Emerald International Journal of Scientific and Contemporary Studies **Vol.** 6. No. 1. February, 2024
Open Access Publications ISSN: 2705-230

https://emeraldacademics.com 125-147. 24

MATHEMATICAL MODELING OF AN INTEGRATED BIOREACTOR FOR ANAEROBIC DIGESTION

[1]**Obasi, U.G.,** [2]**Ayadiuno, G. C.**
[1]Imo State University, Owerri, Imo State
[2] Chukwuemeka Odumegwu Ojukwu University Anambra State
[1]engrucheobasi@gmail.com; [2]gc.ayadiuno@coou.edu.ng

ABSTRACT

The greatest issues that the world is facing today are recent problematic nature of Bioreactors failures Anaerobic Digestion (AD) for methane gas production in both domestic and commercial usages and have opened up the new concepts filling the gap in reestablishing the technology by Modeling Bioreactors for Profitability, Engineering Waste management and Energy Crisis. Most of these problems can be overcome by Mathematical Modeling of Anaerobic Digestion (AD). Because of the growing need of Anaerobic Digestion (AD) of solid waste, increased efforts in reducing Biogas Plant Design cost, Process Operation is crucial and one way of achieving is by employing Modified Gompertz Mathematical Modeling of the Anaerobic Process on a Test Rig of Coupled Bioreactors. It is expected that the incorporation of appropriate flow features in Bioreactor Design would provide the basis of effective digestion of organic waste leading to high yield in Performance with high Biogas Production. Consequently, a test rig of coupled bioreactors constructed was employed for the Gompertz Mathematical Modeling of Anaerobic Digestion (AD) while applying the resulting First Order Kinetic Constant Equation based on a Modified Fenton's First Order Model Equation which showed a good agreement with the working performance as characterizes in the Mathematical Modeling of an Integrated Bioreactor.

INTRODUCTION

Bioreactors are commonly cylindrical, ranging in size from some litres to cubic meters, and are often made of stainless steel, McNaught and Wifkinson (2020). Bioreactors provide the conditions that accelerate the digestion and stabilization of organic matter. Biodegradation of organic matter is normally a naturally occurring phenomenon thus explaining decay/putrefaction associated with municipal waste in given dump sites, Adeoti, et.al (2021). Under uncontrolled conditions, organic matter is subjected to degradation often with undesirable effects. Many factors affect the biodegradation of organic matter, (Boone et al., 2019).. These include, but not limited to, the microbial, concentration, organic content of the substrate, operating temperature, pH, mode and degree of substrate agitation, mixing/flow regimes, First Microbiology Reader Reviewed (2021). When these factors are under control as in bioreactors, degradation or digestion of organic matter can bring about beneficial effects and products. Atiqullah et al (2021) shows biogas and waste organic fertilizer by products can be produced by the biological breakdown of organic matter. Bio-fuel is produced by anaerobic digestion of biodegradable materials such as manure, sewage, organic municipal waste (OMW), green waste plant material, energy crops etc, United Nations Guide (1999). It can be utilized for heat and electricity production in combined heat and power (CHP) Gas Engines.

The quest to obtain the desirable benefits from controlled organic waste degradation has led to the development of bioreactors. According to Kumar (2022), bioreactors are increasingly used to make a variety of products across several industries. They are used, for example, in the manufacture of antibodies such as penicillin. According to same literature, 70% of ingredients for the food industry are made through fermentation, Agdag and Sponza (2021).

A Test Rig Bioreactors with cylindrical configurations made from stainless steel materials constructed in line with the requirements in respect of anaerobic biological degradation of organic waste. The bioreactor will be operated under mesospheric temperatures via the specified flow regimes by employing the basic principles of fluid dynamics in a mathematical model procedure using Modified Gompertz Equation developed to show its Bioreactor performance. The reactors are intended to utilize aqueous organic substrate and configured for up-flow characteristics. It is expected to be coupled to a continuously stirred tank reactor (CSTR). The system is designed to enable variation of flows and mixing regimes.

Materials and Methods

The methodology presented here comprises a system of integrated bioreactor configuration, constructed in terms of identified modules.

