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Design and performance evaluation of a laboratory-scale fluidized bed dryer for polymer particles

Diseño y evaluación del desempeño de un secador de lecho fluidizado a escala de laboratorio para partículas de polímero

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ABSTRACT
The design, construction, and performance evaluation of a laboratory-scale batch fluidized bed dryer for polypropylene particles is presented. Wet polypropylene particles obtained by water-assisted milling require controlled drying to avoid defects during subsequent processing. The proposed system is a simple and cost-effective configuration capable of operating under conditions that prevent polymer melting or thermal degradation. A heat transfer-based model was developed to describe the drying process, incorporating operating variables and dryer characteristics. A correlation for drying time per unit mass of dry polymer was obtained as a function of air properties, system geometry, and thermal driving force. Experimental tests under different operating conditions allowed identification of optimal temperature and air velocity to ensure efficient moisture removal while preserving polymer properties. Results demonstrate that the developed dryer achieves uniform drying and target moisture content within operational constraints, providing a practical framework for the analysis of fluidized bed drying systems at laboratory scale.

Keywords: fluidized bed dryer, polypropylene particles, heat transfer, drying kinetics

RESUMEN
En este trabajo se presenta el diseño, la construcción y la evaluación del desempeño de un secador de lecho fluidizado discontinuo a escala de laboratorio para partículas de polipropileno obtenidas mediante molienda asistida con agua, por lo que requieren un secado controlado para evitar defectos durante el procesamiento posterior. El sistema propuesto es una configuración simple y de bajo costo, capaz de operar en condiciones que eviten la fusión o la degradación térmica del polímero. Para describir el proceso de secado se desarrolló un modelo basado en transferencia de calor, incorporando variables operativas y características del secador. Se obtuvo una correlación para el tiempo de secado por unidad de masa de polímero seco en función de las propiedades del aire, la geometría del sistema y la fuerza impulsora térmica. Ensayos experimentales realizados bajo diferentes condiciones de operación permitieron identificar la temperatura y la velocidad del aire óptimas para asegurar una remoción eficiente de la humedad, preservando al mismo tiempo las propiedades del polímero. Los resultados demuestran que el secador desarrollado logra un secado uniforme y el contenido de humedad objetivo dentro de las restricciones operativas, proporcionando un marco práctico para el análisis de sistemas de secado en lecho fluidizado a escala de laboratorio.

Palabras clave: secador de lecho fluidizado, partículas de polipropileno, transferencia de calor, cinética de secado

INTRODUCTION

Fluidized bed dryers are widely used in the process industry due to their high heat and mass transfer rates, which enable efficient drying of particulate materials such as powders and granules (Di Renzo *et al.*, 2021; Poós & Szabó, 2021; Darweesh & Weis, 2024). Their operation is based on the suspension of solid particles in an upward gas stream, promoting intense mixing and uniform temperature distribution. The working principle of these dryers involves the fluidization of the fed materials. In this sense, hot air is introduced in the system through a perforated bed of wet solids which are lifted from the bottom, and they are suspended in a stream of air (fluidized condition). Hot air acts as a fluidizing and drying medium, favoring an intense mixing that results in a uniform temperature profile. Main advantages related to fluidized bed technology are the high contact area between solids and gas phase, vigorous mixing as well as a fast transfer of heat and moisture, without damaging the properties of heat sensitive materials (Senapati *et al.*, 2021). At the exit, humid air leaves the dryer because of water evaporation from wet particles. In this sense, fluidized bed design is an effective drying process due to the whole particle surface being exposed to hot air, offering intimate contact and leading to efficient heat and mass transfer under controlled drying conditions. These characteristics make fluidized bed technology particularly suitable for applications requiring fast and homogeneous drying under controlled conditions (Majumder *et al.*, 2022; Di Renzo *et al.*, 2021; Askarishahi *et al.*, 2023). Recent experimental, numerical, and CFD-DEM studies have demonstrated the strong coupling between hydrodynamics and heat and mass transfer during drying processes in fluidized beds, significantly improving the understanding of gas–solid interactions, particle mixing, segregation phenomena, and moisture distribution within the bed (de Munck *et al.*, 2023; Ma *et al.*, 2023; Tu *et al.*, 2023). Drying efficiency has been shown to depend strongly on particle mixing and segregation mechanisms, which directly affect local temperature and moisture gradients throughout the fluidized system (de Munck *et al.*, 2023).

