Optimization of enzymes inactivation in High Pressure Processes

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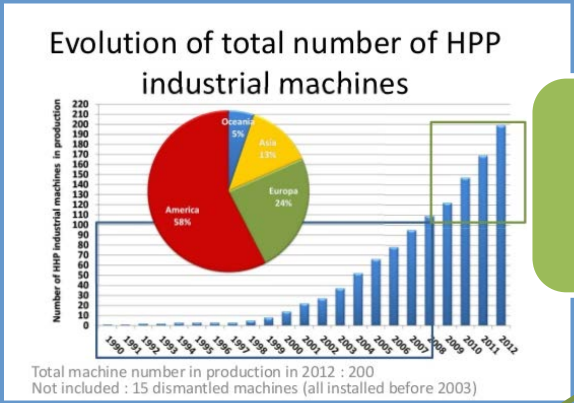
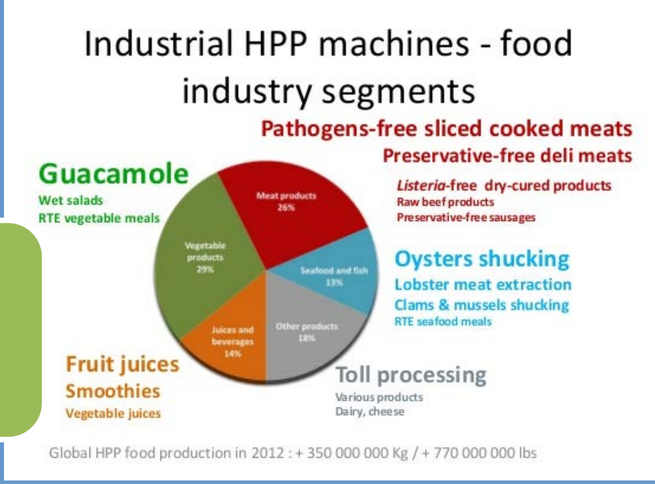
1. Introduction

HP in Food Industry

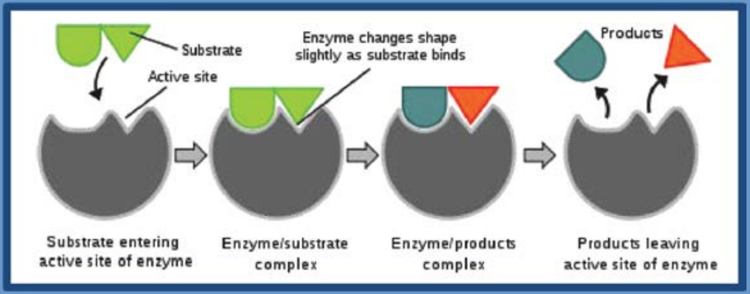


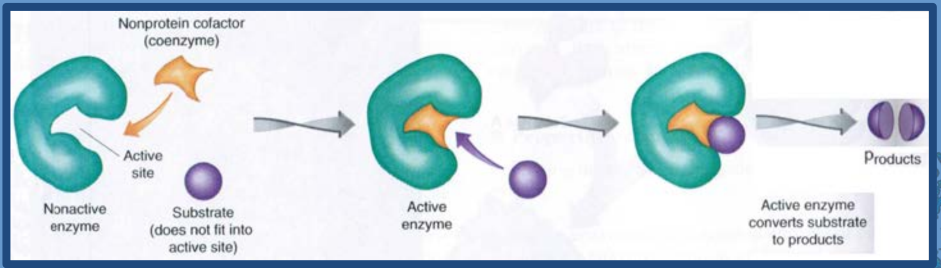


Why HP processes are used?

