COMSOL: A Single-Platform Approach for Kinetics Identification, Reaction Engineering, and Model Deployment

COMSOL
CONFERENCE
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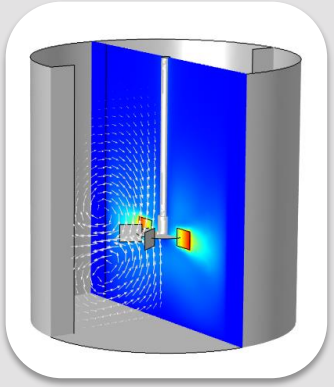
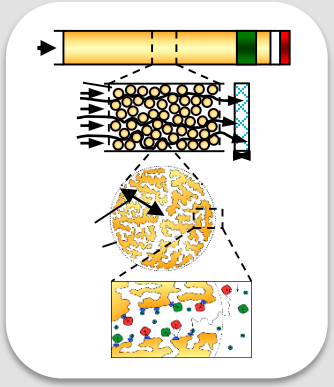
Modeling at Amgen Process Development

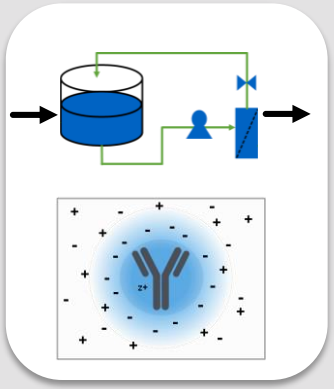
Activities In Both Biologics and Synthetics



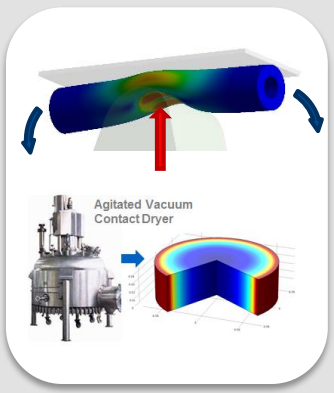
Reactors



Separation



Formulation



Manufacturing

Devices

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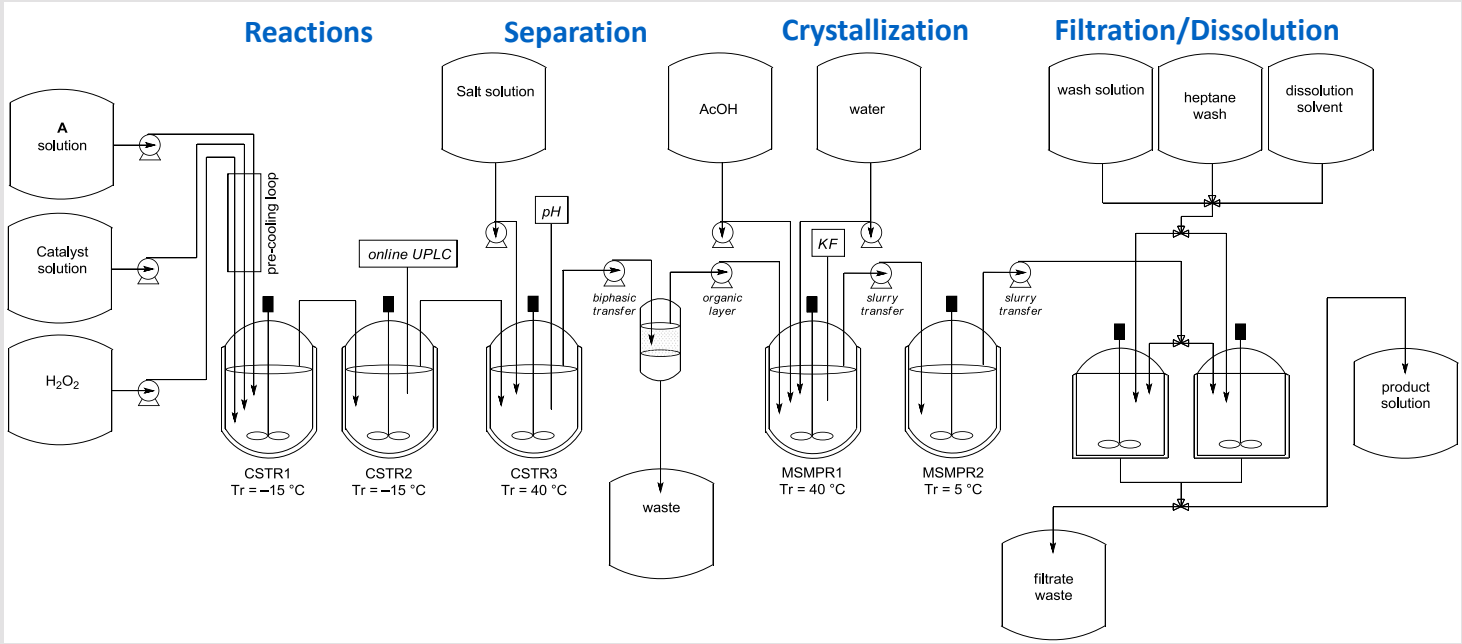
Synthetics Modeling

