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A RESEARCH ON GREENHOUSE HEATING WITH SOLAR ENERGY USING VACUUM TUBULAR COLLECTORS AND NANOFLUID

Bulent AYHAN[1], Hasan Huseyin OZTURK[2], Hasan Kaan KUCUKERDEM[3]

[1]Directorate of Agricultural Production Enterprise, Agricultural Extension and Training Center, Koprulu. Yuregir, Adana, Turkey
[2]University of Cukurova Faculty of Agriculture Dept. of Machinery and Technologies Engineering, 01330, Balcalı, Sarıcam, Adana, Turkey
[3]Igdir University Faculty of Agriculture Dept. of Biosystem Engineering, Igdir, Turkey

Corresponding author email: hhozturk@cu.edu.tr

Abstract

In this research, vacuum tube collectors with high efficiency in converting solar energy to heat energy will be used for heating greenhouse with nano-fluid as working fluid. Since the fluid exiting in such collectors is at a higher temperature (100-120℃.) than plane collectors, they have a wider use than plane collectors. The use of vacuum tube solar collectors increases the usability for storing heat for greenhouse heating in early spring and late autumn seasons. Solar energy and greenhouse heating system will be designed as open system. However, the system will be used as a nano-fluid heat storage and transport fluid (working fluid). The nanofluid water will be mixed with aluminum(Al_2O_3) nanoparticles. In the system, mixing ratios of water and aluminum oxide (Al_2O_3) and appropriate flow rate will be determined for the first time depending on the heat requirement of the research greenhouse. Heat sum, thermal efficiency of storage and greenhouse units energy and exergy analyzes will be determined. In addition, environmental sustainability of the system will be evaluated by exergetic life cycle analysis.

Key words:*vacuum tube collector, greenhouse, heating, nano-fluid.*

INTRODUCTION

Controlling the ambient temperature is an important process in greenhouse technique affecting plant growth and development, yield and quality. All plants need temperatures between certain lower and upper limit values to develop. The lowest air temperature depends on the continuously occurring low temperatures and the difference in temperature between day and night. On the other hand, the highest air temperature depends on the rate of change of relative humidity. In the greenhouse air-conditioning technique, the most suitable air temperature is defined as the highest temperature required for a physiological process that can be maintained continuously without decreasing its speed. The optimum temperature for the plant depends on the physiological process that the plant performs. The air temperature; The effects of air temperature on the physiological processes of plants such as photosynthesis, respiration and water intake are different. If the air temperature in the greenhouse environment is lower than the freezing point of the plant, it can directly cause physical damage to the plant cells. The tolerance of plant cells to the highest and lowest temperatures varies depending on the plant species. The negative effects of low temperatures on plants occur in the form of cold and frost damage. Cold and frost events occurring in plant growing environments can cause plants to die by being damaged (Ozturk, 2017). For the reasons mentioned above, the main purpose in greenhouse cultivation is to maintain the indoor temperature at the optimum level. In order to achieve the highest efficiency expected from the crop production in greenhouses, the greenhouse should be heated in periods when the outdoor temperature is lower than optimal conditions.