In polymer processing, moisture removal is a critical step, as residual water can lead to defects such as bubble formation, poor mechanical properties, and processing instability in operations including extrusion and injection molding (Stan, 2020). This is especially relevant for polymer particles obtained through water-assisted milling processes, where surface moisture must be removed without compromising material integrity. Recent studies have highlighted the importance of controlled drying strategies for polymeric particulates to preserve thermal stability, processability, and final mechanical performance during subsequent manufacturing operations (Ezminadeh *et al.*, 2020; Chen *et al.*, 2022). In the case of polypropylene (PP), although the polymer does not absorb water due to its hydrophobic nature, superficial moisture can significantly affect downstream processing. For the drying of this type of material, certain technical, operational, and economic aspects associated with process efficiency and material preservation must be considered during dryer design. Regarding technical issues, it must be considered that polymer particles can melt or degrade during the drying process. In the case of PP, it has a melting temperature around 160 °C (Osman *et al.*, 2025). Thus, operating temperatures approaching this value should be avoided during drying. In addition to temperature effects, the presence of oxygen can induce thermo-oxidative degradation of polypropylene, promoting chain scission reactions that reduce molecular weight and deteriorate material performance and long-term stability (Esmizadeh *et al.*, 2020; Nguyen *et al.*, 2023; Liu & Yang, 2020). Furthermore, oxidative degradation mechanisms in polyolefins have been reported to significantly affect the mechanical and thermal properties of the material during thermal processing and aging conditions (Grause *et al.*, 2020).

The design of laboratory-scale drying equipment plays an important role in the analysis and understanding of process performance under controlled conditions. Simplified and cost-effective systems can provide valuable insights into heat transfer mechanisms, operating variables, and process optimization, while serving as a basis for scaling up to industrial applications (Poós & Szabó, 2021). Despite the extensive use of fluidized bed dryers, the development of simplified models capable of describing drying behavior under specific operating constraints remains a relevant challenge, especially when material sensitivity imposes limitations on temperature and residence time (Ma *et al.*, 2023). In this context, the integration of equipment design and process modeling is essential to predict performance and support the selection of operating conditions. Moreover, recent studies have highlighted the relevance of coupling experimental analysis with modeling approaches to better predict drying kinetics and optimize operating parameters (Tu *et al.*, 2023; Szabó & Poós, 2021).

This work presents the design, construction, and analysis of a laboratory-scale batch fluidized bed dryer for polypropylene particles obtained by water-assisted milling. A heat transfer-based model is developed to describe the drying process, and a correlation for drying time is proposed as a function of operating variables and system parameters. Experimental validation is carried out to evaluate dryer performance and identify suitable operating conditions that ensure effective moisture removal while preserving polymer properties.

METHODOLOGY

Materials

Wet polypropylene particles come from a company that specializes in grinding plastic materials according to customer needs (Ecotécnica de Pilar S.R.L., Argentina). These particles were produced by milling polymer pellets into a plastic disc shear grinder. Water-assisted milling was employed to reduce frictional heating and prevent thermo-mechanical degradation phenomena as commonly recommended in polymer proccessing (Colin & Tcharkhtchi, 2013; Esmizadeh et al., 2020). The average water content of wet polypropylene homopolymer particles was 14.00 % w/w, determined gravimetrically in a vacuum oven at 70 °C until constant weight. Similar drying conditions procedures have been commonly employed for polypropylene materials prior to thermal processing and characterization (Mattos *et al.*, 2014). Also, the average particle size measured was 1730 ± 475 µm, determined from optical micrographs using image analysis software. Similar methodologies have been employed for particle size characterization and morphology analysis of particulate systems (Grubbs *et al.*, 2021).