Component and System-Wide Models

- Unit Ops
  - Reactors
  - Separators
  - Crystallizers
  - Etc.
- Continuous Manufacturing

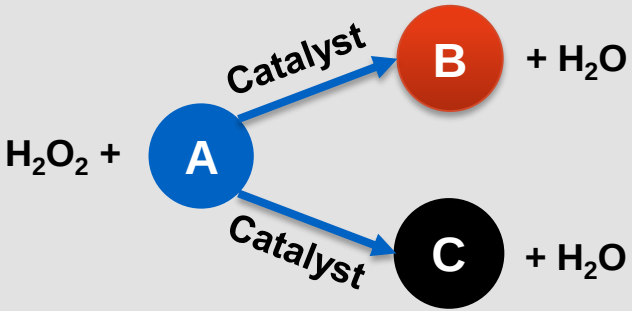


A Reaction System of Interest

Objectives

Experimental design & execution → **Kinetic model & regression** → ***In Silico* predictive design** → Continuous/batch implementation

Reaction Pathway



Rate Law

$$rate_1 = \boldsymbol{k_{ref,1}} e^{-\frac{\boldsymbol{E_1}}{RT}\left(\frac{1}{T}-\frac{1}{T_{ref}}\right)}[cat]^{\boldsymbol{x}}[A][H_2O_2]$$

$$rate_2 = \boldsymbol{k_{ref,2}} e^{-\frac{\boldsymbol{E_2}}{RT}\left(\frac{1}{T}-\frac{1}{T_{ref}}\right)}[cat]^{\boldsymbol{x}}[A][H_2O_2]$$

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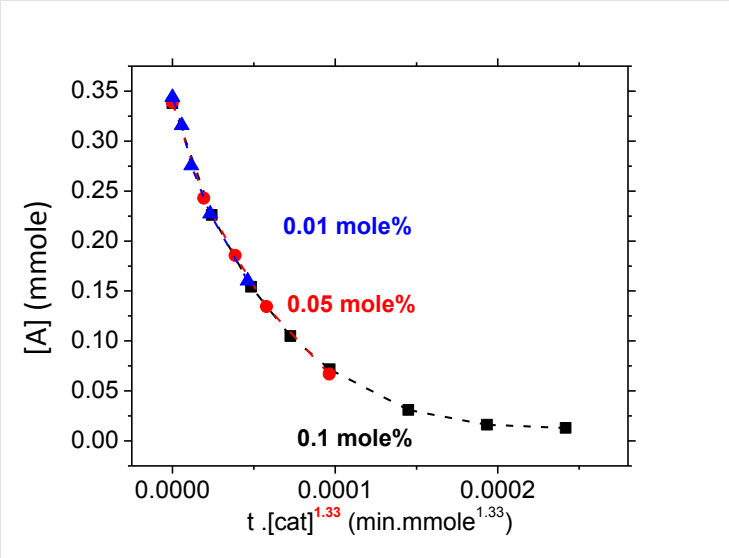
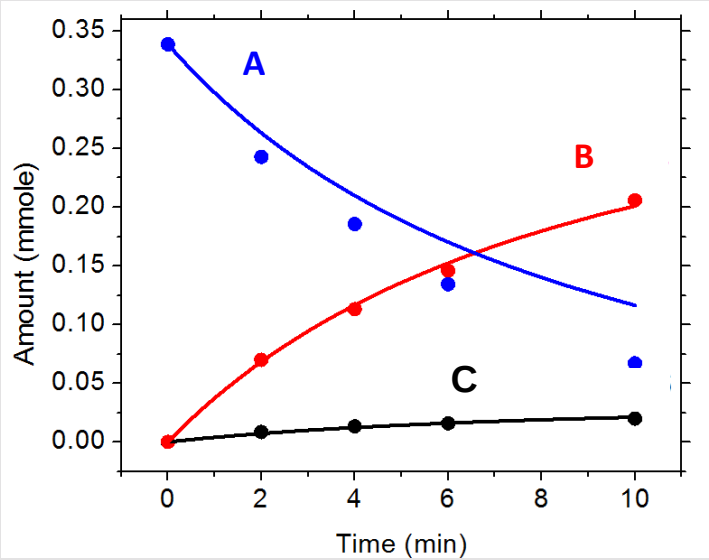
Kinetics Identification: Previously a two-step process