MATERIALS AND METHODS

In this study, it was aimed to store solar energy for short term (day to night) using sensible heat storage method using nanoparticle (Al_2O_3) mixed water (nanofluid) as heat storage material in order to be used in heating the plastic greenhouse with 280 m^2 floor area under Adana climate conditions. The solar energy storage application in the greenhouse aims to reduce the heating energy requirement of the greenhouse. Due to the reduction of the amount of energy that should be used for greenhouse heating, heating expenses will be reduced and energy saving will be provided. As an important result of saving energy, CO_2 consumption, which is one of the main gases creating greenhouse effect in the atmosphere, will also decrease significantly, as fossil fuel consumption will decrease for greenhouse heating applications. So; Important contributions will be made in terms of greenhouse producer, national economy, human health and environmental protection. In solar energy greenhouse heating applications, high heat transfer between the heat collection and storage units and the greenhouse is desired. In addition, studies are carried out to provide solar energy systems, which are a renewable energy source, for high heat transfer applications. However, improving heat transfer in solar energy systems is one of the critical issues in energy saving and compact designs. Water is generally preferred as heat transfer fluid in solar energy systems. Although the heat transfer coefficient of the water between the fluids is high, mixing the nanoparticles with high heat transfer coefficient increases the total heat transfer coefficient. The fluid formed by mixing water and nanoparticles is called nanofluid. Nanofluids improve thermophysical properties, such as thermal diffusion and thermal conductivity, and also create a slight increase in pressure drop and pumping power in the base fluid. (Hong et al., 2006; Hwan et al., 2008; Jang et al., 2007). For this reason, many researchers have pointed out the use of nanofluids as an innovative technique to increase heat transfer efficiency in solar energy systems (Khattak et al., 2016; Azwadi et al., 2016; Azwadi et al., 2014; Lee 2014; Zainal et al., 2016; Mohammed et al. ., 2016). Recently, studies on the suspension of nanoparticles with water as heat storage and transfer fluid, and the use of traditional heat transfer fluids in place (Wen et al., 2009; Ny et al., 2016; Abubakar et al., 2016). As a result, the total efficiency of the system can be increased by using Al_2O_3/water mixture for solar heating and greenhouse heating applications.

The project, which is designed for daily storage of greenhouse heating and solar energy using sensible heat storage method, will be carried out in Adana Agricultural Extension and Training Center Directorate. The schematic view of the solar storage and greenhouse heating system is given in Figure 1. The system mainly consists of the following 4 units: 1) Heat collection unit consisting of vacuum tube solar collectors; 2) Heat storage unit where the collected heat is stored; 3) Plastic greenhouse heated with the stored heat; 4) Heat transfer unit between the heat collection-storage units and the greenhouse.

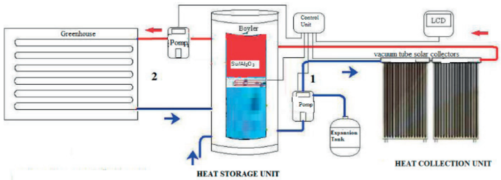

Figure 1. Solar Energy Storage and Greenhouse Heating System

During the daytime, with the operation of the pump unit 1 indicated in Figure 1, the heat energy collected by the solar collectors with vacuum pipes will be stored in the heat storage unit. Depending on the plastic greenhouse indoor temperature, the pump unit 2 will be operated to recover heat from the heat storage unit. In this case, nanofluid circulation will be provided between the heat storage unit and the heating pipes in the plastic greenhouse unit. When the temperature of the nanofluid heated in the solar active heating system is higher than the temperature required to be sent to the greenhouse, the nanofluid heated in the system can be used directly to heat the greenhouse. In cases the operating temperature of the system is low, a higher rate of solar collectors is used.

Plastic Greenhouses

In the research, it will be established in 280 m^2 floor area under Adana climate conditions.

For polyethylene (PE) plastic greenhouses, design variables of solar greenhouse heating system are determined. One of the two plastic greenhouses to be installed in the same design will be used for control purposes. The dimensions of the plastic greenhouses to be installed are: 40 m (length) × 7 m (width) × 7 m (height). Cucumber will be produced in research and control greenhouses.

Heat Distribution System in Greenhouse

For the heat distribution in the plastic greenhouse, 50 mm diameter polyethylene (PE) plastic heating pipes will be placed between the plant rows. The operating temperature of plastic pipe heating systems is 70/50°C. In the technical design of the system, the inlet temperature of the heating fluid is 70°C and the return temperature is 50°C.

Heat Collection Unit

Vacuum Tube Solar Collectors It will be used for collecting solar energy that will be stored as heat energy in the heat storage unit. Since the outputs of vacuum tube collectors are at higher temperatures (100-120°C), they have a wider usage area than plane collectors.

