PROCESS CONTROL

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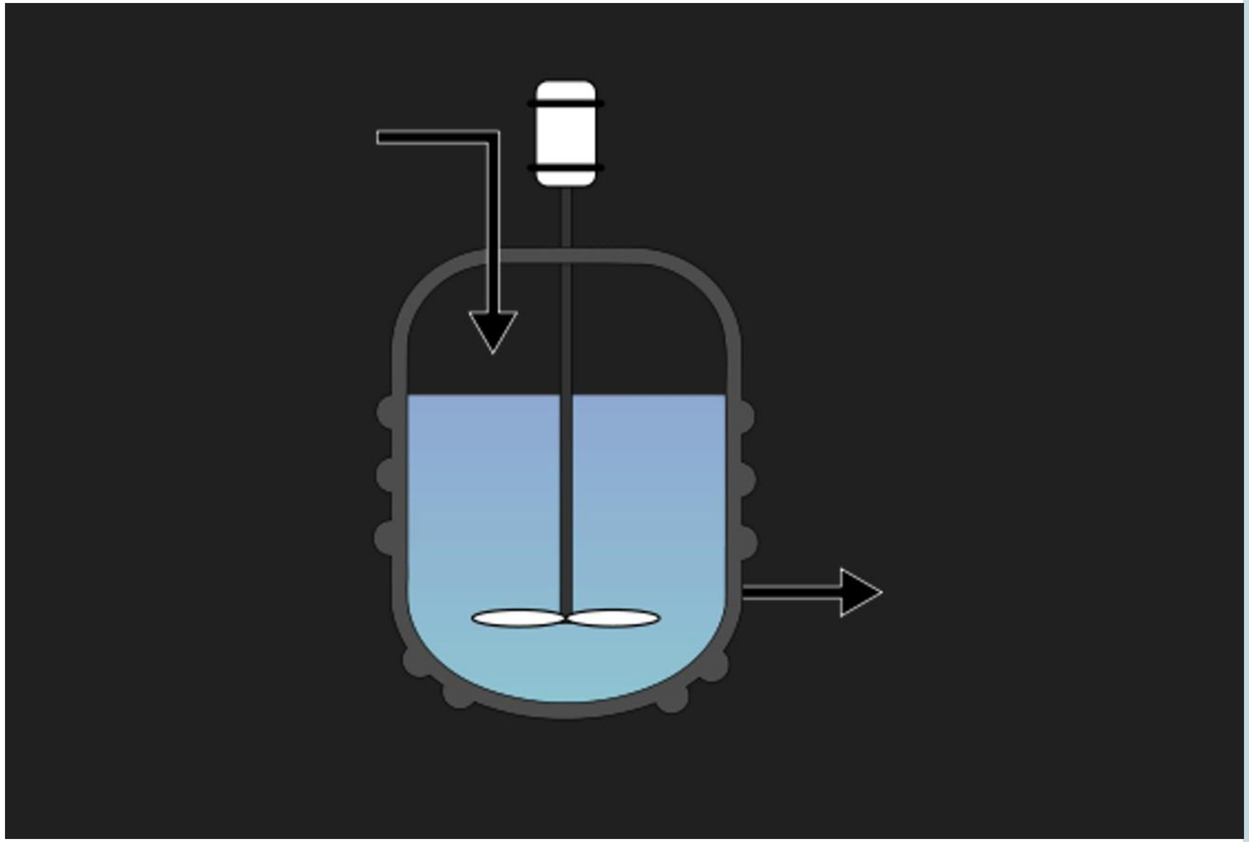


TASK DESCRIPTION &VARIABLES

- **Continuous Stirred Tank Bio-Reactor System (CSTR)**, also known as a **chemostat**. Used for the fermentation process of plant cell cultures.
- The concentrations of **X** (cell concentration) and **S** (substrate concentration) are time-dependent variables.
- **D** is the **dilution rate** (**Manipulated**).
- **Growth rate of the cells (μ(S))** depends on the substrate concentration.

DYNAMIC MODEL EQUATIONS:

- **Cell Growth Rate (X)**:

  - $dX/dt = \mu(S)X - DX$
  - $\mu(S)=(\mu m*S)/(Ks+S)$
      - µm : Maximum specific growth rate.
      - S: Substrate concentration.
      - Ks : Saturation constant.
    - D: Dilution rate, representing the outflow of cells.

1. **Substrate Consumption Rate (S)**:

   - $dS/dt = -(\mu(S)*X)/Y\_xs + D(Sf-S)$
     - Y_xs: Yield coefficient (g of cells per g of substrate).
     - Sf: Feed substrate concentration.

