Advanced Control Technology

SoSe 2019

Bioreactor System (5)

Presented by

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Bioreactor

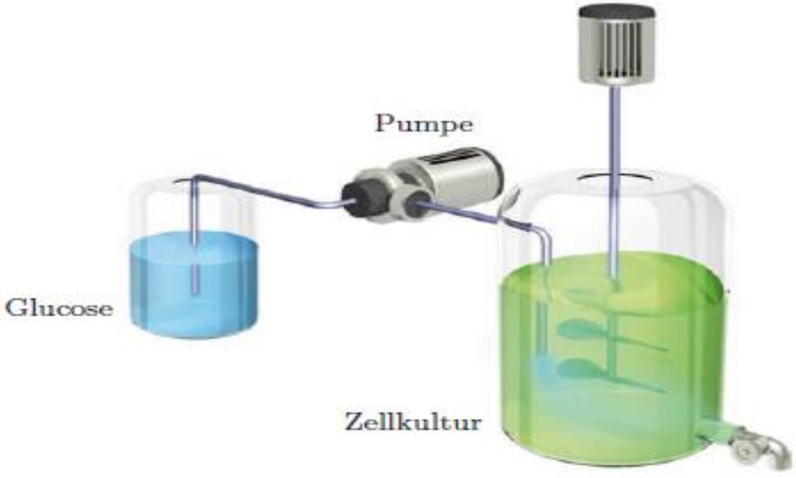

Fig. 1: Bioreactor system

The Bioreactor system can be modeled by the following state space equation:

$$\dot{\boldsymbol{x}} = \boldsymbol{a}(\boldsymbol{x}) + \boldsymbol{b}(\boldsymbol{x}) \cdot u = \begin{bmatrix} \mu(x_2) \cdot x_1 \\ -\frac{1}{\alpha}\mu(x_2) \cdot x_1 \end{bmatrix} + \begin{bmatrix} -x_1 \\ K - x_2 \end{bmatrix} u,$$

$$y = g(\boldsymbol{x}) = \begin{bmatrix} 1 & 0 \end{bmatrix} \boldsymbol{x}\,.$$

Where, $\mu(x_2) = \dfrac{\mu_0 x_2}{k_1 + x_2 + k_2 x_2^2}$

Where:
Maximal growth rate, $\mu_0 = 2$
Affinity constant, $k_1 = 0.06$
Affinity constant, $k_2 = 0.3$
Feed concentration of glucose, K = 2
Yield constant, $\alpha = 0.7$

Concentration of **biomass** =**x1**
Concentration of **substrate** = **x2**

Objectives

- To choose a suitable control method for the Nonlinear system
- To design the controller for the system
- Results
- Comparison of results with Linearized model

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- <u>Step 1:</u> Detect presence of Internal Dynamics using Lie Derivative

System has internal dynamics if, **$\boldsymbol{\delta}$ < n**

Where,
δ = Relative degree,
n = system dimension = **2**

We know for Lie derivative,

$$y^{(\delta)} = L_a^{(\delta)} c(x) + L_b L_a^{(\delta-1)} c(x).u$$

For 1st order derivative, $\delta = 1$,

$$L_a{}^1 c(x) = \frac{\partial c(x)}{\partial x}.a(x) = \mu(x_2).x_1 \qquad \text{and,} \qquad L_b c(x) = \frac{\partial c(x)}{\partial x}.b(x) = -x_1$$

Hence, $\dot{y} = L_a c(x) + L_b c(x).u$

$= \mu(x_2).x_1 - x_1.u;$ which is nonzero. i.e., δ = 1 **<** n (=2)

∴ **System has internal dynamics**

Choosing Control method for Nonlinear System (Contd.)

