International Journal of Advanced Science and Technology
Vol. 29, No. 11s, (2020), pp. 163-172

Study Of The Process Of Anaerobic Digestion Of Biogas From Organic Waste In A Bioenergy Plant

AmirgaliyevYedilkhan[ab] , Kunelbayev Murat[ab], Amirgaliyev Beibut[c], Daulbayev Salauat[ab], Kozbakova Ainur[ab], Auelbekov Omirlan[a] and Katayev Nazbek[a]
[a]*InstituteInformation andComputationalTechnologies CS MES RK, Kazakhstan*
[b]*Al-Farabi Kazakh National University, Kazakhstan*
[c]*InternationalInformation TechnologyUniversity, Kazakhstan*

Abstract

The work here in presents modeling the biogas process of anaerobic digestion from organic wastes. There has been developed a new type of flat solar collector, designed for accumulating the solar irradiation for the aim of automated bio energy installation heat supply. There have been computed corresponding parameters of mathematical model, which have been obtained by means of fulfilling the sensitivity analysis, based on sequential algorithm of quadratic programming. In the model here in there is used experimental data, received from the installation, confirming, that the offered model is able to predict correctly the dynamics of technological procession biogas production.

Keywords: *Flat solar collector, anaerobic digestion, biogas production from organic waste materials, kinetic model of biogas production.*

1. Introduction

Technique of biogas production from anaerobic digestion organic substances is acquiring bigger interest, as it is considered as replacement for natural gas; it helps reduce the dependence on fossil fuel and promotes to cut green house effect from gas burst. Biogas, consisting of methane gases mixture (60-70%), carbon dioxide (30-40%) and less amount of hydrogen sulphide and ammonia might be used as the energy source for getting the heat, used for household activities [1,2]. Thus, the work [3] offers feasible methods of using biogas in the future, including: electric energy production at TPP or fuel elements; heat multi generation, steam, power and cooling; injection into gas networks; transport fuel; production of chemical substances.

It is known, that biogas, being perspective power resource is produced by anaerobic digestion, on the basis of biological process of relative operation simplicity and low cost. Anaerobic digestion process includes four biological processes, namely, hydrolysis, acid genesis and methane genesis. Anaerobic digestion is a complex process, including different groups of bacteria and microbial flora. In fact, the main micro substances groups (form the acid for methane formation) are very different in terms of physiology, in respect of nutritious needs, growth genetics and sensitivity to the environment [4]. Some mathematical models of anaerobic digestion have been offered in different literature sources. AmongstthemADM1 model has become the most used both in researches and industry [5]. ADM1 model describes biological process with different physical-chemical and biological reactions, implemented with differential and algebraic equations systems, based on specifying and using 32 dynamic variables for concentration state [6]. ADM1 model structure includes a big amount of kinetic and stoichio metric parameters. Another, AMOCO model, offered in the work [7] is used for researching water purifying by means of anaerobic digestion. AMOCO model has been used for sustainability researches [8,9] and research of existing differential equations solution systems [10]. Important study of biological processing model in gin anaerobic digestion gives the possibility of getting the idea and specifying the system dynamics of cycle optimization and control design and of regulating increase of the methane flow. The work describes a newly developed calculation technique and the choice of the geometrical parameters of the solar collector with the siphon effect [11].The paper here in considers the study of convective heat transfer in flat plate solar collectors, as it is seen from the analysis on research of the heat transfer by a circular and flat tubes upon conforming the forced and free convections, placed vertically or horizontally with various liquid flow directions. There have been obtained Nusselt criterion dependencies in circular and flat pipes, which shows that corresponding equations allow defining the heat transfer intensity for all fluids with appropriate accuracy [12].

In the present work we submit as imple mathematical model with reduced set of the states and parameters variables. Offered kinetic model includes two biological reactions (acid genesis and methane genesis) with two microorganisms groups.

