



Multiobjective optimization of a food process based on expert knowledge: Example of 0.1 μm skim milk microfiltration

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Multiobjective optimization of a food process based on expert knowledge : Example of 0.1 μm skim milk microfiltration

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Optimal project (2017-2020):

Optimized design of membrane processes for the production of dairy ingredients

OK TO SHARE
ON SOCIAL MEDIA



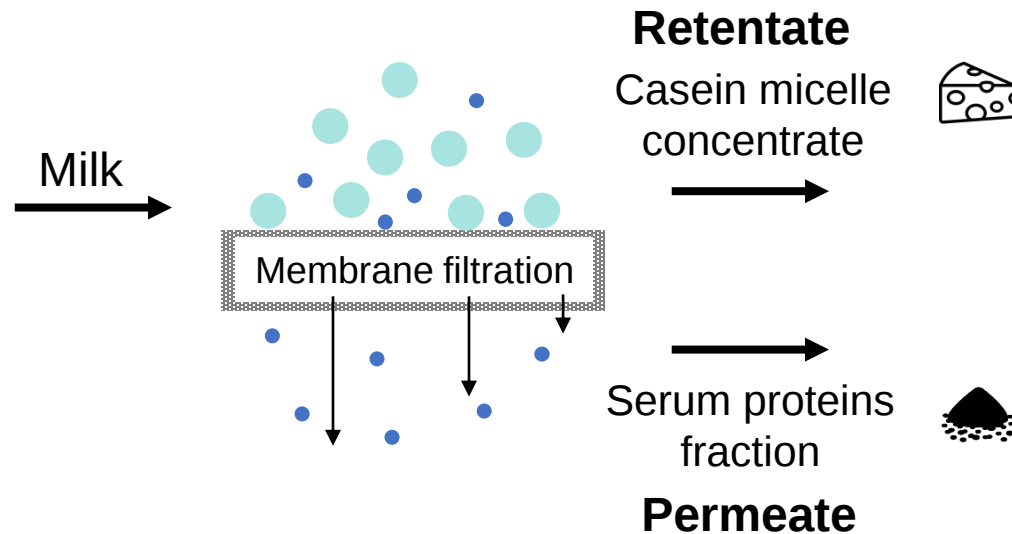
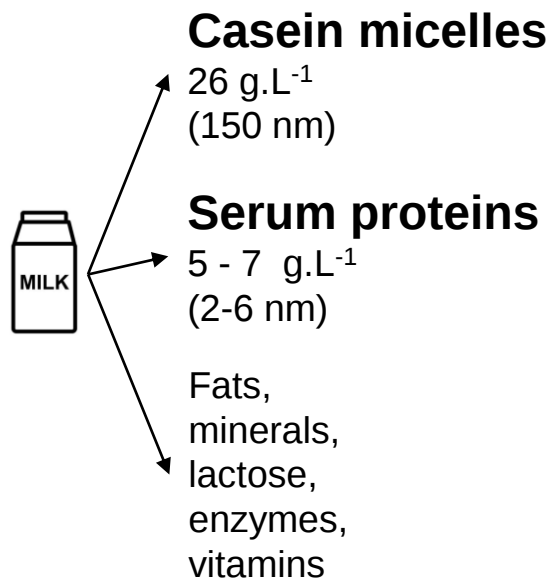
ECONOMIC CONTEXT

▶ Membrane processes

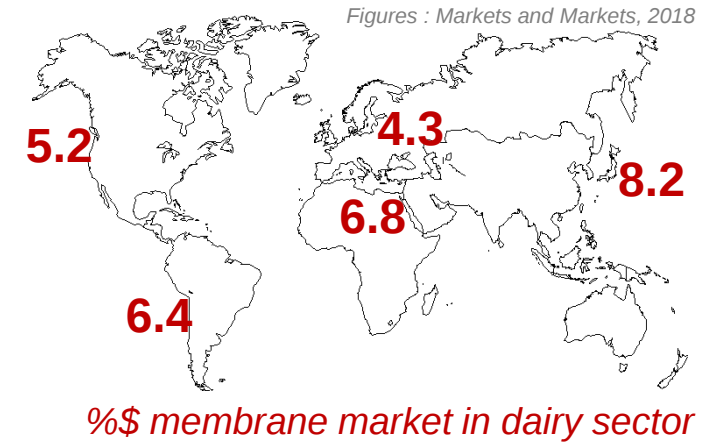
- ▶ Dairy sector
- ▶ Since more than 40 years
- ▶ Estimated market growth of 4-8 % between 2018 and 2023

