UGC Approved Journal
© UNIVERSAL RESEARCH REPORTS | REFEREED | PEER REVIEWED
ISSN : 2348 - 5612 | Volume : 05 , Issue : 04 | January – March 2018

PRODUCTIVITY IMPROVEMENT OF BIO DIGESTION PROCESS USING KINETIC MODELLING-A REVIEW

Manish Baweja[1], Dr. Prashant Baredar[2], Dr. R. R. Lal[3]
PhD Scholar[1], Associate Professor[2], Professor[3]
[1]Department of Mechanical Engineering, Aisect University, Bhopal
[2]Department of Energy, MANIT, Bhopal
[3]Department of Mechanical Engineering, Aisect University, Bhopal

Abstract- In bio digestion process organic waste (animal or human manure, food or agricultural residues, and other organic waste) is transformed into energy (Either biogas or electricity). Besides this, fine- quality organic fertilizer is also produced as a bye product of bio-digestion process. Although there exist numerous models of the Bio digestion process, but these models rely more algebraic equations rather than biochemical reactions. Apart from this they considers numerous outside parameters .So these models become excessively difficult and need plentiful input information and calculation time. This work presents the review of various features of kinetic models of bio digestion process for improving productivity. These kinetic models are also necessary for optimization and design of bio digestion process. The limitations of these models were also discussed.

Keywords: Bio-digestion, fertilizer, pH. Kinetic modelling, organic material.

I. INTRODUCTION

In Bio digestion process organic waste is transformed into energy (Either in form of biogas or electricity). This organic waste consists of agricultural waste, animal and human manure as well. Thus the bio digestion process can be recognized as a means of energy production and waste management.

Waste control is immensely needed in both rural and urban venues. Most engineering elements of the world have by now got waste administration systems, even though they usually may be upgraded with respects to ecofriendly effect. Rural areas normally lack sanitation or dependable waste management systems. So this can be an enormously valued provision for environmental and health motives.

Bio digestion process produces energy for all those rural households who don't have access to modern energy facilities. It also produces clean energy in comparison to traditional fuels in which carbon-intensive energy is produced. Thus bio digestion process provides a better quality life to all those who live in rural regions and low income households. The demand for clean energy is also getting more and more important with growth in world energy consumption.

Besides this the organic fertilizer is also obtained as a derivative in bio digestion process. This adds up to the profitability of a bio digestion system. Once a substrate is utilized by the bio digestion process, the thrown away material may be utilized as a soil improver to support cultivation of crop .In rural locations; this fertilizer is best used locally or on-site of the Bio autoclave.

II. BIOCHEMICAL PROCESS OF BIO- DIGESTION

Bio digestion is a biological process of in which an organic substance is broken down in the absence of oxygen. This process largely takes place in the guts of animal's .The same natural process is carried out externally by engineers. The bio digestion process completes in mainly in four steps shown by figure 1.

UGC Approved Journal
© UNIVERSAL RESEARCH REPORTS | REFEREED | PEER REVIEWED
ISSN : 2348 - 5612 | Volume : 05 , Issue : 04 | January – March 2018

