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ORIGINAL ARTICLE

Investigation of Performance Parameters of Biogas Fueled Power Generation Process

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Abstract

An investigation of the parameters affecting the power output of biogas fueled power system has been carried out in this paper which will help the researchers to promote the power output from the biogas power plant in a significant manner. A good number simulation works has been carried out in MATLAB for showing the importance of parameters in power generation process from a biogas power plant. One of the important parameters is volatile output in the reactor. From the simulation it is seen that maximum volatile output could be around 19 Kg/m3 as a concentration level if the feed flow rate is increased to around 16 m3/day. Throughout the simulation process a good number of factors have been analyzed like volatile acid concentration, reactor temperature, turbine speed etc. Therefore, the simulation work presented in this paper will help the researchers to realize the importance of the parameters in the power generation process from the biogas power plant.

Keywords: Biogas, Temperature, Turbine speed, Methane gas, anaerobic

Introduction

The uses of electricity are continuously increasing everywhere in the globe with the rise of electronic devices. Moreover, these power plants are based on fossil fuel which has a serious effect on the environment. Fossil fuels-based power station generates a huge quantity of carbonic acid gas as well as other gases that are not environment friendly which deteriorates the air quality and cause global warming. By discharging the greenhouse gases (GHG) to the air the temperature of the globe is increasing alarmingly. Renewable energy can reduce the GHG emission significantly. In this circumstance bio energy is an excellent solution. Biogas within the renewable energy can be a future energy solution as substantial amount of GHG like Carbon dioxide (CO2), Methane (CH4), Nitrous oxide (N2O) is emitted from it (Paolini et al, 2018). Biomass is stored chemical energy in plant from the sun by photosynthesis. The plant which is considered as the main source of the biomass can generate the power (Kabeyi et al, 2020)]. Biomass is very much familiar in the third world country (McKendry, 2002). Solid adsorbents and wet scrubbers both increase the methane (CH4) up to 76% which can be used in the electrical generator for power generation process (Njogu et al, 2015). Biogas technology needs to be facilitated especially in the rural areas, so that fuel crisis can be mitigated (Yang et al, 2012). Using biogas as a fuel can reduce the global warming potential (GWP) 83% rather than utilization of traditional biomass (Rahman et al, 2017). In addition, biomass reduces a major GHG emission during the generation of electricity (Ghayal and Pandya, 2012). The populous countries are interested for generation of biogas from biomass (Moreno et al,2019) Biogas yields in biogas plants by the microorganism degradation of biomass under anaerobic digestion (AD) process has huge potentiality all over the world due to the availability of the raw materials such as agricultural waste, plant material, animal manure, municipal waste, industrial by product, expired food or food waste etc. By AD process this organic matter (combustible gas) is generated in a great rate. This gas is used for household stove or lightening purposes mainly in developing countries. The combustible fuel produced from the biogas is connected to a generator to produce the electricity. Biogas is a self-sufficient alternative energy which is a great solution of heat and power crisis.

Wet (40-90%) organic materials and comprising of cellulose are suitable for AD (Omer, 2017). In agricultural biogas plant mean fuel efficiency from four plants was seen 40.5% (Elmar et al, 2016). Grass straw or sugar beet pulp in a plant produces profitable bioenergy (Achinaset al, 2019). The concentration of Hydrogen-ion (PH) in the digestate materials plays a role in AD. Optimal activity value of PH is (Igoni et al, 2007). Combined heat and power (CHP) using biogas is better than that of boiler for GHG reduction in life cycle (Kyung et al, 2020) Though the biogas has many advantages but it has some environmental hazards. The biogas pollutants H2S, Si, NH3, CO and some other volatile organic compounds (VOC) are deleterious to health and environment. H2S and NH3corrosive and destroying combined heat and power (CHP) (Angelidaki et al, 2018).

Bangladesh is a land of 147,570sq km with its 180 million people and increasing every year, resulting in a considerably high electricity demand each year. As a result, Bangladesh experiences unmanageable shortage of electricity every year especially in summer. According to the World Bank report of 2015, 98.77% of power is generated from fossil fuel-based stations. This paper investigates the performance of different parameters related to the power generation process from the biogas power plant.

Anaerobic digestion process

Anaerobic digestion is a process by which the organic materials (biodegradable) converted into biogas; high quality combustible gas CH4 and CO2 as by product under anaerobic conditions. Through this process emissions of certain GHG gases can be reduced and problems of waste management also solved. Anaerobic digesters can also be fed with purpose-grown energy crops, such as maize. This biogas can be used directly as fuel, in combined heat and power gas engines or upgraded to natural gas-quality biomethane. The nutrient-rich digestate can also be used as fertilizer production. Chemical treatment increases the biogas yield (Omar et al, 2018).

With the re-use of waste as a resource and new technological approaches that have lowered capital costs, anaerobic digestion has in recent years received increased attention among governments in several countries, among these the United Kingdom (2011), Germany, Denmark (2011) and the United States. The evolution of biogas happens through the activity of assorted microorganisms in 3 steps; hydrolysis, acidogenesis and methanogenesis (Asgharian et al, 2016).

