Experiments On a Solar Vapour Absorption Refrigeration Cold Storage System

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Abstract

Combining two rapidly growing technologies, such as solar energy and vapour absorption refrigeration cold storage, will result in an innovative solution to address the increasing demand for cold storage for food preservation systems. The effects of several operational parameters such as condenser temperature, evaporator temperature, and generator temperature on the performance of a solar vapour absorption refrigeration cold storage system were studied in this work. Using solar energy, vapour absorption refrigeration system, a cold room cabin temperature of 8°C was achieved with a cooling load of 3.5 kW capacity and a hot water inlet temperature of 103.1°C, and a cooling water inlet temperature of 32.6°C during experimentation.
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Keywords: Solar energy, Vapour Absorption Refrigeration, Cold storage, R134a-DMF

1. Introduction

Absorption refrigeration is being investigated as an alternative to vapour compression refrigeration due to its potential use of solar energy, waste heat utilisation, etc. In India's, the world's energy and environmental scenarios are rapidly changing. As a result of this, renewable energy was considered as one of the options to the Second Law standpoint of energy conversion. According to the World Economic Forum, India has one of the highest rates of food losses as waste in the world, with yearly harvest and post- harvest losses in fruits, vegetables, and grains reaching to Rs 440 billion. One of the primary causes of food waste and loss is a lack of cold chain infrastructure, which includes refrigerated transport, pack houses, collection centers, and cold storage. As a result, in order to reduce wastage of the above, the development of a solar cold storage technique will solve the above, as well as energy and environmental challenges in the natural and international scenarios. Remote places/villages, farmers with enormous output capacity, and others will benefit from a solar-powered cold storage system. Combining two growing technologies like solar energy and vapour absorption cold storage will result in an innovative solution that is environmentally friendly. Solar cold storage systems also have negligible operational costs.

2. Literature Review

Numerous researchers have experimented with different solar-based heating and cooling system applications. Using solar energy, Sozen et al. (2002) conducted experimental research on a prototype aqua-ammonia absorption heat pump system. A parabolic-shaped collector was incorporated into the system's design to provide the generator with the high-temperature water it needs, and a thermodynamic analysis demonstrates that the absorption system's performance depends on both losses and irreversibility. According to research, the system's evaporator and absorber parts of the system have more exergy loss than the other parts. In (2002), Sumathy et al. developed a 100 kW LiBr-H_2O absorption chiller. By utilising a two-stage chiller, the proposed method can achieve nearly the same total COP as the conventional system at a cost reduction of about 50%. It can be used when the generator temperature is between 60 °C and 75 °C. Shaarawi et al. developed solar-powered LiBr-water absorption air conditioning for a typical family home's continual cooling demand of 5 kW. The results show that the most efficient design for consistently delivering the cooling effect throughout the day is the hybrid cold and refrigerant storage system.

The performance of VARS is influenced by the heat of vaporization of the refrigerant, solubility of the refrigerant in solvent and pressure range of the refrigerant over the operating cycle. The choice of the system's working fluids

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should take into account the system's economic, environmental, and thermodynamic characteristics. The commercial working fluids for absorption refrigeration systems are the refrigerant-absorbant combination like Ammonia - Water and Water - LiBr. However, there are significant drawbacks associated with the above two pairs, such as toxicity and corrosion for ammonia systems and vacuum pressure, crystallizationsation effect for LiBr systems. Due to these limitations, alternative refrigerants have been explored by with R134a-DMF emerging as one of the option due to its good thermodynamic, chemical, and transport properties and ODP of 0.001.

