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An experimental study of the drying of granular materials in a packed bed passed by hot air. The local humidity of the material

ANCA MOISE* and RADU Z. TUDOSE

Department of Chemical Engineering, Iasi Technical University, Mangeron nr. 71, Iasi-6600, Romania

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With the purpose of establishing the mechanism responsible for the drying of granular materials in a packed bed passed by a gaseous thermic agent, experimental kinetic study was performed. In a pilot plant, the axial and radial distributions of the local humidity were determined in the non-steady regime. The results show that it is possible for three zones, each at a different state of dryness, to exist in the bed: one zone with initial humidity, one zone with variable humidity and one zone with dried material.

Keywords: drying, packed bed, kinetics of drying.

INTRODUCTION

The drying of granular materials in a packed bed passed by a gaseous thermic agent is, from a theoretical point of view, considered to be a complicated process because it takes place in a non-steady regime and is based on the simultaneous development of three transfer phenomena: gas flow in the intergranular space, heat transfer and mass transfer. The process was considered both under constant external conditions,[1–16] typical for dryers with band and dryers type column, and under intermittent conditions,[15,17,18] typical for rotative dryers.

A pilot plant simulation study performed in this field[19] verified the theoretical models studied under steady and non-steady state conditions, especially for short beds of maximum 100 mm.

For this reason, to obtain information about the drying mechanism of granular materials in packed beds passed by a thermic agent, we have experimentally studied the kinetics of drying large dimension granular materials, under working conditions similar to industrial practice. The study was aimed at obtaining the radial and axial distributions of the local humidity of the granular material, during drying under non-steady state conditions in packed beds of medium to high length, passed by hot air.

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* Author for correspondence: (e-mail: amoise@ch.tuiasi.ro).

EXPERIMENTAL

The drying kinetics were studied using the installation presented in Fig. 1. A column with a 150 mm diameter and 1300 mm height, thermally isolated with asbestos cord, was utilised. A packed bed, of 450 mm height was formed from porous ceramic spheres of 18 mm diameter. Air with a 1.12 kg/m^{2}s mass velocity was used as the drying agent. The experiments were performed at two different temperatures, 70 °C and 95 °C.

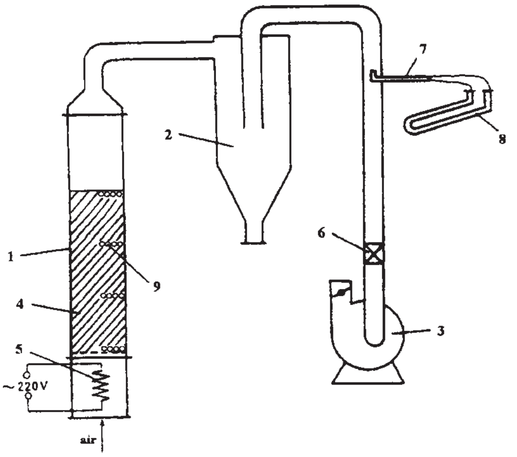


Fig. 1. Schematic presentation of the experimental installation: 1 – column; 2 – cyclone; 3 – fan; 4 – granular bed; 5 – heating system; 6 – valve; 7 – Pitot – Prandtle tube; 8 – inclined gauge; 9 – marked spheres.

The experimental determinations made on this installation permitted curves for the global drying kinetics and the axial and radial distributions of solid humidity to be obtained.

The ceramic spheres were moistened by soaking in distilled water for 24 h. The humid material, was weighed, introduced into the column and dried for a prestablished period. At the end of the drying period, the material was weighed, introduced into a drying chamber at 105 °C and then re-weighed.

The local humidities were determined using 16 marked spheres. The spheres were placed in the granular bed at 4 radial positions at four different distances from the bed base: 10 mm, 140 mm, 290 mm and 440 mm. The marked spheres were also soaked for 24 h, weighed and than introduced into the bed in the mentioned positions. At the end of each period of drying, the spheres were weighed, dried in a drying chamber and then re-weighed.

