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Performance of modified greenhouse dryer with thermal energy storage

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ABSTRACT

In this attempt, the main goal is to do annual performance, environomical analysis, energy analysis and exergy analysis of the modified greenhouse dryer (MGD) operating under active mode (AM) and passive mode (PM). Thermal storage is being applied on the ground of MGD. It is applied in three different ways namely barren floor, floor covered with black PVC sheet (PVC) and Black Coated. Experimental study of dryers in no-load conditions reveals that floor covered with a black PVC sheet is more conducive for drying purpose than other floors. The MGD under AM is found to be more effective as compared to PM for tomato and capsicum, which are high moisture content crops. For medium moisture content crop (potato chips), both dryers show relatively similar drying performance. Crops dried inside the greenhouse dryer are found to be more nutrient than open sun dried crops. The payback period of the modified greenhouse dryer under passive mode is found to be 1.11 years. However, for the active mode of the modified greenhouse dryer is only 1.89 years. The embodied energy of the passive mode of the dryer is a 480.277 kWh and 628.73 kWh for the active mode of the dryer. The CO_2 emissions per annum for passive and active mode greenhouse dryers are found to be 13.45 kg and 17.6 kg respectively. The energy payback time, carbon mitigation and carbon credit have been calculated based type of crop dried. The range of exergy efficiency is 29%–86% in MGD under PM and 30%–78% in the MGD under AM. The variation of Heat utilization factor (HUF) for MGD under PM is 0.12–0.38 and 0.26–0.53 for MGD under AM. The range of co-efficient of performances (COP) for MGD under PM is 0.55–0.87 and 0.58–0.73 for MGD under AM.

1. Introduction

At the present stage, the stock of precious fossil fuel is depleting at a very high rate. It leads to the rise in the price of the fossil fuel along with energy insecurity in the coming future. The burning of fossil fuel also leads to environmental pollution that is the one the primary concern of the world. Hence, researchers and scientists are looking to find the alternate energy sources, which fulfil the energy demand with low-cost along with environmentally friendly. In the present scenario, solar power emerges as an alternative option to provide the energy security. Since significant amount of energy is being used in the field of drying, hence by the use of solar energy, it can reduce up to 27%–80% of precious non-renewable energy (Prakash and Kumar, 2013a). Solar dryer can be used for the low temperature drying. Many researchers have applied this concept and dryer various agricultural produce such as red chilli, fenugreek, jaggery, tomato, onion (Fudholi et al., 2014; Shrivastava and Kumar, 2015; Kumar and Tiwari, 2006a,b; Kumar and Tiwari, 2007; Prakash and Kumar, 2014a). A detailed review on the solar drying by the use of various existing solar dryers in the different part of the globe is being done by the researcher (Kumar et al., 2014).

From a long time, the greenhouse is being used for the purpose of cultivation of the crops. It works on the principle of the greenhouse effect. It is found that crop cultivated in the greenhouse is better developed as compared to the open sun grown crops (Kumar et al., 2006). From last two and half decade, greenhouse structure is also being used for the purpose of low temperature drying by the help of solar radiation. The greenhouse dryer (GD) is being operated in the natural convection heat transfer mode (Passive mode) and forced convection mode of heat transfer (active mode). Prakash and Kumar (2014b) have reviewed various existing greenhouse dryer of both modes. Kumar et al. (2013) have done the study

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Nomenclature

U	Overall heat transfer coefficient (W/m^2 °C)
A_i	Area of the wall where $i = 1$–5 in m^2
T_r	Room temperature (°C)
T_a	Ambient temperature
I_g	Global radiation in W/m^2
A	Effective area of dryer tray in m^2
N	Number of air exchange per hour
V_e	The velocity of exhaust air in m/s.
σ	Standard deviation
X_i'–X'	Deviation from the mean
N	Number of sets
N_0	Number of observation in each set.
T_{gd}	Ground temperature in °C
T_{rm}	Temperature of inside modified greenhouse dryer in °C
T_a	Ambient temperature in °C.
T_t	Total moisture content at any given time
T_o	Initial moisture content prior to drying
T_e	Equilibrium moisture content.
p_1	Number of repressors
n_1	Sample size
Y_p	Predicted value
Y_e	Experimental value
Dr_c	Dryer cost
d	Rate of interest
f	Rate of inflation
W_m	Mass of water removed
E_m	Embodied energy in kWh.
n	Life span of dryer which is 35 years
D	Exchange rate of carbon credit based international policy
E_{cha}	Input energy in the chamber
m_o	At zero moisture content time
$M_{initial}$	Initial moisture content
M_{final}	Final moisture content
L	latent heat of vaporization in kJ/kg
I	Solar intensity in W/m^2.

over GD under passive mode (PM) and active mode (AM) of the roof even span type in the monsoon season in no-load conditions. The result shows that GD under AM is comparatively better thermal performance than PM of the GD due to lower inside humidity.

