

Optimization of enzymes inactivation in High Pressure Processes



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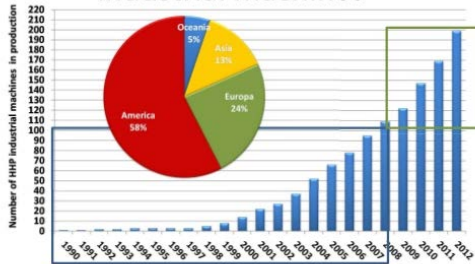
UMH - Elche



1. Introduction

HP in Food Industry

Evolution of total number of HPP industrial machines



Total machine number in production in 2012 : 200
Not included : 15 dismantled machines (all installed before 2003)

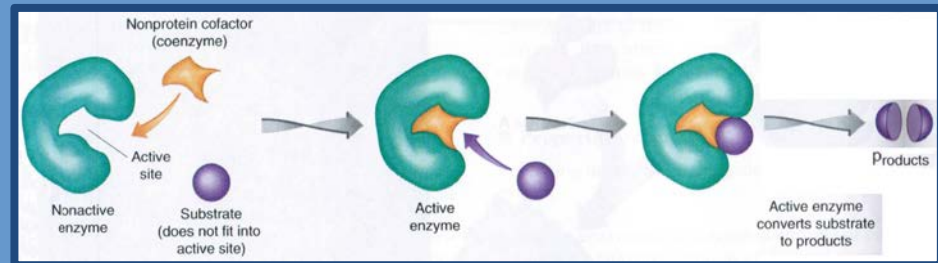
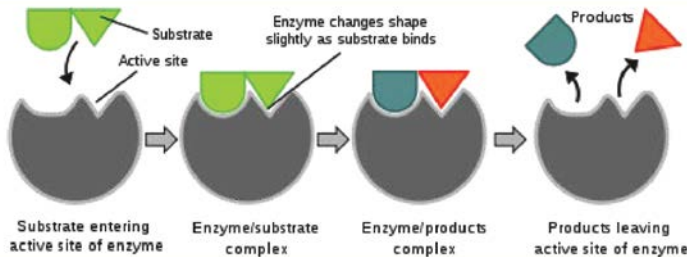
Why HP processes are used?

To inactivate some biological entities

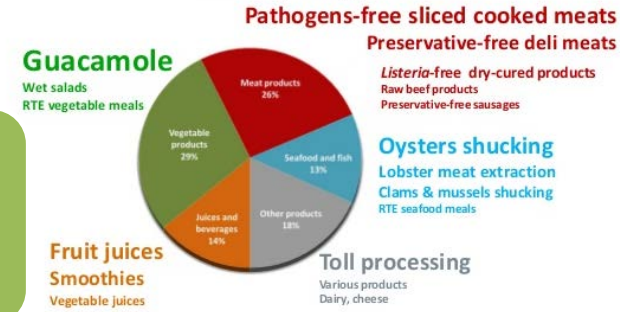
Enzymes

Without damaging some good properties

Vitamins



Industrial HPP machines - food industry segments



Global HPP food production in 2012 : + 350 000 000 Kg / + 770 000 000 lbs

- Pathogens-free sliced cooked meats**
- Preservative-free deli meats**
- Listeria-free dry-cured products**
- Raw beef products**
- Preservative-free sausages**
- Oysters shucking**
- Lobster meat extraction**
- Clams & mussels shucking**
- RTE seafood meals**
- Toll processing**
- Various products**
- Dairy, cheese**

- Guacamole**
- Wet salads**
- RTE vegetable meals**
- Fruit juices**
- Smoothies**
- Vegetable juices**

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**.