Results and Discussion

Hydrolysis Model

The hydrolysis system is the rate of change in the concentration of biodegradable volatile solids (BVS) in the reactor. The system depends on the nature of feed used, material, feed flow rate, amount, and temperature of the reactor. The hydrolysis process is expressed in (i) (Saeed et al, 2018).

$$\frac{d(S_b)}{dt} = \left(S_{b_{in}} - S_b\right)\left(\frac{F_{feed}}{V}\right) + \frac{\mu_m K_1 X_{acid}}{\frac{K_S}{S_b}+1} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(i)}$$

S_b = Concentration of biodegradable volatile solids in the reactor (kg/m^3),

$s_{b_{in}}$ =Concentration of biodegradable volatile solids in the reactor feed (kg/m^3),

F_{feed} = Feed flow rate (m^3/day),

V=Effective reactor volume (m^3), K_1 is the yield factor estimated using experimental data as given in [26] ,
X_{acid} = Concentration of acidogens (kg/m^3),

K_s is the Monod half-velocity constant for acidogens(kg/m^3),

$\mu_{m=}$ Maximum growth rate for acidogens (d^{-1})

X_{meth} =Concentration of methanogens (kg/m^3)

The maximum growth rate of methanogenes is represented in equation (2)

$$\mu_m(T_{react}) = \mu_{mc}(T_{react}) = 0.013T_{react} - 0.129 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(2)}$$

Here μ_{mc} is the maximum growth rate for methanogens (d^{-1}), and T_{react} is the reactor temperature (°C).

Acidogenesis modeling

The stage of acidogenesis represents the rate of change of the volatile concentration of fatty acids during fermentation. This is the process which is dependent on the concentration of total volatile fatty acids in the reactor, the rate of feed flow, volume of the reactor and temperature of the reactor. The equation of acidogenesis is as follows (Saeed et al, 2018).

$$\frac{\mathbf{d(Sv)}}{\mathbf{dt}} = (\mathbf{Sv_{in}} - \mathbf{Sv}) \cdot \left(\frac{\mathbf{F_{feed}}}{\mathbf{V}}\right) + \frac{\mathbf{\mu_m \cdot K_2 \cdot X_{acid}}}{\frac{\mathbf{Ks}}{\mathbf{Sb}}+1} - \frac{\mathbf{\mu_{mc} \cdot K_3 \cdot X_{meth}}}{\frac{\mathbf{Ksc}}{\mathbf{Sv}}+1} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(1)}$$

$K_2 =$ Production factor estimated from experimental data,
k_3 = Production factor related to growth rate of methane, and

$$\frac{d(X_{acid})}{dt} = \left[\frac{\mathbf{\mu_m}}{\frac{\mathbf{Ks}}{\mathbf{Sb}}+1} - \mathbf{K_d} - \left(\frac{\mathbf{F_{feed}/b}}{\mathbf{V}}\right)\right]\mathbf{X_{acid}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(4)}$$

b is the retention time factor measured in experimental data K_d is the specific death rate of acidogens.

Methanogenesis modeling

This is the final stage of anaerobic digestion process to yield methane. This process depends on retention time, the feed flow rate, effective reactor volume, and reactor temperature (Ghayal and Pandya, 2012). Figure 1 shows the simulation model of hydrolysis process.

$$\frac{\mathbf{d(Xmeth)}}{\mathbf{dt}} = \left[\frac{\mathbf{\mu_{mc}}}{\frac{\mathbf{K_{sc}}}{\mathbf{Sv}}+\mathbf{1}} - \mathbf{K_{dc}} - \left(\frac{\mathbf{F_{feed}/b}}{\mathbf{V}}\right)\right].\mathbf{X_{meth}} \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots(2)$$

K_{dc} is the specific death rate of a methanogens (d^1) and X_{meth} is the concentration of methanogens (kg/ m^3).