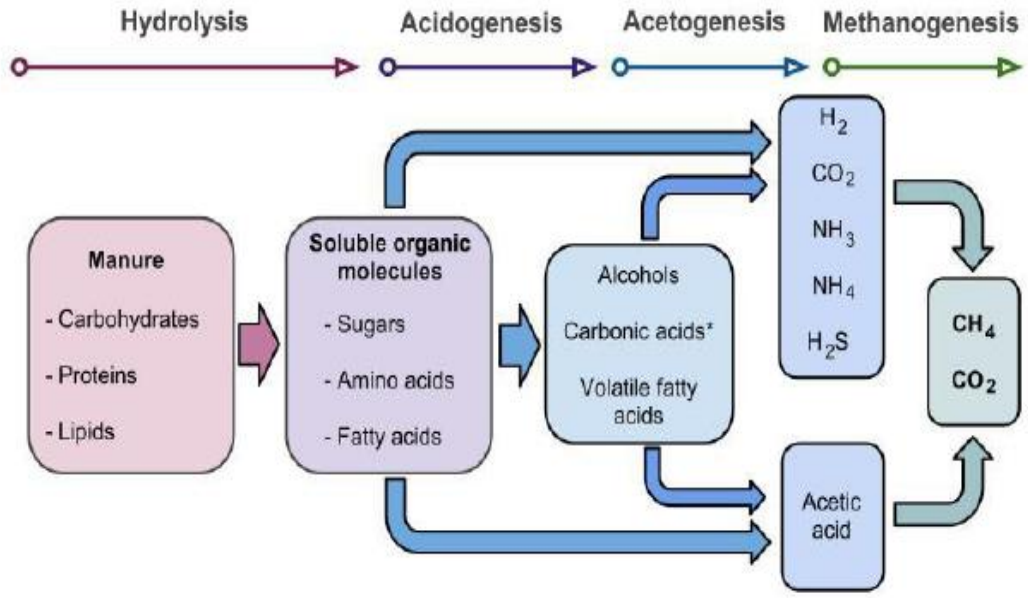


Figure 1 Steps of bio digestion process.

1. Hydrolysis: Hydrolysis is the first step of bio digestion process. In this process the chemical bonds are broken down by adding water. The complex organic compounds are fragmented down into amino acids, fatty acids and simple sugars.

2. Acidogenesis: In this process residual material is converted into volatile fatty acids by acidogenic bacteria. Carbon dioxide, ammonia and hydrogen sulfide are some of the bye products.

3. Acetogenesis: In the third step of anaerobic digestion, acetogenic bacteria further dissolve the volatile fatty acids and manufacture acetic acid.

4. Methanogenesis: In the final step of anaerobic digestion the products obtained as a result of acetogenesis are converted into methane and carbon dioxide by methanogens.

III. KINETIC MODELLING OF BIODIGESTION PROCESS

The bio digestion process takes place due to action of bacteria or microorganisms on the organic waste. When these microorganisms or bacteria stay positioned in closed system in appropriate eco-friendly conditions, the microorganisms grow tremendously. The growth of these microorganisms inside the closed system is recognized as kinetic modelling. This growth of microorganisms will last till all the nutrients of substrate are exhausted and transformed into biogas.

The kinetic modeling of bio digestion process started in 1970 to accomplish the requirement of design and of anaerobic systems so that they can function effectively. At that stage not only the information about complex process of anaerobic digestion was inadequate but there were computational limits also. So the first model was simple and comprised of merely a few equations. But throughout the last thirty years massive research has been taken place not only for the anaerobic digestion process and the factors influencing it but a lot of development has also taken place in

UGC Approved Journal
© UNIVERSAL RESEARCH REPORTS | REFEREED | PEER REVIEWED
ISSN : 2348 - 5612 | Volume : 05 , Issue : 04 | January – March 2018

the arena of computer science. The blending of both these factors lead to the progress of more and more concise and complex models.

IV. KINETICS OF BIO DIGESTION PROCESS

To analyze the kinetics of bio digestion process, one has to understand the complete process of bio digestion. The process is involves the following three stages:

1) Growth of bacteria.
2) Substrate degradation.
3) Product formation.

1.3.1Growth of bacteria

The exponential growth of bacteria in bio digestion process is measured by a surge in its population. This growth usually follows a pattern just like the curve presented in the figure 2

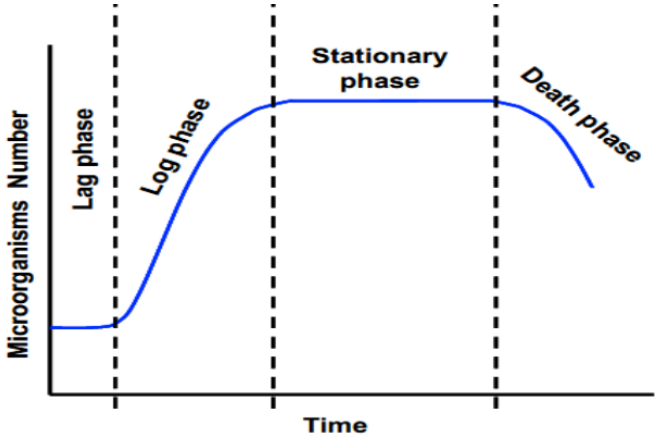


Figure 2 Growth phase of bacteria.