Step 1. Catalyst dependency



Catalyst exponent ***x_cat*** = **1.33**

Step 2. Rate constants



Four parameters ($k_{ref,1}$, $k_{ref,2}$, E_1, and E_2)

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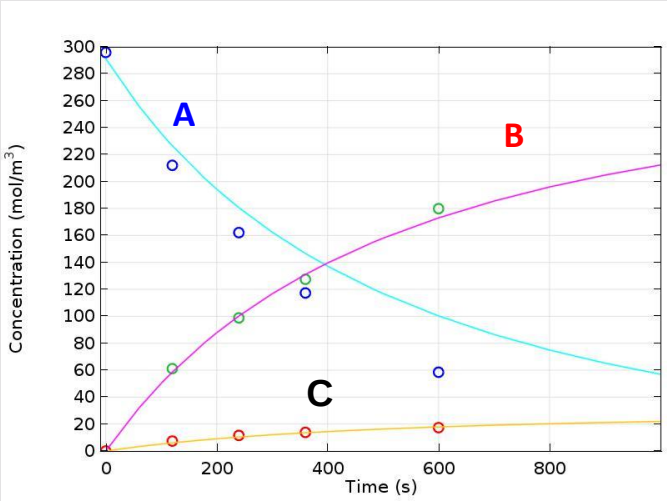
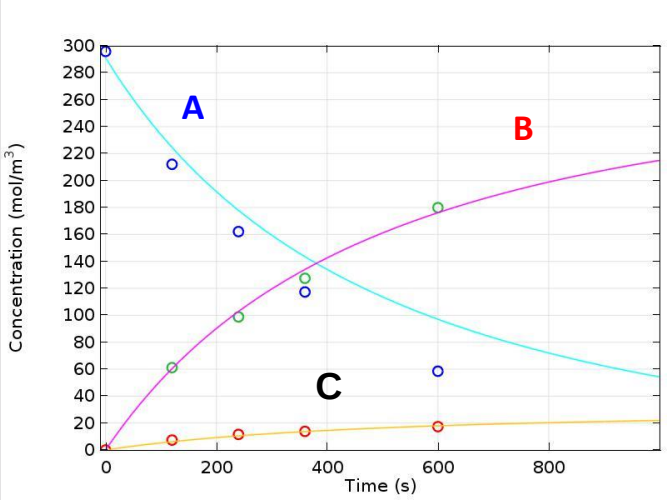
Kinetics Identification: Flexibility in COMSOL

Scenario 1. Two step approach*
(4 parameters)



*Uses catalyst exponent from regression

Scenario 2. One step approach
(5 Parameters)