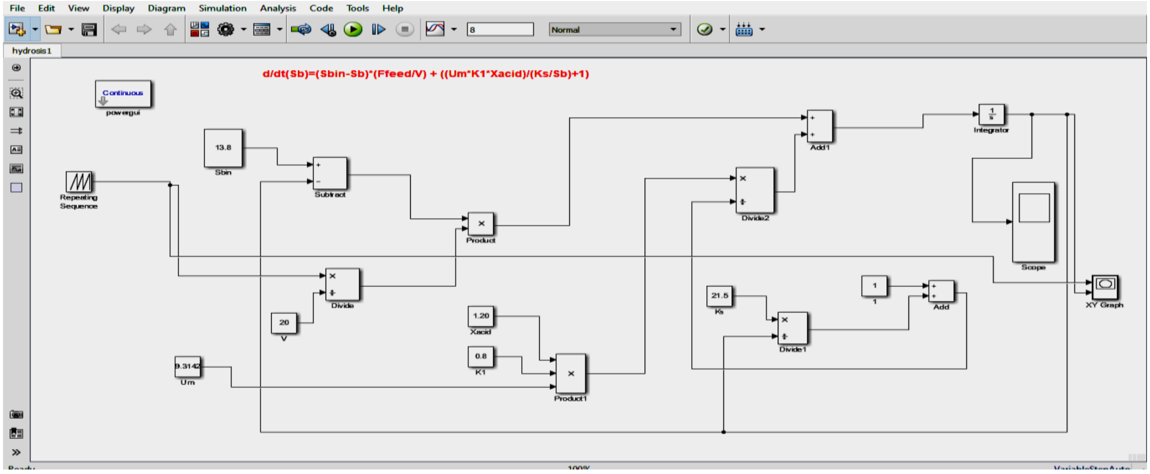


Figure 1. Simulation model of hydrolysis process

Figure 2 shows the simulation model of relation between maximum growth rate and temperature. And figure 3 shows simulation