Energetic and exergetic efficiency of latent heat storage system for greenhouse heating

YASAR DEMIREL
A Bascetincelik
HH. Ozturk
H.O. Paksoy

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ENERGETIC AND EXERGETIC EFFICIENCY OF LATENT HEAT STORAGE SYSTEM FOR GREENHOUSE HEATING

A. BAŞÇETİNÇELİK¹  H. H. ÖZTÜRK¹  H. Ö. PAKOY¹  Y. DEMİREL¹

¹Dept. of Agricultural Machinery, Faculty of Agriculture, University of Çukurova, 01330 Adana-TURKEY
²Dept. of Chemical, Faculty of Art and Science, University of Çukurova 01330 Adana-TURKEY
³Dept. of Chemical Eng., King Fahd Univ. of Petroleum & Minerals, Dhahran 31216, SAUDI ARABIA

ABSTRACT

In this research, solar energy has been stored using the paraffin with the latent heat technique for heating the plastic greenhouse of 180 m². Energy and exergy analyses were applied for evaluation of the system efficiency. An average values of the rates of heat and thermal energy stored into the HUS were 1740 W and 60 W for the charging periods. It was determined that the average values of the net energy and exergy efficiencies of the system were 41.9 % and 3.3 %, respectively.

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KEYWORDS
Solar energy storage; greenhouse heating; energy and exergy efficiencies

INTRODUCTION

Heating applications in the greenhouses have an important effect on the yield as well as on the quality and the culturing time of the products. Because of the relatively high cost and uncertain availability of fossil fuels, considerable attention has been given to new and renewable energy sources as an alternative means of heating greenhouses. Solar energy is an attractive substitute for conventional fuels for passive and active heating of greenhouses. Solar thermal energy can be stored as sensible heat, latent heat, heat of reaction, or combination of these. In most storage systems, it is stored as sensible heat in materials such as water and rocks. In Latent Heat Storage (LHS) systems, the latent heat accompanying a phase change of a material is used for Thermal Energy Storage (TES). Most of the greenhouse heating demand can be supplied by LHS systems.

Traditional energy analysis, based on the First Law of Thermodynamics, is concerned only with the efficiency of energy processes (Fang et al., 1995). Exergy analysis, derived from both the First and Second Laws of Thermodynamics, as compared to energy analysis takes into account the quality of the energy transferred. Exergy analysis is recognised by many engineers to be a powerful tool for the evaluation of the thermodynamic systems in general, and of TES systems in particular (Rosen et al., 1988). Comprehensive studies have been carried out by many researchers concerning the evaluation, designing and modelling of TES applications by using exergy analysis.

The main objectives of this research are to store solar energy using the paraffin as the PCM with the latent heat technique for heating the plastic greenhouse of 180 m² and to investigate the thermal performance of the paraffin LHS unit under the particular operating conditions. In this paper, the performance of the LHS system in which paraffin is used, was evaluated by using energy and exergy analyses and, energy and exergy efficiencies of the system were compared for the charging periods.

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PII: S0960-1481(98)00253-5
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3. In case iterative calculations, stop after the second iteration.
GENERAL DESCRIPTION OF THE SYSTEM

The system consists mainly of four units: solar air heaters, the seasonal Heat Storage Unit (HSU), the plastic greenhouse and a computerized data acquisition/control unit. The external Heat Collection Unit (HCU) consisted of 27 m² of south-facing solar air heaters mounted at a 55° tilt angle. The solar air heaters each with an absorber plate area of 1.5 m² have air-flow passages packed with Raschig rings underneath the absorber plates to increase the heat transfer from the plate to the heat transfer fluid (e.g., air). The absorber surface of the installed air heaters is 0.15 m² per square meter of the greenhouse ground surface. The HCU was supplied with air from the environment by a centrifugal fan (Başçıncelik et al., 1997).

The seasonal HSU consisted of a 1.5 m diameter cylindrical tank with a volume of 10 m³. Two coils of corrugated PVC tube as the heat exchanger in the HSU. The total length of the coiled tubes is 97 m and diameter of the coils is 0.10 m. The HSU volume per square meter of the greenhouse ground surface is 0.055 m³ while the HSU volume per square meter of the solar air heaters is about 0.37 m³. The HSU was filled with 6,000 kg of paraffin equivalent to 33.33 kg of paraffin per square meter of the greenhouse ground surface. The thermal properties of the paraffin used as the PCM were measured with a Differential Scanning Calorimeter (DSC): the melting temperature range and the latent heat of melting were 48-60 °C and 190 KJ/kg, respectively (Öztürk, 1997).

