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Mathematical Modelling of Stereo Selective Synthesis of (1s,2s)-1-Phenylpropane-1,2-Diol By Cell-Freeextract of Lactobacillus Brevis

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Abstract

Mathematical modelling of the mass balance equation of a batch reactor is developed on the basis of (1S, 2S)-1-PPD production and (S)-2-HPP reduction with and without coenzyme regeneration. The reaction rate equations are containing the nonlinear term based on this model. The enzymes are kinetically characterized and the kinetics are determined by using the initial rate method. The nonlinear batch reactor rate equations are solved analytically by using the new homotopy perturbation method (NHPM). In graphically, the effects of various kinetic parameters of all the concentrations are discussed. The relations between all the concentrations are also discussed. Comparing the analytical and simulation results (Scilab program) satisfactory result is achieved.

Keywords: *Stereoselective Synthesis, Phenylpropane 1,2-diolproduction, Coenzymes, Mathematical modelling, Homotopy perturbation method.*

1. Introduction

In chemistry and biochemistry, the stereoselective synthesis process plays an important role to form an unequal mixture of products in a single reactant. Presecki et. al. [1-3] discussed the various elements of the stereoselective synthesis process in chemical sciences by using mathematical modelling. Finniganet. al. [4] conferred the enzyme biotransformation process using mathematical modelling and characterized enzyme parts.

Presecki et. al. [5] and Findrik et. al. [6] conferred that the mathematical modeling of coenzyme regeneration is continuously operated in the enzyme membrane reactor. Tuesket. al. [7] represents the mathematical models of alcohol dehydrogenase-catalyzed hexanol oxidation in a microreac tor and Preseckiet. al [8] developed the modelling of the alcohol dehydrogenase production in baker's yeast.Findrik et. al. [9] developed the mathematical modelling of enzymatic oxidation catalyzed by amino acids. Pavithra et. al. [10] discussed the mathematical models of biotransformation of amino acids and dehydrogenase of formate. Kirthigaet. al. [11] derived a mono enzymatic biosensor analytical approach involving Michaelis–Menten kinetics.

Kirthigaet. al [12] solved the mathematical modelling and kinetics of microchannel reactor. Recent work has been carried out on a theoretical model of enzyme reactions for various analytical methods (HPM, HAM, VIM and ADM) to solving nonlinear differential equations in biosensors [13, 14]. Visuvasam et al. [15] derived an analytical expression of the electrochemical reaction in a porous rotating disk electrode using homogony perturbation method.

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In this paper we have obtain the concentrations of hydroxypropiophenone, phenylpropane-1,2-diol, NADPH, $NADP^+$, alcohol and ketone by solving the nonlinear rate equations using new approach of homotopy perturbation method.

2. The Mathematical Formulation of the Problem

The reaction scheme of phenylpropane 1,2-diolproduction without and with coenzyme regeneration for batch reactor is shown in Figs. 1 and 2.

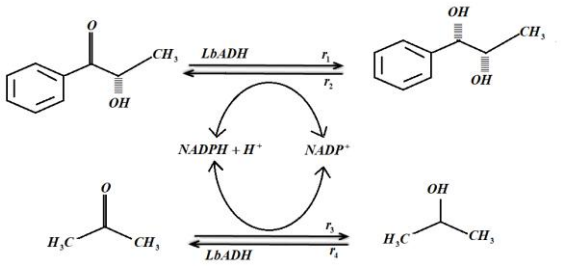

Figure 1: The reaction scheme of (S)-2-HPP reduction with coenzyme regenerationby isopropanol oxidation [16].

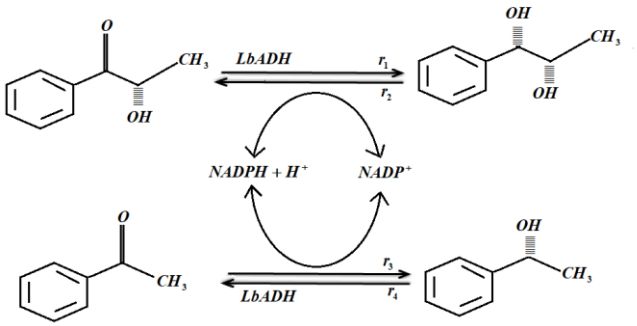

Figure 2: The reaction scheme of (S)-2-HPP reduction with coenzyme regeneration by (R)-1-phenylethanol oxidation [16].

The mass balance equation of hydroxypropiophenone, phenylpropane-1,2-diol, NADPH, $NADP^+$ alcohol and ketonecan bewritten as follows [16].

$$\frac{dc_{HPP}}{dt} = -r_1 + r_2 \tag{1}$$

$$\frac{dc_{PPD}}{dt} = r_1 - r_2 \tag{2}$$

$$\frac{dc_{NADPH}}{dt} = -r_1 + r_2 + r_3 - r_4 \tag{3}$$

$$\frac{dc_{NADP^+}}{dt} = r_1 - r_2 - r_3 + r_4 \tag{4}$$

$$\frac{dc_{alcohol}}{dt} = -r_3 + r_4 \tag{5}$$

$$\frac{dc_{ketone}}{dt} = r_3 - r_4 \tag{6}$$

where $c_{HPP}, c_{PPD}, c_{NADPH}, c_{alcohol}, c_{ketone}$ are the concentrations ofhydroxypropiophenone, phenylpropane-1,2-diol, NADPH, $NADP^+$, alcohol and ketone.

