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Mathematical modeling for greenhouse heating by using thermal curtain and geothermal energy

M.K. Ghosal, G.N. Tiwari *

Centre for Energy Studies, Indian Institute of Technology, Hauz Khas, New Delhi 110016, India

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Abstract

A thermal model has been developed for the heating of a greenhouse by using inner thermal curtain and natural flow of geothermal warm water through the polyethylene tube laid on its floor. The calculations were done for a typical production greenhouse with the climatic data in the central part of Argentina during winter period. From the energy conservations point of view, the greenhouse has been divided into three zones i.e., zone I (plants under thermal blanket), zone II (space under ceiling) and zone III (space between roof and ceiling). The model has been tested with the published experimental data of air temperatures in zone I and zone II of the greenhouse. From the results, it was observed that the temperatures of air surrounding the plant mass in zone I were maintained in the range of 14–23 °C during winter night and early morning resulting in the better growth of winter growing plants against the harmful freezing effects. The predicted values of air temperature both in zone I and zone II of the greenhouse obtained from the proposed model exhibited fair agreement with the published experimental values.

Keywords: Solar energy; Geothermal energy; Greenhouse

1. Introduction

Heating of a greenhouse is an essential requirement for proper growth and development of winter growing crops (Tiwari, 2003). Thermal heating of greenhouse has been studied by various researchers in employing different passive methods (Hussaini and Suen, 1998; Ismail and Goncalves, 1999; Santamouris et al., 1994a,b; Tiwari and Dhiman, 1986; Abak et al., 1994) as well as active modes (Bargach et al., 2000; Connellan, 1986; Santamouris et al., 1996; Kurpaska and Slipek, 2000; Jain and Tiwari, 2003). Among the passive heating modes, a thermal curtain is one of the most practical and appropriate means for reducing the consumption of heat in a greenhouse (Zhang et al., 1996). It is drawn inside or outside of the greenhouse cover in nighttime during winter period to reduce heat losses to the ambient environment resulting in the conservation of energy in the greenhouse. The insulation provided by the curtain helps in retaining thermal energy near the plants and prevents the radiative heat losses to the cold night sky for maintaining better heat distribution inside the greenhouse (Nelson, 1985). The principal effect of the curtain is to provide additional thermal resistance that reduces the overall rate of heat transfer to the surroundings (Arinze et al., 1986). A night curtain placed between the crop and the structural cover of greenhouse is called an internal thermal curtain whereas an external curtain is placed between the greenhouse cover and the surrounding atmosphere. However internal thermal curtain is preferred to the external one as the latter is exposed to the outside weather causing early deterioration. Experimental results (Bailey, 1981; Roberts et al., 1981) and analytical findings (Chandra and Albright,

* Corresponding author. Tel.: +91-11-26591258; fax: +91-11-26862037.

E-mail addresses: mkghosal1@rediffmail.com (M.K. Ghosal), gntiwari@ces.iitd.ernet.in (G.N. Tiwari).

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Nomenclature

A	area, m^2
C_P	specific heat of plant, J/kg °C
F_P	fraction of incoming solar radiation falling on plants, dimensionless, decimal
h_1	convective heat transfer coefficient from floor of greenhouse to air in zone I, W/m^2 °C $(2.8 + 3.0v)$ (Watmuff et al., 1977)
h_2	convective heat transfer coefficient from air in zone I to zone II, W/m^2 °C (h_1)
h_3	convective heat transfer coefficient from air in zone II to zone III, W/m^2 °C (h_1)
h_4	convective heat transfer coefficient from air in zone III to ambient air, W/m^2 °C $(5.7 + 3.8v)$ (Duffie and Beckman, 1991)
h_5	convective heat transfer coefficient from flowing hot water to zone I, W/m^2 °C
h_P	convective and evaporative heat transfer coefficient from plant mass to zone I $(h_{cP} + h_{eP})$, W/m^2 °C
h_{cP}	convective heat transfer coefficient from plant mass to zone I, W/m^2 °C (h_1)
h_{eP}	evaporative heat transfer coefficient from plant mass to zone I, W/m^2 °C $(0.016h_{cP} \times [(P_P - \gamma P_1)/(T_P - T_1)])$
h_∞	heat transfer coefficient from floor to larger depth of ground (K_g/L_g), W/m^2 °C
$I(t)$	solar radiation falling on greenhouse cover, W/m^2
K_g	thermal conductivity of ground, W/m °C
L_g	thickness of ground, m
M_P	total mass of plant, kg
$\dot{m}_w$	mass flow rate of hot water, m^3/s
P	saturated vapor pressure $(\exp[25.317 - (5144/(T + 273.15))])$, Pa
$\dot{Q}_u$	useful energy obtained from flowing hot water to greenhouse, W
T	temperature, °C
T_r	temperature of greenhouse room air, °C
T_w	temperature of hot water from geothermal source, °C
V	volume of greenhouse, m^3
v	velocity of air, m/s

Greek symbols

α	absorptivity, dimensionless
τ_1	transmissivity of thermal blanket, dimensionless
τ_2	transmissivity of thermal curtain, dimensionless
τ_3	transmissivity of greenhouse cover, dimensionless
γ	relative humidity, decimal
∞	infinity (at larger depth)

Subscripts

1	zone I in the greenhouse
2	zone II in the greenhouse
3	zone III in the greenhouse
4	ambient condition
e	east wall of greenhouse
f	floor of greenhouse
i	different walls and roofs of greenhouse
n	north wall of greenhouse
P	plant
R	roof
s	south wall
T	plastic tube
er	east roof
wr	west roof
ww	west wall

1980; Seginer and Albright Louis, 1980) support the use of thermal curtain for conservation of energy in the greenhouse. In addition to the use of thermal curtain for decreasing heat losses in greenhouse, another desired effect needs attention for heating of ground, as thermal condition of ground influences the availability, absorption, utilization of mineral elements, seed germination and rooting system of plant (Buckman and Brady, 1971). Moreover, ground acts as a radiant surface by emitting heat to the greenhouse environment (Pucar, 2002). Experiment in which tomatoes were grown under warm rooted conditions indicated that growth and total yield were increased as compared to plants grown in conventional warm and heated greenhouse (Janes et al., 1981). Considering the increase of temperature in aerial part of the plants as well as ground in the greenhouse, water to air heat exchanger (Saravia et al., 1997) and exploitation of geothermal energy (George et al., 1999) wherever available with the help of polythene tube may be the suitable option due to the higher thermal capacity of water. Moreover geothermal energy is a very economical source of energy to meet the heating requirement of greenhouse, as the global use of geothermal energy in the applications of greenhouse particularly for heating purpose is 9.31% (Lund and Freestone, 2001). But the high concentration of Ca, Mg, Na, K, SiO_2 causes the corrosion and scaling problem in steel pipes (ASHRAE, 1995). Therefore polythene tube resistant to corrosion may be the viable alternative for utilizing the thermal energy of geothermal water as long as the