EASR

Engineering and Applied Science Research

https://www.tci-thaijo.org/index.php/easr/index

Published by the Faculty of Engineering, Khon Kaen University, Thailand

Parameter and heat transfer performance evaluation of an existing dryer mixer for "Irvingia gabonensis" powder

Musliu Olushola Sunmonu[1)], Adeshina Fadeyibi*[2)] and Olawale Saheed Olabanjo[3)]

[1)]Department of Food Engineering, Faculty of Engineering and Technology, University of Ilorin, Nigeria
[2)]Department of Food and Agricultural Engineering, Faculty of Engineering and Technology, Kwara State University, Malete, Nigeria
[3)]Department of Agricultural and Biosystems Engineering, Faculty of Engineering and Technology, University of Ilorin, Nigeria

Received 25 May 2020
Revised 7 December 2020
Accepted 8 December 2020

Abstract

A homogeneous mixing and drying of food substance are required prior to further processing and storage. This research was carried out to determine the heat transfer parameters of an existing dryer-mixer and evaluate its performance for the drying and mixing of Irvingia gabonensis powder. A 1 kg of the powdered product (~ 15 µm particle size and 24.5% initial moisture content) was dried using the mixer-dryer for 5 hours. The average temperature of the drying chamber was preset at 50°C for the drying process, with the help of a thermostat. The heat transfer parameters, which includes the air flow rate and thickness of wall lagging, were determined mechanistically. Also, the drying performance was determined based on the drying rate, drying efficiency, mixing index, and mixing rate of the machine. Results show that an air flow rate of 0.00082 kgs^{-1} and 0.02 m thickness of a fibre-glass lagging material was required in the drying and mixing operation. Energy required to dry the product from 24.5% (wb) to 12.8% (wb) moisture content was 0.08514 kJ/s at a drying rate of 1.8 kgh^{-1}. A mixing index of 0.819 and efficiency of 82.2 % were obtained, and these may imply effective drying and a high degree of homogenization in the system.

Keywords: Energy, Air flow rate, Design, Thermal conductivity, Performance

1. Introduction

An Irvingia gabonensis powder can be used to formulate jelly, jam, juice and wine in the food industry. It can also be used to prepare black dye for cloth coloration [1]. Therefore, preservation of the product for latter application cannot be overemphasized. Several process technologies, which include scanning, freezing and drying, can be employed to preserve the product on a domestic and industrial scales. The most important of these methods of preservation is drying because it permits the application of heat to vaporize moisture from the product [2]. A disadvantage of the drying method is that the removal of moisture however may be accompanied by a loss of nutritional quality of the product. Therefore, drying needs to be selectively applied.

Drying can be regarded as a heat and mass transfer operations occurring simultaneously during postharvest operations [3]. A quantum of heat energy is usually conveyed from the drying medium to the food which allows it to progress by conduction. This allows a mass transfer of the moisture in the food to the surrounding by convection. The drying rate during this period is directly proportional to the rate of transfer of heat to the food. Thus, it is important to comprehend the heat and mass parameters of the product for optimal drying process. This however depends on the heat transfer coefficients of the drying medium and the surface temperatures of the food. An equilibrium moisture content is reach when the rate of moisture drift equates the dehydrating medium. The design of an optimally energy saving food dryer is therefore influenced by the magnitude of these parameters and their interactions [4, 5].

A major drawback in the design of dryers for the processing and preservation of the Irvingia gabonensis powder is its tendency to absorb atmospheric moisture, thereby distorting its morphology in equilibrium state. Traditionally, table salt has been used as preservative, but this may have adverse effect on human health when used in uncontrolled amounts. The product may also be exposed to the sun for several hours to remove moisture to a safe level for storage. The traditional processes described are usually labor intensive, time consuming and a thorough mixing of the preservative with the bulk sample is usually difficult to achieve. However, conventional dryers such as solar dryer, oven dryer and so on, have been successfully used in the past to preserve the product. Again, higher wall temperatures in these technologies will normally speed up the rate of drying but limited by higher quality degradation [6, 7]. However, there is no reported research on the design of a drying equipment for the product. This design will particularly help to improve timeliness in the processing of the product by combining both the mixing and drying unit operations together instead of having them separately. There is therefore the need to design an equipment for drying and mixing of the product. The objective of this research was to determine the heat transfer parameters of an existing dryer-mixer and evaluate its performance for the drying and mixing of Irvingia gabonensis powder.