Modelling

A simplified fluidized bed dryer model was developed considering assumptions commonly adopted in theoretical and semi-empirical analyses of heat and mass transfer phenomena in fluidized bed drying systems (Poós & Szabó, 2021; Tu *et al.*, 2023):

- There is no heat loss through the walls
- Heat supplied by the electrical resistance is constant
- Resistance conductivity is constant during drying
- Bed temperature is constant and equal to the set point value
- Air speed and room temperature are constant in each operation condition
- Air and water properties are constant during drying

The rate of heat transfer from electrical resistances $q^{\bullet}_{max}$ was estimated using Newton's law of cooling (Eq. (1)) (Incropera *et al.*, 2007). The convective heat transfer coefficient (h) depends on fluid properties, air flow conditions and heater geometry, factors that have been extensively discussed in recent studies on convective heat transfer and fluidized bed drying systems (Di Renzo *et al.*, 2021; Darweesh & Weis, 2024). The heat transfer area (At) corresponds to the resistance surface in contact with air, while the temperature difference between the set point (Ts) and the inlet air temperature (T1) represents the thermal driving force for heat transfer. Similar approaches based on convective heat transfer analysis and Newton-type cooling relationships have been employed in recent studies involving fluidized beds and forced convection thermal systems (Majumder *et al.*, 2022).

$$q^{\bullet}_{max} = h\, A_t (T_s - T_1) \quad (1)$$

However, Eq. (1) represents the heat transfer rate under ideal process. In the proposed fluidized bed dryer, the total heat $q^{\bullet}_1$ transferred to the air stream is lower than the theoretical maximum value ($q^{\bullet}_{max}$) due to the influence of finned electrical resistance (η_o) (Incropera et al., 2007). Similar effects associated with finned geometry, thermal resistance, and convective heat transfer performance have been discussed in recent studies involving finned heat exchanger systems operating under forced convection conditions (Unger *et al.*, 2021). Thus, the effective heat transfer rate can be expressed as follows:

$$q^{\bullet}_1 = \eta_o q^{\bullet}_{max} \quad (2)$$

where

$$\eta_o = 1 - N\frac{A_f}{A_t}(1-\eta_f) \quad (3)$$

being *N*= number of fins, A_f= fin surface and η_f= fin efficiency.

Heat transfer modelling in fluidized bed dryers is particularly challenging due to the complex hydrodynamics associated with random particle motion, particle–fluid interactions, and local velocity and temperature gradients within the bed (Taghipour *et al.*, 2005; Ma *et al.*, 2023). Because the heat effectively transferred to wet particles cannot be directly measured experimentally in the proposed system, it was represented as a fraction of the total heat supplied by the electrical resistances. In this sense, the heat fraction (*X*) was defined as the ratio between the heat transferred to wet particles ($q_2^\bullet$) and the total supplied heat.

$$X = \frac{q_2^\bullet}{q_1^\bullet} \quad (4)$$

On the other hand, the heat required (q_e) to evaporate a water mass (m_1) from wet PP particles (Incropera *et al.*, 2007) can be expressed as:

$$q_e = m_1 \Delta H_v \quad (5)$$

where ΔH_v is the latent heat of vaporization of water. Accordingly, the time (t) required to dry the wet particles can be estimated as:

$$t = \frac{q_e}{q_2^\bullet} \quad (6)$$

By combining Eqs. (1-6), the drying time results:

$$t = \frac{m_1 \Delta H_v}{h A_t (T_s - T_1)\eta_0 X} \quad (7)$$

In order to express the water content as a mass fraction (x_1) and to define a new variable t^*, corresponding to the required drying time per unit mass of dry PP, Eq. (7) can be rewritten as follows:

$$t^* = \frac{\Delta H_v x_1}{h\, A_t (T_s - T_1)\eta_o X(1-x_1)} \quad (8)$$

To estimate the heat transfer coefficient, the correlation for the Nusselt number (*Nu*) established by Briggs and Young (1963) was used. Although this correlation is classical, Nusselt-based correlations continue to be widely employed in recent analyses of convective heat transfer and fluidized bed drying systems for the estimation of heat transfer coefficients and thermal performance under different operating conditions (Poós & Szabó, 2021; Darweesh & Weis, 2024).

