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The Vigorous Bubbling Step in the Potato Immersion Frying Process: Influence of a Previous Water Thermal Treatment

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Abstract – *The central aim of the present work is devoted to study the effect on the earlier or Vigorous Bubbling step of the potato immersion frying process when a previous water heating treatment is applied to the potato samples. In such step, the occurrence of a moving Front in the samples, from the external surface toward the symmetry center is experimentally observed. Such Moving Front separates two different zones: peripheral and central. Precisely, the influence of the water heating treatment of the potato samples on the dynamical behavior of the moving front is analyzed.*

Keywords:*Potato immersion frying, Moisture description front, free moving boundary*

Nomenclature

a Parameter defined by Eq. (5)
b Parameter defined by Eq. (4) (s^{-1})
C Volumetric moisture concentration (kg/m^3)
C^0 Total initial volumetric moisture concentration (kg/m^3)
C_0 Total initial volumetric free moisture concentration (kg/m^3)
d Parameter defined by Eq. (4)
E Unknown function introduced by Eq. (1)(mm)
F1, F2 Fractions of potato sample, without and with thermal treatment before frying
K_x Kinetic coefficient or rate constant for free moisture vaporization (min^{-1})
M Parameter defined by Eq. (6)
R Radius of a cylindrical potato sample (mm)
S^0 Position coordinate of the moving free moisture desorption front (mm)
t Time independent variable
v Unknown function defined by Eq. (2)
x spatial independent variable(mm)
X_0 Initial moisture content (kg/kg db)
X_e Equilibrium moisture content (kg/kg db)

Greek letter
ρ_S Bulk density of potato (kg/ m^3)

I. Introduction

It was experimentally observed that along the earlier step of the potato immersion frying process, the occurrence of a moving front initially coincident with the interfacial contact potato sample-oil bath, which moves toward the symmetry center of the sample, take place.

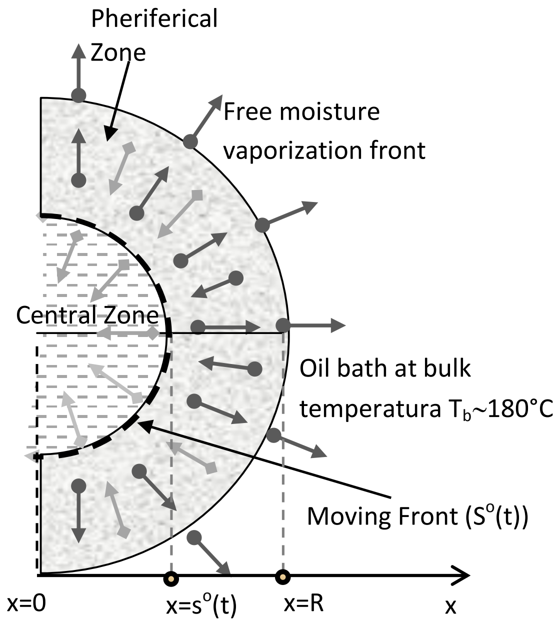

Fig.1 Cross Section of a cylindrical potato sample during the Vigorous Bubbling Step of a Immersion Frying Process.

We claim that such moving front localize a free moisture desorption surface.Such desorbed moisture diffuses to the vaporization front, while the process go on (see Villa et al [1]). For the case of a cylindrical sample of radius R and length L, in Figure 1 above what was consigned in precedence is schematized.

The function E= E(t) , which provide the thickness of the Peripheral Zone as Fig. 1 show, is introduced here:

$$E(t) = R - S^o_{(t)}, \quad t > 0 \tag{1}$$

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II. Experimental

Samples of cylindrical and prismatic shaped of FRITAL INTApotato variety were prepared. Such samples weredivided in two fractions denoted respectively as F1 and F2.

Then, F1 and F2 were submitted to the earlier step (up to 100 seconds) of a immersion frying process in oil hot (~180°C), in such a way that on F2, before to frying, a water heating bath (~60°C) during a minute was applied.

To take a case, in what follow we provide details for a cylindrical sample.Experimental tests were conducted at frying times of 3, 5, 8, 10, 20, 30, 40, 50, 60 and 70 seconds.

In Figure 2 photographic registrations of cross-sections samples submitted to an immersion frying process (earlier step) at level time consigned above, are ilustrated.

