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Modelling of high quality pasta drying: mathematical model and validation

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Abstract

The pasta drying process was studied using an engineering approach. The phenomena of mass and heat exchange between pasta samples and air was modelled according to the classic transport approach applied to a hollow cylindrical shape pasta. Data from the literature and from measurements were used to fix the material parameter values of both the air and dough phases. Theoretical correlations were used to obtain a good estimate of mass and heat exchange coefficients between dough samples and air. The proposed model was set by choosing the mass transfer coefficient as the unique optimisation parameter, determined by best fitting of the experimental water content data obtained under given conditions in a static dryer. The model was then validated at different temperature and air humidity drying profiles and a good agreement with the experimental results was found. Finally the model was applied to different process conditions and the drying time was calculated from the simulations.

Keywords: Drying; Food processing; Heat transfer; Mass transfer; Modelling; Pasta production

1. Introduction

In the last 10 years, owing to an increased market demand for dry pasta in many countries, the requirements of both product quality and production rate have increased too. These two aspects are very often considered in contrast each to the other because it is thought that high production rates, characterized by somehow severe process conditions, induce thermal and mechanical damages into the products. These aspects may strongly decrease pasta quality as evidenced by nutrient loss, bad colour, poor texture, marked consistency loss when overcooking, etc. Of course only a careful control of the process conditions coupled to a deep knowledge of the material properties, may avoid those undesired effects, while still maintaining high production rates. Nevertheless, the production process is currently carried out in a rather empirical way, because it is still based on the practical knowledge of pasta-makers, instead of standing on very well consolidated process engineering basis. In fact, the choice of raw materials and process conditions is made by following "rules of thumb" that do not allow any control on the product quality, and they do not match high production rates.

Starting from this point, it clearly appears that an engineering approach has to be developed establishing the influence of the main process variables on the final product quality, in order to apply an effective production control. This objective may be achieved by making a global model capable of simulating what happens

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Nomenclature

a_w	water activity coefficient, –
b	gradient pulse of strength in NMR measurements
C	heat capacity, $J\,kg^{-1}\,K^{-1}$
C_p	specific heat, $J\,kg^{-1}\,K^{-1}$
D	water diffusivity, $m^2\,s^{-1}$
E_a	activation energy, $kJ\,gmol^{-1}$
F	echo attenuation in NMR measurements
h	global heat exchange coefficient, $J\,m^{-2}\,K^{-1}$
I	signal intensity in NMR measurements
J_h	Colburn factor for heat transfer, –
J_m	Colburn factor for mass transfer, –
k	thermal conductivity, $W\,m^{-1}\,K^{-1}$
k_x	global mass exchange coefficient, $kg\,m^{-2}\,s^{-1}$
L	pasta sample length, m
M	molecular weight, dalton
N	mass flux, $kg\,m^{-2}\,s^{-1}$
P	pressure, Pa
$p°$	vapour pressure, Pa
q	thermal flux, $W\,m^{-2}\,K^{-1}$
R	sample radius, m
r	variable radius, m
R_g	universal gas constant, $J\,gmol^{-1}\,K^{-1}$
SQM	square quadratic deviation, %
T_∞	air temperature in bulk phase, K
T	temperature, K
t	time, s
U	dough water content on wet basis, w/w
UR_∞	relative water content of air in bulk phase, w/w%
v_∞	air velocity, $m\,s^{-1}$
x	dough water content on dry basis, –
y	molar fraction in air, –
$y_{w,\infty}$	water molar fraction in air in bulk phase, –

Dimensionless numbers

Nu	Nusselt
Pr	Prandtl
Re	Reynolds
Sc	Schimdt
Sh	Sherwood

Greek symbols

Δ	space variation
α	shrinkage coefficient, –
δ	pasta sample thickness, mm
β	theoretical and optimised mass exchange coefficient ratio, –
λ	water latent heat of vaporization, $J\,kg^{-1}$
ρ	dough density, $kg\,m^{-3}$
σ	time between 90° and 180° *rf* in NMR measurements
ψ	duration of the gradient pulse in NMR measurements
ζ	magnetogyric ratio in NMR measurements

Subscripts

0	initial condition
a	air
d	dough
exp	experimental value
f	film condition
i	generic point of calculation grid
sim	simulation value
w	water

Superscripts

eq	equilibrium conditions
ext	referred to external surface
int	referred to internal surface

during the process and therefore to predict "a priori" the values of the desired properties.

In this work attention was focused on the study and modelling of the pasta drying process, because during this step pasta is subjected to rather severe conditions that are fully responsible for the final product quality. In fact, drying is usually realised by using wet hot air with temperatures ranging between 80 and 120 °C, and a controlled relative humidity *UR* ranging between 40% and 70%. The actual industrial trend is to get rather high production rates over 3–4000 kg/h, that are obtained by reducing the drying time by means of a process characterised by high temperature and low moisture drying air, this choice in turn reduces the microbiological risk because of the strong heat treatment. Moreover, according to the market request for high quality production, these severe process conditions may cause a so-called "thermal damage" that is evidenced by a poor texture, a decrease in the mechanical resistance, a lower nutrient content, a darker colour, etc. This kind of product obviously does not fit with consumer expectations, even if safer from a microbiological point of view, owing to the poorness of most of the quality indices.

Dried pasta production process can be represented schematically as a rather simple chain of unit operations (see Fig. 1). Ingredients, basically water and durum wheat flour, are usually mixed together under vacuum to give a dough with a water content percentage close to 30% (wet basis). Then the resulting dough is sent into an extruder press and finally extruded through a head in order to obtain the desired pasta shape.