of Acidogenesis modeling whereas Figure 4 shows simulation model of methanoenesis process.

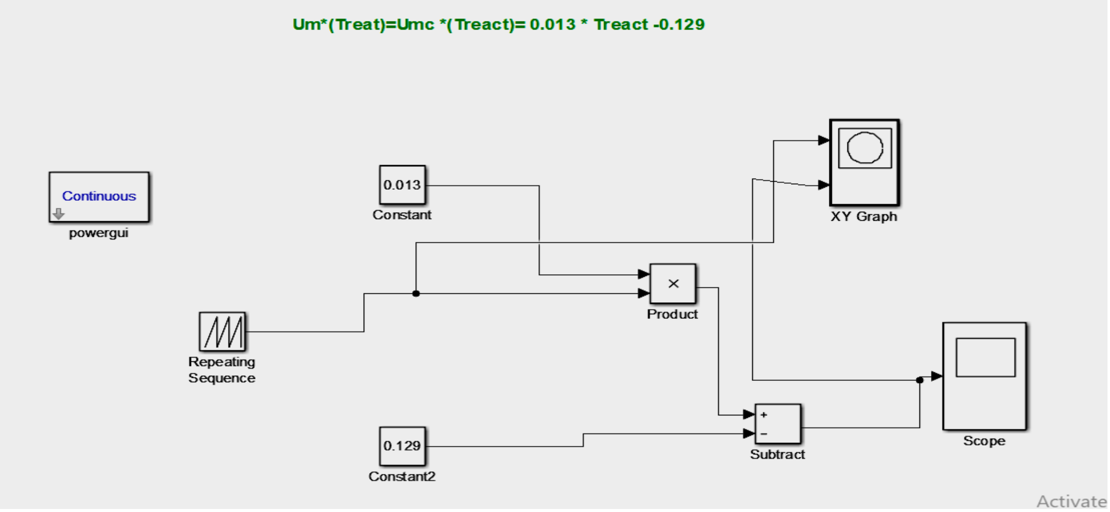
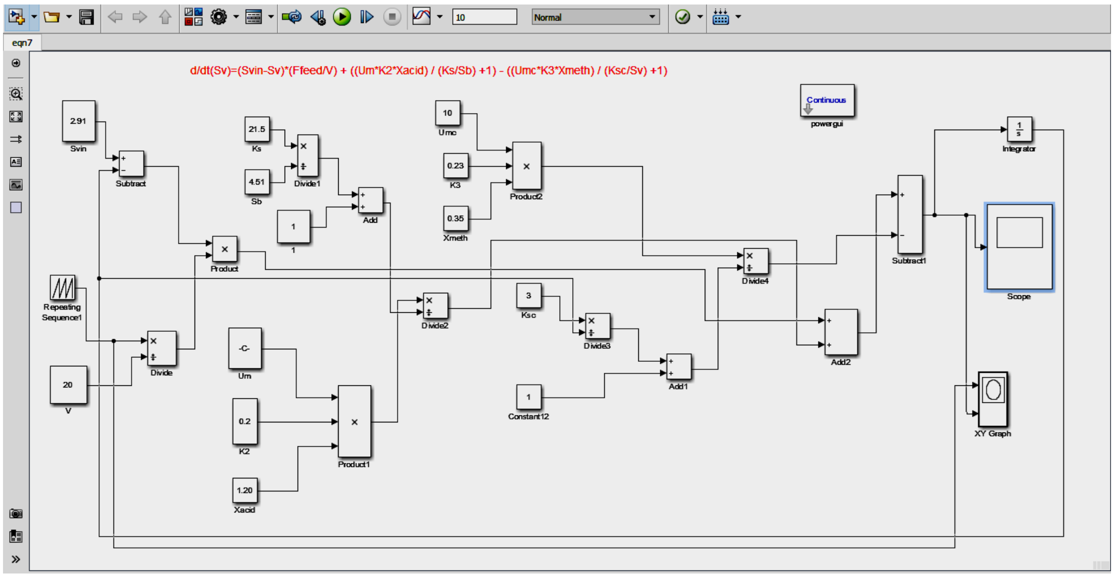
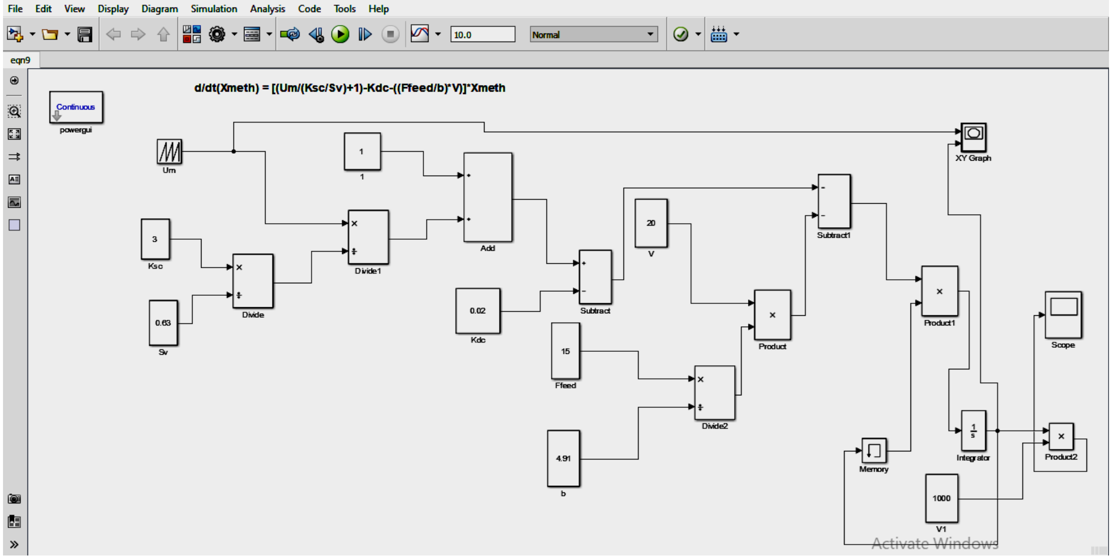


