International Journal of Engineering Science Invention Research & Development; Vol. III, Issue VII, January 2017
www.ijesird.com, e-ISSN: 2349-6185

BIOLOGICAL REACTIONS AND THEIR MODELLING- A BRIEF INSIGHT ON RESEARCH AND STUDIES

Sunil Jayant Kulkarni[1]
[1]*Chemical Engineering Department, Datta Meghe College of Engineering, Airoli, Navi Mumbai, Maharashtra, India, Mobile: 9664213953*,
suniljayantkulkarni@gmail.com.

***Abstract*— The application of biotechnology spreads across wide range of sectors. In fertilizer industry it can be used to increase crop yield, increase the fertility of animals. Also development of hybrid clones, different of drugs and insecticides etc can be achieved by using various biological techniques. The biological reaction is carried out in a medium called as substrate. The cell mass concentration(x), initial and final substrate concentration, rate of substrate utilization and specific growth rate are important parameters in the reactions. Biological synthesis of few compounds is being explored instead of chemical synthesis due to advantages such as low activation energy and high specificity. Enzyme catalyzed reactions are important part of the biological processes. Monod growth kinetics is most commonly used to study cell growth. Michele Menten and Lineweaver Burk plots are also used to explain the kinetics. The current review summarizes research and studies on biological reactions and their modeling.**

***Keywords*— Kinetic models, substrate, cell mass, growth, nutrients.**

I. INTRODUCTION

Biotechnology and biochemical engineering finds application in synthesis of various chemicals, compounds and treatment of waste water. The application of biotechnology in fertilizer industry to increase crop yield, increasing the fertility of animals, development of hybrid clones, development of drugs and insecticides etc.. The biological reaction is carried out in medium called as substrate. The cell mass concentration(x), initial and final substrate concentration, rate of substrate utilization and specific growth rate are important parameters in the reactions. Biological synthesis of few compounds is being explored instead of chemical synthesis due to advantages such as low activation energy and high specificity. Enzyme catalyzed reactions are important part of the biological processes. Immobilization can be used to obtain more yield. Kinetics of substrate utilization and cell growth can be modeled by different models such as Monod model, Moser model. Monod growth kinetics is most commonly used to study cell growth. Michele Menten and Lineweaver Burk plots are also used to explain the kinetics. The current review summarizes research and studies on biological reactions and their modeling.

II. INSIGHT ON RESEARCH ON BIOLOGICAL REACTIONS

Singh et.al. carried out investigation on biodegradation of p-nitrophenol by arthrobacter chlorophenolicus[1]. They carried out experiments to study biodegaradation of p-nitrophenol at different initial p-nitrophenol concentrations. Also they varied operating conditions. At 30^{O}C and pH 7, they observed maximum rate of degradation of p-nitro phenol. Haldane model explained the results. They concluded that wastewater containing phenolic compounds such as p-nitrophenol can be treated effectively by using Arthrobacter chlorophenolicus. Ardestani investigated the nutrient uptake and cell growth kinetics [2]. He applied Monod and Moser kinetic for behavior of Penicillium brevicompactum in submerged batch bioreactor culture. The regression values of 0.87 indicated relatively better fit for the Monod and Moser kinetic models. Bren et.al. studied bacterial