The test rig of integrated bioreactors is constructed to have the following features:

(i) An overhead tank which feeds substrate to coupled bioreactor systems by gravity.

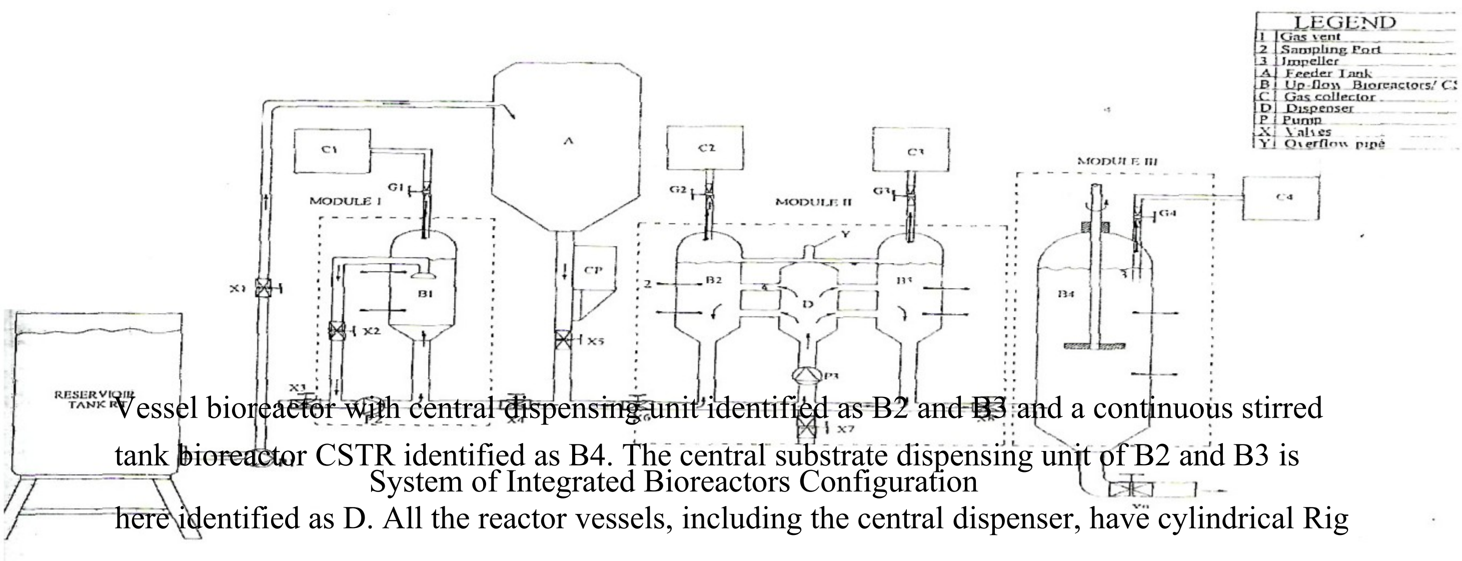
(ii) Isolation of bioreactor systems into experimental modules capable of independent operation and observation.

(iii) An ergonomic design with a centralized system control for bioreactor operation.

(iv) A dedicated gas collector and metering device for each bioreactor operation.

(v) A mechanism for flushing and cleaning the bioreactor vessels.

Accordingly, the configuration of the rig of the system of integrated bioreactors investigated is illustrated schematically below.