The kinetic equation for the given reaction given below [16]:

$$r_1 = \frac{V_{m1}\,\varphi_{Lb}\,c_{HPP}\,c_{NADPH}}{\left[c_{HPP} + K_m^{HPP}\left(1+\left(c_{alcohol}/K_{i1}^{alcohol}\right)\right)\right]\left[c_{NADPH} + K_{m1}^{NADPH}\right]} \tag{7}$$

$$r_2 = k\,\varphi_{Lb}\;c_{PPD}\,c_{NADP^+} \tag{8}$$

$$r_3 = \frac{V_{m3}\,\varphi_{Lb}\,c_{alcohol}c_{NADP^+}}{\left[c_{alcohol} + K_m^{alcohol}\left(1+\left(c_{ketone}/K_i^{ketone}\right)+\left(c_{HPP}/K_i^{HPP}\right)\right)\right]\left[c_{NADP^+} + K_{m3}^{NADP^+}\left(1+\left(c_{NADPH}/K_{i3}^{NADPH}\right)\right)\left(c_{NADP^+}^2/K_{is}^{NADP^+}\right)\right]} \tag{9}$$

$$r_4 = \frac{V_{m4}\,\varphi_{Lb}\,c_{ketone}\,c_{NADPH}}{\left[c_{ketone} + K_m^{ketone}\left(1+\left(c_{alcohol}/K_{i4}^{alcohol}\right)+\left(c_{ketone}^2/K_{is}^{ketone}\right)\right)\right]\left[c_{NADPH} + K_{m4}^{NADPH}\left(1+\left(c_{NADP^+}/K_{i4}^{NADP^+}\right)\right)\right]} \tag{10}$$

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Initial conditions are

$$(c_{HPP})(t)=(c_{HPP})_i,\ c_{PPD}(t)=(c_{PPD})_i, c_{NADPH}(t)=(c_{NADPH})_i, c_{NADP^+}(t)=(c_{NADP^+})_i,$$
$$c_{alcoho}(t)=(c_{alcohol})_i, c_{ketone}(t)=(c_{ketone})_i \quad at \quad t=0$$
(11)

3. Approximate Analytical Expressions of Concentrations.

Most of the mathematical modelling problems of physics, chemistry, engineering and biology are developed in the form of linear and nonlinear differential equations. These equations are solved analytically by using various methods like HPM, HAM, VIM and ADM. Here HPM was extensively used to solve problems of nonlinear boundaries and initial values because of many researchers had great interest to this method. Initially, JiHuan He[17-19] was developed in this method. In HPM, complicated problems are deformed continuously into simple problems that are an easy way to solve and obtain an analytical or approximate solution [20].Iswarya et. al. [21, 22] solved rate equations in batch reactor by using NHPM. We can obtain the concentrations of hydroxypropiophenone, phenylpropane-1,2-diol, NADPH, $NADP^+$, alcohol and ketone using this method as follows (Appendix A):

$$c_{HPP}(t)=b_1/a_1+\left[(c_{HPP})_i-(b_1/a_1)\right]e^{-(a_1t)}$$
(12)

$$c_{PPD}(t)=a_2/b_2+\left[(c_{PPD})_i-a_2/b_2\right]e^{-(b_2t)} \quad (13)$$

$$c_{NADPH}(t)=g_2/g_1+\left[(c_{NADPH})_i-(g_2/g_1)\right]e^{-(g_1t)}$$
(14)

$$c_{NADP^+}(t)=g_3/g_4+\left[\left(c_{NADP^+}\right)_i-(g_3/g_4)\right]\ e^{-(g_4t)}$$
(15)

$$c_{alcohol}(t)=f_2/d_3+\left[(c_{alcohol})_i-(f_2/d_3)\right]e^{-(d_3t)}$$
(16)

$$c_{ketone}(t)=d_1/f_3+\left[(c_{ketone})_i-(d_1/f_3)\right]e^{-(f_3t)}$$
(17)

where

$$a_1=a(c_{NADPH})_i, b_1=b(c_{PPD})_i(c_{NADP^+})_i, a_2=a(c_{HPP})_i(c_{NADPH})_i, b_2=b(c_{NADP^+})_i,$$
$$a_3=a_1(c_{HPP})_i, d_1=d(c_{NADP^+})_i(c_{alcohol})_i, f_1=f(c_{ketone})_i, a_4=a(c_{HPP})_i(c_{NADH})_i,$$
$$b_3=b(c_{PPD})_i, d_1=d(c_{alcohol})_i, f_2=f(c_{ketone})_i(c_{NADPH})_i, b_3=b(c_{diol})_i(c_{NAD^+})_i,$$
$$d_3=d(c_{NADP^+})_i, b_4=b(c_{diol})_i, g_1=a_3+f_1, g_2=b_1+d_1, g_3=a_2+f_2, g_4=b_3+d_2$$
(18)

$$a=\frac{V_{m1}\varphi_{Lb}}{\left[(c_{HPP})_i+K_m^{HPP}\left(1+((c_{alcohol})_i/K_{i1}^{alcohol})\right)\right]\left[(c_{NADPH})_i+K_{m1}^{NADPH}\right]}$$
(19)

$$b=k\varphi_{Lb}$$
(20)

$$d=\frac{V_{m3}\varphi_{Lb}\left[(c_{NADP^+})_i+K_{m3}^{NADP^+}\left(1+((c_{NADPH})_i/K_{i3}^{NADPH})\right)((c_{NADP^+}^2)_i/K_{is}^{NADP^+})\right]^{-1}}{\left[(c_{alcohol})_i+K_m^{alcohol}\left(1+((c_{ketone})_i/K_i^{ketone})+((c_{HPP})_i/K_i^{HPP})\right)\right]}$$
(21)

$$f=\frac{V_{m4}\varphi_{Lb}\left[(c_{NADPH})_i+K_{m4}^{NADPH}\left(1+((c_{NADP^+})_i/K_{i4}^{NADP^+})\right)\right]^{-1}}{\left[(c_{ketone})_i+K_m^{ketone}\left(1+((c_{alcohol})_i/K_{i4}^{alcohol})+((c_{ketone}^2)_i/K_{is}^{ketone})\right)\right]}$$
(22)

4. Numerical Simulation

In numerically the nonlinear differential equations (1)-(6) are solved. In Scilab software, the function pdex4 is used for solving the differential equations. The Scilab coding is given in Appendix B. Our analytical results for the concentrations of hydroxypropiophenone, phenylpropane-1,2-diol, NADPH, $NADP^+$, alcohol, and ketone using the Eqns. (12)-(17) are compared with the simulation (Scilab program 4.1) program. It is represented in Figs. (3)-(8). For all values of t satisfactory results are achieved.