Heat Storage Unit

As heat storage unit will be used, cylindrical storage tank to be designed from corrosion-resistant metal material.

Measurements

In the greenhouse in teriors, sensors will be placed in three different areas, namely the entrance-middle-exitsections. Sensors will be measured at two different heights, air temperature and relative humidity. The temperature of the nanofluid circulating between the heat collection and storage unit sand the plastic greenhouse will be measured. In the external environment; air temperature, air relative humidity, solar radiation intensity and wind speed values will be measured.

Determination of Greenhouse Heat Demand

The amount of heat required per floor area for the heating of the plastic greenhouse to be installed is determined from the following equation (Ozturk, 2008b).

$$q_s = \frac{A_ö}{A_t} \cdot u(T_i - T_d) - I.\tau.\gamma \ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Where:

q_s = Heat requirement per floor area (W/m^2);
$A_ö$ = Greenhouse cover surface area (m^2);
At = Greenhouse floor area (m^2);
U = Total heat loss coefficient (W/m^{2}°C);
T_i = Greenhouse indoor air temperature (°C);
T_d = Outdoor air temperature (°C);
I = Total solar heat (W/m^2);
t = Total radiation permeability of the greenhouse;
γ = Total radiation at indoor temperature effective is the rate of conversion to irradiation.

$$Q_s = q_s \times A_s \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Where:

Q_s = Greenhouse total heating requirement (W);
q_s = Heat requirement per floor area (W/m^2);
A_s = Floor area of greenhouse (m^2).

Overall Heat Loss Coefficient

The overall heat loss coefficient (u, W/m^2, °C); for the 1°C difference between sera in door temperature and outdoor temperature, it indicates the total heat loss of each m^2 of greenhouse surface area (Ozturk, 2003a). In the Mediterranean Region climate conditions. For plastic greenhouses covered with UV+IR added PE, the overall heat loss coefficient can be determined from the following equation (Ozturk, 2003a).

$$u = 2.83+0.10\, v_r \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

Where, v_r = the wind speed (m/s).

Indoor Air Temperature

In order to grow different types of plants in greenhouses, the indoor air temperature should be adjusted in the range of 10-28°C. The heat requirement of the plastic greenhouse to be installed will be calculated depending on the indoor temperature of 12°C.

Outdoor Air Temperature

In determining the outdoor temperature, the average of the lowest temperatures occurring at the coldest time of the year depending on the climatic conditions of the region where the greenhouse is located is taken in to account. For the design of heating systems, the heat requirement of the plastic greenhouse to be installed will be calculated depending on the outdoor temperature of 0°C

Sizing of the Greenhouse Heating System

Determination of Heating Pipe Length

Total heating pipe length to be used in hot water heating systems in greenhouses, total heat requirement of the greenhouse and the heat gained from the unit length of the heating pipe intended to be used. Depending on the amount, it is calculated as follows (Ozturk, 2012).

$L_b = Q_s/Q_b$……………………………….(4)

Where:

L_b = Length of the heating pipe (m);
Q_s = Greenhouse total heat requirement (W);
Q_b = Amount of heat gained from the pipe (W/m).

Determination of Heat Transfer from the Heating Tube

The total amount of heat transferred from the heating pipe to the greenhouse environment is calculated from the following equation. (Ozturk, 2012). For the heating system in the plastic greenhouse, 50 mm diameter polyethylene (PE) pipe will be used as the heat exchanger.

$$Q_b = \frac{4\pi L_b \Delta T_b}{\frac{1}{\alpha_i d_i}+\frac{\ln(d_d/d_i)}{\lambda_b}+\frac{1}{\alpha_d d_d}} + Q_r \quad \text{(5)}$$

Where:

L_b = Length of the heating pipe(m);
Q_b = Heat gained from the pipe (W/m);
ΔT_b = Temperature difference (°C);
α_i = Internal surface heat transfer coefficient (W/m^2°C);
α_d = External surface heat transfer coefficient (W/m^2°C);
d_d = Tube outer diameter (m);
d_i = Tube inner diameter (m);
Q_r = Amount of thermal power passing by radiation (W);
λ_b = Heat transmission coefficient (W/m°C).