$$Nu = \frac{2hr_1}{k_g} = 0.134\left(\frac{2\nu\rho_g r_1}{\mu_g}\right)^{0.681}\left(\frac{\mu_g cp_g}{k_g}\right)^{1/3}\left(\frac{s}{l}\right)^{0.2}\left(\frac{s}{w}\right)^{0.1134} \quad (9)$$

where r_1= resistance radii without fins, k_g= air thermal conductivity, ν= air velocity, ρ_g= air density, μ_g= air viscosity, cp_g= air calorific capacity, *s*= distance between successive fins, *l*= fin height and *w*= fin thickness. The expression for h is cleared from correlation (9) and then it is substituted in Eq. (8). After reordering terms, the required time to dry wet particles per dry PP mass results:

$$t^* = \left(\frac{2r_1}{0.134\, \eta_o A_t \left(\frac{S}{l}\right)^{0.2} \left(\frac{S}{w}\right)^{0.1134} (2r_1 v)^{0.681}} \right) \left(\frac{\Delta H_v}{cp_g^{1/3} k_g^{2/3} \rho_g^{0.681} \mu_g^{-0.348}} \right) \left(\frac{1}{(T_s - T_1)X} \right) \left(\frac{x_1}{(1 - x_1)} \right) \quad (10)$$

The first term in Eq. (10) comprises dryer variables as well as dimensions and efficiency parameters of the electrical resistances. Meanwhile, the second term includes air and water properties. The third term is related to the heat fraction (*X*) and the thermal driving force (T_s-T_1). Particularly, the last term, associated with water mass fraction, was assumed to follow a decreasing trend with drying time, consistent with typical drying kinetics behavior reported for particulate systems and fluidized bed dryers (Szabó & Poós, 2021; Ma *et al.*, 2023). In this sense, Eq. (10) can be rewritten as follows:

$$t^* \left[\frac{s}{kg_{PP}} \right] = \frac{\psi_{dryer} \psi_{fluid}}{(T_s - T_1)X} [C(t)]^{-n} \quad (11)$$

where

$$\psi_{dryer} = \frac{2r_1}{0.134\, \eta_0\, A_t \left(\frac{S}{l}\right)^{0.2} \left(\frac{S}{w}\right)^{0.1134} (2r_1\, v)^{0.681}} \quad (12)$$

$$\psi_{fluid} = \frac{\Delta H_v}{{cp_g}^{1/3} {k_g}^{2/3} {\rho_g}^{0.681} {\mu_g}^{-0.348}} \quad (13)$$

RESULTS AND DISCUSSION

The laboratory-scale fluidized bed dryer was successfully designed and assembled using commercially available and low-cost components, resulting in a simple and flexible configuration suitable for experimental studies under controlled operating conditions. Figure 1 shows both a schematic diagram and a photograph of the designed and assembled fluidized bed dryer. The proposed drying process operates in a batch mode, where set point temperature and air flow rate are the main operating variables. Similar laboratory-scale fluidized bed systems have been reported in the literature for the evaluation of drying kinetics, hydrodynamic behavior, and heat transfer phenomena in particulate materials (Nabizadeh *et al.*, 2020; Poós & Szabó, 2021; Ma *et al.*, 2023; de Munck *et al.*, 2023). Several recent studies have incorporated advanced instrumentation, numerical simulations, or CFD-based approaches for process analysis, whereas the present work proposes a simplified experimental setup combined with a physically based model capable of describing the drying process using measurable operating variables.