5. Result and Discussion

Eqns. (12)-(17) represents the new approximate analytical expression of the concentrations. Also from the Eqns. (1) and (2), (3) and (4), (5) and (6) we get the following relations.

$$c_{HPP}(t)=\left[(c_{HPP})_i+(c_{PPD})_i\right]-c_{PPD}(t)$$
(23)

$$c_{NADPH}(t)=\left[(c_{NADPH})_i+\left(c_{NADP^+}\right)_i\right]-c_{NADP^+}(t)$$
(24)

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$$c_{alcohol}(t) = \left[(c_{alcohol})_i + (c_{ketone})_i \right] - c_{ketone}(t) \quad (25)$$

From the fig 3 it is inferred that the concentration of hydroxypropiophenone decreases when V_{m1}, φ_{Lb} increases and K_{m1}^{NADPH}, K_m^{HPP}, k decreases. The concentration of hydroxypropiophenonehas no significance difference for the values of the parameter $K_{i1}^{alcohol}$.

The reverse process is taken forthe concentration of C_{PPD} (phenylpropane-1,2-diol) (Figure 4).

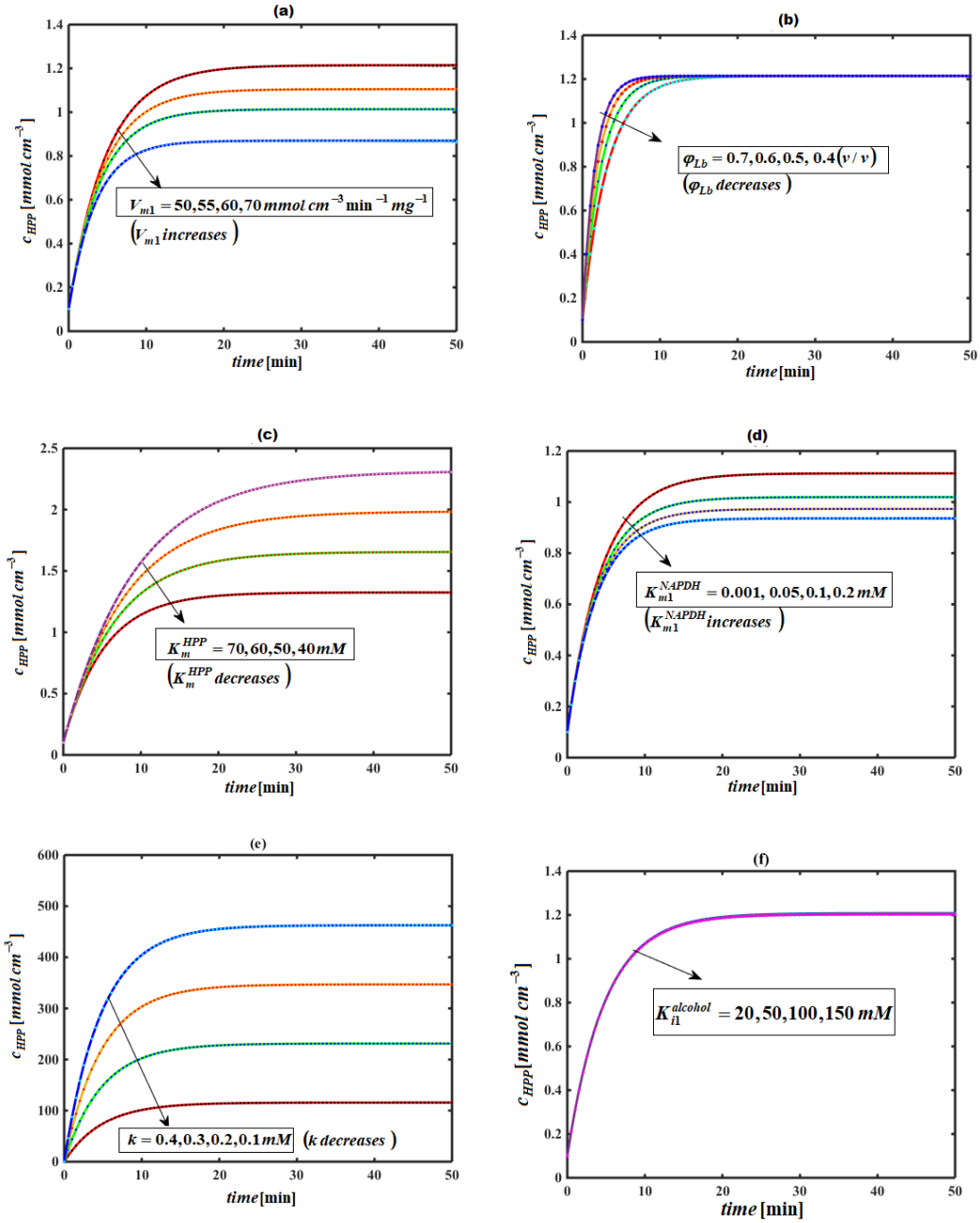

Figure 3: Comparison between the analytical expression of concentration of hydroxypropiophenone (Eqn. (12)) and the simulation results in several parameters.

Key to the graph:The hard and sprinkled line represents the Eqn. (12) and numerical results respectively