2. Materials and methods

The data, used in the research herein, has been obtained from anaerobic reactor, functioning in the Institute of information and computational technologies Republic of Kazakhstan. Schematic representation is given in the Figure 1

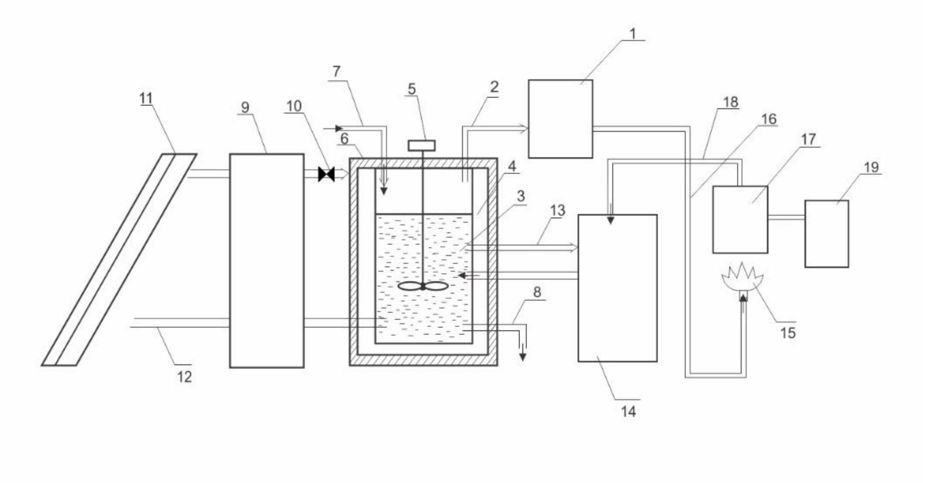


Figure 2. Principle diagram of modular bioenergetics installation

The installation contains gas-holder 1, pipe line of biogas output 2, digestion tank 3 with water chamber 4, mixing device 5 and heat insulation 6, loading 7 and unloading 8 adapters, accumulator tank 9 and valve 10 for hot water, flat solar collector 11, water ducks 12 and 13, electric water heater 14, biogas burner 15 and biogas supply pipeline 16, axial reactive thermal engine17 and system of electric connection 18, double-circuit generator on stable magnets 19.

Operation of bio-energetic installation, according to technological diagram, presented in the Figure1, is fulfilled as follows. Initial biomass in the form of cattle breeding organic wastes through loading adapter 7 is loaded into anaerobic digester 3 with water chamber4, mixing device 5 and thermal insulation 6. Necessary temperature regime of anaerobic process of biomass digestion indigestion tank 3 is provided by means of transformed into thermal energy, in the flat solar collector 11,of solar radiation energy, heated in flat solar collector 11 and accumulated in accumulator tank 9, water through the valve 10 of hot water and water pipeline 12 enters the water chamber 4 of anaerobic digester 3.Intheprocessof anaerobic bacteria destruction of organic biomass substances in anaerobic digester 3 exhaled biogas, which through biogas bleed pipeline 2 enters and accumulates in gas holder 1. Further there is executed the obtained biogas utilization: part of received biogas is used through direct firing in domestic heating gas devices; part of it is used as and when necessary, in the periods of solar irradiation absence along the pipeline for biogas supply 16 for firing in the biogas burner 15, located from the bottom side of axial reactive-centrifugal thermal engine17. In axial reactive –centrifugal heat engine 18, in the form of the rmomechanical generator, the fired heat energy in biogas burner is transformed into electric energy by means of double rotor generator with stable magnets 19. Obtained in such away electric energy via electric water heater 14 and water pipeline 13 is supplied for heating the biomass in the digestion tank up to the needed temperature and keeping it in the normal mode. Further biogas and electric power production and usage is continued, as it is mentioned above.