- Step 2: Choose Fuzzy Logic Control Method
  - Experience-based approach
  - Mechanism logic based on experience of human operator
  - Easy to manipulate
  - Can process analog input with continuous values (between 0 and 1)

Mamdani Fuzzy Controller

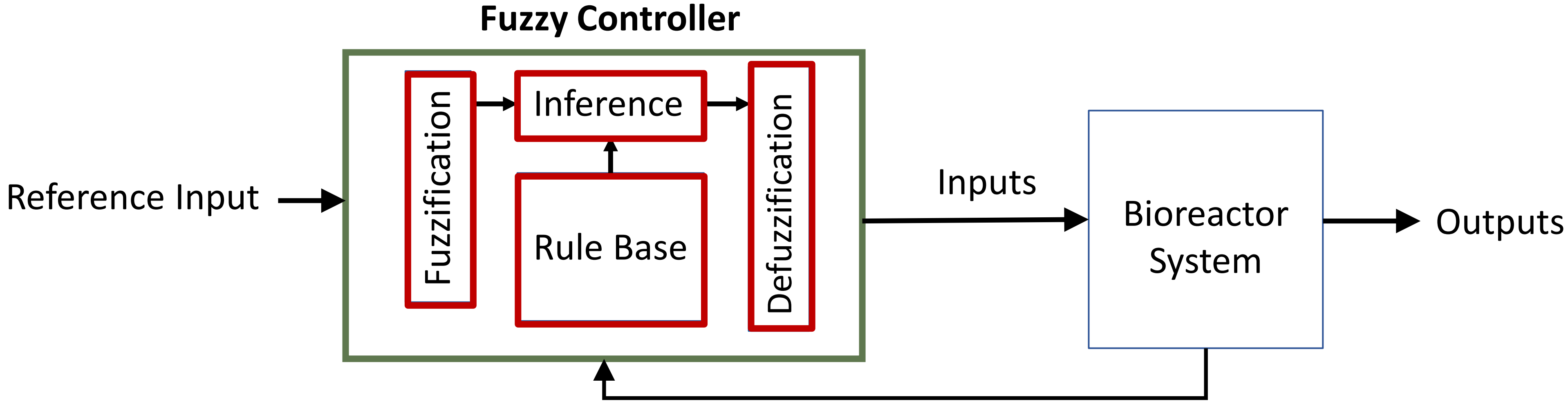
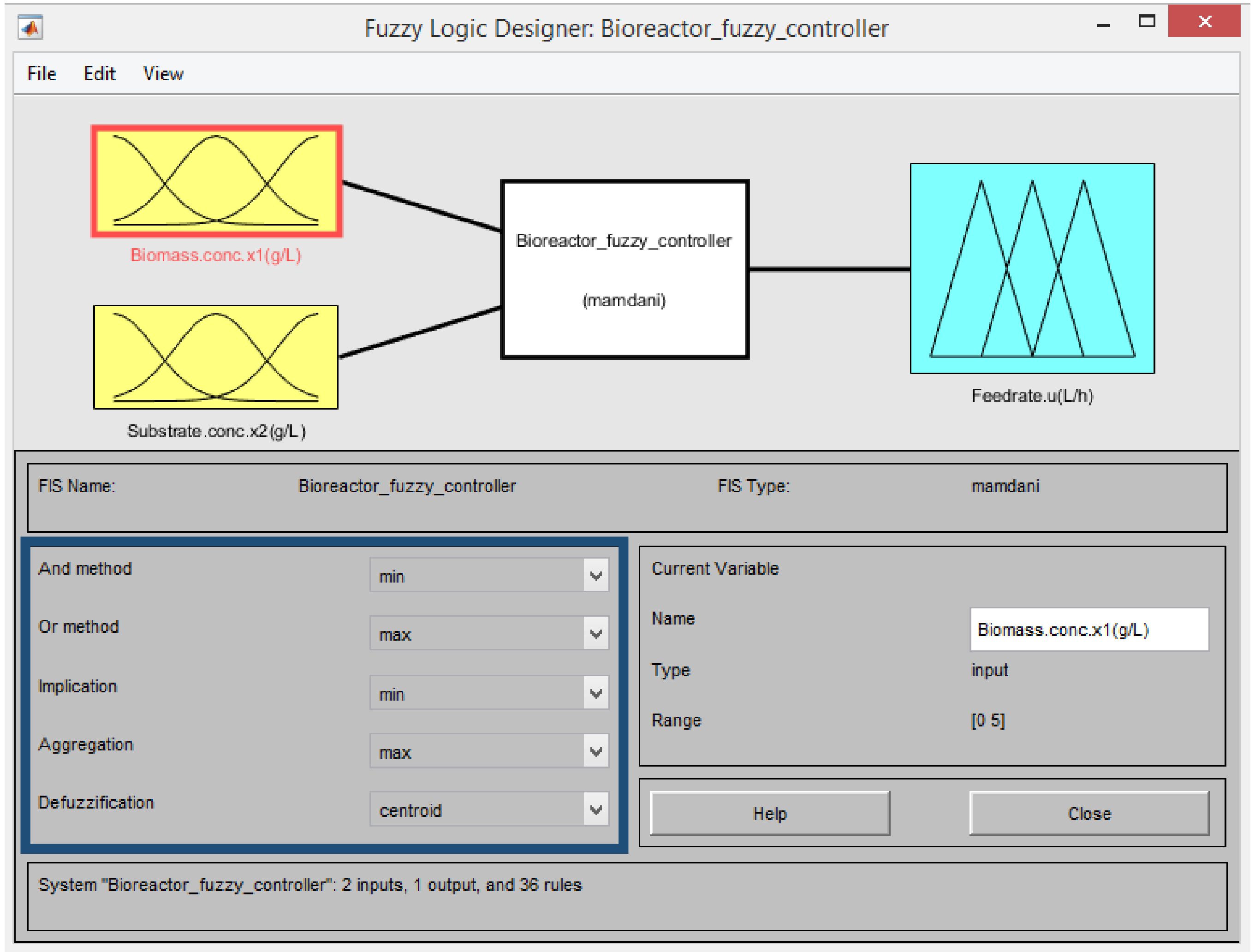