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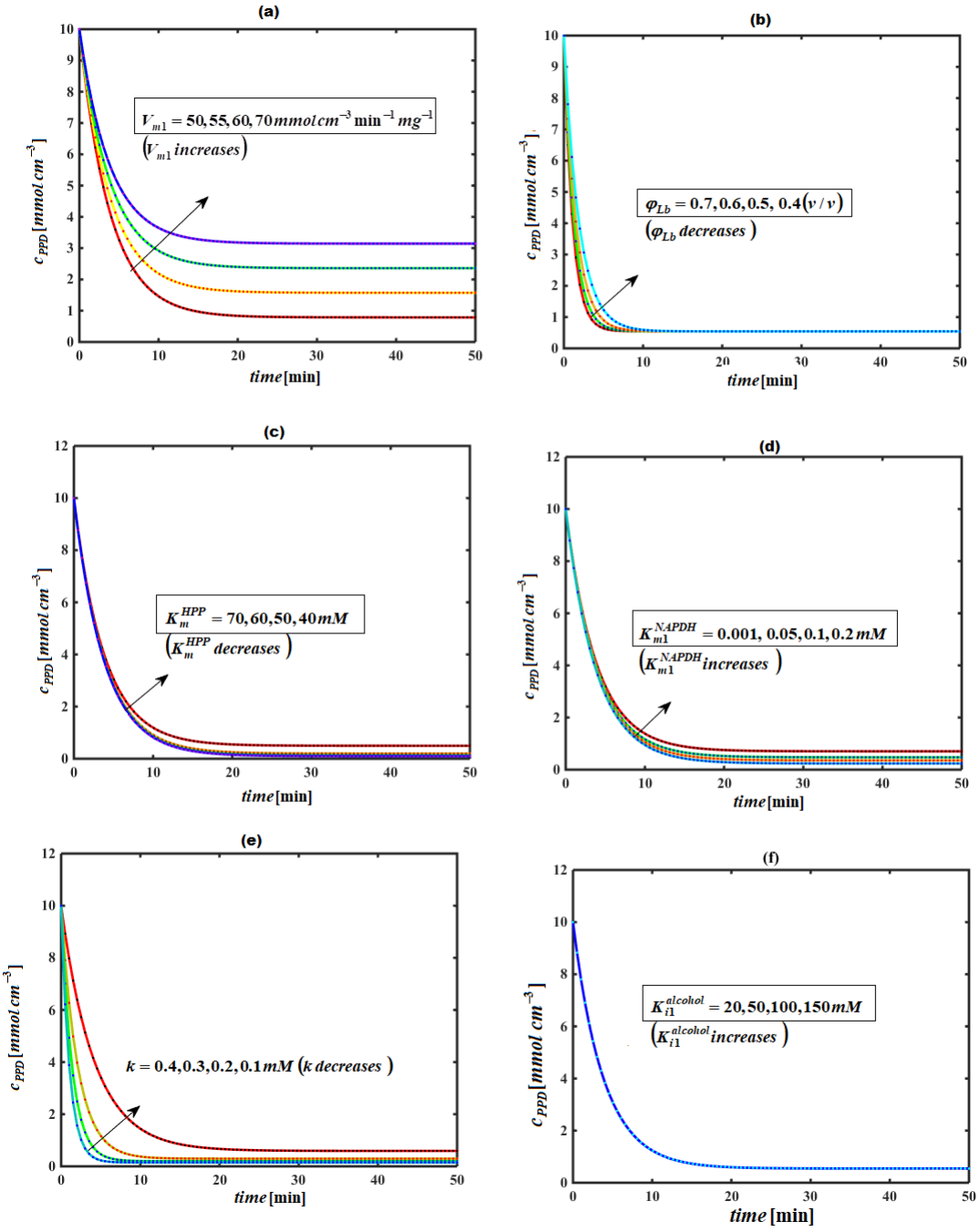

Figure 4: Comparison between the analytical expression of concentration of phenylpropane-1,2-diol (Eqn. (13)) and the simulation results in several parameters.

Key to the graph: The hard and sprinkled line represents the Eqn. (13) and numerical results respectively

Figures 5 and 6 shows that the concentration of NADPH and $NADP^+$for various value of parameters.It is observed from figure 5 that the concentration of nicotinamide adenine dinucleotide phosphate initially rises from the initial value at the time t=5 for different values of other parameters reach the steady-state.The steady state value of NADPH increases when $V_{m1}, K_{i1}^{alcohol}$ decreases and $\varphi_{Lb}, K_m^{HPP}, K_{m1}^{NADPH}$,

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$k, K_m^{alcohol}, K_i^{ketone}$, K_{i3}^{NADPH} increases. The concentration decreases when V_{m3}, K_i^{HPP}, $K_{i3}^{NADPH}, K_{iS}^{NADP^+}$ decreases. There is no significance change when $V_{m4}, K_{m4}^{NADPH}, K_{i4}^{NADP^+}$, $K_{i4}^{alcohol}, K_m^{ketone}, K_{iS}^{ketone}$ increases. This function has a reverse property of the concentration of $NADP^+$(Figure 6).

