MONITORING AND SIMULATION OF PARABOLIC TROUGH COLLECTOR POWERED VAPOR ABSORPTION REFRIGERATION SYSTEM FOR RURAL COLD STORAGE

by

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India is one of the largest contributors to the world's agricultural products. The majority of people's livelihood in India depends on agriculture and its allied sectors. According to an economics survey in the agricultural year of 2019-2020, India is estimated to have produced around 292 million tonnes of food grain. The share of agriculture in India's GDP is 19.9%. Even though India is an active participant in global agricultural trade, the total agricultural product export is only 2.5%. Agricultural produce is easily perishable and the quality gets affected which will then affect their market value. To meet the future food demands, agricultural produce must be able to store for a longer amount of time for round the year availability. The traditional food storage practices cannot satisfy that condition. These perishables need a proper cold supply chain to increase the shelf life. In this paper performance of a parabolic trough collector integrated vapor absorption refrigeration system was developed and studied. Renewable integrated cold storage would open door to the sustainable energy future.

Keywords*: agricultural product, cold supply chain, parabolic trough collector, thermal integration, sustainable, vapor absorption refrigeration*

Introduction

In the modern world, each and every person tries to achieve socio-economic growth. Socio-economic growth would directly or indirectly influence the increase in the need for food. With many countries still struggling to achieve food security, an imbalance in meeting everybody's food need will be increased. Per capita calorie consumption changes not only differ between developed and developing countries but also changes within the country based on their economic growth. So, food is directly or indirectly related to the country's economy. Not only the quality but quantity of food is also needed to be improved to solve the hunger and malnourishment problems.

By surveying and predicting the future, the author has stated that to protect the people from getting malnourished government should allocate a separate share to increase the income of a specific group [1]. In developed countries, agricultural waste occupies a signifi-

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cant part of their total waste generation [2]. India is the second-largest producer of food following China. The post-harvest losses of fruits and vegetables in India alone is about 30% to 40%. This loss is due to the lack of value addition and low shelf life. This large-scale loss also has a fair share of impact on the Indian economy [3]. Concentrating on increasing the agricultural production to meet the food need without proper planning would only increase wastage. This problem can be solved by proper handling and reducing post-harvest waste.

Due to lack of logistics and poor storage every year 92651 crores are lost in the agricultural sector [4]. The majority of India's cold storages are mainly located in four states in North India. The majority of the cold storage is owned by private sectors. Cold storage is primarily used for potatoes as they can be stored easily [5]. Cold storage itself is a separate sector that requires a huge development to revolutionize the agriculture sector.

Coal, oil, and natural have been the primary source of fuel for a long period of time. After identifying certain environmental effects caused by the concerned organizations suggested the usage of renewable energy. The barrier to this technology implementation is cost. As the need for energy grows an inexhaustible form of energy s the only solution [6].

In 2005, 40% of electricity was from coal and only 2% was from renewable energy around the world. Coal is one of the biggest contributors to carbon. A huge amount of renewable energy potential is from the Sun. Solar technology has also shown higher efficiency [7]. India is already making an effort to move towards renewable energy technology [8]. For example, the government is providing a lot of support for solar pumping [9]. Solar energy is also proven to provide clean water in rural areas [10] and also institutions [11]. Technology has improved even for solar PV disposal solutions [12].

According to a 2010 report, with 70.5% solar water heater, China occupies the first place. India is also in the list of the top ten with 1.2% of its share in the solar water heater. The basic model of the water heater is a flat plate collector. The next one is an evacuated tube collector. Another solar concentrating collector model and compound parabolic collector (CPC) were also reviewed. Solar water heating is a popular solar technology because of its economic viability [13]. Most commonly used water heater technology, flat plate collector have salt deposition problems in the riser tubes [14]. Financial viability study for the concentrated collector has shown that parabolic trough collector (PTC) is suitable for hot and dry location [15]**.** Thermal losses in this system are very small and do not affect the difference in experimental and simulation results [16]. To improve the storage and increase the viability of the system, PV and PTC can be used in a hybrid [17].

