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Experimental investigation of an active direct and indirect solar dryer with sensible heat storage for camel meat drying in Saharan environment

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ABSTRACT

An indirect and direct forced convection solar dryer integrated with pebble sensible heat storage medium was developed and investigated under Saharan prevailing weather conditions. The setup consists of a direct chamber superimposed to an indirect drying one. A first pebble bed is placed in a plenum, below the direct drying chamber, a second in a cavity below the solar collector. The sensible heat storage system maintained the thermal efficiency of the solar collector until one hour after sunset and enhanced it by 28%. The thermal efficiency of the direct chamber was enhanced by 11.8%. Experiments of drying camel meat without salting were carried out under the different climatic conditions of July and November months. The drying kinetic evolution was investigated under each experiment conditions. The drying is faster in July than in November. Several mathematical models were tested to describe the best, in terms of statistical parameters, the drying behavior of camel meat slices. Logarithmic model and Midilli-Kucruk model are respectively the most suitable for July and November experiments. The average of indirect drying efficiency over diurnal period reached 18.34% in July and 15.52% in November. The direct drying efficiency reached the average of 10.35% and 7.88% respectively in July and November. In order to preserve the protein rate of the dried camel meat, salting which inhibits decay, pretreatment usually reserved for meat products before drying has been suppressed. Microbiological and physicochemical monitoring has been carried out to ensure the final quality of the dried product. The results obtained, compared to an open sun-dried samples were satisfactory according to the norms imposed by the Algerian legislation.

1. Introduction

Abundant, inexhaustible, and nonpolluting, renewable energies are obviously an alternative of choice to fossil energies. Peoples of the tropics and semi-tropics use solar energy for thermal applications, such as cooking, heating, and drying (Bal et al., 2010). The purpose of drying products is to reduce their moisture content. The decay caused by growth and reproduction of microorganisms is inhibited by the removal of moisture which minimizes many of the moisture-mediated deteriorative reactions (Kamil sacilik, 2007). In developing countries, the popular, efficient and economical method used for drying and preserving agricultural food and many other products is the open sun drying (Kumar et al., 2016). This traditional method of drying has many disadvantages. It can cause not negligible losses during natural sun drying because of various influences, such as rodents, birds, insects, rain, storms, and microorganisms (El-Sebaii et al., 2002). To overcome these inconveniences and ensure better control of solar drying aspects, different researches have been conducted over decades to develop solar dryers. The arrangement of the system components and mode of solar heat utilization categorizes the solar dryers as direct, indirect and mixed modes (Vijayan et al., 2016). Solar dryers are classified passive in the case of natural air circulation, forced if the latter is controlled by the use of a fan to pump air through the dryer. Prakash and Kumar (2013) reported in a review on recent researches that compared to natural circulation type solar dryers, forced convection (active solar dryers) are very effective and more controllable. This choice is all the more motivating as the electrical energy required to power the fan is low. Transmitting much thermal energy as possible to the air,

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Nomenclature

AE	daily average of thermal efficiency
As	surface area of flat plate collector (m^2)
AVG	average of moisture content in indirect chamber
ATE	daily average of thermal efficiency
CF	Fecal coliforms
CT	*Total coliforms*
I_g	global solar radiation (W/m^2)
GAMT	*Mesophilic germs total aerobia*
L	latent heat of vaporization of water (J/kg)
m_a	mass flow rate of air (kg/s)
P_f	power consumed by fan (W)
PH	Level of acidity
R^2	correlation coefficient
RMSE	root mean square error
S	Salmonella
SA	Staphylococcus aureus
T	temperature (°C)
UC	under collector
W	weight of water evaporated from the product (kg)
W_0	initial weight of sample (kg)
W_d	weight of dry matter (kg)
W_t	weight of sample at any time t (kg)
X_e	equilibrium moisture content on dry basis (kg/kg)
X_f	final moisture content on dry basis (kg/kg)
X_i	Initial moisture content on dry basis (kg/kg)
X_t	moisture content at any time on dry basis (kg/kg)
X_R	moisture ratio
χ^2	reduced chi-square
η_c	thermal efficiency of collector
η_d	forced convective drying efficiency

facilitating maximum moisture removal for the desired final condition of the product is one of the major goals in the design and optimization of a solar air heater (Esakkimuthu et al., 2013). Several researchers worked on improving solar dryers performance by developing the dryer component design technology as PVT collectors (Slimani et al., 2015a, 2015b, 2016, 2017), using different modes of air circulation, resorting to auxiliary heating sources (electricity and fossil fuels), and exploiting heat storage systems. Added to the fact that energy storage plays an important role in conservation the energy, it also improves the performance and reliability of a wide range of energy systems (Mahmud et al., 2011). Thermal energy can be stored as sensible heat, latent heat (PCM) or chemical energy. Sensible heat storage materials are cheaper and their thermal conductivity is usually larger than phase change material's (PCM) (Zhao et al., 2011). Being non-toxic and non-flammable, inexpensive and acting as both a heat transfer surface and storage medium represent some of the advantages provided by the use of rocks for thermal (Harmeet et al., 2010).

