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Hybrid Model and Optimization of Bioreactor of Wastewater

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Abstract

This work deals with modeling and operation optimization of lab-scale continuous biochemical reactor. Wastewater is feeding to reactor contaminated with different concentration of glucose. The reactor is non-linear with stochastic changing in optimum operating conditions. Simulated model could develop the process and generate extra-confirmed data. The selected process variables are: dilution rate (D), feed substrate concentration (Si), pH and temperature (T). Simulated model could develop the process and generate extra-confirmed data. The effect of D was observed within Si of 20 g/L, while pH and T are affecting within Si of 60 g/L.Si has major effect on dynamic characteristics of the reactor. Reasonable agreement has been found when compared the simulated result with the previous work. Optimization technique helps the decision maker to select best operating conditions. This could reduce the risk of experimental runs and consumed cost for operating and design. Global Genetic algorithm (GA) has been found more reliable than deterministic search for the bioreactor. Optimization results are based on maximizing biomass growth. Optimal results indicate that maximum biomass concentration (X) is 80.57 g/L could be obtained at high value of Si (197.56 g/L) and low D (0.1hr-1).Si is sensitive variable for stochastic mutation of biomass growth.

Index terms— biochemical reactor; stochastic optimization; simulation.

1 Introduction

ee **??**1] and Kapadia etal. [2] described the concept and applications of the biochemical reactors.The stirred-tank bioreactor is one of the most commonly used types for large scale production in industrial applications such as food, pharmaceuticals, various commodity and specialty chemicals .It is used mainly in two modes: the continuous mode and the fedbatch mode.In the continuous mode, the limiting substrates are constantly added to the reactor, while the output stream is simultaneously removed at the same rate, to keep the reactor volume constant. The continuous stirred biochemical reactor is widely used in the treatment of liquid wastes.Its process kinetic can be characterized by the following reaction scheme: Substrate ? Biomass +Gas Henson [3] explained that as compared to conventional chemical reactors, bioreactors present Author: Chemical Engineering Department, University of Technology, Iraq. e-mail: ghanim.alwan@yahoo.com unique modeling and control challenges due to complexity of the underlying biochemical reactions.

Karadag and Puhakka [4] and Garhyan etal. [5] studied the bioreactor performance using mixed cultures influenced by several operational parameters which affect its static and dynamic behavior such as: dilution rate, feed substrate concentration pH, hydraulic retention time, organic loading rate and temperature. In particular, the role of pH seems the most important parameter in the regulation of enzymes pool production. Ruggeri etal. [6] indicated that the pH adjustments validated the dynamics of the system. Charoenchai, et al. [7] concluded that the temperature is a variable that directly affects the growth rate of organisms.

Annamalai and Doble [8] had found the mathematical modeling of fermentation process helps to; elucidate the mechanism of production process, estimate kinetic parameters such as specific growth rate of biomass and product formation rate develop the understanding between effects of operational conditions on production, and reduce laboratory experiments thereby saving time and resources.

Alhumaizi and Ajbar [9] and Shimizu [10] proved the biological processes are inherently very nonlinear and had frequently been changing optimum operating conditions. Many available mathematical models for biological reactions were not suitable for a control design since no accurate biological law had been proposed. Kapadia etal. [11] proposed a novel robust controller for a continuous stirred biochemical reactor that controls the culture dilution rate into the reactor in order to maximize a cost function representing the biomass yield.

Genetic algorithm (GA) is global stochastic search based on mechanics of natural selection and natural genetics.GA is based on Darwin's theory of 'survival of the fittest'. There are several genetic operators. Such as; selection, crossover and mutation?etc. Gupta and Srivastova [12] concluded that the deterministic algorithms for function optimization are generally limited to convex regular functions. However, many functions are either not differentiable or needed a lot of difficult mathematical treatment: decomposition, sensitivity computing?etc.