growth as a function of nutrient [3]. They found that under limiting nitrogen or carbon, the growth stops abruptly. It slows when nutrients are not limiting. They also observed a pulse-like up-regulation of the expression of genes. Liu and Li studied kinetics of ethanol fermentation[4]. According to them, the empirical models are unsuitable for the optimization and expansion of real processes. Based on adsorption mechanism, they devised a new ethanol fermentation kinetic model. They found that maximum specific growth rate μ_{max} and adsorption equilibrium constant K_S of glucose decreased with the increase in initial glucose concentration. Hansford studied biological treatment of metal-containing effluent[5]. He reviewed literature related to the pathway from complex organics through to sulfate reduction and methane formation. He also found that the aspects such as the effect of sulfate or sulfide and pH on the rates of hydrolysis are not much investigated topics. He developed a simulation model using the package AQUASIM. From his experimental results, he predicted that the pellet reactor was better choice for the precipitation of a metal hydroxy-carbonate salt from a synthetic nickel sulfate stream.Wijngaard et.al. carried out investigation on kinetics of bacterial growth on chlorinated aliphatic compounds[6]. They found that the kinetic properties and cellular content of the first catabolic enzyme influenced the efficiency of chlorinated compound removal. Studies were carried out by Slininger et.al. for studying growth, death and oxygen uptake kinetics of pichia stipitis on xylose[7]. They found that specific uptake rate was proportional to growth rate. Muthuvelayudham and Viruthagiri carried out comparative studies on various carbon sources on the production of cellulase using different strains [8]. They studied Monod growth kinetics and Leudeking piret product formation kinetic models. In their investigation, they optimized parameters like inoculum concentration, D.O. level, agitator speed, temperature and pH. They observed maximum activity at pH 4. At temperature 28°C, they obtained maximum cellulose activity. Bouville investigated Fermentation kinetics along with studies on product and substrate inhibitions[9]. He proposed an analytical treatment of the kinetic equations. He obtained biomass concentration as a function of the substrate concentration. Garcia-Ochoa et.al. reviewed the production and properties of xanthan[10]. They observed that the microbial strain influenced yield and properties of the product. Also the factors such as the dissolution temperature, the measurement temperature, and the presence of other non-xanthan polymers affected properties of xanthan solutions. Mahanta et.al. studied four mathematical models for bacterial growth rate [11]. Models namely Blackman, Monod, Moser and Powell were examined by them.They used Gauss - Newton iteration procedure for estimating the parameters of these models. For selecting best fit model, they used root mean square error (RMSE) and R^2 values. They found that Moser model provided better fits than the other models. Okpokwasili and Nweke, in their review, examined various kinetic models applied in the prediction of microbial removal of organic contaminants from the environment[12]. According to them, optimization of several controlling factors is major factor in the success of any treatment protocol. In their investigation, Jablonski et.al. utilized resorcinol as the sole carbon and energy source by Enterobacter cloacae[13]. They found that Michaelis-Menten and Monod models were able to explain the batch experimental results. Their was first of its kind investigation describing aerobic degradation kinetics for resorcinol. Dutta et.al. used tomato-peel extracted cutin, for cutinase production by Pseudomonas cepacia[14].They found that the maximum specific growth rate was the most sensitive parameter. For analysis of inhibition kinetics, they used various 3, 4 and 5 parametric Monod-variant models. They found that 4-parameter Webb model showed the best-fit. They concluded that it is possible to minimize substrate inhibition by adopting Fed-batch culture strategy. Malik carried out investigation on the effect of substrate concentration in production of sorbitol in fermentation process [15]. According to his studies, specific growth rate assumes saturation kinetics. He also observed that there was increase in the growth rate of the bacteria, with increase in substrate concentration. Baei et.al. obtained a kinetic model for cupriavidus necator in batch culture[16]. They

considered glucose, fructose and molasses as carbon source. They used The Lineweaver-Burk plot for defining biokinetic coefficients. These biokinetic parameters were described by simplified Monod's rate model. They used MATLAB software for evaluating kinetic constants on the basis of non-linear regression. They observed that there was good agreement between the experimental and the predicted values. Baranyi in his work, investigated bacterial growth with distributed lag time[17]. He carried out modeling and parameter estimation. Amenaghawon et.al. carried out studies on inhibitive effect of ethanol on the growth of fermenting organism in batch ethanol fermentation[18]. They adopted a low order kinetic growth model. While testing validity of kinetic models, they observed that only Hinshelwood model was followed by kinetic data. They also observed that ethanol inhibition affected cell yield, product yield, specific growth rate and specific ethanol production. Decreasing biomass yield, according to them, may be reason for this inhibition. Uzir and Don explained various aspects of cell growth[19]. They discussed in detail, effect of various parameters on cell growth. The important parameters were pH, temperature and oxygen. They explained classification of cells, psychrophiles, mesophiles and thermophiles based on temperature adoptibility. Also according to them, enzymes are normally active only within a certain pH interval. Acidophiles are microorganisms that grow at an optimum pH well below neutrality (7.0). In the similar way alkalifiles and neutrofiles are defined. Kim et. al. investigated kinetics of benzene biodegradation by pseudomonas aeruginosa[20]. In their studies they determined the model parameters describing biodegradation of benzene. For this purpose they conducted kinetic microcosm batch tests in both pure solution and saturated aquifer material conditions for various initial benzene. In order to investigate suitable equation for benzene biodegradation, they monitored benzene and microbial concentrations over a time period. They found that, because of the gradual increase of microbial population in the growth curve, the best fit of the numerical solution was significantly different than the measured benzene concentrations for Monod with growth model. There was reasonable agreement with Monod with no growth model. Singh and Sharma carried out investigation on growth kinetics and modeling of ethanol production [21]. They used wilds and mutant saccharomyces cerevisae MTCC 170. They used physical and chemical mutagen for Saccharomyces crevisiae treatment. The optimum pH was 6 and temperature was 30^{o}C. Mutants showed high ethanol production than wild types. Compared the wild type strain, the resulting yield by mutants was 2.9-fold for mutants. Osman et.al. carried out investigation on kinetic models like Monod, Contois and Chen and Hashimoto[22]. They carried out experiments on up-flow anaerobic sludge blanket reactor (UASB) for treatment of flax retting wastewater. Also they found that the system efficiency was greatly influenced by SRT and OLRs. A review was carried out on kinetics of biological reactions with emphasis on substrate utilization by Kulkarni[23]. According to him, Biochemical reactions are utilized in wastewater treatment and synthesis of many compounds such as lactic acid, citric acid, ethanol. He also found that utilization of mathematical model can contribute to a better understanding of effects of various factors affecting the production. According to this review, Monod growth kinetics is often used for explaining kinetics of substrate utilization. Abdullah et.al. carried out studies on cell growth kinetics of aspergillus oryzae[24]. They carried out studies on industrial natural rubber effluent serum. They investigated relationship between specific growth rate and the concentration of a substrate, which is one of the basic tools in microbiology. Also they carried out experimentation for the nutrient uptake and cell growth kinetics of a nonpathogenic fungus Aspergillus oryzae. They found that Tessier model was best fitted with the experimental data. Dewi et.al. carried out studies on kinetic growth of saccharomyces cerevisiae in non dairy creamer wastewater medium[25]. According to them non dairy creamer (NDC) can be used as a medium for microorganisms growth. They examined the growth kinetics of Saccharomyces cerevisiae for protein production.Abuhamed et.al. studied the effect of adaptation of pseudomonas putida F1 ATCC