To inactivate some biological entities → **Enzymes**

Without damaging some good properties → **Vitamins**

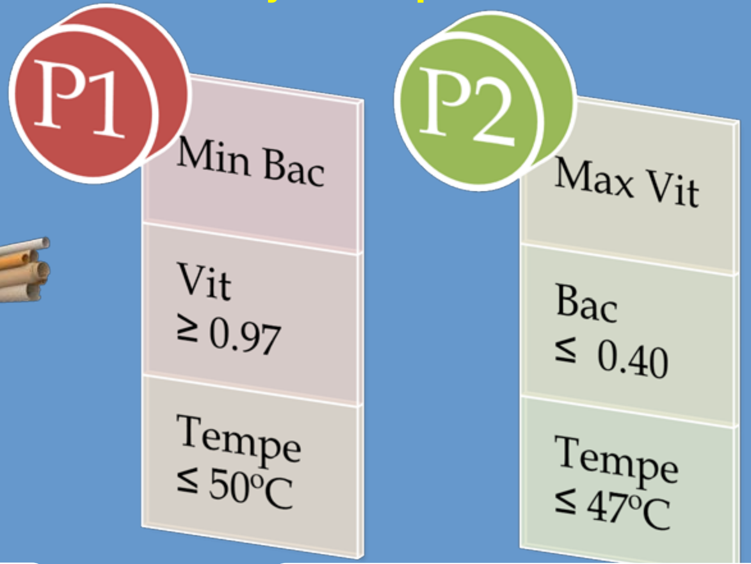




1. Introduction

Our proposal: A decision tool

- **Different treatments satisfying specific quality requirements** can be demanded.
- The general idea: is to provide to the decision maker a **set of points** which are individually **good solutions for many different constrained mono-objective problems**.



Mono-objective Problem 1

$$\begin{aligned} \min \quad & f_1(T_0, T_r, P_1, \ldots, P_{n-2}) = \text{Bac} \\ s.t. \quad & \text{Vit} \geq 0.97 \\ & \text{Tmax} \leq 50 \end{aligned}$$

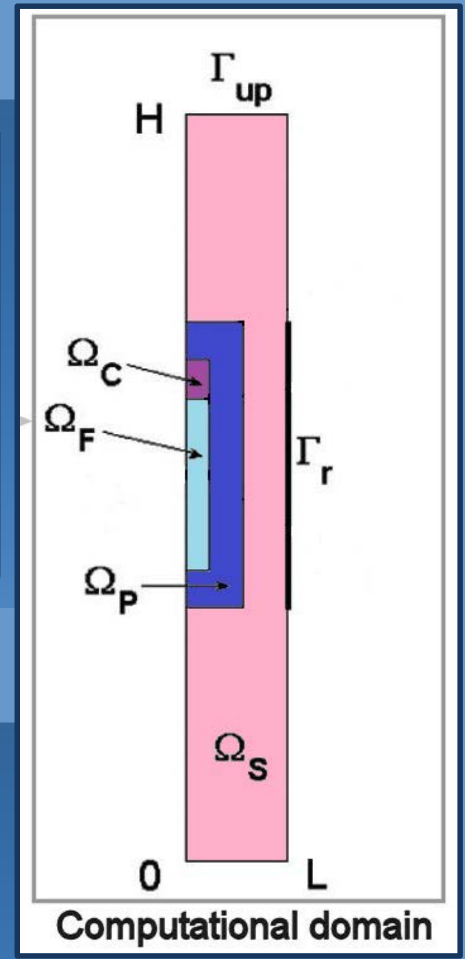
Mono-objective Problem 2

$$\begin{aligned} \min \quad & f_1(T_0, T_r, P_1, \ldots, P_{n-2}) = 1 - \text{Vit} \\ s.t. \quad & \text{Bac} \leq 0.4 \\ & \text{Tmax} \leq 47 \end{aligned}$$