Yokozeki (2005) estimated the performance of VARS by combining various absorbents with various refrigerants. R134a-DMF pair has a greater COP than other R134a combinations and requires a lower circulation ratio than other combinations. The performance of the intended solar collector will have the most impact on the choice of an absorption cooling device. The most popular kind of solar collector is flat-plate collectors, including a metallic absorber and an insulated housing on top of which are placed glass plates. In high temperatures, evacuated collectors function better and lose less heat. In order to endure the pressure differential between the atmosphere and the vacuum, evacuated collectors are commonly constructed with a metallic absorber placed within an evacuated glass tube. The experimental investigation of a LiBr-water absorption system run by evacuated tubes and flat plate solar collectors was provided by Darkwa et al. (2012). There are four hot water storage tanks connected to the system. According to the experiment results, water heated to 96.3 °C and supplied by solar collectors can achieve a coefficient of performance (COP) of 0.69.

Numerous experts have reported on the impact of different designs and parameters that are operational on the COP of solar refrigeration systems. The generator that is optimal was determined to be greater than the constant temperature process under constant pressure, according to a study on phase-change materials, the system's COP can increase by up to 2.4 times compared to a single stage as the latent heat of the refrigerant increases. The efficiency of the absorption that is solar is increased when a heat pump is added to the refrigeration system, making it easier to achieve cooling under various climatic conditions.

3. Fabrication of solar cold storage system

The three main categories in which the fabrication work for the solar cold storage system is done are Vapour absorption refrigeration cold storage systems, solar photovoltaic systems and solar thermal collection systems. The schematic diagram for the solar cold storage system shown in Fig.1 is created by combining these three subsystems.

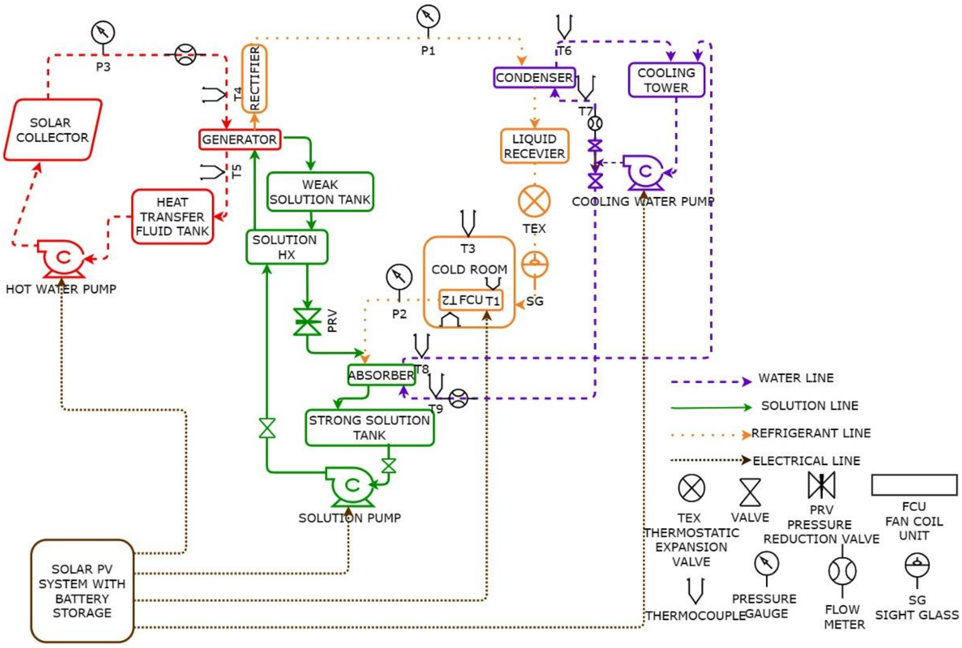

Fig. 1: Schematic diagram of solar cold storage experimental setup.

3.1 Solar PV system

Solar Photovoltaic system is designed to supply the electrical power required to run Pumps, Fans of the system. In general, the Solar PV system mainly consists of solar panels, Inverter, battery, electrical control system with necessary electrical wiring connections. Solar panels are used to convert incident solar energy into electrical energy. Crystalline silicon is the predominant material used in most of the solar panels. Inverter is used to convert the DC power produced by solar panels into AC power. Battery is used to store the DC power for back up time duration likely considering cloudy phenomena. Electrical control system mainly consists of Variable frequency drive along with electrical switches, relays and PLC's.