   Initial Values

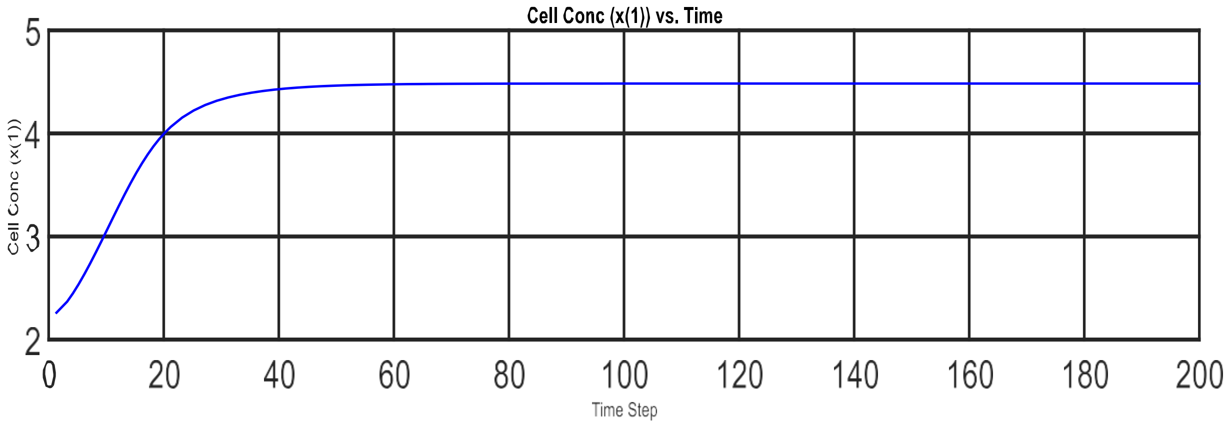
$D=0.1\ h^{-1}$	X=2.25 g/L
S=1.0 g/L	Sf=10 g/L.
$\mu m=0.20\ h^{-1}$	Ks=1.0 g/L
Y_xs=0.5 g/g	

Manipulated Variable – Dilution Rate (D)

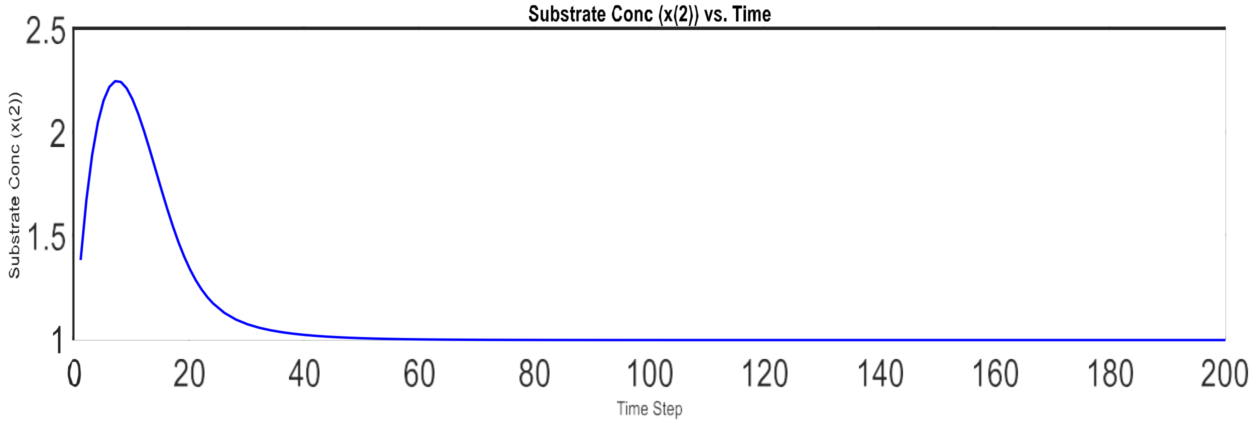
Controlled Variables – Cell Conc.(X) & Substrate Conc.(S)

Disturbance Variable – Substrate Feed Conc.(S_f)

