Bioreactor Model Simulation Using Simulink

CH 331: Process Control Lab

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Problem Statement

- The bioreactor system involves a fermenter operated at constant volume, where a single rate-limiting substrate promotes biomass growth and fermentation.
- The system follows nonlinear dynamics due to inhibition effects from both the substrate and product.
- The objective is to simulate and analyze the behavior of biomass, substrate, and product concentrations under open-loop conditions using Simulink.

System Variables

- **Constants:** $Y_{X,S}, \alpha, \beta, \mu_m, K_m, K_i, P_m, S_f$
- **Manipulated Input:** Dilution Rate ()
- **Disturbance Variables:** Substrate (S)
- **Controlled Variables:** Biomass (), Product ()
- **Sampling Time:** 1 min

Parameter	Values
$Y_{X,S}$	0.4 g/g
β	0.2 h^{-1}
P_m	50 g/L
K_i	22 g/L
α	2.2 g/g
μ_m	0.48 h^{-1}
k_m	1.2 g/L
S_f	20 g/L

Assume that the nominal operating point is D = 0.202.

Governing Equations

$$\frac{dX}{dt} = -DX + \mu(S,P)X$$

$$\frac{dS}{dt} = D(S_f - S)\frac{1}{Y_{X,S}}\mu(S,P)X$$

$$\frac{dP}{dt} = -DP + [\alpha\mu(S, P) + \beta]X$$

Growth Rate Model

- Specific Growth Rate Function:

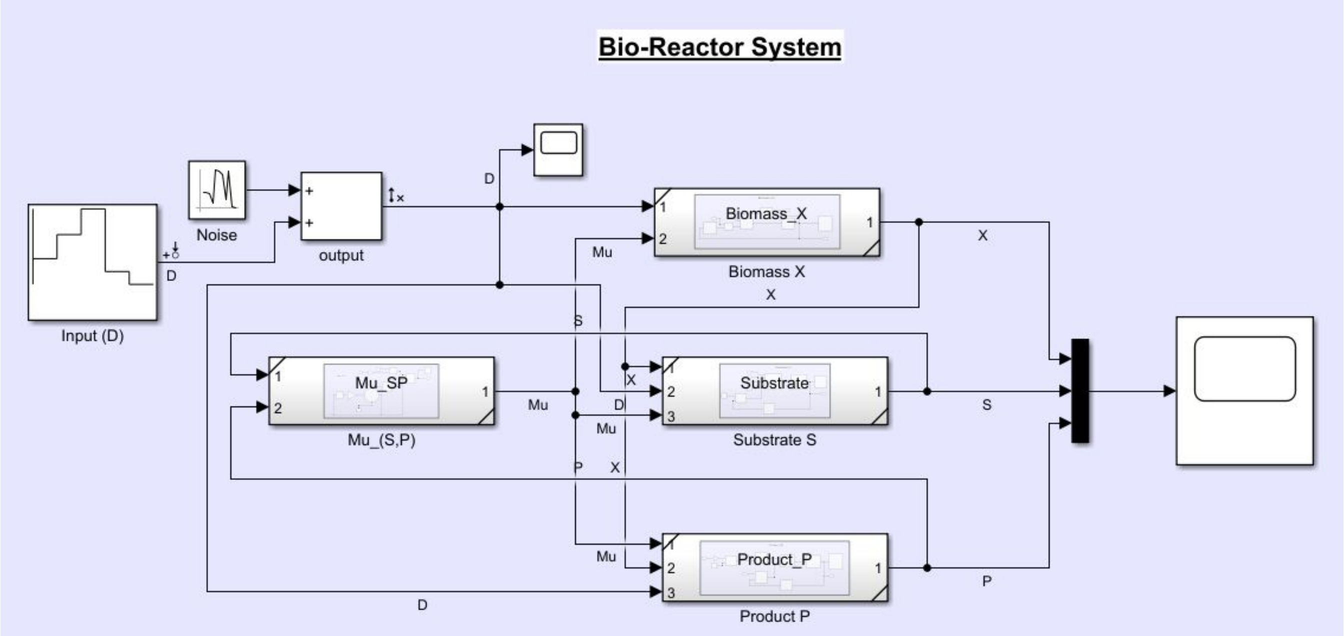
  $$\mu(S,P) = \frac{\mu_m(1-\frac{P}{P_m})S}{K_m+S+\frac{S^2}{K_i}}$$