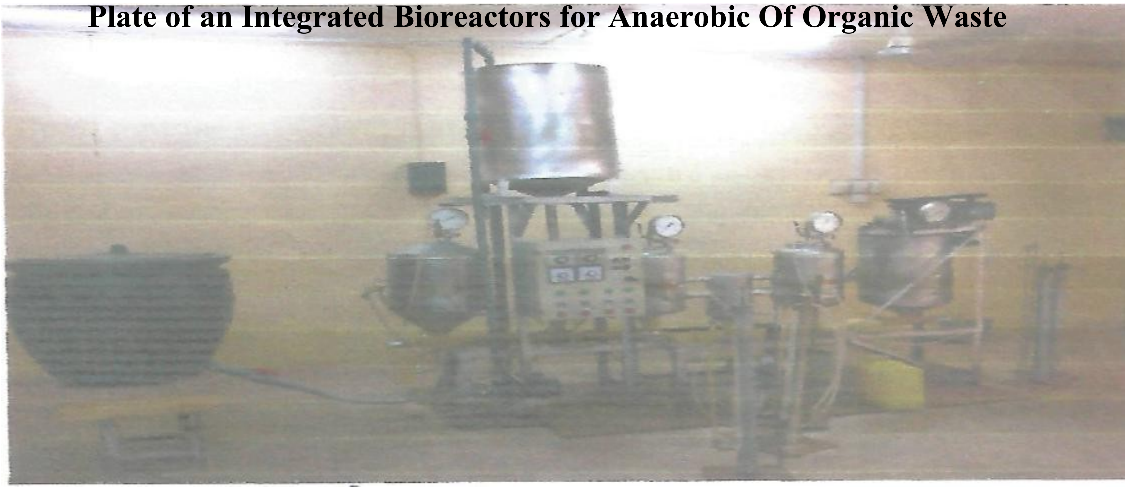


System of Integrated Bioreactors Configuration

Vessel bioreactor with central dispensing unit identified as B2 and B3 and a continuous stirred tank bioreactor CSTR identified as B4. The central substrate dispensing unit of B2 and B3 is here identified as D. All the reactor vessels, including the central dispenser, have cylindrical Rig configuration. There is an overhead feeder tank identified as A. This overhead tank is fed with substrate slurry from a surface tank reservoir identified as RT, where the organic substrate slurry is prepared.

An electric pump delivers slurry from the reservoir to the feed tank. Thereafter, the substrate slurry is fed into all the bioreactors by gravity while opening valves X4, X5, X6 and X8. The closure of valves X3, X4, X6, X7, X8 and X9 configures the rig into three experimental modules I, II and III, each of which is capable of independent operation and observation. Each module of the bioreactor rig has a sampling port, a gas vent and provisions for attachment of sensors for temperature and gas pressure monitoring devices. Modules I and II bioreactors each have additionally, a metering pump for substrate recirculation. Also, module has a continuous stirred, tank reactor [CSTR] with a centrally located vertical shaft-impeller assembly unit which rotates with the aid of a geared electric motor through a belt-pulley power transmission drive. The pumps and geared electric motor are for the purposes of flow control and substrate mixing. The rig instrumentation is to be controlled from a central instrument panel. All pumps, inclusive of the geared electric motor of the CSTR; are each to be controlled electrically by direct on-line starter switches via the panel.

Plate of an Integrated Bioreactors for Anaerobic Of Organic Waste



Modified Gompertz Mathematical Modeling of Anaerobic Digestion (AD)

Hence a model hyperbolic equation was developed on the basis of first reaction rate for substrate degradation. The mathematical model was employed using GOMPERTZ EQUATION as follows:

Based on mass balance of influent and effluent materials the following expression was determined thus;

$$M_0.C_0-M_e.C_e-M_g = 0$$

Where M_0 - daily substrate input.

Co = concentration of volatile solids (VS) of the input

M_e = mass of effluent

C_e = VS concentration of effluent

M_g = the, difference between the supplied and the removed - organic matter.

The products M_0.Co = supplied organic matter.

And $M_e.C_e$ = removed organic matter.

The degradation of substrate in the CSTR was assumed to follow a substrate removal rate S_r (c) which depends on C at a steady state concentration in the reactor.

An expression for M_g was obtained. Thus,

Where : V_i = volume of CSTR (which is constant and predetermined)

Ps= density of the effluent

= substrate removal rate a first-order reaction with a react constant K

= K

Vi=

.Pe. K

Were Bt= volatile solid (VS) biogas yield,

.K.