A 36 panels of 11.5 kW (34 × 325W, 2 × 340W) capacity is installed for running cooling water pump, hot water pump, solution pump, cooling tower motor, evaporator unit fan and lighting arrangements of the cold room. First of all, the supporting structure made up of aluminium frames for placing the panels are installed. Over the supporting structure, the panels are mounted in series array arrangement. The supporting structures are further strengthened by providing concrete civil work to withstand natural disasters like cyclone. Figure.2 shows the assembled view of Solar PV Panels.

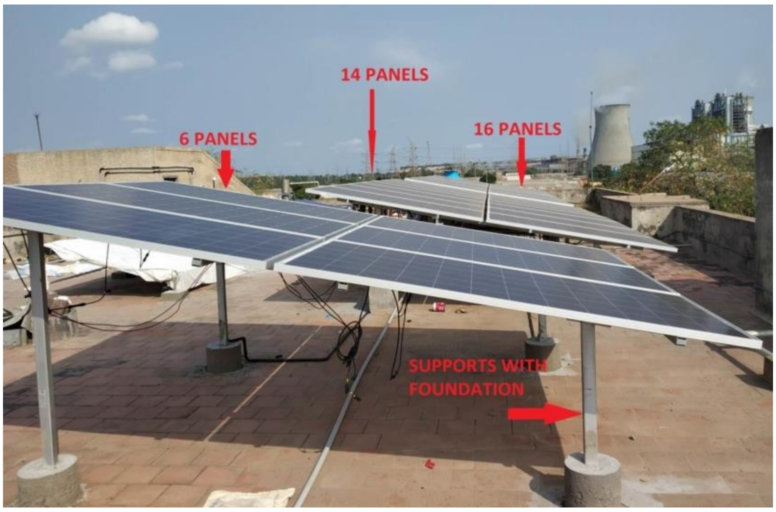

Fig. 2: Photograph of solar photovoltaic panels

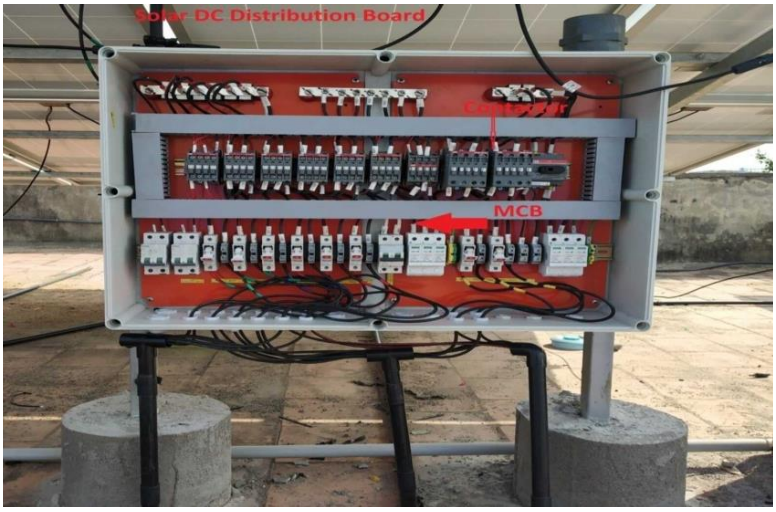

Fig. 3: Photograph of solar DC distribution board

The electrical connections from the panels are connected to Inverter through DC distribution board. DC distribution board mainly consist of contactors, Multiple Circuit Breaker and fuse arrangements as shown in Figure 3. The DC distribution is connected in such way that 2 series of 18 panels each for the rated supply to cater all pumps and fans. However, in starting time of system operation, a delay of two minutes is required to start the motor of solution pump. The energy produced from solar in that two minutes are used to charge the battery backup. A 10 kVA capacity Inverter is used to convert the solar produced DC power to AC power to run the pumps, fans and lighting arrangements. The inverter, battery bank and control board are shown in Figure 4. The electrical control board consist of two VFD's , PLC with Relay arrangement, MCB and control switches to motors of each pump separately. One VFD is used to control the cooling water pump, hot water pump, cooling tower motor and another is used to control the solution pump.