The measurements of the local humidity were made by stopping the drying after 10, 20, 30, 40, 50, 60 and 85 min for the experiment with air at 95 °C and at 10, 20, 30, 40, 50, 60, 70, 80 and 100 min times for the experiment with air at 70 °C. After each period of time, the drying was resumed from the beginning, repeating each time all the operations of wetting an weighing the bed and marked spheres.

RESULTS AND DISCUSSIONS

The global kinetics of drying curves, presented in a previous paper,[20] showed that the diminution of the material humidity with time is linear up to quite small humidities, under 5 %, after that it tends asymptotically to the equilibrim humidity. The existence of a period of constant drying rate could not be established from the curves depicting the rate of global drying with time.

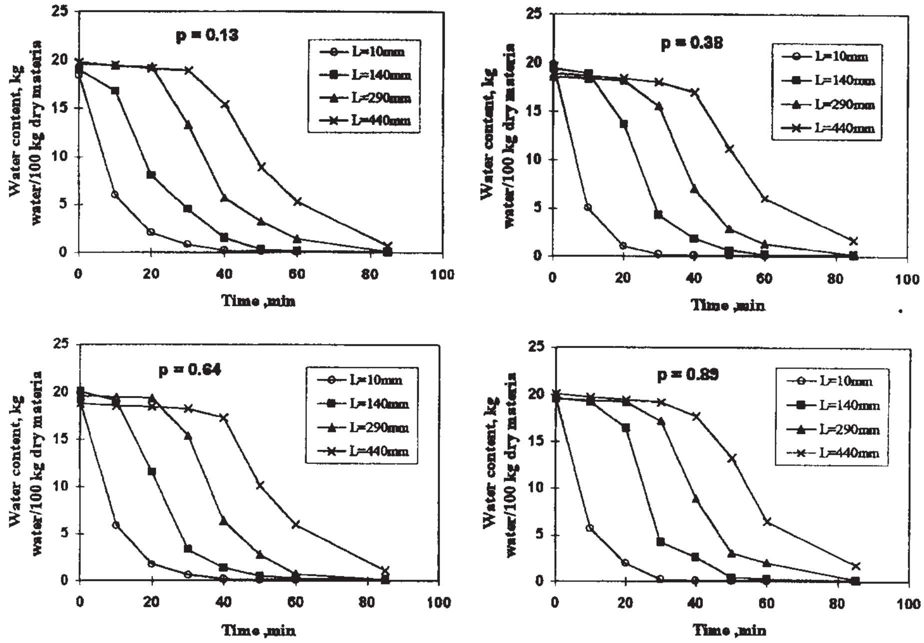


Fig. 2. The distributions of the local humidities at various radial positions for drying with hot air at 95 °C.

The local humidity of the solid material was based on the humidity of the 16 marked spheres. For each sphere, the humidity represents the ratio between the mass of water in the solid material and the mass of the completely dried sphere. The humidity of every sphere was considered as being uniformly distributed in its interior.

The distributions of the local humidities in all the four radial positions are presented in Fig. 2 for the experiment with hot air at 95 °C. The radial coordinate is specified by the relative distance from the wall, p, calculated with $p = (R - r)/R$, where r is the radial coordinate, and R is the bed radius. It can be observed that, while in the lower zone of the bed the humidity of the spheres decreases immediately, in the upper zone the spheres maintain their initial humidity. This means that in the bed, different zones can be distinguished, each of them in another stage of the bed global drying process. At one moment, in the entering zone of the thermic agent, the spheres are completely dried, at greater lengths of the bed the spheres have humidities that increase in the flow direction of the thermic agent, while in the upper zone spheres exist with the initial humidity.

It was also found that, in any one drying zone, the humidity of the material depends on the radial position. In a column section, the spheres adjacent to the wall begin drying before those in the bed centre, but arrive at the equilibrium humidity at approximately the same time.