Figure 1 shows the mockup of a flat solar collector. Content and novel to consist in the fact, that in distinction from the known design principle the collector contains transparent double-glazed window 2 with reduced pressure double glass, as well, parametric frame 1. Wooden frame bottom 7 is made of 8 mm width plywood attached with heat insulating 5 foils. In the gap between double-glaze window and frame bottom there is laid flexible thin-walled stain less corrugated pipe 4Æ16 mm, in the coil form. Pipe edges are fixed to inlet and outlet protruding pipes 6.

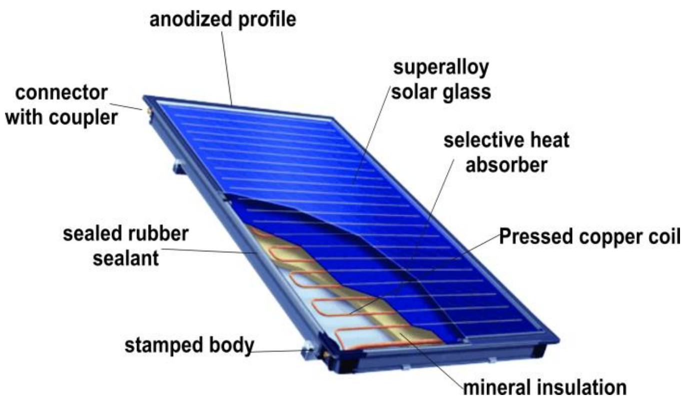


Figure 2- Principal diagram of flat solar collector

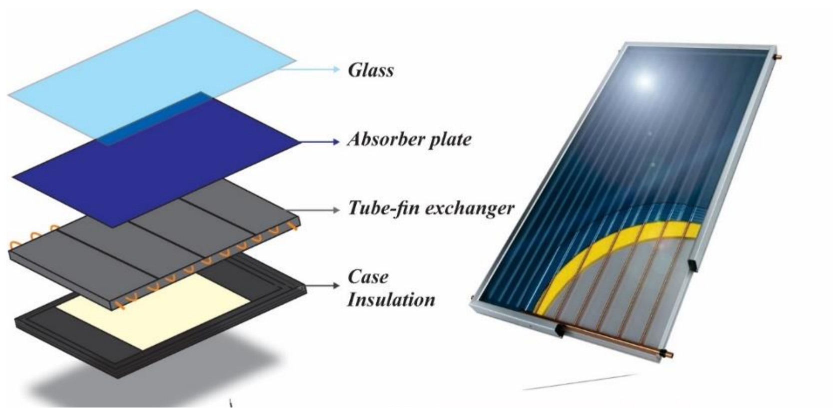


Figure 3. Principal diagram of flat solar collector, non-assembled

A sit is shown in the Figure 3, the solar energy goes through the glass and bumps at an absorber plate, which is heated, transforming the solar energy into thermal one. The heat is transmitted to the working liquid, which passes through pipes, attached to an absorber plate.

Figure 4- Flat solar collector mockup

Figure 4 presents flat solar collector mockup. Solar collector is the main heat generating unit of the solar collector. To achieve the stated aim, we have developed principally new flat solar collector, on the base of which there will produced different types of solar collectors, used for heating water, premises and buildings.

Table 1–Technical specification of flat solar collector

Parameters	Value
Absorbing plate material	Copper
Absorbing plate dimensions	2 m×1 m
Plate thickness	0.4 mm
Glazing material	Hardened glass
Glazing sizes	2 m×1 m
Glazing thickness	4 mm
Insulation	Foamplexus (foam polyurethane)
Collector tilt	45^0
Absorber heat conductivity	401 W/(m K)
Insulation heat conductivity	0.04 W/(m K)
Transmittance-absorption factor	0.855
Apparent solar temperature	4350 K
Ambient temperature	303 K
Irradiation intensity	1000 W/m^2