*Corresponding author. Tel.: +23470 3486 7681
Email address: adeshina.fadeyibi@kwasu.edu.ng
doi: 10.14456/easr.2021.44

2. Materials and methods

2.1 Material selection

Materials used for the development of the mixer-dryer were selected locally, and they permit easy maintenance and repair. The physical and chemical properties of the materials are strong enough to withstand heat, vibration, fatigue and stress without failure during operation. Table 1 shows the materials, measurements and SI units used in the analysis.

Table 1 Materials used for dryer-mixer development

Materials	Measurements	Units
Galvanized steel sheet	1 standard size	mm
Galvanized mesh	2.4 × 1.2	mm
Mild steel sheet	2 standard size	mm
Blower	0.5	HP
Fibre-glass lagging	k = 0.04	Wm-1K-1
R- value	0.44- 0.65	m2K.W-1
Square pipe	25 × 25	mm
Heater	1000	W

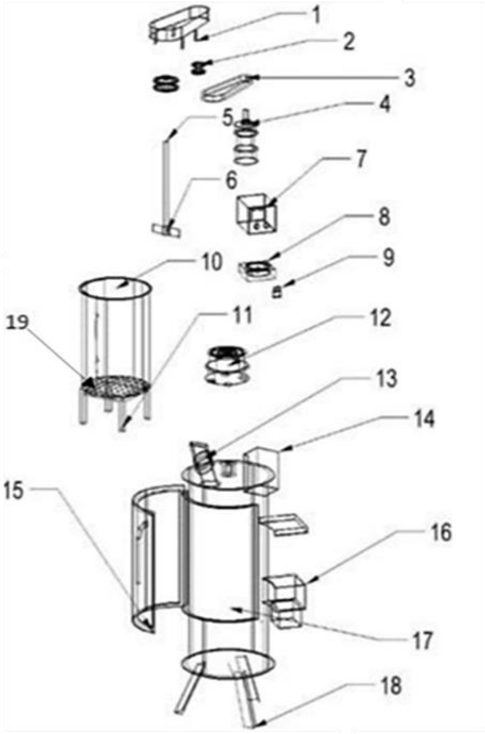
2.2 Design consideration and assumptions

The strength and stability of the materials used in the fabrication of the mixer-dryer was considered. Initial moisture content of the Irivingia gabonensis powders used in this investigation was found to be 24.5% [8, 9]. The relevant physical and mechanical properties of the powder reported by Sahin and Samu [10] were used in this study. The energy required for the drying was generated from the heater. Environmental conditions used were: dry-bulb temperature (T1) of 28^{o}C, average relative humidity (RH) of 70%, initial humidity ratio of 0.01 kg/kg dry air and maximum drying temperature achievable in the drying chamber (T2) of 150 ^{o}C, which is the maximum temperature calibration on the thermostat. The drying chamber has a 25 cm internal diameter and an internal cylindrical height of 70 cm from the base of the dryer to its false floor. It was designed to have a capacity of 1 kg/batch. The chamber was double walled and insulated with a fibre-glass lagging material.

2.3 General description and component parts of the existing dryer-mixer

The combined mixing and drying system consisting of several functional units including the blower, electrical heat source (heater), a combined cylindrical mixing and drying chamber, thermocouple, and an electric motor, is described in Figure 1. The blower transferred sensible heat of the heated air generated by the heater to the wet powder in the combined cylindrical mixing and drying chamber. The inlet vent, through which the air enters the system, is located at the upper part of the dryer, as shown in Figure 2. The heater, which is located close to the inlet pipe, heats up the incoming air by convection. The blower consists of centrifugal fan which blows the hot air radially in the drying chamber. A prime mover of 0.5 HP was attached to the impeller shaft for mixing the food material at a speed of 24 revolutions per second. A thermostat (0 ^{o}C to 150 ^{o}C design temperature range) was attached to the side wall of the dryer to regulate the temperature condition to a preset value of 50 ^{o}C. The hot moisture air exits the drying chamber via the opening at the bottom of the system. The temperature and relative humidity of the hot air at the exit point were 32 ^{o}C and 83%, respectively.

