Energy Reports 2 (2016) 107–116

Contents lists available at ScienceDirect

Energy Reports

journal homepage: www.elsevier.com/locate/egyr

Performance analysis of greenhouse dryer by using insulated north-wall under natural convection mode

Prashant Singh Chauhan [a,*], Anil Kumar [a,b]

[a] Department of Energy (Energy Centre), Maulana Azad National Institute of Technology, Bhopal-462051, India

[b] Department of Mechanical Engineering, Faculty of Engineering, Prince of Songkla University, HatYai, Songkhla-90112, Thailand

ARTICLE INFO

Article history:
Received 22 January 2016
Received in revised form
15 March 2016
Accepted 16 May 2016

Keywords:
Greenhouse dryer
Insulated north wall
Solar collector
Coefficient of performance
Heat utilisation factor

ABSTRACT

A prototype north wall insulated greenhouse dryer has been fabricated and tested in no-load conditions under natural convection mode. Experimentation has been conducted in two different cases. Case-I is when solar collector placed inside the dryer and Case-II is North wall insulated greenhouse dryer without solar collector. Coefficient of performance, heat utilisation factor, convective heat transfer coefficient and coefficient of diffusivity have been evaluated in thermal performance analysis. The difference of the highest convective heat transfer coefficient of both cases is 29.094 W/m^2 °C which is showing the effectiveness of insulated north wall and solar collector. The maximum coefficient of diffusivity (0.0827) was achieved during the third day of experiment in Case-II. The inside room temperature of wall insulated greenhouse dryer for Case-I is 4.11%, 5.08 % and 11.61 % higher than the Case-II during the day 1, day 2 and day 3 respectively. This result is also showing the effectiveness of solar collector and insulated north wall. The highest heat utilisation factor (0.616) is obtained during the second day for Case-I while for Case-II it is 0.769 during the third day of experimentation. Maximum coefficient of performance achieved is 0.892 during the third day of the experiment for Case-I whereas 0.953 is obtained on the first day of experimentation for Case-II.

1. Introduction

The production of fruits and vegetables in the world has been estimated around 392 million and 486 million tons, respectively in which 30%–40% is spoiled of total production due to lack of postharvest handling up to consumption in developed country (Sharma et al., 2013). India is a developing country and it is second the largest producer of fruits and vegetables (Sharma et al., 2013; Singh et al., 2014). Nearly 35% losses are estimated during postharvest period of fruits & vegetables (Sharma et al., 2013; Singh et al., 2014; Singh and Kumar, 2012b). Fruits and vegetables with higher water content help the easy attack of the micro-organism and the microbial effect plays a very important role in spoilage of fruits and vegetables (Singh et al., 2014; Singh and Kumar, 2012b). The financial value of those losses is approximately 104 million dollars annually and the reasons of these losses are poor preservation approaches, improper handling and improper storage facilities (Singh and Kumar, 2012b; Fudholi et al., 2015).

Food preservation is a process of moisture removal from agricultural produce up to a safe limit and this process is known as crop drying. Crop drying is a process of dehydration using the heat. That heat can be generated by burning of fossil fuels, through the electricity and by the solar radiation (Singh and Kumar, 2012b; Fudholi et al., 2015; Prakash et al., 2013). But consumption of fossil fuel again a problem like burden of foreign exchange on developing country and other problem is environmental concern (GHG emission). Other sources of heat energy can be electricity. But after a lot of practices and efforts, lot of villages of developing countries are still waiting for the continuous and sufficient supply of electricity. So avoid such problems, renewable energy can be best solution. Renewable energy is not available in the form of heat but sun can generate enormous amount of heat energy through various available technologies like solar collectors, solar concentrators and solar dryers which had been developed in past. Solar energy is a rising and smart option for the rural occupiers and farmers (Ekechukwu and Norton, 1999; Singh et al., 2006; Prakash and Kumar, 2014c,d).

The sun has great potential to fulfil our energy needs. Solar drying is one of the traditional and general methods of

* Corresponding author. Tel.: +91 9926754737, +66 950439186; fax: +91 755 2670562.
E-mail addresses: prashant_srit@yahoo.co.in (P.S. Chauhan), anilkumar76@gmail.com (A. Kumar).

http://dx.doi.org/10.1016/j.egyr.2016.05.004

Nomenclature

A_c	Cross sectional area of the ventilator (m^2)
A_i	Cross sectional area of the inlet hole (m^2)
A_v	Cross sectional area of vent (m^2)
C	Constant
C_{df}	Coefficient of diffusivity
h_{cvt}	Convective heat transfer coefficient of the air (W/m^2 °C)
I_{gr}	Global solar radiation (W/m^2)
I_{dr}	Diffuse solar radiation (W/m^2)
$I(t)$	Solar intensity inside the NWIGHD (W/m^2)
N'	Number of sets
N'_0	Number of observations in each set
n	Constant
$P(T)$	Vapour pressure of humid air at temperature T, N/m^2
ΔP	Partial pressure difference between room temperature and ambient air (N/m^2)
Q_{lf}	Heat loss factor (W)
Rh_a	Ambient relative humidity (%)
Rh_{gh}	Inside greenhouse relative humidity (%)
T_{rm}	Temperature inside the North wall insulated greenhouse dryer (°C)
T_a	Ambient temperature (°C)
T_{gd}	Ground temperature (°C)
v_s	Surface Velocity air (m/s)
U'	Internal uncertainty
$X_i - X'$	the deviation from the mean
σ'	Standard deviation,
ρ	Density of humid air (kg/m^3)
η_{ith}	The instantaneous thermal loss efficiency factor
COP	Coefficient of performance
HUF	Heat utilisation factor
WSC	with solar collector
WOSC	without solar collector

