# Multiobjective optimization of a food process based on expert knowledge : Example of 0.1 $\mu$m 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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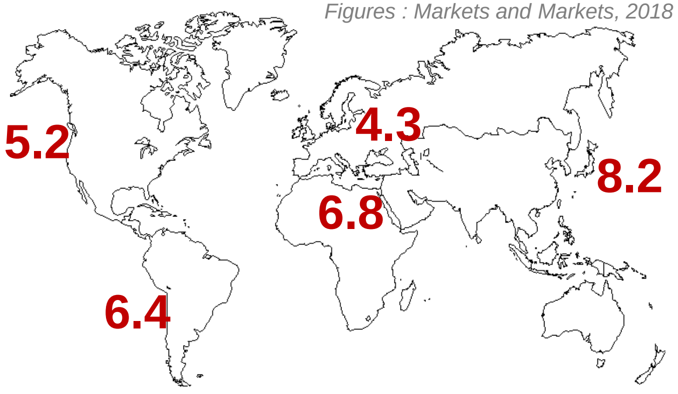
Optimal project (2017-2020):
Optimized design of membrane processes for the production of dairy ingredients

OK TO SHARE ON SOCIAL MEDIA

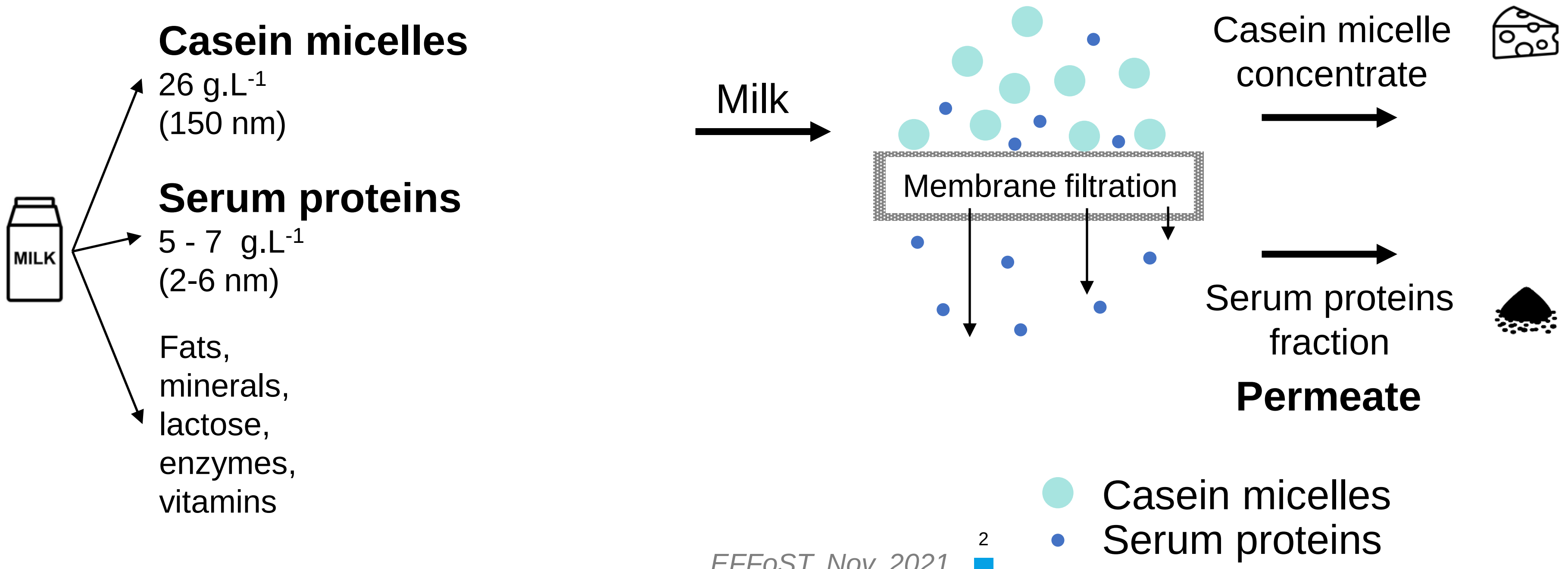
# ECONOMIC CONTEXT

- 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)