Figure 1 A model of the dryer-mixer



1 Belt Guide
2 Pulley
3 Belt
4 Electric Motor
5 Shaft
6 Stirrer
7 Control Box
8 Blower
9 Thermocouple controller
10 Sieve
11 Sieve Stand
12 Electric Heater
13 Air inlet pipe
14 Electric Motor Stand
15 Door/ Product Inlet
16 Blower Case
17 Cylindrical Body
18 Stand
19 Air Outlet

Figure 2 Component parts of the dryer-mixer

2.4 Heat transfer parameter design

2.4.1 Quantity of hot air required for drying

The quantity of hot air required for the drying of the *Irvingia gabonensis* powder was determined using Equation (1), as reported by Ichsani and Wulandari [11]. The psychometric properties of the heating process at 50°C heated air temperature and 70% RH were 200.6 $kJkg^{-1}$ enthalpy, 1.06 kgm^{-3} density, 8.643 kPa partial vapour pressure, 12.35 kPa saturated vapour pressure, 1.001 m^3kg^{-1} specific volume and 0.0580 $kg.kg^{-1}$ humidity ratio. Also, the psychometric properties of the heating process at 32°C exit air temperature and 83% RH were 96.77 $kJkg^{-1}$ enthalpy, 1.14 kgm^{-3} density, 3.951 kPa partial vapour pressure, 4.759 kPa saturated vapour pressure, 0.900 m^3kg^{-1} specific volume and 0.0252 $kg.kg^{-1}$ humidity ratio.

$$M_a = \frac{M_w}{(Hr_0 - Hr_1) \times n} \tag{1}$$

where: Ma = quantity of air required for drying (kg)
Hro = initial humidity ratio at 50°C and 70% RH = 0.0580 $kg.kg^{-1}$ dry air
Hr1 = final humidity ratio at 32°C and 83% RH = 0.0252 $kg.kg^{-1}$ dry air
Mw = amount of moisture loss $= 1 \times \left(\frac{24.5-12.45}{100}\right)$kg = 0.1205 kg
n = the pick-up factor, which considers the nature of the food material to be dried and the ease with which it releases moisture to the air. Base on this therefore, we assumed a pickup factor of 0.25 for the drying of the Irvingia gabonensis powder to cater for the actual amount of moisture to be removed from the product per kg of the drying air [12].

2.4.2 Size and type of blower selection

The fan size in the blower was determined by computing the volumetric flow rate of the drying air over a 5 hours drying time using the expression in Equation (2), according to Axtell [12].

$$m_v = m_k \times v_s \tag{2}$$

where: m_v = volumetric flow rate of the drying air in m3s-1
m_k = mass flow rate of the drying air = $\frac{M_a}{\text{drying time}} = \frac{14.695}{5\times3600} = 0.00082$ kgs^{-1}
vs = specific volume of the drying air at 50°C and 70% RH = 1.001 m^3kg^{-1}

2.4.3 Volumetric capacity of the drying chamber

The volume of the drying chamber was calculated using the expression in Equation (3) [13].

$$V = \pi r^2 h \tag{3}$$

where: V = volume of cylindrical chamber (m^3)
r = radius of the cylindrical chamber = $\frac{\text{diameter}}{2} = \frac{25}{2} = 12.5$ cm = 0.125 m
h = height of the cylindrical chamber = 0.70 m

2.4.4 Bulk density of the material

The bulk density was determined using the empirical expression in Equation (4) as reported by Liu and Bakker-Arkema [14].

$$\rho_{wm} = 10^{-5}[7 \times 10^4 + \frac{0.016}{10^{-5}} m_o - 116{m^2}_o + 1.8{m^3}_o] \quad (4)$$

where: ρ_{wm} = bulk density at a given moisture content, kgm^{-3}
m_o = initial moisture content of the product in % wet basis = 24.5% wb [14]

2.4.5 Determination of energy required for drying

The quantity of heat energy required for the dryer-mixer was calculated using Equation (5), as expressed by Axtell [12].

$$q = m_k(h_2 - h_1) \quad (5)$$

where: q = amount of heat energy in kJs^{-1};
m_k = air mass flow rate = 0.00082 kgs^{-1} as obtained earlier
h_1 = specific enthalpy of inlet air at 50 °C and 70% RH = 200.6 $kJ.kg^{-1}$ air;
h_2 = specific enthalpy of outlet air 32 °C and 83% RH = 96.77 $kJ.kg^{-1}$ air.

