steel which was 2.45m long, 76.2mm in diameter and 1.5 mm in thickness. The generator in this system also acts as receiver. It contained the mixture of Calcium Chloride and ammonia. The outer surface of the generator was black colored with black so that it can absorb maximum heat reflected from the solar collector. One end of the generator was closed and other end was open to the condenser through PVC pipe.

The condenser was a stainless steel tube which had 12 turns and the diameter of the condenser tube was 9.5mm. The condenser coil had a diameter of 29.2cm and the total length of the tube was 6m. The condenser was fixed into a cylindrical box containing water at the day cycle. At the night cycle there was no water into the condenser containing box. As the water got hotter after taking heat so hot water was brought out and cool water was supplied to the condenser box. The condenser box was surrounded by cork sheet box to ensure no other heating source of water except vapor ammonia.

The system used a stainless steel cylinder for the purpose of storage tank which was about 60.9cm long, 2 mm in thickness and 10.16cm in diameter. In the day cycle the liquid ammonia stored in the storage tank.

Here the proposed evaporator was a rectangular box made of galvanized sheet. The evaporator was surrounded by evaporator coil made of stainless steel pipe .The diameter of the evaporator coil was 9.5mm and thickness was 1mm. The evaporator was placed into a box made of cork sheet so that an even temperature can be maintained all over the box and also ensuring heat entrapment by keeping felt on the gap between the galvanized sheet box and cork sheet box.

Fig 3.0 Actual design of the whole intermittent vapor absorption refrigeration system

IV. RESULT AND DISCUSSION

The entire components were assembled and tested perfectly before taking observational data. Several measurements were taken at different days. Data were taken from 10.30 am to 4.00 pm with 30 minutes interval. Figure 4.0 describes the temperature variation of different component (generator tube, condenser, temperature of water surrounding the condenser coil) with time. The temperature of the generator tube fluctuated between 95^0C to 102^0C and the pressure range in the generator tube were 1.2MPa to 0.45MPa. The supplied water in and
out temperatures in condenser box were nearly 25^0C and 34^0C respectively. At the night cycle, several evaporator temperatures were taken and the minimum temperature in evaporator reached within about 6 hrs. The range was 4 ^{0}C to 8.5^0C.
It was assumed that the vapor generating from the generator was 100% pure ammonia vapor [10]. The thermal energy input was calculated by the equation (2) where collector efficiency was assumed 10 percent [11]and collector mirror surface area was 3.5 $m^{2,}$
Thermal energy input =Solar intensity × collector mirror surface ×collector efficiency [12]

Or , $Q_g = I \times A \times \eta$………………...……………………..………………...…..(2)

Table 3.0 COP Calculation

No of days	Solar intensity I (W/m^2)	Generator temp (^{0}C)	Evaporator temp (^{0}C)	Thermal energy collected Q_g(kW)	Cooling Capacity Q_e(kW)	COP
01	740	102	4	0.259	0.0326	0.126
02	730	100	4.6	0.255	0.0318	0.125
03	715	99	5	0.250	0.0311	0.124
04	710	97	7	0.248	0.0280	0.112
05	700	95	8.5	0.245	0.0256	0.104

The variation of temperature of different components with time ,variation of COP with generator tube temperature and variation of solar intensity with time are shown in the following figures-