▶ Among membrane processes

- ▶ Tangential microfiltration 0,1 μm of skim milk (= MF)



- Casein micelles
- Serum proteins



*Standardization of
milk for cheese
processing*

*Manufacturing of
functional and
nutritional ingredients*

TECHNICAL CONTEXT

Membranes

Ceramic



Polymeric



Various
Operating
Conditions

Temperature

Concentration factor

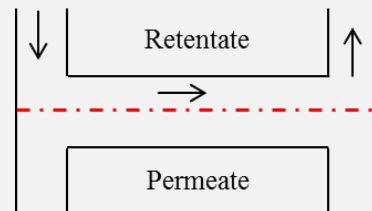
Transmembrane pressure

Crossflow velocity

...

Classic

$$P_{re} > P_{ro}$$



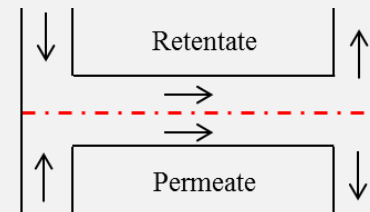
$$P_{pe} = P_{po}$$

Various Designs

UTP

Uniform transmembrane pressure

$$P_{re} > P_{ro}$$



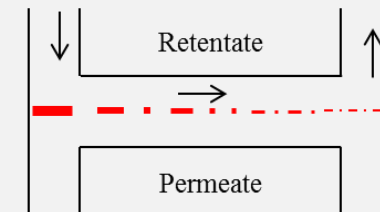
$$P_{pe} > P_{po}$$

Circulation of
permeate

GP

Permeability gradient

$$P_{re} > P_{ro}$$

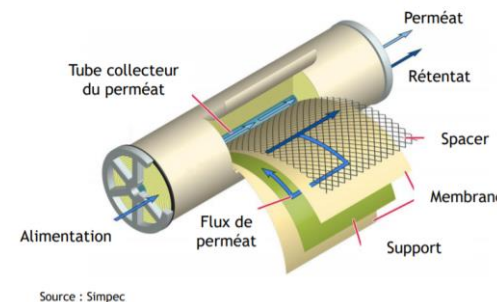
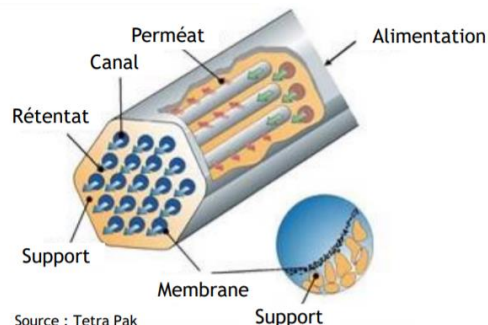


$$P_{pe} = P_{po} \neq 0 \text{ bar}$$

Permeate under
pressure

TECHNICAL CONTEXT

- ≠ Membranes
- ≠ Materials
- ≠ Multiple designs
- ≠ Filtration performances



Performances for VRR = 3	Ceramic		Polymeric
	UTP	GP	SW
Filtration temperature	50°C	50°C	12°C
Permeation flux	75-100 L.h ⁻¹ .m ⁻²	75 L.h ⁻¹ .m ⁻²	10 L.h ⁻¹ .m ⁻²
Serum proteins transmissions	65-70 %	60 %	20-50 %
Membrane lifetime	10 years	10 years	2 years
Membrane costs	+	++	- -
Example of production for 24h	At 50°C : 2 productions of 8h + 2 cleanings		At 12°C : 1 production of 20h + 1 cleaning