2.4.6 Thickness of lagging material

We considered the theory of heat flow through a cylindrical wall since the heat was to be transferred radially from the ambient air environment through the fibre glass lagging material to exit the surrounding as a damped hot air, as shown in Figure 3 [13-15].

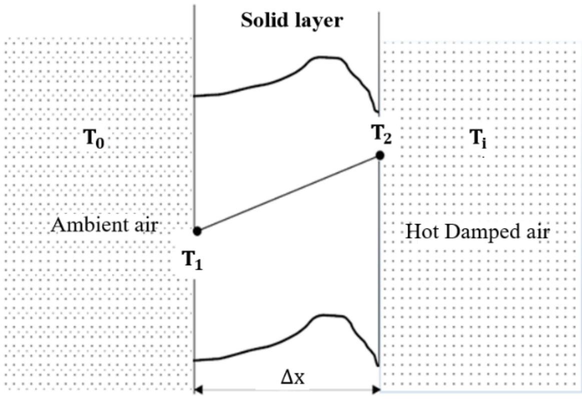


Figure 3 Heat transfer through the fibre glass arrangement in the dryer

The heat was first transferred from the ambient air at the temperature T_o to the fibre-glass lagging material at the temperature T_1. The rate of heat transfer is directly proportional to the temperature difference between the fibre glass material, the mass of the air and the area of cross-section. This relationship was mathematically expressed according to Newton's law, in Equation (6) [16-18].

$$q = hA(T_o - T_1) \quad (6)$$

The heat is then transferred by conduction through the fibre glass material of thickness Δx with a temperature difference of T_2-T_1. Finally, the heat is transferred by convection process as a damped hot air from the other surface of the material to the surrounding. Therefore, we evaluated the total heat flow across all the sections of the material according to Equation (7) [17].

$$q = h_oA(T_o - T_1) + h_iA(T_2 - T_i) - \frac{kA(T_2 - T_1)}{\Delta x} \quad (7)$$

Where: T_o is the ambient air temperature = 28 °C.
T_i is the air temperature at the surrounding (°C).
T_1 is the Preset temperature in the drying chamber = 50 °C
T_2 is the temperature of the damped air at the exit = 32°C
h_i and h_o are inside and outside heat transfer coefficients, respectively ($W/m^2.K$)
A is the cross-sectional area of the lagging material (m^2)

However, since the lagging material is to prevent heat loss in the drying chamber, it is in fact an adiabatic system [16-19], which involves no transfer of heat energy to the surrounding [19]. Therefore, the total heat loss is approximately zero (ie. q = 0). Based on this, we modified Equation (7) as follows:

$$0 = h_oA(T_o - T_1) + h_iA(T_2 - T_i) - \frac{kA(T_2 - T_1)}{\Delta x}$$

$$\frac{kA(T_2 - T_1)}{\Delta x} = h_oA(T_o - T_1) + h_iA(T_2 - T_i)$$

But we know that for adiabatic process, To = Ti = 28°C and ho = hi = U (overall heat transfer coefficient, W/m2.K), so that:

$$h_oA(T_o - T_1) + h_iA(T_2 - T_i) = UA(T_2 - T_1) = \frac{kA(T_2 - T_1)}{\Delta x}$$

Thus, $\frac{kA(T_2 - T_1)}{\Delta x} = UA(T_2 - T_1)$

$$\Delta x = \frac{kA(T_2 - T_1)}{UA(T_2 - T_1)}$$

$$\Delta x = \frac{k}{U}$$

Since U = 1/R

$$\Delta x = \frac{k}{1/R}$$

$$\Delta x = kR$$

The R-value and k-value for fibre-glass has been given, by McQuiston et al. [20] and reported by the American Society of Heating, Refrigerating and Air-Conditioning Engineer [21], in the range of 0.44- 0.65 m^2K/W and 0.04 $Wm^{-1}K^{-1}$, respectively. Also, the k-value for the fibre-glass was reported as 0.04 $Wm^{-1}K^{-1}$. We therefore choose R = 0.5 and k = 0.04 $Wm^{-1}K^{-1}$ in this analysis.