By the relation matter is completely converts to biogas a correlation between on the sides of y and the theoretical maximum biogas yield Bmass on the graphically expression below

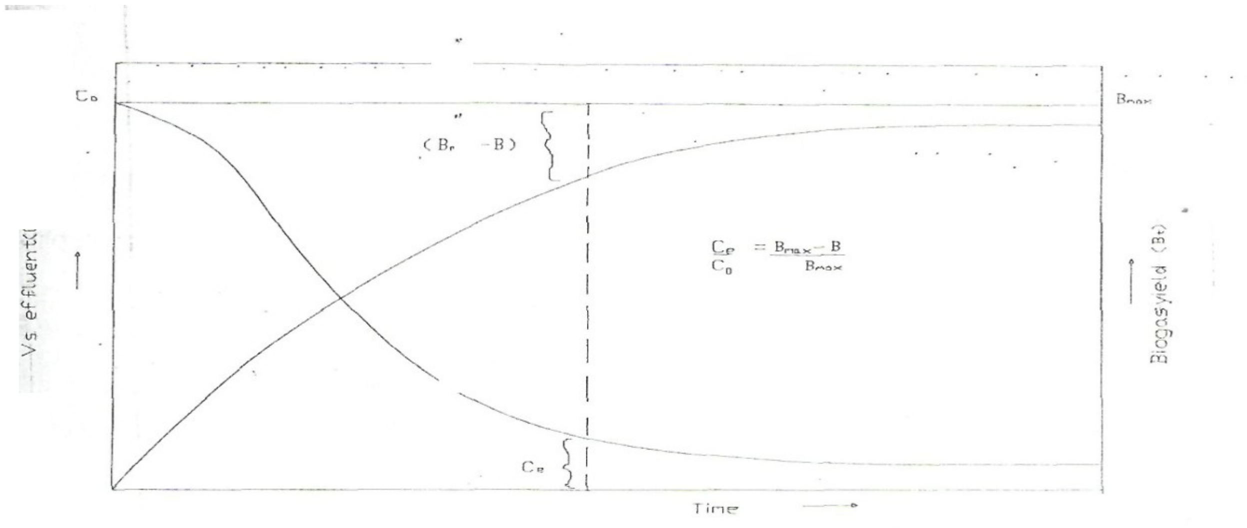


Fig 2.18: The correlation between the Vs-Biogas yield B_t, the maximum eld B_{max} and Vs-concentration of the input C_o and effluent C_e

From above k=

$^{-Bt}$/

B_t=$^{-Bt}$/

B_t=

Which gives, $Y=a.b(b+ax)^{-1}$.

First Order Kinetic Constant Equation based on a Modified Fenton's First Order Model Equation Approach

Determining the test Rig integrated bioreactor working performance by applying the total volume internal void space V_t of the feeder tank is the sum of the volumes, V1 and V_2 of the cylindrical and frustum sections respectively and V_2 are given by the following equations:$V_1D^2H_1V_1$

V_2H_2 3.1

Combining eqns. gives:

V_1=V1+V2=$V_1D^2H_1V_1+V_2H_2$

$V_1D^2H_1+D^2+$ +

$0.25= [(0.6x0.6)H_1+[((0.6x0.6)+(0.6x0.05)+(0.05x0.05)$

$= 0.36H_1+0.0654] = 0.2829H_1 +0.0514$

$0.25 = 0.2829H_1 +0.0514 =0.1986$

$0.2829H_1=0.25 -0.0514 = 0.1986$

$H_1 = =702mm$

For a selected working volume of 2501, choosing a pipe diameter of 50mmfrom a Table above of commercially available stainless steel pipes (DN50mm,XS 80mm) a cylinder diameter of 600mm and height of the cylindrical section as 500mm, the height cylindrical section, H_1 can be obtained from eqn. as:

$H = H_1 + H_2 = 0.702+0.50 = 1.202m$

The shell thickness in mm, of the feeder tank can be determined using the relationship presented in BS 2654- British standard, Olsson (2018), for storage tanks. Thus

$_{max}$ - 0.3) + P_{df}] + CA

Where D is the tank diameter in m, $a_a$is the allowable design stress in MP_a, p_s is the substrate density in g/ml, P_{dl} is the design pressure in mbar and CA the corrosion allowance in mm. The maximum pressure in the tank relates to the maximum hydraulic head h_{max} by the equation.

$$P_{dl} = pg^{h}{}_{max}$$

p_s = *1250kgm*$^{-3}$ *or 1.250g/ml (*Measured with Density meter KEM, model DA-130N)