The proposed system includes an air pump connected to a variable-speed electric motor, finned electrical resistances for air heating, a temperature control system, an acrylic fluidization column, and a particle collection system. This configuration allowed operation in batch mode under different air velocities and temperatures while maintaining stable fluidization conditions. The use of transparent acrylic column also enabled direct visual observation of particle motion and bed behavior during operation, which is advantageous for laboratory-scale analysis and experimental evaluation of fluidization quality. Similar transparent columns and visualization approaches have been employed in experimental fluidized bed studies to investigate particle dynamics and bed hydrodynamics (Taghipour *et al.*, 2005; de Munck *et al.*, 2023).

Approximately 200 g of wet polypropylene particles were processed in each experiment until a final moisture content close to 0.1 % w/w was achieved, consistent with recommended moisture levels for polypropylene processing operations (Polypropylene Processing Guidelines, 2018). In agreement with previous studies on polymer drying and thermal processing, the removal of superficial moisture is important to minimize defects during subsequent operations such as extrusion and injection molding (Chen *et al.*, 2022; Esmizadeh *et al.*, 2020). Since polypropylene is considered a non-hygroscopic polymer, moisture is predominantly present on the particle surface rather than absorbed into the bulk structure. Therefore, the drying process was mainly governed by surface water evaporation, with a lower contribution of internal diffusion mechanisms compared to highly hygroscopic polymers (Ceretti *et al.*, 2023).

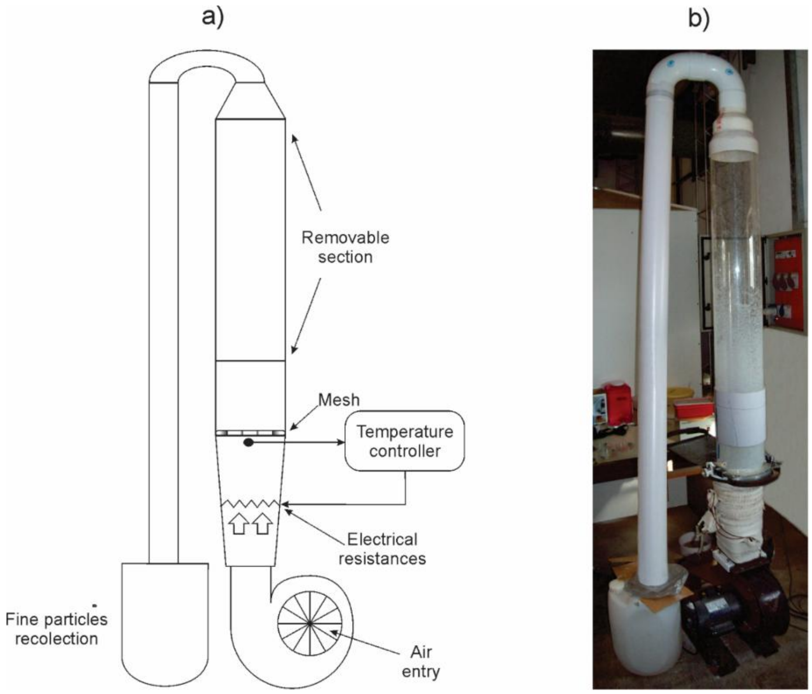

Fig. 1: The laboratory fluidized bed dryer: a) a schematic representation identifying its main components and b) a photograph.

Air at room temperature was supplied by a pump and subsequently heated before entering the fluidization column. The air pump was driven by single-phase electric motor operating at 1450 rpm, and 3 HP. Air velocity and relative humidity were measured using a thermo-anemometer (Heavy Duty Vane Thermo-Anemometer Model 407122, Extech). Four finned electrical resistances with a maximum power (P_{max}) of 1000 W each were arranged in parallel to efficiently heat the incoming airflow. These resistances were connected to a temperature control system with a sensor located below the supporting mesh, allowing operation under controlled thermal conditions. Table 1 summarizes the geometrical configuration parameters of the electrical resistances. The mesh allowed airflow through the system while supporting the particle bed and preventing fine particles from falling through the column. The acrylic tube included a removable section to facilitate particle feeding and discharge operations. Once fluidization conditions were achieved, the finest and driest particles were entrained by the airflow and collected in a dedicated container. At the end of each batch experiment, the remaining particles were discharged through the removable section of the column.