2. Mathematical model

Heat transfer

$$\begin{cases} \rho C_p \dfrac{\partial T}{\partial t} - \dfrac{1}{r}\dfrac{\partial}{\partial r}\left(rk\dfrac{\partial T}{\partial r}\right) - \dfrac{\partial}{\partial z}\left(k\dfrac{\partial T}{\partial z}\right) = \alpha \dfrac{dP}{dt} T & \text{in} \quad \Omega \times (0, t_{\mathrm{f}}) \\ k\dfrac{\partial T}{\partial \mathbf{n}} = 0 & \text{on} \quad \Gamma \backslash (\Gamma_{\mathrm{r}} \cup \Gamma_{\mathrm{up}}) \times (0, t_{\mathrm{f}}) \\ k\dfrac{\partial T}{\partial \mathbf{n}} = h(T_{\mathrm{amb}} - T) & \text{on} \quad \Gamma_{\mathrm{up}} \times (0, t_{\mathrm{f}}) \\ T = T_{\mathrm{r}} & \text{on} \quad \Gamma_{\mathrm{r}} \times (0, t_{\mathrm{f}}) \\ T(0) = T_0 & \text{in} \quad \Omega \end{cases}$$



Enzymatic inactivation

$$A(r,z,t) = A(r,z,0)\exp\left(-\int_0^t \kappa(P(\sigma), T(\sigma))d\sigma\right)$$

κ(P, T) is the **inactivation rate** (min−1)

$$\kappa(P,T) = \kappa_{\mathrm{ref}} \exp\left(-B\left(\frac{1}{T} - \frac{1}{T_{\mathrm{ref}}}\right)\right)\exp\left(-C(P - P_{\mathrm{ref}})\right)$$

3. Optimization

Multi-objective problem

Find the optimal HP configuration

$$\min\{f_1(\mathbf{x}), \ldots, f_m(\mathbf{x})\}$$
$$\text{s. t. } \mathbf{x} \in S \subseteq \mathbb{R}^n$$

T_0 (initial temperature),
T_r (refrigeration temperature)
$P(t)$ (pressure)

$(T_0, T_r, P_1, \ldots, P_{n-2})$ decision vector $\mathbf{x} = (x_1, \ldots, x_n)$

such that

$f_1, \ldots, f_m : \mathbb{R}^n \longrightarrow \mathbb{R}$

objective functions

Bacteria

$$\text{Bac} = \int_{(r,z)\in\Omega_F} A_{\text{bac}}(r, z, t_f)$$

The average of the final bacterial activity in the food sample is **minimal**

Vitamin

$$\text{Vit} = \int_{(r,z)\in\Omega_F} A_{\text{vit}}(r, z, t_f)$$

The average of the final vitamin activity in the food sample is **maximal**

Maximum Temperature

$$\text{Tmax} = \max_{(r,z)\in\Omega_F,\ t\in[t_0,t_f]} T(r, z, t)$$

The maximum temperature reached in the food sample along the whole process is **minimal**

3.1. Algorithm WASF-GA

Basic concepts

WASF-GA is an evolutionary multi-objective optimization algorithm which takes into account the **DM's preferences** using an achievement scalarizing function (ASF)

Wierzbicki's ASF

$$s(\mathbf{x}) = \underbrace{\max_{i=1,\dots,m} \{\mu_i(f_i(\mathbf{x}) - q_i)\}}_{L_\infty \text{ distance}} + \rho \sum_{i=1}^{m} \mu_i(f_i(\mathbf{x}) - q_i)$$