Determination of the Amount of Thermal Power Transmitted from the Heating Pipe to the Greenhouse Environment by Radiation

The amount of thermal power (Q_r, W) transmitted from the heating pipes in the plastic greenhouse to the greenhouse environment by radiation is calculated as follows (Ozturk, 2012).

$$Q_r = \varepsilon \cdot \sigma \cdot A_b (T_b^4 - T_s^4) \quad \text{(6)}$$

Where:

ε = Radiation emission value,
σ = *Stefan-Boltzmann* constant (2.6697×10^{-8}W/m^2 K^4),
A_b = Pipe surface area (m^2),
T_b = Absolute temperature of the heating pipe (K),
T_s = Absolute temperature of greenhouse ambient air (K).

Sizing of the Heat Storage Unit

Determining the Amount of Heat Storage Material

The amount of heat storage material that should be used as sensible heat storage material in the heat storage unit will be calculated from the equation below (Ozturk, 2012).

$$m = \frac{Q_s}{c_p \times \Delta T} \quad \text{(7)}$$

Where:

m = Amount of heat storage material (kg);
Q_s = Greenhouse heat requirement foreseen to encounter solar energy (kJ/day);
c_p = Specific heat of water (kJ/kg °C);
ΔT = Temperature increase in water(°C).

Determination of Heat Storage Unit Volume

In determining the volume of the heat storage unit (heat tank), the maximum amount of heat that can be stored daily is taken into account. The volume of the heat storage unit will be determined from the equation below (Ozturk, 2012).

$$V = \frac{Q_s}{p_s \times c_{ps} \times \Delta T} \quad \text{(8)}$$

Where:

V = Heat storage unit volume (m^3);
Q_s = Greenhouse heat requirement foreseen to encounter solar energy (kJ/day);
p_s = Water density (kg/m^3);
c_{ps} = Specific heat of water (kJ/kg K);
ΔT = Average heat of the heat storage material for the heat storage phase (°C).

Determination of the Heat Collection Unit Surface Area

After determining the amount of heat energy required meeting a certain ratio of annual heat requirement for greenhouse heating, the required collector area for this energy collection is calculated. The efficiency of the

vacuum tube solar collectors to be used in the heat collection unit to be designed will be considered as ç = 60%.
The collector area to be used in the heat collection unit will be calculated from the following equation (Ozturk, 2012).

$$A_t = \frac{Q_s}{I \times \eta_t} \qquad (9)$$

Where:

A_t	=	Collector surface area (m^2);
Q_s	=	Greenhouse heat requirement foreseen to encounter solar energy (kJ/day);
I	=	The amount of solar energy coming to the collector surface (kJ/m^2);
η_t		Collecting efficiency (%).

Determination of Circulating Pump Flow

After determining the amount of heat energy required to meet a certain ratio of annual heat requirement for greenhouse heating, the required collector area for calculating this energy is calculated.
The efficiency of the vacuum tube solar collectors to be used in the heat collection unit to be designed will be considered as n = 60%.
The collector area to be used in the heat collection unit will be calculated from the equation below (Ozturk, 2012).

$$V_p = \frac{Q_s}{c_p \cdot \rho \cdot (T_g - T_ç)} \qquad (10)$$

Where:

Vp	=	Flow rate of circulating pump (m3/s);
Qs	=	Required heat quantity (kW);
ρ	=	Density of the fluid (kg/m3);
cp	=	Specific heat of fluid (kJ/kg°C);
Tg	=	Fluid inlet temperature (°C);
Tç	=	Fluid outlet temperature (°C).

Determining the Amount of Fuel to Be Saved and the Fuel Expense

In case the plastic greenhouse to be installed is heated by solar energy, the thermal values and cycle efficiencies related to fuels and fuel unit prices will be taken into consideration in order to determine the fuel quantity values to be saved.