*Figures : Markets and Markets, 2018*




*%$ membrane market in dairy sector*




*Standardization of milk for cheese processing*

*Manufacturing of functional and nutritional ingredients*



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# TECHNICAL CONTEXT

## Membranes

**Ceramic**

**Polymeric**

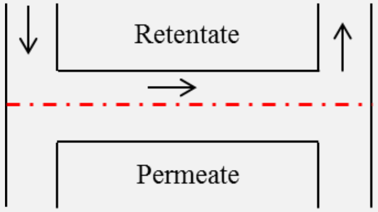
## Various Operating Conditions

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

## Various Designs

### Classic

$P_{re} > P_{ro}$

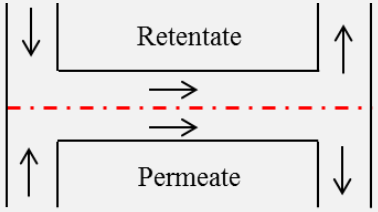



$P_{pe} = P_{po}$

### UTP

Uniform transmembrane pressure

$P_{re} > P_{ro}$



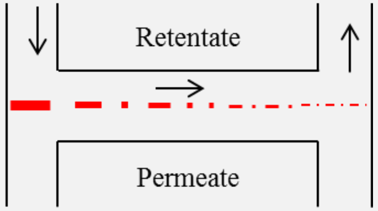

$P_{pe} > P_{po}$

***Circulation of permeate***

### GP

Permeability gradient

$P_{re} > P_{ro}$




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

***Permeate under pressure***

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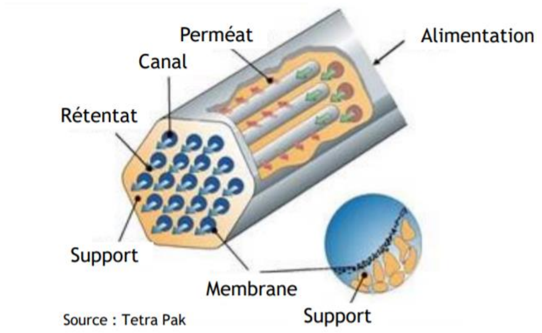
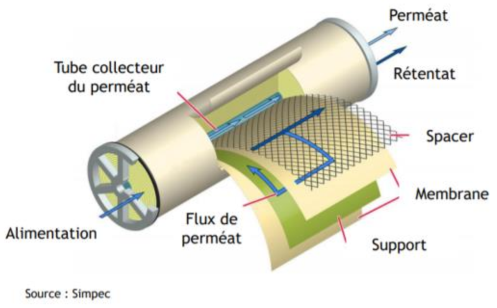
# TECHNICAL CONTEXT

≠ 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**

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# 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

| $\max CD_{CN,r}$ | $\max CD_{SP,p}$ | $\max \eta_p$ | $\min CI$ | $\min CPR$ |
|---|---|---|---|---|
| *Casein concentration in retentate on dry basis* | *Serum protein concentration in permeate on dry basis* | *Serum protein protein recovery ratio* | *Investment cost* | *Production cost* |