RESEARCH PROBLEM

Product
Milk

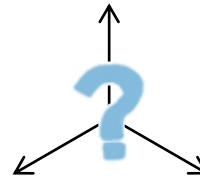
Membrane
type



Processing
designs

Operating
conditions

Multiple designs but no existing rules to guide the design of this process



Technical objectives



Economic objectives

Conflicting objectives



Lack of
knowledge



Lack of
methodology

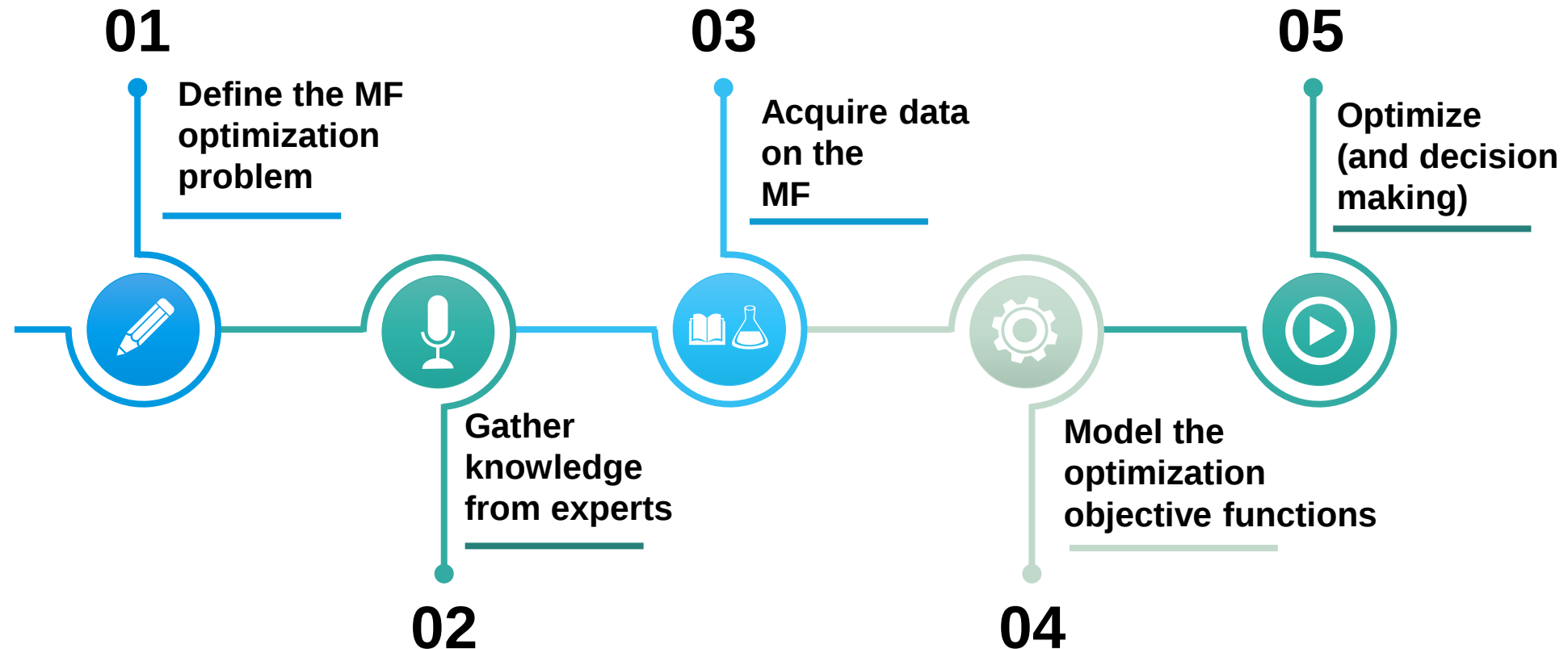


Need a systemic approach to optimize considering several objectives

METHODOLOGY

Steps for solving a multi-objective optimization problem using expert knowledge

Application to 0,1 μm skim milk microfiltration (MF)