$\Delta x = 0.04 \times 0.5 = 0.02$ m

Therefore, the fibre-glass material thickness was 0.02 m

2.5 Heat transfer evaluation of the Irvingia gabonensis powder

Hot air drying and mixing of food powder around 150°C may lead to drying of the food in a very short time [22]. The low thermal conductivity and heat transfer coefficient of the powder at that temperature maybe responsible for the drying behaviour of the food [23]. The heat transfer method in this study involves making powder from the sample of the irvingia gabonensis and placing it in an existing dryer mixer, which was designed specifically for the product. The temperature on the surface of the equipment was monitored throughout the experiment using a thermostat. A small variation in the inside temperature was initially observed (< 4°C) in the first 30 minutes of loading but this became constant as the drying continues with time. A 1 kg of the freshly harvested irvingia gabonensis of 24.5% moisture content was ground into powder using an attrition mill, until the particle size was 15 µm. The powdered material was poured into the existing dryer-mixer, as shown in Figure 4, and operated for 5 hours. The temperature of the drying chamber was maintained between 40-60 °C throughout the drying process, with the help of the thermostat. After drying, the final moisture content of the Irvingia gabonensis powder was found to be 12.8% (wb). The heat treatment of the product was adequately achieved by this approach.

Figure 4 Pictorial view of the existing dryer-mixer

2.5.1 Drying rate

The drying rate can be defined as the ratio of the amount moisture removed from the product to the length of time required for the drying process. The amount of the moisture removed increases with the temperature and time of drying until a certain threshold moisture content was reached, called the critical moisture content. In our analysis, this critical moisture value of the product was found to be 10.69 % (dried basis). Beyond this moisture level, the material becomes borne-dried and obsolete for its intended use at the falling drying period. Thus, the drying rate of the product was computed, at constant drying rate, using the expression in Equation (8) [24-26].

$$R_a = m_i\left(\frac{m_{db} - m_c}{t}\right) \quad (8)$$

where: R_a = drying rate, kg/h
m_i = mass of the product = 1 kg
m_c = critical moisture content % (dried basis) = 10.69 % db
m_{db} = initial moisture content of the product in % dried basis = $\frac{100m_o}{100+m_o}$ = 19.68 % db
t = drying time = 5 hours.

2.5.2 Drying efficiency

This indicates the performance of the machine for drying the Irvingia gabonensis powder. It is necessary we determine the drying efficiency of the machine since it provides information about the machine performance. It also gives insight about the drying pick-up factor, which is a necessary parameter for evaluating the quantity of hot air required in the drying process. The drying efficiency was computed using Equation (9) [25].

$$E_d = \frac{w_3}{w_2} \times 100(\%) \tag{9}$$

where: w_2 = weight of fresh Irvingia gabonensis powder (kg)
w_3 = weight of dried Irvingia gabonensis powder (kg)
E_d = drying efficiency (%)

2.5.3 Mixing index

This was calculated in other to understand the extent or degree of mixing of the material in the machine. We determined the moisture content of the powder for the 5 h drying period at interval of 30 minutes. This gives a total of 10 moisture samples of the powder from the performance analysis. Therefore, the expression in Equation (10) was used to compute the mixing index of the machine for drying the Irnvingia gabonensis powder [25].

$$D_m = \frac{\sigma_i^2 - \sigma^2}{\sigma_i^2 - \sigma_t^2} \tag{10}$$

where: σ^2 = Average standard deviation of the powder moisture content
σ_i^2 = Initial standard deviation of the powder moisture content at time t = 0 s of drying,
σ_t^2= Final standard deviation of the powder moisture content at time t = 5 hours of drying,
D_m = Mixing index

