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Proceeding Paper

Thermal Analysis of a Solar Assisted Cold Storage Unit for the Storage of Agricultural Perishables Produce †

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Abstract: A solar based cold storage unit for the preservation of food products is an excellent way to reduce post-harvest losses at lower energy costs. Energy optimization is essential to improve the reliability of the system. In the case of cooling, a major factor to reduce energy consumption is the uniform distribution of air inside the cooling chamber to maintain the even temperature of stored products. For this, a detailed thermal analysis is required to analyse the cooling process for energy saving and optimum conditions. In the current study, an energy and exergy based thermal analysis of a solar assisted cold storage unit is presented. A parametric investigation and a proper understanding about the influence of thermodynamics on the cooling process were obtained. All the experimentally calculated parameters (energy utilized, energy utilization ratio, energy loss and exergy efficiency) were subjected to a model curve fitting using Sigmaplot-12 and a polynomial cubic model was found best fitted based on the values of coefficient of determination. Thermal analysis showed variations in the rate of energy utilization, energy utilization ratio, exergy losses and exergy efficiency in the range of 3–18 kJ/s, 0.37–0.80, 0.8–2.25 kJ/s and 40–60%, respectively. The average value of COP of the system was found to be 3.95.

Keywords: solar energy; thermal analysis; food storage

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1. Introduction

Post-harvest losses of fruits and vegetables are estimated to be between 30 and 40%, contributing towards a significant portion of total loss due to lack of storage facilities and poor infrastructure. Several methods are available for the preservation of food, the most common being preservation through heat exclusion [1]. A cold storage unit is therefore effective for this purpose. The current total estimated capacity of cold storage for fruit and vegetables in Pakistan is 0.85 million tons, 90% of which exist in big cities, such as Punjab. Cooling is an energy intensive unit operation. A reduction in energy consumption and the utilisation of sustainable and renewable energy technologies are essential in order to meet the increasing demand for cooling, using environmentally friendly methods [2]. Uniform temperature distribution inside the chamber is not only important to maintain the quality of stored products, but also helpful in reducing energy consumption. The optimization of a newly developed system is therefore essential. In this regard, a thermal-based system requires a detailed thermal analysis. Thermal analysis, especially energetic analysis, is a method used to assess the performance of the processes and investigate exergy at various positions in the system's components using energy conversion. In this study a detailed thermal analysis was performed on a 4.5-ton capacity cold storage unit to assess energy distribution and to define the optimum operating conditions to save energy.

2. Methodology

System description: Figure 1 shows the cold storage unit with a capacity of 5 ton used in this study. It consists of two major parts, namely the cooling chamber and the vapor compression refrigeration system. The cold storage room was insulated and airtight to achieve the required temperature setting. Thermal pads (each of 4 ft length × 2 ft width × 0.16 ft thick) containing a brine solution as a PCM material were employed in the cooling chamber. A vapor compression refrigeration unit with a capacity of 3.5 ton was installed. The main components of the refrigeration unit mainly consist of the evaporator, compressor, condenser, and expansion valve. A solar system of 10 kW was installed for powering the system. For the experiments, a data logger was incorporated for continuous monitoring and data acquisitions. Several parameters were measured such as solar irradiance, cold storage temperature, ambient temperature, compressor outlet temperature, condenser outlet temperature, expansion valve temperature, and brine pads temperature. To measure these parameters, thermocouples and a pyranometer were connected to the data logger.

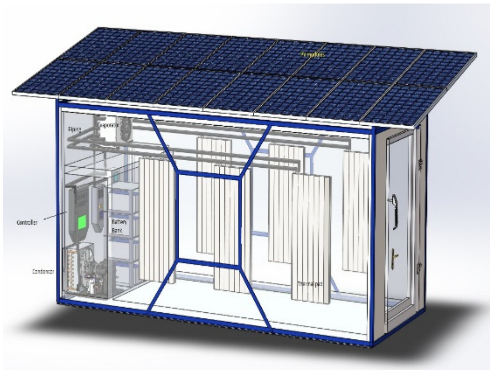

Figure 1. 3D layout of solar assisted cold storage unit.