DEFINITION OF THE OPTIMIZATION PROBLEM

► Optimization of MF

► Scope of the optimization

skim milk 0,1
 μm
microfiltration

history of milk
=
constant

TMP
=
constant

filtration
temperature
=
12°C polymeric
50°C ceramic

casein
permeation
=
not considered

cleaning &
desinfection
=
efficient and
reproducible

► Optimization objectives

$\max CD_{CN,r}$ 
*Casein concentration
in retentate on dry
basis*

$\max CD_{SP,p}$ 
*Serum protein
concentration in
permeate on dry basis*

$\max \eta_p$ 
*Serum protein
protein recovery
ratio*

$\min CI$ 
*Investment
cost*

$\min CPR$ 
*Production
cost*

 Casein micelles
 Serum proteins

GRAPHICAL REPRESENTATION OF OBJECTIVES

► Gather knowledge from experts

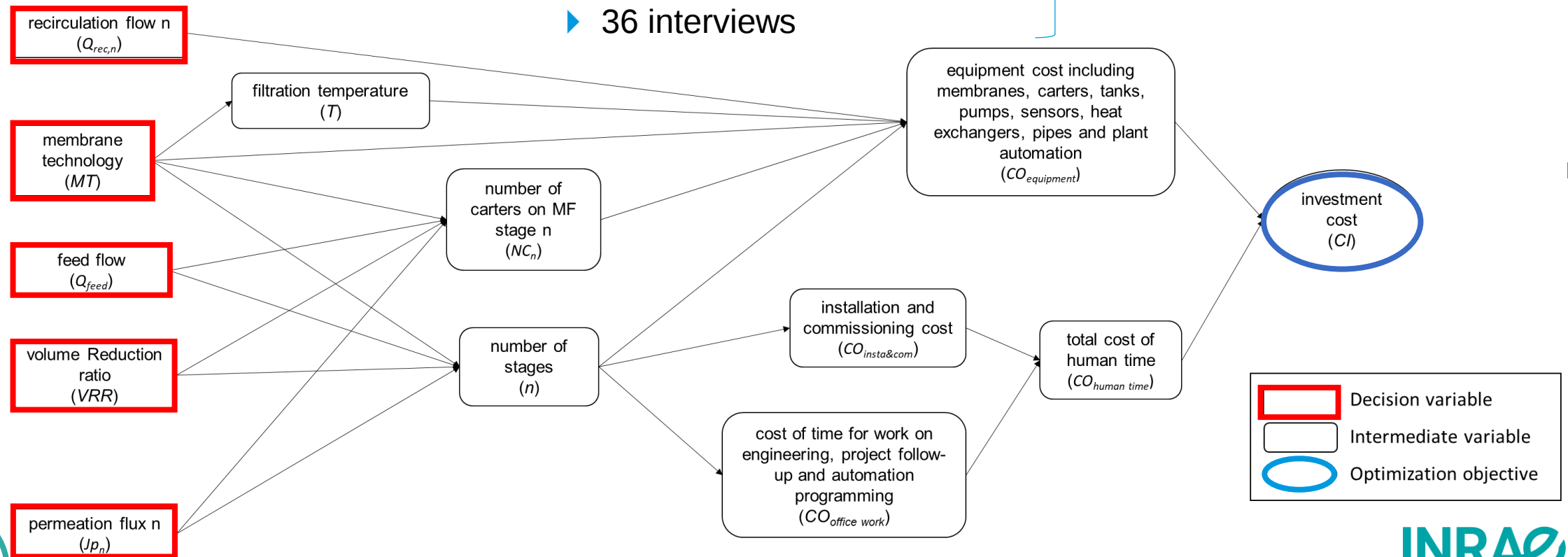
► Semi-structured interview

► 11 experts

- Dairy manufacturers
- Researchers
- Equipement manufacturers

► 36 interviews

- 5 optimization objectives
- 6 decision variables
- 31 intermediate variables



$$\min CI = f(CO_{equipment}, CO_{human\ time}(CO_{insta\&com}(n), CO_{office\ work}(n)))$$