Fig. 9: Fuzzy logic controller with Bioreactor system

Design of Mamdani Fuzzy Controller

- <u>Step 1:</u> Assign Inputs and Output

➢ Using MATLAB Fuzzy Logic Designer App



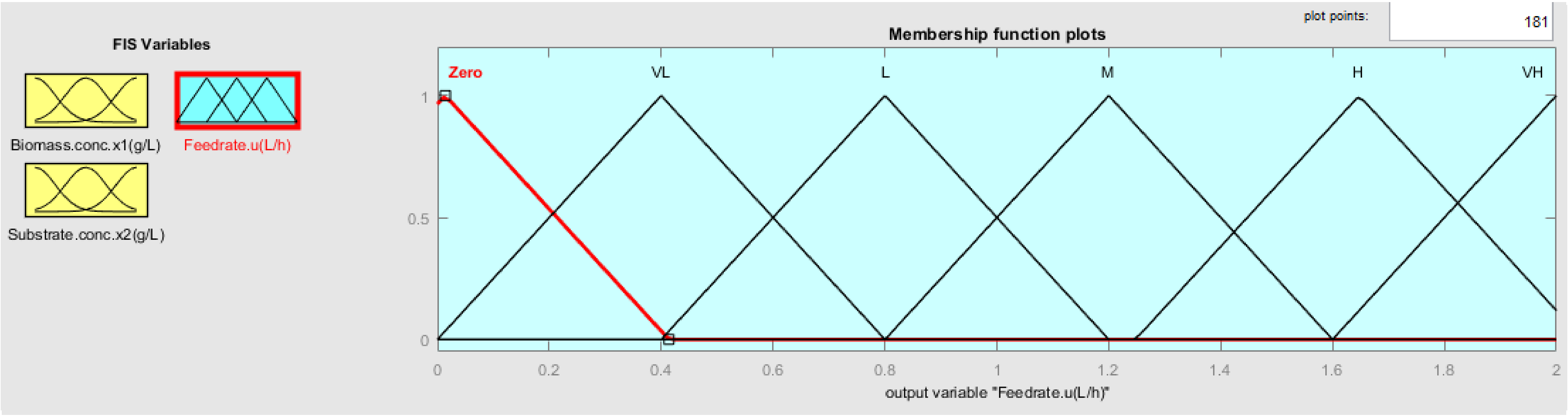
Design of Mamdani Fuzzy Controller (Contd.)