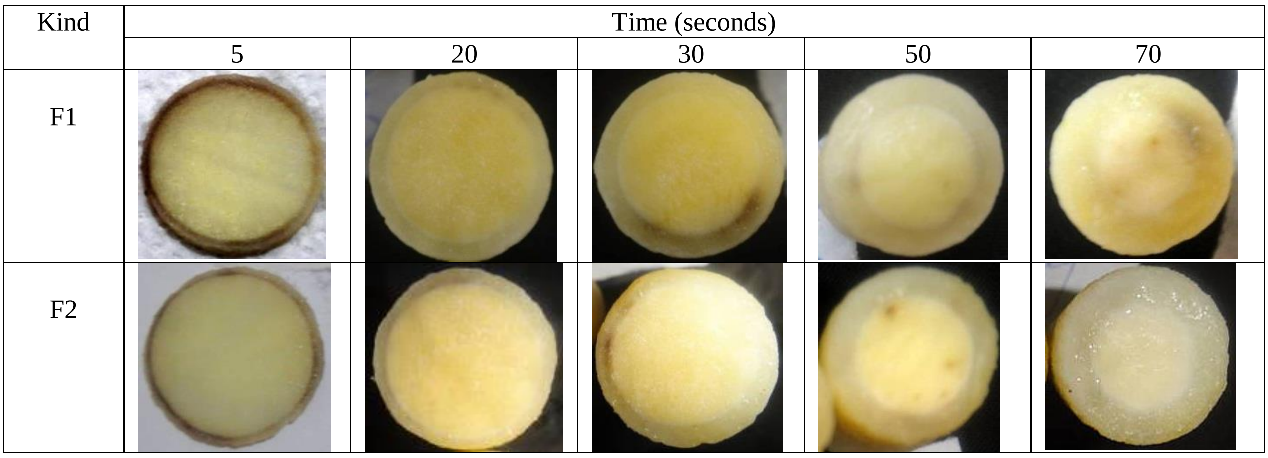


Fig. 2.Photos of cross sections submitted to immersion frying

In Table 1, the time evolution of the function E=E(t) given by equation (1), corresponding to the times tested , is reported.

Table 1.Experimental values E (t) for the indicated times.

Time (s)	E(t) (mm)	
	F1	F2
3	0,35	0,53
5	0,68	0,94
8	0,97	1,20
10	1,06	1,58
20	1,59	2,01
30	2,09	2,47
40	2,53	2,94
50	3,20	3,51
60	3,50	3,98
70	4,01	4,60

In Figure 3, experimental data (t,E(t)) reported in table 1, and the corresponding fitting curves for both fractions F1 and F2 are illustrated. As Figure 3 show, become clear the influence of the thermalbath on the dynamical behavior of the function E=E(t) and hence on the moving free moisture desorption front S°=S°(t), along the evolution of earlier step under analysis. In fact, the fitting curve for E(t) (F2) is always above respect to the fitting curve for E(t)(F1).On the other hand we claim that the starch gelatinization imply an important increasing in the kinetic coefficient, K_x, for free moisture vaporization on the fixed front potato-oil.

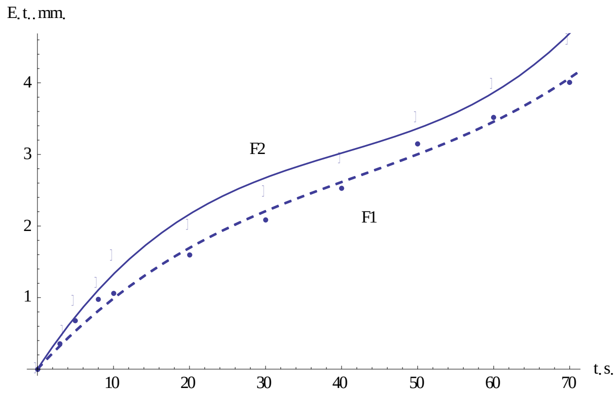


Fig. 3. Experimental data reported in table 1 and the corresponding fitting curves.

Remark 1. Totally similar experimental conclusions were found for prismatic potato samples.
Remark 2. At this point it is opportune take into account the following fact involved in the previous water thermal bath of potato samples:

Taking into account thatthetemperature range for potato starch gelatinization go from 59 to 68 °C, being the potato samples submitted to a water thermal bath with temperature around 60°C along a minute, gelatinization occur securely on some fraction of potato starch. On the other hand, it is known that such process implies free water penetration inside the starch grain with the consequent swelling of these, changing the microstructure of the potato sample, since the starch gelatinization imply to immobilize a fraction of free moisture (hydrogen bond), we invoke this fact to explain the difference in the dynamical behavior of the functions

E(t), for fractions F1 and F2. In such sense, in the following section some details are provided.