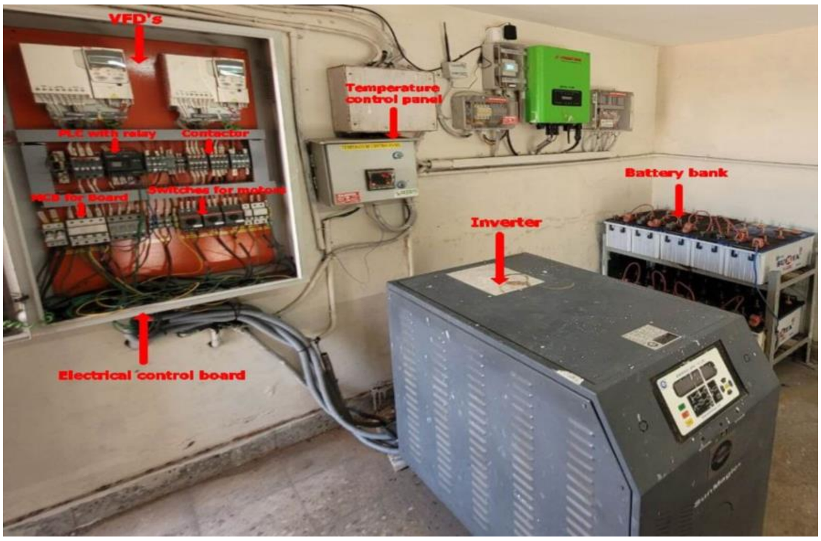

Fig. 4: Photograph of electrical control panel containing inverter, VFD, battery bank etc.,

3.2 Solar thermal collection system

Fig. 5: Solar thermal evacuated tube collector system

Solar collectors are special kind of heat exchangers that transform solar radiation into heat. The collector is a device which absorbs the incoming solar radiation, converts it into heat, and transfers this heat to water flowing through the collector. Evacuated tube collectors (ETC) are used in this project because of their excellent performance at high temperatures. ETC mainly made up of evacuated tube, heat pipe with heat transfer fluid, heat transfer fins. Solar thermal system consists of ETC, solar thermal energy storage tank, hot water pump with required pipe connections. In the system De-Mineralized water is used as heat transfer fluid to transfer the heat from collector system to vapour absorption refrigeration system. Solar ETC collector system is shown in Figure.5

Fig. 6: Sensible thermal storage tank with hot water pump

Fig.7: Cooling tower with cooling water pump

The piping connections involved in the solar collector system are well insulated in such a way that there will be minimal heat loss during the transfer of DM water from one component to another. A 70 mm thickness of glass wool is used as an insulating material. Figure.6 shows the sensible thermal storage tank and hot water pump. Figure.7 shows the cooling tower with cooling water pump which is used to chill the heated water coming from the condenser and absorber by rejecting heat to ambient air.

3.3 Vapour absorption refrigeration and cold storage system

Liquid refrigerant evaporates in the evaporator by absorbing heat from the product's cold room thereby producing refrigeration. Refrigerant vapour from the evaporator is absorbed in the absorber by a stream of weak refrigerant solution. The heat of mixing is removed by the cooling water. Strong refrigerant solution formed after absorption is pumped to the generator by solution pump. Solar energy in the form of hot water is supplied to the generator to boil off the refrigerant vapour from the strong solution. This vapour also contains some absorbent vapour due to affinity between refrigerant and absorbant and low boiling point difference between absorbant and refrigerant. The refrigerant vapour is rectified in the heat exchanger to get refrigerant vapour. This vapour is condensed in condenser by supplying cooling water, and liquid refrigerant is stored in the condensate tank. This tank supplies liquid refrigerant to the evaporator through thermostatic expansion valve and capillary tube. Weak refrigerant solution leaving the generator is sent to absorber for absorption through pressure reduction valve. A solution heat exchanger is provided to cool the weak hot solution before entering the absorber and preheat the strong solution before entering the generator. Thus VARS undergoes cyclic operation to produce continuous refrigeration effect. Cooling water is supplied by cooling tower through cooling water pump to both absorber, condenser by parallel connection. Figure.8 shows cold room with Vapour Absorption Machine.