For a hydraulic head h_{max} equal to 1,202m, the height of the tank and substituting p_s and g into eqn. above yields;

P_{dl} = 1250 x 9.81 x 1.202 = *14,739.525 Nm-*^{2}= 147.39525*mbar.*

This is taken to be the design pressure for the constructed feeder tank BS2654

defines allowable design stress as 2/3 of the yield stress which gives =1/2

= *yield stress = 2lSMPa for AISI* 304 *stainless steel* (Aerospace specification Metal (ASM) Inc)

Substituting for in eqn3.6 gives

th =[981250(1.202 -0.3) + 147.39525] + 0.5

=0.055+ 0.5 = 0.55mm

Structural Stand Constructed proved the total weight Wt_s, of 250I substrate slurry is given by

$Wt_s = m_g g = V_t p_s g$

Substituting $V_t p_s g$ *and* g in eqn3.7 gives

Wt_s = 3,065.63/V

WeightW_{tT} of empty feed tank vessel can be expressed by

Wt_T = *[volume occupied by vessel* V_T*— void volume* V_i*].* $p_{ss} g$

$wt_T = (V_T - V_i) p_{ss} g$

Where, p_{ss} density of AISI 304 stainless steel

Expressing the total volume, V_T occupied by the feeder tank vessel in terms of the external diameters D_0 and d_{fo}, eqn. above is rewritten as

V_2=[$D_0^2H_1$+(D_0^2+$D_0^2d_{fo}$+d^2_{fo})

But D_0= D+ 2th

d_{fo}= d_f+2th (Where th is the thickness of shell) hence,

$$V_T = \pi/_4\left[(D+2th)^2 H_1 + \frac{H_2}{3}\{(D+2th)^2 + (D+2th)(d_f+2th) + (d_f+2th)^2\}\right]$$

Substituting the values of D, th, d_f, HI and H_2 gives

V_T= 0.3847m^3

Density p_{ss} of AISI 304 stainless steel is equal to 8000kgnY^3 (ASM data sheet)

For a total void volume V_i, of tank equal to 250L and substituting V_t, p_{ss} and g yields

Wt_T = (0.3847 - 0.25) x 8000 x 9.81 = 10,571.256*N*

The weight, Wt of feeder tank filled with substrate is given by

$Wt = Wt_s + Wt_T$

Substituting Wt_s *and* Wt_T into eqn3.13, yields *Wt*= 13,636.886*N*

From the American standards s-shaped, I-beams Tables [Beer and Johnson 1979] an I-beam of designation 524x100 is selected, and then subjected to check for critical length at which buckling occurs. The cross-section of S24 x100 I-beam, from the standards I-beams Table Beer and Johnson (1979), the second moment of area I_y for the beam about the Y-axis is given as

I_y- 47.8m^4 =1.989436 x 10-^{5} m^4

The material of the beam is Society of Automotive Engineers (SAE)- 950A Alloy steel with young modulus $E = 210x10^9 Nm^{-2}$(EFUNDA, Product catalogue).

Applying Euler's equation (Beer and Johnson 2019), the critical load W_c that will result to the buckling of I-beam is given by

$$W_C = \frac{\pi^2 EI}{L_e^2}$$

Where L_e - effective length of-beam.

Taking a factor of safety of 2 on the compressive load of the total weight of substrate filled feeder tank the critical load becomes

W_c = 2(13, 63.6886) = 27,273.*772N*

Re-arranging.eqn 3.14 and making L_e the subject of equation we have

L_e=c

Substituting E, I and W_c into eqn3.15 yields

$L_e=^9$X=38.898m

This value of L= 38.898m is the length after which buckling of beam may occur. This leaves us with a wide range of choices for lower than 38.898m. Thus, we have the following:

Height of feeder tank vessel H_f = 1.202m (computed)

Height of structural stand H_s= 3.00m

Total height H_T= 1.202 + 3.00 = 4.202m

This leaves us a room head space of 4.8 - 4.202 = 0.598m. The head space satisfies our requirement.