(i) **Lag phase:** Lag first phase in which bacteria gets accepted or become familiar to the new substrate and then start to grow. The time period of lag phase depends on culture medium and age of cell.

(ii) **Log phase or growth phase:** The log phase or growth phase is a period when microorganism's population grow exponentialy .These bacteria grows by dividing into two, generating two bacteria(child organisms). These two bacteria then grows into four bacteria and so on till the stationary stage is reached.The growth of microorganisms is dependent on factors like composition of substrate,temperature of biodigestion process and type of microbial population.The growth rate of exponential phase changes only if :

1. Nutrients of substrate are exhausted .
2. Poisonous metabolic yields are collected.
3. The ionic balance and as a consequence the pH value alters due to degradation of substrate .

As a consequence of this the growth rate falls till the value zero is touched.

UGC Approved Journal
© UNIVERSAL RESEARCH REPORTS | REFEREED | PEER REVIEWED
ISSN : 2348 - 5612 | Volume : 05 , Issue : 04 | January – March 2018

(iii) **Steady state or maturity phase:** In this phase the microbial population halts growing or turn steady. This is because the bacteria population growth rate is same as bacteria population death rate. In the course of stationary phase the number of cell or bacterial population remains constant however a proportion of cell actions keep on going such as energy consumption due to mechanisms or biosynthetic process.

(iv) **Decline phase:** In this phase when the death rate of bacterial population is greater than the growth rate of bacterial population and therefore the active population of bacteria or microbes nearly disappears, This is due to lack of nutrients and generation of toxic compounds in the anaerobic digester.

1.3.2 Substrate Degradation

The bacterial growth can be mathematically described using an appropriate model for growth kinetics and including inhibition by concentration of product and substrate, ionic equilibrium, pH value, gas liquid equilibrium and temperature.

The result is the specific growth rate dependent on the medium growth and growth requirements

The substrate degradation (dS/dt)r can be calculated based on the specific growth rate,
to complete the substrate balance because microorganisms need substrate:
1) For synthesizing new cell material (dS/dt)x,
2) To yield produces such as exoenzymes, acetic acid or methane (dS/dt) c, and
3) To source necessary growth and maintenance energy (dS/dt)e
The complete substrate degradation can be measured by adding these three terms:

$$\left(\frac{dS}{dt}\right)_r = \left(\frac{dS}{dt}\right)_x + \left(\frac{dS}{dt}\right)_e + \left(\frac{dS}{dt}\right)_c$$

To produce new cell material, microbes have to degrade the substrate. The substrate degradation of biomass can be defined stoichiometrically. An instance is the relation given by Moletta et al. (1986) for acid-forming microorganisms, which use glucose as substrate:

$$C_6H_{12}O_6 + 1.2\ NH_3 \rightarrow 1.2C_5H_7NO_2 + 3.6\ H_2O \qquad (1)$$

As per this relation 1.2 mol acid-forming bacteria are produced by 1 mol glucose. Seeing the molar mass of glucose and biomass and assuming that the empirical formula, C5H7NO2, denotes 92% of the dry biomass, the yield coefficient of glucose to acid-forming bacteria, Yx, is 0.82 g/g.