700007 (Pp F1) to the biodegradation of benzene (B), toluene (T) and phenol l(P)[26]. They observed that, the biodegradation time decreased after the adaptation of microorganism to BTP. They used Andrews kinetics model for estimation of maximum specific growth rates, half saturation and substrate inhibition constant. They concluded that the biodegradation of BTP by adapted cells was more rapid than the non adapted cells. A general model for microbial growth was developed by Liu[27]. According to his studies, a general model for microbial growth can be reduced to the Monod equation, Grau equation and Hill or Moser equation. He found that Monod constant (Ks) has non-equilibrium thermodynamic characteristics. Lyberatos and Skiadas carried out investigation on modeling of anaerobic digestion[28].They found that the precise mechanism of granule formation still remains unknown. However, there is enough understanding on their composition and the factors influencing their formation. He identified the key areas that require further research endeavors. According to him, the rate determining step in most of the anaerobic digestion processes is hydrolysis of the organic compounds into soluble intermediates. He expressed need for development of a sufficiently general framework as a standard for the hydrolysis and acidogenesis steps. Bowen et.al. carried out investigation on Photorhabdus luminescens[29].They carried out investigation for the specific growth rates of the bacterium in various glucose concentrations in batch cultures. Studies undertaken to ascertain the effect of population density upon specific growth rate were reported by Contois[30].According to Lele and Watve growth rate and growth yield are critical parameters in microbial ecology and physiology[31]. A positive rate yield correlation was proposed by few investigators as the classical Monodian assumption of constant growth yield was found unsupported. They discussed various opinions regarding selective forces, mechanisms shaping the relationship and appropriate experimental approaches.

III. CONCLUSIONS

The cell mass concentration(x), initial and final substrate concentration, rate of substrate utilization and specific growth rate are important parameters in the reactions. Biological synthesis of few compounds is being explored instead of chemical synthesis due to advantages such as low activation energy and high specificity. Enzyme catalyzed reactions are important part of the biological processes. It was found that the empirical models are unsuitable for the optimization and expansion of real processes. Many investigations confirmed that specific uptake rate was proportional to growth rate. Wastewater treatment and synthesis of many compounds such as lactic acid, citric acid, ethanol can be economically carried out by biological methods. In case of anaerobic digestion, the investigators expressed need for development of a sufficiently general framework as a standard for the hydrolysis and acidogenesis steps. Kinetics of substrate utilization and cell growth can be modelled by different models such as Monod model, Moser model. Monod growth kinetics is most commonly used to study cell growth. Michele Menten and Lineweaver Burk plots are also used to explain the kinetics.

