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Thermodynamic Analysis of Solar Heat Exchanger Assisted Ammonia-Water VARS System

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Abstract

This research focused on the importance of the Ammonia Water Vapour Absorption Refrigeration (VARS) system using solar heat exchangers. The thermal energy needed to operate the VARS through electrical energy can be saved by means of a solar heat exchanger during the daytime. In this case, the strong solution of NH_3-H_2O passed through a copper/aluminium pipe of the solar flat-plate collector. The top ceiling flat-plate collector is covered with transparent glass through which the solar radiation heats the pipe and the strong solution of NH_3-H_2O within it passes. Due to heating the NH_3 vaporizes and separates out from the strong solution in the flash chamber. Then the vapour NH_3 flows into the condenser due to the buoyancy effect.

It is interesting to discern the significance of solar-assisted heat exchangers to operate VARS and save electrical energy during the daytime. However, the daytime temperate variation is due to solar radiation in the heat supplied to any solar heat exchanger. The performance of the heat exchanger is governed by the mass flow rate binary solution. The effectiveness significantly affects the COP of VARS. Moreover, the VARS operating cost is reduced.

Keywords: Solar heat exchanger, Vapour *absorption*, Dittus Boelter equation

1. INTRODUCTION

One of the significant resources of unconventional energy is solar energy which is very huge, and boundless. The power that comes to earth from the sun is approximately 1.8 x 1011 MW, which is much higher than the present ingestion rate of the earth. Solar energy can fulfil the demands of present and future energy crises of the world in an unremitting way [1].Generally, wood, agricultural and animal wastes, and solar energy are the most commonly accessed and used renewable energy which is mainly used for domestic purposes, cottage industry, and in the open-to sun drying process [3].Vapour compression or vapour absorption refrigeration system is most commonly used for cooling effect producers. However, Vapour compression refrigeration systems consume the vast amount of electric energy generated by fossil fuels. The scarcity of fossil fuel sources around the world develops a requirement to run the refrigeration system on alternative sources of energy, i.e Unconventional sources of energy. Hence, a solar heat exchanger-assisted ammonia-water VARS system would be one of the prodigious options [4].The basic property of a suitable refrigerant and absorbent is that the refrigerant should be more volatile than the absorbent. They can be dispersed easily from each other. In two fluid VARS systems for solid absorbents, water is used as a refrigerant [5]. A number of researchers have discussed the use of solar energy in the vapour *absorption* refrigeration systems with Ammonia – Water [6], [7], [8], and [9]. [10], [11], and [12] have discussed for Water –Lithium Bromide. Lithium Bromide – Zinc Bromide Methanol VARS have been discussed in [13]. Lithium Chloride – Water are discussed in [14]. The Ammonia –Calcium Chloride VARS are discussed in [15], and [16]. Ammonia –Water and Water-Lithium Bromide are the most commonly used binary fluid for vapour absorption refrigeration systems. However, the Water-Lithium Bromide system can develop a temperature above the freezing point from water at 40 ºC to 50 ºC while NH_3–H_2O would develop subzero refrigerant temperatures [17]. A flat-plate solar solid-absorption refrigeration has been discussed by [18] operated with activated carbon/methanol which can run an ice plant. A vivid study is carried out by [19] on the operation of a novel solar-powered vapour absorption system. The experimental investigation of an absorption refrigeration system operated by solar cells has been conducted by [20] where at a very low COP of 0.25 refrigeration temperature is 5.8 ºC. The performances of vapour compression refrigeration systems operated by the solar electric system are investigated by [21]. The performances of vapour compression refrigeration systems operated with the solar electric systems are investigated by [21]. Double generator solar operated ammonia–water VARS are discussed in [22, 23]. The MHD effect on convective heat transfer due to rotating flow has been discussed in various research articles [24-28]. This MHD effect enhances the heat flow rate in some processes. [29]. The finding of $GD_5Si_2Ge_2$ has created an interest in the research of magnetic refrigeration systems. In the magnetic refrigeration system, the refrigerating effect is directly reliant on the strength of the magnetic field [30].

Under the influence of strong magnetic field strength, higher cooling effects are observed. It influences the thermal capacities of the condenser and evaporator positively [30]. The importance of solar energy to run a VARS system has been discussed by so many researchers. The present research work tried to develop a thermodynamic model of a solar heat exchanger-assisted ammonia-water vapor absorption refrigeration system.