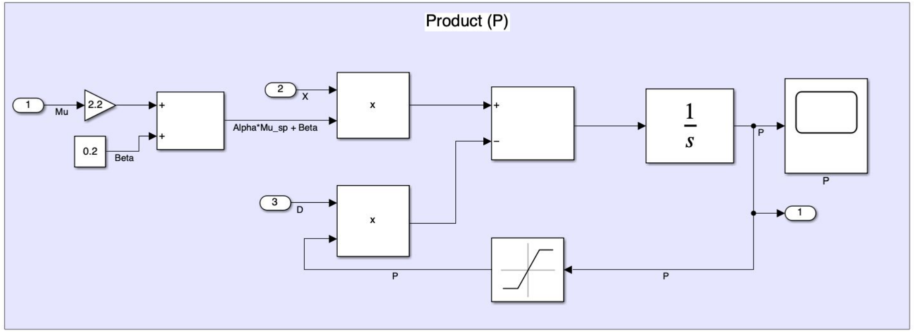
- Parameters:
  - $\mu_m = 0.48\ \text{h}^{-1}$
  - $P_m = 50$ g/L
  - $K_m = 1.2$ g/L
  - $K_i = 22$ g/L

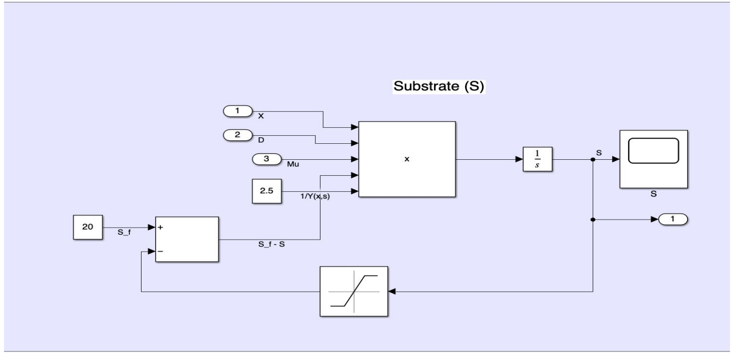
Key Aspects of the Problem

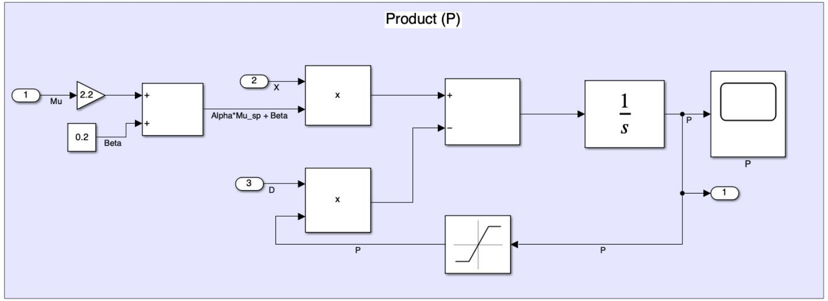
- Nonlinear system due to complex growth rate dependence on substrate and product.
- System involves transient and steady-state responses.
- Open-loop simulation performed in Simulink to observe process behavior under step changes.
- Comparison of nonlinear and linearized system responses.