The empirical formula of biomass was published by Loehr (1974). Other representative molecular structures are C75H105O30N15P (Loehr, 1974) or C5H9O3N (Mosey, 1983). The chemical composition of the formed biomass is not constant and varies with microbes group, growth phase and used substrate. The degradation of substrate due to biomass formation (dS/dt)x is determined by the change of concentration of cell over over a period of time dX/dt and can be stated as

$$\left(\frac{dS}{dt}\right)_x = -\frac{1}{Y_x}\cdot\frac{dX}{dt} = -\frac{\mu\cdot X}{Y_x}$$

Energy Supply of Microorganisms

UGC Approved Journal
© UNIVERSAL RESEARCH REPORTS | REFEREED | PEER REVIEWED
ISSN : 2348 - 5612 | Volume : 05 , Issue : 04 | January – March 2018

Microorganisms need energy for their existance to synthesize cell constituents, which are degraded Constantly, or for osmotic actions to sustain the concentration gradient between cell interior and cell exterior, see e.g. (Sinclair & Kristiansen, 1993) The energy demand can be divided into growth energy and maintenance energy. The required energy is provided by the substrate. However, the substrate limiting the growth is not necessarily the same as the substrate limiting the energy supply (Stouthamer, 1976).

The energy storage of a microbe's cell is ATP (Adenintriphosphat). Fragmentation of ATP in ADP (Adenindiphosphat) results in release of energy. Energy is required for recycling of ADP to ATP During the breakdown of one molecule of glucose to three molecules of acetic acid 6 molecules of ATP will be produced (Moletta et al., 1986). As per Stouthamer (1976), the maximum yield for cell production is 32 g biomass per mol of ATP. This means 0.938 g Glucose is needed to synthesize 1 g biomass. This coefficient is called growth energy rate Ksx.
The maintenance energy coefficient is specified by Moletta&Albagnac (1984) with 0.0169 mol ATP per g biomass and per hour. Assuming that degradation of 1 molGlucose to 3 mol acetic acid will result in 6 ATP, the maintenance energy rate Kmx is 12.1 g glucose per g active biomass and per day.According to Moletta et al. (1986), the substrate degradation for energy supply can be written as:

$$\left(\frac{dS}{dt}\right)_e = K_{sx} \cdot X \cdot \mu + K_{mx} \cdot X \cdot \frac{S}{K_s + S}$$

The first part on the right side is the substrate degradation for growth energy supply and the second part on the right side is the substrate degradation for maintenance energy supply.

Substrate conversion

The alteration of substrate to products is can also be considered stoichiometric
e. g. acetic acid is degraded to to methane:

$$CH_3COOH \rightarrow CH_4 + CO_2 \qquad (2)$$

So, 1 mole acetic acid degrades to produce 1 mole methane. By means of the molar mass of methane and acetic acid the yield coefficient of acetic acid to methane, Ys, is 0.27 g/g. Using the calculated yield coefficient, the substrate degradation due to Product formation can be found out as:

$$\left(\frac{dS}{dt}\right)_c = \frac{1}{Y_s} \cdot \left(\frac{dP}{dt}\right)_p$$

Vavilin et al. (1994), e. g., specified representative molecular composition of proteins (C16H30O8N4, 404 g/mol), lipids (C47H96O9, 804 g/mol) and carbohydrates (C6H12O6, 180 g/mol). Using these molecular arrangements, a stoichiometric concern of the hydrolysis step is also possible.

1.3.3 Formation of Product

Biogas is the produce of bio digestion process. But, along with biogas other important intermediates are also produced in this process. The product formation kinetics can be calculated on the basis of microbial growth kinetics and substrate degradation kinetics respectively. Gaden (1959) examined bio digestion processes and classified products into three types:
Type I: Products, which are result of digestion of primary energy.
Type II: Products, which are indirect result of energy digestion.
Type III: Products, which clearly are not result of energy digestion.