Fundamental equations for the conservation of the mass as well as material, principles of energy and exergy balance were used. Heat transfer and interaction of inlet and outlet streams were governed considering a control volume approach for each system component. The energy utilization ratio can be calculated as;

$$\mathrm{EUR} = \frac{\text{Energy Utilized}}{\text{Energy Supplied}} = \frac{(C_{pi}T_i - C_{po}T_o)}{(C_{pi}T_i - C_{pa}T_a)} \tag{1}$$

where, C_{pi} = inlet specific heat of air; C_{po} = outlet specific heat of air; C_{pa} = ambient specific heat of air; T_i = inlet temperature; T_o = outlet temperature; T_a = ambient temperature.

The general applicable exergy equation for the determination of the total exergy of inflow, outflow and losses is as follow [3];

$$\text{Exergy} = c_{pca}\left[(T_a - T) - T\ln\frac{T_a}{T}\right] \tag{2}$$

where T_a = Temperature of ambient air, T = Temperature at respective point

$$\text{Exergy rate} = \mathrm{Ex}' = Q\left(\frac{\text{Tambient air}}{\text{Trespective point}} - 1\right) \tag{3}$$

Generally, the exergy inflow at the cooling chamber can be determined as;

$$\mathrm{Ex_{in}}' = Q * \left(\frac{\text{Tambient air}}{\text{Texpansion valve}} - 1\right) \tag{4}$$

At cooling chamber, exergy output can be calculated as;

$$Ex_{out}' = Q * \left(\frac{\text{Tambient air}}{\text{Tchamber}} - 1\right) \quad (5)$$

Using Equations (3) and (4), exergy loss can be calculated as;

$$\text{Exergetic loss} = \text{Exergetic inflow} - \text{Exergetic outflow} \quad (6)$$

The ratio of exergy outflow to exergy inflow for cold chamber is used for the calculation of exergy efficiency given as;

$$\text{Exergetic Efficiency } (\eta\text{Ex}) = \frac{\text{Exergy inflow} - \text{Exergy loss}}{\text{Exergy inflow}} \quad (7)$$

3. Results and Discussion

Figure 2a, shows the rate of energy utilization, which is also known as cooling load with respect to time. At the early stages of the cooling process, the rate of energy utilization was high due to the increase in temperature inside the cooling chamber for both modes of operating supplies, such as the grid and solar PV. The cooling load reached peak value when the ambient temperature was 34.4 °C at 3:13 p.m. As the cooling process proceeded, a decline in the energy utilization occurred due to a decrease in temperature inside the cooling chamber. For both supplies, it took nine hours to reach the required temperature, with a similar trend for rate of energy utilization. During the entire cooling process, the energy utilization values ranged from 3 kJ/s to 18 kJ/s. Based on the energy input to the storage chamber and energy utilized within it, the energy utilization ratios (EUR) were calculated and plotted against the cooling time and chamber temperature, as shown in Figure 2b. It can be observed that the EUR of the cooling chamber reduced as the cooling time proceeded due to the variation in the temperature differences of chamber and ambient temperatures. When the system tripped, the EUR suddenly reduced to 0.66 to 0.37.

Figure 2c shows the energy loss (energy destruction) in the cooling chamber, which decreased as the cooling time preceded. This can be explained the same way as explained for the energy utilization. Hence, exergy loss is directly proportional to energy utilization, and both are influenced by cooling temperature airflow rate. The range of exergy loss was found to be 0.80 kJ/s to 2.25kJ/s, respectively. Based on the exergy loss and exergy inflow and exergy outflow, the values of exergy efficiency were calculated and plotted against the cooling time, as shown in Figure 2d. The energetic efficiency can also be explained by the fact that energy availability in the cooling chamber increased with the increase in cooling time. It can be observed that the exergy efficiency increased as the cooling time increased. The overall scenario of the exergy analysis of a solar assisted cold storage unit is shown is Figure 3. The values shown in the chart were investigated when the system attained its set temperature i.e., 4 °C in 9 h.

