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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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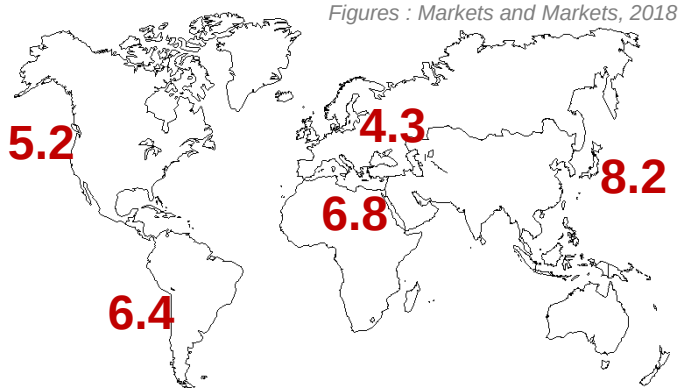
Optimal project (2017-2020):
Optimized design of membrane processes for the production of dairy ingredients

OK TO SHARE ON SOCIAL MEDIA

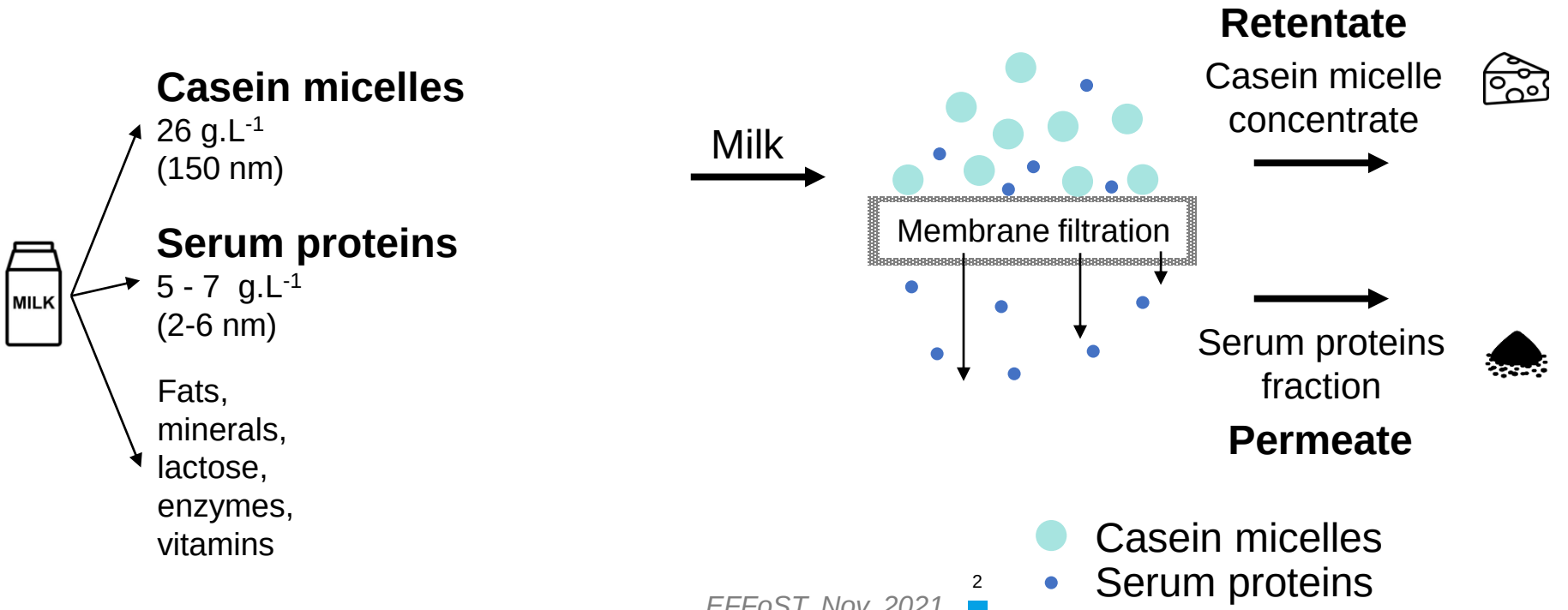
ECONOMIC CONTEXT

- 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)