UGC Approved Journal
© UNIVERSAL RESEARCH REPORTS | REFEREED | PEER REVIEWED
ISSN : 2348 - 5612 | Volume : 05 , Issue : 04 | January – March 2018

Type I: This kind of product is formed at the same instance when substrate degrade occurs ; an example is the fermentation of alcohol .

$$\frac{dP}{dt} = Y_{p1} \cdot \mu \cdot X = Y_{p1} \cdot \frac{dX}{dt}$$

Type II: This type of product is formed at side reactions or subsequent contacts of direct metabolic products; an illustration is the fermentation of glucose into lactic acid (Luedeking&Piret, 1959). Consequently, the formation of product is delayed and two maxima appear in bacterial growth and substrate degradation.

$$\frac{dp}{dt} = Y_{p1}\mu x + Y_{p2}x = Y_{p1}\frac{dx}{dt} + Y_{p2}x$$

Type III: Development of complex molecules (biosynthesis), for instance the formation of antibiotics. Energy breakdown is practically complete while the complex product mounts up.

V. MATHEMATICAL MODELS OF MICROBIAL GROWTH

The start of kinetic modelling of bacterial growth was carried out by the two German scientists Menten and Michaelis .They established a model, in 1913. This model articulates the enzyme activity of enzyme subject to substrate concentration. This reliance can be rearranged to growth of microorganism, since the microorganism growth is also a autocatalytic reaction (Wolf, 1991).

This model persevered till 1940 till Monod formulated the non-linear relation amongst specific growth rate and limited substrate concentration, when he discovered the growing of bacteria cultures and the parallelism to the Michaelis-Menten model.

For microbial growth, Monod formulated: μ μ = · + max s S K S (8) According to monod's model, the specific growth rate surges strongly for low concentration of substrate. and slowly for high concentration of substrate, until a saturation of microbes is touched .This boundary is the extreme specific growth rate μmax. The Monod-constant Ks is the concentration of substrate at 50% of the maximum specific growth rate (μmax/2).

VI. The Monod model

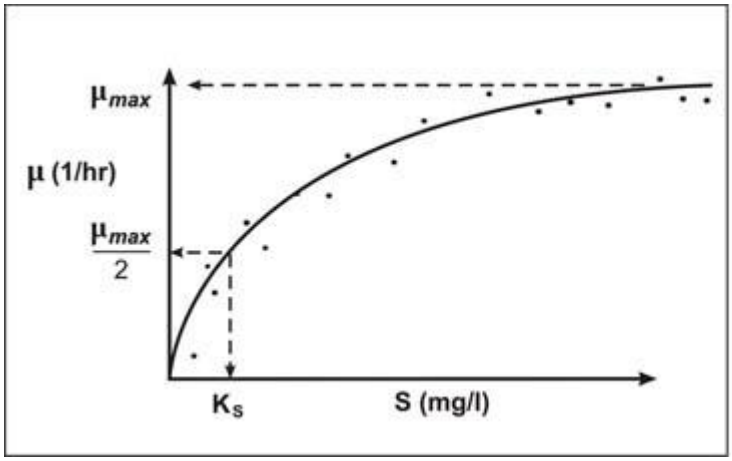
Monod model is the most frequently used kinetic model. It was established in 1942 by Jacques Monod. This model articulates the growth of microorganism with respect to time, and to the concentration of substrate or nutrient. It is an empirical equation that states that the microbe growth rate is nil when there is no substrate and it touches its peak once there is excess of substrate (Lorby et al. 1992).

The Monod model for microbial growth is:

$$\mu = \mu_{max}\left(\frac{s}{ks+s}\right)$$

Where μ= specific growth rate.
s= substrate concentration
$K_{s=}$ affinity constant or half saturation constant

UGC Approved Journal
© UNIVERSAL RESEARCH REPORTS | REFEREED | PEER REVIEWED
ISSN : 2348 - 5612 | Volume : 05 , Issue : 04 | January – March 2018



$$\mu = \mu_{max}\left(\frac{S}{S+K_S}\right) \quad (5)$$

Figure 3 The Monod model

where, X is the microorganism concentration, μmax the maximum specific growth rate, S the substrate concentration, KS the substrate concentration when the specific growth rate is half the maximum specific growth rate and t is time.