MATHEMATICAL MODELLING OF OBJECTIVES

► Acquisition of data on the MF



literature



*lab & industrial
datasets*



experimentations



*expert
knowledge*



assumptions

► Modelling the optimization objective functions

- Heterogeneous data
- Few experimental points
- Model validated on dataset ranges
- Model representative of MF optimization objectives



*Pilote plateforme STLO
Tetra Alcross MFS-7, TetraPak Filtration
System*

Strongly constrained model

OPTIMIZATION SETUP

► Optimization

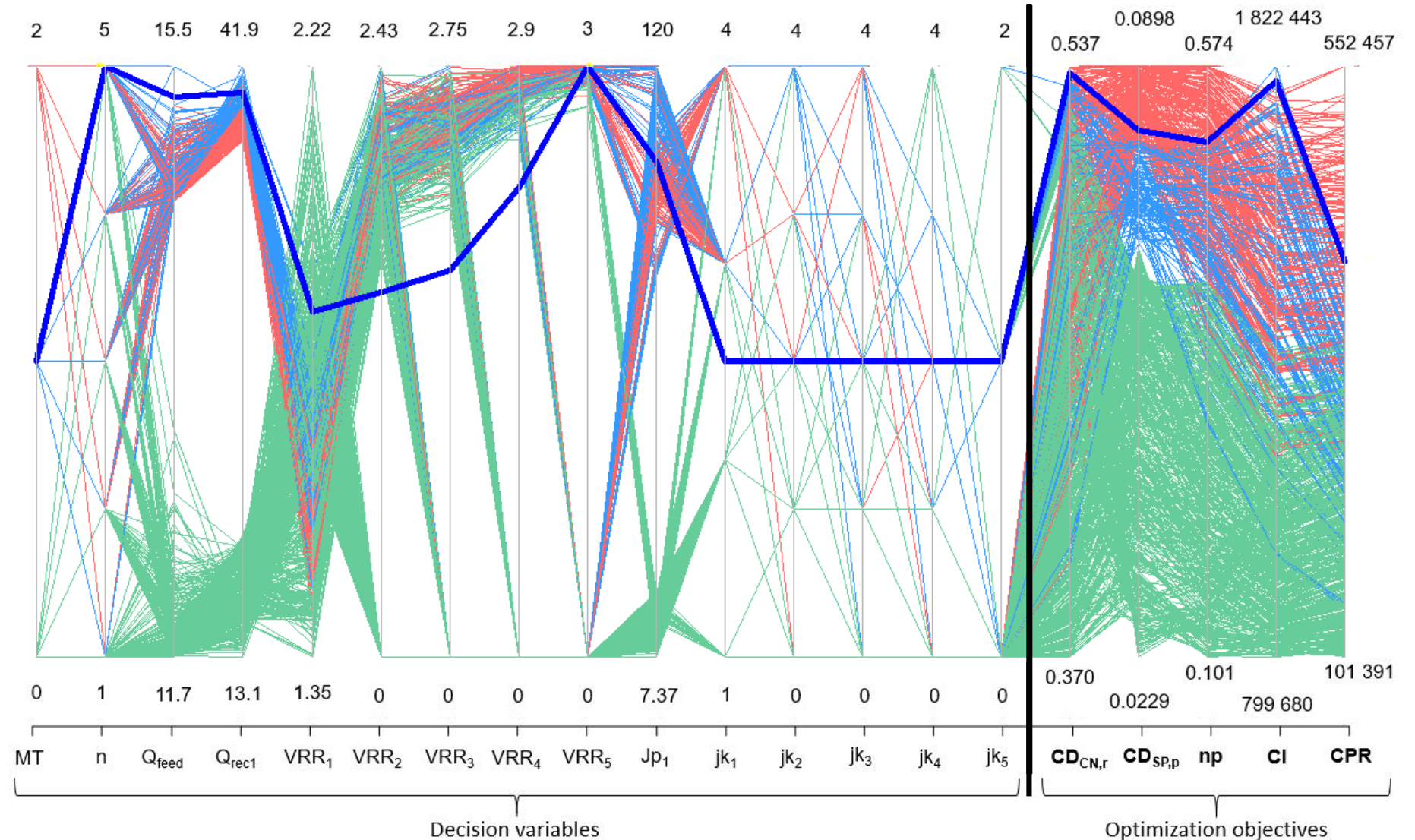
- ▷ NSGA-II, Pymoo framework (*Blank and Deb, 2020*)
- ▷ Population size was set to 1000 and offspring to 2500
- ▷ Distribution parameter was set to 30
- ▷ Crossover and mutation operator probabilities set to resp. 0.9 and 0.5
- ▷ Tolerances on decision variables, objective functions and constraints set resp. to 0.1, 0.01, and 0.
- ▷ Termination criterion was the maximum number of evaluations, set to 5 000 000.