STEADY STATE IDENTIFICATION

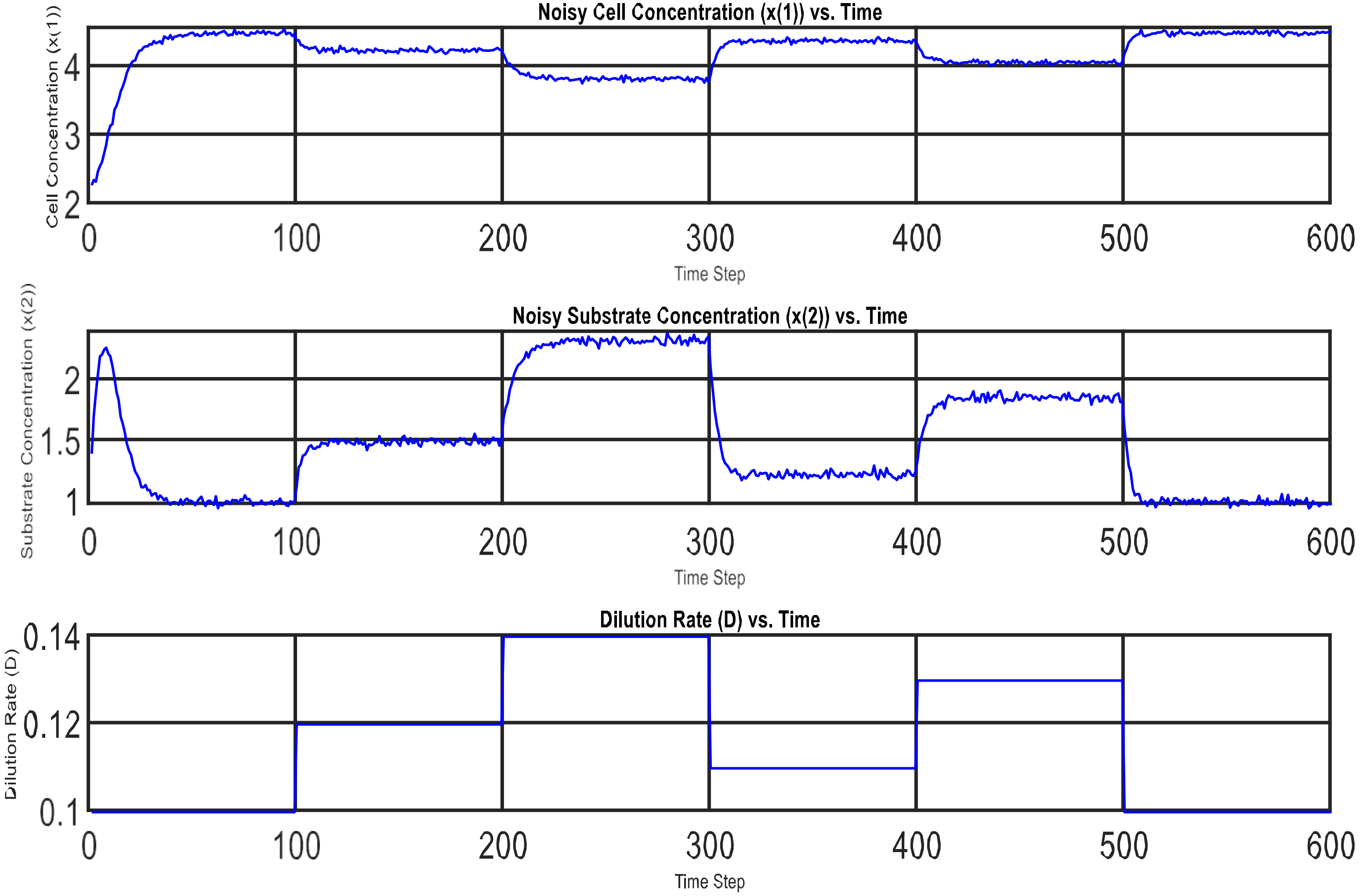


X_ss = 4.5g/L



S_ss = 1.0g/L

DYNAMIC SIMULATION ALONG WITH NOISE AND STEP CHANGE:



Step input for every 100 iterations.

20% –> X is 4.25g/L ; S is 1.5g/L

40% –> X is 3.84g/L ; S is 2.3g/L

10% –> X is 4.40g/L ; S is 1.25g/L

30% –> X is 4.05g/L ; S is 1.85g/L

FOPTD MODEL

- A First-Order Plus Time Delay (FOPTD) model was identified by **optimizing parameters** (process gain, time constant, time delay) **using empirical methods.**

- The optimization **minimized the sum of squared errors** (SSE) between **model predictions and plant data.**

- No explicit time delay considered in this specific implementation, as we can see from figures it follows first order model.

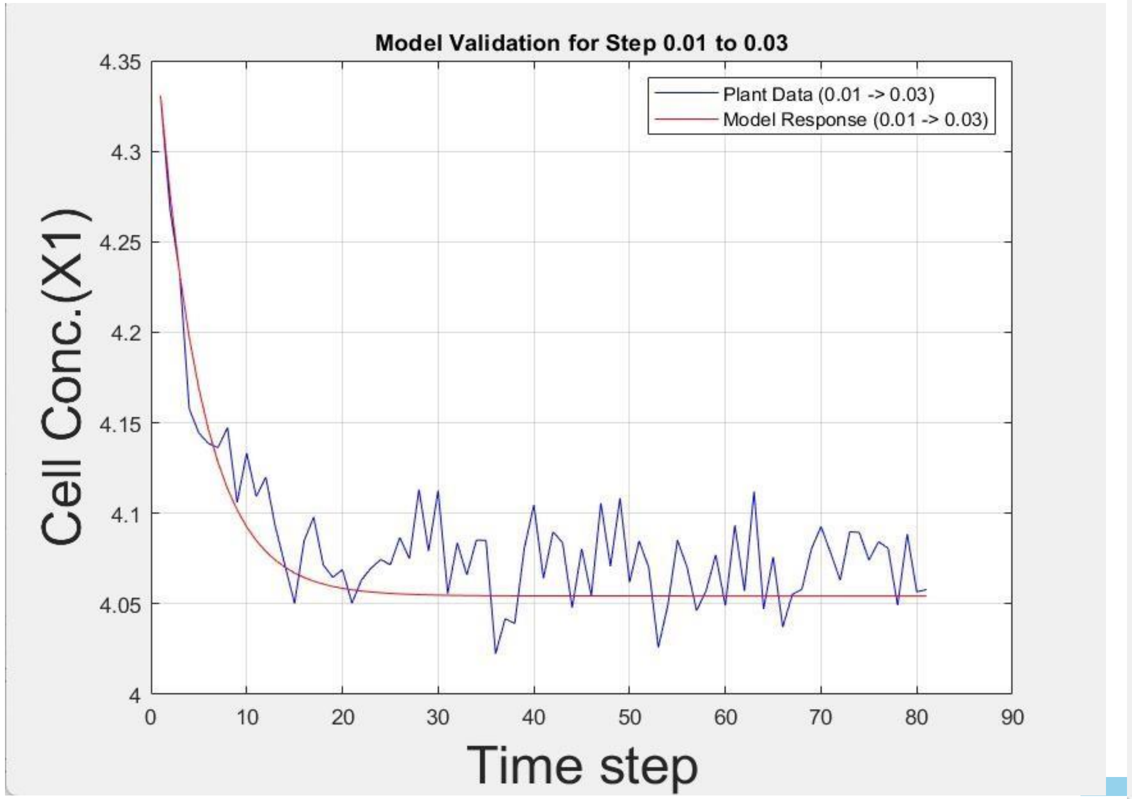
- We took the first 3 step changes for data training and validated the trained data on 4th step.