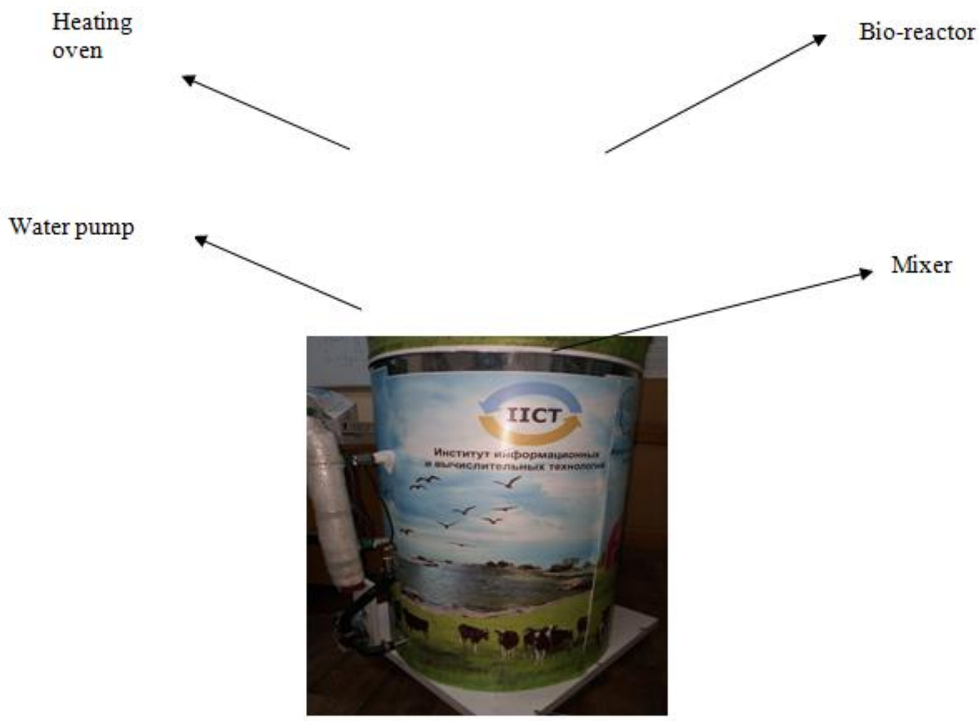


Figure 5. Laboratorymodularbioenergy installation

3. Mathematical model

Let's consider the simplified model of anaerobic process, where organic substratum (S1, ingCOD / L) resolves into VFAs (S2, inmmol / L), with acid genesis bacteria (X1, ingCOD/L); afterwards, VFA resolve in methane (CH4, in L/d) with methanogenic microorganisms(X2, ingCOD / L).
By means of (1) and (2) there is presented the kinetic model of two biological reactions

$$k_1S_1 \xrightarrow{r_1} X_1 + k_2S_2 \quad (1)$$

$$k_3S_2 \xrightarrow{r_2} X_2 + k_4CH_4 \quad (2)$$

Where, accordingly,k_1 (gCODS$_1$ / gCODX$_1$), gCODS$_1$/gCODX_1), k_2 (mmolVFA/gCODX_1),k_3 (mmolVFA/gCODX_2) and k_4(mmoleCH_4 /gCODX_2)

Processes r_1(r_1= μ_1X_1) andr_2 (r_2 = μ_2X_2) present bacteria growth rate, linked with two biological processes. Parameters $\mu_1$and $\mu_2$representconcreteacid genesis and methane genesis growth rate, accordingly.

