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A Decision Support Tool to Predict Mass Transfer and Microorganism Growth in Modified Atmosphere Packaging of Fresh Food Products

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Context of the study:

In **Modified Atmosphere Packaging** system (MAP) of fresh food products, one of the main roles assigned to the packaging material is to control gas transfer from the surrounding atmosphere toward headspace. Beyond gas losses toward external atmosphere, the gases dissolve and diffuse in the product leading to gas modification in headspace. Most of the studies recently carried out to evaluate the impact of gases on microorganism growth used the "pack and pray" empirical methodology. Different gas mixtures (mainly O2/CO2/N2) are successively tested on the product until the right combination (O2/CO2 ratio, package surface/volume, mass of food, etc.) is found. In this approach, mass transfer phenomena through the packaging material are seldom taken into account.

The **objective** of this work is to develop a **Decision Support Tool** aiming at predicting the shelf life of fresh food. This tool is based on mathematical models coupling mass transfer models and predictive microbiology. The originality of the approach is that it takes into account, in a dynamic system, the impact of gradients of dissolved gases within the product (due to mass transfer trough packaging and within headspace and food matrix) on microorganism growth, that was never done until now in predictive microbiology. It would be helpful to simplify the package design steps by being able to predict in advance the required window of packaging permeability for maintaining the quality of the packed food.

Theory

Mass transfer

The mass transfer is supposed monodirectional along the [O x] abscissa and modeled using Fick's laws. In headspace, the concentration of species is considered uniform along the [-e_F 0] axis. The tray in which is placed the food is supposed to be impermeable to any gas flow except through the lid film (called 'packaging film' on the schema). The total pressure inside the headspace is supposed constant and **variations of headspace volume** (VHS) due to mass transfer are thus taken into account as follows:

$$\frac{dV_{HS}}{dt} = \frac{RT}{P_T}\left(\frac{\phi_{O,I}+\phi_{O,F}}{M_O} + \frac{\phi_{D,I}+\phi_{D,F}}{M_D} + \frac{\phi_{N,F}}{M_N}\right)$$

Variation of [gases] in headspace

$$\frac{dV_{HS}C_{j_g}}{dt} = \phi_{j,I} + \phi_{j,F}$$

Mass flow of gases through the packaging material

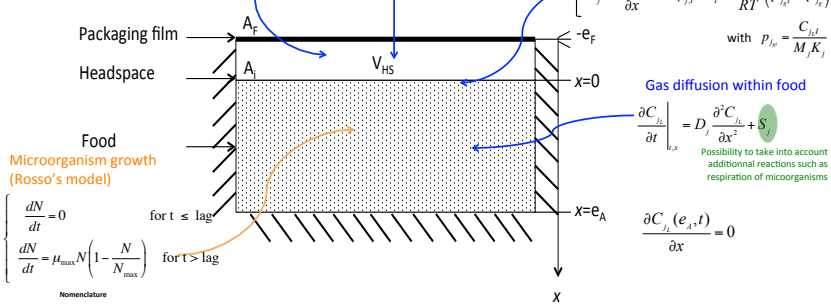
$$\phi_{j,F} = M_j P_j \left(S_F / e_F\right)\left(p_{j_{ae}} - p_{j_g}\right)$$

Mass flow of gases through food/ packaging interface

$$\phi_{j_I} = \frac{kM_j}{RT}\left(p_{j_g I} - p_{j_g}\right) S_I$$

$$D_j \frac{\partial C_{j_L}(0,t)}{\partial x} = \phi_{j,I} / S_I = \frac{kM_j}{RT}\left(p_{j_g I} - p_{j_g}\right)$$

with $p_{j_{gI}} = \frac{C_{j_L I}}{M_j K_j}$



Gas diffusion within food

$$\left.\frac{\partial C_{j_L}}{\partial t}\right|_{t,x} = D_j \frac{\partial^2 C_{j_L}}{\partial x^2} + S_j$$

Possibility to take into account additionnal reactions such as respiration of micoorganisms

$$\frac{\partial C_{j_L}(e_A,t)}{\partial x} = 0$$

Microorganism growth (Rosso's model)

$$\begin{cases} \frac{dN}{dt} = 0 & \text{for } t \le lag \\ \frac{dN}{dt} = \mu_{max} N\left(1 - \frac{N}{N_{max}}\right) & \text{for } t > lag \end{cases}$$

Nomenclature

j=[O,D,N] represents respectively *oxygen, carbon dioxide and nitrogen*
g =gaseous phase, I= interface and F= film
V_{ae}= volume of headspace (m^3)
M_j= molar mass ($kg.mol^{-1}$) of specie j
P_j= permeability ($mol.m^{-1}.s^{-1}.Pa^{-1}$) of gas j
S_F = film surface (m^2)
e_F= film thickness (m)