In the case of meat products, one of the purposes of drying is to give them new organoleptic properties that are highly appreciated by some consumers. In Algeria, the consumption of dried meat called ''El Keddid", is widespread. In the Saharan areas of the country, where the solar drying under the open sky is very widespread because of the lack of adequate access to the electrical network, a special taste is reserved for camel meat and its derivatives. Camel meat in some areas is more consumed than other species such as beef and sheep (Shalash, 1998; Wilson, 1984). Meat products are very perishable, among other things, because of their important microbial load; satisfactory solar drying must preserve their sanitary quality, physico-chemical and organoleptic and allows their storage over an extended period. Camel meat, which is a favorable medium for the profiling of Mesophilic germs total aerobia (ElMalti, 2008), its solar drying becomes even more delicate. A pretreatment of meat products by salting before drying acts as an antimicrobial and protects against microbiological degradation, Camel meat, which is a good source of protein containing about 20–23% (Kadim et al., 2008; Kilgour, 1986), loses much of this component by chemical degradation due to this salting (Chaouch, 2016).

The present work was aimed at generating a system that was supposed to combine three imperatives: to overcome the failures of the electrical network in the field of food preservation, to democratize the use of solar dryers for a safe and sanitary drying, and to guarantee the microbiological quality of the meat to be dried by faster drying thanks to an efficient and inexpensive energy storage system considering the very limited economic means of the local population.

In this paper, we present in first the design of a direct and indirect dryer. The circulation of the drying air in it is forced by ventilation and its heating is reinforced by a bed of pebbles for the sensible heat storage. The body of the dryer consists of a direct drying chamber superimposed on another indirect drying chamber whose circulating air passes by a solar collector. This vertical assembly makes it possible to optimize the drying space with respect to the quantities to be dried and to exploit the advantages of each drying mode (direct and indirect) according to the quality objectives to be achieved. Then, we give the results of investigation experiments conducted about the effect of sensible storage heat on solar collator performances. Drying experiments were conducted on two different seasons of the year to compare the performance of the system and the drying behavior of camel meat under different climatic conditions. The kinetic behavior of meat camel drying is also subject to monitoring and mathematical modeling. The evolutions of drying efficiencies of both direct and indirect drying chambers were indicated. Finally, the results of microbiological and physicochemical of monitoring the quality of camel meat dried under direct, indirect mode and open sun are presented and discussed.

2. Materials and methods

2.1. Description of the setup

The solar dryer object of the experiment was designed, constructed and investigated experimentally within the Unit of Research on Renewable Energies in the Saharan Environment of Adrar (URER/MS d'Adrar) in Algeria. As shown in Fig. 1, the solar drier consists of the following elements.

The components of the setup are presented in details in Fig. 1. On the descriptive scheme (Fig. 1c), the solar collector (A) is placed at 28° tilt angle, the latitude of the place. It is composed of a glass cover and an absorber plate of metal of thickness 5 mm with black coating. The glass cover and the absorber plate are associated on an aluminum frame; it gives the duct where the inlet air is heated from the incident solar irradiation. The duct has a parallelepiped shape with 95 × 100 × 4 cm. Its entrance is perforated with equidistant holes to provide uniform air circulation.

The solar collector is placed above a box body which serves as a cavity for containing pebbles bed acting as sensible heat storage medium intended to provide a heat supplement to the air entering the indirect drying chamber. The profile of the box body containing the pebbles is triangular. It is made, from outside to inside, of metal plates, a layer of polystyrene then a layer of plywood superposed on the lateral walls and at the base of the body in order to limit thermal losses.

An indirect drying chamber (B) equipped with several trays to contain the meat to be dried superimposed at a distance of 15 cm from each other is connected to the solar collector.

The volume of the indirect drying chamber is equal to (90 × 60 × 15) cm^3. That of the direct chamber is equal to [(50 × 50 × 50)/2] cm^3 with one tray to support the meat.