$\mu = (\mu_1, \dots, \mu_m)$ Weights vector

$\mathbf{q} = (q_1, \dots, q_m)$ Reference point

Domain space

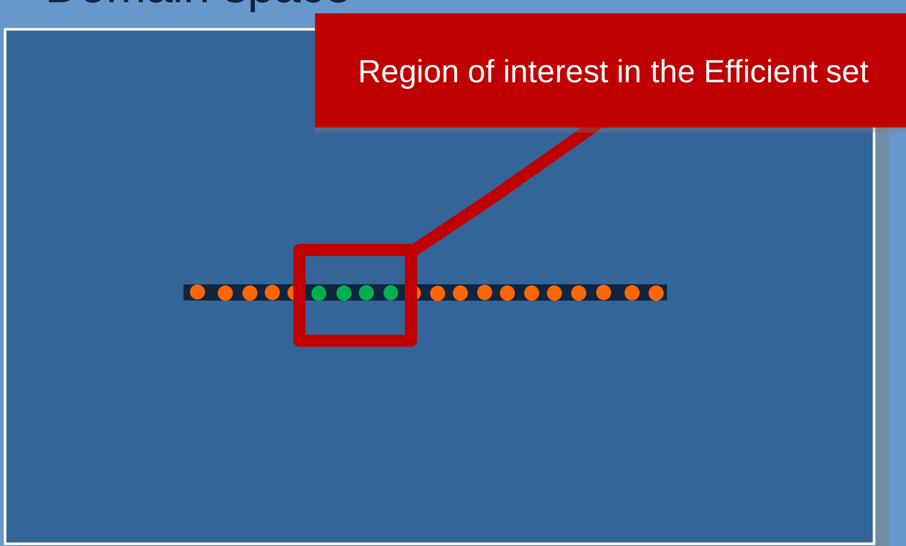
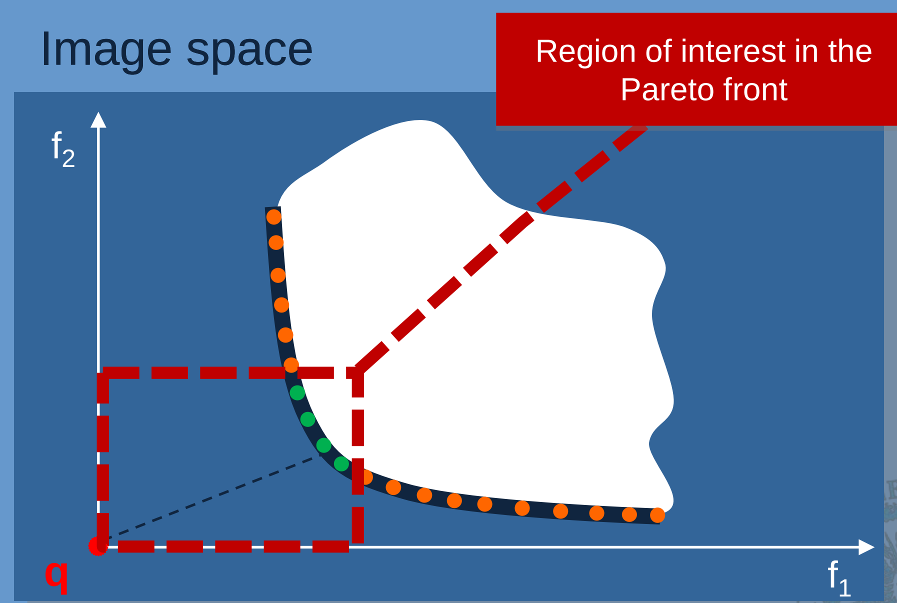


Image space



4.Computational experiments

Decision tool

- We want to show that, in the practice, if the food engineer has available the set of points belonging to this three-dimensional Pareto front approximation, then he/she has individually **good solutions for many different constrained mono-objective problems**.

- For instance:

Mono-objective Problem 1

$$\begin{array}{ll} \min & f_1(T_0, T_r, P_1, \ldots, P_{n-2}) = \text{Bac} \\ s.t. & \text{Vit} \geq 0.97 \\ & \text{Tmax} \leq 50 \end{array}$$

Mono-objective Problem 2

$$\begin{array}{ll} \min & f_1(T_0, T_r, P_1, \ldots, P_{n-2}) = 1 - \text{Vit} \\ s.t. & \text{Bac} \leq 0.4 \\ & \text{Tmax} \leq 47 \end{array}$$

	Bac	Vit	Tmax
Mono	0.2519	0.9777	49.9721
Multi	0.2518	0.9892	49.7714

	Bac	Vit	Tmax
Mono	0.3973	0.9933	46.9664
Multi	0.3832	0.9957	46.5664