Performance of vapor absorption refrigeration (VAR) system was studied and found to have less environmental effects in comparison with the commercially available vapor compression system. The VAR also has easy adaptability to renewable energy technologies [18]. In high cooling demand industries absorption chiller are used. Operating at the optimal condition would reduce the levelized total cost of the system [19]. Solar PV integrated system was studied and found to have a better solution for tropical agricultural produce storage for the rural environment. Renewable integrated VAR is an apt technology especially for rural areas [20]. A 5 kW cooling capacity system driven by a solar collector field with a storage tank was studied. It was used by the absorption cycle to produce air conditioning in a laboratory building. This system has a cooling tower to remove heat produced by the absorption machine. The 24 CPC's were used to supply the required heat input. Even though it rains a lot during early summer in the selected region, the maximum temperature can be noted. The average outdoor temperature was between 32 ^{o}C and 37 ^{o}C. The COP lies in the range of 0.28 to 0.48. The solar collector efficiency varied between 0.35 and 0.53. Evaporator temperature as low as 7 ^{o}C can be achieved [21].

The studied system used concentrating solar collector as the absorber/desorber unit with ammonia as a refrigerant and $SrCl_2$ as an absorbent. During the testing period, the evaporator temperature never raised above 6 °C. If extra heat would be added even after desorption it would cause superheating and adds burden on the system and hence undesirable. The COP value recorded in this system was 0.045-0.082 [22].

A TRNSYS simulation program using meteorological data was studied for Cyprus. In the selected area solar energy is abundant with 300 sunshine days. The system was investigated for flat plate collector, CPC, and evacuated tube collector. When the working temperature lies below the optimum value then the boiler would operate. This extra heat generated by increasing collector area can be used for domestic water heating applications. The final selected system uses CPC tilted at 30° from the horizontal [23]. There are several studies for PTC and VAR but there are not many studies that bring these technologies together. This paper would act as a common ground to bring together the two most sustainable technologies together.

Parabolic trough collector

Reflector: The parabola-shaped mirror reflector would reflect the beam radiation falling on its surface towards the focal line of the parabola structure. Since PTC can operate by utilizing only beam radiation, it has to be continuously aligned towards the direction of the Sun as the position of the Sun varies every 15 minutes. The system is provided with a manual tracker to position the collector towards the Sun. *Collector*: It is located at the focal line of the reflector. The receiver is the absorber tube black coated with nickel/chromium that is sealed inside a glass tube. The glass tube would help decrease the convective losses from the tube. Figure 1 shows the concentrated collector consists of a reflector of aperture length 1500 mm and aperture width of 2065 mm. The collector tube is made up of stainless steel with a 74 mm outer tube diameter and 28 mm inner tube diameter.


Figure 1. Parabolic trough collector

The thermal efficiency of the system is:

$$\eta = \dot{m}C_p \frac{T_o - T_i}{AI_b} \tag{1}$$

Not all the heat absorbed by the receiver is utilized for water heating. A certain amount of heat gets lost due to various parameters like wind velocity, ambient temperature, and emissivity of the receiver:

$$U_L = 1.7 \cdot 10^{-9} \left(T_r + T_a\right)\left(T_r^2 + T_a^2\right) + 25.746\left(s\right)0.6 \quad \text{for} \quad s < 0.67 \tag{2}$$

$$U_L = 1.7 \cdot 10^{-9} \left(T_r + T_a\right)\left(T_r^2 + T_a^2\right) + 0.427 + 277.76\left(s\right)0.53 \quad \text{for} \quad s > 0.67 \tag{3}$$

Once the water is heated will leave the receiver and enter the VAR generator unit. There will be a fall in temperature during this transmission through the pipe:

$$\text{Heat loss in the piping} = \dot{m}C_p\left(T_o - T_{i\text{VAR}}\right) \tag{4}$$

Vapor absorption system

The VAR requires four major parts which include an absorber, generator, condenser, and evaporator. The VAR could be driven by low-grade energy *i.e.*, heat energy. Usually, in electrically driven systems the required heat is supplied to the generator using an electric heater. In this experiment, the required heat is supplied by a PTC instead of utilizing electrical energy

Figure 2 shows the additional set-up made for the PTC-driven system. It is made of copper and provided with a valve to control the flow rate of hot water. The selected VAR system is a 40 L capacity with NH_3-water working fluid. By integrating with one of the renewable energy technologies this zero CFC technology would become even more environmentally friendly.

Figure 2. Integration set-up

Experimental set-up

Figure 3 shows the experimental set-up with a monitoring unit for continuous monitoring and recording of data. Electronic monitoring unit helps measure the temperature, flow rate, and record the data in the data logger. This set-up allows data storage for up to 1 year.