2. METHODOLOGY

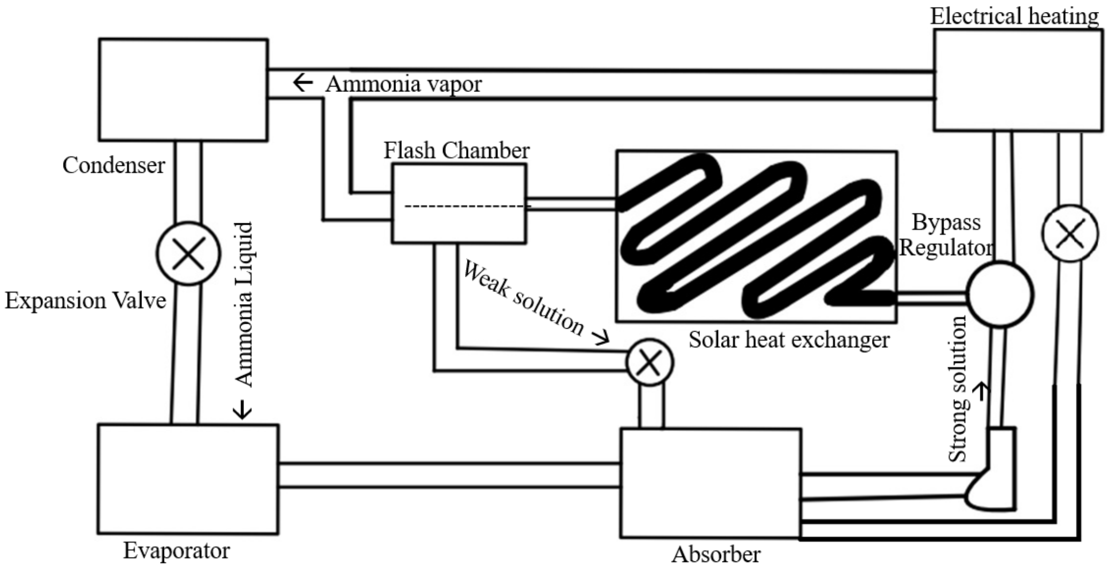


Figure 1. Schematic model of a solar heat exchanger assisted NH_3-H_2O VARS model

2.1. Solar heat exchanger assisted Nh_3-H_2O vars model

This model consists of a VARS system with a solar heat exchanger and flash chamber shown in Figure 1. During the daytime, the NH_3-H_2O liquid flows from the absorber to the condenser through the solar heat exchanger and flash chamber. The NH_3-H_2O liquid after gaining heat from the solar heat exchanger comes with a heat exchanger where vapour NH_3 flows to the condenser and the weak solution comes to the absorber. So, electric power consumption by a generator in the daytime can be avoided. However, in the absence of sunlight, i.e.at night time, the bypass valve restricts the flow of strong solution to the heat exchanger and it flows to the main electrical heating generator. In this way, an uninterrupted refrigeration effect can be achieved and huge power consultations can be saved during the daytime. The present solar heat exchanger consists of an aluminium coil tube having a diameter of 0.5cm and negligible thickness packed within a box whose top is covered with transparent glass exposed to sunlight. The heat exchanger box rotates with

2.2. Governing equation

The heat energy gained by heat exchanger is due to conduction and convection and radiation. The heat gained due to surface radiation of heat exchanger tube absorbed by the binary solution of NH_3-H_2O. The product of intensity of emission (I_e) due to surface radiation and projected area of aluminium coil tube of heat exchanger is the total heat due to surface radiation. The heat gained due to flow of Binary solution is the convective heat transfer. The conduction heat flows from outer surface of heat exchanger (HE) tube to inner surface. However, the temperature difference of inner and outer surface of HE tube having insignificant conduction resistance. During the daytime, the sun locations with respect to earth are varying. Hence the variations in temperature as well as the radiation intensity are changing. As a result, the heats supplied to the solar heat exchanger are varying. Based on the available solar radiation intensity at the lection JUET, Guna, India, this solar heat exchanger can run the ammonia-water VARS system from 9 AM to 5 PM.

Hence, the total heat absolved per unit time is varying.

$$Q_{total} = Q_{convection} + Q_{radtiation} + Q_{conduction} \tag{1}$$

$$Q_{total} = hA\Delta T + I_e A + kA\left(\frac{dT}{dx}\right) \tag{2}$$

Heat gain due to convention heat transfer is

$$Q_{Convection} = hA\Delta T = \dot{m}C_{PMixture}(T_e - T_i) \tag{3}$$

Where T_i and T_e are the inlet and exit temperature of binary solution i.e. NH_3-H_2O. The coefficient of specific heat at constant pressure of the mixture of NH_3-H_2O is given in equation (3).

$$C_{PMixture} = \left(\frac{m_1}{m_{mixture}}\right)C_{PNH3} + \left(\frac{m_2}{m_{mixture}}\right)C_{PH_2O} \tag{4}$$

The mass flow rate of binary solution has significant role on the heat gain from inner surface of coil tube of heat exchanger. The heat gain from inner surface of tube to fluid can be predicated with the help of Dittus Boelter equation. So, the Reynolds number, Prandtl number and Nusselt Number are calculated based on thermo physical property of the binary solution.