- Step 2: Assign Membership Functions (MF) and Linguistic Variables

	Inputs												Output					
Parameters	Biomass Concentration **(x1)**						Substrate Concentration **(x2)**						Feed Rate **(u)**					
Linguistic Variables	L	MTL	M	H	VH	VVH	VL	L	M	H	VH	VVH	Z	VL	L	M	H	VH
Type of MFs	TRIANGULAR																	

Design of Mamdani Fuzzy Controller (Contd.)

- Step 2: Assign Membership Functions (MF) and Linguistic Variables (Contd.)



Design of Mamdani Fuzzy Controller (Contd.)

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- Step 3: Create Rule Base

Number of rules in Rule Base system is given by,

$$R = \prod_{j=1}^{n} N_j$$

∴ Number of rules in Bioreactor system = 6 x 6 = 36.

	If **x1** is	And **x2** is	Then **u** is
1	L	VL	VH
2	L	L	H
3	L	M	M
4	L	H	L
5	L	VH	VL
6	L	VVH	Z
7	MTL	VL	VH

	If **x1** is	And **x2** is	Then **u** is
8	MTL	L	H
9	MTL	M	M
10	MTL	H	L
11	MTL	VH	VL
12	MTL	VVH	Z
13	M	VL	H
14	M	L	H

Design of Mamdani Fuzzy Controller (Contd.)

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- <u>Step 3:</u> Create Rule Base (Contd.)