III. Microscopical analysis

A Scanning Electron Microscope (JEOL model JSM-6480LV) was used to perform the observations on cross –section of cylindrical potato samples (R=10mm, thickness 2mm) according to following scheme:

F0: raw potato sample.

F1: potato sample submitted to immersion frying in oil hot(~180ºC) during 50 s.

F2: potato sample submitted to a previous water bath (~60ºC) along 1minute and then to immersion frying in oil hot (~180ºC) during 50 s.

In Figures 4 to 7, the corresponding obtained photos are illustrated.

Remark 3. In what follow, the nomenclature: Peripheral Zone, Central Zone, are those already consigned in Fig. 1 of section I.

Concerning photographs, the following facts deserved to be remarked.

In fig. 4, starch grains frompotatosampleswith typicalovoidandspherical shapesare observed. The image shows spherical and ellipsoidal shapesfor small and large sizes, respectively. Thesphericalradiivaryfrom 8 to27µm, withan average of 17µm. In the caseof ellipsoidalformthemajor axismay rangebetween27and60µm

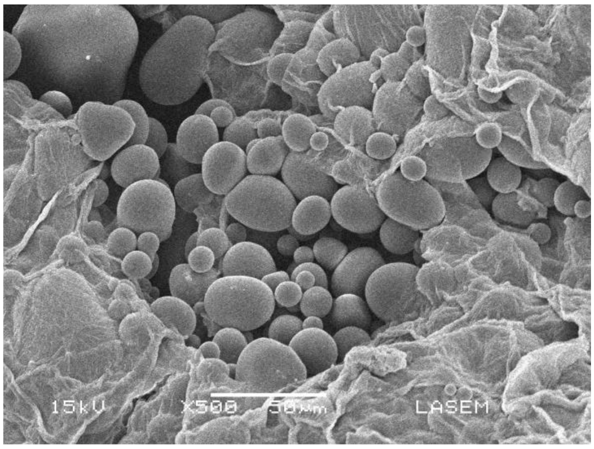


Fig.4.Microscopic view of raw potato.

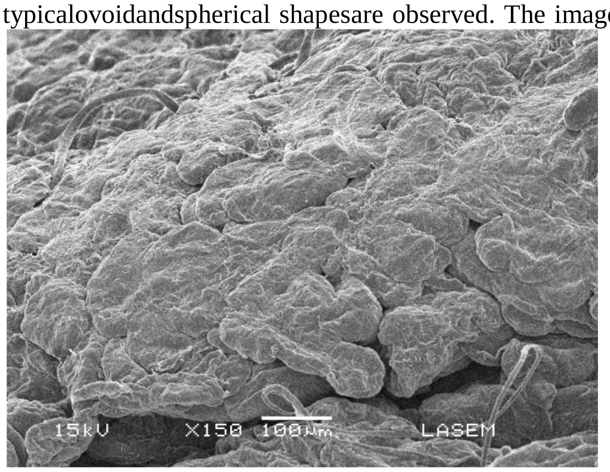


Fig.5a.Peripheral zone. For case F1

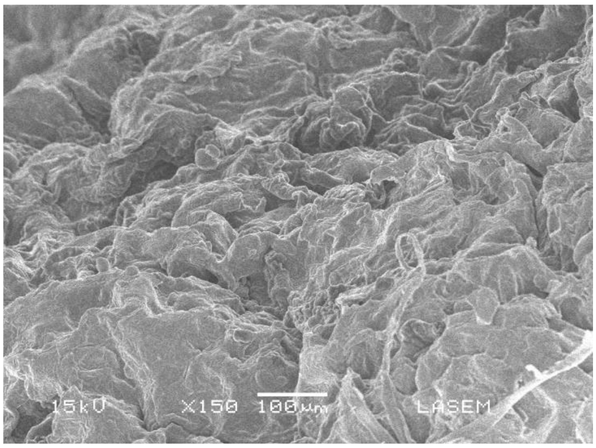
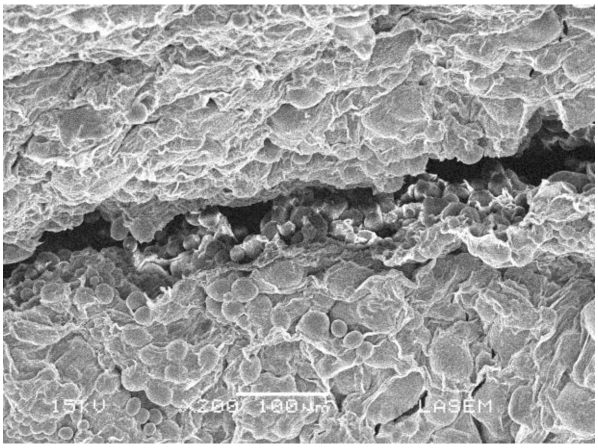
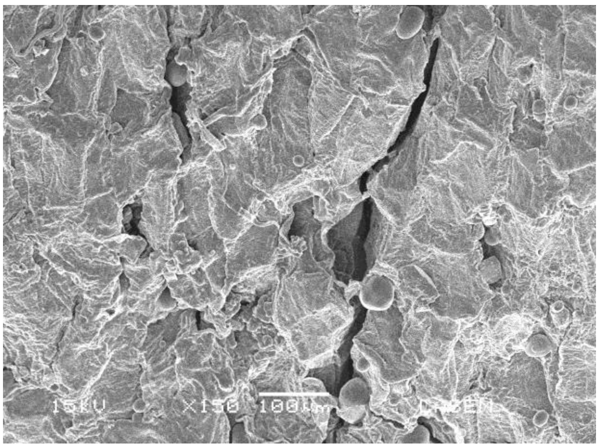