Figures : Markets and Markets, 2018



%$ membrane market in dairy sector



Standardization of milk for cheese processing

Manufacturing of functional and nutritional ingredients

TECHNICAL CONTEXT

Membranes

Ceramic

Polymeric

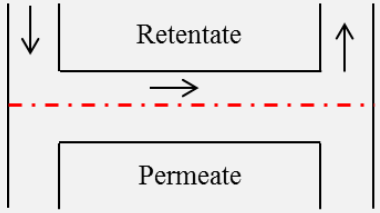
Various Operating Conditions

- Temperature
- Concentration factor
- Transmembrane pressure
- Crossflow velocity
- …

Various Designs

Classic

$P_{re} > P_{ro}$

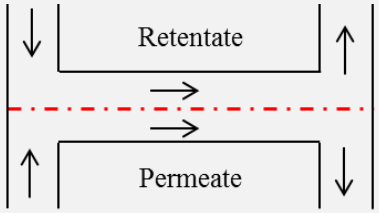


$P_{pe} = P_{po}$

UTP

Uniform transmembrane pressure

$P_{re} > P_{ro}$



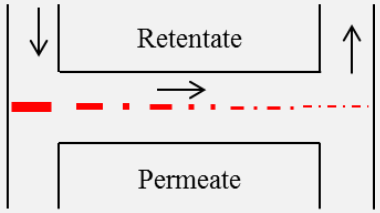
$P_{pe} > P_{po}$

Circulation of permeate

GP

Permeability gradient

$P_{re} > P_{ro}$

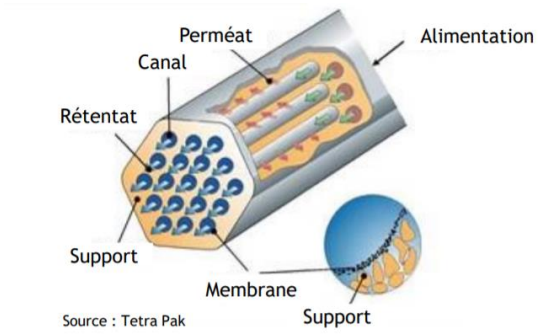


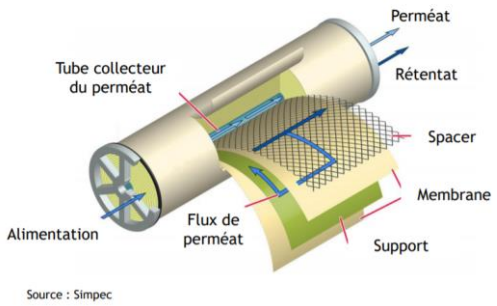
$P_{pe} = P_{po} \neq 0$ bar

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

Lack of knowledge

Technical objectives

Economic objectives

Conflicting objectives

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)