conservation of food crops. Solar drying is a combined process of heat and mass transfer. In this first heat is supplied to the product from the sun and then mass transfer form crop surface to the surrounding in terms of moisture content. According to heat utilisation technique, solar dryer can be classified as: direct, indirect and mixed mode (Prakash et al., 2013; Chauhan et al., 2015; Kumar et al., 2014).

Each dryer can be operated in either passive (natural convection) or active mode (forced convection). The passive mode of greenhouse dryer works on the principle of thermosyphic effect. The humid air gets ventilated through the ventilator provided at the roof or through the chimney of the dryer. Humid air is ventilated by the help of an exhaust fan provided at the ventilator. It is generally provided in the upper portion of the west wall (Kumar et al., 2006; Kumar and Tiwari, 2006b,a).

Greenhouse dryer is direct type solar dryer and crop can be dried in bulk. This is most suitable solar dryer for small farmer. A significant interest among researchers has been observed in the field of greenhouse drying for designing, development and testing of different kind of greenhouse dryers. The review revealed that the greenhouse effect can also be used for low and medium temperature drying application inside the greenhouse dryer accepting its other application, like plant soil solarisation cultivation, aquaculture and poultry (Prakash et al., 2013; Kumar et al., 2014; Prakash and Kumar, 2015). For small-scale greenhouse dryer, losses of incident solar radiation through the north wall is a major problem and so as to make the greenhouse more effective than previous designs, the losses through the north wall is to be eliminated. The researchers anticipated numerous ideas to minimise the losses through the north wall of the dryer.

A packed bed even shape greenhouse dryer introduced for onion drying. In this dryer to a solar energy collector was used to store the heat energy for crop drying. A brick made north wall was made to reduce the thermal losses from the greenhouse and the inside surface of the north wall was painted black (Jain, 2005). An inclined north wall reflection was applied under both modes of the greenhouse dryer to optimise the design of the system. This idea enhanced the drying performance of the system (Sethi and Arora, 2009). A phase change material based dryer was introduced. In this dryer, phase change material was applied in the north to store the heat energy during the sun shine hours. This was another approach for enhancing the efficiency of the greenhouse drying system and it increased the inside greenhouse room temperature (Berrouga et al., 2011). In another approach a mirror was placed in the north wall to improve the use of solar radiation. A black PVC sheet was also put on the ground to minimise the heat loss from the ground. The idea was found more effective, but there were again heat losses through the north wall (Prakash and Kumar, 2014d,b).

Coefficients of Performance (COP), Heat utilisation factor (HUF) and Convective heat transfer coefficient (h_{cvt}) are essential parameters to understand the greenhouse effectiveness and performance. Many researchers have studied on convective heat transfer coefficient under load and unload conditions. However, it is rare to see the study on coefficient of performance and heat utilisation factor for greenhouse drying systems under unload condition.

In this present experimental work, a North wall insulated greenhouse dryer (NWIGHD) with solar collector is introduced with novelty. The modification of NWIGHD is done by the use of the nickel polished aluminium sheet in the north side for maximum utilisation of solar radiation and this north wall is made insulated with the help of 10 mm thick Thermocol sheet. A solar collector made by the black PVC sheet is also placed inside the NWIGHD to enhance the performance of the dryer and eliminate the heat loss from the ground.

All the experiment has been carried out in two different cases, namely Case-I and Case-II. In Case-I solar collector is placed inside the NWIGHD and in Case-II dryer is tested without solar collector (i.e. simply keeping on the barren concrete floor). The objectives of this investigation were: (i) experimentations in no-load condition (ii) to study the thermal behaviour of designed greenhouse dryer in ambient conditions (iii) to compare the COP of the system in each case and (iv) to evaluate the HUF.

2. Material and methods

2.1. Experimental setup

The volumetric dimension of the roof type even span North wall insulated greenhouse dryer is $1.5 \times 1.0 \times 0.5$ m^3 and the effective floor area of drying chamber is 1.35×0.85 m^2. The structure of NWIGHD is made using box-type aluminium strip to provide the strength with less weight for the basic structure and it was covered with 3 mm thick UV treated polycarbonate sheet. The Polycarbonate sheet was fixed using screws and it was also tilted at 23.5° to allow the maximum solar radiation inside the NWIGHD according to the Bhopal latitude (23.5°). The central height of the east and west wall is 0.712 m while the height of north and south wall is 0.5 m. For the inlet air, two circular holes were provided just below the tray having the diameter of 0.15 m and for the exhaust air one rectangular air outlet vent is provided in the middle of the roof top with an area of 0.0255 m^2. The north wall of the dryer is made by 1.0×1.5 m^2 nickel polished aluminium sheet which