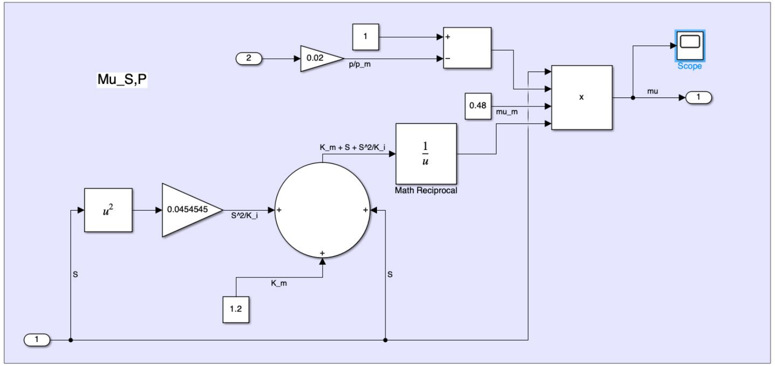
Simulink Model of Nonlinear Bioreactor



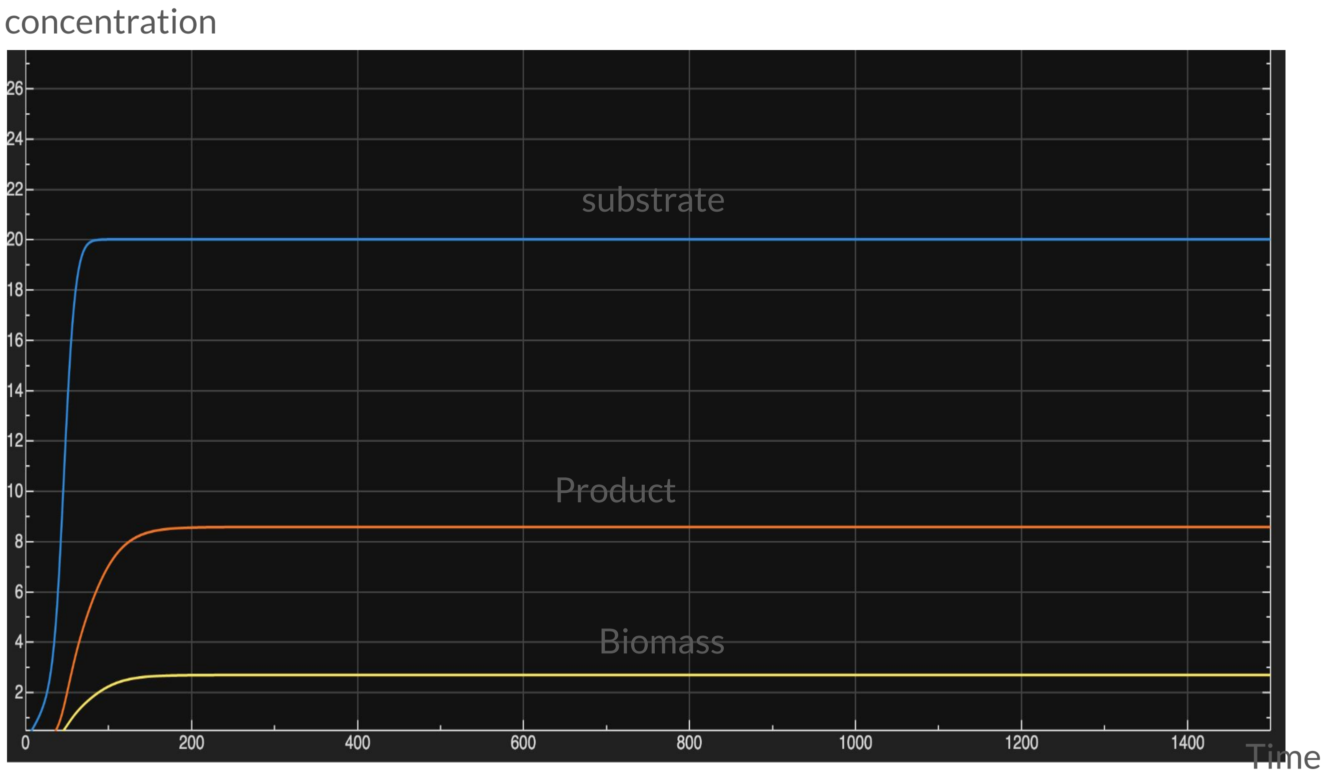

Product (P)
1
Mu
2.2
0.2
Beta
Alpha*Mu_sp + Beta
2
X
x
3
D
x
1/s
P
P
1
P
P


Substrate (S)
1
X
2
D
3
Mu
2.5
1/Y(x,s)
x
1/s
S
S
1
20
S_f
S_f - S


Product (P)
1
Mu
2.2
0.2
Beta
Alpha*Mu_sp + Beta
2
X
x
3
D
x
1/s
P
P
1
P
P


Mu_S,P
2
0.02
p/p_m
1
0.48
mu_m
x
mu
1
Scope
K_m + S + S^2/K_i
1/u
Math Reciprocal
u^2
0.0454545
S^2/K_i
K_m
1.2
S
S
1

Steady State - Non-linear System (without noise)