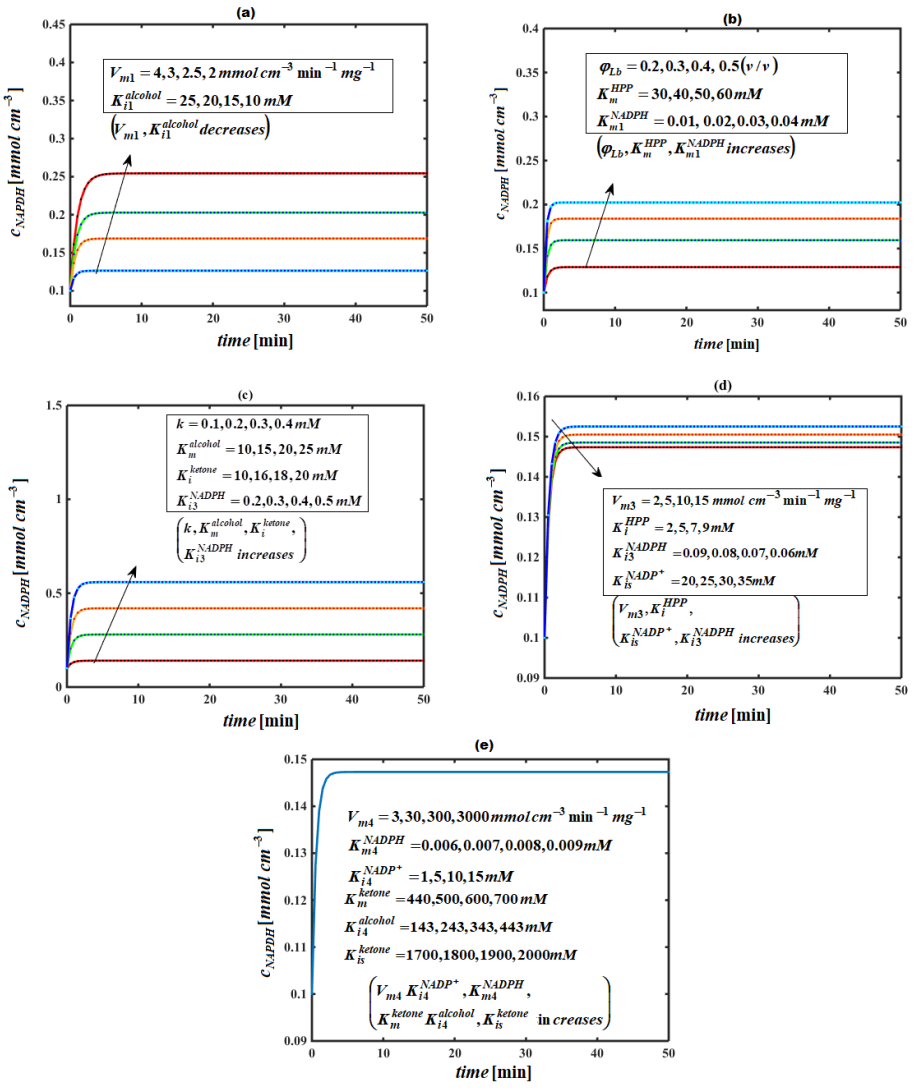

Figure 5: Comparison between the analytical expression of concentration of NADPH (Eqn. (14)) and the simulation results in several parameters.

Key to the graph: The hard and sprinkled line represents the Eqn. (14) and numerical results respectively.

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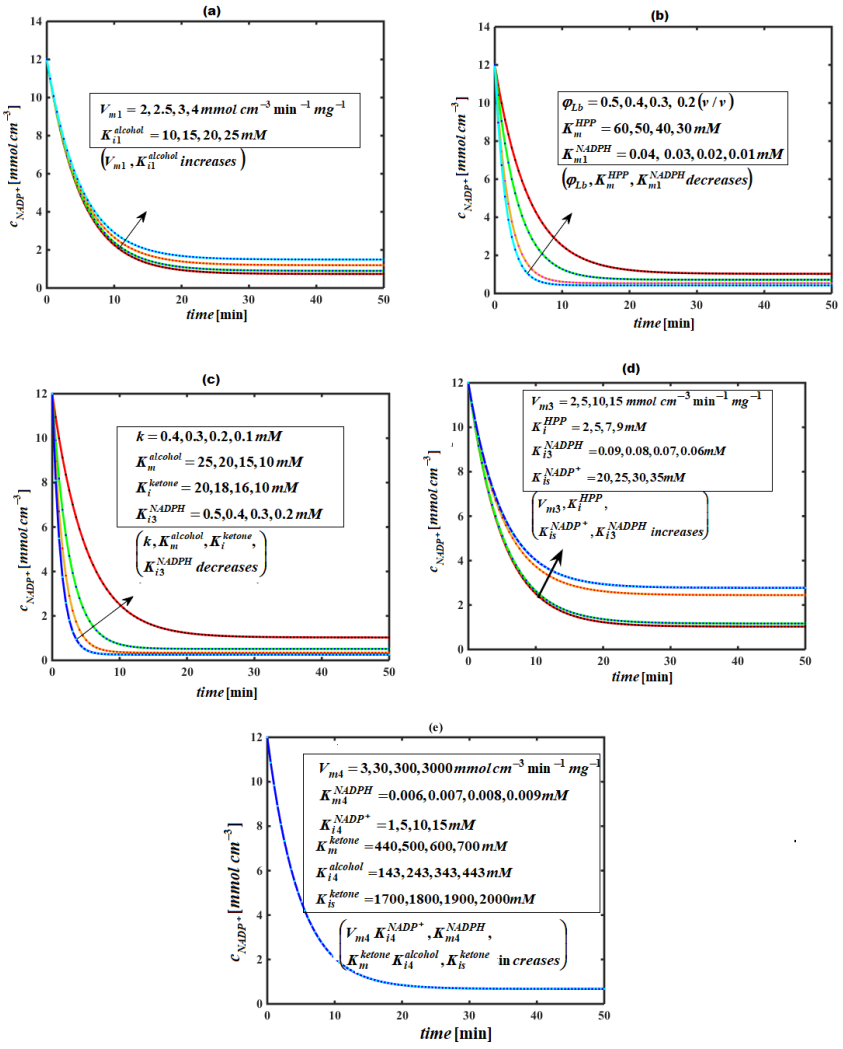

Figure 6: Comparison between the concentration of analytical expression of $NADP^+$(Eqn. (15)) and the simulation results in several parameters.

Key to the graph: The hard and sprinkled line represents the Eqn. (15) and numerical results respectively.

Figure 7 and 8 represents the concentration ofalcohol and ketone for various values of parameters. From figure 7 it is observed that the concentration of alcohol initially rises from the initial value and reaches the steady state at time t=20 for various values of other parameters. The concentration of alcohol increases when $K_m^{alcohol}, K_i^{HPP}, \varphi_{Lb}\ K_{m4}^{NADPH}, K_{i4}^{NADP^+}, V_{m4}$ increases and $V_{m3}, K_i^{ketone}, K_{m3}^{NADP^+}, K_{i3}^{NADPH}, K_{iS}^{NADP^+}$ decreases. The concentration of alcohol decreases when $K_m^{ketone}, K_{i4}^{alcohol}, K_{is}^{ketone}$decreases. The concentration of ketone has a reverse property of theconcentration of alcohol(figure 8 (a)-(d)). From figure 8 (e) inferred that the concentration of ketone has no significance change when $K_{m3}^{NADP^+}, K_{i3}^{NADPH}, K_{iS}^{NADP^+}$ increases.