Once the fluidized bed dryer was designed and assembled, different operating conditions were evaluated in order to identify suitable drying parameters. In this sense, the set point temperature and air flow rate were varied to achieve efficient drying of PP particles under stable fluidization conditions. For each operating condition, the final moisture content of the particles was determined at the end of the drying process. The selected operating conditions allowed adequate particle fluidization without significant agglomeration or evidence of thermal degradation. This represents an important advantage of the proposed dryer configuration since polymer particles may soften, deform or partially melt when exposed to excessive temperatures or non-uniform heating conditions. Similar operational limitations have been reported in fluidized bed drying studies involving polymeric and thermally sensitive materials (Majumder *et al.*, 2022; Nguyen *et al.*, 2023). In the present work, the combination of moderate temperatures combined and forced convection promoted efficient moisture removal while preserving particle integrity and process stability. The optimal operating conditions of the laboratory-scale fluidized bed dryer, together with the corresponding fluid properties, are included in Table 2.

Table 1: Configuration parameters of finned resistances

Number of fins per tube	100
Number of fins per inn	6
Radii of resistance without fins (r_1)	5 mm
Radii of finned resistance (r_2)	10 mm
Fin thickness (w)	1 mm
Fin separation (s)	3 mm

Table 2: Dryer operating conditions and fluid properties

Operating conditions	
Set point temperature (T_s)	348 K
Room temperature (T_1)	286 K
Air velocity (ν)	10 m/s
Air properties	
Density (ρ_g)	1.199 kg/m^3
Viscosity (μ_g)	1.7 10^{-5} Pa.s
Specific heat (cp_g)	1004.88 J/(kg.K)
Thermal conductivity (k_g)	0.024 W/(m.K)
Water properties	
Latent heat of vaporization (ΔH_v)	2397 kJ/kg

The estimated convective heat transfer coefficient obtained from the Nusselt correlation was h=122.69 W/m2K. This value is consistent with the range commonly reported for forced convection and fluidized bed drying systems operating under similar airflow conditions (Poós & Szabó, 2021; Darweesh & Weis, 2024).

To obtain the mathematical expression describing dryer operation, the constants related to dryer parameters (ψ_{dryer}) and fluid properties (ψ_{fluid}) were calculated. Particularly, ▫dryer includes the estimation of fin efficiency (η_f) and overall finned surface efficiency (η_o). The analytical expression for annular fins with non-uniform cross section was employed to determine η_f. Consequently, modified Bessel functions of first and second kind were solved according to the formulation proposed by Incropera *et al.* (2007), as follows:

$$\eta_f(m, r_1, r_{2c}) = \frac{\left(\frac{2\ r_1}{m}\right)}{(r_{2c}^2 - r_1^2)} \left[\frac{K_1(m\ r_1)I_1(m\ r_{2c}) - I_1(m\ r_1)K_1(m\ r_{2c})}{I_0(m\ r_1)K_1(m\ r_{2c}) + K_0(m\ r_1)I_1(m\ r_2)}\right] \tag{14}$$