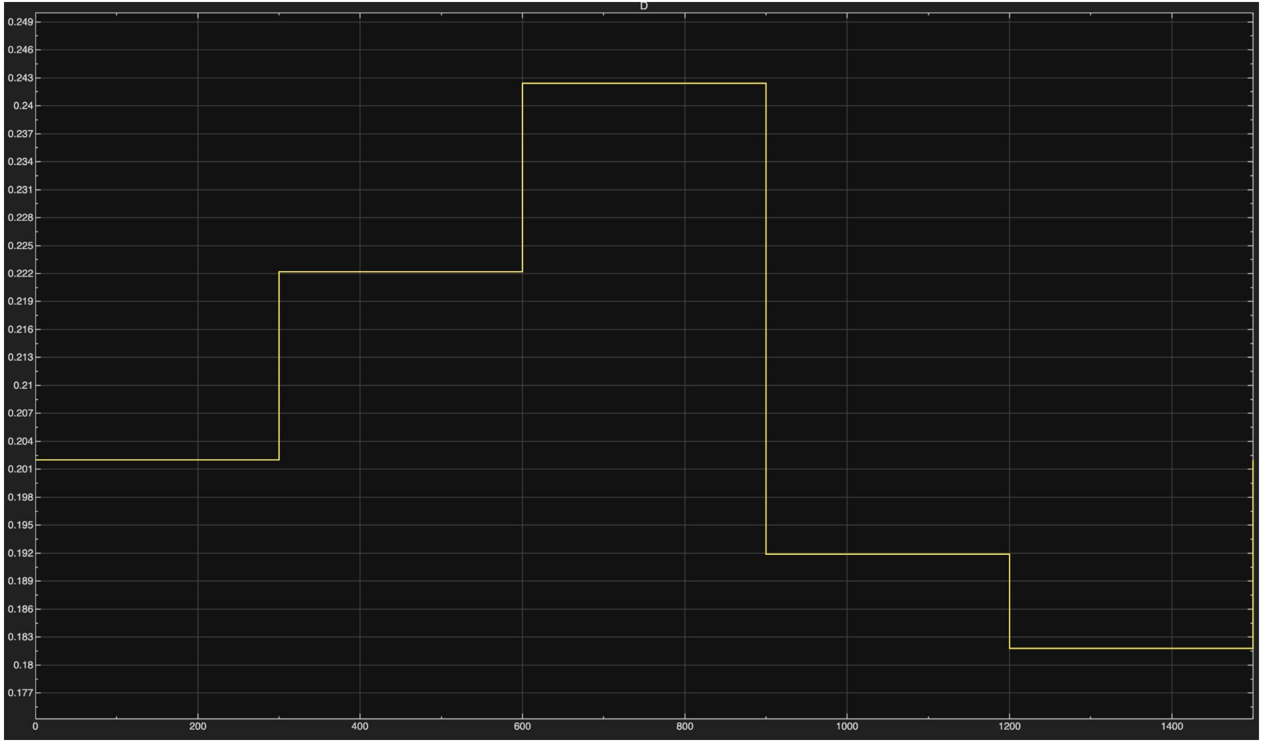


Substrate: S≈19.999 g/L

Biomass: X≈2.6855 g/L

Product: P≈ 8.5670 g/L

Input step change



Step change in time stamps of 300 min

0.202

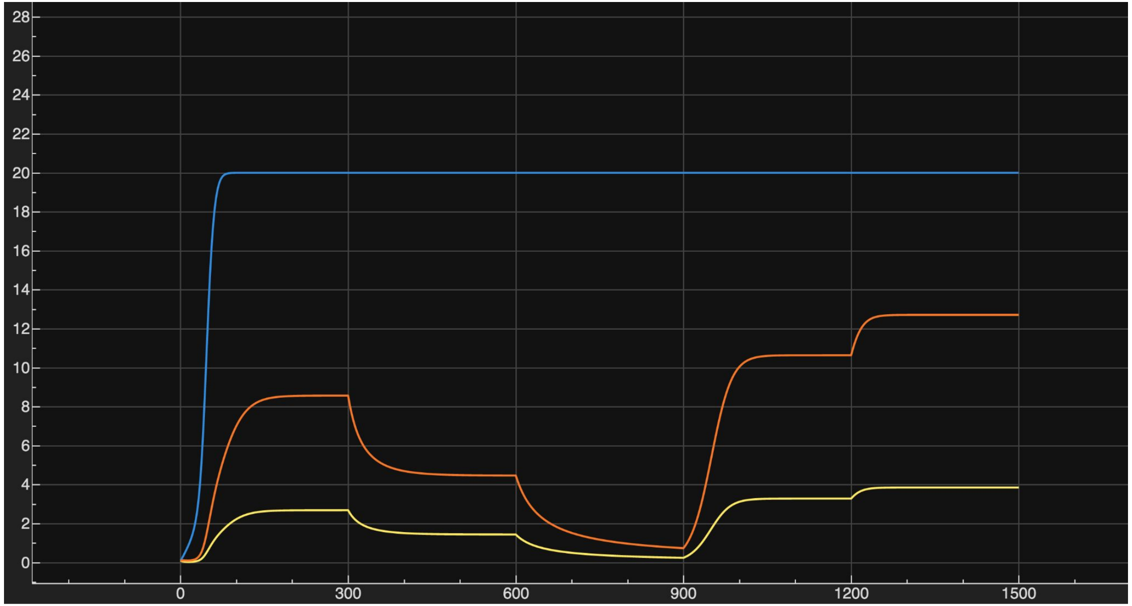
0.2222

0.2424

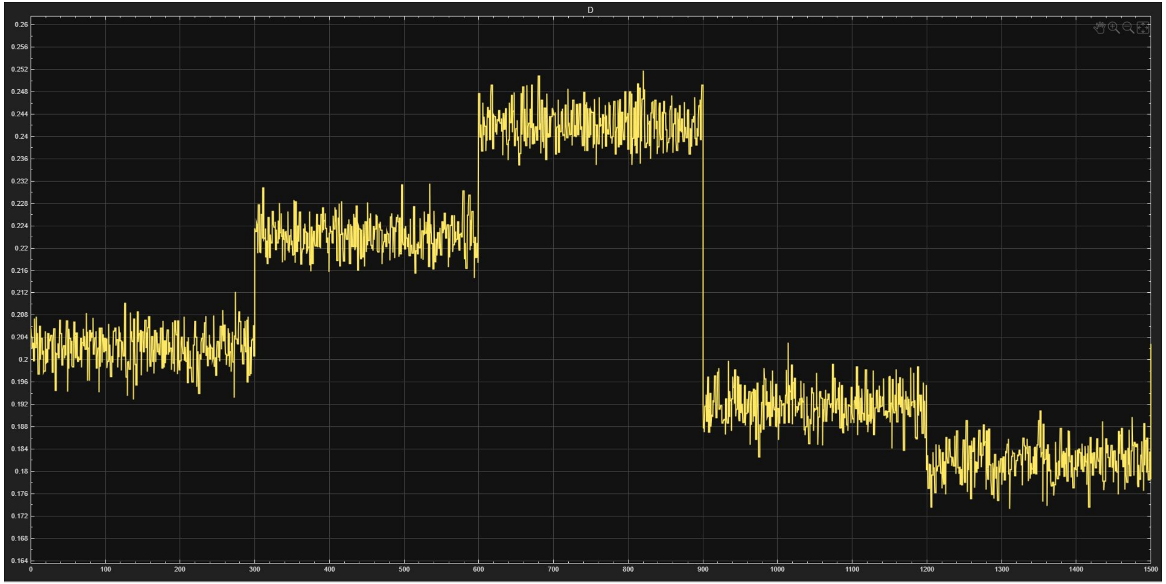
0.1919

0.1818