Figure 3 shows a Monod curve as well as the meaning of KS and μmax. As per the Monod curve, in the beginning growth rate of microorganism is exponential. But, by the passage of time, the growth rate can fall owing to a deficiency of nutrients or substrate. The growth rate may also fall due to added difficulties like accrual of poisonous metabolites (Krylów 2003), predation (protozoa are predators of bacteria) (Bitton 2005) and lysis (Kalyuzhnyi et al. 2006).

A decay constant, Kd, is therefore introduced into the Monod Equation and the amount of microorganisms in the reactor may reach a steady state. If the conditions are unfavorable, the amount the microorganisms may in fact decrease. Kd is a function of the operating conditions. Taken into account the Kd, the Monod equation for microorganism growth is: (2) Monod's equation is based on the growth rate and the substrate utilization rate during biodegradation. For an Anaerobic Hybrid Reactor without biomass recycle, the Figure2. Monod curve, μ is the specific growth rate.

VII. CONTOIS MODEL

The Contois model was established after 20 years of Monod model. This model refer to the growth of microbes by the passage of time. The major difference between the two models is that the Monod model considers that the limiting substrate concentration KS (once the growth rate is half of maximum growth rate,) does not depends on population density, whereas the Contois model says that KS is a function of population density (Contois 1959).

CONCLUSION

This review explains the bio digestion process and the steps involved in the process. The main aim was to discuss kinetic modelling and its role in increasing the productivity of anaerobic digestion. The role of the various models that were developed to to enhance and optimize design as well as operation of bio gas plants was also discussed. The main models used to optimize The role of kinetic modelling in improving the productivity of bio digestion process was discussed.

REFERENCES

[1]. Chasnyk, O., Sołowski, G., Shkarupa, O. "Historical, technical and economic aspects of biogas development: Case of Poland and Ukraine". Renew. Sust. Energy Rev. 52, 2015, pp 227-239.

[2]. Chettiyappan Visvanathan and Amila Abeynayaka, "Developments and future potentials of anaerobic membrane bioreactors (AnMBRs)", Membrane Water Treatment, Vol. 3, No. 1, 2012, pp 1-23

[3]. Anthony Njuguna Matheri, Mohamed Belaid and Tumisang Seodigeng, Jane Catherine Ngila, "The Role of Trace Elements on Anaerobic Co-digestion in Biogas Production", Proceedings of the World Congress on Engineering 2016 Vol II WCE 2016, June 29 - July 1, 2016, London, U.K

[4]. Iqbal Syaichurrozi, "Review – Biogas Technology to Treat Bioethanol Vinasse", Waste Technology, Vol. 4(1), 2016, pp 16-23

[5]. Ilona Sárvári Horváth , Meisam Tabatabaei, Keikhosro Karimi and Rajeev Kumar, "Recent updates on biogas production - a review", Biofuel Research Journal 10, 2016, pp 394-402

[6]. Anthony Njuguna Matheri, Mohamed Belaid and Tumisang Seodigeng, Jane Catherine Ngila, "Modelling the Kinetic of Biogas Production from Co-digestion of Pig Waste and Grass Clippings" Proceedings of the World Congress on Engineering 2016 Vol II WCE 2016, June 29 - July 1, 2016, London, U.K.

[7]. Anthony Njuguna Matheri, Mohammed Belaid, Tumisang Seodigeng, and Catherine Jane Ngila, "The Kinetic of Biogas Rate from Cow Dung and Grass Clippings", th International Conference on Latest Trends in Engineering & Technology (ICLTET'2015) Nov. 26-27, 2015 Irene, Pretoria (South Africa)

[8]. Elena Cristina Rada, Marco Ragazzi, Paolo Stefani, Marco Schiavon and Vincenzo Torretta, "Modelling the Potential Biogas Productivity Range from a MSW Landfill for Its Sustainable Exploitation", Sustainability 2015, 7, pp 482-495

[9]. G. K. Latinwo and S. E. Agarry, "Modelling the Kinetics of Biogas Generation from Mesophilic Anaerobic Co-Digestion of Sewage Sludge with Municipal Organic Waste", Chemical and Process Engineering Research, Vol.31, 2015, pp 43-53