Figure 2. Simulation model of relation between maximum growth rate and temperature



d/dt(Sv)=(Svin-Sv)*(Ffeed/V) + ((Um*K2*Xacid) / (Ks/Sb) +1) - ((Umc*K3*Xmeth) / (Ksc/Sv) +1)

Figure 3. Simulation of Acidogenesis modeling



d/dt(Xmeth) = [(Um/(Ksc/Sv)+1)-Kdc-((Ffeed/b)*V)]*Xmeth

Figure 4. Simulation model of methanogenesis process

The volume of methane output from reactor is represented by the equation (6) (Saeed et al, 2018)

$$\mathbf{F_{meth}} = \mathbf{V} \cdot \frac{\mu_m}{\frac{K_{sc}}{Sv}+1} \cdot \mathbf{K_4} \cdot \mathbf{X_{meth}} \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots (6)$$

Here, K_4 =Factor related to the methane gas flow and measured from experimental data source with respect to fuel flow and turbine speed are given by the following equations:

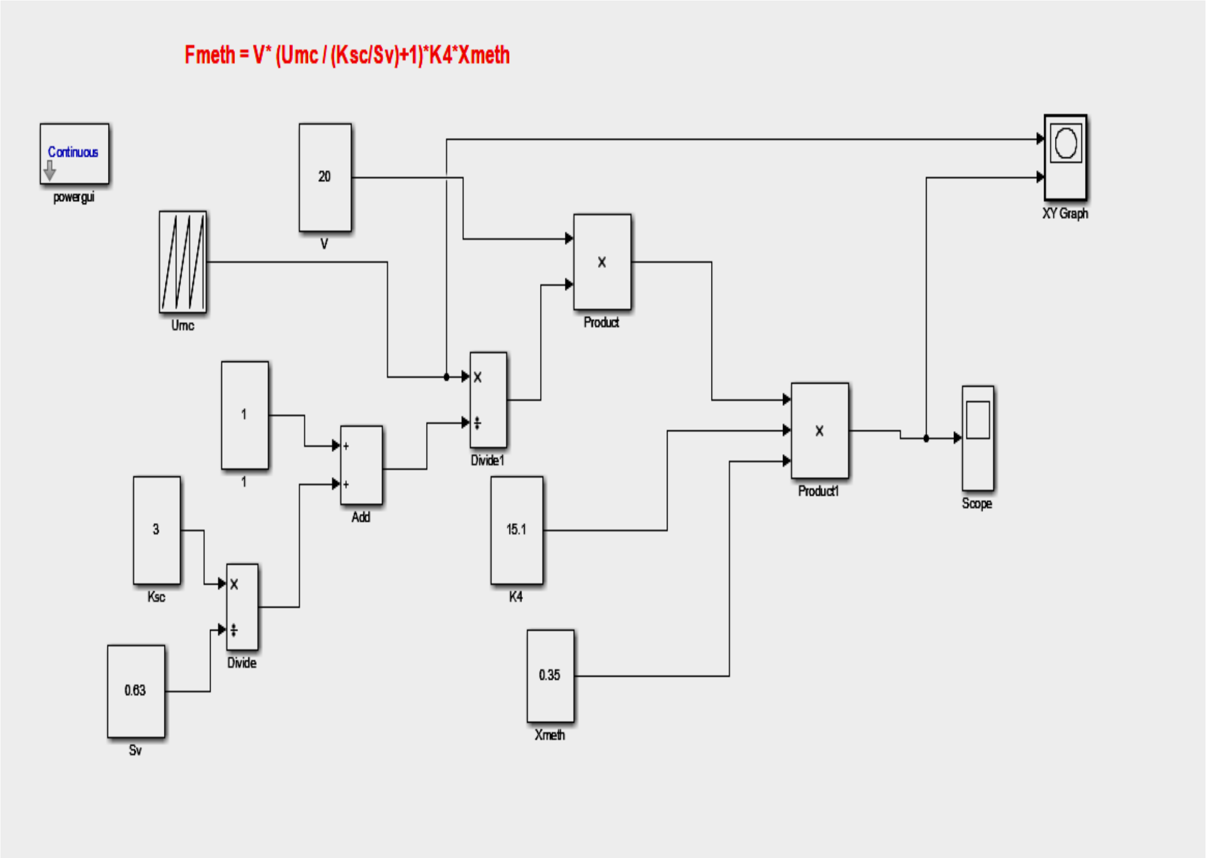


Figure 5. Simulink model represent amount of methane output from reactor.

MT (micro turbine) is small gas turbine required to generate the power of electric generator using biogas.

Compressor-Turbine

The feature of the MT compressor is to deliver air in enough quantity to meet the necessities of the burners. This will increase the stress of air inlet duct and pass it to the combustion burner at needed stress with respect to turbine speed and fuel flow represented by the following equation.

$$\mathbf{T = KH(Wf - 0.23) + 0.5(1 - N)} \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots (7)$$

$$\mathbf{T_x = T_R - 700(1 - W_f) + 550(1 - N)} \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots (8)$$

Where

KH is a coefficient considering effect of enthalpy of the gas stream in the combustion chamber, T_R is the reference temperature, N is the p.u. turbine speed and W_f is the p.u fuel demand signal.

Table 1 shows the factors used in the model. The generation rate of methanogens with respect to fluid flow rate in hydrolysis process is represented in Figure 6.

Table 1. Factors used in the proposed model (Haugen et al, 2012)

AD		MT	
B	4.91	K	25
K_s	21.5kg/m^3	K_1	0.8
K_{sc}	3 kg/m^3	K_2	0.2
K_d	0.02 d^{-1}	T_1	0.4
K_{dc}	0.02 d^{-1}	T_2	1
K_1	9.66	T_3	15
K_2	6.97	T_4	2.5
K_3	31.8	T_5	3.3
K_4	15.1	T_t	450 ºF
XmethXacid	0.35 kg /m^3	Z	3
Sb_{in}	1.20 kg /m^3	K_v	1
Sb	13.8 kg /m^3	T_v	0.05
	4.51 kg /m^3	C	1
Sv_{in}	2.91 kg /m^3	K_3	0.23
Sv	0.63 kg /m^3	K_f	1
V	20 m^3	T_R	950 ºF
T_f	0.04		
T_{CR}	0.01		
T_{TD}	0.04		
T_{CD}	0.2		
KH	1.2		