$p_{j_{ae}}$ and p_{jg} = external (atmospheric) and headspace gas partial pressure (Pa) of specie j
K = external mass transfer coefficient ($m.s^{-1}$)
R = perfect gas constant ($J.mole^{-1}.K^{-1}$)
T= temperature (°K)
p_{jgI} =partial pressure of gas j at the interfaceheadspace/ food (Pa)
S_I= interface headspace/food surface

K_j = Henry's coefficient of specie j in mole.$Pa^{-1}.m^{-3}$
D_j =Diffusivity of the specie j in the food ($m^2.s^{-1}$)
x =distance from headspace/food interface (m)
t =t ime (s)
S_j = net volumic production rate of specie j in the food due to reactions ($kg.m^{-3}.s^{-1}$)
N_{max} = maximal number of microorganisms (CFU/g) at the end of the growth curve

N= number of microorganisms at time t (CFU/g)
μ_{max} = maximal growth rate
γ_i = inhibitor or activator parameters
μ_{opt} = optimal growth rate
MIC =Minimal Inhibitory Concentration
%CO2=concentration of CO2 (in %) imposed to the microorganism culture as a function of time and position in the food

Predictive microbiology

Gamma-concept (Zwietering et al., 1992) was chosen to simulate microbial growth μ_{max} rate as :

$$\mu_{max} = \mu_{opt} \cdot \gamma_T \cdot \gamma_{PH} \cdot \gamma_{a_w} \cdot \gamma_{int} \cdot \gamma_{CO_2}$$

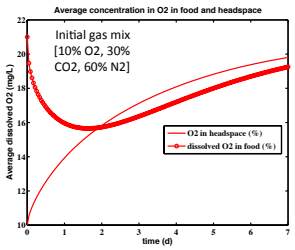
Where μ_{opt} is the optimal growth rate and γi are functions corresponding to each environmental factors effects (*i.e.* temperature, pH, water activity, interactions and CO2). To take into account the inhibitor effect of CO2, we consider that:

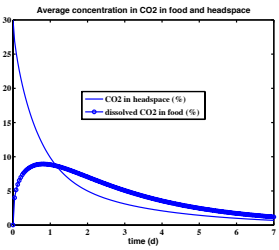
$$\gamma_{CO_2} = 1 - \left(\frac{\%CO_2(t,x)}{MIC}\right)^{\alpha}$$

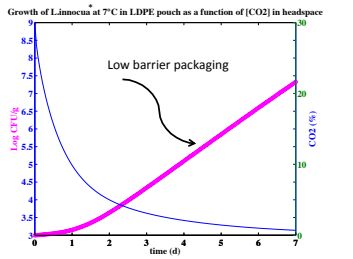
Finally, microbial concentration N is given according to the primary growth model of Rosso (1995).

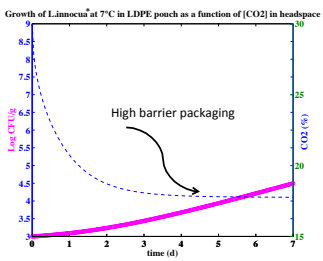
Preliminary simulations

Low barrier packaging

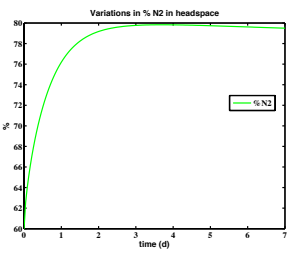


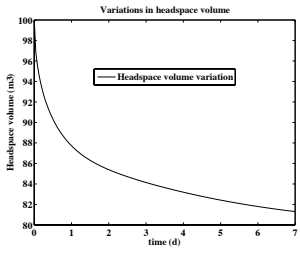






* Input parameters for predictive microbiology taken from Geysen et al International Journal of Food Microbiology 105 (2005) 333-345





Conclusion: This Decision Support Tool appears very interesting from a practical point of view, to help food manufacturer to choose the packaging material that best suits to a given food product to ensure food safety.

Perspectives: To go further, this modeling tool should be experimentally validated. An update version taking into account the respiration of microorganisms and its impact on gases concentrations is foreseen. A global sensitivity analysis will be performed to identify the less influential factors among the existing input parameters in order to simplify the model and reduce the experimental cost of parameters determination.

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Zwietering M.H., Wijtzes, T., De Wit, J.C. & Van't Riet K., 1992. A decision support system for prediction of the microbial spoilage in foods. J. Food Protection, 55, 973-979;
Rosso L., Lobry J.R., Bajard S. and Flandrois J.P. (1995). A convenient model to describe the combined effects of temperature and pH on microbial growth. Appl.Env.Microbiol. 61. 610-616.