[10]. Maša Čater, Lijana Fanedl, Špela Malovrh and Romana Marinšek Logar, "Biogas Production from Brewery Spent Grain Enhanced by Bioaugmentation with Hydrolytic Anaerobic Bacteria", Bioresource Technology, 5 March 2015, pp 1-35

[11]. Veronika Dollhofer, Sabine Marie Podmirseg, Tony Martin Callaghan, Gareth Wyn Griffith and Kateřina Fliegerová; "Anaerobic Fungi and Their Potential for Biogas Production", Springer International Publishing, Switzerland 2015, pp 41-61

[12]. S.J. Grimberg, D. Hilderbrandt, M. Kinnunen and S. Rogers, "Anaerobic digestion of food waste through the operation of a mesophilic two-phase pilot scale digester – Assessment of variable loadings on system performance", Bioresource Technology 178, 2015, pp 226–229

[13]. Giovanni Esposito, Luigi Frunzo, Antonio Panico and Francesco Pirozzi, "Enhanced bio-methane production from co-digestion of different organic wastes", Environmental Technology, Vol. 33, No. 24, December 2012, pp 2733–2740

[14]. My Carlsson, Anders Lagerkvist and Fernando Morgan-Sagastume, "The effects of substrate pre-treatment on anaerobic digestion systems: A review", Waste Management 32 , 2012, pp 1634–1650

[15]. Gergely Forgács, "Biogas Production from Citrus Wastes and Chicken Feather: Pretreatment and Co-digestion", Phd Thesis, Department of Chemical and Biological Engineering, Chalmers University of Technology, Göteborg, Sweden 2012

[16]. Jon K. Pittman, Andrew P. Dean and Olumayowa Osundeko, "The potential of sustainable algal biofuel production using wastewater resources", Bio resource Technology 102 , 2011, pp 17–25

[17]. M.O.L. Yusuf, A. Debora and D.E. Ogheneruona, "Ambient temperature kinetic assessment of biogas production from co-digestion of horse and cow dung", Res. Agr. Eng. Vol. 57, 2011, No. 3, pp 97–104

[18]. Elias Jigar. "Study on Renewable Biogas Energy Production From Cladodes Of Opuntia Ficus-Indica", M.Tech Thesis, School of Graduate Study, Addis Ababa University, July, 2010
[19]. Tadious Tesfaye Tefera, "Potential for biogas production from slaughter houses residues in Bolivia", Master of Science Thesis, STOCKHOLM 2009
[20]. Yadvika, Santosh, T.R. Sreekrishnan, Sangeeta Kohli and Vineet Rana, "Enhancement of biogas production from solid substrates using different techniques—a review", Bio resource Technology 95, 2004, pp 1–10
[21]. A.S. Sambo, B.Garba and B.G. Danshehu, "Effect of some operating parameters on biogas production rate", Renewable Energy, Vol. 6, No. 3, pp. 343-344, 1995
[22]. Judd, S, "Principles and applications of membrane bioreactors for water and wastewater treatment". MBR Book, Elsevier, Oxford. 2010.
[23]. Wikandari, R., Youngsukkasem, S., Millati, R., Taherzadeh, M.J., "Performance of semi-continuous membrane bioreactor in biogas production from toxic feedstock containing D-Limonene. Bioresour". Technol. 170, 2014, pp.350-355.
[24]. Syaichurrozi, I., Budiyono, Sumardiono, S. "Predicting Kinetic Model of Biogas Production and Biodegradability Organic Materials: Biogas production from Vinasse at Variation of COD/N" , Bio resource Technology, 149, 2013, pp 390-397.
[25]. Pagés-Díaz, J., Westman, J., Taherzadeh, M.J., Pereda-Reyes, I., Sárvári Horváth, I. "Semi-continuous co-digestion of solid cattle slaughterhouse wastes with other waste streams: Interactions within the mixtures and methanogenic community structure". Chem. Eng. J. 273, 2015, pp 28-36.