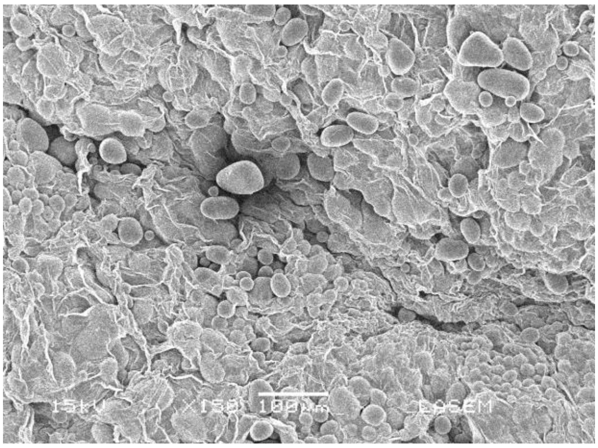
Fig.5b. Peripheral zone. For case F2



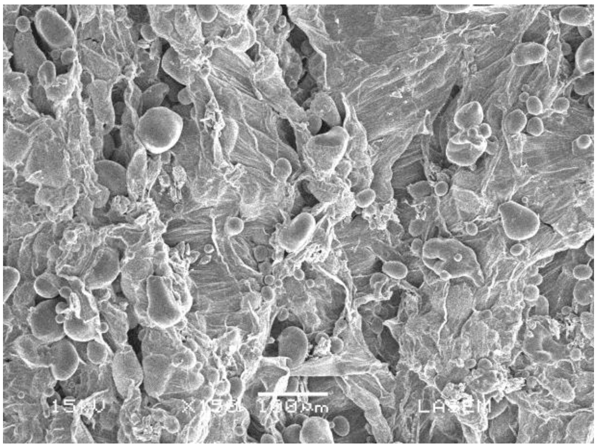
Fig, 6a. Interface zone (peripheral-central) for case F1



Fig, 6b. Interface zone (peripheral-central) for case F2



Fig, 7a. Central zone for case F1



Fig, 7b. Central zone for case F2

In Figs. 5a and 5b there is not presence of starch grains,this is explained by the gelatinization process.

Figs.6aand 6b shows at microscopic levelthepositionof the moving free moisture desorption front (horizontal in 6a and vertical in 6b).In Fig. 6a it can be observed the presence of some amount of starch grains in the central zone below of such front. On the other hand in Fig 6b it is observed the presence of starch grains at right of the moisture desorption front.

The Figs. 7aand 7ballowus to have a clear picture ofthe influence ofhot waterpretreatment. In facts, it can be observed that in Fig.7b, the starch grains have experimented swelling as a consequence of water penetration.

IV. A descriptive model for the dynamical behavior of the free moisture desorption front

IV.1 Physical Data.Empirical Parameters

The physical data ρ_s, C^0, C_0, X_0, relative to the potato sample, denote respectively bulk density (kg/m^3), total initial volumetric moisture concentration (kg/m^3), initial volumetric free moisture concentration(kg/m^3) and initial moisture content (kg/kg db).

The empirical parameters K_x, X_e (see Krokida et al [2]) denote respectively the kinetic coefficient or rate constant for the moisture vaporization of potato sample (min^{-1}) and moisture content at an infinite process time (kg/kg db).