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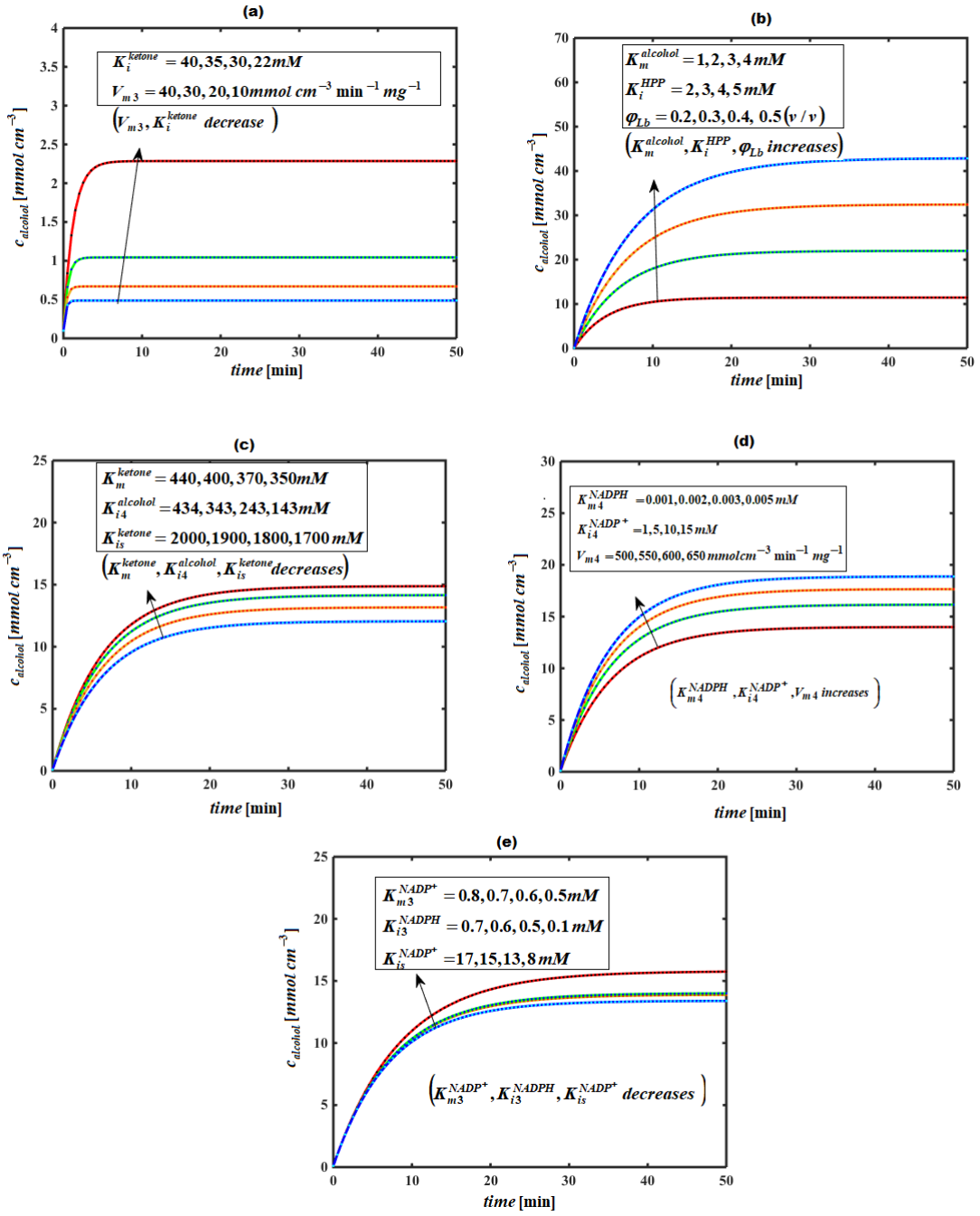

Figure 7: Comparison between the analytical expression of concentration of alcohol (Eqn. (16)) and the simulation results in several parameters.

Key to the graph: The hard and sprinkled line represents the Eqn. (16) and numerical results respectively

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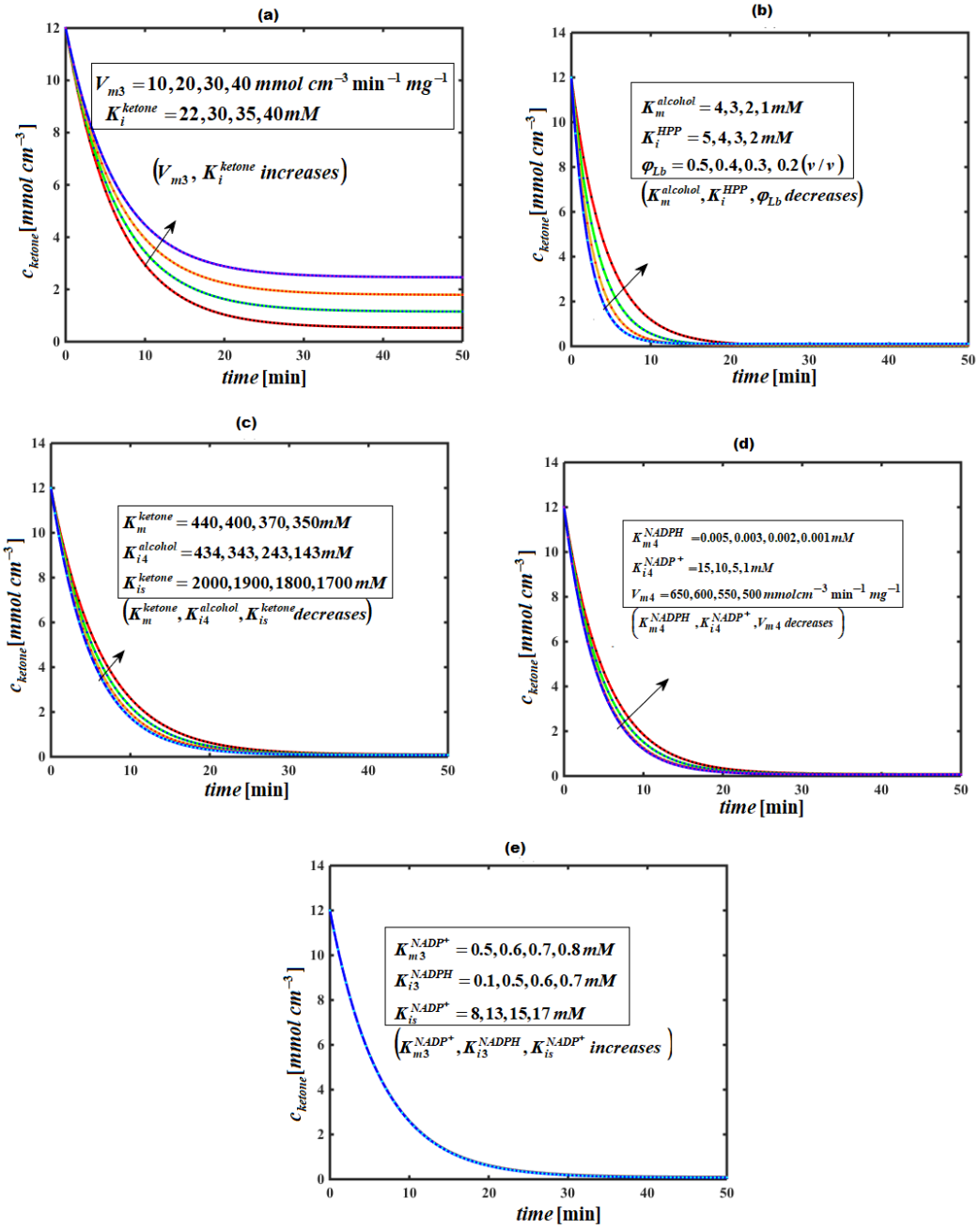