2 II.

3 Scope of the Work

The objective of this work is to simulated hybrid model for lab-scale biochemical reactor. Study of effect of effective process variables on dynamic behavior of the reactor. The system is non-linear with stochastic mutations in operating conditions. Reasonable simulated model can generate confirmed data for formulating the optimization problem. Stochastic globe genetic algorithm search is implementing to select the best operating conditions.

4 III.

5 Dynamic of Hybrid Model

Dynamic modeling for optimization and control requires models that describe the essential dynamic characteristics of the process under study. In the present work, the following assumptions have been adopted for the model:

1. Homogenous liquid-phase system. 2. Non-isothermal conditions.

3. Acidity of water is variable. 4. Pseudo first order irreversible reaction. 5. Constant hold-up. 6. Follow the Monod law.dX/d t = r1-(F/V) X (1) dS/dt = (F/V) Si -(F/V) S-r2**(2)**

In addition, the reaction rate equations are:r1=µ(s) X1**(3)**

And, Y = r1/r2 (4)

For Monod law;µ(s) = (µmax *S)/ (Km+S)**(5)**

?max=-40.5+11.78pH-0.0691pH^2+1.65T+0.003T^2-0.468pH.T

Equations (1&2) can be simplified to:dX/dt = (µ(s) -D)X (7) dS/dt = D (Si -S) -(X/Y)µ(s)**(8)**

Where D=F/V Eq.6 was correlated depended on the experimental data of Lopez etal. [13].Eqs.6, 7 and 8 represent the hybrid model of reactor.

The simulated model will implement for the wastewater contains glucose with different concentrations from 6.0 to 200.0 gm/L. Temperature of water are varied from 20 to 30 C° and the acidity are from pH2 to pH4.The kinetic parameters of the biological reaction are; maximum specific growth rate coefficient (µmax=0.3 hr-1), saturation constant (Km=1.0 g/L) and yield (Y=0.4) depended on the results of Lopez etal. [13] ,Cutlip and Shacham [14].

IV.

6 Results and Discussion

7 a) Optimal operating Conditions

The initial optimal operating conditions of the system (Table 1) were estimated by the nonlinear Levenberg-Marquardt method with the aid of the MATLAB computer program. The present bioreactor can be viewed as nonlinear dynamic system and the simulation is very useful tool for model validation .The unsteady-state model (Eqs. 7 and 8) are solved numerically using 4th order Runge-Kutta method with the aid of the MATLAB program, starting from steady-state operating conditions (Table1). Figs. 1-7 explain the behaviors of the biochemical process under different operating conditions. Dynamically, the system behaves as the firstorder lag system. The dynamic model appears that the biomass concentration curves have S-shape and more sluggish when compared with the substrate curves, which have an exponential shape because of the rate of consumed substrate is more than the rate of biomass cell generation in the reactor. The response speed of the biomass and substrate curves increase with Si and decreases with D as shown in Figs.1,2 and 3.The intersection point between two curves indicates to the local optimal point of the system, where the concentration of the biomass equal to that of the substrate. These points are depending on the operating conditions. The concentration of the biomass in the reactor decreases with increasing D (Fig. **??**a) for low and high Si. In the contrast, the increasing of Si increases the concentration of biomass in the reactor as shown in Fig. **??**b.This is due to the fact; that Si has a positive effect on the specific growth rate constant (µ) regarding to the Monod law (Eq.5).While the increasing of D tends to increase the dilution of the substrate which could moderate the growth rate then reduces the concentration of the biomass in the biochemical reactor. The sensitivity of the process (steady-state gain) against Si (Fig. **??**b) is more than that with D (Fig. **??**a).The effect of Si is more pronounced at low D as shown in Figure **??**. Jarzebski

[15] also concluded these behaviors. Reasonable result can observe when compared the simulated results with these obtained by Cutlip and Shacham [14] as shown in the Fig. 9 .The deviation is about 8%.This indicates that the proposed simulated model is agreed for the present biochemical reactor. Therefore, the reliable model could use to generate the desirable data for formulating the optimization equation. The available simulated data have been used to correlate the objective (concentration of biomass) with the decision variables to facilitate the optimization scheme. The selected effective decision variables are; dilution rate (D) and inlet concentration of substrate (Si). Nonlinear regression (Levenberg-Marquardt) method was implemented with the aid of the computer program (Statistica version10). The optimization equation is: X=0.409 Si -0.575D-0.028DSi +0.02 (9) Subject to inequality constraints: 6.0? Si ? 200 (10) 0.1? D ?0.8

Eq.9 indicates that the dilution rate (D) has negative effect on the biomass concentration while the inlet concentration of substrate (Si) has positive effect.