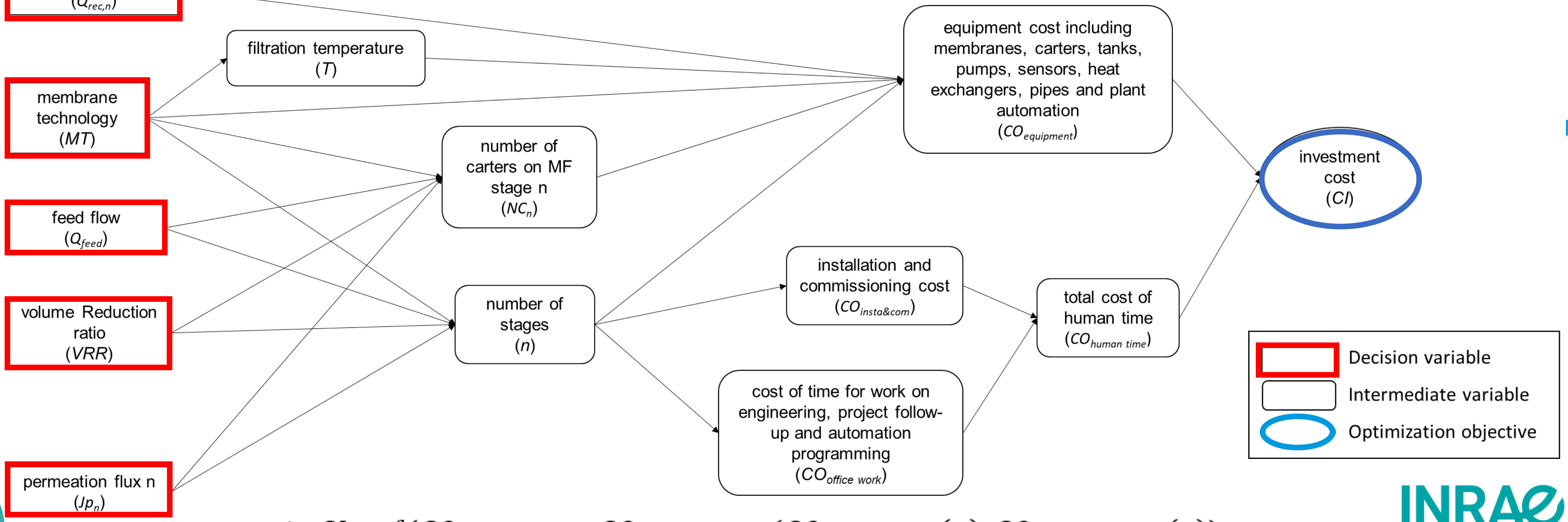
Casein micelles
Serum proteins

# 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

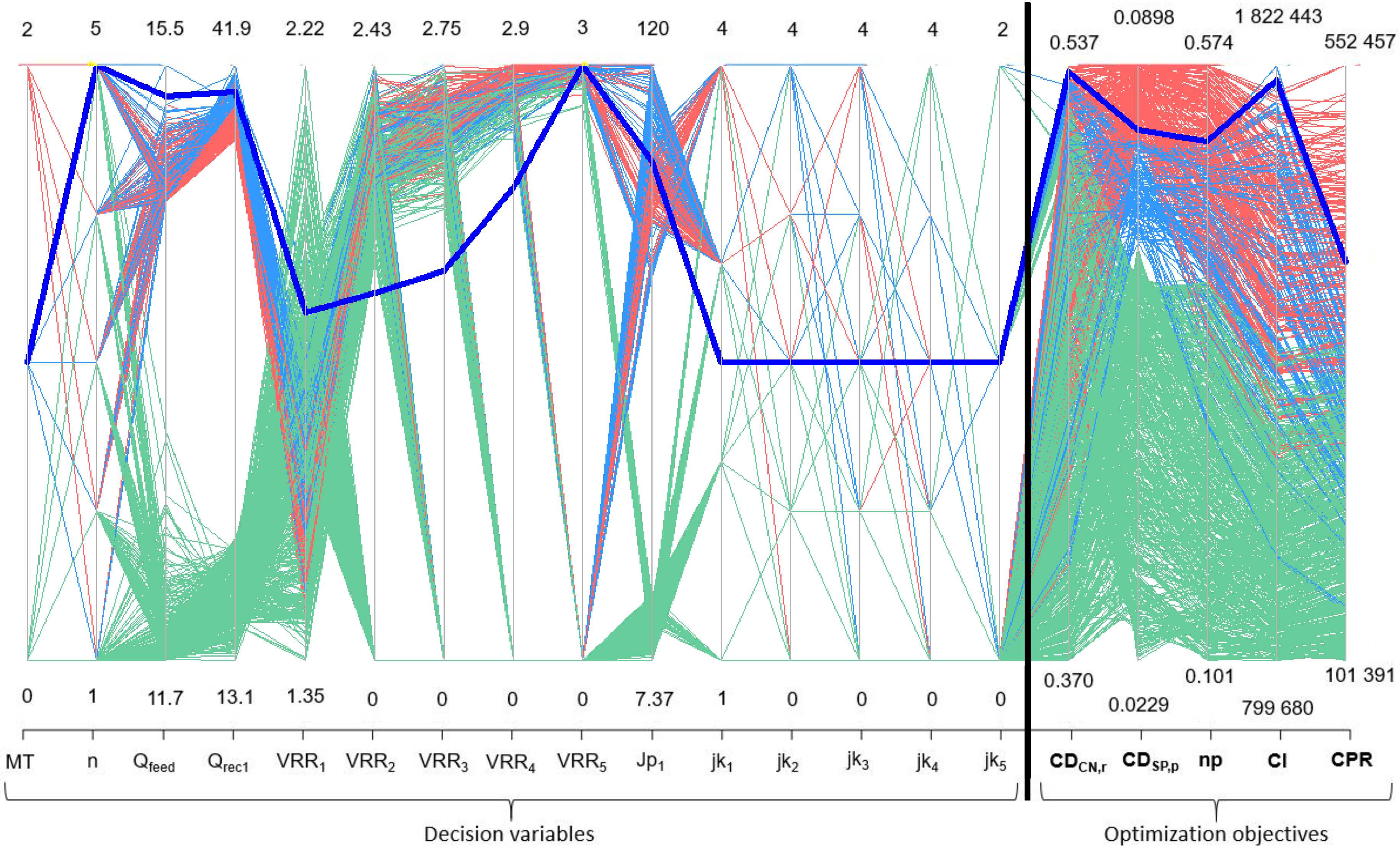
- NSGA-II, Pymoo framework *(Blank and Deb, 2020)*
- Population size was set to 1000 and offspring to 2500
- Distribution parameter was set to 30
- Crossover and mutation operator probabilities set to resp. 0.9 and 0.5
- Tolerances on decision variables, objective functions and constraints set resp.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