Kumar and Tiwari (2006a,b) have dried jaggery in the roof even span type greenhouse dryer under passive and active mode. The thermal model predicted the important drying parameters such as jaggery temperature, jaggery mass and room temperature. The result shows that the thermal model can predict with fair accuracy. Kumar and Tiwari (2007) have studied the effect mass of onion flakes to the convective mass transfer coefficients in three different ways of drying—open sun drying, greenhouse drying under forced convection and greenhouse dryer under natural convection. The study reveals that the convective mass transfer coefficients strongly depend upon mass of the onion flakes in tray. The result shows that for high moisture content crop, greenhouse dryer under AM is found to be more efficient and for low moisture content crop, greenhouse dryer under passive mode is found to be more effective. For the medium moisture content crop, both dryers' shows almost similar drying effect. Kumar and Tiwari (2006c) have studied the effect of various shapes and size of jaggery to the convective mass transfer coefficient of the roof even span type greenhouse dryer of both modes. Study shows that for the larger pieces of jaggery, greenhouse dryer under active mode was found to be high convective mass transfer coefficients than passive mode dryer.

Researchers have applied the novel soft-computing prediction models to predict the important drying parameters for the greenhouse dryer such room temperature, room relative humidity, ground temperature (Prakash and Kumar, 2013b, 2014c,d,e). The model was able to predict with high-level accuracy which far superior to a thermal model. To make greenhouse dryer more efficient, some modification is being incorporated in the conventional greenhouse dryer. Two significant thermal losses take place in the greenhouse dryer namely through the north wall and ground of the greenhouse. In order to minimize the ground loss, Study is being carried out in different floor conditions for the greenhouse dryer and opaque mirror is applied in the north wall of the greenhouse to minimize the thermal losses from the north wall (Prakash and Kumar, 2014f,g,h). Result shows the significant improvement in system efficiency as compared to the traditional greenhouse dryer. The study of the modified greenhouse dryer under AM in the load condition is being conducted for the tomato flakes drying (Prakash and Kumar, 2014a). An experiment was carried out simultaneously in the open sun drying as well as in the dryer. Environomical analysis and mathematical modelling were being performed for the same dryer. The study has shown that this dryer is more efficient than all other existing greenhouse dryers.

The objectives of this research are to perform: (i) annual performance of the both dryers in the three different floor conditions (barren concrete floor "BCC", floor covered with double layer of black PVC sheet with holes in upper layer "BPVC" and black painted concrete floor "BPCF") (ii) drying simultaneously in all three modes for three different crops and compares its biochemical properties (iii) cost and energy analysis of the both dryers.

2. Materials and methods

Both modified greenhouse dryer is being made by the aluminium frame due its light in weight and other important technical properties. The frame was enveloped with the transparent polycarbonate sheet except north wall. The opaque mirror is applied in northern wall of the dryer. The dimension of length, width and side height is 1.5 m, 1.0 m and 0.5 m respectively. The roof top of the dryer is the even span and inclination is the 23.5° because this angle is the latitude of the Bhopal. The exhaust fan of the active mode of the dryer is powered by the 6 W of solar panel with battery backup. *The mass flow rate is found to be* 0.0375 m^3/s *in the modified greenhouse dryer under active mode*. Experimental observations were taken in hourly basis. To measure the weight of the crop, top weighing machine—model no TTB 10, Wensar weighing Scales Limited, India, of capacity 10 kg were used. The hygrometer by Lutron (HT-305) was used to measure temperature and relative humidity. For measuring the crop and ground temperature, Mini Temp portable infrared thermometer were used and solar power meter was used to measure the global solar radiation.

After fabrication of the both dryers, these were tested round the year in the no-load conditions to evaluate its thermal performance. Experiments were conducted from October 2012 to May 2103 in no-load condition except June–September 2013 due to rainy season. Every month from 15th to 17th observation were taken in the three different floor conditions for both dryers from 9:00 am to 5:00 pm. First day dryers were kept on the BCC, second day on the BPVC and on the third day, dryers were kept on the BPCF. After testing of the dryer in no-load conditions, three different crops of 3500 gm namely tomato flakes, potato chips and capsicum flakes were dried in the three different modes simultaneously from 20th to 25th October 2013 in the Department of Energy (Energy Centre), Maulana Azad National Institute of Technology, Bhopal, India as shown in Fig. 1. All crops were purchased in local market of Bhopal. Capsicum and tomato did not require any pre-treatment except washing and removing any foreign impurities on the surface of