8 d) Optimization Technique

The objective is to maximize the biomass concentration in the reactor. The optimization equation (Eq. 9) is interacted and nonlinear, so that the deterministic search is unsuccessful. GA has been found suitable for the present biochemical process. GA is stochastic global search based on mechanics of natural selection. Fig. 9 illustrates the results/solution of the algorithm scheme. The parameters of the GA were adapted, and the selected operators are suitable for solving the problem to obtain the best optimal values. Hybrid function implemented as the combined search between genetic algorithm and pattern search to refine the values of decision variables. 51 generations occurred regarding to the nonlinearity of the process. The adapted operators of GA are explained in the Table **??**. Table **??** explains the best operators of the genetic algorithms. Fig. 10 illustrates the outputs of the algorithms solutions/operators of genetic algorithm.GA is implemented with the pattern search by using the hybrid function as shown in Table **??** to refine the decision variables .The best fitness, best function and score histogram as shown in Figure 10 illustrate that the maximum biomass concentration is 80.57 g/L.The histogram of decision variables indicates that the optimal values are; Si=197.56 g/L (variable 1) and D=0.1hr-1 (variable 2), which are within the limit of inequality constraints (Eq.10). The histogram of the variables in Fig. 10 indicate that Si (variable 1) is the effective variable on X. Due to the nonlinearity of the bioreactor process, the optimization equation(eq. 9) was solved by (51) generations as shown in Fig. 10. The optimal sets of the decision variables are illustrated in Figs.11a and 11b corresponding to the objective X.The scattering and stochastic of the results are appeared in these figures as a results of natural selection by GA .It is found that the optimal values of the dilution rate (D) is approximately constant within its lower bound as explained in Fig. 11a.Inlet substrate concentration (Si) is more sensitive to the optimal objective change(X) as shown in Fig. 11b .This is because of that Si is the effective variable on X as shown in Fig. 10.Si is changed within its upper bound (Fig. 11b).These behaviors are because of Si has positive effect while D has negative effect on X as shown in the Eq. 9.This confirmed by Alwan [16] .Optimal values of the two decision variables are stayed within optimal value of X, which equal to 80.57 g/L as shown in Fig. 11. V.

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10 Conclusions

Simulated model helps study of dynamic characteristics of the biochemical reactor. Reliable model could use to generate extra data in the case of unavailable experimental results. Effect of dilution rate was observed at low feed substrate concentration that is within 20 g/L. Effect of pH and temperatures were observed within concentration of 60 g/L. Feed substrate concentration has been found effective process variable on the growth rate of the biomass cell in the reactor. Maximum concentration of the biomass cell could be obtained at high concentration of substrate and low dilution rate. Feed substrate concentration is more sensitive to stochastic mutations of the biomass concentration. Reasonable agreement has been obtained when compared the simulated results with the previous work. Stochastic genetic algorithm has been found best global search for the nonlinear biochemical reactor process.