Min Bac

Vit
 ≥ 0.97

Tempe
 $\leq 50^\circ\text{C}$



Max Vit

Bac
 ≤ 0.40

Tempe
 $\leq 47^\circ\text{C}$

Mono-objective Problem 1

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

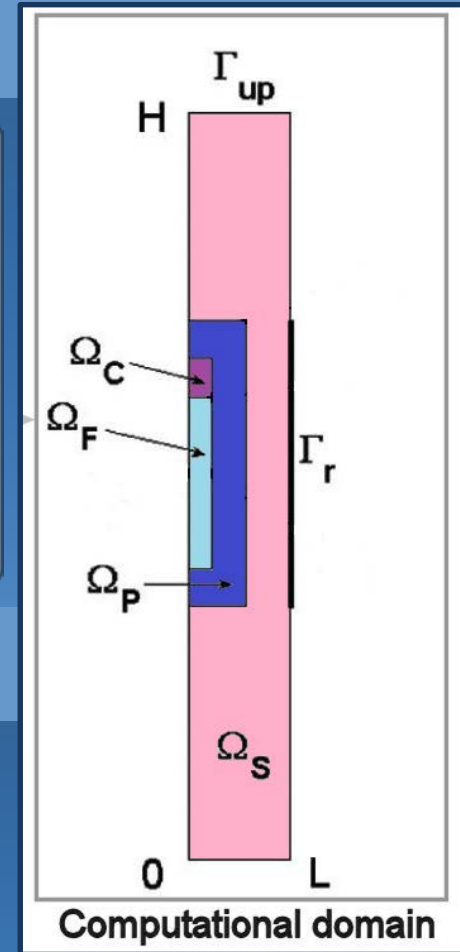
Mono-objective Problem 2

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

2. Mathematical model

Heat transfer

$$\left\{ \begin{array}{ll} \rho C_p \frac{\partial T}{\partial t} - \frac{1}{r} \frac{\partial}{\partial r} \left(r k \frac{\partial T}{\partial r} \right) - \frac{\partial}{\partial z} \left(k \frac{\partial T}{\partial z} \right) = \alpha \frac{dP}{dt} T & \text{in } \Omega \times (0, t_f) \\ k \frac{\partial T}{\partial \mathbf{n}} = 0 & \text{on } \Gamma \setminus (\Gamma_r \cup \Gamma_{\text{up}}) \times (0, t_f) \\ k \frac{\partial T}{\partial \mathbf{n}} = h(T_{\text{amb}} - T) & \text{on } \Gamma_{\text{up}} \times (0, t_f) \\ T = T_r & \text{on } \Gamma_r \times (0, t_f) \\ T(0) = T_0 & \text{in } \Omega \end{array} \right.$$



Enzymatic inactivation

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

$\kappa(P, T)$ is the **inactivation rate** (min^{-1})

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

3. Optimization

Multi-objective problem

Find the optimal HP configuration

$$\min\{f_1(\mathbf{x}), \dots, f_m(\mathbf{x})\}$$

$$\text{s. t. } \mathbf{x} \in S \subseteq \mathbb{R}^n$$

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

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

such that

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

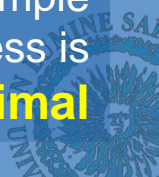
$$T_{\text{max}} = \max_{(r,z) \in \Omega_F, t \in [t_0, t_f]} T(r, z, t)$$

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

$f_1, \dots, f_m :$

$\mathbb{R}^n \rightarrow \mathbb{R}$

objective functions



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

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

L_∞ distance

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

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

Domain space

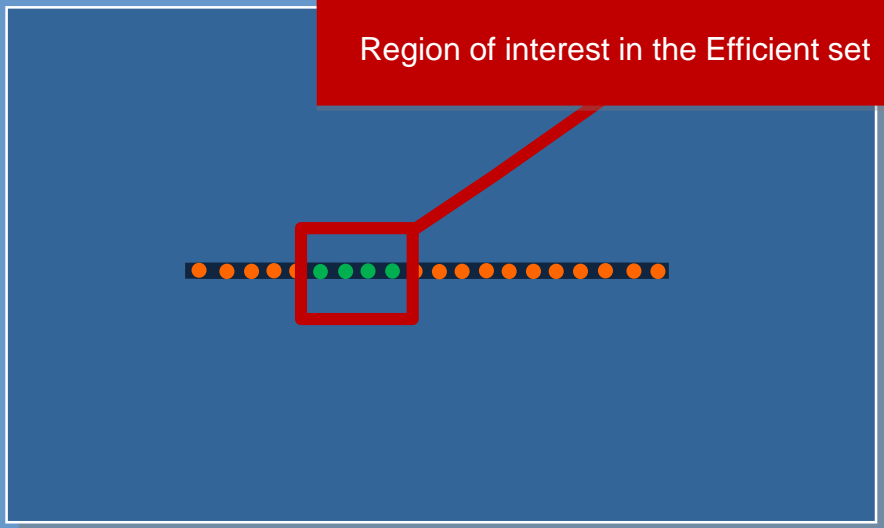
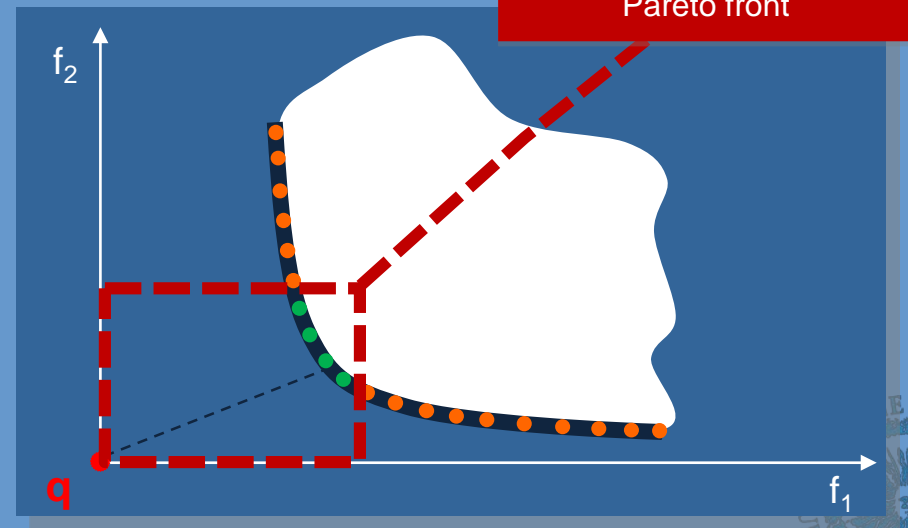


Image space



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**

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

Mono-objective **Problem 2**

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

| | 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 |

