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Effect of various drying bed on thermodynamic characteristics

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ABSTRACT

In this study thermodynamic parameter and energy consumption in drying of two plant dill and mint in three bed drying including fix, semi fix and fluid with using a hot air drying was investigated. Experimental was conducted in three bed drying including fix, semi fix and fluid and four levels temperature (30, 40, 50 and 60 °C). Maximum energy consumption in dill drying at 40 °C and fluid bed to be 16.41 MJ and minimum energy consumption at 30 °C and fix bed to be 2.77 MJ. Also minimum energy consumption in mint drying at 60 °C and fix bed to be 3.64 MJ and maximum energy consumption at 40 °C and fluid bed to be 28.65 MJ. The highest energy, drying and thermal efficiency for both mint and dill was achieved at 60 °C on the fixed bed, whereas the lowest efficiency was at 40 °C and on the fluidized bed. Also the highest power and specific heat consumption for both mint and dill was achieved at 40 °C on the fluid bed, whereas the lowest efficiency was at 30 °C and on the fluidized bed.

1. Introduction

Historically, solar energy has been used for the drying of agricultural produce. However, this practice has multiple downsides including undesirable changes in food quality, lack of sufficient control over the drying process, longer drying periods, and contamination [1–4]. On the other hand, industrial dryers (hot-air dryer with fluidized bed) bring about several advantages including longer storage time, reducing food weight and volume, preventing perishing and preserving its qualitative properties [5].

Drying is a highly energy-consuming process as it accounts for 12% of total world energy consumption in industry and agriculture. Industrial dryer, including the hot-air dryer, consume a large portion of energy in the drying industry, rendering drying an energy-intensive important industrial process [6]. This is mainly due to using high temperature air at high flow rates. Moreover, as for cereals, drying processing takes about 60% of total generated energy. This is a considerable amount when compared to mean energy consumption for tilling (16%), planting and cultivating (12%), harvesting (6%) and transporting (6%) [7].

Fluidizing is a widely-used practice for the drying of agricultural and food stuffs. The fluidized bed drying is known as a slow, uniform drying method capable of efficiently reducing moisture content of materials [8]. This technique is characterized by being applicable to highly moist materials and proper thermal control due to mixing the drying materials. Fluidized bed drying can be a continuous or batch process [9]. Therefore, this dryer is a proper alternative for drying of different products and vegetables including dill and mint [10].

Fluid bed drying advantages are several including uniform moisture content, using higher temperatures for drying, higher drying capacity thanks to its better mass and heat transfer, using smaller drying chambers, lower costs and higher product quality [5].

Extensive studies have been conducted on energy consumption and thermodynamic parameter of fixed bed drying in hot-air dryers, *e.g.* drying of pomegranate arils [2], mushroom slices [3], bereris [1], jujube [11], azarole [12], urtica [13], paper pulp [14],

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Nomenclature

A	Tray area (m^2)
C_a	Specific heat (kJ/kg °C).
C_m	Material specific heat (kJ/kg K)
C_p	Air specific heat at constant pressure (kJ/kg K)
E_{mec}	Energy consumption of fan (MJ)
EU_{mec}	Mechanical energy consumption (MJ)
EU_{ter}	Thermal energy consumption (MJ)
h_{fg}	Latent heat of vaporization (kJ/kg)
M_0	Final product moisture content (w.b%)
M_i	Initial products moisture content (w.b%)
M_p	Particle moisture content, dry basis (kg water/kg solid)
M_w	Weight of loss water (kg)
P_{vs}	Saturated vapor pressure of air (kP_a)
Q_m	Energy for the material heating (MJ)
Q_w	Energy for the moisture evaporation (MJ)
RH	Relative humidity (%)
SEC	Specific energy Consumption (MJ/kg $_{water}$)
T	Temperature (°K)
t	Total time for drying each sample (h)
T_{m1}	Inlet material temperature (K)
T_{m2}	Outlet material temperature (K)
v	Velocity (m/s)
w	Relative humidity (%)
W_0	Weight loss (kg)
$w_1, w_2, \ldots, w_n$	uncertainties in the independent variables
W_d	weight of dry material (kg)
w_R	uncertainty in the result
W_w	weight of moist material (kg)
$\times_1, \times_2, \times_3, \ldots, x_n.$	independent variables
ΔP	Different pressure (mbar)
ΔT	temperature difference (°C)
ρ_a	Air density (kg/m^3)

chamomile flower [4], moist particles [15] and of fluidized and semi-fluidized bed dryers, *e.g.* pistachio [16] and garlic slices [17], Soybeans [18].

