



# Modeling and simulation of drying operations in PVC powder production line: Experimental and theoretical study of drying kinetics on particle scale



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## ABSTRACT

An experimental method to determine drying kinetic at a particle scale and a pneumatic dryer model are presented. The particle scale kinetics were obtained by immersion of a fixed mass of wet PVC particles (cake) in a batch dense fluidized bed containing inert hot particles (glass bead). It appears clearly that the PVC drying is controlled by a competition between internal and external transfers. The drying kinetic was described by a shrinking core type model and integrated in a one-dimensional steady-state model simulating a pneumatic dryer. A two-phase continuum model was used to describe the steady-state flow of a diluted dispersed phase (wet PVC powder) and a continuous phase (humid air) through dryer. The model takes into account the convective heat, mass and momentum transfers. The numerical results are compared with industrial experimental data. The results show that the inlet temperature is the most important parameter in the operation.

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## 1. Introduction

This study has been realized in the Chemical Engineering Laboratory in Toulouse in partnership with INEOS ChlorVinyls. In PVC powder production line, after the polymerization step, a suspension, composed of water and PVC particles, is obtained. Most of this suspension water is eliminated during a centrifugation step, leading to a wet porous powder, called cake (with a humidity between 0.2 and 0.35 kg of water/kg of dry PVC). The cake drying occurs essentially in a pneumatic dryer coupled with a fluidized bed dryer with a role of eliminating the residual humidity of PVC (less than 0.05 kg of water/kg of dry PVC). This operation, which consumes a lot of energy, between 800 and 1500 kJ/kg dry PVC, in accordance to the operating conditions and the PVC grade, represents 30% of the production cost. With the purpose of reducing drying cost, it is important to understand the different physical phenomena involved (mass transfer, heat transfer, hydrodynamic phenomena specific to the dryers). This study focuses firstly on the acquisition of the kinetics data in a batch dense fluidized bed, and secondly on the modeling of the dehydration of PVC particles in a pneumatic dryer.

The drying kinetic is obtained by immersing a small amount of PVC particles (mean diameter: 143  $\mu\text{m}$ ) in a hot fluidized bed filled with glass beads (mean diameter: 324  $\mu\text{m}$ ). These bigger particles' role is to

suppress the agglomeration phenomena between PVC particles and to realize the drying in isothermal conditions. The experimental results show that the drying kinetic is strongly dependent on air temperature and humidity.

These experimental results were represented according to a kinetic model based on heat and mass exchanges between PVC and air (external transfers), and heat and mass diffusion inside the particle (intern transfers). That kinetic model is then included in a steady-state one-dimensional pneumatic dryer model, which simulates the industrial dryer.

## 2. Background

Porous media drying is a complex problem and still not well-understood despite of the numerous studies that can be found in the literature, due to the coupled exchanges (mass, heat, and momentum transfers) between the gas and the particles [1], depending on solid particles' morphological parameters and water/solid affinity. As shown in Fig. 1, during the drying of a porous particle, two periods can be distinguished. The first period consists in the elimination of free water located at its surface. In this period the evaporation is controlled by external transfers which can be, in accordance to the dryer technology, e.g., conductive, convective or radiative. In our case (pneumatic and fluidized bed dryer), these transfers are convective and depend on the local relative velocity between air and particles, called slip velocity. These transfers depending on the drying technology have been widely studied, and the literature provides a lot of correlations, sometimes

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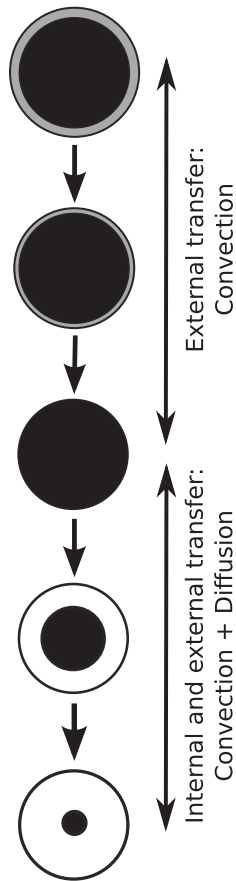


Fig. 1. Different phases of the particle drying.

contradictory, for its estimation ([2–4]). In the second period, the water located in the particles' pores is eliminated: the drying is controlled by a combination between internal and external transfers. The internal transfers depend on the solid properties and structure. The literature shows that many elementary phenomena may occur during drying. Such phenomena are complex and depend on the structure of the solid particle, the water–solid liaison, and the water composition. These elementary mechanisms, represented in Fig. 2 can be ([5,6]):

- capillary forces, depending on liquid wetting on the solid surface ( $\gamma_{LV} \cdot \cos(\theta)$ ), temperature and particle pore size and distribution. These last properties affect the saturation water vapor tension at the solid/liquid interface and the internal liquid movement in the pores.
- vapor diffusion through the pores under the influence of temperature and water vapor partial pressure,
- solid diffusion, corresponding to bound water migration on the solid surface. This mechanism occurs in the case of a solid partially dissolved in water and with a strong liaison between water and solid (chemical interaction, hydrogen liaisons, ...).