► Milk characteristics to be filtered :

- ▷ $V_{\text{feed}} = 230 \text{ m}^3$
- ▷ $C_{\text{CN,milk}} = 27 \text{ g.kg}^{-1}$
- ▷ $C_{\text{SP,milk}} = 6.32 \text{ g.kg}^{-1}$
- ▷ $\rho_p = 990 \text{ kg.m}^{-3}$
- ▷ $\rho_{\text{milk}} = 1032 \text{ kg.m}^{-3}$

RESULTS

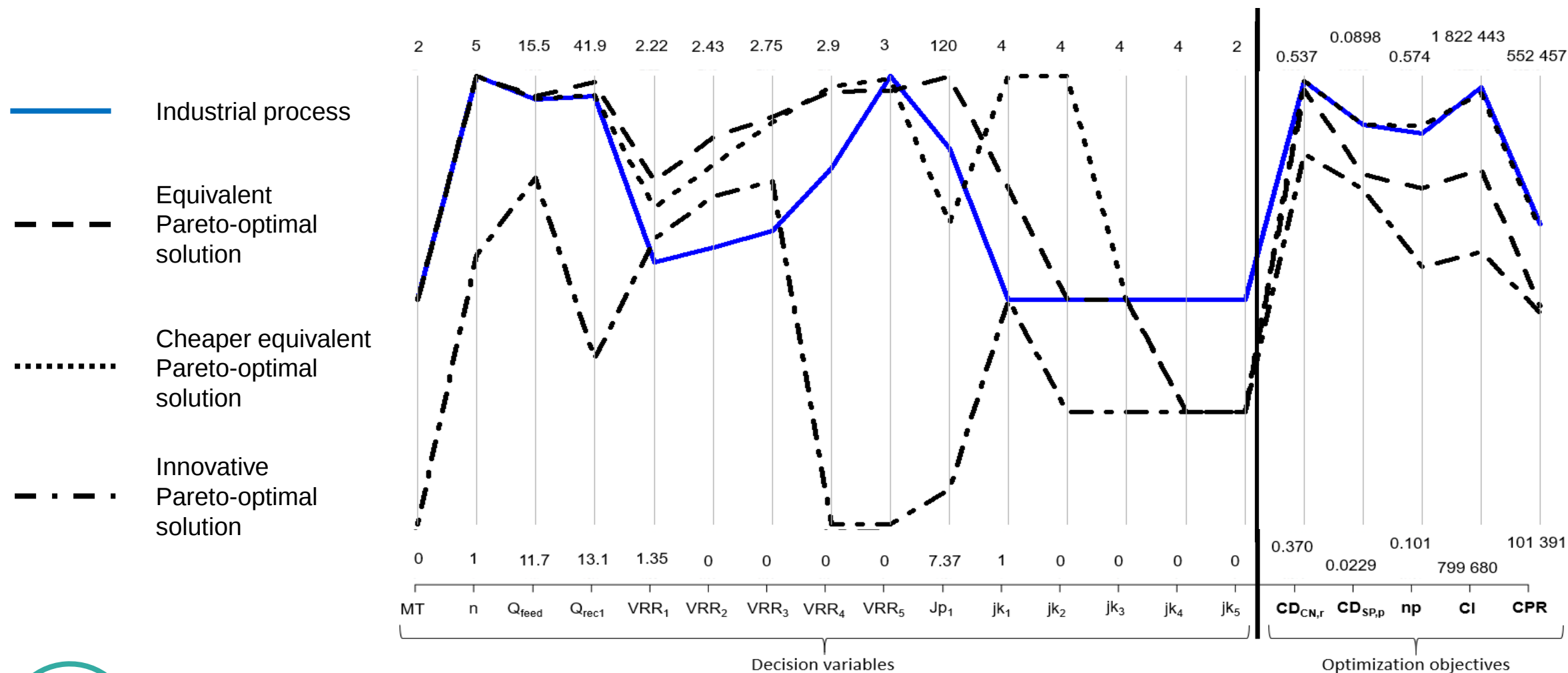
- ▶ Over 1000 Pareto-optimal solutions
- ▶ Consistent with literature
- ▶ Polymeric membrane compared to ceramic :
 - ▶ Technical objectives **less efficient**
 - ▶ BUT
 - ▶ **Less expensive**