IV.2 Descriptive Mathematical Model

From Villa et al [1], the following nonlinear coupled Initial Value Problem (IVP) to be satisfied by the functions E=E(t) introduced by eq. (1) and v = v (t) defined as

$$v(t) = \int_{S^0}^{R} C(x,t)dx \qquad (2)$$

is obtained:

$$\begin{cases} \frac{dE}{dt} = \frac{d\,exp\,(-bt)}{l[2R-E(t)]+v(t)}\,, t > 0 \\ \frac{dv}{dt} = \left[\frac{-1}{2\,R} + \frac{C^0}{l[2R-E(t)]+v(t)}\right] d\,exp(-b\,t)\,, t > 0 \\ E(0)\ =\ 0\,, v(0)\ =\ 0 \end{cases} \qquad (3)$$

where the parameters b, d, l are given as

$$b = \frac{K_x}{60}, = \frac{a}{8\,L}, l = \ C^0 - 2\,C_0 (4)$$

with

$$a = 2R^2L\,(\rho_s + C^o)b(X_o - X_e) \qquad (5)$$

Remark 4. At this point we remark that the (IVP) consigned by (3) was already proved to be a good descriptive mathematical model in order to fit the experimental data concerning fraction F1 (potato samples submitted to the earlier step of immersion frying without a previous water thermal treatment). In view of such fact, in this work such model is also postulate as a descriptive model for the earlier step of immersion frying for fraction F2 with opportune empirical data.

Remark 5. Notice that geometrical data R, L and physical data ρ_s , C^0, C_0, X_0 are identical for both F1 and F2 samples fractions.

Remark 6. Assuming an identical empirical data X_e for F1 y F2, and introducing the constant M as

$$M = \frac{1}{8\,l}\left[R\left(\rho_s + C^0\right)(X_0 - X_e)\right] > 0 \qquad (6)$$

from (3) it follows that

$$\frac{dE}{dt}(t = 0) = M\,b \qquad (7)$$

which means that in a right neighborhood of t = 0, the function E = E(t) should be an increasing function of the empirical parameter b. This fact agree with what was claimed in Remark2.

V. Solution of the model.Validation.

The descriptive mathematical model of the process under study reported by eqs.(3) was solved computationally using Wolfram Mathematica program,version 9.0.1.0. In Fig. 8 the solution curve corresponding to the unknown function E = E (t), as well as the curve corresponding to experimental data are illustrated graphically. Such solution was obtained using the following set of values for parameters in the processed model.

$d = 0.0014,\ b = 0.03,\ l = 436,\ R = 0.01,\qquad C^0 = 870 \qquad (8)$

An acceptable agreement among E(t) and experimental data is observed.

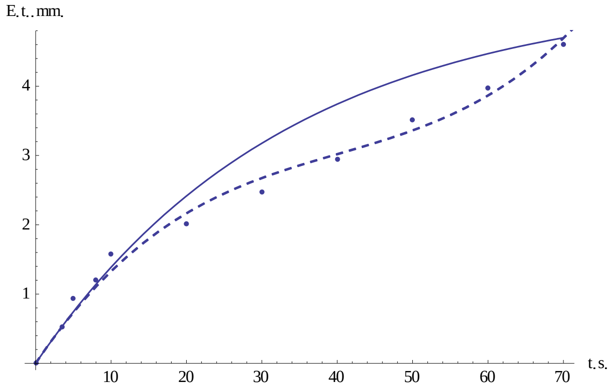


Fig. 8.Computational Solution E(t) for system (3) and experimental data for fraction F2.

VI. Conclusions

The earlier step of potato immersion frying in hot oil was taken into account. Specifically, the influence of a thermal treatment applied to cylindrical and prismatic slices of potato samples (~ 60ºC water bath along 1 min.) before to submit to immersion frying was studied. Concerning such objective,some importantfacts occurring in the internal structure of potato slices, along the dynamical evolution of the earlier step of the immersion frying processes have been revealed.

-We claim that the gelatinization of potato starch contributes to change the dynamical behavior of the free moisture desorption front (see photos of cross sections in figs. 7).

- We postulate that such phenomena not only alter the fraction of free moisture, but also the solid structure in such a way that the free moisture diffusion coefficient is increased respect to the corresponding one in absence of thermal treatment.

On the other hand the experimental tests were also exploited to put in evidence what happens below the 10 seconds in the process. So, the first zone in the temporal evolution of the function E = E(t), defined by equation 1 was completed.

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