$$Re = \frac{\rho VD}{\mu} \tag{5-a}$$

$$Pr = \frac{\mu C_p}{k_f} \tag{5-b}$$

$$Nu = \frac{hD}{k_f} \tag{5-c}$$

Dittus Boelter equation for heating (Temperature of tube wall > Temperature of fluid)

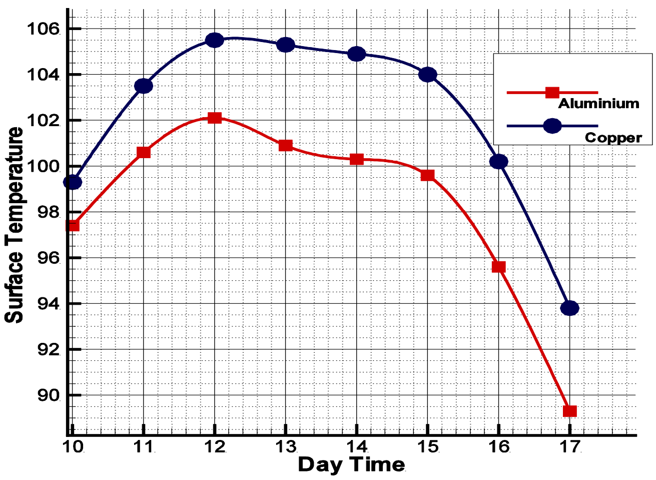
$$Nu = 0.023Re^{0.8}Pr^{0.4} \quad (6)$$

From Eq.6 the variation in coefficient of convection can be calculated.

3. RESULT AND DISCUSSIONS

The basic discussions on the performance of solar heat exchanger are considered here. The prime objective is to verify the exit temperature of the binarysolution after leaving the solar heat exchanger (SHE). When the exit NH_3-H_2O mixture from (SHE) enters into the flash chamber, due to buoyancy effect, from flash chamber the vaporized NH_3 from flash chamber enters into the condenser coil. The weak solution goes down and enters into the absorber. Furthermore, the condensed ammonia from condenser comes to evaporator coil where it provides the refrigerating effect. After absorbing heat from evaporator the vaporised NH_3 again returns to absorber. Thus the entire operation is performed smoothly for cooling.

(a)



(b)

Figure 2. (a) Solar Radiation intensity (W/m^2) (b) Surface temperature of SHE pipe copper/aluminium **($^\circ$C)**at Juet, Guna, MP, India (28th April 2022)

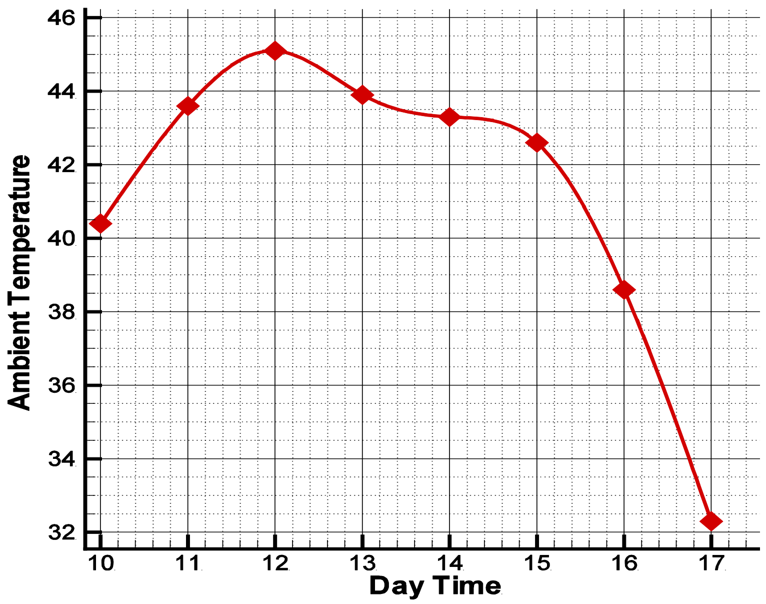


Figure 3. Variation in Ambient temperature with respect to time **(°C)** at Juet, Guna, MP, India (28th April 2022)

The variations in solar radiation intensity that strike on the projected area of SHE pipe made-up of copper and aluminium during day time are shown in Figure 2(a). However, it is experimentally observed that the surface temperature of cupper pipe SHE is greater than the surface temperature of aluminium pipe SHE shown in Figure 2(b).The maximum temperature of copper pipe surface is 105 ºC whereas the peak temperature attended by aluminium SHE pipe surface is 102 ºC. At that time the recoded ambient temperature was shown in Figure 3 which may be required to calculate the rate of heat rejection to atmosphere from condenser coil.