01
Define the MF optimization problem

02
Gather knowledge from experts

03
Acquire data on the MF

04
Model the optimization objective functions

05
Optimize (and decision making)

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

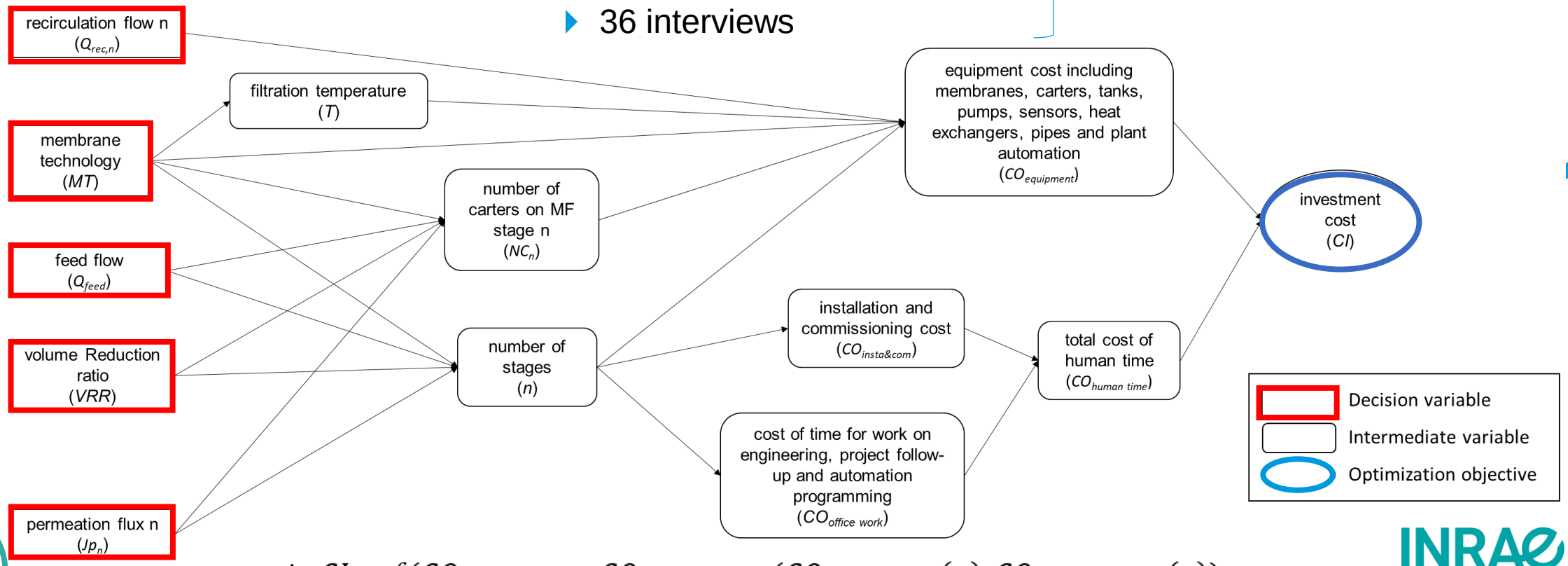
Casein micelles

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

<u>Strongly constrained model</u>

OPTIMIZATION SETUP

Optimization

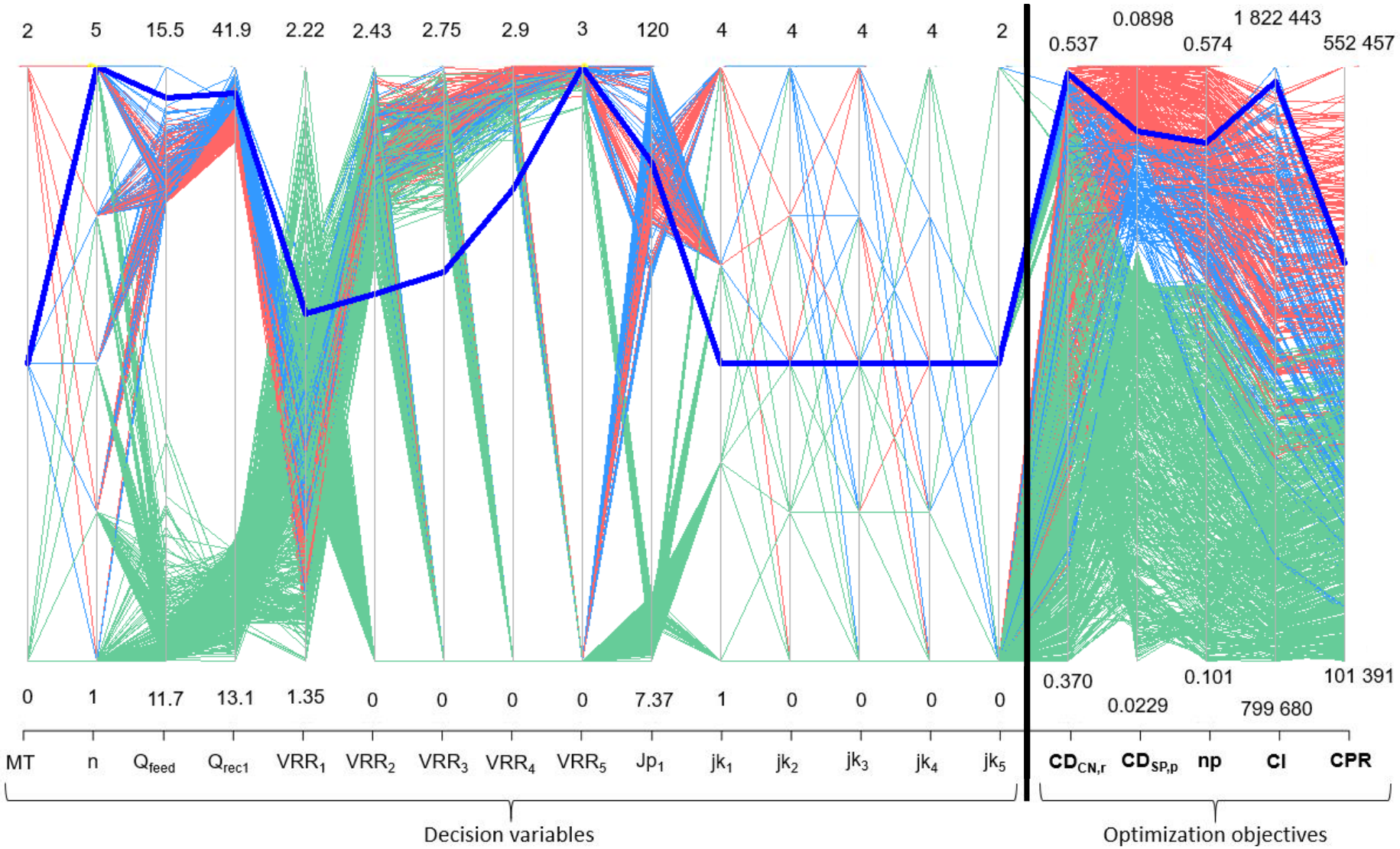
- NSGA-II, Pymoo framework *(Blank and Deb, 2020)*
- Population size was set to 1000 and offspring to 2500
- Distribution parameter was set to 30
- Crossover and mutation operator probabilities set to resp. 0.9 and 0.5
- Tolerances on decision variables, objective functions and constraints set resp. 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 :