Differential equations system, received according to the continuous process balance total mass:

$$\frac{dX_1}{dt} X_1(\mu_1 - D) \text{ (Acid forming biological masses)}$$

3.1 Mathematical modeling of biogas production from organic wastes

Biogas production from organic wastes consists of:

$$\frac{dX_2}{dt} X_2(\mu_2 - D)\text{(methane genic biomass)}$$

$$\frac{dS_1}{dt} D_2(S_1^{in} - S_1) - k_1\mu_1 X_1 \text{ (organic substratum)}$$

$$\frac{dS_2}{dt} D_2(S_2^{in} - S_2) - k_2\mu_1 X_1 - k_3\mu_2 X_2 \text{ (fatty acid)},$$

Where D (D = Q|V; in d[-1]) there is computed pressure drop, based on the ratio between inlet signal flow rate (Q) and reactor's effective volume (V). S_1^{in} and S_2^{in} are inputs of organic substrata of concentration band concentration of input signal VFA, accordingly. There is presented the model of kinetics of acid genesis bacteria at mono-kinetics (3) and methane genic microorganisms. Kinetics has been designed according to Haldane kinetics (4). The latter is used for emphasizing accumulation, that is the state of metabolic reactions retardation.

$$\mu_1 = \mu_{1max}\frac{S_1}{K_{S_1}+S_1} \text{(Acid genesis bacteria kinetics)(3)}$$

$$\mu_2 = \mu_{2max}\frac{S_1}{K_{S_2}+S_2+S_2^2/K_I} \text{ (Methane genic bacteria kinetics) (4)}$$

Where μ_{1max} maximum bacteria growth rate, K_{S_2} and K_I are constants of half-saturation, connected with organic S_2.

It is known, that methane is a low soluble product, it means, that all methane is produced in biogas along with organic substance resolving.

$$q_M = k_4\mu_2 X_2 (5)$$

4. Specifying to ichio metric and kinetic factors

Estimation of stoichiometric coefficients of pseudo stoichiometric matrix has been carried out according to the method, offered in [10]. From the equations (1) and (2)

$$k = \begin{pmatrix} -k_1 & 0 \\ 1 & 0 \\ k_2 & -k_3 \\ 0 & 1 \\ 0 & k_4 \end{pmatrix}; \quad k = \begin{pmatrix} S_1 \\ X_1 \\ S_2 \\ X_2 \\ P \end{pmatrix}.$$

As X_1 and X_2arenotmeasured, we will concentrate on the state c_m, connected with sub matrix K:

$$K = \begin{pmatrix} -k_1 & 0 \\ k_2 & -k_3 \\ 0 & k_4 \end{pmatrix}; \quad c_m = \begin{pmatrix} S_1 \\ S_2 \\ P \end{pmatrix}; c_u = \begin{pmatrix} X_1 \\ X_2 \end{pmatrix}.$$

From which

$$\tilde{K} = \begin{pmatrix} -1 & 0 \\ \frac{k_2}{k_1} & -\frac{k_3}{k_4} \\ 0 & 1 \end{pmatrix}; \quad \lambda = \begin{pmatrix} \frac{k_2}{k_1} \\ 1 \\ \frac{k_3}{k_4} \end{pmatrix}.$$

Thus, u_1, u_2иu_3 are connected with the following ratio:

$$u_2(t) = -\left(\frac{k_3}{k_4}\right) u_3(t) = -\left(\frac{k_2}{k_1}\right) u_1(t) \quad (7)$$

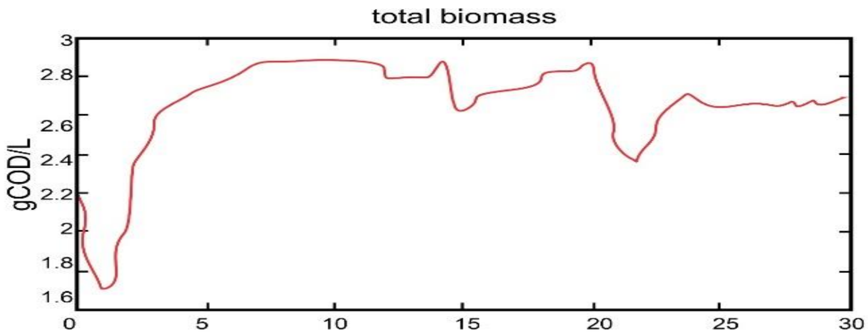
Stoichiometric coefficients are defined through solving the adjustment optimization problem using the algorithm, based on sequential quadratic programming [11].Using the data, close to the stationary condition, the optimization problem might really be recorded as:

We will minimize $f(y(t)), k$with limits $(k_i \geq$, where f-aim function for to reaching the minimum (an error is minimized between experimental data and model prediction), y denotes the vector condition and -stoichiometric coefficients. Limitation on have been included, in order to avoid negative values. Table 2. For stoichiometric coefficients, multiple optimizations have been made randomizing the initial valuesC, which allow obtain the function best minimum. Finally, kinetic parameters between simulated values and measurements in MatLab have been evaluated using non-linear technique of least squares

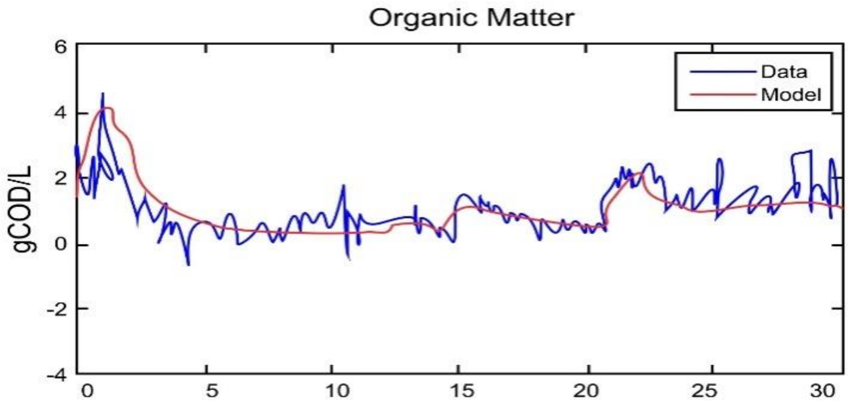
Table 2 –Stoichiometric coefficients and kinetic parameters

Coefficient	Value	CV	UOM
k_1	6,56	0.15	$g_{COD}S_1/g_{COD}X_1$
k_2	11,67	0.08	$mmol_{VFA}$/ $g_{COD}X_1$
k_3	70,00	0.01	$mmol_{VFA}$/ $g_{COD}X_2$
k_4	120,5	0.008	$mmole_{CH4}$/ $g_{COD}X_2$
μ_{1max}	2.00	0.50	d^{-1}
K_{S_1}	5.97	0.19	$g_{COD}S_1/L$
μ_{2max}	3.02	0.46	d-1
K_{S_2}	42.5	0.02	$mmol_{VFA}/L$
K	13.34	0.001	$mmol_{VFA}/L$

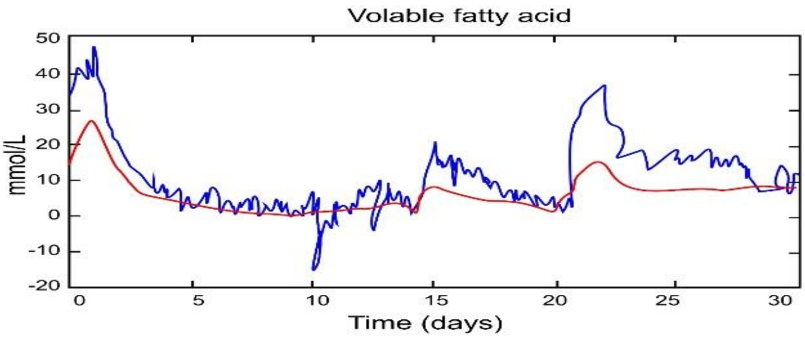
CV-variationcoefficient, computed, basedonsubmitted outcomes by means of function.



