IMPROVISE


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Rigorous Dynamic Simulation Models

- Set of mathematical relationships and data
- Implemented within a process modeling environment
- Predictive capability
- Many options

The Impact of Model Based Technology on Controls

1. Jack Little, The Impact of Model Based Design on Controls IFAC World Congress, August 2014
Roadmap of Presentation

• Project Objectives, Scope and Technical Goals
• Case Study: Whey Separation Process
  • Dynamic Modeling
  • Optimal Operation and Start Up Policy
  • Varying Transmembrane Pressure
• Conclusions
Overview of the IMPROVISE Project
Objectives:
1. Integrating rigorous models into daily operation of processes
2. Reduction of operational costs by use of model based decision making

Scope and Technical Goals
1. Online model based process monitoring, control and decision making
2. Online Model Maintenance
3. Model reduction for monitoring/control purposes
4. Considering model uncertainty
5. Validation on Case Studies
Industrial Cases

• Case 1: Whey Separation Process
  • UltraFiltration membrane unit

• Case 2: Polyesterification for special resins
  • Reactive Batch Distillation Column

• Case 3: Crystallization
  • Batch to Continuous Operation
Whey Separation Process

- Whey
- Reverse Osmosis
- Pasteurizer
- Ultrafiltration
- Evaporator
- Spray Drying
- Protein Powder

- Decide when to include a new membrane
- Minimize amount of material in buffer tanks
- Automate the control
- Monitor performance deterioration (fouling)
- Extend the operation time of membranes
Modeling and Validation - Unit Level

Purpose of Modeling
- Control and Monitoring of Ultrafiltration unit
- Assumptions
  - Other unit operations at steady state
  - No spatial dependence
- What should the model include?
  - Input – Output (Measured)
  - Performance indicators
  - Fouling – Start up
  - Concentration
  - Efficiency (complexity) vs. Physical insight
Modeling and Validation

• We need a dynamic model with pressure and flux relation.

\[ J = \frac{\Delta P}{R} \]

- Transmembrane pressure
- Membrane resistance

• Observations:

  • Flux depends on protein concentration
  • Fouling expressed by increasing resistance

\[ R = R_{\text{dyn}} + R_{\text{static}} \]
Dynamic Modeling - Parameter Estimation Results

Validation Results
Optimal Operation and Start up

What Do We Optimize?

• Maximize UF membrane uptime
  - Reduce/slow down accumulation of fouling
• Keep retentate protein concentration at desired level

\[ |x_r^{N_{s,prot}}(\sigma, t) - x_r^{des} | \leq \epsilon_x \]

Ultrafiltration

- Feed
- Pressure
- Retentate
- Retentate Prot. Conc.
Optimal Operation and Start Up

Operator control

Low pressure control

Membrane Loop 10 Resistance

Time [h] 0 2 4 6 8 10 12 14 16 18

Pressure [bar] 0.5 1 1.5

Feed Massflow

Feed Pressure

Massflow [L/h] 0 10^8 2 3 4 5 6 7 8 9 10

Operator control

Low pressure control
Transmembrane Pressure Control

Optimal Transmembrane Pressure Per Loop

Membrane loop dynamic resistances

- Equal TMP Loop 1
- Equal TMP Loop 10
- Loop specific TMP Loop 1
- Loop specific TMP Loop 10

Dynamic resistance [\text{\text{-}}]

Time [\text{h}]

Almost equal distribution of fouling
Conclusions \(^{(1,2)}\)

- Switch on all membranes at the start of the operation
  - For longer operation
  - Less disturbance during operation
  - Smaller pressure values
- Use Transmembrane Pressure to equally distribute fouling over membrane loops
- Premise of results:
  - ‘Better’ (in several aspects) operation compared to current way of operation

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Conclusions

- Within RFC, insights from IMPROVISE have led to
  - Multiple loops switched from flow control to pressure control
    - Less fouling,
    - High capacity
    - Less variation in product
- Modeling is an iterative exercise
- Commitment of parties involved is important
  - Intensive almost biweekly telcon meetings
Dynamic World of Modeling

Off-line application of models:
Simulation of the process behaviour:
• Operator and Engineering training
• Optimisation of operating strategies for existing products, new products and changing operating conditions

On-line application of models:
Following process behaviour
• Making the unmeasurable visible in real time
• Predicting the future of the process at any time instant (predictive maintenance)

What if a model can be tuned on actual process behaviour?

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