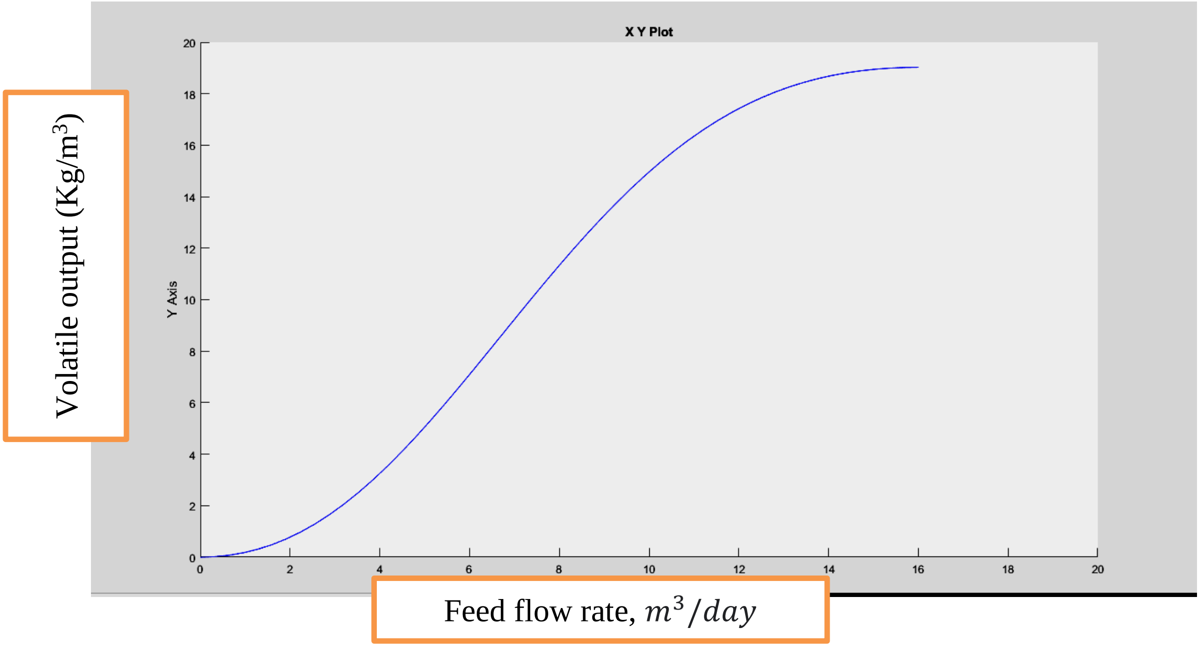


Figure 6. Hydrolysis process of biogas production

Figure 6 shows the hydrolysis process of biogas production. This model represents the hydrolysis processing. Here we found the value of Sb, contingent ofF_{feed}. X axis represents the F_{feed}& Y axis is Sb (concentration of biodegradable volatile solids in the reactor (kg/m^3). The value of F_{feed}(feed flow rate) is $16m^3/day$ for the maximum volatile output of around 19 Kg/m3.

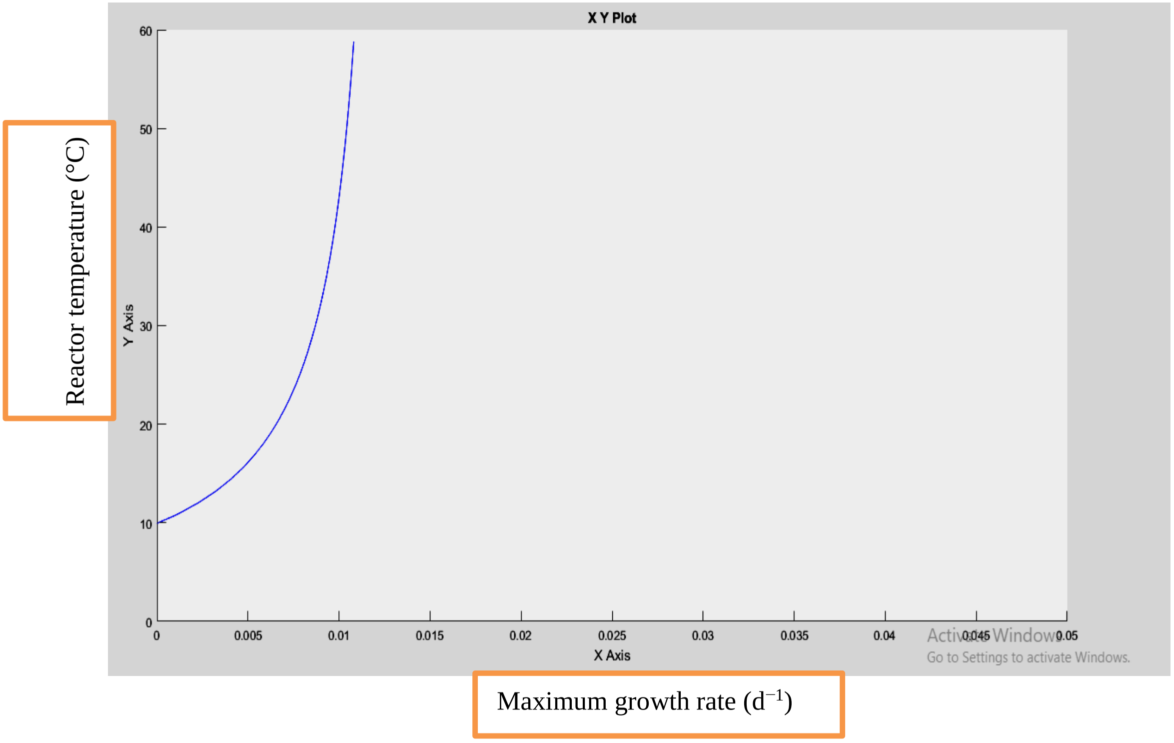


Figure 7. Maximum growth rate with reactor temperature

Figure 7 shows that maximum growth rate with reactor temperature. The figure shows the biogas generation growth is very rapid with the increment of reactor temperature. From the figure it is seen that the temperature is increased tremendously with the increment of maximum growth rate.

Here we made a graph for U_m (T_{react}) & T $_{react}$. The value of U_m (T_{react}) is 0.23 $h^{-1.\ Treact}$ is 300°C. We should find the U_m (T_{react}), contingent of T_{react}. Here U_m is in X axis & T_{react} is in Y axis. This is also for the hydrolysis process.