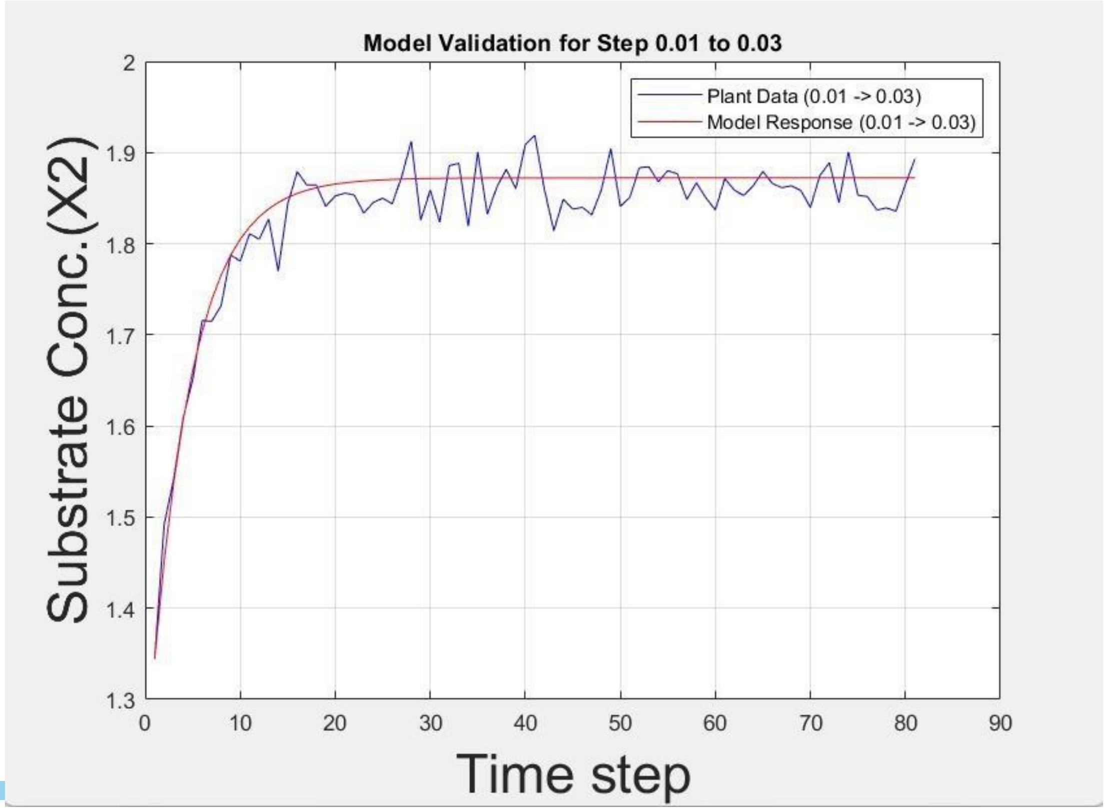
FOPTD MODEL

	Kp1	Kp2	Kp3	Toe1	Toe2	Toe3	Kp	Tœ
X	-7.039	-17.875	-16.544	4.6404	5.846	3.145	-13.569	5.2214
S	18.438	31.484	29.287	2.887	6.585	3.641	26.4035	4.371

- **Blue Line**: Plant Data
- **Red Line**: Model Predicted Data

REGRESSION MODEL

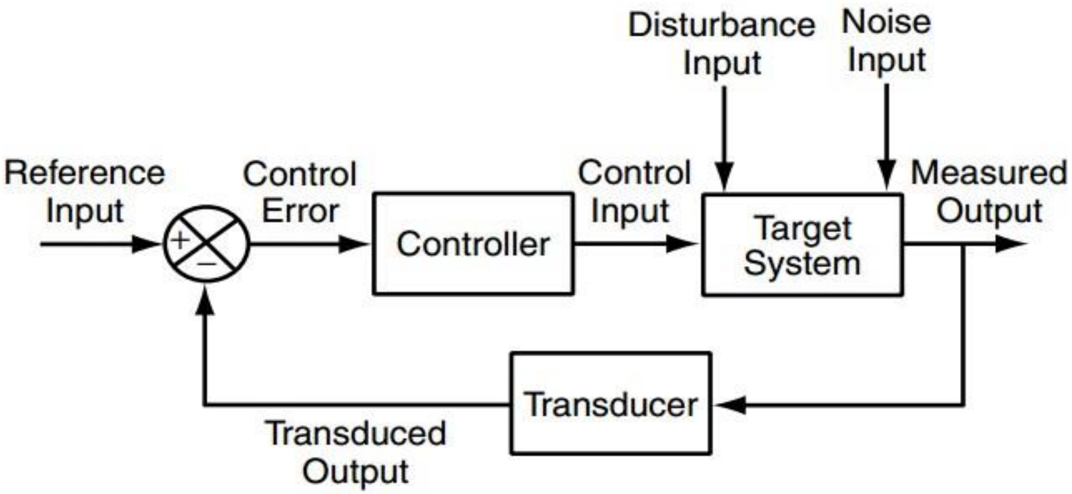




Kp – -13.89, Toe – 4.544min

Kp – 26.403, Toe – 4.307min

FEEDBACK CONTROL



Closed Loop Transfer Function

$$Y = \frac{G_p G_c}{1 + G_p G_c} Y_{sp} + \frac{G_d}{1 + G_p G_c} D(s)$$

Servo-Problem

$$D(s) = 0$$

$$Y = \frac{G_p G_c}{1 + G_p G_c} Y_{sp}$$

Regulatory-Problem

$$Y_{sp} = 0$$

$$Y = \frac{G_d}{1 + G_p G_c} D(s)$$

STABILITY ANALYSIS

u(t) = u_ss + Kc·e(t) …Where:

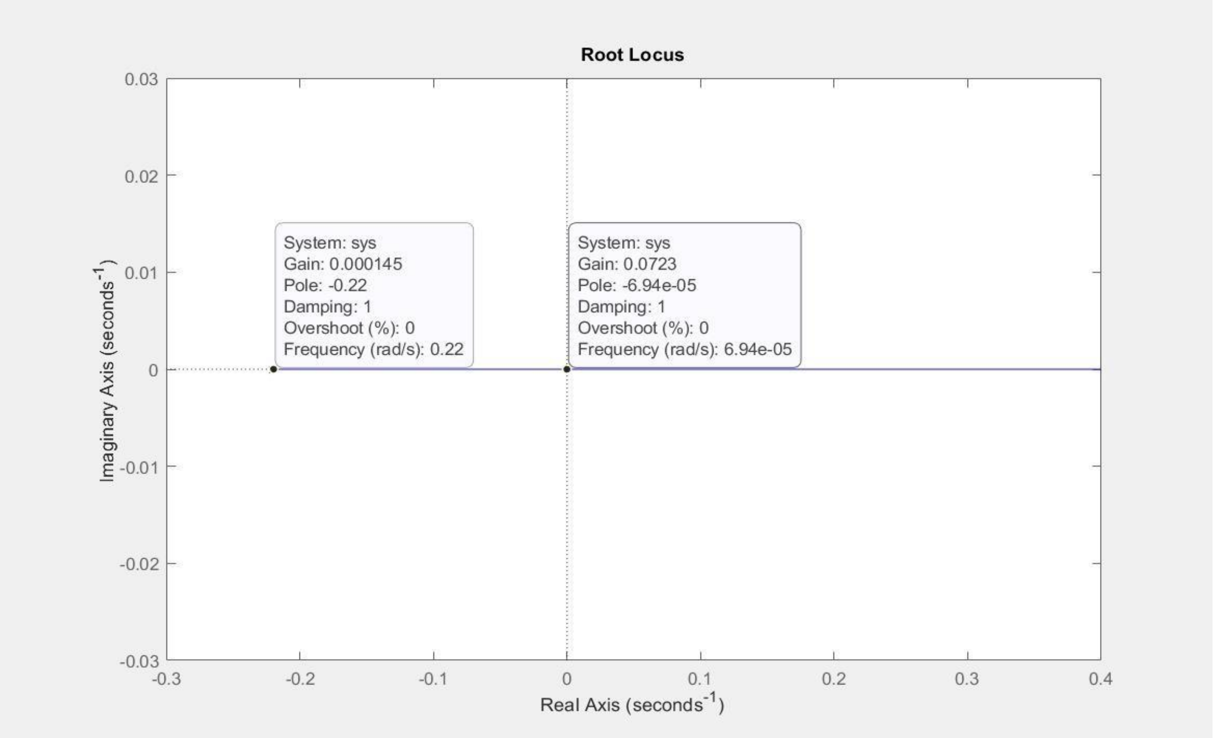
- u(t) = Control output
- Kc = Proportional gain
- e(t) = Error signal (Setpoint - Process variable)

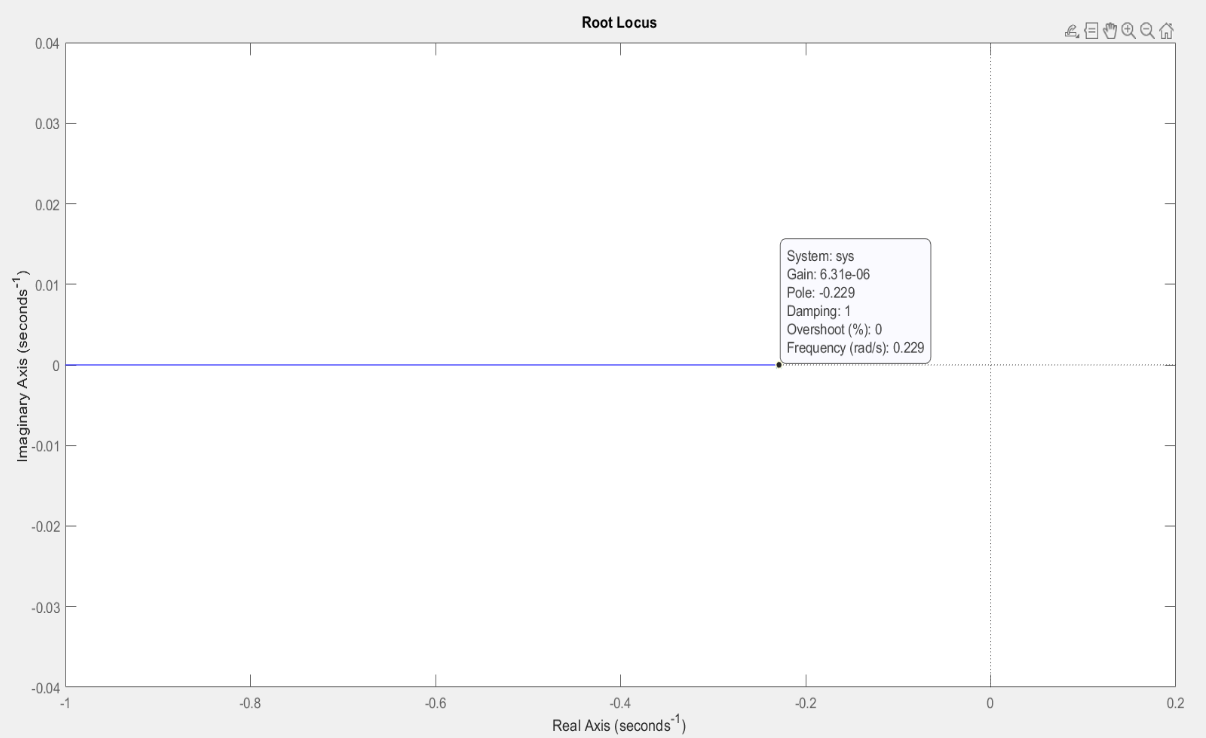
Characteristic Equation – (1 + Kp.Kc/(t*s+1))