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

RESULTS

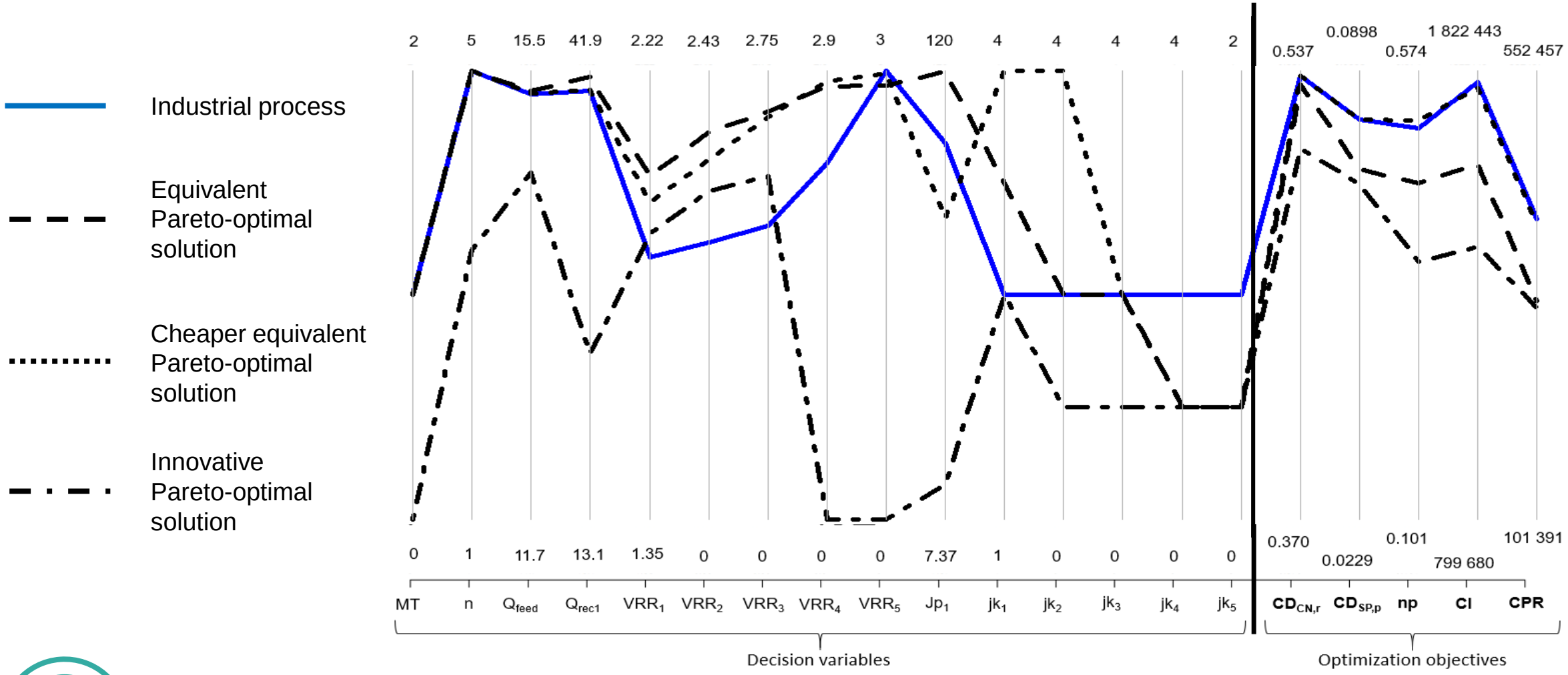
- Over 1000 Pareto-optimal solutions
- Consistent with literature
- Polymeric membrane compared to ceramic :
  - Technical objectives **less efficient**
  - BUT
  - **Less expensive**