Fig.8: Vapour absorption refrigeration and cold storage system

4. Experimental setup and Procedure

To experiment with the system, first, ensure that all of the panels are correctly connected according to the design. Then, turn on all of the MCBs in the solar DC distribution panel and ensure that the DC power produced by the solar panels is sent to the inverter. Then, turn on the inverter input, output, battery, and solar MCB in the inverter board, and press the START button in the inverter panel. After that, turn on the MCBs in the control panel in the following order: solar supply, input to control board, PCU switch, pressure switch, output to DC distribution board, and all motors and then, test the solar collector system's functioning. Check that all valves in the vapour absorption refrigeration system are open for operation. Open the bypass valve in the pump line at first, and gradually close it as the pressure rises. Take temperature and pressure readings at all pre- determined locations and combine them. To find the water flow rate at the absorber, generator, and condenser, measure the pressure drop across the respective orifice plates. Measure the airflow rate and temperature differential across the evaporator coil for evaporator side cooling. To examine the performance of the system using time-to-time operation, repeat the observations for each predetermined time interval of 30 minutes.

For evaluating the performance of vapour absorption refrigeration system (VARS), the following procedures are followed.

Evaporator load, Qe :

$Q_e = m_a \times Cp_a \times \Delta T_e - (Q_{losses,wall})$

Where,

ma = mass flow rate of air across evaporator

T_3= Average air side temperature around the evaporator fan coil unit

T_{10}=Ambient Temperature

ma = ρa × Acoil × Vair

A_{coil} = Area of FCU coil

Condenser heat rejection rate, Qc :

$Q_c = m_{cw,c} \times C_{pw} \times \Delta T_{cw.c}$

Where,

$m_{cw,c}$ = mass flow rate of cooling water across condenser = ρw × Qcw,c

$V_{cw,c} = 6.943984 \times 10\text{-}6 \times \sqrt{(\Delta P2)}$

$\Delta_{Tcw,c}$ = cooling water temperature difference across condenser

Absorber heat rejection rate, Qa :

$Q_a = m_{cw,a} \times C_{pw} \times \Delta T_{cw,a}$

Where,

$m_{cw,a}$ = mass flow rate of cooling water across absorber = $\rho_w \times Q_{cw,a}$

$V_{cw,a} = 6.943984 \times 10\text{-}6 \times \sqrt{(\Delta P3)}$

$\Delta_{Tcw,a}$ = cooling water temperature difference across absorber

Generator heat load, Qg :

$Q_g = m_{hw,g} \times C_{pw} \times \Delta T_{hw,g}$

Where,

$m_{hw,g}$ = mass flow rate of hot water across generator = $\rho_w \times Q_{hw,g}$

$V_{hw,g} = 5.980159 \times 10\text{-}6 \times \sqrt{(\Delta P1)}$

$\Delta_{Thw,g}$ = hot water temperature difference across generator

Coefficient of Performance for VARS, COP = Q_e / Q_g

Where,

Qe = evaporator load

Qg = generator heat load

5. Results and Discussion

From the experimental studies, the overall performance of the vapour absorption refrigeration system is presented based on the various operational parameters like hot water and cooling water inlet and outlet temperatures.

