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Semi-industrial drying of vegetables using an array of large solar air collectors

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ABSTRACT

The design, structure, and evaluation of an indirect solar tunnel dryer are presented. This dryer corresponds to the air forced convection type. Two similar solar dryers were built and tested with vegetables on an industrial scale in Huacalera, northern Argentina, and operated by a cooperative of small agricultural producers. Each dryer consisted of a tunnel chamber of 450 kg load capacity and a bank of 10 solar collectors of 92 m^2. The bank of large solar collectors allowed temperatures in the drying chamber above 50 °C for 6 h a day, mixing with ambient air to produce the correct temperature for drying vegetables. A maximum rank of outlet temperatures of 80–90 °C and temperature differences of 50–60 °C were obtained with minimum air flow of 0.06 kg/s and without load. The dryers were operated with different vegetables, obtaining e.g. dried slicing onion with final moisture content 0.09 in approximately 16 h of sun. The optimum point of the collector efficiency was determined with airflow of 0.4 kg/s, however, lower than 0.23 kg/s airflow is needed to obtain outlet temperatures above 50 °C. A financial evaluation of the dryer was also performed as a clean energy project, reflecting that the investment return rate of the device is 13 months. In this scenario NPV improves in a 438% compared with the conventional scenario and SNPV is suitable only in the case of solar dryer. Solar drying at semi-industrial scale is feasible with the proposed technology due to the gusts of wind and the day-night thermal amplitude of Huacalera.

Introduction

Regions of Northern Argentina lack adequate access to conventional energy sources. In these places the main source of subsistence is the family agriculture, with small producer cooperatives that achieve significant production volumes. The local production is entirely destined for the fresh market, thus, the solar drying can be a tool for adding value to this activity, allowing the access to other markets. Numerous successful experiences exist worldwide in relation to solar drying technology with different agricultural products (Ringeisen et al., 2014; Stiling et al., 2012; Soponronnarit, 1995).

Even though there is a lot of work done in solar drying technology, solar dryer on an industrial scale has not been sufficiently studied and further research to optimize appropriate solar dryers is required. This application requires large banks of solar collectors to ensure energy supply (VijayaVenkataRamana et al., 2012; Sharma et al., 2009). The main aspects to achieve are to minimize the drying time and satisfy the product's quality requirement. The dryer production must be optimized to achieve the investment return rate. It is important to keep the drying rate as high as possible and assure a continuous production, since the final income is directly related to the drying costs by kilogram of dried product. Consequently, hybrid solar dryers with auxiliary heating systems and forced air circulation are normally used.

In 2007, a regional project including the construction of two industrial solar dryers started in Huacalera. The main objective pursued by the project was the improvement in the living conditions of the local population, generating sustainable added value to the production. This project, involved the participation of local NGO's with funding from the Spanish Agency for International Cooperation.

The town of Huacalera (latitude 23° 26′ S; longitude 65° 21′ W), is placed in Quebrada de Humahuaca at north of Argentina, at a height of 2462 m above the sea level. Crossed by the Capricorn Tropic, this zone was declared as natural and cultural heritage of humanity by UNESCO. The climate is arid with an average annual temperature of 13 °C and an annual average rainfall of 121 mm concentrated in December to March. The annual average wind speed is 5 m/s with gusts of intensity. There is no adequate supply of conventional energy, however, the solar resource is abundant (Reghini et al., 2005; Altobelli et al., 2014; Belmonte et al., 2009). The heliophany and the solar radiation level of this region are considered among the highest in the world. However, open sun drying is hard to be implemented due to the temperature amplitude, the strong winds and the risks of dust pollution.

