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Convective drying characteristics of sludge from treatment plants in tomato processing industries

A. Ruiz Celma[a,*], F. Cuadros[b], F. López-Rodríguez[c]

[a] Department of Mechanical and Energy Engineering, University of Extremadura, Avda Elvas s/n, 06006 Badajoz, Spain
[b] Department of Applied Physics, University of Extremadura, Avda Elvas s/n, 06006 Badajoz, Spain
[c] Department of Engineering Projects, University of Extremadura, Avda Elvas s/n, 06006 Badajoz, Spain

ABSTRACT

The present work is mainly focused on the study of the thin layer drying behaviour of sludge from water treatment plants in tomato processing industries, using a convective dryer. The drying experiments were conducted at inlet temperatures of drying air of 30 °C, 40 °C and 50 °C and at an airflow rate of 0.9 m/s and 1.3 m/s. The drying rate was found to increase with temperature and velocity, hence reducing the total drying time. In particular, as drying temperature was raised from 30 °C up to 50 °C, the time period needed to reduce the moisture content of the sample from 173 wt% down to 7 wt% (dry basis) was observed to decrease from more than 760 min to 470 min (0.9 m/s) and from 715 min to 295 min (1.3 m/s).

Using a non-linear regression (Marquart's method) together with a multiple regression analysis, a mathematical model for the thin-layer convective drying process of sludge from treatment plants in tomato processing industries was proposed. The values of the diffusivity coefficients at each temperature were obtained using Fick's second law of diffusion, and varied from 6.11×10^{-10} m^2/s to 2.54×10^{-9} m^2/s over the temperature and velocity range. The temperature dependence of the effective diffusivity coefficient was described following an Arrhenius-type relationship. The activation energy for the moisture diffusion was determined as 30.15 kJ/mol and 36.70 kJ/mol, for airflow rates of 0.9 m/s and 1.3 m/s respectively. Air temperature 40 °C and drying airflow rate 1.3 m/s were found adequate to reduce drying energy consumption as well as to optimise the dryer loading/unloading periods.

Keywords: Tomato residue; Infrared drying; Moisture-ratio models; Statistical test; Activation energy

1. Introduction

The cultivation of tomato (*Solanum lycopersicum*) is widespread throughout the world. In particular, 90% of world output is produced in the northern hemisphere (Mediterranean area, California and China). Although tomato is cultivated in more than one hundred countries, both for fresh consumption and for industrial processing, the top ten producers account for more than 80% of world output: United States, China, Italy, Iran, Turkey, Spain, Brazil, Portugal, Greece and Chile. The total world production exceeded 125 million tons in 2006 (FAO, 2006), thus representing one of the most relevant crops in terms of employment and wealth generation.

The industrial processing of tomato leads to a great variety of output products. Some of the most relevant are the following: concentrated tomato products, either as puree or paste depending on the percentage of natural soluble solids; pizza sauce, from peels and seeds; tomato powder, as dehydrated concentrated tomato; peeled tomato, either whole or diced; ketchup, tomato sauce seasoned with vinegar, sugar, salt and some spices, etc.

High volumes of water are consumed during the first operations in plants where tomato is processed to obtain concentrated and diced output products. Some of the operations involved are the following: washing of raw material, scalding, cooling, thermal treatment, and cleaning operations in processing lines. Water consumption in such operations is estimated to approach 3 m^3 per ton of product (Agenex, 2008). After those operations are held, water is channeled to a wastewater treatment plant to undergo the three following

* *Corresponding author*.
E-mail address: antoniorcelma@gmail.com (A.R. Celma).