The local drying rate was calculated using the relation: $U = \Delta m/(\Delta t S)$, where S is the external surface of each of the 16 marked spheres. Because the quantity of wa-

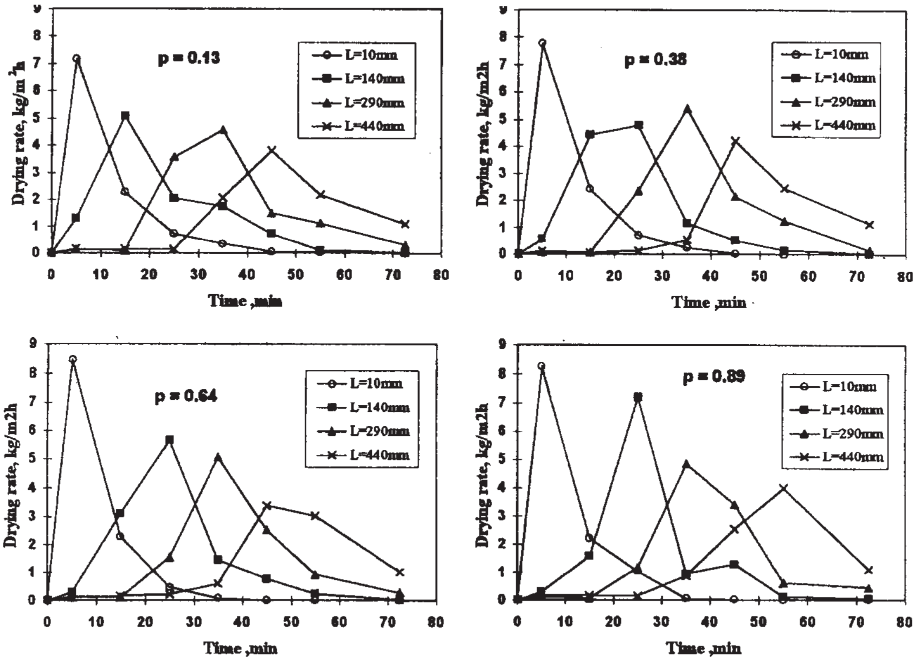


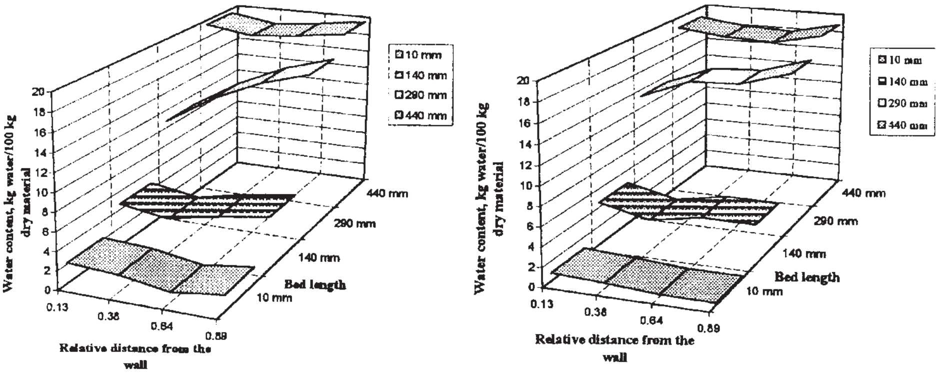
Fig. 3. The distributions of the local drying rates at various radial positions for drying with hot air at 95 °C.

ter Δm is evaporated during the period of time Δt, the local drying rate represents an average for the respective period of time. For this reason, the value obtained by calculation of the drying rate is related with the time corresponding to the middle of this period.

The local drying rate in the four radial positions where the marked spheres were placed are rendered in Fig. 3 for the same experiment with 95 °C hot air. The very large values for the drying rate in the bed-entering zone are particularly clear. But these representations do not permit any inference about the radial variation of the local drying rate, also probably because the period of time (10 min) between the measurements is large.