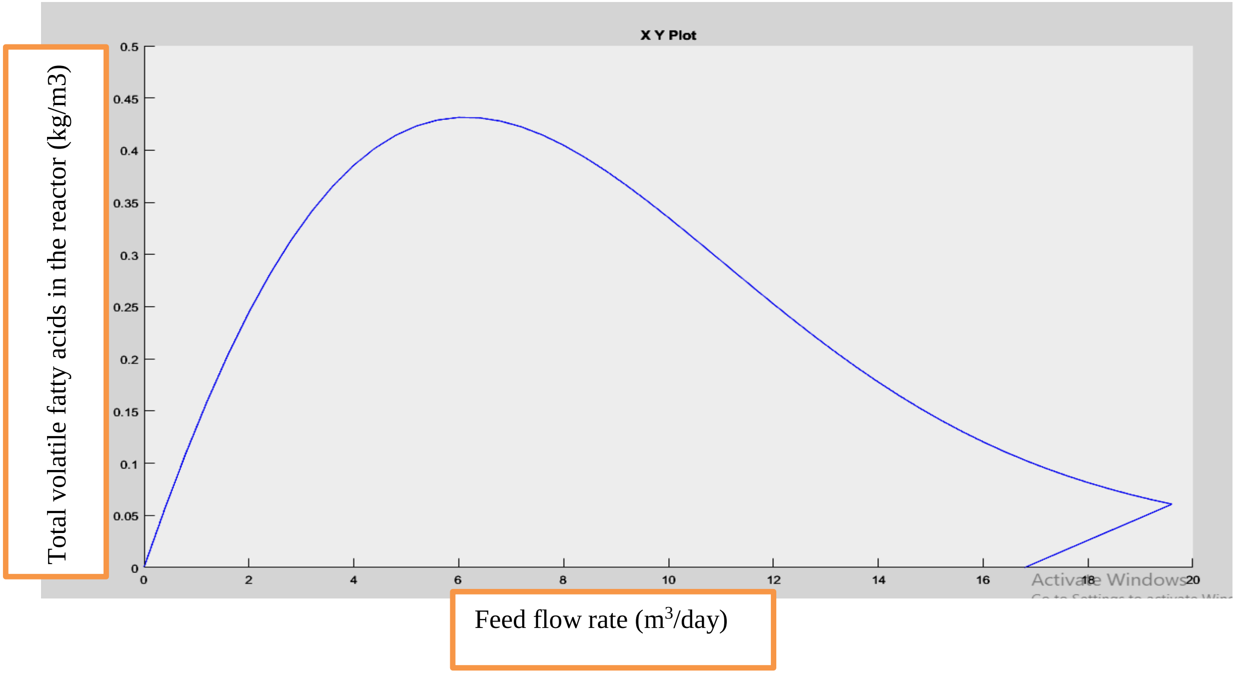


Figure 8. Rate of change of the volatile concentration of fatty acids

This model shows the acidogenesis process. Figure 8 shows the rate of change of the volatile concentration of fatty acids where it is found that total volatile fatty acid is reached maximum at 0.43 Kg/m3 for the feed flow rate of around 6 m3/day.