$Q_{feed} (m^3.h^{-1}) ; Q_{rec1} (m^3.h^{-1}) ; Jp_1 (L.h^{-1}.m^{-2}) ; CD_{CNr} (g.kg^{-1} DM) ; CD_{SPp} (g.kg^{-1} DM) ; CI (€) ; CPR (€)$

— UTP ceramic
— GP ceramic
— SW polymeric

PARTICULAR PARETO-OPTIMAL SOLUTIONS ANALYSIS



$Q_{feed} (m^3.h^{-1}) ; Q_{rec1} (m^3.h^{-1}) ; Jp_1 (L.h^{-1}.m^{-2}) ; CD_{CNr} (g.kg^{-1} DM) ; CD_{SPp} (g.kg^{-1} DM) ; CI (€) ; CPR (€)$

RESULTS

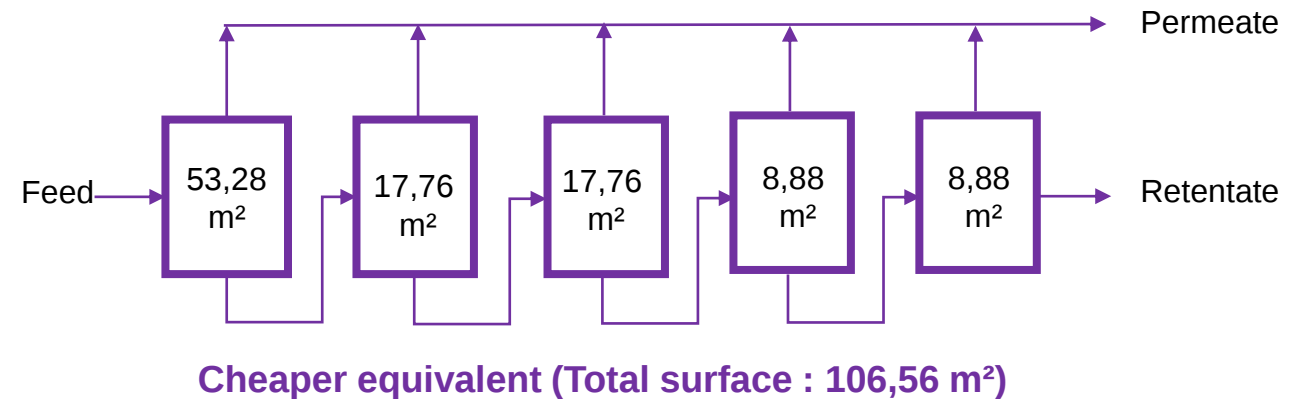
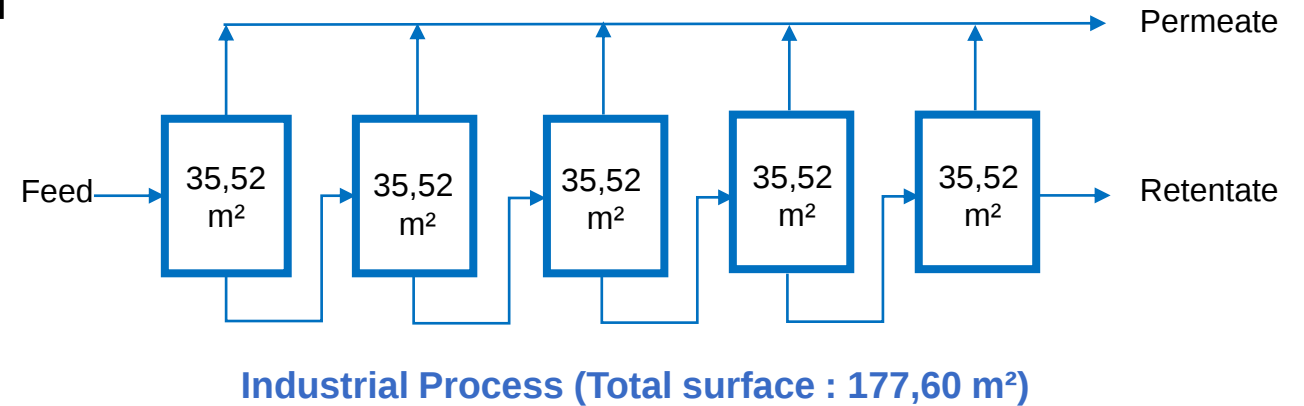
► Cheaper equivalent Pareto-optimal solution