Considering the substrate working volume of 250 litres selected for the feeder tank, each of the three bioreactor modules in K: the integrated system of four reactor vessels will therefore not exceed 80 litres to fit into the construction

The up-flow bioreactor vessel shows

The height H of the vessel can be expressed as

$H = H_l + H_2$

Selecting a height $H_l$equal to 420mm, for the cylindrical section of the vessel, the height H_2 of the frustum section as

H_2 = 600 - 420 = 180mm.

The pipe carrying the substrate into the reactor vessel is selected to be50mm diameter [i.ed_f = 50mm]. Substituting for H_1, the void volume V_i of the bioreactor vessel can be expressed by the following equation:

$V_i =^2 + 0.05D + (0.05)^2]$

MATLAB version R12 software programmed was applied for values of D [ranging from 360 to 488mm in a step of 10mm] and the result of the iteration process is as shown in Tables 1, 2, 3, 4 and 5 below.

TABLE 1 of MATLAB Table result for diameter D and internal volume V_i.

BIOREACTORS BI AND	DISPENSER D_d	TWIN REACTORS B2 AND

B4				B3	
D_i (m)	$V_i(m^3)$	D (m)	$V_i(m^3)$	D (m)	$Vi(m^3)$
0.3880	0.0596	0.0940	0.0031	0.1440	0.0148
0.3980	0.0626	0.1040	0.0037	0.1540	0.0168
0.4080	0.0657	0.1140	0.0044	0.1640	0.0189
0.4180	0.0688	0.1240	0.0052	0.1740	0.0211
0.4280	0.0760	0.1340	0.0061	0.1840	0.0234
0.4480	0.0787	0.1440	0.0070	0.1940	0.0258
0.4580	0.0821	0.1540	0.0080	0.2040	0.0284
0.4680	0.0856	0.1640	0.0090	0.2140	0.0311
0.4780	0.0892	0.1740	0.0101	0.2240	0.0339
0.4880	0.0929	0.1840	0.0113	0.2340	0.0368
0.4980	0.0166	0.1940	0.0125	0.2440	0.0390
				0.2540	0,0430
				0.2640	0.0643
				0.2740	0.0498
				0.2840	0.0598

The choice of H_1 which will enable the determination of H_2 and D depends on the designer.

If H_1 is selected to be 520mm, gives H_2 = 80mm. Substituting H_1: H_2 and d_f into eqn3.2, the internal volume Vi of each of the twin vessels can be expressed by the equation

Therefore, $V_I = {}^2 + {}^2 + 0.05D + (0.05)^2]$

the total height y of the dispenser is factored on 0.8 of the reactor vessel height. Thus,

y = 0.8 (600) =480mm

The dispensing unit will have same shape as the reactors. Thus, it will

Consist of part cylinder and part frustum. Therefore y

= $y_1 + y_2$ = 480mm

y_1 and y_2 are defined. In order to reduce the complexity of using reducers during connection with existing pipe network of 50mm diameter specification, the inverted frustum peak diameter of the dispenser vessel is selected to be 50mm.

If y_1 is selected to be equal to 380mm, gives $y_2 = 100mm$

The internal volume v_i of the dispenser unit becomes

$$V_I = {}^2 + {}^2{}_d + 0.05D_d + (0.05)^2]$$

MATLAB version R12 software programmed was applied to equation for the twin reactors to obtain various vessel volumes V_i for the range of D [144 - 244mm in steps of 10mm] as shown in Tables 1,2,3,4 and 5.

Furthermore, the same MATLAB software programmed was applied to equation [for the dispensing unit] to obtain values of vessel volumes V_i for range of diameter values

D_d [94 - 194mm in steps of 10mm]. The iteration process generated the results shown From Table.3.3, the following data were selected during construction:

For each twin reactor, V_i = 28.4 litres, D = 204mm

For the dispensing unit, V_i = 28 litres, D = 204mm

Total void volume V for the twin bioreactor system is given by

V = 2 x 28.4 + 8 = 64.8 *litres*

This scale of experimentation is expected to meet our requirements for characterization of this new twin bioreactor system above micro scale laboratory investigation. This is an important step to an effective scale up to successful larger systems. The total internal volume V_i requirement

forall the reactors is the sum of each of the vessel volumes and is given by;

V= 76 + 76 + 64.8 = 216.8 *litres.*The outstanding balance in the feeder tank = 250-216 = 33.2 *Litres.*

This outstanding balance of 33.2 litres is expected to take care of remnant substrate in pipelines and other incidental experimental needs and also holds for Table 3, Table 4 and Table 5.