Since drying is ranked first for energy consumption in the agriculture sector, the required energy and various thermodynamic parameter for drying vegetables such as dill and mint by a hot air dryer with different drying beds was measured and compared.

The research objectives included:

- Determining and comparing the different thermodynamic parameter and energy consumption of three different drying beds for dill and mint;
- Studying the effects of input parameters (temperature and hot air flow) on energy consumption and specific required energy.

2. Materials and methods

In order to measure the moisture content (M.C.) of dill leaves, AOAC Standard (1980) was used. In doing so and to determine the actual M.C., five 5 g samples were first randomly selected from a pile of the products and were placed in an oven. The AOAC Standard requires placing the samples for 3–4 h at 100 °C inside the oven, for determining dill M.C. Once dried, the samples were removed from the oven and weighed immediately. The initial M.C. of dill leaves was 0.833 (d.b.) and 0.06 ± 0.01 (w.b.) for dill's.

Experiments were performed in a dryer capable of creating different bed types (fixed, semi-fluidized, and fluidized). To control for air flow velocity, a centrifugal blower driven by a three-phase 0.375 kW motor was used. To control the rotary speed of the electromotor from zero to its rated speed, an inverter (Vincker VSD2, made in Taiwan) capable of controlling speed with 0.1 Hz accuracy was also used. The required thermal energy was provided by two 2 kW thermal elements inside the drying bed. The incoming air's temperature was adjusted by a K-type thermostat (Pooyesh, ± 0.1 °C) within 0–100 °C. Atbin Mega (made in Iran, ± 0.1 °C) sensors were used to measure temperatures at the inlet and outlet of the dryer. Relative humidity of incoming and outgoing air was measured by Lutron TM-903 (± 3% RH, made in Taiwan), and air velocity was also measured by a vane anemometer (Testo 505-P1). The drying chamber was a cylinder with a 150 mm diameter and 320 mm height. The ambient temperature during the experiments

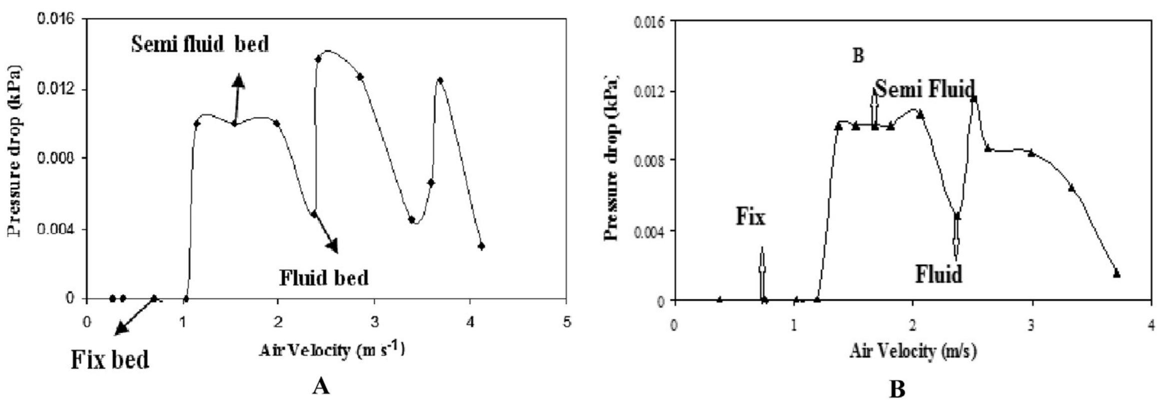

Fig. 1. Various drying bed in drying of A) Dill B) Mint.