The highest drying rates occur at the bed entrance, because here the temperature of the thermic agent is the largest, while contact with the metallic screen influences thermic transfer possibly by a conductive mechanism between the screen and the ceramic spheres. In each of the four axial positions, a maximum in the local drying rate was registered, the occurrence of which was later the longer the distance of the respective section from the base of the bed. This means that the drying of granular bed follows a model zone, the proper drying zone advancing with time in the flow direction of the thermic agent.

The existence in the bed of three zones in three different drying regimes is also confirmed by the fact that the drying rate is zero for a time in the upper part of the



a)

b)

Fig. 4. Experimental distributions of the local humidities: a) Drying for 40 min with air at 70 °C, b) Drying for 30 min with air at 95 °C.

bed, where the spheres maintain their initial humidity, and in the lower zone it becomes zero when the spheres have achieved the equilibrium humidity.

The local drying rate also changes with the radial position. When the spheres in a column section start to dry, the drying rates increase in the direction of the column wall. In the final period of drying, the drying rates are larger in the centre of the bed. The combined effect is that spheres situated at the same height in the bed obtain equilibrim humidity at approximately the same time.

The experimental results confirmed that, during the drying, three zones could be differentiated in the bed: one zone where the material has the initial humidity, one zone where humidity of the material is changing and one zone where the material has obtained the equilibrium humidity. The humidity distributions for a drying time when all the three zones exist are presented in Fig. 4a and b for drying temperatures of 70 °C and 90 °C, respectively. On analysing these Figures, it can be seen that the separation surface between the dried zone and the zone with variable humidity is approximately plane, whereas the surface which separates the zone with variable humidity from the zone with initial humidity has a convex surface in the direction of the gas flow. At the entrance to this zone, in the column section drying of the spheres situated near the wall, where the volume of the free space is bigger than in rest of the bed, commences. In the low humidity domain, the distribution of the local humidity is not dependent on the radial position, and the separation frontier with the zone with dried material may be considered planar.

CONCLUSIONS

An experimental study of the kinetics of drying granular material in a fixed bed passed by hot air has been performed for long beds containig spherical granules with an 18 mm diameter. The radial and axial distributions of the solid humidities have been obtained in the non-steady state regime, for two different air temperatures, 70 °C and 95 °C.

The variation of both the solid humidity drying the drying and the local drying rate confirm the fact that it is possible for three zones to exist in the bed: one zone with dried material, one drying zone and a zone with the material with initial humidity. The frontiers, which separate the three zones, may be considered planar surfaces.

In the initial phase, as a result of the upward flow of the gaseous agent, drying starts from the base of the bed. Thus, a zone with variable humidity appears. With time, the height of this zone increases and at one moment the granules from the base of bed become dried and the zone without humidity appears. If the bed is high enough, the zone with initial humidity is maintained for a time at the upper region part, but its length decreases continuously with time. The zone with variable humidity moves upwards in the sense of the flow of the drying agent until only two zones remain in the bed. After this, the zone with variable humidity decreases in height, until if completely disappears and all the bed is dreid.

ИЗВОД

ЕКСПЕРИМЕНТАЛНО ПРОУЧАВАЊЕ СУШЕЊА ГРАНУЛИСАНОГ МАТЕРИЈАЛА У ПАКОВАНОМ СЛОЈУ КРОЗ КОЈИ ПРОЛАЗИ ВРУЋ ВАЗДУХ: ЛОКАЛНА ВЛАЖНОСТ МАТЕРИЈАЛА

ANCA MOISE и RADU Z. TUDOSE

Departmet of Chemical Engineering, Iasi Technical University Mangaron nr. 71, Iasi-6600, Romania

У циљу утврђивања механизма сушења гранулисаног материјала у пакованом слоју кроз који пролази гасовити топлотни флуид изведено је експериментално кинетичко проучвање. У пилот постројењу су одређена аксијална и радијална расподела локалне влажности у нестационарном режиму. Резултати показују постојање три зоне: прве са почетном влажношћу, друге са промењљивом влажношћу и треће у којој се налази осушени материјал.

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