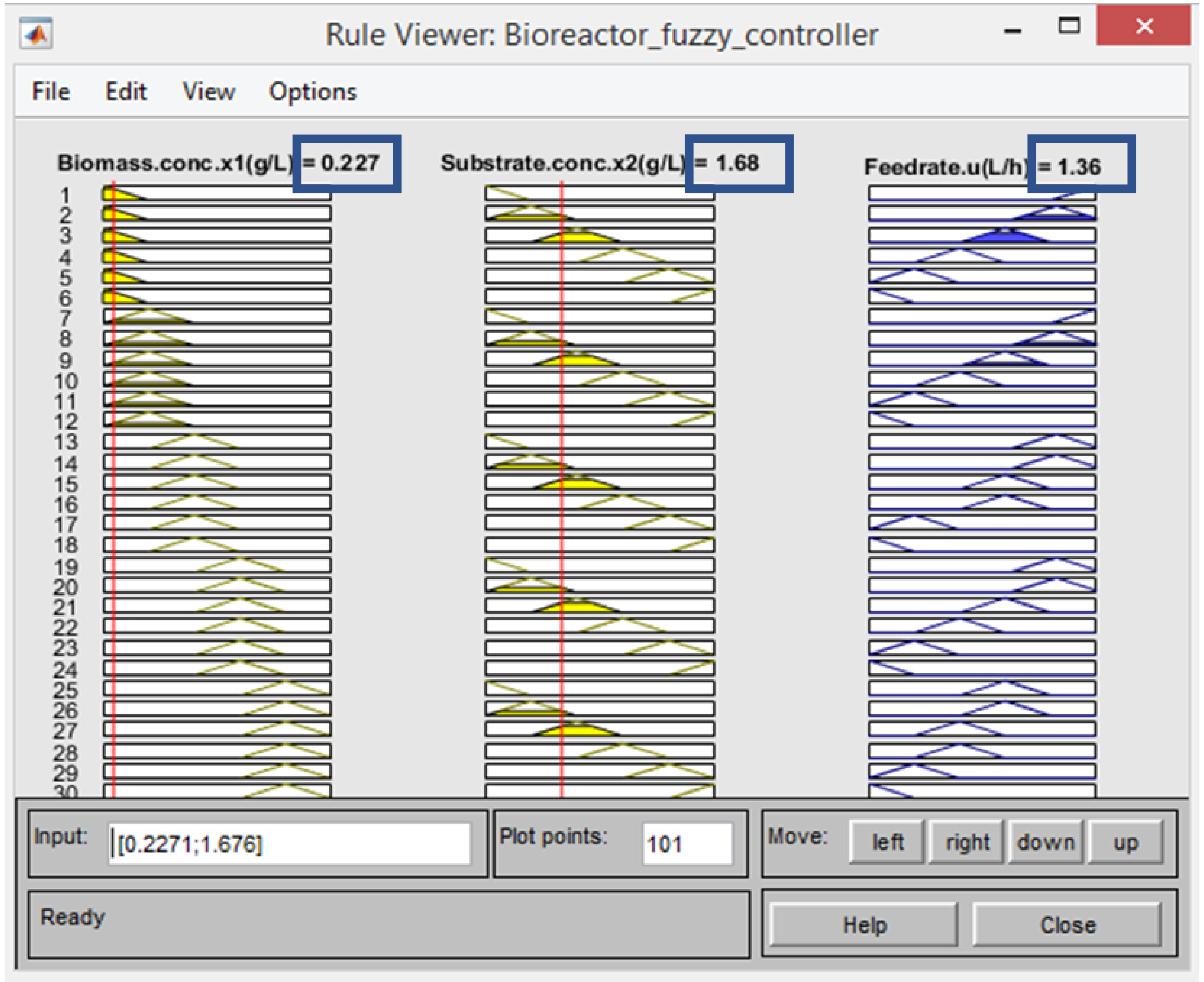
	If **x1** is	And **x2** is	Then **u** is
15	M	M	M
16	M	H	M
17	M	VH	VL
18	M	VVH	Z
19	H	VL	H
20	H	L	H
21	H	M	M
22	H	H	L
23	H	VH	VL
24	VH	VVH	Z
25	VH	VL	M

	If **x1** is	And **x2** is	Then **u** is
26	VH	L	M
27	VH	M	L
28	VH	H	L
29	VH	VH	VL
30	VH	VVH	Z
31	VVH	VL	Z
32	VVH	L	Z
33	VVH	M	Z
34	VVH	H	Z
35	VVH	VH	Z
36	VVH	VVH	Z

Design of Mamdani Fuzzy Controller (Contd.)

- <u>Step 3:</u> Create Rule Base (Contd.)

Rule Viewer



For, x1 = 0.2271 *and* x2 = 1.676,

u = 1.36

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- <u>Step 3:</u> Create Rule Base (Contd.)