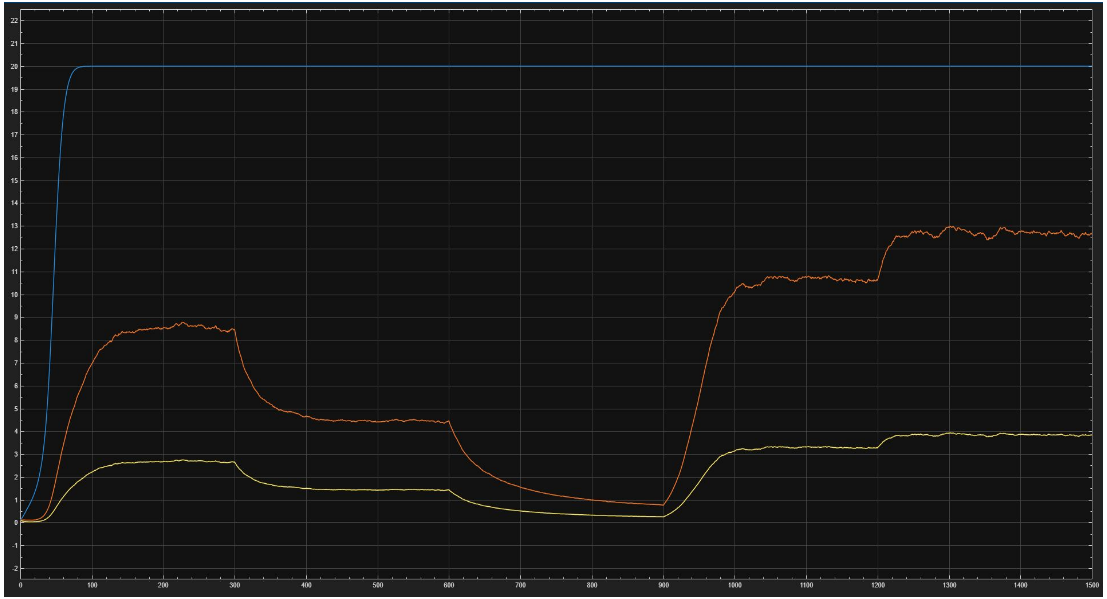
Output after step change without noise



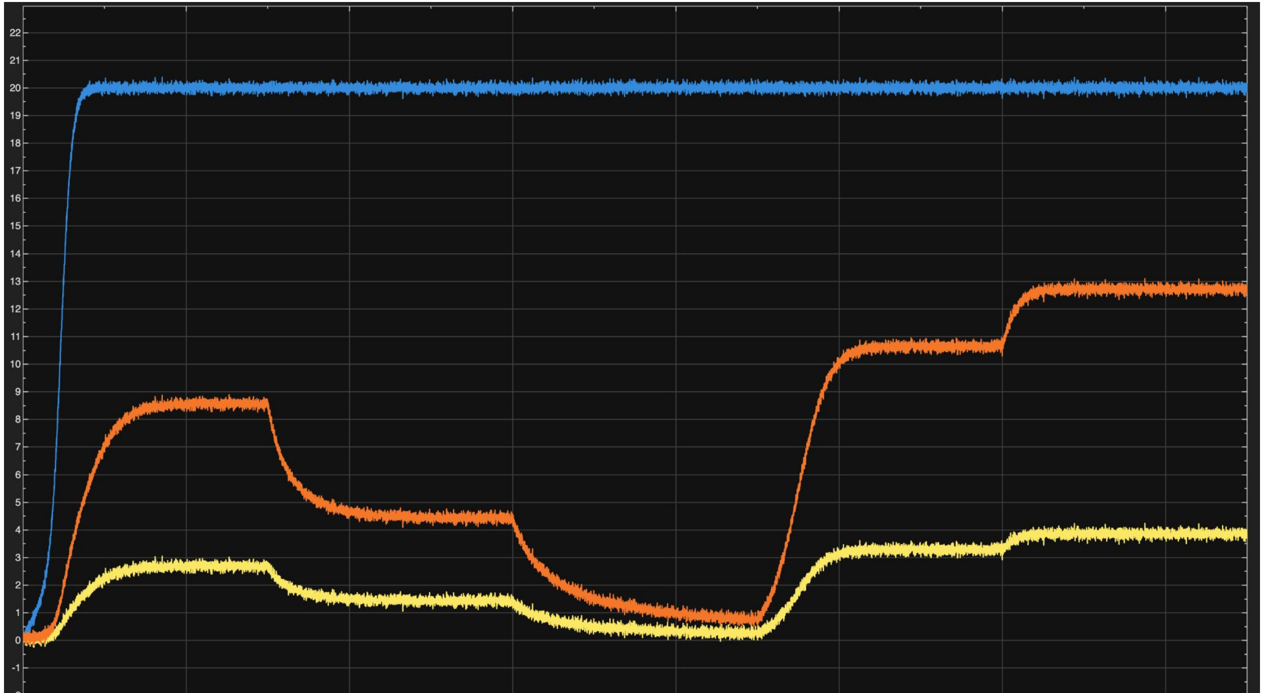
Input at step change with noise



Output at step changes with noise



Output at step changes with noise



Conclusion

Step changes in DDD directly impact biomass, substrate, and product concentrations.

There is a trade-off—too high DDD leads to biomass washout, too low DDD causes product inhibition.

The system takes time to stabilize, meaning real-time control is necessary for smooth operation.

Noise affects system performance, requiring feedback control strategies to reject disturbances.