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Experimental performance of mushroom fluidized-bed drying: Effect of osmotic pretreatment and air recirculation

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ABSTRACT

The present work evaluates the effect of osmotic pretreatment (OP) and air recirculation (AR) on energy and exergy analyses of fluidized bed drying of sliced mushroom at different drying conditions. The drying was carried out at drying temperatures of 30, 40 and 50 °C, air superficial velocities of 3, 5, and 7 m/s for osmotic pre-treatment and untreated (control) samples under with/without air recirculation. Results showed that both air recirculation and osmotic pretreatment significantly effect on energy and exergy parameters. The energy consumption increased with increasing air velocity and drying temperature while it decreased with using osmotic pretreatment and air recirculation techniques. The energy utilization ratios vary between 0.10 and 0.269 for control/NAR and 0.890 to 0.964 for OP/100% AR, while exergy efficiency vary from 10.40 to 30.57% and 0.81–3.94% for OP/100% AR and control/NAR, respectively. Exergy loss significantly decreased with recycling the exhaust air.

1. Introduction

Due to their high moisture content, mushrooms are highly perishable as they start deterioration soon after harvest, with a shelf life of 1–2 days at room temperature [1,2]. Several methods employed for the preservation of mushroom in food industry such as canning, pickling, and drying. Dried mushroom is a common ingredient in several food formulations including instant soups, pasta salads, snack seasonings, stuffing, casseroles, and meat and rice disks [2]. There are several studies in the literature related to the drying characteristics of mushroom [1,3–10].

Drying combined with some pretreatments appears to be a cost-effective method of preservation. Pretreatments of some agricultural foods prior to drying have been reported to help reduce some of the undesired changes such as color and textural changes. Also, they reduce drying time by relaxing tissue structure and yield a good quality to dried product [4,10,11]. Literature review shows that the osmotic pre-treatment of mushroom improves nutritional, sensorial and functional properties of the dehydrated mushroom without changing its integrity [2,4,7,9,10,12,13]. At all the resources mentioned, the researchers studied the mathematical modeling of drying kinetics and effect of osmotic pre-treatment on qualitative aspects of dried mushroom.

Energy is an essential factor in overall efforts to achieve sustainable development. Drying accounts for 12% of all energy consumption in the food industry where the cost of drying can approach to 60–70% of the total cost [14,15]. Therefore, it is vital for researchers and engineers to reduce the energy consumption energy for maximum moisture removal and increase the thermal efficiency of drying systems using engineering analysis. There are many studies on the energy consumption of mushroom in different drying methods [3,16,17]. The energy analysis provides no information about the quality of energy and is, therefore, useless for sustainable design or optimization purposes [18]. From second law of thermodynamic point of view, exergy is defined as a quantitative measure of the quality of energy or the maximum useful work possible during a process [19–21]. Recently, several reviews have been undertaken on of energy and exergy analyses of food drying such as Dincer and Rosen [22]; Panwar et al. [23]; Aghbashlo et al. [18], and Hepbasli [19].

The literature review showed that no information is available on the effect of osmotic pre-treatment on the energetic and exergetic performance of fluidized bed drying of vegetables such mushroom.

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Nomenclature

A_{ch}	cross surface of chamber column (m^2)
AR	air recirculation
C_p	specific heat (kJ/kg K)
E	energy (J)
E_{sc}	specific energy consumption (J/kg water)
EU	energy utilization (kJ/s)
EUR	energy utilization ratio (−)
EX	exergy (J)
E_{loss}	energy loss (J)
EX_{loss}	exergy loss (J)
ex	specific exergy (KJ/kg water)
h	specific enthalpy (kJ/kg)
h_{fg}	Latent heat of water (kJ/kg)
m	mass (kg)
m_w	total of mass water evaporated (kg)
$\dot{m}$	mass flow rate (kg/s)
m_{pt}	mass of sample at any time (kg)
NAR	no air recirculation
OP	osmotic pretreatment
P	atmospheric pressure (Pa)
P_{vs}	saturated pressure (Pa)
Pv	vapor partial pressure (Pa)
T	temperature (K)
t	time (s)
T_0	inlet temperature of air to heater (°C or K)
T_{ave}	product average temperature (°C)
u_a	air velocity (m/s)
x	absolute humidity of air (kg water/kg drying air)
η_{ex}	exergy efficiency (%)
ρ	density (kg/m^3)
φ	relative humidity of air (%)