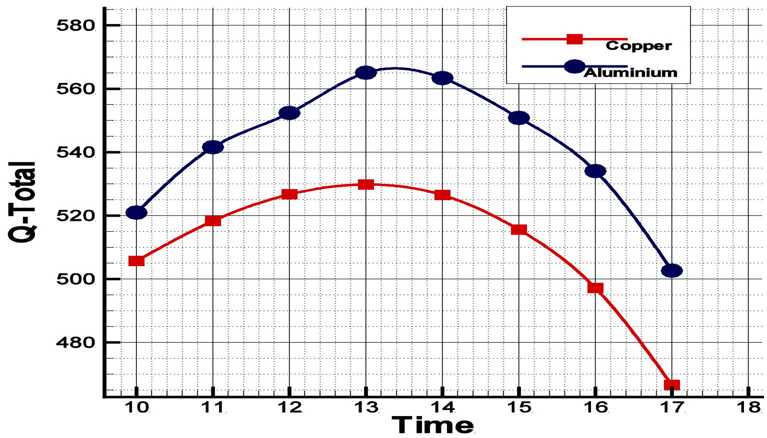


Figure 4. Variation in total heat exchange **(Watt)** with respect to time at different position of sun Red colour-Cupper blue-Aluminium, at Juet, Guna, MP, Idia (28th April 2022)

Also, the net heat gain by SHE due to solar energy varies with respect to sun location i.e. at different time which can be observed from Figure 4. The peak value of heat energy absorbed by copper tube SHE at 1 PM i.e. 560 kW and the aluminium SHE 530 kW which is sufficient to vaporize the NH_3 from NH_3-H_2O binary solution. At morning 10 PM it is 505 KW for aluminium SHE and around 520 kW. The amount of heat energy gained by NH_3-H_2O binary solution from SHE depends upon the mas flow rate though the pipe. This analogy has been performed numerically in this study which can be seen in Figure 5. Based on the analysis of Dittus Boelter equation (Eq. 5) for heating where the Temperature of tube wall > Temperature of fluid. It is observed that the Nussalt number magnitude increases with an increase in the Reynolds number. As the Nussalt number increases the coefficient of convention increases. Hence, the rate of heat exchange increases. However, the heat exchange process depends upon NTU (number of transfer units). The fluid and solid surface of pipe interaction time enhance the heat exchange process. The present study can be further extended in this connection.

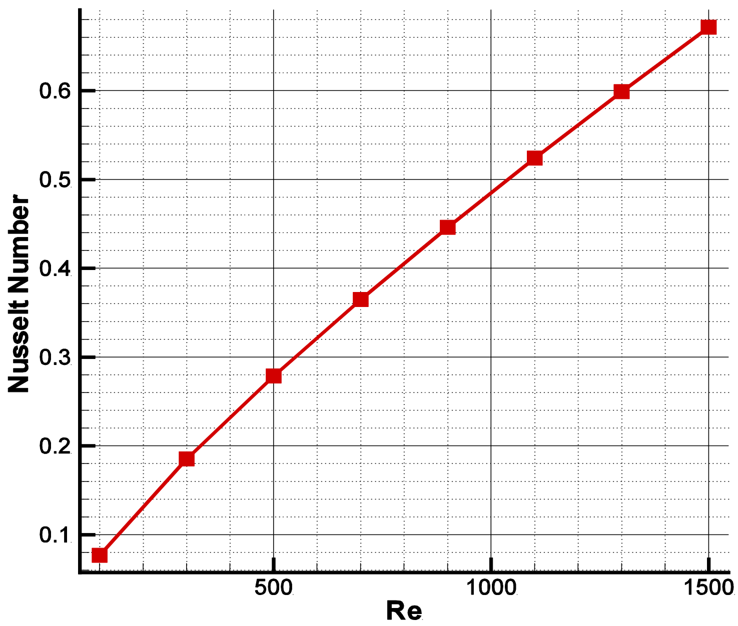


Figure 5. Variation of Nusselt Number with respect to Reynolds number

4. CONCLUSION:

The present investigation has developed a basic model of solarheat exchanger assisted ammonia-water VARS system which can develop refrigerating effect for domestic as well as industrial proposes. It is observed that the SHE made up cupper pipe is more effective than aluminium pipe. The maximum heat gained by a SHE made of copper can supply more heat at lower solar radiation. During a sunny day, the binary solution of VARS can easily attain a temperature which can vaporise and separate out the NH_3 from NH_3-H_2O.

This VARS model can save the electric power consumption during day time i.e. from 10 AM to 5 PM. The mass flow rate of NH3-H_2O binary solution through solar heat exchanger can control the heat exchange process i.e. heat transfer from solar heat exchanger copper/aluminium tube to binary solution. This study can be further extended to investigate the percentage of commercial benefit. Also, an intense study is required to analysis mass and energy balance NH_3 and H_2O in flash chamber of SHE assisted VARS system.

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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