Renewable and Sustainable Energy Reviews 34 (2014) 463–470

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

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

Performance study of different solar dryers: A review

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ARTICLE INFO

Article history:
Received 6 August 2012
Received in revised form
23 February 2014
Accepted 9 March 2014

Keywords:
Solar energy
Convective solar dryer
Indirect solar dryer
Direct solar dryer

ABSTRACT

Crop drying is essential for preservation in agricultural applications. It is performed either using fossil fuels in an artificial mechanical drying process or by placing the crop under the open sun. The first method is costly and has a negative impact on the environment, while the second method is totally dependent on the weather. By contrast, using a solar dryer is comparatively cheaper and more efficient. Some solar dryers run without electrical grid power or fossil fuels. This paper presents the state of various kinds of solar dryers that are widely used today. The indirect, direct, and mixed mode dryers that have shown potential in drying agricultural products in the tropical and subtropical countries are discussed. Aside from identifying the active and passive mode solar dryers, we also highlight the environmental influence on solar energy (harnessing) that plays a vital role in the solar drying sector. This paper also presents the related technologies that can help improve existing solar dryers.

Contents

1. Introduction

Most developing countries are unable to solve their food problems for the entire population because of the rapidly increasing number of people in their respective territories. This rapid population increase has a direct impact on food balance. The quality and quantity of food grains are deteriorating because of poor processing techniques and shortage in storage facilities. To maintain the right balance between food supply and population growth, reducing food losses during production time is mandatory. However, maximizing the food production capabilities of small farmers in rural areas is difficult. To solve the problem, drying has become one of the main processing techniques used to preserve food products in sunny areas.

However, traditional open sun drying has some disadvantages. For the past few years, scientists and researchers have been trying to find the best alternative to overcome this problem. They invented various kinds of solar dryers for agricultural products and have continuously worked to improve these dryers.

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http://dx.doi.org/10.1016/j.rser.2014.03.020
1364-0321/

The Earth has abundant solar radiation. In recent years, the use of solar energy has become more popular. Solar energy can be used in various processes such as drying, heating, cooking, and distilling. In terms of energy application, solar energy is categorized into electrical and thermal applications. In the agricultural sector, the use of solar thermal systems to conserve grains, fruits, and vegetables is feasible, economical, and ideal for farmers in many developing countries.

In the two stages of the drying process, the first phase occurs when heat is applied to the surface of the drying material at a constant rate, and the second process involves decreasing the drying rate [1]. Using a solar dryer is also advantageous for drying foods, vegetables, and grains so that they can be stored for a long time. Comparing solar drying and open sun drying, the former has many advantages compared with the latter. For example, solar drying increases the quality of products. Solar dryers in different sizes and types are used to dry various agricultural materials. Therefore, dryer selection is very important in this sector as the economic aspect should also be considered [2]. At present, researchers are finding ways to reduce the use of fuels in solar drying.

Renewable energy can play an effective role to meet energy demand. Among all, solar energy is most reliable and environmental friendly. We can use it as solar PV, solar thermal for pumping and drying crops in agricultural sectors [3,4]. Drying is an essential process in the conservation of agricultural products. In the drying sector, the supply and demand of energy is an important consideration. Solar energy storage can minimize the gap between supply and demand in this case. At steady state conditions, more efficient and cost-effective dryers play a vital role in substituting for the demand for fuel in many developing countries. Solar drying has very few barriers that can be improved and is already being applied in the agricultural sector with positive results.

Having a solar storage system is important in energy conversion and is responsible for drying many agricultural products even when direct sunlight is not available [5]. Although many agricultural food products, such as fruits, grains, and vegetables are often dried under the open sun, this method can lead to reduced quality and quantity [6]. Among all renewable energy sources, such as air, wind, and water, solar energy has the least impact on the environment. Therefore, in many tropical and subtropical areas in the world, open sun drying is still used. However, despite the fact that it is inexpensive, the final quality of the dried products is not up to international standard. Open sun drying also has other disadvantages. First, it is labor intensive [7–9]. Second, the products being dried can be spoiled because of rain, wind, moisture, and dust. Third, the quantity of the product may be reduced when birds, animals, or insects “attack” the products being dried. Fourth, this process fully depends on excellent weather conditions.