REFERENCES

[1] Ravi Kant Singh, Avni Agarwal, Arinjay Kumar, Shashi Kumar And Surendra Kumar, *"Studies On Biodegradation Of P-Nitrophenol By Arthrobacter Chlorophenolicus And Its Metabolites*", Research Journal Of Pharmaceutical, Biological And Chemical Sciences, Vol. 3, No.4, pp.695-704, October - December 2012.

[2] Fatemeh Ardestani, "*Investigation Of The Nutrient Uptake And Cell Growth Kinetics With Monod And Moser Models For Penicillium Brevicompactum Atcc 16024 In Batch Bioreactor*", Iranica Journal Of Energy & Environment, Vol. 2 , No.2, 117-121, 2011.

[3] Anat Bren, Yuval Hart, Erez Dekel, Daniel Koster And Uri Alon, "The Last Generation Of Bacterial Growth In Limitingnutrient", BMC Systems Biology, Vol. 7, No.27, 2013.

[4] Z. Liu And X. Li, "*The Kinetics Of Ethanol Fermentation Based On Adsorption Processes"*, Kem. Ind., Vol.63, No.7-8, pp. 259–264, 2014.

[5] Gs Hansford, "*The Mechanisms And Kinetics Of Biological Treatment Of Metal-Containing Effluent*", Water Research Commission, WRC Report No 1080/1/04, ISBN No 1-77005-14, 1-4, March 2004.

[6] Van Den Wijngaard, Abraham; Wind, Richele, Janssen, Dick, "*Kinetics Of Bacterial Growth On Chlorinated Aliphatic Compounds"*, Applied And Environmental Microbiology, Vol.59, No.7, pp.2041-2048, 1993.

[7] P. J. Slininger, L. E. Branstrator, R. J. Bothast, M. R. Okost And M. R. Ladischt, *"Growth, Death, And Oxygen Uptake Kinetics Of Pichia Stipitis On Xylose*", Biotechnology And Bioengineering, Vol. 37, No.1, pp. 973-980, 1991.

[8] Muthuvelayudham, R. And Viruthagiri, T., "*Fermentative Production And Kinetics Of Cellulase Protein On Trichoderma Reesei Using Sugarcane Bagasse And Rice Straw",* International Journal of Engineering Research and Applications, Vol. 5, No. 20, pp.1873-1881, 16 October 2006.

[9] Mathieu Bouville, "*Fermentation Kinetics Including Product And Substrate Inhibitions Plus Biomass Death: A Mathematical Analysis*", Arxiv:Q-Bio/0509014v2 [Q-Bio.Qm], 9 Oct 2005.

[10] F. Garcoaa-Ochoaa, V.E. Santosa, J.A. Casasb, E. Goamez, *"Xanthan Gum: Production, Recovery, And Properties*", Biotechnology Advances, Vol.18, pp. 549-579, 2000.

[11] Dimpal Jyoti Mahanta, Munindra Borah And Pallabi Saikia, "*A Study On Kinetic Models For Analysing The Bacterial Growth Rate*", American International Journal Of Research In Science, Technology, Engineering & Mathematics, Vol.1, 68-72, 2014.

[12] G. C. Okpokwasili And C.O. Nweke, "*Microbial Growth And Substrate Utilization Kinetics*", African Journal Of Biotechnology, Vol.5, No.4, pp. 305-317, 16 February, 2005.

[13] Marissa R. Jablonski, Shraddha Shaligram, Asifa Qureshi, Hemant Purohit And John R. Reisel, "*Degradation Kinetics Of Resorcinol By Enterobacter Cloacae Isolate*", African Journal Of Microbial Research, Vol.7, No.28, pp.3621-3641, 2013.

[14] K. Dutta,A V. Venkata Dasu,A, B. Mahanty, B And A. Anand Prabhua, *"Substrate Inhibition Growth Kinetics For Cutinase Producing Pseudomonas Cepacia Using Tomato-Peel Extracted Cutin*", Chem. Biochem. Eng. Q., Vol. 29, No.3, pp. 437–445,2015.

[15] Nurhafizah Binti Abdul Malik, "*Effect Of Substrate Concentration On Production Of Sorbitol*", Thesis Submitted In Partial Fulfillment Of The Requirements For The Award Of The Degree Of Bachelor Of Chemical Engineering (Biotechnology) Faculty Of Chemical & Natural Resources Engineering Universiti Malaysia Pahang, pp.1-24, January 2014.