Necessary Condition – All the coff of characteristics eqn should be positive.

Sufficient Condition – Routh Hurwitz Criteria

ROOT LOCUS





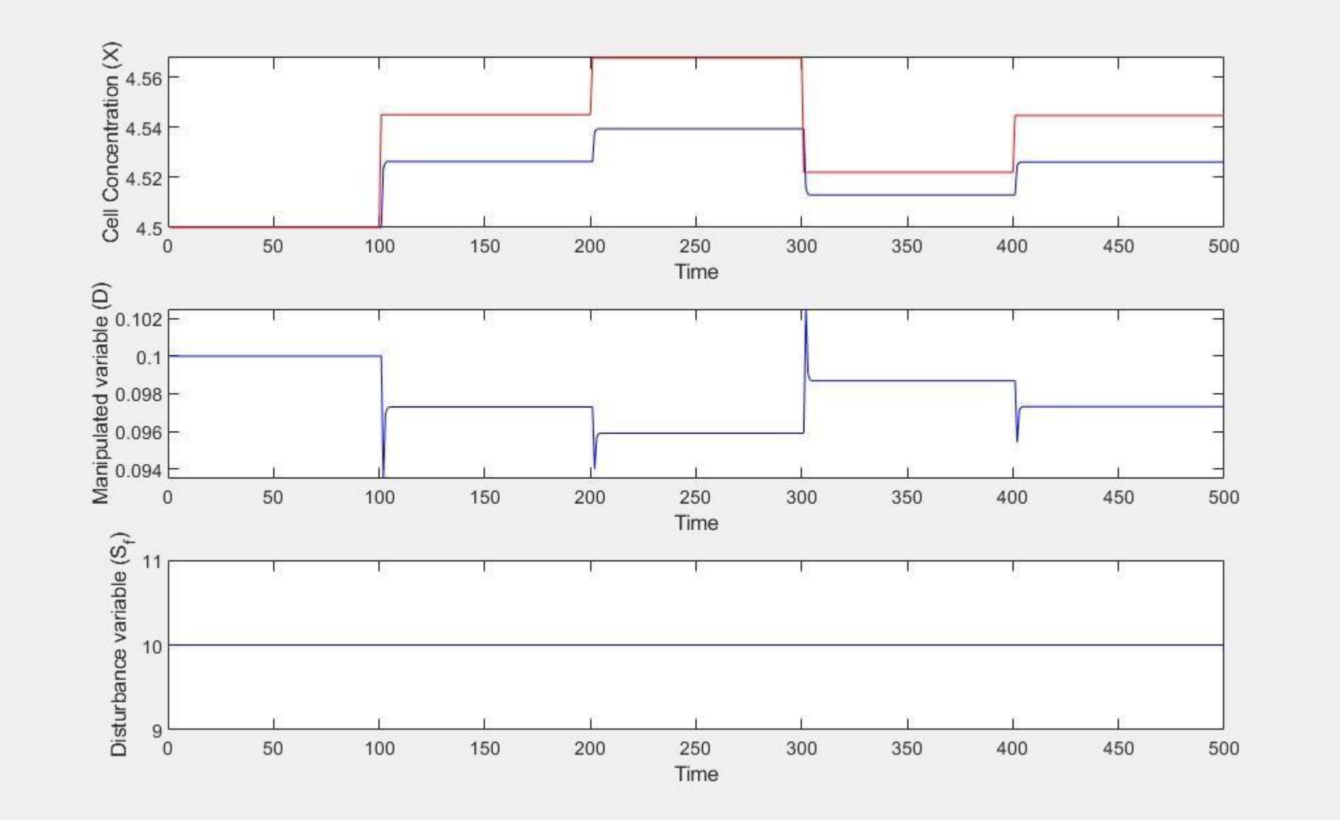
$-0.072 < Kc < 0.071$

For X.