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Figure 1: © 8 CeFig. 2 : 8 GlobalFig. 3 :

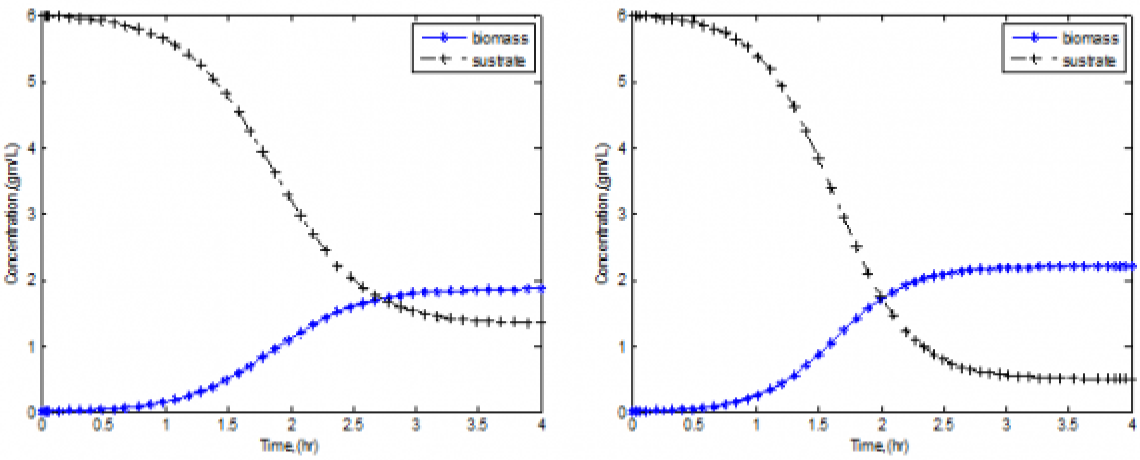

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Figure 2: Fig. 4 :Fig. 5 :Fig. 6 :Fig. 7 :Fig. 8 :