Figure 8: Comparison between the analytical expression of concentration of ketone (Eqn. (17)) and the simulation results in several parameters.

Key to the graph: The hard and sprinkled line represents the Eqn. (17) and numerical results respectively

6. Conclusion

Thereaction rateequationsof enzyme kinetics are solved analytically in enzyme kinetics by using new homotopy perturbation method. In this paper, the concentrations of hydroxypropiophenone, phenylpropane-1,2-diol, NADPH, $NADP^+$, alcohol and ketone are solved analyticallyfor all values of parameters.We have compared the analytical results with the numerical simulation using Scilab software and reach satisfactory results. The relation between the concentrations is also reported.

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APPENDIX A: Approximate Analytical Solutions of the Eqn. (1) Using New Homotopy Perturbation Method

The Eqn. (1) can be written as follows:

$$\frac{dc_{HPP}}{dt} = -r_1 + r_2 \qquad \text{(A1)}$$

$$\frac{dc_{HPP}}{dt} = -\left[\frac{V_{m1}\,\varphi_{Lb}\,c_{HPP}\,c_{NADPH}}{\left[c_{HPP} + K_m^{HPP}\left(1+\left(c_{alcohol}/K_{i1}^{alcohol}\right)\right)\right]\left[c_{NADPH} + K_{m1}^{NADPH}\right]}\right] + k\,\varphi_{Lb}\,c_{PPD}\,c_{NADP^+} \qquad \text{(A2)}$$

In Eqn. (A2) using new homotopy as follows:

$$(1-p)\left[\frac{dc_{HPP}}{dt} + \frac{V_{m1}\,\varphi_{Lb}\,c_{HPP}\,c_{NADPH}}{\left[\left(c_{HPP}(t=0)\right) + K_m^{HPP}\left(1+\left(\left(c_{alcohol}(t=0)\right)/K_{i1}^{alcohol}\right)\right)\right]\left[\left(c_{NADPH}(t=0)\right) + K_{m1}^{NADPH}\right]} - k\,\varphi_{Lb}\,c_{PPD}\,c_{NADP^+}\right] + p\left[\frac{dc_{HPP}}{dt} + \frac{V_{m1}\,\varphi_{Lb}\,c_{HPP}\,c_{NADPH}}{\left[\left(c_{HPP}(t=0)\right) + K_m^{HPP}\left(1+\left(\left(c_{alcohol}(t=0)\right)/K_{i1}^{alcohol}\right)\right)\right]\left[\left(c_{NADPH}(t=0)\right) + K_{m1}^{NADPH}\right]} - k\,\varphi_{Lb}\,c_{PPD}\,c_{NADP^+}\right] = 0 \qquad \text{(A3)}$$

The approximate analytical solution of eqns. (1)-(6),

$$c_{HPP} = (c_{HPP})_0 + p(c_{HPP})_1 + p^2(c_{HPP})_2 + \ldots..$$
$$c_{NADPH} = (c_{NADPH})_0 + p(c_{NADPH})_1 + p^2(c_{NADPH})_2 + \ldots.$$
$$c_{PPD} = (c_{PPD})_0 + p(c_{PPD})_1 + p^2(c_{PPD})_2 + \ldots..$$
$$c_{NADP^+} = (c_{NADP^+})_0 + p(c_{NADP^+})_1 + p^2(c_{NADP^+})_2 + \ldots. \qquad \text{(A4)}$$

Substitute the Eqn. (A4) in (A3) we get,

$$(1-p)\left\{\frac{dc_{HPP}}{dt} + \left[\begin{array}{l} a\left((c_{HPP})_0 + p(c_{HPP})_1 + p^2(c_{HPP})_2 + \ldots..\right) \\ \left((c_{NADPH})_0 + p(c_{NADPH})_1 + p^2(c_{NADPH})_2 + \ldots\right) \end{array}\right] - \left[\begin{array}{l} k\,\varphi_{Lb}\left(c_{PPD} = (c_{PPD})_0 + p(c_{PPD})_1 + p^2(c_{PPD})_2 + \ldots..\right) \\ \left(c_{NADP^+} = (c_{NADP^+})_0 + p(c_{NADP^+})_1 + p^2(c_{NADP^+})_2 + \ldots\right). \end{array}\right]\right\} + p\left\{\frac{dc_{HPP}}{dt} + \left[\begin{array}{l} a\left((c_{HPP})_0 + p(c_{HPP})_1 + p^2(c_{HPP})_2 + \ldots..\right) \\ \left((c_{NADPH})_0 + p(c_{NADPH})_1 + p^2(c_{NADPH})_2 + \ldots\right) \end{array}\right] - \left[\begin{array}{l} k\,\varphi_{Lb}\left(c_{PPD} = (c_{PPD})_0 + p(c_{PPD})_1 + p^2(c_{PPD})_2 + \ldots..\right) \\ \left(c_{NADP^+} = (c_{NADP^+})_0 + p(c_{NADP^+})_1 + p^2(c_{NADP^+})_2 + \ldots\right). \end{array}\right]\right\} = 0 \qquad \text{(A5)}$$