$Kc > -0.037$

For S

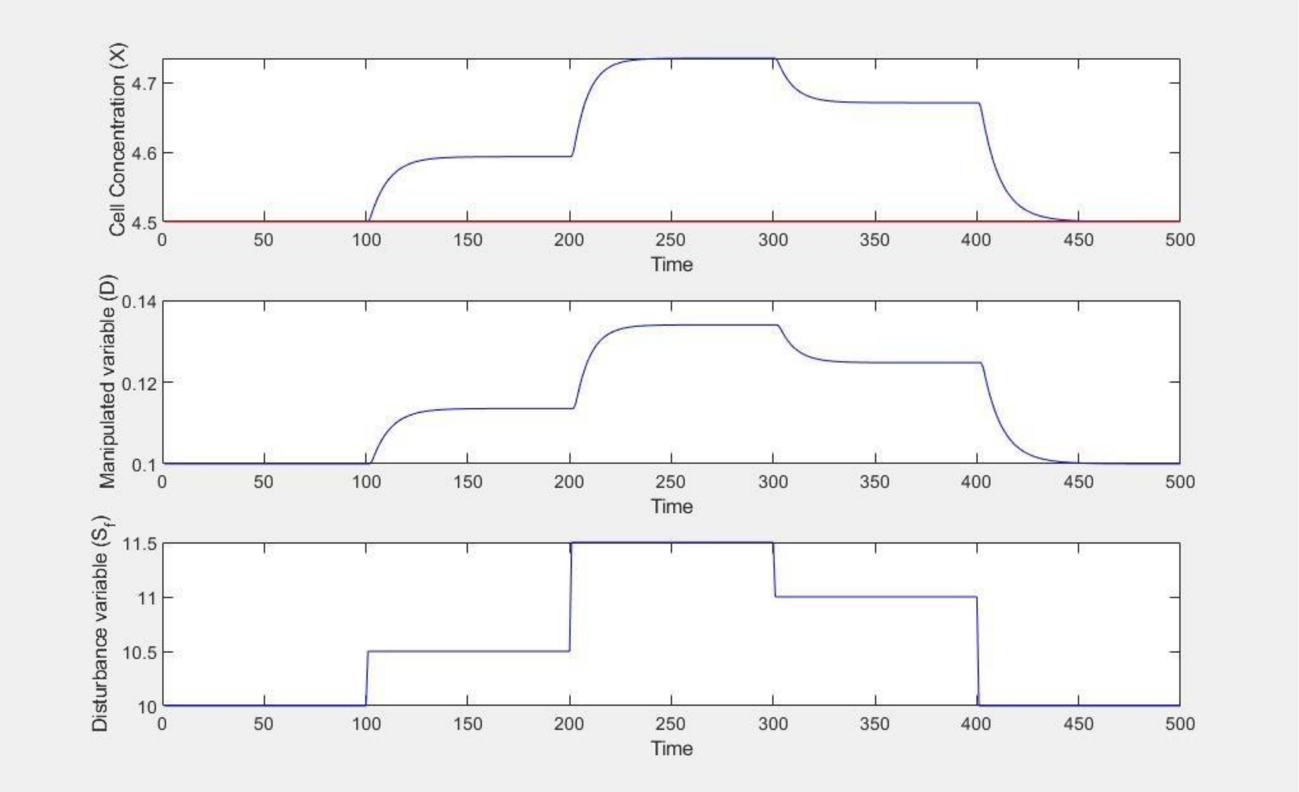
SERVO PROBLEM



Offset is present.

