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Solar dryer with thermal energy storage systems for drying agricultural food products: A review

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ABSTRACT

Developing efficient and cost effective solar dryer with thermal energy storage system for continuous drying of agricultural food products at steady state and moderate temperature (40–75 °C) has become potentially a viable substitute for fossil fuel in much of the developing world. Solar energy storage can reduce the time between energy supply and energy demand, thereby playing a vital role in energy conservation. The rural and urban populations, depend mainly, on non-commercial fuels to meet their energy needs. Solar drying is one possible solution but its acceptance has been limited partially due to some barriers. A great deal of experimental work over the last few decades has already demonstrated that agricultural products can be satisfactorily dehydrated using solar energy. Various designs of small-scale solar dryers having thermal energy storage have been developed in the recent past, mainly for drying agricultural food products. Therefore, in this review paper, an attempt has been taken to summarize the past and current research in the field of thermal energy storage technology in materials as sensible and latent heat in solar dryers for drying of agricultural food products. With the storage unit, agricultural food materials can be dried at late evening, while late evening drying was not possible with a normal solar dryer. So that, solar dryer with storage unit is very beneficial for the humans and as well as for the energy conservation.

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Nomenclature

a_m	fraction melted
a_r	fraction reacted
C_{ap}	average specific heat between T_i and T_f (J/kg K)
C_{lp}	average specific heat between T_m and T_f (J/kg K)
C_p	specific heat (J/kg K)
C_{sp}	average specific heat between T_i and T_m (kJ/kg K)
Δh_m	heat of fusion per unit mass (J/kg)
Δh_r	endothermic heat of reaction
m	mass of heat storage medium (kg)
Q	quantity of heat stored (J)
T	temperature (°C)
T_f	final temperature (°C)
T_i	initial temperature (°C)
T_m	melting temperature (°C)

1. Introduction

Drying is an essential process in the preservation of agricultural products. Food products, especially fruits and vegetables require hot air in the temperature range of 45–60 °C for safe drying. Drying under controlled conditions of temperature and humidity helps the agricultural food products to dry reasonably rapidly to a safe moisture content and to ensure a superior quality of the product [1]. Controlled drying is practiced mostly in industrial drying processes. Hot air for industrial drying is usually provided by burning fossil fuels, and large quantities of fuels are used worldwide for this purpose. High cost of fossil fuels, gradual depletion of its reserve and environmental impacts of their use have put severe constraints on their consumption. Many rural locations of developing countries suffer from non-access to grid electricity; supplies of other non-renewable sources of energy are also either unavailable, unreliable or, for many farmers, too expensive. In such areas, crop-drying systems that employ electrically operated fans, heaters and other accessories are inappropriate. The large capital and running costs of fossil fuel-powered dryers are often not affordable for small farmers.

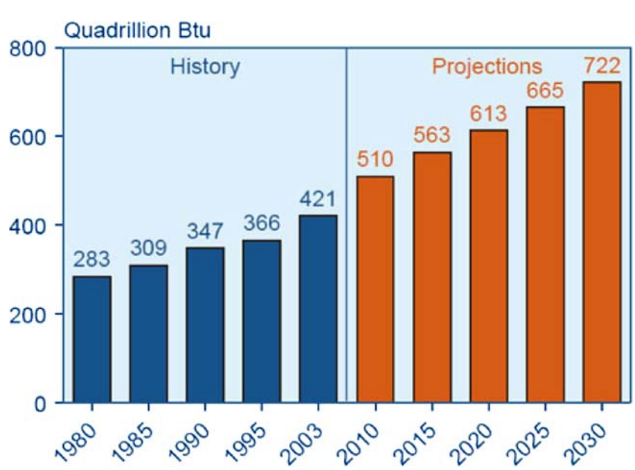

Fig. 1. Showing World marketed energy consumption, 1980–2030.*Source*: IEO2006 [2].

According to the International Energy Outlook 2006 [2], total World marketed energy consumption grows from 421 quadrillion British thermal units (Btu) in 2003 to 563 quadrillion Btu in 2015 and 722 quadrillion Btu in 2030 on an average by 2.0% per year shown in Fig. 1 and India is the fifth largest energy consumer, Fig. 2 [3]. Energy consumption for drying in developing countries is a major component of the total energy consumption, including commercial and non-commercial energy sources. Utilization of solar energy for thermal applications, like cooking, heating and drying, is well recognized in tropical and semitropical regions. Harnessing solar energy for drying offers significant potential to dry agricultural products such as food grains, fruits, vegetables and medicinal plants, thereby eliminating many of the problems experienced with open-sun drying and industrial drying, while saving huge quantities of fossil fuels. Various drying techniques are employed to dry different food products. Each technique has its own advantages and limitations. Industrial drying offers quality drying whereas its high cost limits its use. Open-sun drying suffers from quality considerations though it enjoys cost advantage. A solar air heater provides the hot air with a large variation in the temperature to the dryer only during sunshine hours. Whereas, drying of many agricultural products (e.g. cereals, pulses, foods and vegetables) are performed at the steady and moderate temperature and continuously for few days. In such a case, the thermal storage is required with a solar air heater for continuous drying so that possibility of drying during partial clouds and/or in late evening hours continuously for few days and hence, the storage will increase the utility and reliability of the solar dryers. A thermal storage unit integrated with the solar air heater may be charged during the peak sunshine hours and utilized (discharged) during off-sunshine hours for supplying the hot air to the dryer. The performance of solar air heaters has been simulated, designed, tested and suggested by many researchers for crop-drying purposes [4–9]. Choosing the right drying system is thus important in the process of drying agricultural products. Especially, in the tropical regions, where some crops have to be dried during rainy season, special care must be taken in choosing the drying system.

India is blessed with good sunshine. Most parts of the country receive mean daily solar radiation in the range of 5–7 kWh m^{-2}, and have more than 275 sunny days in a year [10]. Hence, solar drying has a high potential of diffusion in the country, and offers a viable option in the domestic sector. It is identified as an appropriate technology for Indian masses, and has numerous advantages such as no recurring costs, potential to reduce drudgery, high nutritional value of food, high durability, etc. In spite of these advantages, the main hurdles in its dissemination are reluctance to acceptance as it is a novel technology, intermittent nature of sunshine, limited space availability in urban areas, higher initial costs and convenience issues [11].

Solar energy is free, environmentally clean, and therefore is recognized as one of the most promising alternative energy recourses options. In near future, the large-scale introduction of

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