2.5.4 Mixing rate

In order to calculate the time required for any desired degree of mixing, we assumed that bending forces are not likely in the machine operation so that the mixing rate constant, β takes a unit value. Thus, the mixing rate of the dryer-mixer was computed using the expression in Equation (11) [26].

$$t = \frac{1}{\beta} \ln\left(\frac{1 - \frac{1}{\sqrt{\alpha}}}{1 - D_m}\right) \tag{11}$$

where: α = number of moisture samples of powder from the performance analysis (10)
β = mixing rate constant (s^{-1})
t = mixing rate (s)

3. Results and discussion

3.1 Conductive heat transfer performance

At constant pressure, heat supplied to the system of the dryer-mixer would contribute to both the work done and the change in internal energy. The results of the conductive heat transfer parameters of the dryer-mixer is presented in Table 2. The drying system required 0.08514 kJs-1 of energy to dry and mix the Irvingia gabonensis powder to safe moisture level. The heat energy supplied may end up as energy of motion and energy stored in force fields [27], both at macroscopic and atomic scales. Then the change in temperature will depends on the path that the system followed through its phase space between the initial and final states. The presence of 0.02 m thick lagging material helps to ensure that only negligible heat energy is lost to the surrounding. Therefore, the bulk of the heat energy supplied was utilized in the drying and mixing process.

Table 2 Conductive heat transfer parameters of the dryer-mixer for the product

s/n	Heat process parameter	Value	SI Unit
1	Quantity of hot air required for drying	14.6950	kg
2	Volumetric flow rate of the hot air	0.00082	m^3s^{-1}
3	Volumetric capacity of the drying chamber	0.03436	m^3
4	Bulk density of the material	0.00385	kgm^{-3}
5	Mass of material in the drying chamber	1.00000	kg
6	Energy required for drying	0.08514	kJs^{-1}
7	Thickness of lagging material	0.02000	m

3.2 Performance of the mixer-dryer

A measure of how well the operation of an equipment is utilized in terms of the available facilities, time and material compared to its full potential, during the periods when it is scheduled to run is referred to performance evaluation. It identifies the percentage of manufacturing time that is truly productive. In this investigation, the results of the performance evaluation of the dryer-mixer is thus presented in Table 3. The rapid rate of drying and mixing reveals its ability to dry and mix the Irvingia gabonensis powder. The drying rate of 1.80 kgh^{-1} obtained was quite enough to remove substantial amount of the moisture from the powder within the constant drying period, thereby enhancing the keeping quality of the product. This means only 0.03 kg of the moisture content of material is evaporated per minute or 0.0005 kg per seconds. This was also enough to homogenize the system with a mixing index of 81.9%. The research findings of Aregbesola et al. [27] corroborate the present investigation, in their work on the formulation of mathematical modeling for predicting the thin layer drying characteristics of Irvingia gabonenesis nuts and kernels. Also, Fadeyibi et al. [28] reported similar findings in their work on the effects of diameter of holes in breaker plate and glycerol on the performance of a single screw mixer. The authors suggested a food mixer will perform optimally if the mixing index is greater or equal to 80%. Thus, in the case of the mixer-dryer a homogeneous product is expected since the mixing index exceed this threshold. A significant effect of many drying methods on the physicochemical properties of ready-to-cook Irvingia gabonensis have been reported [29]. The authors reported that tray drying was superior to the oven drying because of their different drying rates. This may therefore mean that the greater the drying rate, the greater the amount of moisture drift from the product.

Table 3 Performance evaluation of the dryer-mixer

S/N	Parameters	Values	SI Unit
1	Mass of moisture removed	0.1205	kg
2	Drying Rate	1.8000	kgh-1
3	Drying Efficiency	82.160	%
4	Mixing Index	0.8190	-
5	Mixing Rate	1.3290	s

4. Conclusions

The performance of a mixer-dryer for Irvingia gabonensis powder was evaluated based on its heat transfer parameters. The drying system required 0.085 kJs^{-1} of energy to dry and mix the product to safe moisture level. A drying rate of 1.800 kgh^{-1} was obtained, and this was quite enough to remove substantially the moisture present in the powder within the constant drying period, thereby enhancing the keeping quality of the product. This was also enough to homogenize the system with a mixing index of 81.9%. The bulk of the heat energy supplied was utilized in the drying and mixing process. Thus, the heat transfer parameters are needed for the analytical prediction of the drying behaviour and in the design of postharvest handling and processing systems for Irvingia gabonensis.