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Nomenclature

a, b, c, y, g, h	empirical constants
k, k_1, k_2	drying rate constants (1/s)
D_{eff}	effective diffusivity (m^2/s)
D_0	pre-exponential factor (m^2/s)
DR	drying rate (g water/g dry matter s)
E_a	activation energy (kJ/mol)
E	energy needed (MJ)
E_e	specific energy requirement (MJ/kg)
L	thickness of the slab (m)
M_e	equilibrium moisture content (g water/g dry matter)
M_0	initial moisture content (g water/g dry matter)
M_t	moisture content at time t (g water/g dry matter)
MR	moisture ratio
MR_{exp}	experimental moisture ratio
MR_{pre}	predicted moisture ratio
N	number of observations
n	positive integer
p	number of constants
R	universal gas constant (kJ/kmol K)
r	diffusion path (m)
$RMSE$	root mean square error
r^2	coefficient of determination
T	temperature (K)
t	drying time (s)
V	airflow rate (m/s)
W_0	initial weight of dried product (g)
W_d	weight of dried product (g)
W_t	weight of product to be dried at any time (g)
χ^2	reduced chi-square

operating steps: pretreatment in rotating and sand filters, bio-oxidation and decanting. It is after the latter operation that sludge is obtained as semisolid waste from the wastewater treatment plant, with a moisture content approaching 60–70% (wet basis). A detailed characterization of such product is presented in Table 1.

The abovementioned residue from industrial processing of tomato is used in the experiments performed in the present work, and represents between 1.5% and 1.7% (in weight) of fresh product. Important costs are derived from transport of wastes with significant moisture content, thus impeding a direct and reasonable use. Therefore, a thermal drying process of such waste product is highly recommended in order to optimise handling logistics, so that it can be finally used as soil amendment.

The most relevant aspects of drying technology are the mathematical modelling of the process and the experimental setup (Akpinar et al., 2006). The modelling is basically based on the design of a set of equations to describe the system as accurately as possible. Drying characteristics of the particular products being dried and simulation models are needed in the design, construction and operation of drying systems (Toğrul and Pehlivan, 2002). Many authors have focused their efforts on the study of the drying behaviour of different products, mainly vegetables, fruit and agrobased products. The falling rate period appeared as the most relevant variable in all those studies, and Fick's law of diffusion was used to describe the drying process. In particular, empirical and semi-theoretical models – which consider only the external resistance to moisture transfer between product and air – are the most widely used. The basic reason for such election lies in the fact that those models need no geometric, mass diffusivity nor conductivity assumptions (Parry, 1985). However, no information on the convective drying process of sludge from wastewater treatment plants in tomato industries at low drying temperatures is reported in the scientific literature.

The aim of the present experimental work was to investigate the thin-layer convective drying behaviour of such waste product at drying temperatures 30 °C, 40 °C and 50 °C and at an airflow rate of 0.9 m/s and 1.3 m/s. For such purpose, the mathematical modelling of the drying curves is presented, a first useful approach to the moisture diffusivity values for each drying temperature and drying air velocity are given, and finally the activation energy of sludge is evaluated. Note that these features are crucial for the effective design and the setting-up of specific drying plants for particular sample products. In addition, the calculations regarding the energy requirements for drying operations involved in the present work are also reported.

Table 1 – Characterization of sludge samples from wastewater treatment plants of tomato transformation industries.

Parameter	Value
Moisture content (wt% wb)	63.36
Dry matter (wt% wb)	36.64
pH	7.23
Organic matter (%)	7.43
Nitrogen (%)	0.2
Phosphorus (ppm)	935.61
Zinc (ppm)	12.22
Copper (ppm)	6.72
Lead (ppm)	4.09
Mercury (ppm)	639
Nickel (ppm)	1998.5
Cadmium (ppm)	<10

2. Materials and methods

2.1. Materials

The samples of fresh sludge were obtained from the wastewater treatment plant of a local tomato industry located in the province of Badajoz (in the Southwest area of Spain) in August 2009. They showed an initial moisture content (172.92 ± 0.50)% by weight (dry basis). Such value was determined after a drying process in an oven at 105 °C for 4 h, which led to the achievement of a percentage dispersion below 2% for the values of the moisture content in the three first experiments. This way, the final value for the initial moisture content was taken as the arithmetic mean of those data, as stated by the Norm UNE 32001 (1981).

2.2. Convective drying experiment

In this study, a convective dryer, Fig. 1, was used as experimental equipment. It consists of a fan, a resistance battery and a heating control system, air-duct, tray and measurements instruments. The air fan has a maximum volumetric flow rate of 700 m^3/h and a power of 33 W. The airflow was controlled by a revolution speed regulator. The air-