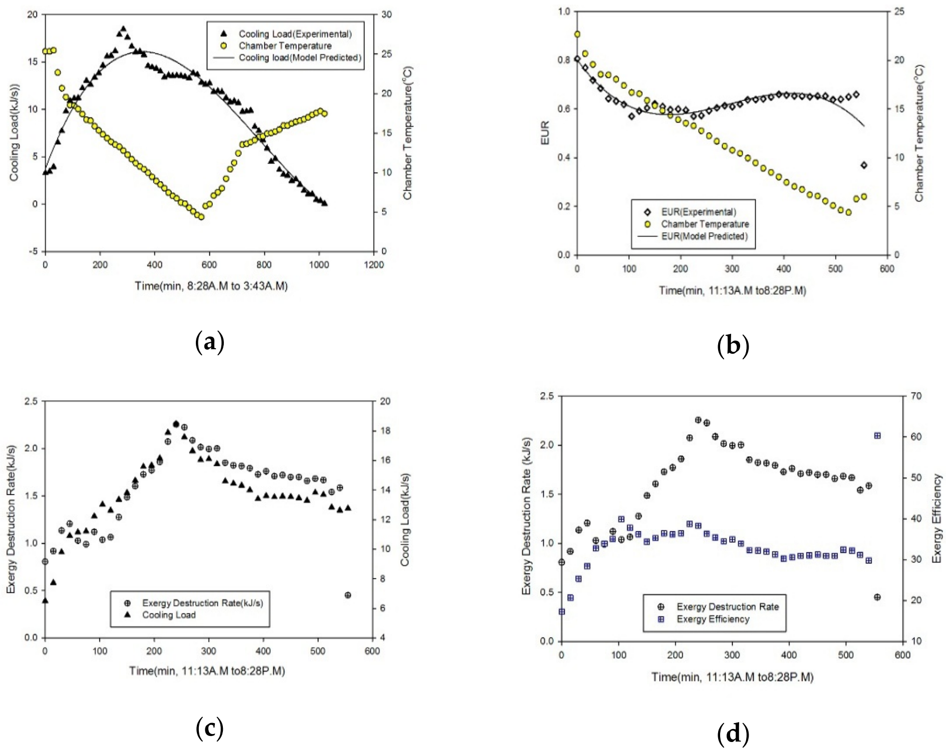

Figure 2. Energy and exergy analysis of solar cold storage unit, showing variation of cooling load with chamber temperature (**a**) Energy utilization ratio with chamber temperature (**b**) Exergy destruction rate during the cooling process with respect to the cooling load (**c**) Variation of exergetic destruction rate with exergy efficiency (**d**).

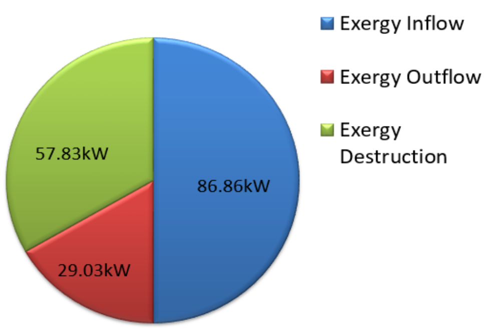

Figure 3. Overall exergy analysis of a solar cold storage unit.

4. Conclusions

In the present study, thermal analysis (energy and exergy analysis) of a solar assisted cold storage unit was performed experimentally and the following outcomes were concluded.

- Cooling Load (Q) was calculated to be in the range of 3–18 kJ/s.
- Exergy inflow and outflow rates were found in the ranges of 0.97–3.65 kJ/s and 0.16–1.4 kJ/s, respectively, while exergy destruction was 0.8–2.25 kJ/s, leading to an exergetic efficiency of 40–60%.
- Energy Utilization Ratio (EUR) was calculated to be 0.37–0.80 with a system Coefficient of Performance (COP) value of 3.95.
- Total electrical consumption to attain 4 °C in 9 h was 6.179 kWh.

So, it shows that solar energy is a viable solution for running a cold storage unit for the storage of perishable horticultural produce at farm level.

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Conflicts of Interest: The corresponding author declares that this submission has no conflict of interest of any type, on behalf of all authors.

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