5. Acknowledgements

The authors acknowledge the technical assistance provided by the staff of the Food Engineering Laboratory of the University of Ilorin.

6. Abbreviations

Symbol	Meaning	SI Unit
M_a	Quantity of air required for drying	kg
H_{ro}	Initial humidity ratio at 50ºC and 70% RH	$kg.kg^{-1}$ dry air
H_{r1}	Final humidity ratio at 32ºC and 83% RH	$kg.kg^{-1}$ dry air
M_w	Amount of moisture loss	kg
m_v	Volumetric flow rate of the drying air	m^3/s
m_k	Mass flow rate of the drying air	kgs^{-1}
v_s	Specific volume of the drying air at 50 ºC and 70% RH	m^3/kg
V	Volume of cylindrical chamber	m^3
r	Radius of the cylindrical chamber	m
h	Height of the cylindrical chamber	m
ρwm	Bulk density at a given moisture content	kg/m^3
m_o	Initial moisture content of the product in % wet basis	% wb
m_{db}	Initial moisture content of the product in % dried basis	% db
q	Amount of heat energy	kJs^{-1}
h_1	Specific enthalpy of air at inlet at temperature of 50 °C and 70% RH	$kJkg^{-1}$ air
h_2	Specific enthalpy of air at the exit with a temperature of 32°C and 83% RH	$kJkg^{-1}$ air
To	Ambient air temperature	°C
T*i*	Air temperature at the surrounding	°C
T_1	Preset temperature in the drying chamber	°C
T_2	Temperature of the damped air at the exit	°C
m_i	Initial mass of the material	Kg
m_f	Final moisture contents of the material	% wb
m_c	Critical final moisture contents of the material at constant drying rate	% wb
R_a	Drying rate	kgh^{-1}
t	Total time	h
W_2	Weight of fresh *Irvingia gabonensis* powder	kg
W_3	Weight of dried *Irvingia gabonensis* powder	kg
E_d	Drying efficiency	%
σ^2	Average standard deviation of the powder moisture content	%, wb
σ_i^2	Initial standard deviation of the moisture content at time t = 0 s of drying,	%, wb
σ_t^2	Final standard deviation of the moisture content at time t = 5 h of drying,	%, wb
D_m	Mixing index	-
α	Number of moisture samples of powder from the performance analysis	-
β	Mixing rate constant	s^{-1}