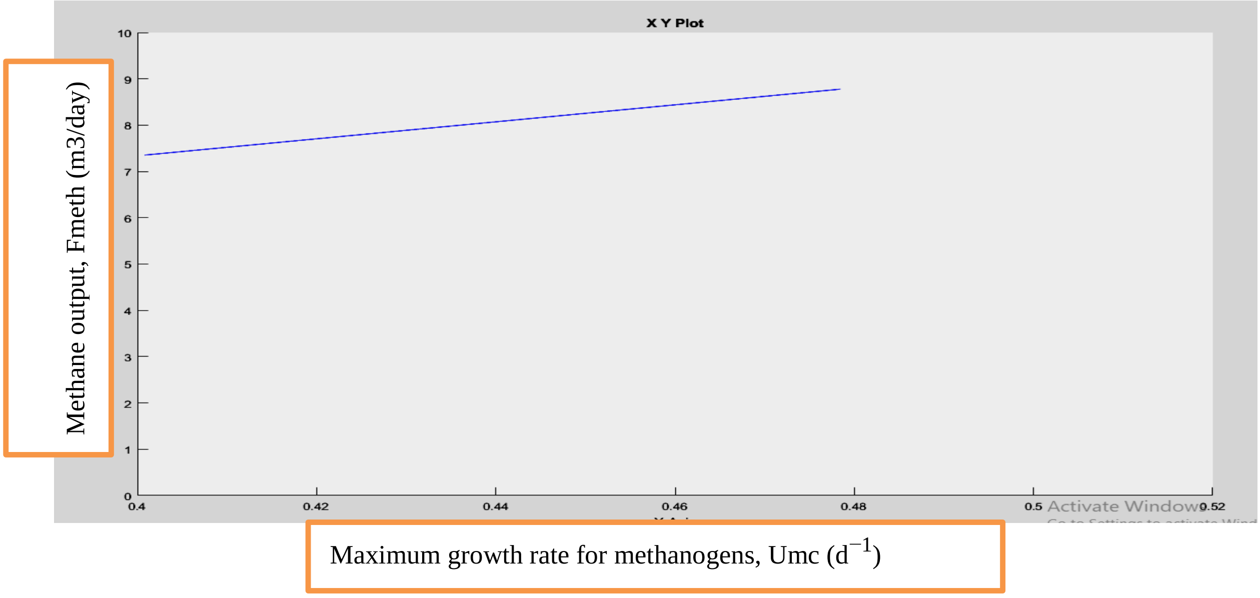


Figure 9. Change of Methane gas

This model represents the methanogenesis process. Here we need to find F_{meth}, contingent of Umc where F_{meth} is feed flow rate of methane. From the curve it is seen that methane flow rate is almost constant level with the increment of maximum growth rate for methanogens.

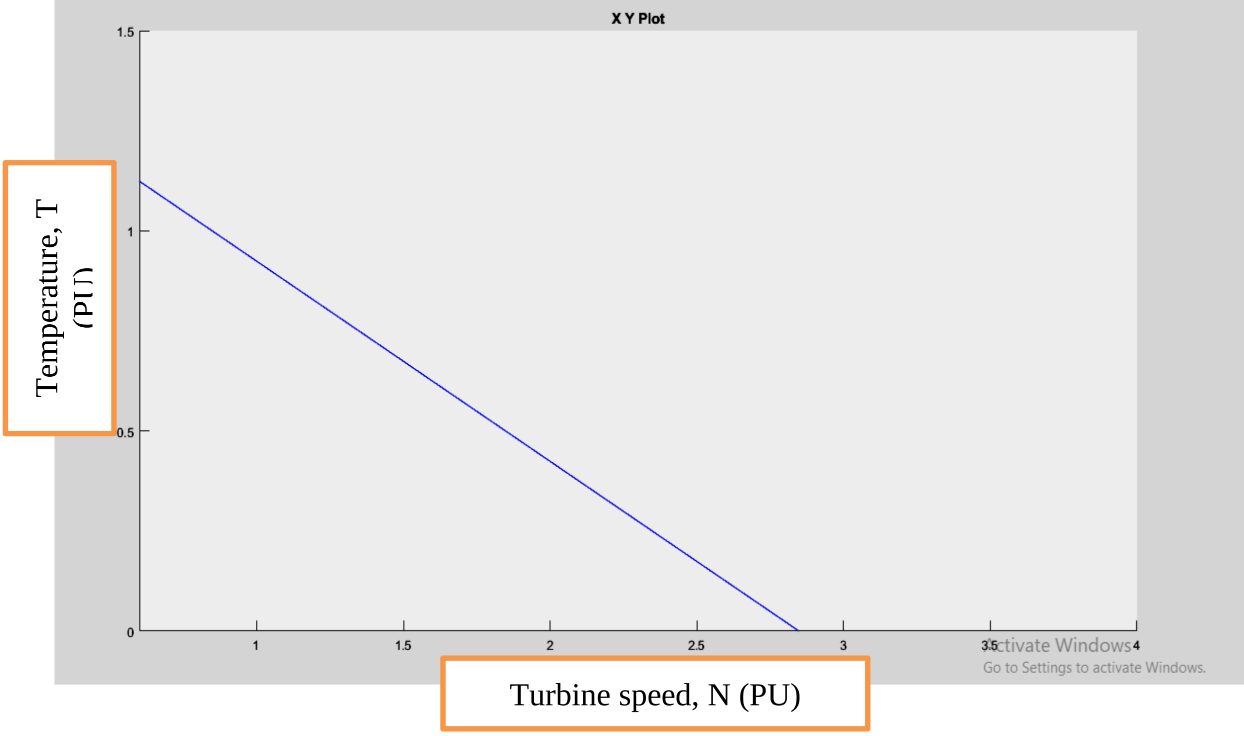


Figure 10. Change of temperature with turbine speed

Figure 10 represents the change of temperature with turbine speed. Here we need to find the T, contingent of N. From figure 10, it is seen that the temperature goes down with increment of turbine speed.

Conclusion

Anaerobic fermentation causes the formation of biogas in the reactor. For optimum generation of the biogas, it is very important for parameter analysis of the biogas power plant. The biogas generation process is highly dependent on some important factors like feed flow rate, volatile acid generation, volatile output etc. From the analysis it is seen that the generation volatile acid is increased at maximum of 0.43 Kg/m3 as a concentration level for the feed flow rate of 6 m3/day whereas this concentration level decreases in a significant manner for the further increment of feed flow rate in the reactor. From the simulation result it has been observed that at the feed flow rate of 16 m3/day, the volatile output is maximum at 19 kg/m3. The simulation result provides the deep analysis of the parameters that can affect the power generation effectively.

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