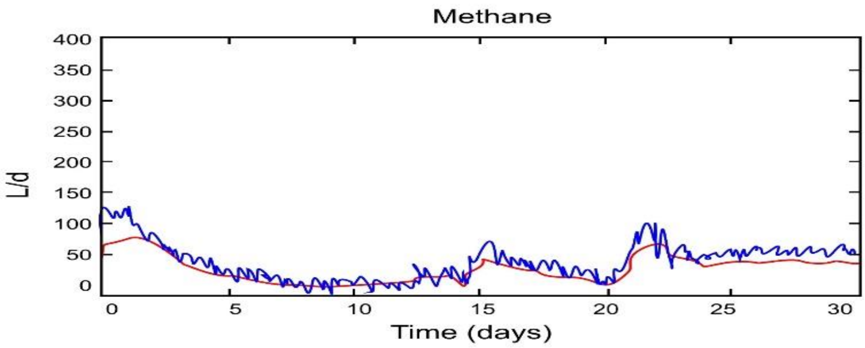
a)



b)



c)



d)

Figure 6. Stoichiometric coefficients a,b and kinetic parameters c,d

Experimental data (grey line) and model (red line) have several values. It can be explained with the model's non-linearity. In the work here in we oriented ourselves at getting the kinetic parameters first assessment. Experimental data has been divided into two sets: the first set has been used for calibration, and the second set – for confirmation. In the course of modeling there have been received kinetic parameters, which demonstrate, that methane genesis growth rate is limited, that is, acid genesis growth rate is rapid and methane genesis one is slow.

5. Conclusions

The given work has considered the methodology of constructing simple representation of anaerobic digestion model. There has been carried out the analysis, representing a precious tool for specifying the most important parameters, which are necessary to be defined. Sensitivity analysis has shown, that parameters, linked with methane genic reaction, has big influence at biogas production, based on anaerobic digestion, it is possible due to the fact, that the microorganisms are less annoyed with presence of inhibitive compounds. An offered model is able to predict the behavior of methane production from several key measures in the process of anaerobic digestion.

There have been computed corresponding parameters of mathematical model, which have been obtained by means of executing the parameters sensitivity analysis on the basis of quadratic programming methods. In the course of work there has been used experimental data, received from the installation and which confirms, that, at large, the offered model is able to predict correctly the dynamics of technological process for biogas production.

References

[1] Weiland, P. (2010) ‘Biogas production: current state and perspectives’, Applied Microbiology and Biotechnology, Vol. 85, No. 4, pp.849–860.

[2] Uddin,W., Khan, B., Shaukat, N., Majid, M., Mujtaba, G., Mehmood, A. and Almeshal, A.M. (2016) ‘Biogas potential for electric power generation in Pakistan: a survey’, Renewable and Sustainable Energy Reviews, Vol. 54, pp.25–33.

[3] Budzianowski, W.M. (2016) ‘A review of potential innovations for production, conditioning and utilization of biogas with multiple-criteria assessment’, Renewable and Sustainable Energy Reviews, Vol. 54, pp.1148–1171.

[4] Yenigün, O. and Demirel, B. (2013) ‘Ammonia inhibition in anaerobic digestion: a review’, Process Biochemistry, Vol. 48, Nos. 5–6, pp.901–911.

[5] Batstone, D.J., Keller, J., Angelidaki, I., Kalyuzhnyi, S.V., Pavlostathis, S.G., Rozzi, A., Sanders,W.T.M., Siegrist, H. and Vavilin, V.A. (2002) ‘The IWA anaerobic digestion model no 1 (ADM1)’, Water Science and Technology, Vol. 45, No. 10, pp.65–73.

[6] Batstone, D.J. and Keller, J. (2003) ‘Industrial applications of the IWA anaerobic digestion model No.1 (ADM1)’, Water Science and Technology, Vol. 47, No. 12, pp.199–206.

[7] Batstone, D.J., Keller, J. and Steyer, J.P. (2006) ‘A review of ADM1 extensions, applications, and analysis: 2002–2005’, Water Science and Technology, Vol. 54, No. 4, pp.1–10.