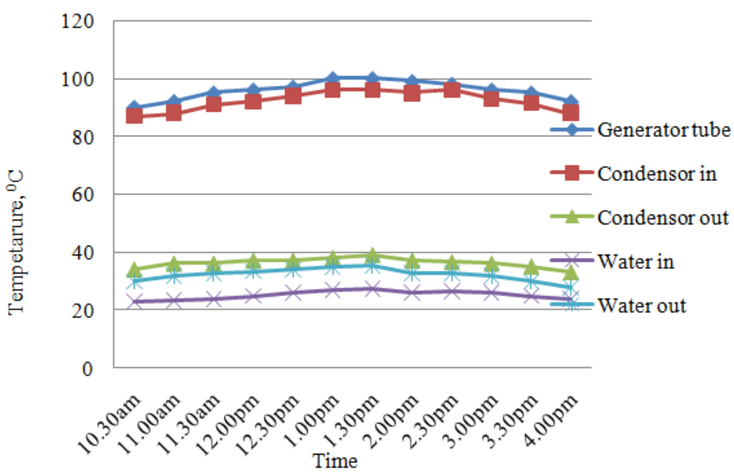

Fig 4.0 Variation of temperatures of different components with time

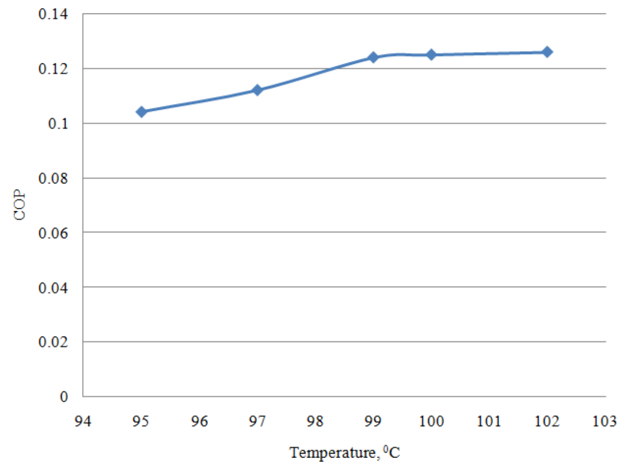

Fig.5.0 Variation of COP with generator tube temperature

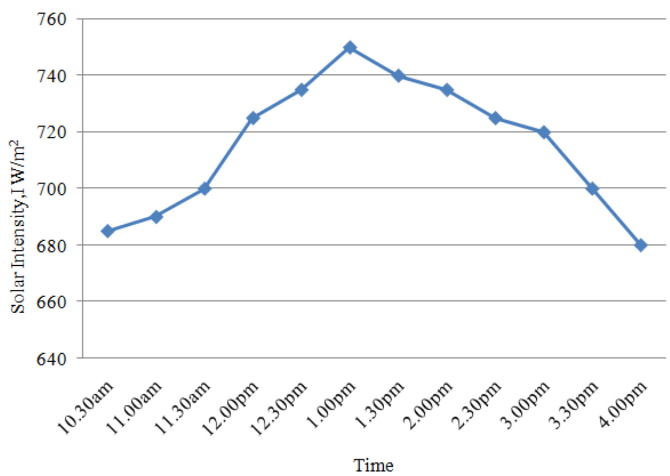

Fig 6.0 Variation of Solar Intensity with time.

Figure 5.0 describes the variation of COP with the generator tube temperature and figure 6.0 describes the solar intensity with time. From the observational data it is clear that for the first observation the COP was maximum (0.126) and evaporator temperature minimum (4^{0}C) because of high solar intensity, generator tube temperature as well as accumulating maximum amount of ammonia in storage tank. Again from the observation no 1 to 5, the generator tube temperature reduced gradually at different days, hence less amount of ammonia was accumulated in storage tank. As a result, high temperature (8.5^{0}C) was found in evaporator and COP reduced to (0.104).

The average coefficient of performance of the system was around 0.118 which was in agreement with some previously designed intermittent systems [13][14][15] .Again, the system would be more efficient (desired temperature at evaporator was 2^{0}C) if the desired amount of ammonia would be stored, pressure and insulation would be exactly maintained. Our system used felt but there was also some heat loss to the surroundings due to air filtration. Keeping the whole system sealed throughout the various pressure and temperature changes was very hard. As our system was a compact and built for small unit, so maintaining this high pressure was challenging task. So there might be some leakages through the measuring devices like thermocouple and pressure gauge.

V. CONCLUSION AND RECOMMENDATION

A small capacity intermittent vapor absorption refrigeration system was designed based on some correlations and formulae. The average experimental COP was 0.118 .It was observed that the accumulation of ammonia, solar collector efficiency, clearness of sky played great factor for overall efficiency. The present cost of the absorption unit together with its running cost is economically viable.

Considering also the destruction of the ozone layer caused by the use of electric chillers, absorption units will offer a better environment, especially if some form of renewable or waste energy is used for their operation. It is recommended to use an expansion valve to increase the pressure difference which also effects on the increment of the refrigerant effect and use felt on the outside of the pipe it would be better for insulating the system with round insulated flexible duct.

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