A STUDY OF HEAT AND MASS TRANSFER IN A DRYER WITH IMMERSED CHANNELS

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Men have always tried to improve drying techniques of food products so as to reduce their weight and sometimes their volume which gives great advantages for conservation and transport purposes. However, some studies have led to the development of the drying theory and a better understanding of the water migration or any for volatile liquid and more efficient dehydration engineering system.

Several studies on dryers with immersed channels have been performed with the use of specific air injection apparatus for a homogeneous diffusion of the drying air repartition, thus inducing both uniform mass and heat transfer. Besides, the flow under gravity and at very low velocity kept the granular food products from crumbling under the attrition effects.

The dryer with immersed channels and a judicious extraction system gives products with an even water content throughout the grains. However, the ways taken by the grains in the process are complex and the mathematical model becomes more difficult to define. We developed another approach based on the distribution function determination of the grains in the dryer. It appeared that the piston-flow pattern under axial dispersion simulated rigorously the grains flow behavior. However, a global hydrodynamic model must be defined in order to give users of the system the required tools for scaling efficiently the dryer with the immersed channels.

The dispersive piston model relies on the superposition of a convectional piston flow with the random distribution related to the Fick's law for unidirectional transfer :

$$\phi = UC - D\frac{\partial C}{\partial y} \tag{1}$$

Let us suppose that the media is homogeneous and the density of the grains constant. The following expression is obtained from the mass conservation balance :

$$\frac{\partial C}{\partial t} + U\frac{\partial C}{\partial y} - D\frac{\partial^2 C}{\partial y^2} = 0 \tag{2}$$

In the present experimental method, a signal is monitored with a tracer (of rectangular form in this case) at the inlet of the system and its deformation is analyzed at the outlet. However, the resolution of the differential equation (2) depends on the conditions at the limits which rule at the injection point of the tracer and the analysis point of the signal; this differential spatial-temporal equation takes the following form when the extraction time remains constant :

$$\frac{\partial C}{\partial m} = D\frac{\partial^2 C}{\partial y^2} - D'\frac{\partial C}{\partial y} \tag{3}$$

This results finally in a distribution function as follows :

$$E(m) = \frac{C(m)}{M_i} = \frac{1}{2}\left[\frac{Pe}{\pi m_t m}\right]^{1/2} \exp\left[-\frac{Pe(m_t - m)^2}{4 m_t m}\right] \tag{4}$$

In industry, food products are at first pre-processed which leads in the drying process to water diffusion phenomena through the pores of the grains ; this is ruled by the second law of Fick for the transition state :

$$\frac{\partial W}{\partial t} = \mathrm{div}\left(D^{''} \mathrm{grad} W\right) \qquad \text{(5the}$$

solution of this equation takes the form:

$$W^* = \frac{W\_W_{eq}}{W_{cr}\_W_{eq}} = \frac{6}{\pi^2} \exp\left[-\frac{4\pi^2 D^{''} t}{\psi^2 d_p^2}\right] \qquad (6)$$

As the drying velocity is of the first order, the parallel net model may be applied to compute the remaining water content from the following equation:

$$\overline{W} = \int_0^m \left[\frac{1}{2}\left(\frac{Pe}{\pi m_t m}\right)^{1/2} \exp\left(-\frac{Pe(m_t - m)^2}{4 m_t m}\right)(W_{cr} - W_{eq}) \exp\left(-\frac{4\pi^2 D^{'''} m}{\psi^2 d_p^2 Q}\right)\right] dm \qquad (7)$$

The coupling of the hydrodynamic model and dehydration kinetics allows to formulate a general law predicting the remaining water content in a dryer with immersed channels.

The experimental apparatus, is composed of a rectangular parallelepiped made of plexiglas for visual observation. Inside the apparatus are set series of dihedrals which are used as inlet channels and drying air extraction outlet. The size of the dihedrals lowest series and horizontally set is chosen in order to allow the slits cover to be retracted underneath the dihedrals during the extraction with no grain leaking.
The apparatus, functioning intermittently, has a non-working period of 5 minutes during which the grains do not move and an extraction period lasting 0.5 seconds; this second period during which the air injection is stopped, is related to the flow under gravity around the dihedrals and a particular attention will be taken in this present study.
Moreover, the Residence Time Distribution (RTD) of chickpeas (ρ_s = 1280 kg/m^3, ε = 0,5, d_p = 9,37 mm) in the column is determined.