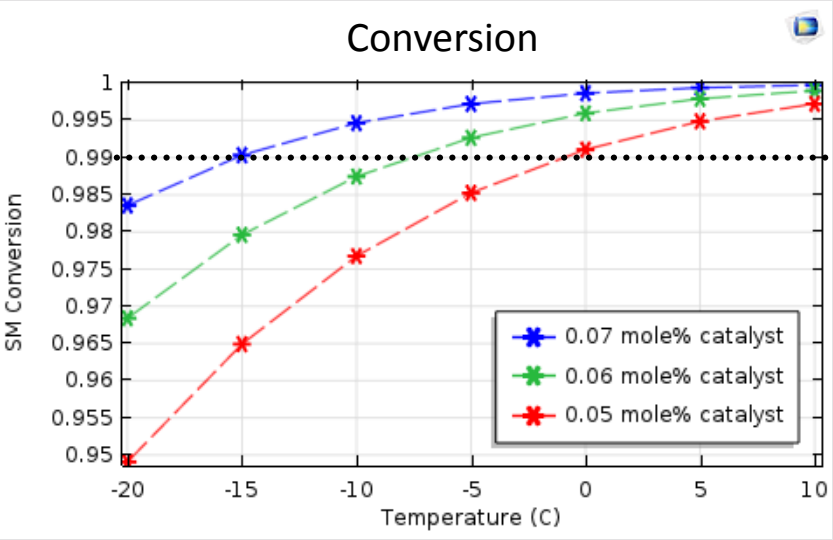
Estimation Results Comparison

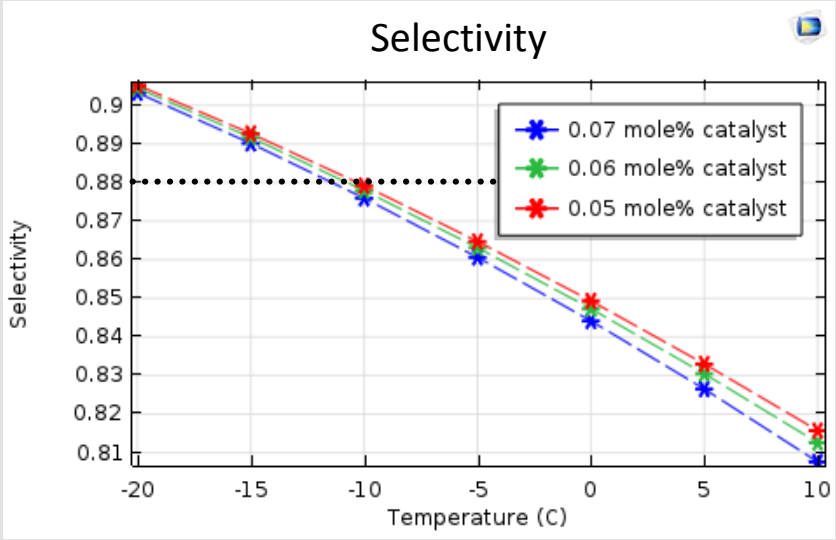
	Previous Tool	COMSOL (4 Params)	COMSOL (5 Params)
$k_{ref,1}$ $(m^3/mol)^{(1+x\_cat)}/s$	4.7 x 10^{-5} (± 6%)	4.66 x 10^{-5}	5.94 x 10^{-5}
$E_{a,1}$ (kJ/mol)	14 (± 52%)	13.91	19.71
$k_{ref,2}$ $(m^3/mol)^{(1+x\_cat)}/s$	5.3 x 10^{-6} (± 5%)	5.25 x 10^{-6}	6.63 x 10^{-6}
$E_{a,2}$ (kJ/mol)	29 (± 22%)	29.56	36.12
x_cat	1.33*	1.33*	1.42

*Obtained via separate regression.

Plug Flow Reactor Design

- Non-isothermal condition
- Straightforward extension from batch kinetics model to PFR