Two similar solar dryers were built in Huacalera. A bank of solar collectors was used as air heating system, having the design criteria of provide temperatures above 50 °C during 6 or 7 h per day, from the total of

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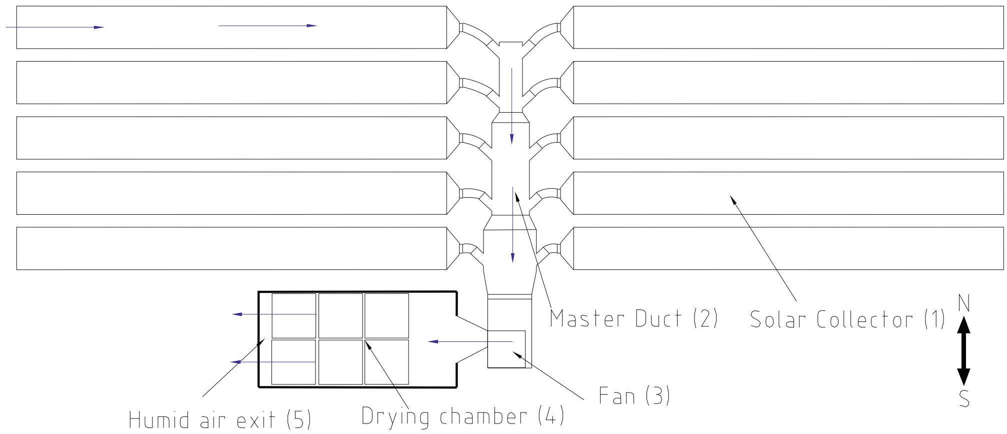

Fig. 1. Solar dryer plant view. The main parts are highlighted and air circulation is shown in blue arrows.

sunny hours. It is necessary to perform a mix with ambient air to prevent product burning. As a result, the dryer allow completing the drying in one or two sunny days, depending on the product conditions. These dryers can be classified as indirect according to the relation with sunlight, and as a tunnel type of semi-industrial scale if load capacity is considered (Mujundar, 1987; Duffie and Beckman, 2006).

Solar dryer construction

The dryers were constructed by local labour with basic training in blacksmithing. A plant schema of the dryer is shown in Fig. 1 and photography in Fig. 2. The main parts are the collector array, a master duct, fan cabinet and drying chamber. For operating reasons, the drying chambers were faced by the output doors, leaving a corridor in the middle to allow the carts movement. A first bank of collectors was placed north of the chamber, while a second bank of collectors was placed at the south side of the other chamber, but facing north and far enough from the chamber shadows, taken the average winter day as reference. The collector array was built with 10 solar air collectors, 5 on each side of the master duct, and including an electric fan to force the air circulation. Inside the drying chamber the product was distributed on six carts of 15 trays each.

The ambient air enters the solar collectors forced by the fan, and passes through them increasing its temperature, (1). An air filter of synthetic fiber is placed at the inlet of each collector to prevent the dust access. The master duct collects all contributions of collectors and it also works as another solar collector, (2). Before the fan, there is also a metal filter to remove particles, (3). The air is then forced into the drying chamber where it is laden with moisture, (4). All the humid air is discarded through two windows placed at the entrance gate of fresh product, (5). These windows also have air filters to prevent dust or insects entrance.

All collectors and master duct work in low air pressure while the drying chamber makes it at over pressure. The product is placed on trays, which are stacked on six carts. The carts are moved manually inside the chamber in the counter current direction of the air flow, producing a drying gradient along the tunnel. That is, the product located near the entrance of warm air has lower water content than that placed in the humid air exit. The carts with fresh products are entered into the chamber by this last side, and moved forward while the dried product is removed from a door place alongside the inlet air.

The solar collectors were separated 0.4 m to avoid shading between them and to allow operator transit. They are faced north, where five vertical supports, regularly spaced along the collector, are used to fit the slope. One of the long sides of the collectors is attached to these vertical supports while the other side rests on the floor. The supports consist of square structural pipes of 40 mm side and 0.7 m long; those were founded on the ground by concrete and were united to the external racks of the collectors by screws. Since only one side of the collectors was fixed, the collector slope can be changed seasonally according to the midday sun altitude, improving the direct solar radiation on the collector plane.

Large air solar collectors were used in the design of the dryers. These collectors are an improved version of the solar collector single pass with suspended flat plate, which allows the passage of air flow above and below the absorber (Ekechukwu and Norton, 1999). In this study, a

Fig. 2. Photograph of solar dryer. The collector array, fan cabinet and drying chamber are shown.