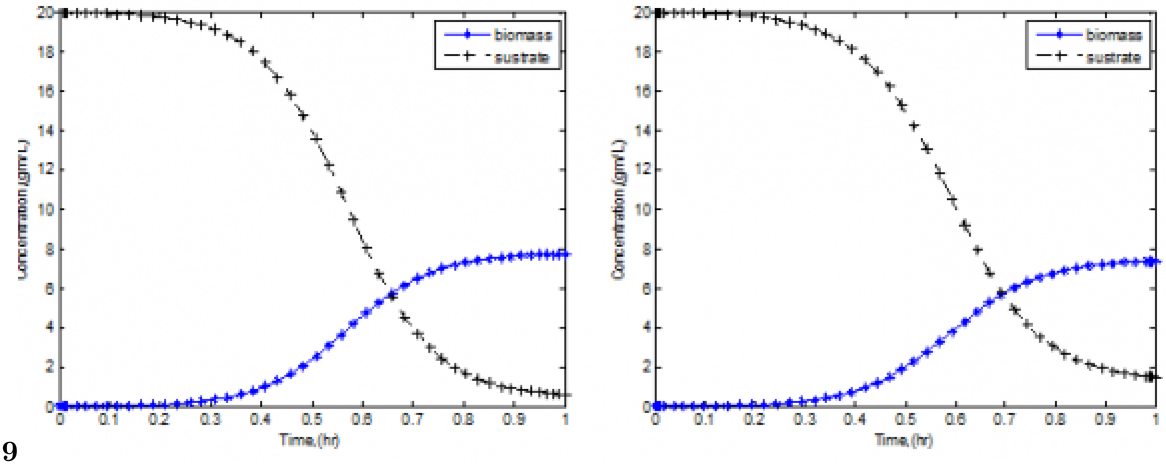

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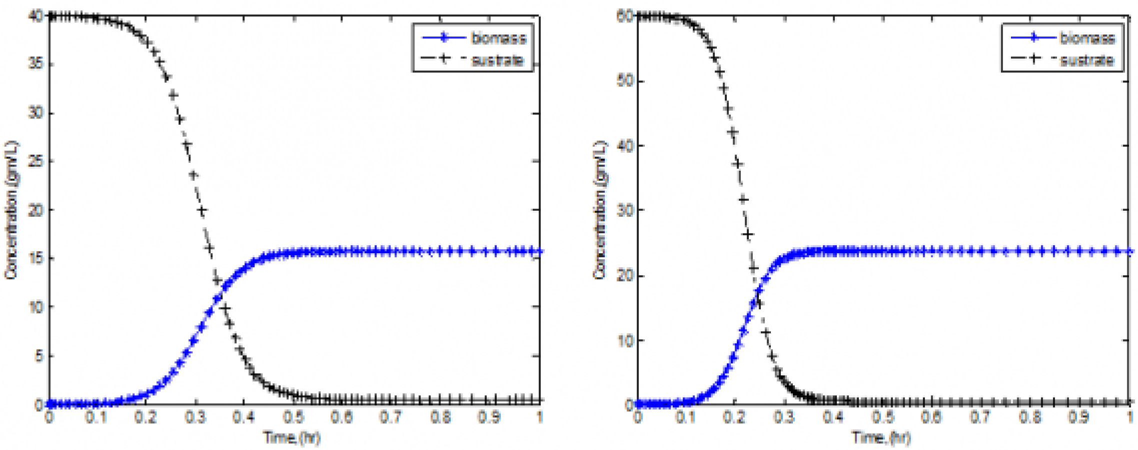
Figure 3: Fig. 9 :



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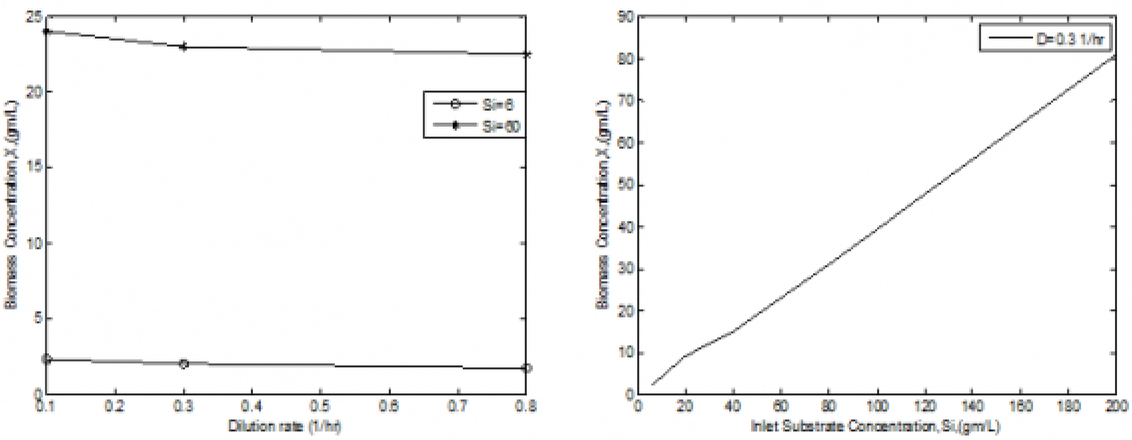

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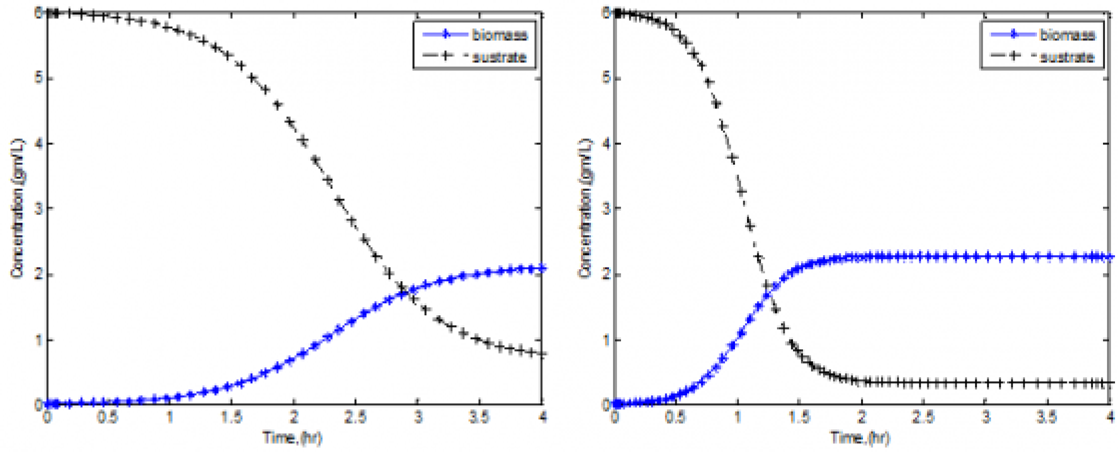