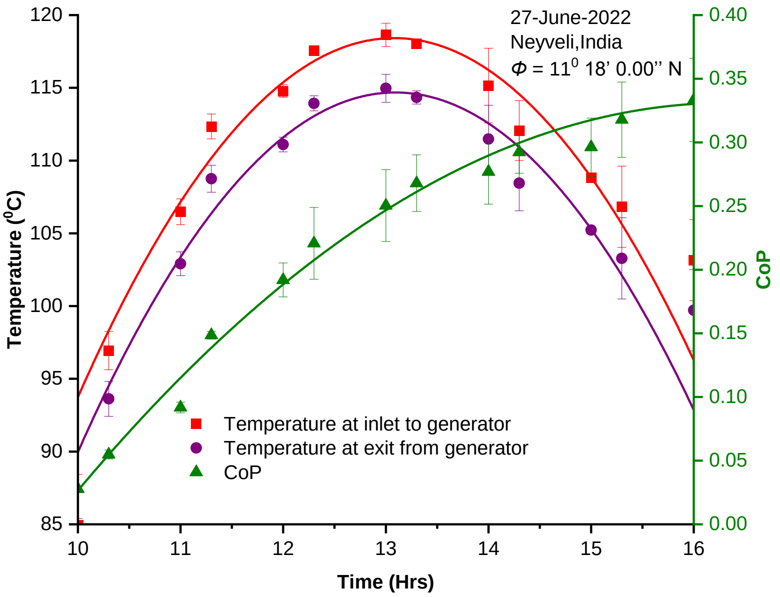

Fig. 9: Effect of variation of generator temperature and CoP with time

The performance of the VAR system along with generator inlet and outlet temperature with respect to time is shown in Fig.9. The hot water give heat to generator, as the outlet temperature is always less than that of inlet conditions. As the hot water inlet temperature increases with time, the generation of refrigerant vapour increases. So the evaporator temperature in cold room cabin decreases as the result of increased CoP.

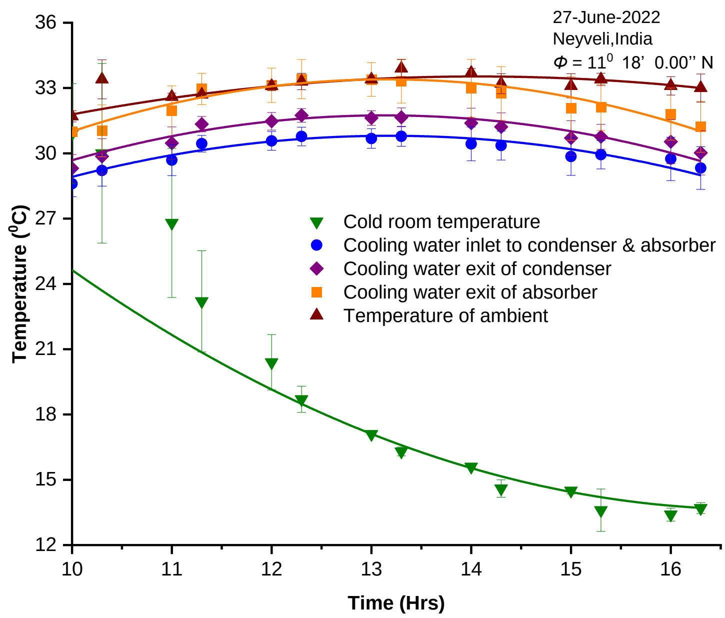

Fig. 10: Variation of cold room temperature, Ambient temperature, Cooling water inlet temperature for condenser and absorber and Cooling water outlet temperature for condenser and absorber with time

Variations of cold room cabin temperature, ambient temperature, cooling water inlet temperature for condenser and absorber and outlet temperature of condenser and outlet temperature of absorber variation with time is shown in Fig.10. The cooling water inlet to both absorber and condenser is made in parallel connection to increase the performance of the system, so that inlet condition of cooling water to both absorber and condenser is same. As the cooling water in absorber and condenser upon removing the heat from the respective components, the outlet conditions is higher than that of inlet conditions.