Cell Concentration

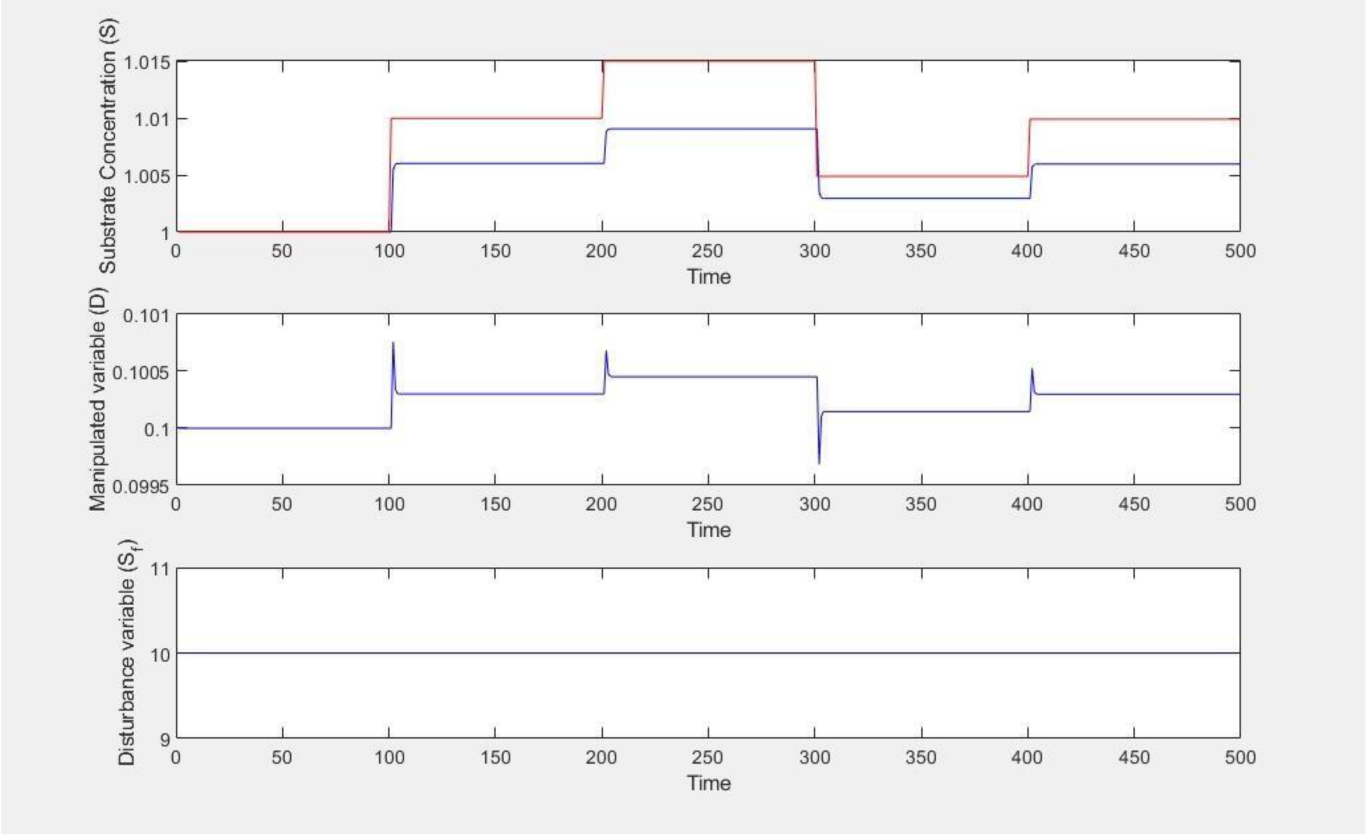
REGULATORY PROBLEM



Offset is present.

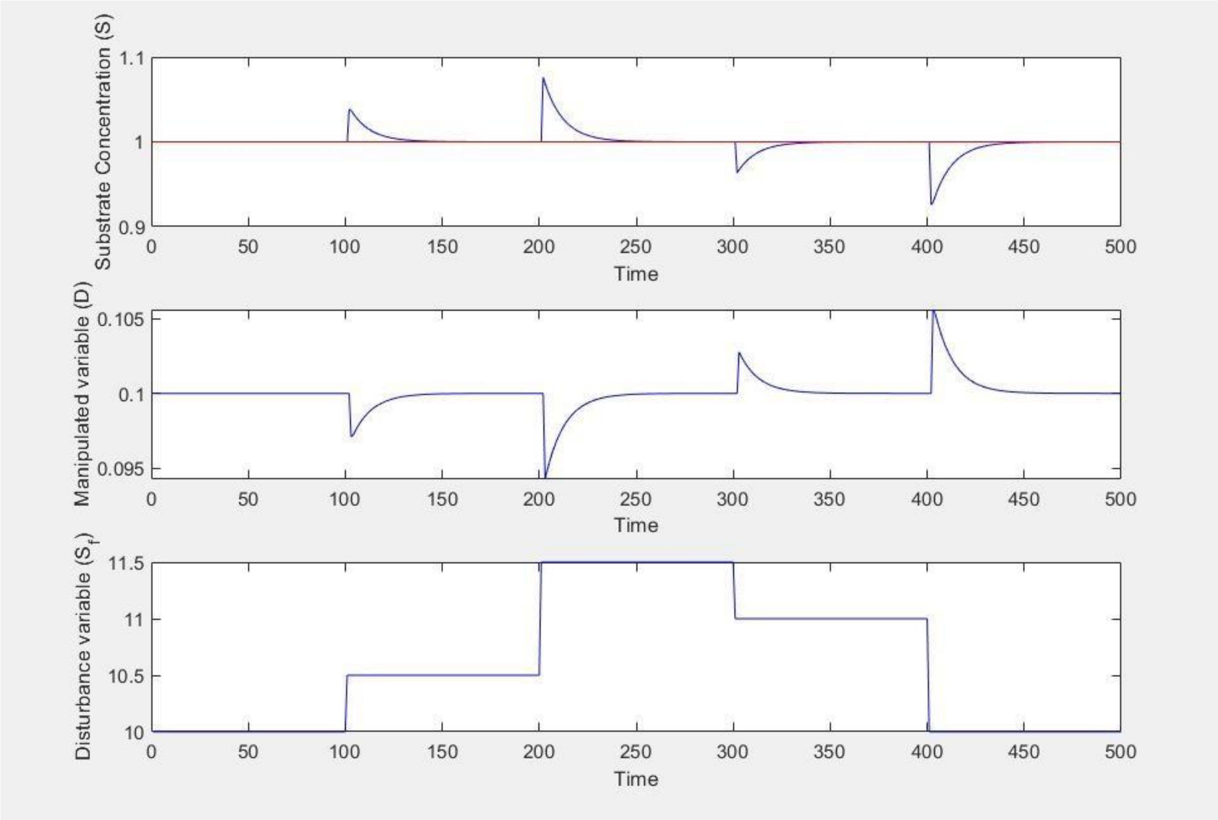
Cell Concentration

SERVO PROBLEM



Substrate Concentration Graph

REGULATORY PROBLEM



Substrate Concentration

CONCLUSION

- Steady State, $X_{ss} = 4.5$ g/l, $S_{ss}=1.0$ g/l.
- The cell and substrate conc. are measured, while giving the noise and changing step inputs.
- The data is trained 3 times to get the good results, and than it is validated.
- For X -> $-0.072 < Kc < 0.072$
- For S -> $Kc > -0.037$
- Proportional Controller is applied in the system, and graphs are plotted.

ACKNOWLEDGEMENT

I would like to express our sincere gratitude to Prof. Jayaram and TA Varsha

for their invaluable guidance and support throughout the completion of this project.

Their insightful teachings in the CH303: Process Control course during

this semester have provided me with the knowledge and skills necessary to successfully implement this work.

THANK YOU