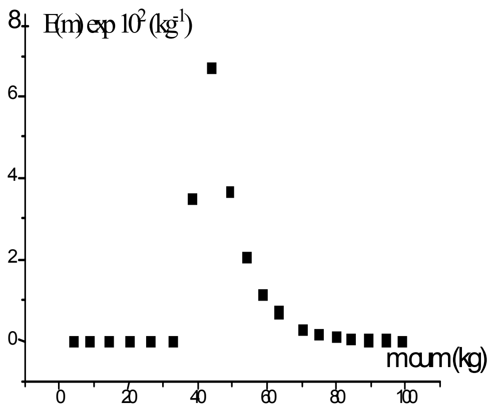

Figure 1 : Graph of the distribution function.

For this purpose, at the top of the column, an embattled signal was poured (h = 0,63 m) in the form of coloured grains; this is used as a tracer which is detected at the outlet of the dryer by the measure of the coloured grains concentration.
The curve of E (m) variation as a function of the extracted mass is shown on figure 1.
The obtained Gaussian type curve is inferred for the random distribution of the grains behavior throughout the different flow periods.
A graphs comparison of both hydrodynamic model defined by equation (4) with a Peclet number equal to 106 and the experimental data shows a slight shift inferred mainly on a slowing-down of grains fraction in some zones, figure 2.

It is also observed under the dihedrals, the presence of sloping zones, which are breaking zones where the grains are retained under swirling effect.

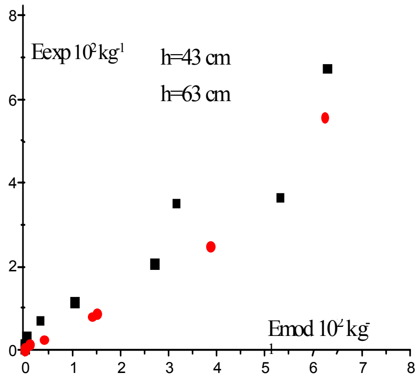

Figure 2: Comparison of experimental results and the theoretical model

Other experiments, based on independent dispersion coefficient, with an injection height of the tracer show that the hydrodynamic model may be applied; as a matter of fact, the plot of the distribution function obtained experimentally and the model show that all the points pass through the first bisecting, figure 2.

To study the humidity diffusion inside the chickpeas, samples are put in an oven with a previously set temperature and weighed regularly.

The graph of the drying velocity, defined as -dW/dt as a function of time, also shows two periods, one at constant velocity and the other at decreasing velocity, figure 3.

1st period : During this period, a rapid decrease of the product water content is observed; in this very short period, the superficial water of the chickpeas evaporates.

2nd period : When all the superficial water is evaporated, the remaining water content has a value called the critical water content; this water is contained in the pores of the grains and starts to diffuse up to the surface before evaporation. This drying period at decreasing velocity thinners down as the equilibrium water content of the product is reached.

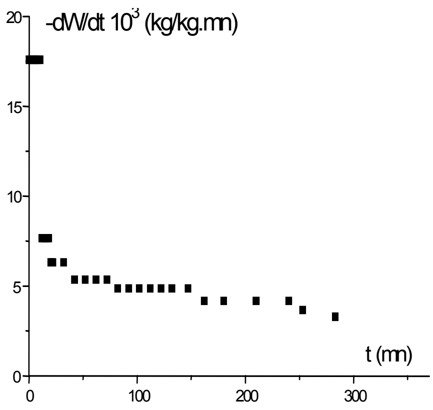

Figure 3: Graph of the drying velocity

In conclusion, based on realistic hypothesis, a mathematical model was developed to give the chemical in drying technology engineer of a useful tool to master food dehydration processes

Nomenclature

C	concentration of the product tracer	kg coloured grains /kg total
d_p	mean diameter of the particles	m
D'	dispersion coefficient	m^2/s
D''	diffusion coefficient of water in the solid	m^2/s
E(m)	distribution function of the extracted mass	kg^{-1}
m_T	total mass in the studied part of the column	kg
Pe	Peclet number	-
Q	mass flowrate of the solids	kg/s
T	temperature	°C
t	time	s
U	flow velocity of the grains	m/s
y	flow abscissa	m
W	humidity	kg of water/kg dried solid
W_{cr}	humidity at critical time	kg of water/kg dried solid
W_{eq}	equilibrium humidity	kg of water/kg dried solid
ε	porosity of the granular media	
φ	sphericity coefficient	
ρ_s	volumic mass of the solid product	kg/m^3