[8] Benyahia, B., Sari, T., Cherki, B. and Harmand, J. (2010) ‘Equilibria of an anaerobic wastewater treatment process and their stability’, IFAC 8.Proceedings Volumes, Vol. 43, No. 6, pp.371–376.

[9] Bernard, O. and Bastin, G. (2005) ‘On the estimation of the pseudostoichiometric matrix for macroscopic mass balance modelling of biotechnological processes’, Mathematical Biosciences, Vol. 193, No. 1, pp.51–77.

[10] Machado-Higuera, M. and Sinitsyn, A.V. (2015) ‘Existence of lower and upper solutions in reverse order with respect to a variable in a model of acidogenesis to anaerobic digestion’, Bulletin of the South Ural State University. Ser.

Mathematical Modelling, Programming and Computer Software, Vol. 8, No. 2, pp.55–68.

[11] Aceves-Lara, C.A, Aguilar-Garnica, E., Alcaraz-González, V., González-Reynoso, O., Steyer, J.P., Dominguez-Beltran, J.L. and González-Alvarez, V. (2005) 'Kinetic parameters estimation in an anaerobic digestion process using successive quadratic programming', Water Science and technology: A Journal of the International Association on Water Pollution Research, Vol. 52, Nos. 1–2, pp.419–426.

[12] Ye.Amirgaliyev,M.Kunelbayev,B.Amirgaliyev,A.Kalizhanova,O.Auelbekov,N.Katayev,A.KozbakovaJournalWSEASTransactionsonSystemsandControlISSN:1991-8763E-ISSN:2224-2856.Volume 14, 2019, Pages129-137.

[13] Ye.N. Amirgaliyev, M. Kunelbayev, A.U.Kalizhanova, W.Wójcik, B.Amirgaliyev, O.A.Auelbekov, N.S.Kataev, A.Kh.Kozbakova, Calculation and selection off lat-platesolar collector geometric parameters with thermosiphoncirculation Journal of Ecological Engineering, Volume 19,Issue 6, 2018, Pages 176-18

[14] Reza, Farhadur, and Mohammad Farzid Hasan. "Potential for recovery of resources from food market refuse: a case study in Dhaka, Bangladesh." International Journal of Environment, Ecology, Family and Urban Studies (IJEEFUS) 6.1 (2016):59-70

[15] Chandrasekaran, Tha Murugan 1 & r. "A study and development of comprehensive solid waste management plan for Panchayat unions in Coimbatore district under the context of municipal solid waste rules." International Journal of Business Management & Research (IJBMR) 6.2 (2016):1-14

[16] Das, Amaresh, GG Patel, and MC Patel. "Transforming plant wastes along with cattle dung and other substrates into organic wealth through partial decomposition and vermi composting." International Journal of Agricultural Science and Research (IJASR) 7.4 (2017):441-446

[17] Kinoshita, H. I. R. O. Y. U. K. I., et al. "Environmental Harmony-Type Pavement Blocks Made from Clay and Waste GFRP." International Journal of Civil, Structural, Environmental and Infrastructure Engineering Research and Development (IJCSEIERD) 6.1 (2016): 51-60.

[18] Priyanga, S., Et al. "Biogas production from sericulture wastewater as feed stocks in batch process using rumen fluid." International Journal of Agricultural Science and Research (IJASR) 9.4 (2019):27-34

[19] Pushparaj, Pramila, and Chitdeshwari Thiyagarajan. "Efficiency of Organic and Inorganic Amendments in Reclaiming Calcareous Sodic Soils: Changes in Physicochemical Properties." International Journal of Agricultural Science and Research (IJASR) 6.3(2016):495-502.

[20] Mnaathr, Satar Habib, and Abdullh Saiwan Majli. "The exploration of Bioenergy generator processing based on the information and communication technology." International Journal of Mechanical and Production Engineering Research and Development (IJMPERD) 8.6 (2018):359-364.