[16] M. Sharifzadeh Baei G.D. Najafpour H. Younesi F. Tabandeh H. Issazadeh M. Khodabandeh, "*Growth Kinetic Parameters And Biosynthesis Of Polyhydroxybutyrate In Cupriavidus Necator Dsmz 545 On Selected Substrates*", Chemical Industry and Chemical Engineering Quarterly, Vol. 17, No.1, pp. 1-8, 2011.

[17] Jozsef Baranyi, "*Modelling And Parameter Estimation Of Bacterial Growth With Distributed Lag Time*", Phd Thesis, Doctoral School Of Informatics University Of Szeged, Hungary 2010, Vol.1, pp.1-94, 2010.

[18] Amenaghawon, N.A, Okieimen, C.O And Ogbeide, S.E, "*Kinetic Modelling Of Ethanol Inhibition During Alcohol Fermentation Of Corn Stover Using Saccharomyces Cerevisiae*", International Journal Of Engineering Research And Applications, Vol. 2, No. 4, pp.798-803, July-August 2012.

[19] Mohamad Hekarl Uzir, Mashitah Mat Don, "*Biochemical Engineering A Concise Introduction",* School Of Chemical Engineering Universiti Sains Malaysia Penang, 1-109, December 2007.

[20] Song-Bae Kim, Choon-Hwa Park, Dong-Ju Kim, And William A. Jury, "*Kinetics Of Benzene Biodegradation By Pseudomonas Aeruginosa: Parameter Estimation*", Environmental Toxicology And Chemistry, Vol. 22, No. 5, pp. 1038–1045, 2003.

[21] Jagdish Singh And Rinkey Sharma, "*Growth Kinetic And Modeling Of Ethanol Production By Wilds And Mutant Saccharomyces Cerevisae Mtcc 170*", European Journal Of Experimental Biology, Vol. 5, No.4 , pp.1-6, 2015.

[22] Randa M. Osman, Azza I. Hafez, Maaly A. Khedr, "*Flax Retting Wastewater Part 2.Microbial Growth And Biodegradation Kinetics*", International Journal Of Engineering Science And Innovative Technology,Vol.3, Vol. 4, pp.783-792, July 2014.

[23] Sunil Jayant Kulkarni, "*A Review On Research And Studies On Kinetics Of Biological Reactions With Emphasis On Substrate Utilization",* Int. J Res Rev., Vol.3, No.9, pp.12-15, 2016.

[24] Nurul Ain Harmiza Abdullah, Nor Amirra Nayan, Nor Helya Iman Kamaludin, Zulkarnain Mohamed Idris,And Mohamad Fahrurrazi Tompang, "*Cell Growth Kinetics Of Aspergillus Oryzae In Industrial Natural Rubber Effluent Serum*", ARPN Journal Of Engineering And Applied Sciences, Vol. 11, No. 4, pp.2687-2692, February 2016.

[25] Endah Rita Sulistya Dewi, Anang M. Legowo, Munifatul Izzati, And Purwanto Purwanto, "*Kinetic Growth of Saccharomyces cerevisiae in Non Dairy Creamer Wastewater Medium*", J Environ Stud., Vol.2, No.1, pp.1-5, May 2016.

[26] Tarık Abuhamed, Emine Bayraktar, Tanju Mehmeto Glu , Zulku Mehmetoglu, "*Kinetics Model For Growth Of Pseudomonas Putida F1 During Benzene, Toluene And Phenol Biodegradation*", Process Biochemistry, Vol. 39, pp. 983–988, 2004.

[27] Yu Liu, *"A Simple Thermodynamic Approach For Derivation Of A General Monod Equation For Microbial Growth*", Biochemical Engineering Journal, Vol. 31, pp.102-105, 2006.

[28] G. Lyberatos, I.V. Skiadas, *"Modelling Of Anaerobic Digestion - A Review*", Global Nest: The Int. J., Vol. 1, No. 2, pp. 63-76, 1999.

[29] Matt Bowen, "*Microbial Kinetics of Photorhabdus Luminescens in Glucose Batch Cultures*", Explorations Biology and Biotechnology, Vol.1, pp.14-23, 2013.

[30] D. E. Contois, "*Kinetics Of Bacterial Growth: Relationship Between Population Density And Specific Growth Rate Of Continuous Cultures*", J. Gen. Microbial., Vol. 21, pp.40-50, 1959.

[31] Uttara N Lele And Milind G Watve, "*Bacterial Growth Rate And Growth Yield: Is There A Relationship?*", Proc Indian Natn Sci. Acad., Vol. 80, No. 3, pp. 537-546, September 2014.