Subscripts

0	inlet to heater
a	air
en	energy
ex	exergy
in	inlet
loss	loss
out	outlet
s	specific
P	product
t	time
v	Evaporated
w	water

Also, we found very few studies about of air recirculation effect on the exergetic performance of hot air dryers [24–26]. Therefore, the objective of this study is to evaluate the effect of osmotic pretreatment and air recirculation on the overall energy and exergy efficiency of fluidized bed drying of mushroom at different drying air temperatures and air velocity.

2. Materials and methods

2.1. Preparation of samples

The white button mushrooms were procured from Vartash Mushroom Farm, Gorgan, North of Iran, washed with clean water to remove dirt and cut into slices of thickness about 2 mm. In order to prevent enzymatic browning by reducing the rate of reaction, the slices were put into 100 °C boiled water for 1 min, then were taken out and cooled to room temperature by 18 °C water [27]. Optimal conditions for osmotic dehydration process of button mushroom were 46 °C for osmotic temperature, 7% for salt concentration (osmotic solution: Sodium chloride + water), 85 min for osmotic time and 638.69 mbar for pressure system that reported by Rasouli Ghahroudi et al. [2]. We used the conditions listed to provide the pretreatment osmotic of sliced mushroom. The sample/solution ratio was kept as 1:5. After the specified immersion time, the osmotically heated samples were quickly rinsed, gently blotted dry with absorbing paper in order to remove adhering osmotic solution. The moisture content of fresh slices mushroom was determined by heating in a electrical oven at 103 °C for 24 h [4] and obtained 13.71 kg water/kg dry matter (or 93.2 ± 1.5% wet basis). The effect of osmotic pre-treatment on the water loss and solid gain of mushroom samples was determined according to Rasouli Ghahroudi et al. [2] and Bchir et al. [42].

2.2. Drying apparatus and procedure

The drying of sliced mushroom was investigated on a laboratory-scale fluidized bed dryer was shown in Fig. 1. The fluidized bed consisted of a Plexiglas cylindrical chamber (210 mm in diameter and 800 mm in height), 5 kW hot-air heaters controlled by a PID controller (with accuracy of ±1 °C) and a backward curve centrifugal fan was driven by 3 kW motor that was connected to a frequency inverter to precisely adjust the flow rate. Fluidized bed dryer operated at 100% air recirculation due to reducing energy consumption [28]. In order to eliminate the effects of the reduction of moisture gradient inside the drying chamber resulting in air recirculation, the drying process is done with 5 min closed cycle/10s open cycle (In fact, in the interval of 10 s measured sample mass changes. The air with high moisture is removed from the drying chamber and it is replaced with hot air with low moisture). This cause removes moisture from inside the air cycle system and will increase the moisture gradient, improve the drying rate, decrease drying time and energy consumption [28,29]. Air velocity was measured using an anemometer (AM-2416, Lutron, Taiwan) with

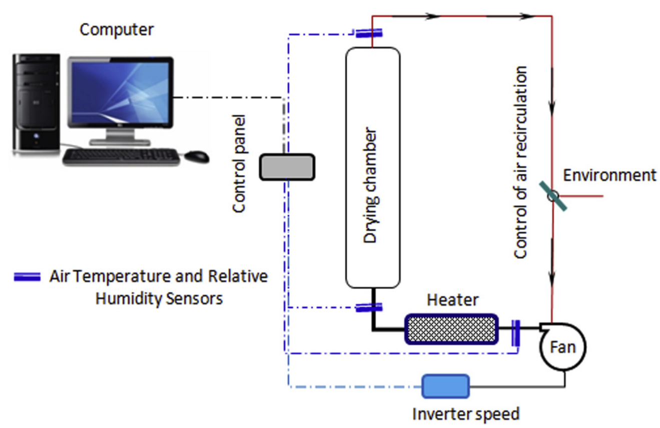

Fig. 1. Fluidized bed dryer setup.