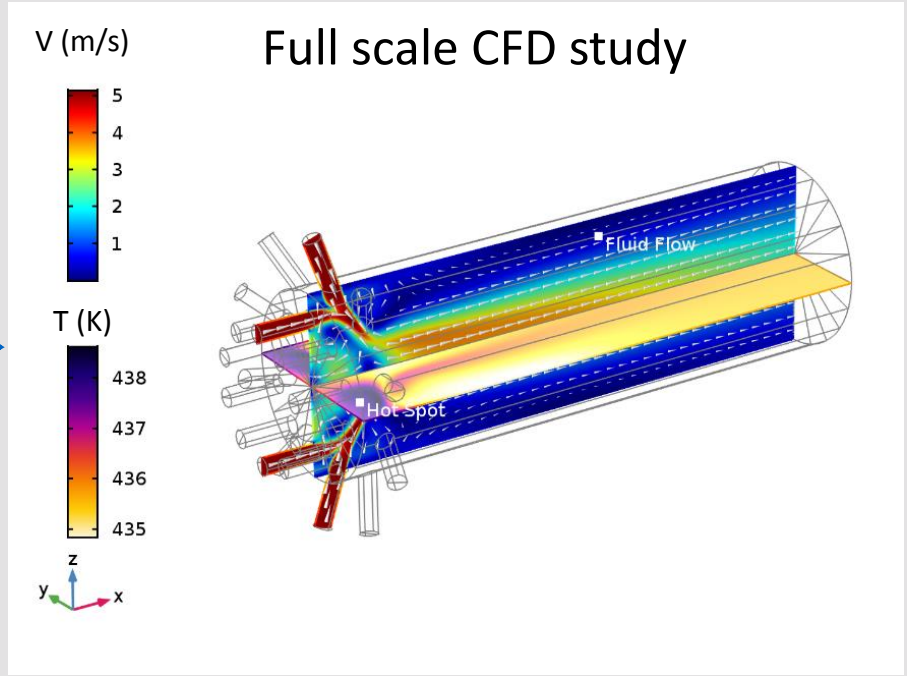


Reaction engineering modeling with non-idealities

CFD Integration

- Trouble shooting non-idealities in reactor (hot spot, mixing, etc.)

1-D Ideal PFR Model → extend



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MODEL DEPLOYMENT AS WEB APPLICATION

Enables

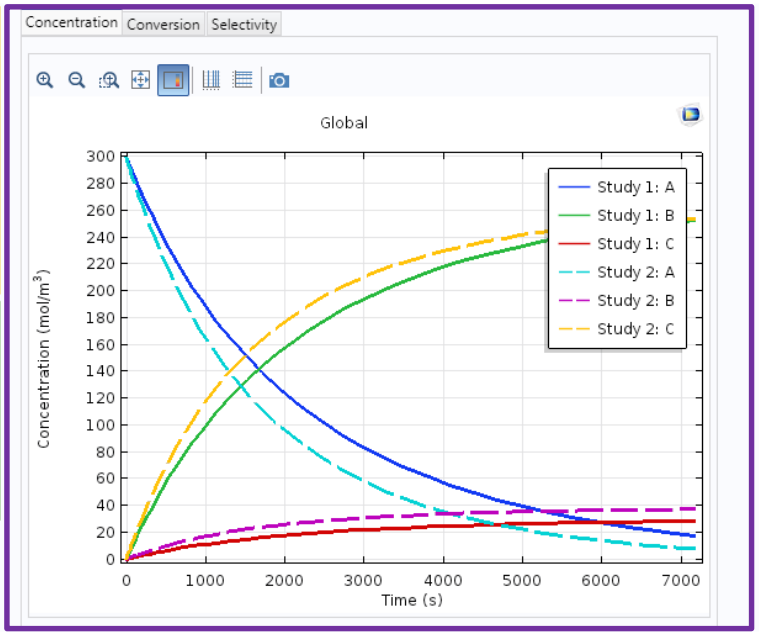
- Online access
- Non-modelers

File

menu bar (model documentation, automatic report, etc.)

	Reactor A		Reactor B	
Inputs				
Initial volume:	1	ml	1	ml
Initial temperature:	-15	°C	-5	°C
Initial Moles				
Inital moles of A:	0.3	millimole	0.3	millimole
Initial moles of H2O2:	1	millimole	1	millimole
Percent catalyst:	0.01	%	0.01	%
Computation				
End Simulation Time:	7200	s	7200	s
Results				
Conversion:	0.9397		0.9727	
Selectivity:	0.8978		0.8712	
Final Concentrations				
A	18.08	mol/m³	8.185	mol/m³
B	28.82	mol/m³	37.58	mol/m³
C	253.1	mol/m³	254.2	mol/m³

inputs results plotting



Summary

COMSOL as a Modeling Platform:

- Flexible parameter estimations for kinetic identification
- Straightforward extension from kinetics model to reactor modeling
- Integrated platform for non-ideal reactors using CFD simulation
- Accessible web deployment for non-modelers

END

Supplementary Slide – 4 Parameter Estimation in COMSOL