Determination of the Amount of Reduction in Carbon Dioxide Emission

Along with the energy conservation efficiency, the environmental impacts of solar energy storage application will be evaluated as well. The reduction in the emission of carbon dioxide (CO_2) gas, which is one of the main gases that create a greenhouse effect in the atmosphere, will be determined.

Al_2O_3Preparation of Water Nanofluid

In this study, Al_2O_3-water nanofluid was chosen as heat transfer fluid in solar-tube solar collectors for greenhouse heating. In experiments, Al_2O_3 will be used as nanoparticle and pure water will be used as basic fluid. Two-step method will be used to calculate Al_2O_3-water nanofluid. An ultrasonic homogenizer will be used to prevent lumps that may occur while preparing nanofluids and to increase the stability of the nanofluid. While preparing the nanofluid, a 4 L capacity reactor will be used to prevent its heating. The properties of Al_2O_3 nanoparticles are shown in Table 1.

Table 1. Properties of Nanoparticles Used in the Study (Ghaderian and Sidik, 2017)

Formula	Molecule mass	Phase	Particle size	Surface area	Melting	Thermal conductivity
Al_2O_3	101.96	Gama	< 50nm	35-43	2040°C	37.14
	g/mol			m^2/g		W/mK

While preparing the nanofluid, the Al_2O_3 nanoparticle will be added to the water in a different volumetric ratio and the Al_2O_3-Water nanofluid will be prepared using the two-step method. The volume concentration of the Al_2O_3 particle to be added to the water is expressed by the following equation (Sharafeldin and Grof, 2019).

$$\phi\ (\%) = \frac{\frac{m_{np}}{p_{np}}}{\frac{m_{np}}{p_{np}} + \frac{m_{bf}}{p_{bf}}} \times 100. \qquad (11)$$

Equality ϕ refers to volumetric ratio (%), m mass (kg), p density kg / m^3, bf basic fluid (water) and np nanoparticle.
Thermal conductivity of Al_2O_3-Water nanofluid will be measured with the hot wire method commonly used in this project. Measurement results will be compared with the results in the literature. Specific heat plays an important role in the entropy production and thermal efficiency of a solar thermal application. The specific heat of nanofluids is determined by the equation below (Palm, et al., 2006).

$$C_{p,nf} = \phi C_{p,np} + (1-\phi) C_{p,bf} \qquad (12)$$

In the equation above, *Cp*, *nf*, *Cp*, *bf* and *Cp*, *np* represent the specific heat values of the nanofluidic, basicfluid (water) andnanoparticle, respectively. At the end of the study, how much the conductivity of water increases with Al_2O_3 nanoparticle will be numerically revealed. The Al_2O_3-water nanofluidto be prepared will be put in the heat storage tank for heating purposes in the experimental system and experiments will be carried out.

CONCLUSIONS

In case of using solar energy in greenhouse heating; The greenhouse producer will contribute to the country's economy, human health and environmental protection. In case solar energy is stored for the purpose of greenhouse heating with sensible heat storage method, heating costs, which have a large place in the total production expenses of greenhouse agriculture, will decrease. As a result of thecalculations, it has beendeterminedthat 60-70% savingwill be achievedfromtheamount of coalrequiredforgreenhouseheatingapplicationwith solar heatingsystem. Due to the decrease in heating costs, the production cost of the products grown in greenhouses will decrease. Decreasing the production costs of the products grown in the greenhouse will facilitate the marketing of these products in the foreign and domestic markets. Depending on the reduction of the amount of energy that should be used for greenhouse heating, significant energy savings will be achieved. As an important result of saving energy, CO_2 consumption, which is one of the main gases that create a greenhouse effect in the atmosphere, will decrease significantly, as fossil fuel consumption will also decrease for greenhouse heating applications. Thus, contribution will be made to environmental protection.

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