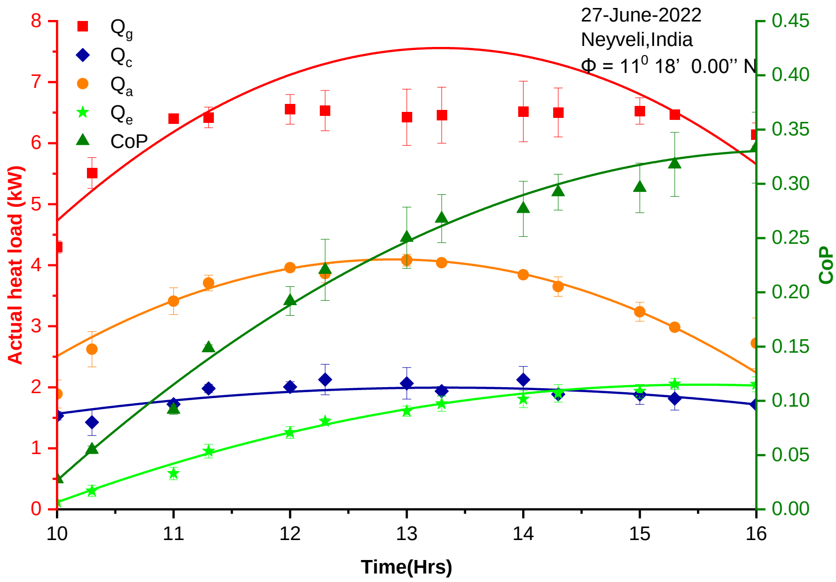

Fig. 11: Effect of variation of actual heat load and CoP with time

From Figure 11. The generator and evaporator heat load increases with time and then decreases. CoP of the system increases with time as the increases in Q_e is higher than Q_g.

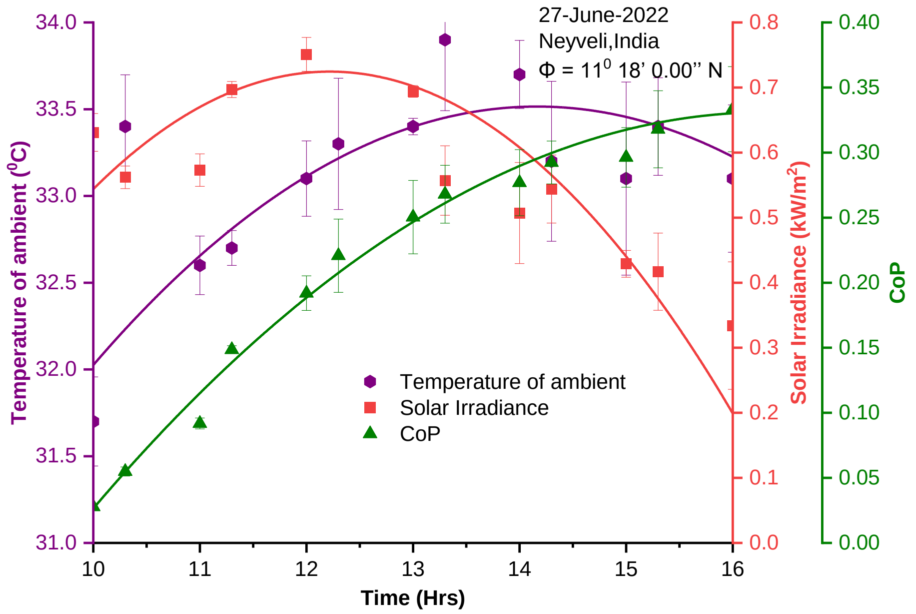

Fig. 12: Effect of variation of solar irradiance, ambient temperature and CoP with time

Figure.12 shows the variation of the ambient temperature, solar irradiance, and COP with time. The Solar Irradiance increases with time and then decreases and ambient temperature keeps in phase with time. CoP of the system increases with time due to increase in Q_e.