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

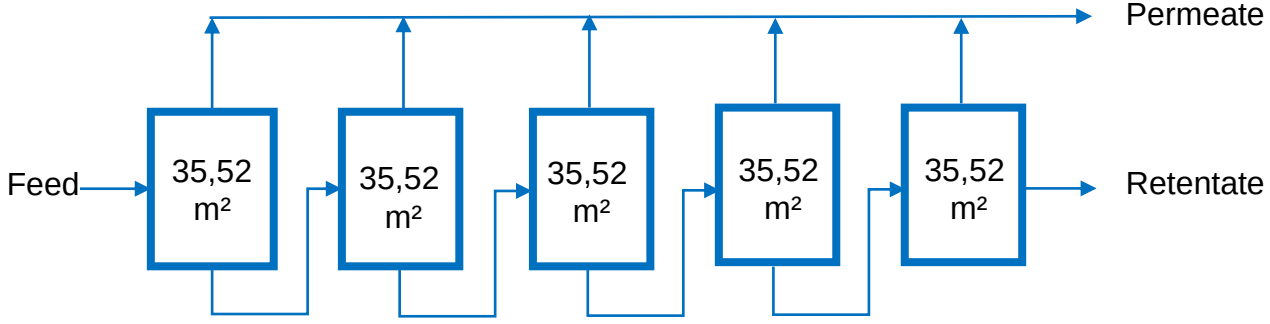
Cheaper equivalent Pareto-optimal solution

Optimization objectives

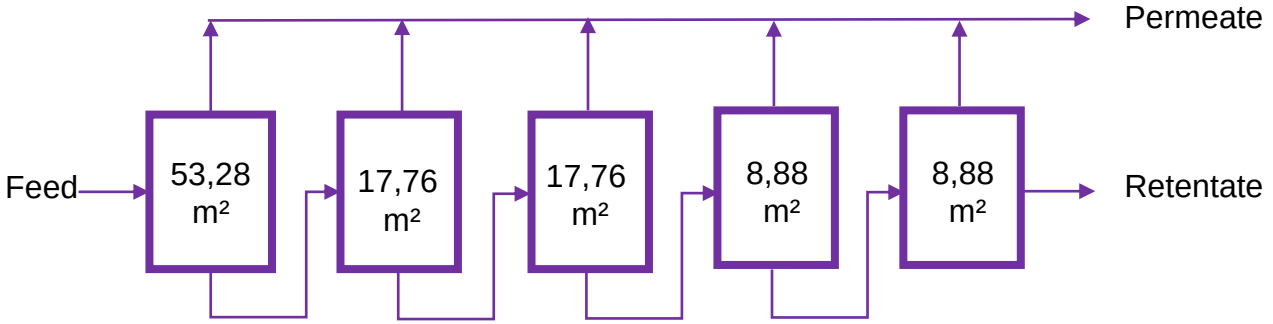
	$CD_{CN,r}$ (g.kg^{-1} DM)	$CD_{SP,p}$ (g.kg^{-1} DM)	ηp (-)	CI (€)	CPR (€)
Indus. process	a	b	c	1 774 431	370 162
Cheaper eq.	a	b	d	1 443 187	269 114
Improvement	=	=	-14 %	-19 %	-27 %

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



Industrial Process (Total surface : 177,60 m²)



Cheaper equivalent (Total surface : 106,56 m²)

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

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boccard
Alliance for success

1918
Boccard foundation year in France

55
Business Units worldwide

3500
experts worldwide

4 th family generation dedicated to industrial development

35
countries

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