Comparing the coefficients the first iteration can be written as follows:

$$p^0 : \frac{d(c_{HPP})_0}{dt} + a(c_{NAPDH})_i(c_{HPP})_0(t) - b(c_{PPD})_i\left(c_{NADP^+}\right)_i = 0 \qquad \text{(A6)}$$

Solution of the above equation becomes

$$c_{HPP}(t) = b_1/a_1 + \left[(c_{HPP})_i - (b_1/a_1)\right]e^{-(a_1 t)}$$

where,

$$a_1 = a(c_{NADPH})_i,\ b_1 = b(c_{PPD})_i\left(c_{NADP^+}\right)_i \qquad \text{(A7)}$$

$$a = \frac{V_{m1}\,\varphi_{Lb}}{\left[(c_{HPP})_i + K_m^{HPP}\left(1+\left((c_{alcohol})_i/K_{i1}^{alcohol}\right)\right)\right]\left[(c_{NADPH})_i + K_{m1}^{NADPH}\right]} \qquad \text{(A8)}$$

$$b = k\,\varphi_{Lb} \qquad \text{(A9)}$$

Using the same procedure we can also solve the other equations.

Appendix B: Scilab Program to Find the Numerical Solution of Eqns. (1) – (6).

```
function main1
options= odeset('RelTol',1e-6,'Stats','on');
Xo = [0.1;10;0.1;12;0.1;12];
tspan = [0,50];
tic
[t,X] = ode45(@TestFunction,tspan,Xo,options);
toc
figure
holdon
%plot(t, X(:,1))
%plot(t, X(:,2))
%plot(t, X(:,3))
```

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```
%plot(t, X(:,4))

%plot(t, X(:,5))

plot(t, X(:,6))

return

function [dx_dt]= TestFunction(t,x)

c1i=0.1,c2i=10,c3i=0.1,c4i=12,c5i=0.1,c6i=12,fi=
0.2,k1=36.652,k2=10.0338,k3=0.031,k4=0.0105,k
5=15.056,

k6=22.893,k7=2.957,k8=0.533,v1=2000.453,v3=1
.8917,v4=3.458,k9=0.096,k10=21.732,k11=439.3
53,

k13=1708.612,k14=0.034,k15=1.445,k12=143.76
4;

r1=(v1*fi)/((c1i+k1*(1+(c5i/k2)))*(c2i+k3));

r2=k4*fi;

r3=(v3*fi)/(c5i+k5*(1+(c6i/k6)+(c1i/k7)))*(c5i+k
8*(1+(c2i/k9)+((c4i*c4i)/(k10))));

r4=(v4*fi)/(c6i+k11*(1+(c5i/k12)+((c6i*c6i)/k13)
))*(c2i+k14*(c4i/k15));

a1=(r1*c3i);b1=(r2*c2i*c4i);a2=(r1*c1i*c3i);b2=
(r2*c4i);

a3=(r1*c1i);b1=(r2*c2i*c4i);d1=(r2*c5i*c4i);f1=(
r1*c1i);

g1=a3+f1;g2=b1+d1;

b3=r2*c2i;d2=r3*c5i;f2=r4*c6i*c3i;

g5=a2+f2;g4=b3+d2;

d3=r3*c4i;f2=(r4*c6i*c3i);

d1=(r3*c5i*c4i);f3=(r4*c3i);

dx_dt(1)=-(a1*x(1))+b1;

dx_dt(2)=a2-(b2*x(2));

dx_dt(3)=-(g1*x(3))+g2;

dx_dt(4)=g5-(g4*x(4));

dx_dt(5)=-(d3*x(5))+f2;

dx_dt(6)=d1-(f3*x(6));

dx_dt = dx_dt';

return
```

Appendix C: Experimental values of parameter Svarc et.al. [16].

Parameter	Value
V_{m1}	2.072 (U cm^{-3}) or 3.453 $\left(mmolcm^{-3}\,mg^{-1}\,\min^{-1}\right)$
K_m^{HPP}	36.652mM
K_m^{NADPH}	0.031mM
V_{m3}	1.135 (U cm^{-3}) or 1.8971 $\left(mmolcm^{-3}\,mg^{-1}\,\min^{-1}\right)$
$K_m^{alcohol}$	15.056mM
$K_m^{NADP^+}$	0.533mM
$K_{is}^{NADP^+}$	-
K_{i3}^{NADPH}	0.0966mM
K_i^{ketone}	22.893mM
K_i^{HPP}	2.957mM
V_{m4}	2.075(U cm^{-3}) or 3.458 $\left(mmolcm^{-3}\,mg^{-1}\,\min^{-1}\right)$
K_m^{ketone}	439.353mM
K_{m4}^{NADPH}	0.034mM
K_{is}^{ketone}	1708.612mM
$K_{i4}^{NADP^+}$	1.445mM
$K_{i4}^{alcohol}$	143.764mM

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Nomenclature

c_{HPP}	Concentration of hydroxypropiophenone(mmol dm^{-3})
c_{PPD}	Concentration of phenylpropane-1,2-diol (mmol dm^{-3})
c_{NADPH}	Concentration of nicotinamide adenine dinucleotide phosphate(mmol dm^{-3})
c_{NADP^+}	Concentration of nicotinamide adenine dinucleotide coenzyme(mmol dm^{-3})
$c_{alcohol}$	Concentration of alcohol(mmol dm^{-3})
c_{ketone}	Concentration of ketone(mmol dm^{-3})
K_i	inhibition constant(mmol dm^{-3})
K_m	Michaelis–Menten constant (mmol dm^{-3})
r	reaction rate (Umg^{-1}, mmol dm^{-3} min^{-1} mg^{-1})
t	time (min)
V_m	maximal reaction rate (U mg−1, mmol dm^{-3} min^{-1} mg^{-1})
k	Kinetic constant of second order reaction (mmol^{-2}dm^{-6})

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