Thus, the modeling of a wet particle drying by hot air has to consider: water evaporation at the particle surface during constant drying rate period, and the movement of an evaporation zone between the wet core and the dry crust of the particle. This zone progresses from the particle surface to its core. Several numerical simulations were realized on porous material ([7,8]). The thickness of that drying zone is due to the wetting properties of the liquid in the pores: if the wetting is perfect, the liquid can spread on the pores' internal surface and affect the thermal gradient [9].

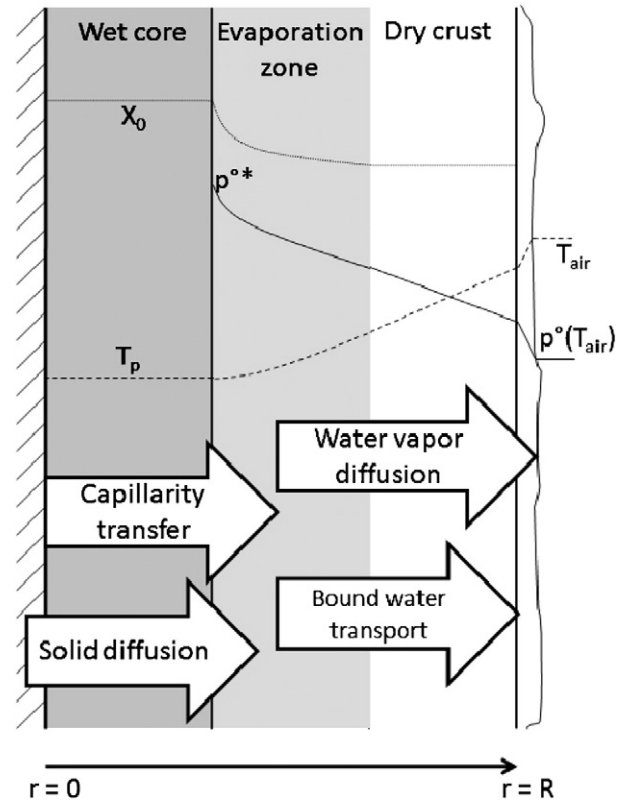


Fig. 2. Internal transfer in a porous particle [23].

In the present case, the wetting properties of PVC, which depends on the superficial tension ( $\gamma_{LV}$ ) of the aqueous solution introduced during the polymerization step and the affinity between the solid particles and this solution, are represented by the contact angle ( $\theta$ ). The low values of liquid superficial tension and high values of the contact angle (between  $80^\circ$  and  $94.7^\circ$  [10,11]), lead to suppose that the drying zone could be modeled by a surface of discontinuity.

Concerning the capillarity effect, the pore-size distribution of a PVC particle, presented in Fig. 3, shows that the minimal pore size is about 30 nm. The Kelvin law expresses water activity ( $p_w/p^o$ ) as a function of pore radius and shows that, for pore radius higher than 10 nm, the water activity is equal to 1. Hence the capillary effect does not influence the liquid/water equilibrium in this study. Concerning the solid and liquid diffusion, previous analysis on INEOS's PVC shows that it is non soluble in water and that the PVC has a small affinity

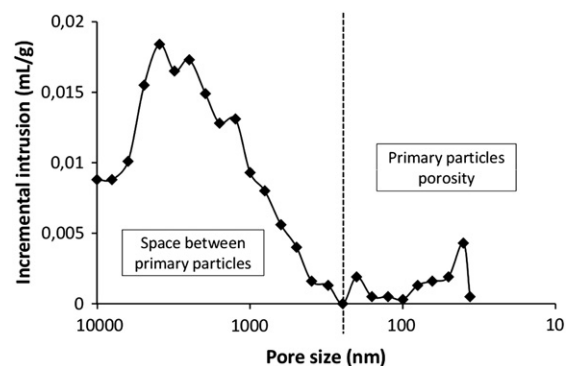


Fig. 3. Pore size distribution of a PVC particle, determined by mercury porosimetry (Micrometrics – Autopore IV).

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