The experimental greenhouse was a galvanized steel pipe structure covered with a single-layer PE film; it has a floor area of 180 m² (15 m x 12 m) and a gutter height of 2.3 m. The warm air supplied by the seasonal HSU was distributed by means of perforated PE ducts lying on the ground surface in the greenhouse. All air temperatures, at the inlets and outlets of the HSU and the solar air heaters, and inside greenhouse were measured by thermistors. To measure the temperatures of the paraffin and the circulating air, the thermistors were placed at various points of the inner and outer coils, and within the paraffin in the HSU. All the temperatures were measured every second, and 15-minute averages were recorded. The measurements were fed into the data-logger and computer control system.

RESULTS AND DISCUSSION

The results of energy and exergy analyses of the LHS system for the greenhouse heating were evaluated for the first (from 3 to 23 August, 1994) and second (from 24 August to 20 September, 1994) charging periods.

The Rate of Heat Stored into the HSU

The changes of the rates of heat transferred and stored into the HSU during the first and second charging periods are shown as a function of time in Fig. 1a and 1b, respectively. The rates of heat transferred and stored into the HSU increased with the increases in the inlet temperature of the heat transfer fluid.

![Fig. 1](image_url)  
*Fig. 1. The rates of heat transferred and stored into the HSU
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In the first charging period for the period of time as covered by Fig. 1a, the rate of heat stored into the HSU changed between the values of 0.158 kW and 2.560 kW, while the rate of heat transferred from the HCU into the HSU changed between the values of 0.682 kW and 2.996 kW. Daily average values of the rates of heat transferred and stored into the HSU were 2.19 kW and 1.75 kW, respectively. The rate of the total heat losses from the HSU changed between the values of 0.416 kW and 0.484 kW for the first charging period. It was calculated that daily average value of the rate of the total heat losses from the HSU was 0.44 kW for this charging period. In the second charging period (Fig. 1b), the rates of heat transferred and stored into the HSU changed between the values of 1.049 kW and 3.014 kW and 0.523 kW and 2.617 kW, respectively. An average value of the rates of the heat transferred and stored into the HSU were 2.18 kW and 1.73 kW, respectively, while an average value of the rate of the total heat losses from the HSU was 0.45 kW for the second charging period.

The Rate of Thermal Exergy Stored into the HSU

The rates of thermal exergy transferred and stored into the HSU for the first and second charging periods are shown in Fig. 2. In the first charging period during the days (Fig. 2a), the rate of thermal exergy stored into the HSU changed between the values of 4.4 W and 135.8 W, while the rate of thermal exergy gained from HCU changed between the values of 24.9 W and 156.3 W. Average values of the rates of thermal exergy gained from the HCU and stored into the HSU were 97.5 W and 77.4 W, respectively. The rate of the total thermal exergy losses associated with the total heat losses from the HSU changed between the values of 18.4 W and 21.8 W. It was calculated that the daily average value of the rate of the total thermal exergy losses from the HSU was 20.1 W for the first charging period. In the second charging period (Fig. 2b), the rates of thermal exergy transferred and stored in the HSU changed between the values of 44.5 W and 77.3 W and, 25.8 W and 60.5 W, respectively. An average value of the rate of thermal exergy stored into the HSU was 42.2 W, while an average value of the rate of thermal exergy transferred into the HSU from the HCU was 30.5 W for the second charging period.

![Fig. 2. The rates of thermal exergy transferred and stored into the HSU](image)

Energy Efficiency for the Charging Period

The changes of the total and net energy efficiencies for the first and second charging periods are shown as a function of time in Fig. 3a and 3b, respectively. The total and net energy efficiencies increased with the increases in the inlet temperature of the heat transfer fluid. The net energy efficiency changed between the values of 8.2 % and 54.2 %, while the total energy efficiency was changed between the values of 28.9 % and 85.8 % during the first charging period (Fig. 3a). The daily average values of the total and net energy efficiencies for the first charging period were determined as 73.4 % and 41.4 %, respectively. For the second charging period (Fig. 3b), the total and net energy efficiencies changed between the values of 48.9 % and 86.8 % and, 18.4 % and 55 %, respectively. In this charging period, daily average values of the total and net energy efficiencies were determined to be higher than that for the first charging period. An average values of the total and net energy efficiencies were calculated as 76.1 % and 42.3 %, respectively.
Exergy Efficiency for the Charging Period

The total and net exergy efficiencies for the first and second charging periods is shown in Fig. 4. In the first charging period (Fig. 4a), the total exergy efficiency changed between the values of 17.6 % and 86.9 %. On the other hand, it was determined that the net exergy efficiency changed between the values of 0.3 % and 7.2 % for this charging period, daily average values of the total and net exergy efficiencies were calculated as 70.1 % and 4.2 %, respectively. In the second charging period (Fig. 4b), an average value of the net exergy efficiency was 2.3 %, while an average value of the total exergy efficiency was 67.3 %. As can be seen from Fig. 3 and 4, the net exergy efficiency of the system was lower than the energy efficiency for both the first and second charging periods.

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**REFERENCES**


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