7. References

[1] Egras AM, Hamilton WR, Lenz TL, Monaghan MS. An evidence-based review of fat modifying supplemental weight loss products. J Obes. 2011;11(1):1-10.
[2] Guine RP, Fernandes RM. Analysis of the drying kinetics of chestnuts. J Food Eng. 2006;76(3):460-7.
[3] Ahromrit A, Nema PK. Heat and mass transfer in deep-frying of pumpkin, sweet potato and taro. J Food Sci Tech. 2010;47(6):632-7.
[4] Bonazzi C, Dumoulin E. Quality changes in food materials as influenced by drying processes. Mod Drying Tech. 2011;20(3): 1-20.
[5] Kurozawa LE, Hubinger MD, Park KJ. Glass transition phenomenon on shrinkage of papaya during convective drying. J Food Eng. 2012;108(1):43-50.
[6] Onwude DI, Hashim N, Janius RB, Nawi NM, Abdan K. Modeling the thin-layer drying of fruits and vegetables: a review. Compr Rev in Food Sci Food Saf. 2016;15(3):599-618.
[7] Strande L, Ronteltap M, Brdjanovic D. Faecal sludge management- systems approach for implementation and operation. Water Intell Online. 2014;1:139-43.
[8] Ames NP, Clarke JM, Marchylo BA, Dexter JE, Schlichting LM, Woods SM. The effect of extra-strong gluten on quality parameters in durum wheat. Can J Plant Sci. 2003;83(3):525-32.
[9] Joseph JK. Physico-chemical attributes of wild mango (Irvingia gabonensis) powders. Bioresource Tech. 1995;53(2):179-81.
[10] Sahin S, Sumnu SG. Physical properties of foods. USA: Springer; 2006.
[11] Ichsani D, Wulandari DA. Design and experimental testing of a solar dryer combined with kerosene stoves to dry fish. American Society of Agricultural and Biological Engineers Annual International Meeting; 2002 Jul 28-31; Chicago, USA. USA: ASABE; 2013. p. 1-11.
[12] Axtell BL. Drying food for profit: a guide for small businesses. 2nd ed. Rugby: Business and Economics; 2002.
[13] Yisa MG, Fadeyibi A, Adisa OI, Alabi KP. Finite element simulation of temperature variation in grain metal silo. Res Agric Eng. 2018;64(3):107-14.
[14] Khujakulov UK. Kinetic dependences of the drying process. Int Sci Tech J. 2020;1(1):15-22.
[15] Fu BA, Chen MQ, Li QH. Non-equilibrium thermodynamics approach for the coupled heat and mass transfer of wet mineral porous media in dielectric and magnetic drying. Drying Tech. 2019;23:1-6.
[16] Misra NN, Martynenko A, Chemat F, Paniwnyk L, Barba FJ, Jambrak AR. Thermodynamics, transport phenomena, and electrochemistry of external field-assisted nonthermal food technologies. Crit Rev Food Sci Nutr. 2018;58(11):1832-63.
[17] Kaveh M, Karami H, Jahanbakhshi A. Investigation of mass transfer, thermodynamics, and greenhouse gases properties in pennyroyal drying. J Food Process Eng. 2020;43(8):1-12.
[18] Srivastava AK, Shukla SK, Singh UK. The first and second law analyses of thermodynamics of potato slices drying process. Distr Generat Alternative Energ J. 2017;32(4):7-25.
[19] Liu Q, Bakker-Arkema FW. Stochastic modelling of grain drying: part 2. Model development. J Agr Eng Res. 1997;66(4):275-80.
[20] McQuiston FC, Parker JD, Spitler JD. Heating, refrigerating and air-conditioning: analysis and design. 6th ed. Hoboken: Wiley; 2005.
[21] American Society of Heating, Refrigerating and Air-Conditioning Engineer. ASHRAE Handbook, Fundamentals (SI edition). Units and Conversions. Atlanta: ASHRAE; 2013. p. 391.
[22] Keppler S, Bakalis S, Leadley CE, Sahi SS, Fryer PJ. Evaluation of dry heat treatment of soft wheat flour for the production of high ratio cakes. Food Res Int. 2018;107:360-70.
[23] Tiwari G, Wang S, Tang J, Birla SL. Computer simulation model development and validation for radio frequency (RF) heating of dry food materials. J Food Eng. 2011;105:48-55.
[24] Yisa MG, Fadeyibi A. Modification and evaluation of an electric dryer for high moisture vegetables. Eng Sci. 2018;13(1):70-84.
[25] Fadeyibi A, Osunde ZD, Agidi G, Evans EC. Mixing index of a starch composite extruder for food packaging application. In: Inamuddin, editor. Green polymer composites technology: properties and applications. UK: CRC Press; 2016. p. 335-47.
[26] Wallace D. Gravity, entropy, and cosmology: in search of clarity. Br J Philos Sci. 2010;61(3):513-40.
[27] Aregbesola OA, Ogunsina B, Sofolahan AE, Chime NN. Mathematical modeling of thin layer drying characteristics of dika (Irvingia gabonensis) nuts and kernels. Niger Food J. 2015;33(1):83-9.
[28] Fadeyibi A, Osunde ZD, Yisa MG. Effects of glycerol and diameter of holes in breaker plate on performance of screw mixer for nanocomposites. Agr Eng. 2017;21(4):15-26.
[29] Ogunbusola EM, Arinola SO, Adubiaro HA. Effect of drying on the physicochemical properties of ready-to-cook Ogbono mix (Irvingia gabonensis). Food Sci Qual Manag. 2014;33(4):36-40.