Optimization objectives

	$CD_{CN,r}$ (g.kg ⁻¹ DM)	$CD_{SP,p}$ (g.kg ⁻¹ DM)	ηp (-)	CI (€)	CPR (€)
Indus. process	a	b	c	1 774 431	370 162
Cheaper eq.	a	b	d	1 443 187	269 114
Improvement	=	=	-14 %	-19 %	-27 %
	⊖	⊖	☹	☺	☺

Decision variables

	Indus. process	Cheaper eq.
MT	1 (GP)	1 (GP)
Q_{feed} (m ³ .h ⁻¹)	14.71	14.84
Q_{rec1} (m ³ .h ⁻¹)	40.01	41.32
n	5	5
Jp_1 (L.h ⁻¹ .m ⁻²)	100.63	119.67
VRR_1	1.3	1.7
VRR_2	1.5	2.1
VRR_3	1.8	2.5
VRR_4	2.3	2.8
VRR_5	3.0	2.9



CONCLUSION & OUTLOOK

- ▶ Innovative approach combining :
 - ▶ *integration of different knowledge*
 - ▶ *modelling of the objectives of the optimization problem*
 - ▶ *multiobjective optimization itself*
- ▶ Optimization provided over 1000 Pareto-optimal solutions
 - ▶ Solutions *close to industrial process*
 - ▶ Solutions with *comparable results but at lower costs*
 - ▶ Solutions that are new *reflection tracks* that need to be validated in order to assess their *feasibility at industrial scale*
- ▶ **Successful method for modelling food processes which are scientifically not well-known**



- ▶ The computational approach help us to :
 - ▶ **Get out of the classical** schemes of design MF
 - ▶ **Re-evaluate** technical solution a priori unattractive
 - ▶ Scientifically **validate technical solutions**
- ▶ Major **drawback** is the large number of solutions
 - ▶ Need to add a **multicriteria decision support**
 - ▶ Guide the decision maker **in selected the preferred solution** among the Pareto-optimal solutions



THANKS FOR YOUR ATTENTION

mbelna@boccard.fr



1918

Boccard foundation year
in France



55

Business Units
worldwide



3500

experts worldwide



4

th family
generation dedicated to
industrial development



35

countries

ENERGY SOLUTIONS



Oil & Gas



Nuclear



Energy



Steel & Mining

LIFE SOLUTIONS



Brewery



Food &
Ingredients



Cosmetics &
hygiene



Pharma &
Biotech