with

$$m = \sqrt{\frac{h\ P}{k\ A_c}} \tag{15}$$

$$r_{2c} = r_2 + \frac{w}{2} \tag{16}$$

where *m*= fin parameter, r_{2c}= corrected radius, I_1 and K_1= modified first order Bessel functions of first kind and second kind, respectively, Io and Ko= modified zero order Bessel functions of first kind and second kind, respectively, *P*= perimeter of the fin section, *k*= fin thermal conductivity (138 W/mK) and A_c= cross-sectional area of the fin. Particularly, for thin fins, P/A_c ratio in Eq. (16) can be approximated by 2/t (Thirumaleshwar, 2009). Considering this approximation, the calculated m value was 42.17 m^{-1}, while the corrected radius (r_{2c}) was 0.0105 m. Modified Bessel functions were solved using Matlab software, resulting in a fin efficiency of η_f= 0.97 from Eq. (15). The use of finned electrical resistances increased the effective heat transfer area and contributed to improved thermal performance of the heating system. The calculated fin efficiency (η_f=0.97) indicates relatively low thermal losses during heat transfer. Similar effects associated with enhanced heat transfer performance and fin efficiency have been reported in compact forced-convection systems employing thin annular fins (Basavarajappa *et al.*, 2020). The fin surface area (A_f) and the total heat transfer area (A_t) were determined from the geometrical parameters reported in Table 1, resulting in values of 5.356 10^{-4} m^2 and 0.233 m^2, respectively. Using Eq. (3), the overall surface efficiency was estimated at 0.97. Consequently, the values obtained for ψ_{dryer} and ψ_{fluid} constants were 54425 [$s^{0.681}/m^{2.36}$] and 1.549 [$s^{0.319}$ $m^{2.36}$ K/kg], respectively.

In order to estimate the $C(t)^{-n}$ function from experimental data, Eq. (11) was linearized, resulting in the following expression:

$$ln(t^*) = -n\, ln(C(t)) + \frac{\Psi}{X} \quad (17)$$

Although simplified, the proposed model captures the main heat transfer phenomena associated with superficial water removal from polypropylene particles under the operating conditions studied. Similar semi-empirical approaches combining heat transfer correlations with experimentally fitted parameters have been successfully applied in analyses of fluidized bed drying systems and particulate materials (Poós & Szabó, 2021; Majumder *et al.*, 2022). One of the main contributions of the present work is the development of a simplified heat transfer-based model capable of correlating drying time with operating variables and material properties using measurable experimental parameters. In contrast to CFD–DEM and advanced numerical approaches recently reported for fluidized bed systems (Ma *et al.*, 2023; Tu *et al.*, 2023), the proposed model does not require high computational resources or detailed hydrodynamic simulations. Instead, it provides a practical analytical framework suitable for rapid estimation of drying behaviour at laboratory scale. This represents an important advantage for preliminary equipment design, parametric studies, and laboratory-scale process evaluation.

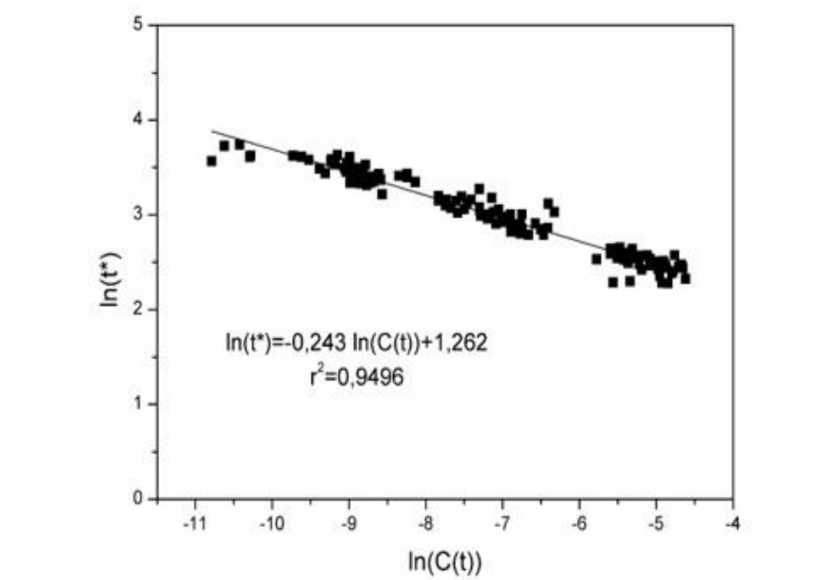

Fig. 2: Dependence of water mass fraction with the drying time (ln(t*) versus ln(C(t))) that describes the operation of laboratory fluidized bed dryer at the selected operation conditions.