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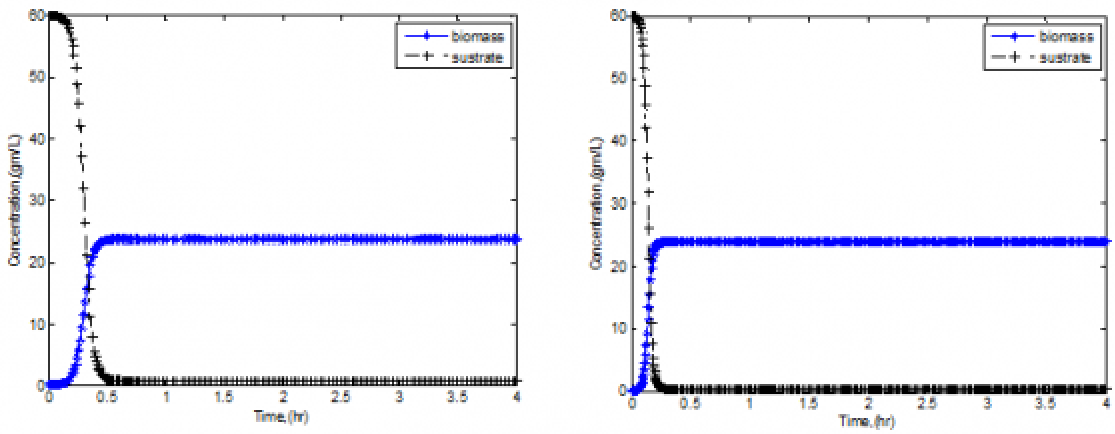
Figure 6: Fig. 11 :



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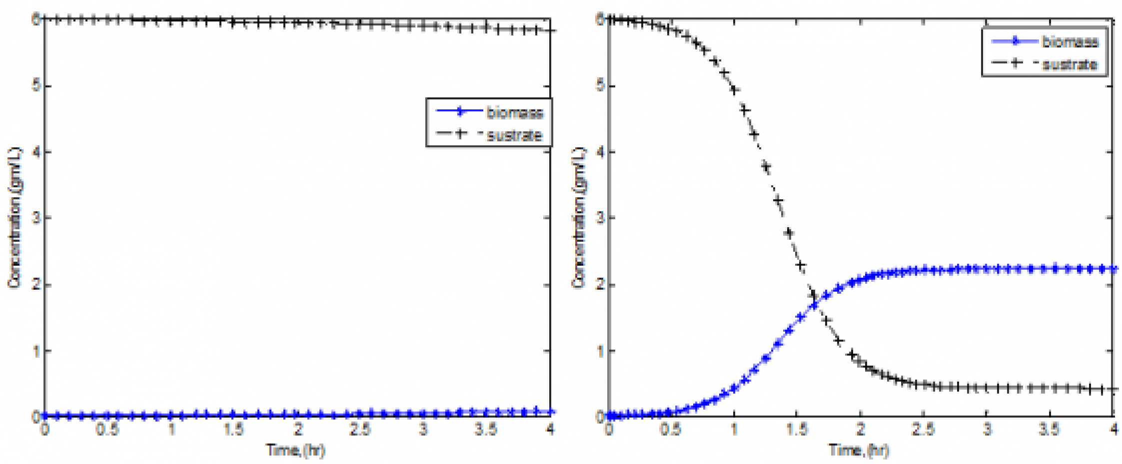