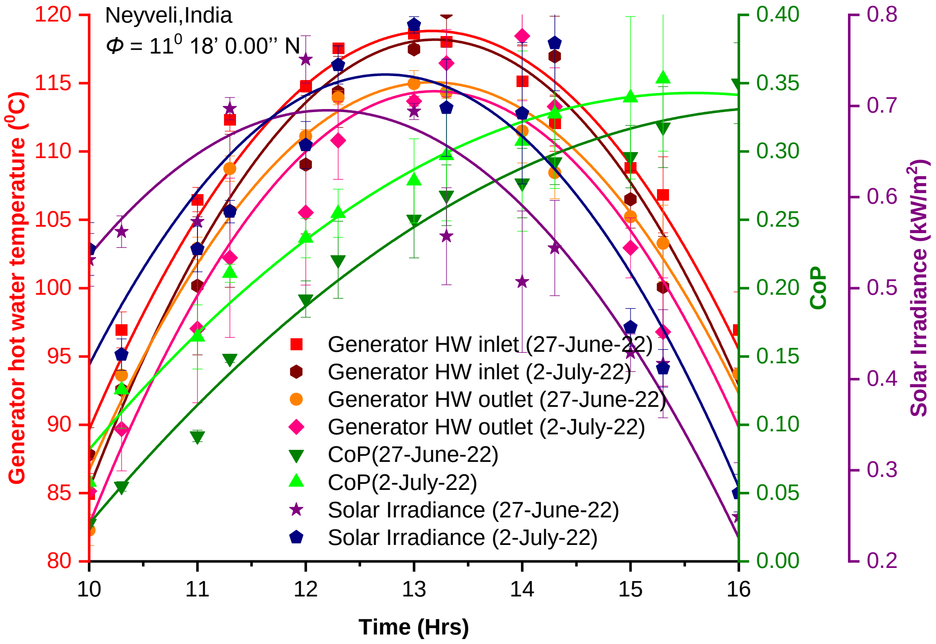

Fig. 13: Variations of operational parameters in the solar vapour absorption refrigeration system.

Temperature at the generator's hot water inlet and outlet vary in phase with solar irradiance on two distinct days. Thus, whenever solar irradiance increases, the Coefficient of performance of the system increases as shown in figure 13.

6. Conclusions

The influence of different operational parameters such as condenser temperature, evaporator temperature, and generator temperature on the performance of the solar Vapour absorption refrigeration cold storage system has been carried out. From the system's performance, the following conclusions have been drawn.

i. As the generator temperature rises, the evaporator temperature decreases, increasing the condenser heat rejection rate. As the generator's heat load decreases, the system's overall performance improves.

ii. The generator hot water inlet temperature, generator hot water exit temperature and CoP increase with increasing solar Irradiance.

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Appendix: Units and Symbols

Table 1: symbols for miscellaneous quantities

Quantity	Symbol	Unit
Area	A	m^2
Volume flow rate	V	$m^3\ s^{-1}$
Mass flow rate of air	m_a	$kg\ s^{-1}$
Mass flow rate	$\dot{m}$	$kg\ s^{-1}$
Evaporator load	Q_e	kW
Condenser heat rejection rate	Q_c	kW
Absorber heat rejection rate	Q_a	kW
Generator heat load	Q_g	kW
Temperature	T	^0C
Overall heat transfer coefficient	U	$W\ m^{-2}\ K^{-1}$
Efficiency	η	
Density	ρ	$kg\ m^{-3}$
Time	t	s

Abbreviations

VARS- Vapour Absorption Refrigeration system

ODP- Ozone depletion potential

DMF-Dimethylformamide

CoP-Coefficient of Performance

PV-Photovoltaic

VFD-Variable Frequency Drive

PLC-Programmable logic controller

DC-Direct current

AC-Alternating current

MCB-Multiple circuit breaker

ETC-Evacuated tube collector

DM-Demineralized

VAM-Vapour Absorption Machine