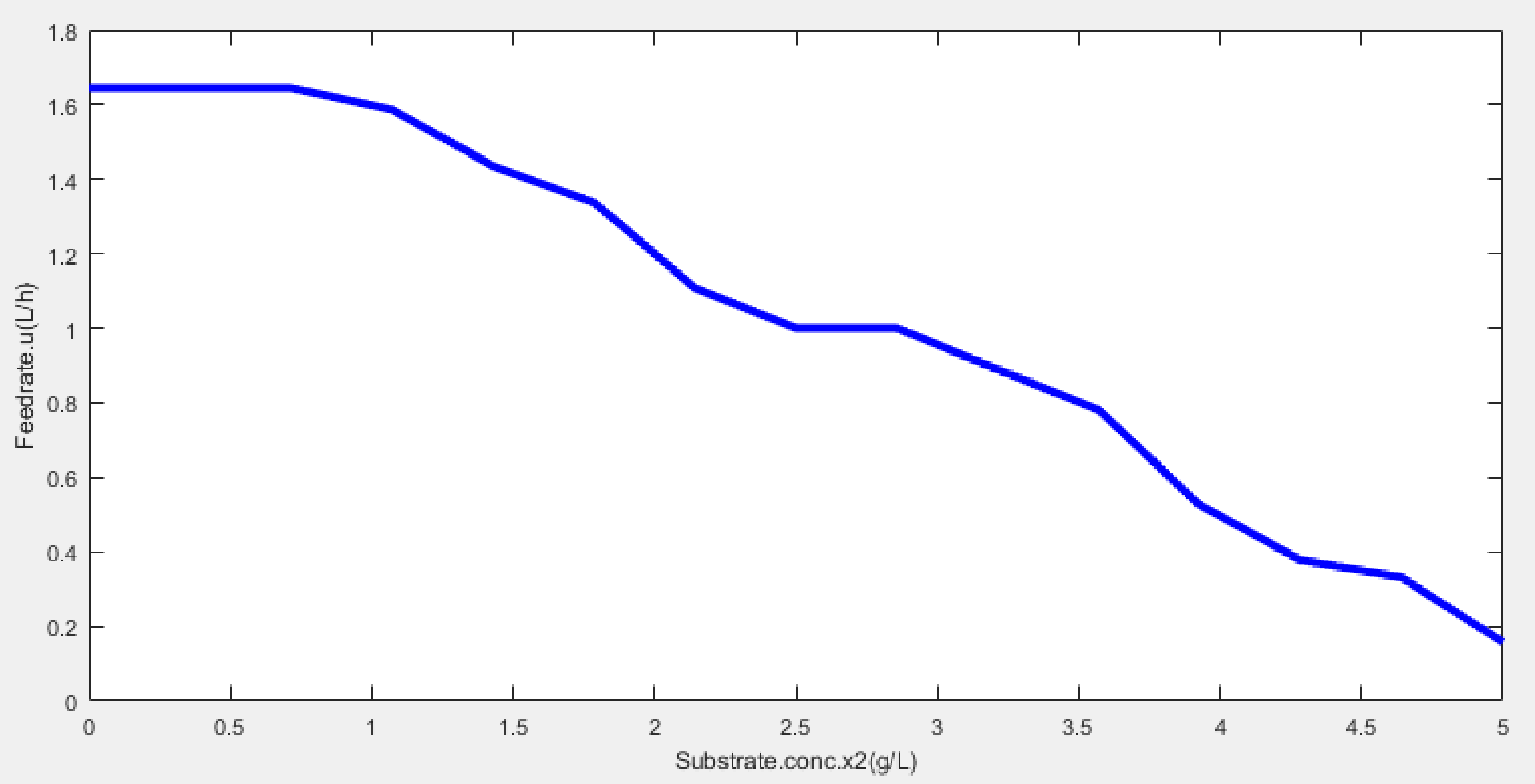

Fig. 10: Fuzzy Controller Surface plot

Fig. 12: Substrate concentration (X2) vs Flow rate (u) plot.

Design of Mamdani Fuzzy Controller (Contd.)

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- <u>Step 4:</u> Mamdani Fuzzy Controller + Bioreactor System (Simulink Block)

