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# Energy and Exergy Analysis of a Greenhouse Heating System Equipped with a Parabolic Trough Concentrator and a Flat -Plate Solar Collector

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## Introduction

Greenhouse cultivation has been increased in response to population growth, reduction in available supplies and arable lands and raising the standards of living. The quality and quantity of the products are profoundly affected by the greenhouse temperature. Therefore, providing an appropriate heating system is an elementary requirement for greenhouse cultivation. A number of factors such as glazing material, greenhouse configuration, product type, and climate conditions should be considered to design a greenhouse heating system.

Due to the environmental concerns associated with the fossil fuels, renewable energy-powered heating systems such as geothermal, solar and biomass- are increasingly considered as the alternative or supplementary to the traditional fossil fuel heating equipment in greenhouses. In this way, a number of researchers have developed different greenhouse heating systems to reduce fossil fuel consumption. In Iran, because of appropriate available solar irradiance, the solar heating systems can be efficiently employed for greenhouse cultivation.

A compound solar greenhouse heating system was experimentally and analytically investigated in the present study. To verify the obtained heat transfer equations, a set of experiments were carried out at Biosystems Engineering Campus of the Shahid Bahonar University of Kerman.

## Material and Methods

The designed system was comprised of a Parabolic Trough solar Collector (PTC), a dual-purpose modified Flat Plate solar Collector (FPC) and a heat storage tank. The modified FPC was located inside the greenhouse to act as a heat exchanger to transfer the stored heat to the greenhouse atmosphere during the night. The FPC also collects the solar radiations during the sunshine hours to enhance the thermal energy generation. Heat transfer equations of the PTC and the FPC were written and the useful energy gain of the heating system was determined at the quasi-static condition during the day. Experimental verification of the analytical models was conducted using regression coefficient (r) and root mean square percent deviation (e) criteria as follows:

$$r = \frac{n\sum X_i Y_i - (\sum X_i)(\sum Y_i)}{\sqrt{n\sum X_i^2 - (\sum X_i)^2}\sqrt{n\sum Y_i^2 - (\sum Y_i)^2}} \quad (1)$$

$$e = \sqrt{\frac{\sum (e_i)^2}{n}} \quad (2)$$

where

$$e_i = \frac{X_i - Y_i}{X_i} \quad (3)$$

where $X_i$ and $Y_i$ are respectively the *ith* analytical and experimental data and *n* shows the number of observations.

Exergy analysis of the PTC and the FPC were carried out and the effect of the different fluid flow rates through the PTC on the exergy efficiency of the different components was investigated using the experimental data.

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**Results and Discussion**

Increasing the fluid flow rate increased outlet temperature of the PTC due to the increase in heat removal factor and inlet temperature; whereas, caused a reduction in outlet temperature of the FPC. Since the thermal efficiency of the PTC improved with the fluid flow rate, the PTC fraction enhanced when the flow rate increased from 0.5 to 1.5 kg $min^{-1}$. However, the PTC fraction values were less than 50% and sometimes have dropped below zero.

The exergy efficiency of the PTC improved with increasing the flow rate. The reason was that the difference between the inlet and outlet temperatures of the PTC increased with the flow rate at the similar conditions of solar irradiance and ambient temperature. The highest exergy efficiency of the FPC was observed at the flow rate of 0.5 kg $min^{-1}$.

**Conclusions**

The results of the study revealed that:

- There was a suitable agreement between the obtained analytical expressions and the experimental data based on root mean square percent deviation and regression coefficient criteria.
- The highest stored energy in the tank was around 40.02 MJ at the flow rate of 0.5 kg $min^{-1}$.
- Increasing the flow rate improved the PTC exergy efficiency.

**Keywords:** Exergy efficiency, Experimental verification, Heat transfer, Parabolic trough solar collector, Stored energy