As alternatives, appropriate drying technologies can be used so that the product quality can be improved and product losses can be reduced. Solar drying is the best alternative that can help improve the quality of products [10,11]. One example is presented by Barnwal and Tiwari (2008) [12], who developed a photovoltaic (PV) greenhouse thermal dryer for seedless grapes. In their system, they calculated the evaporation of moisture, surrounding grape temperature, ambient air humidity, and greenhouse temperature to examine heat and mass transfer. They obtained satisfactory results [12].

During the drying period, maximum SR, maximum efficiency, and minimum moisture content at ambient temperature and humidity should be considered. In the previous studies, some AI techniques such as artificial neural network, genetic algorithm, web-based expert system, fuzzy logic and neuro-fuzzy inference systems etc. are used to obtain the optimal range of solar radiation that can increase the drying rate. Experimentally, it has been proven that such techniques are used in predicting the dryer operation and obtaining excellent output.

In drying system the equilibrium theoretical model does enhance the understanding of the physics of moisture sorption. Purely empirical equations for specific conditions offer better alternatives until fairly accurate theoretical or semi-theoretical models are developed. The models have fallen short of predicting accurately the exact processes involved in drying, due to over implication of assumptions. These models for specific products and conditions offers better predictions. In this study some established moisture equilibrium models are mentioned.

The isothermal moisture equilibrium theory by Langmuir [13] is based on the classical kinetic model of balance of evaporation and condensation rates of vapor for a monolayer of water vapor on the internal surface of materials. This gives the volume of water absorbed by a product isothermally at a vapor pressure P_v as

$$V_v = V_m\left[\frac{bP_v}{(1+bP_v)}\right] \tag{1}$$

A model by Kelvin [14] which considers moisture absorption in a solid based on capillary condensation within the pores of the material. The Kelvin equation expresses the relationship between the vapor pressure over a liquid in a capillary and the saturated vapor pressure at the same temperature as

$$\ln\left(\frac{P_v}{P_{vs}}\right) = \frac{2\sigma V\ \cos\ \alpha}{r' R_0 T} \tag{2}$$

Harkins and Jura [15], based on the theory of an existence of a potential field above the material surfaces, considers a balance between the work required to absorb or desorb a molecule of water and the sum of work against the potential field in bringing a vapor molecule to the surface and the energy of condensation.

$$\ln(P_v/P_{vs}) = d - e/{V_v}^2 \tag{3}$$

Henderson's semi-theoretical model [16] which is the most versatile moisture equilibrium model yet, expresses the relationship between the equilibrium moisture content and equilibrium relative humidity at a given temperature as

$$1-\phi = e^{-KTM_e^n} \tag{4}$$

In solar drying system the condition of solar activity is very important. Solar activity depends on many forms of transient behavior of sun, specially its atmosphere, which depends upon magnetism. A deep-seated dynamo mechanism produces the sunspot-scale fields, but in the quiet Sun other effects may play a role as well [17].

Solar activity depends on some phenomena such as sunspots which are magnetic storms on the surface of the sun, solar flares that are intense blooms of radiation, coronal mass ejections that bursts of solar material that shoot off the sun's surface. In 24 h solar cycle, two types of radiations are found: solar minimum cause due to weak solar activity, galactic cosmic ray and solar maximum cause when sun's global magnetic field is about to reverse polarity. In drying sector, the maximum solar gives the maximum efficiency [18].

Application of automatic control systenm in drying sector cab be justified by the possible reduction of manpower as well as by the higher reliability compare to manual control. Basically two types of control system used in dryer such as open-loop control system and closed loop or feedback control system. Open loop control is used when the input parameters should be constant or in case when the feedback control is not good enough. It is also called feed-forward control when one of the input variables is measured and used for adjusting of another input variable. Colsed loop control is automatic control system. It is used to comparing a