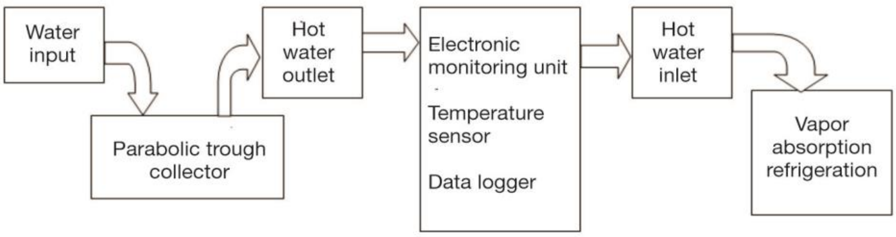

Figure 3. Block diagram of the PTC integrated VAR

The experimental arrangement is shown in figs. 4 and 5. The study was done at Dindigul district, Tamil Nadu. With an average temperature of more than 30 °C the selected location is a good choice for solar thermal energy utilization. The hot water output from the concentrator collector is used as input to the vapor absorption refrigerator. The PTC is located in an open area such that there is no tall build or any other barrier that could cast their shadow on the reflector plate. A nearby large barrier could also reduce the beam radiation. The performance of refrigeration can be affected by external environmental conditions [24]**.** So, it is

Figure 4. The PTC located in outdoor

Figure 5. Refrigerator placed indoor

placed inside a nearby building to reduce sun exposure. The connecting pipe was made as short as possible to reduce the pipe losses.

Results and discussion

Figure 6 shows the water heater outlet temperature. At the beginning of the operation due to lower direct normal irration (DNI), the outlet temperature of the water heater matches with the inlet temperature. As the Sun's position changes the amount of DNI increases. So, the outlet temperature has reached up to 98 $^{\circ}$C during the peak radiation time. Hot water leaving the generator will also have a reduced temperature, which can be utilized for process heating like drying onions. After peak duration, a gradual decrease in PTC outlet temperature can be noted. Since this design uses manual tracking continuous monitoring is compulsory. The fig. 7 shows the efficiency of the PTC. The output valve is opened completely and study is done for a single flow rate. The efficiency of the system is also dependent on the radiation. During peak hours the maximum efficiency recorded was 67% while the average efficiency during the period of operation is 60%. As stated earlier this system requires continuous monitoring otherwise due to not aligning with the sun, beam radiation falling on the reflector would reduce abruptly affecting the efficiency of the system.

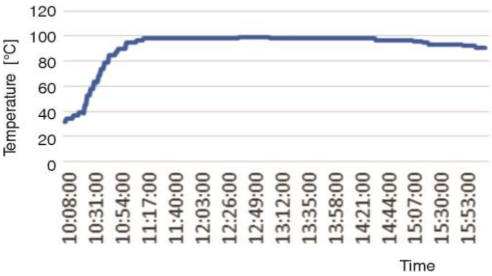

Figure 6. The PTC outlet temperature

Figure 7. The efficiency of the PTC

Figure 8 shows the increase in VAR generator temperature with respect to time. Unlike the electrically powered system, in this PTC integrated system, generator temperature increases gradually. This is because its temperature rise is dependent on the solar radiation and heat transfer rate between the hot water from the PTC and VAR working fluid. Figure 9 shows the evaporator temperature. Even from the start of the experiment a small temperature change can be noted. But it takes around three hours to reach the lowest temperature of 11 °C. In the selected location fruits and vegetables like tomato, green chili, grapes, and mango, *etc*., and most of the agricultural produce from these locations are tropical fruits and vegetables. So, it is a suitable cold storage unit for the local agricultural produce.

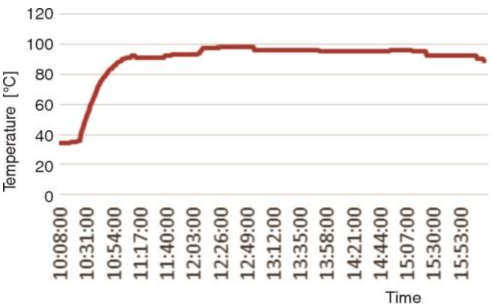

Figure 8. Generator temperature

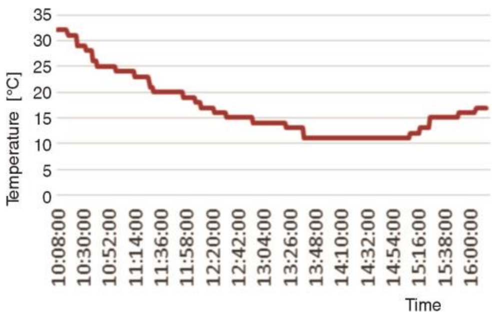

Figure 9. Evaporator temperature

The temperature is maintained at the lower range only during peak durations. It starts raising once the sun starts going down. For the system to operate for 24 hours it requires a hot water storage tank. The feasibility of the system with a storage tank is studied with the help of a simulation model which is, more economical than the direct implementation. So, a simulation model for the system using TRNSYS was designed.