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

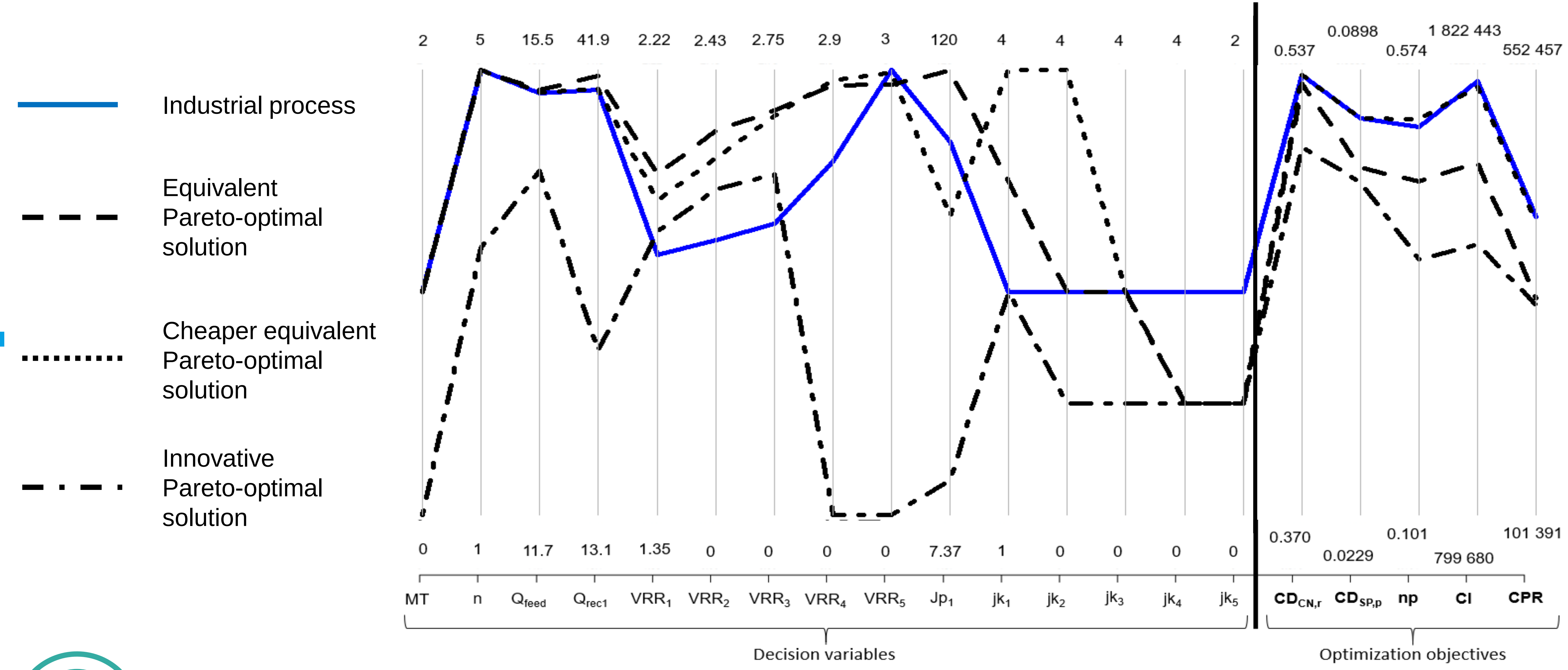
# RESULTS

- 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 (€)*

# 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

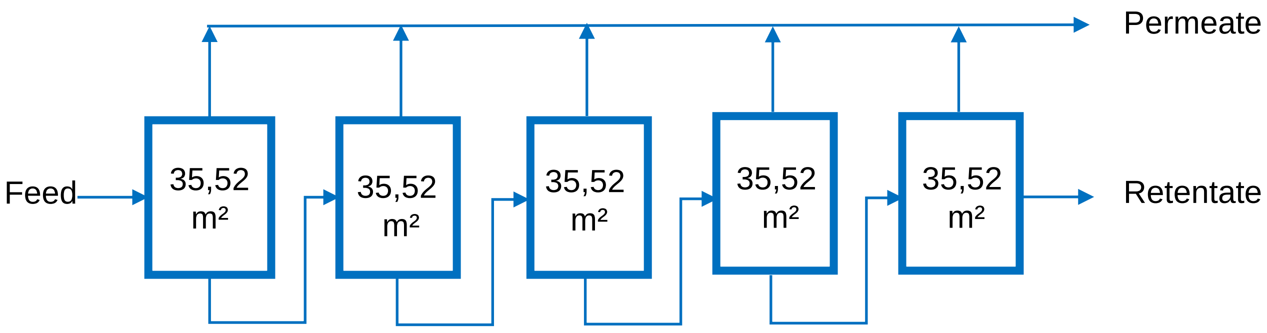
## Cheaper equivalent Pareto-optimal solution

***Optimization objectives***

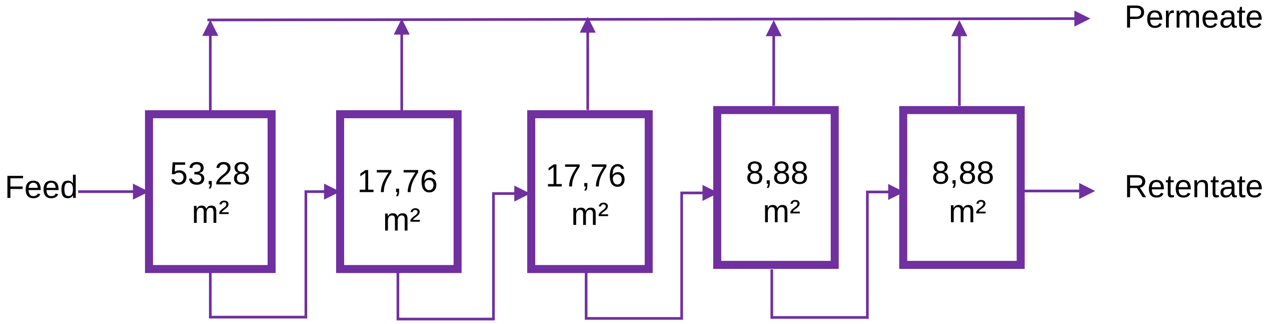
| | $CD_{CN,r}$ *(g.kg⁻¹ DM)* | $CD_{SP,p}$ *(g.kg⁻¹ DM)* | ηp *(-)* | CI *(€)* | CPR *(€)* |
|---|---|---|---|---|---|
| **Indus. process** | a | b | c | 1 774 431 | 370 162 |
| **Cheaper eq.** | a | b | d | 1 443 187 | 269 114 |
| **Improvement** | = | = | -14 % | -19 % | -27 % |

***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

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## 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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- Energy
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