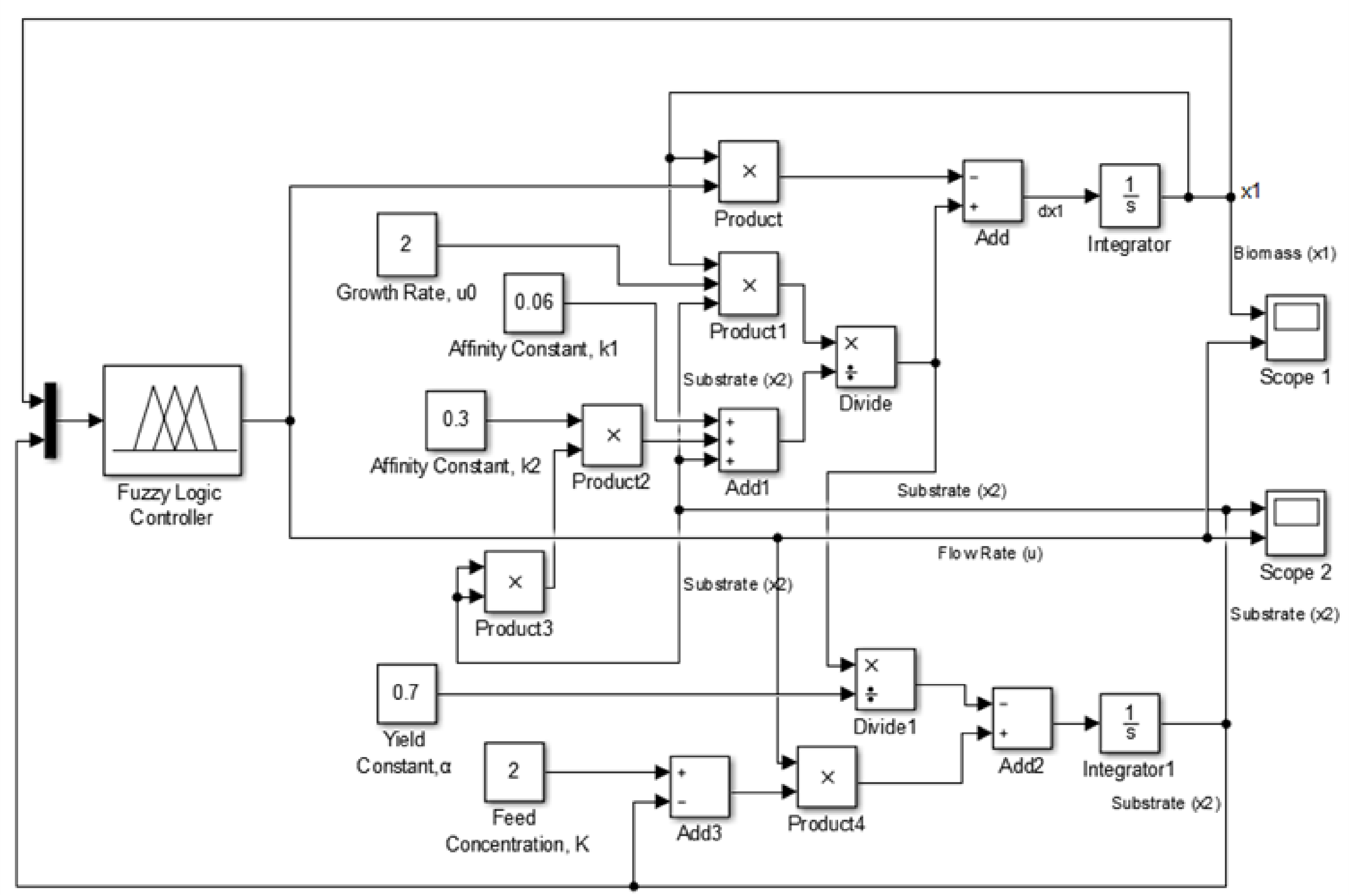

Fig. 13: Simulink diagram of Mamdani Fuzzy controller with Bioreactor system

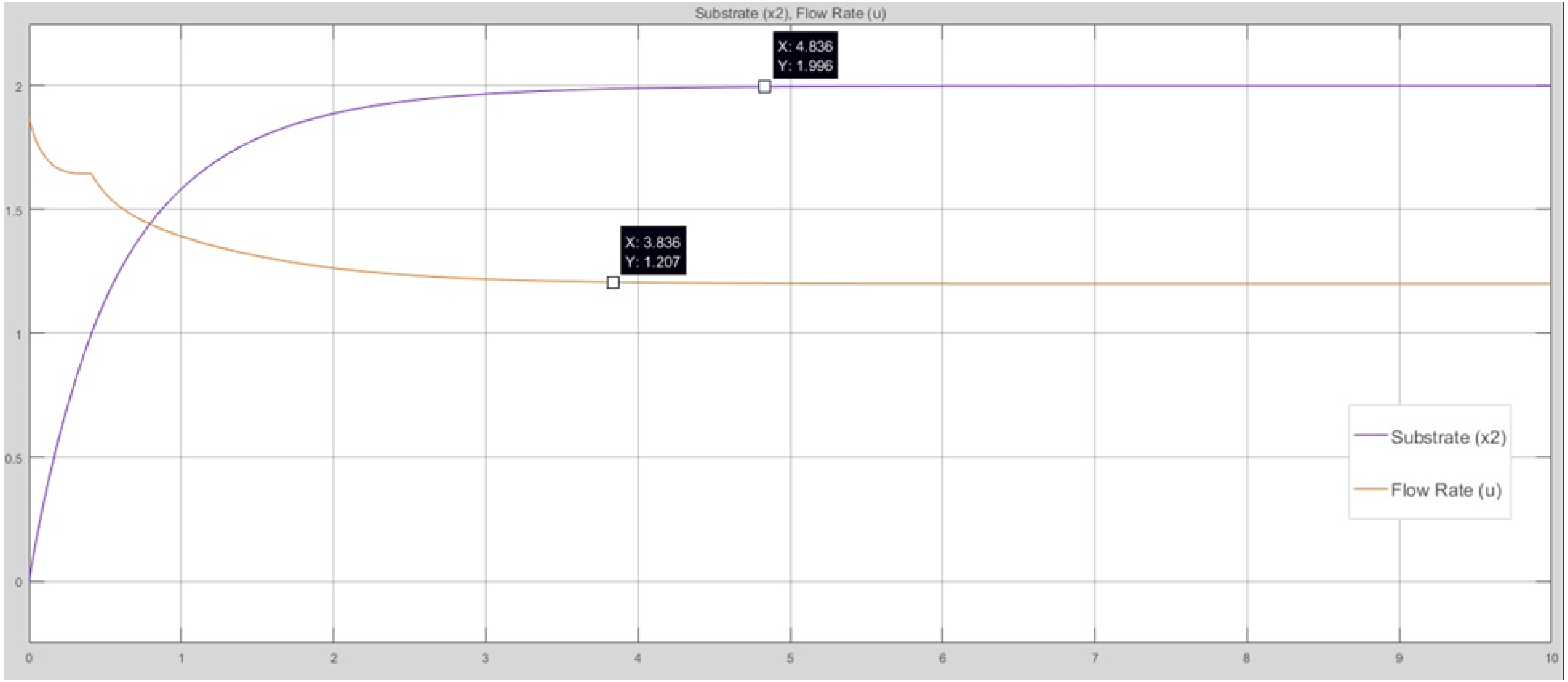

Fig. 14: Response of u and x2 of Bioreactor system with Mamdani Fuzzy controller

Comparison of Results with Linearized model

<table>
<tr><th colspan="4">Stabilization time for x1 & x2</th></tr>
<tr><td></td><td colspan="2">Linear Feedback Controller</td><td rowspan="2">Mamdani Fuzzy Controller</td></tr>
<tr><td></td><td>Poles at -2 ± 0.3j</td><td>Poles at -2 ± 5j</td></tr>
<tr><td>X1
(Biomass Concentration)</td><td>3.2 s</td><td>2.5 s</td><td>No response</td></tr>
<tr><td>X2
(Substrate Concentration)</td><td>3.2 s</td><td>2.5 s</td><td>4.8 s</td></tr>
</table>

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THANK YOU!

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