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Solar dryer efficiency considering the total drying potential. Application of this potential as a resource indicator in north-western Argentina

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Abstract

Indicators of drying potential for a region based on a model of free water evaporation in a solar dryer are presented. In these indicators, the total solar radiation and the saturation deficit of ambient air are considered as driving forces for solar drying process. The indicators were used to define the solar dryer performance considering the drying potential of the site. The performance definition was applied to a forced solar dryer placed in the town of San Carlos, (Salta, north-western Argentina) and was loaded with 30 kg of trays filled with water. The results were compared with other performance definitions. A standard dryer of 0.1 kg s^{-1} airflow was defined to estimate the potential indicators for 18 locations of the north-western Argentina using daily historical data. A mapping of dryer potential was obtained for the entire region through interpolating of results, showing similarity in relation to the distribution of phytogeographic areas. September was the month with the highest potential for solar drying on account of the end of the dried season and the influence of the local warm wind. The indicators also were obtained for San Carlos using recently measured data. Deviations from these potentials with respect to those obtained from the historical database were analyzed and similar results were obtained. The usefulness of these indicators was showed as a tool to be considered when variables other than solar radiation – such as temperature and relative humidity – are taken as energy sources.

Keywords: Performance indicators; Solar drying; Dryer efficiency; Drying potential

1. Introduction

The interest in the use of renewable energy with aim to reduce the dependence on conventional sources is increasing worldwide. The concern about the depletion of traditional energy sources and the growing energetic demand has arisen lately. This situation is accompanied with the worry of the greenhouse gases issues related to the burn of fossil fuels. In this context, renewable energies are in a growing phase and more actions are necessary to guarantee that these energy sources are put to good use. Energy planning studies including developing renewable energy source at a region level are more frequent (Mourmouris and Potolias, 2013; Ramachandra, 2009). Energy planning must appreciate the energy source in each region considering the available technologies, conversion efficiencies and optimizing use of the energetic resource. In this sense, efficiency indicators are necessary.

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Nomenclature

P_i	potential related to the solar energy (W)	$\bar{T}$	maximum average temperature (K)
P_a	drying potential of air (W)	$\bar{t}$	minimum average temperature (K)
P_T	drying potential (W)	η_{d1}	first-day drying efficiency (–)
Z	drying index (–)	η_c	heat collection efficiency (–)
h_a	air specific enthalpy (J/kg)	E	evaporative capacity
$\dot{m}_w$	mass flow rate of moisture (kg s^{-1})	η_p	pick-up efficiency (–)
$\dot{m}_a$	mass flow rate of air (kg s^{-1})	η_d	overall drying efficiency (–)
l_v	water evaporation latent heat evaluated at air saturation temperature T_s (J/kg)	a_w	water activity of the product (–)
W_i	inlet absolute humidity (kgw/kga)	A_d	dryer-collector surface exposed to the incident solar energy (m^2)
W_a	ambient absolute humidity (kgw/kga)	I	total solar radiation (W m^{-2})
W_o	dryer outlet absolute humidity (kgw/kga)	P_f	energy consumed by the fan (W)
W_s	absolute humidity of saturation (kgw/kga)	C_{pa}	specific heat of air (kJ/kg K)
T_a	ambient dry-bulb temperature (K)	$\bar{K}_t$	Clearness index (–)
T_i	inlet temperature (K)	P_{ws}	saturation vapor pressure in air (Pa)
T_o	outlet temperature(K)	P_w	vapor pressure in air (Pa)
T_s	saturation temperature (K)	H_R	relative humidity (–)

Solar energy is a real alternative in providing low temperature heat for many industrial applications. Among the applications of solar energy, solar drying is perhaps the most widely used. North-western Argentina is characterized by a suitable climate for solar energy use (high values of daily solar irradiation and high heliophany). This has promoted the development of solar drying systems for agricultural products on an industrial scale. There are numerous examples of solar dryers in which this technology has enabled a reduction in the consumption of conventional sources, such as gas and wood, (Condorí and Saravia, 1998, 2003; Condorí et al., 2001; Durán et al., 2010).

Productive development, such as large-scale solar drying, must be based on a good knowledge of the energy resource. The contribution of all environmental variables such as the solar radiation, ambient temperature and the ambient relative humidity must be considered important in solar dryers design. For performance comparison of different dryer designs, the tests must take into account the influence of these climatic variables on the drying efficiency. There are many studies of the thermal efficiency of solar dryers. However, there is not general agreement on methodology to compare their performances (Singh and Kumar, 2012). In the case of solar dryer, one of the main difficulties is the dependence on energies sources that vary in time and with the geographic location. Moreover, the products have different drying speeds according to the prevailing environmental conditions. This makes it difficult to compare the results obtained from tests on the performance of dryers even if the same type of dryer is considered.

Some authors have proposed different definitions of solar dryer performance trying to deal with these difficulties. Mulet et al. (1993) defined a pattern to compare the performance of solar dryers in different locations and proposed the open sun drying as a natural reference but using a standardizing time based on solar radiation collected to obtain drying curves to allow better evaluation of the experiments carried out under different circumstances. Jannot and Coulibaly (1998), defined a performance index (the “evaporative capacity”), that is understood as the maximum drying rate at which water can actually be extracted by the air mass flow that comes from a solar collector. Together with the thermal efficiency equation of a solar collector, this is an indicator that can be used to select the best flow rate in a solar dryer depending on the state of the product. The pick-up efficiency was considered as more useful for evaluating the actual evaporation moisture from the food in the drying chamber (Tiris et al., 1995). More recently, a methodology was established to characterize the solar dryer performance using the following indicators: Pick-up efficiency, overall system drying efficiency, first-day drying efficiency, and heat collection efficiency (Leon et al., 2002; Banout et al., 2011).

1.1. Drying performance

Solar dryers are classified into direct and indirect in relation to the incident solar radiation on the product. In a psychrometric chart, the sensible heating phase is associated with the solar air heating and is obtained through trials with unloaded dryers of product. For the drying phase, the direct solar dryers may have bigger slopes than indirect ones due to the energy gain in the chamber. The psychometric chart for the air processed in a direct solar dryer is shown in Fig. 1. The properties of the ambient air inlet