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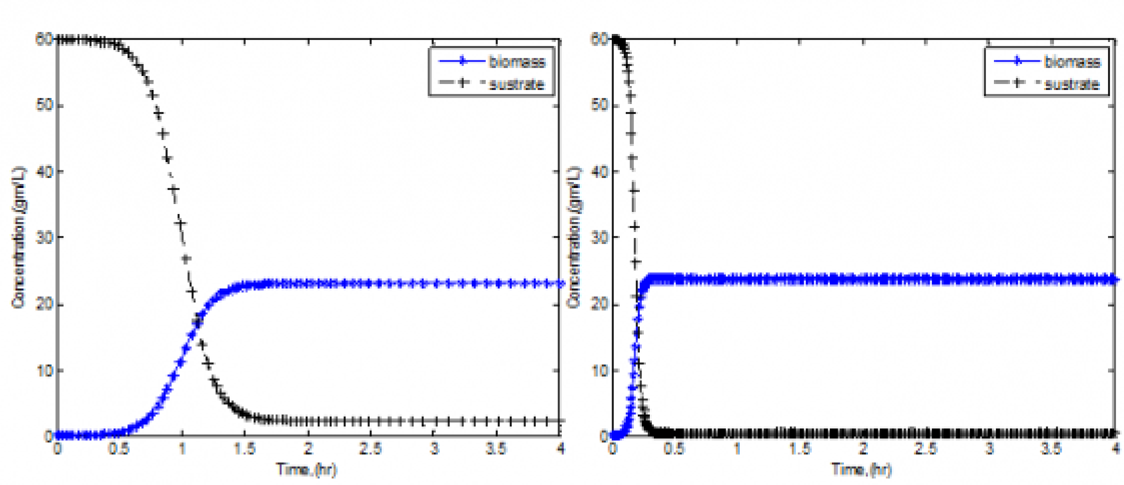

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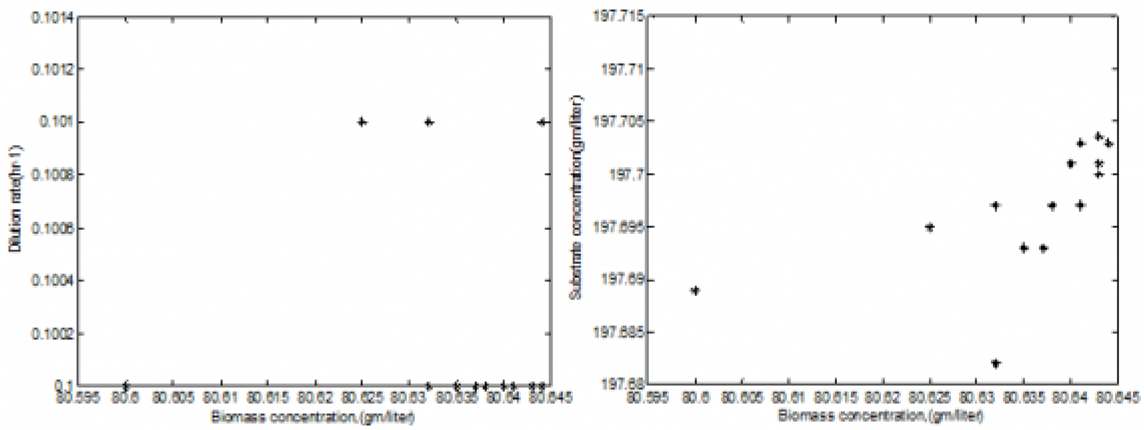

Figure 10:

1

X(gm/l)	Si(gm/l)	D(hr -1)	Y(-)	μ(1/hr)
0.001	6.0	0.3	0.4	0.4

b) Unsteady State Conditions

Figure 11: Table 1 :

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[Nomenclatures] 'Km: Saturation constant'. D Nomenclatures . r1: Rate. *Dilution rate*, (L/hr. g/L.hr] r2: Rate of substrate consumption. g/L.hr] S: Substrate concentration in the reactor. g/L] T: Temperature, [C°)

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[X: Biomass concentration in the reactor] *X: Biomass concentration in the reactor*,