Development of an original lab-scale filtration strategy for the prediction of microfiltration performance: application to fruit juices clarification

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Outlines

Context

Scientific strategy

Results and discussion

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Context of the work

Consumption of fruit juices and drinks containing fruit juices

• Safe product
• Fresh-like quality

Thermal treatments

Consumer Industrial

Cross-flow microfiltration

• Water treatment
• Pharmaceutical field
• Food industries (wine, beer, milk…)

Membrane separation process

Fruit juices industries

• High-quality clarified juices
• Beverage made of clarified juices
• Step before other specific treatments

Advantages

Membrane fouling

Membrane permeability decrease

Predicting and controlling juice fouling behavior

Outlines

Consumption of fruit juices and drinks containing fruit juices

Cross-flow microfiltration

Membrane fouling

Membrane permeability decrease

Optimization approaches and strategies concerning juices microfiltration

Prediction of juices microfiltration performance

Choice of relevant operating conditions, pre-treatment and/or conditioning of juices to be filtered

Few adequate prediction tools are proposed to anticipate membrane fouling (Vaillant et al., 2008)

Evaluate fruit juices fouling behavior using conventional filterability tests

Develop a simple and fast prediction tool to anticipate fruit juices fouling behavior

Most of publications

Lack of knowledge
Conventional filterability tests

- Dead-end filtration
  - Evaluate the filterability of various suspensions (wine, activated sludge, etc.)

- Cake filtration
  - Silt density index (SDI), modified fouling index (MFI), specific cake resistance, etc.
  - (Hong et al., 2009; Alhadidi et al., 2011; Alhadidi et al., 2012)

Fouling during fruit juices cross-flow microfiltration is more likely associated to other pore blocking mechanisms (Machado et al., 2012, de Oliveira et al., 2012)

Scientific strategy

- Membrane characteristics
  - Filterability response
  - Hydrodynamic conditions

Exploring a broad range of operating conditions in a dead-end filtration cell in order to anticipate orange juice fouling propensity during microfiltration

Suspension characteristics (fruit juices)

- Suspension characteristics
- Hydrodynamic conditions

Filterability response

Membrane characteristics

- Relevant prediction ??

Pressurized and agitated filtration cell

- 25 ml
- Membrane surface of 17 cm²

Two different orange juices
- Commercial pasteurized orange juice (J1)
- Fresh squeezed orange juice (J2)
- Different physico-chemical characteristics

SIS = 3.2 g.l⁻¹
SIS = 1.9 g.l⁻¹

Volume density (%) vs. Particle diameter (μm)
Different centrifugation treatments (acceleration-time) to isolate some populations of juice particles.

Two different orange juices:

- 3000g-10 min >1 µm
- Soluble and macromolecules
- Colloids
- Supra-colloids
- Large particles

Ceramic (0.2µm) Glass fiber (1.2µm)

D-optimal experimental design (32 experiments)

The model was analyzed separately for J1 and J2. Both models were significant and validated for prediction (R²>0.93).
Experimental design results

Based on the same strategy of surface response and resistances in series analysis
- supra-colloids and particles
- fine colloids aggregates
- colloids and solubles

**Hydro-dynamically reversible fouling**

In this case:

\[ R_{<1.2 \mu m} = R_{membrane} \rightarrow R_{>1.2 \mu m} \]

**Experimental design results**

Conclusions concerning the experimental design

The experimental design highlighted the important role of the experimental configuration on the response of a filterability test:

- Depending on the membrane used different fouling mechanisms can occur involving different juice components
- **Hydrodynamic conditions** influence significantly the intensity of the external fouling
- Two different suspensions can present the same fouling behavior but involve different components

**How can this strategy be used to anticipate fruit juices fouling propensity during microfiltration?**
Laboratory pilot-scale results

Pilot-scale unit

4 tubular ceramic membranes (0.2 µm), cross-flow velocity of 5 m·s\(^{-1}\) and pressure of 1.5 bar

According to Hernia’s model

\[
\frac{d^2t}{dt^2} = \frac{kM}{V} \left( \frac{dV}{dt} \right)^n
\]

According to inertial lift

\[
R = \frac{V^2}{0.036} \frac{1}{\mu}
\]

Intermediate pore blocking

Only juice compounds with diameter above 1 µm are involved in the fouling mechanisms

Permeate flux (l·h\(^{-1}\)·m\(^{-2}\))

Time (s)

0 500 1000 1500 2000 2500 3000 3500

200 400 600 800 1000

J1

J2

60 l·h\(^{-1}\)·m\(^{-2}\)

80 l·h\(^{-1}\)·m\(^{-2}\)

Close fouling propensity and fouling behavior of the two juices in the chosen working conditions

Filtration cell results

What will be the operating conditions in the filtration cell giving similar fouling propensities of the two studied juices?

Centrifugation of 500g during 1 min

stirring of 1000 rpm

Compounds with size lower than 6 µm

Only juice compounds with diameter above 1 µm are involved in the fouling mechanisms

Ceramic membrane 0.2 µm

Coherent with inertial lift model data

Coherent with crossflow condition

Coherent with working conditions and the observations at pilot-scale

Conclusion

This experimental strategy showed that the conventional dead-end filterability test could be used not only to estimate fruit juices fouling propensity but also to anticipate membrane fouling

- Identify the role of the different compounds (particles, supra-colloids, colloids and soluble) of juices on the membrane fouling
- Identify fouling mechanisms (external or internal) and their hydrodynamic reversibility
- Identify suitable operating conditions to anticipate juices fouling propensity

References


Laboratory pilot-scale description and procedure

The volume-weight experimental data were smoothed using the Robust Loess algorithm with span of 0.4 (MATLAB®). The smoothed data was numerically differentiated and the real-time permeate flux ($J$) was calculated up to a VRR of 2.

Conclusions concerning juices

$$ R = \sqrt[2]{\frac{\pi^2 \times 0.036}{\mu}} $$

$R$=particle radius (m)
Suspension viscosity kg/ms
Wall shear rate