Simulation study

A simulation model was developed to study the possible changes that can be brought to improve the system performance without any physical alteration. A simulation model for absorption chiller was developed using a TRNSYS model as shown in fig. 10. Type-109 was used as input for weather data. Type-4 hot water storage tank was used as a heat buffer to run the chiller completely solar dependent for 24 hours. Type-107 absorption chiller was used to provide the required cooling. The simulation result is shown in figs. 11 and 12. This simulation model has proven that a 24 hours water heater integrated system is possible. The simulated result has shown that up to 7.9 °C can be reached with the COP of 0.46.

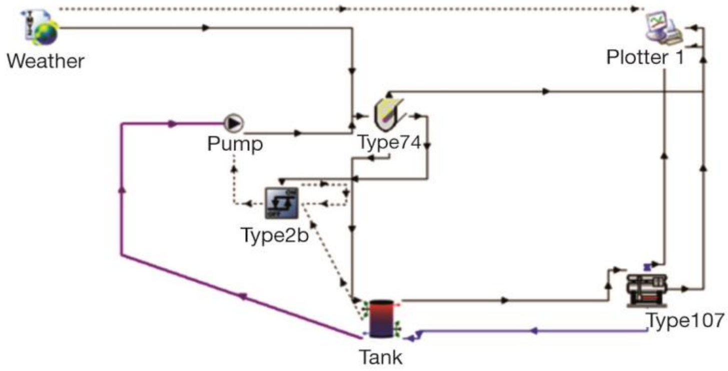

Figure 10. The TRNSYS simulation model

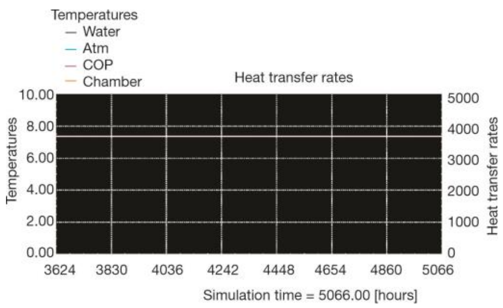

Figure 11. Chamber temperature of TRNSYS simulation model

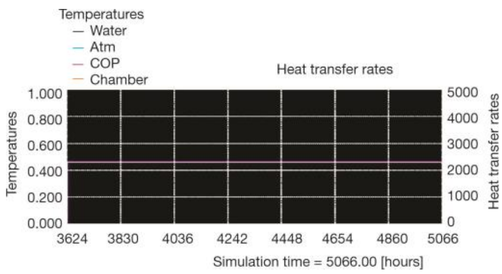

Figure 12. The COP of TRNSYS simulation model

Conclusion

With low-grade energy requirements, absorption refrigeration has many possible energy sources. The presence of various technology would give a wide range of options for the absorption technology to choose from based on location, environment, raw source availability, and cost. Being the second-largest GDP contributor, reducing the post-harvest waste would not only help food security but also improve the economic growth of the country. The PTC integrated VAR system would help reduce post-harvest waste by providing a solid foundation for cold storage in India. Solar thermal is already a mature technology so it can easily adapt to VAR integration. The 60% average thermal efficiency of the system has proven this statement. The TRNSYS model with thermal storage tank gives the reliability of the system for around the clock operation.

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Nomenclature

A – collector area, [m^2]
C_p – specific heat capacity, [kJkg^{-1}°C^{-1}]
$\dot{m}$ – mass-flow rate of the heat transfer medium, [kgs^{-1}]
s – wind velocity, [ms^{-1}]
T_a – ambient temperature, [°C]
I_b – incident beam radiation, [Wm^{-2}]
T_i – tube inlet temperature, [°C]
$T_{i\mathrm{VAR}}$ – vapor absorption refrigerator inlet temperature, [°C]
T_o – tube outlet temperature, [°C]
T_r – receiver temperature, [°C]
U_L – temperature coefficient

Acronyms

CPC – compound parabolic collector
DNI – direct normal irration
PTC – parabolic trough collector
VAR – vapor absorption refrigeration

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