Experimental measurements performed during drying allowed determination of moisture evolution as a function of time. Figure 2 shows the linearized relationship between ln(t∗) and ln(C(t)), from which the empirical model constants were obtained.

The resulting expression adequately represented the drying behavior under the evaluated operating conditions:

$$t^*\left[\frac{s}{g_{PP}}\right] = 3.5325\left[\frac{x_1}{1-x_1}\right]^{-0.243} \quad (18)$$

The exponent value obtained (−0.243) suggests a progressive reduction in drying rate as moisture content decreases, which is consistent with drying kinetics commonly reported for particulate systems in which surface evaporation mechanisms play a dominant role (Tu *et al.*, 2023; de Munck *et al.*, 2023).

Compared with previous studies, the proposed system presents several practical advantages. First, the dryer was constructed using inexpensive and commercially available components, reducing implementation complexity and costs compared to more sophisticated laboratory-scale or pilot-scale drying systems reported in the literature (Majumder *et al.*, 2022). Second, the proposed analytical model requires only easily measurable operating variables, facilitating practical implementation without the need for advanced numerical simulations or computationally intensive approaches. Third, the system successfully achieved the target moisture content while maintaining stable fluidization conditions and avoiding observable thermal degradation of the polymer particles. Nevertheless, some limitations of the present approach should also be considered. The model assumes constant thermophysical properties and neglects heat losses through the dryer walls, which may introduce deviations under different operating scales or at higher temperatures. Additionally, the model does not explicitly account for local hydrodynamic phenomena such as bubble formation, particle segregation, or transient temperature gradients, factors that have been reported to influence drying performance and heat transfer behavior in fluidized beds systems (de Munck *et al.*, 2023; Ma *et al.*, 2023). More advanced CFD–DEM models may provide improved predictive capabilities for these complex phenomena, although at the expense of significantly higher computational cost and model complexity's. Despite these limitations, the proposed methodology provides a useful framework for the analysis and preliminary design of laboratory-scale fluidized bed dryers for polymer particles. The combination of experimental evaluation and simplified heat transfer modelling represents a practical alternative for studying drying kinetics and identifying suitable operating conditions in systems where thermal sensitivity imposes important processing constraints.

CONCLUSIONS

A laboratory-scale batch fluidized bed dryer for polypropylene particles was successfully designed, constructed, and experimentally evaluated using a simple and low-cost configuration based on commercially available components. The proposed system demonstrated the ability to efficiently remove superficial moisture from wet polypropylene particles obtained by water-assisted milling while operating under controlled conditions that prevented particle agglomeration, thermal degradation, and polymer melting. A simplified heat transfer-based model was developed to describe the drying process, resulting in a correlation capable of relating drying time to operating variables, material properties, and thermal driving force. The proposed model adequately represented experimental drying behavior and provided a practical analytical framework for evaluating process performance without the need for computationally intensive CFD-based simulations. Experimental results confirmed that the combination of moderate operating temperatures and forced convection allowed effective and homogeneous drying, achieving the target moisture content under stable fluidization conditions. The estimated heat transfer parameters and drying kinetics behavior were consistent with trends reported in recent studies on fluidized bed drying systems and particulate materials. Compared with more sophisticated drying and modelling approaches reported in the literature, the present methodology offers advantages associated with reduced implementation complexity, low operational cost, and simplified experimental analysis. Nevertheless, the proposed model neglects local hydrodynamic effects and assumes constant thermophysical properties, which may limit its applicability under different scales or operating conditions. The integration of experimental evaluation and simplified heat transfer modelling constitutes a useful approach for the analysis, preliminary design, and optimization of laboratory-scale fluidized bed dryers for polymer particles and other thermally sensitive particulate materials. Future work may focus on incorporating hydrodynamic effects and transient heat transfer phenomena in order to improve predictive capability and facilitate scale-up.

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