The condition th/D < 1/10 holds for thin shells while th/D > 1/10holds for thick shells.

Table 3 shows the various ratios of th/D for the reactors for nominal values of th = 1mm and 2mm (Available stock of stainless steel sheets).

Table 2 Wall Thickness Ratios to Bioreactor Vessel Diameter (Th/D)

Bioreactor vessel	Diameter (mm)	Th/D th=1mm	Th/D th=1mm
B_1	428	1/428	1/214
B_2 and B_3	204	1/204	1/102
Dispenser	154	1/154	1/77
CSTR (B_4)	428	1/428	1/214

In accordance with the maximum shear stress theory of failure, Khurmiand Gupta [2022], we can write the equation: (-)

the maximum shear stress, is computed for each reactor vessel and the results are also shown in Table 3.4

Table 4 Stress and safety factor (SF) computation for reactor vessels

Bioreactor Vessel/diameter				TRESCA SF		Von Mises SF
bioreactor ϕ428mm	321	160.5	80.25	13.4	278	7.7
Twin vessel Bioreactor ϕ204mm	153	76.5	38.25	28	132.5	16.2
Dispenser ϕ 154mm	115.5	57.75	28.875	37	75	28.
CSTR *ϕ428mm*	321	160.5	80.25	13.4	278	7.7

While,

Table 5 Bioreactor System characteristics

Bioreactor Vessel	**A_s m^2**	**Ew/m2₀c**	**Qw**
Up-flow Bioreactor	0.58344	3.35	25.41
Twin Bioreactor	0.35627	3.18	14.73
CSTR	0.58344	3.35	25.41

Table 6 Kinetic Model Equations for Biogas Production

BIOREACTOR MODULE	**R_2 VALUE**	**CUMMULATIVE BIOGAS PRODUCTION (B_1) AS FUNCTION OF TIME (hr)**

MODULE I UPFLOW BIOREACTOR BI	0.953	**EXCEL PLOT** $B_t = 8791/n(t_s) - 6075$
MODULE II TWIN BIOREACTOR B2&B3	0.932	$B_t = 19160/n(t_s) - 17648$
MODULE III CSTR	0.947	$B_t = 11026/n(t_s) - 7428$
MODULE I UPFLOW BIOREACTOR BI	0.92	**MATLAB PLOT** $B_t = [- 0.0001t_s^2 + 0.325t_s - 2.9192] . 10^3$
MODULE II TWIN BIOREACTOR B2&B3	0.97	$B_t = [- 0.0001t_s^2 + 0.4972t_s - 4.9528] 10^3$
MODULE III CSTR	0.91	$B_t = [-0.0014t_s^2 + 0.4347t_s - 4.2345] . 10^3$

Results and Discussions

The Data analysis mathematical modeling results shows for module I up flow, module III twin vessel and module III CSTR above tables show good fit conformity and the bioreactors biogas performance respectively Znad, H.T., and Kawase, Y. (2019). Cumulative biogas yield via time is shown in (Table 6) the evaluation of the biogas yield was characterized out for each of the three bioreactor modules using the modified Gomperts equation presented, Thompson, M. T and Johnson, S. (2020). The constants B, R_b and were determined for each of the bioreactor modules using the non-linear regression approach with the aid of MATLAB R12 software programmed and the resulting kinetic parameters are presented for module I up flow, module II twin vessel and module III CSTR above shows parameters were estimated by minimizing the sum of Square of errors between experimental data and estimation from corresponding theoretical models in Tables 1, 2, 3, 4, 5 and 6.

Conclusion

The Modified Gompertz Model Equation, for Biogas Yield increases for each of the Bioreactor Modules which showed a good agreement with the Working Performance as characterizes in the Mathematical Modeling of a Test Rig coupled on an Integrated Bioreactor.

References

Acharya, B.K, Mohana, S. & Madamwar, O. (2020), Anaerobic Treatment of Distillery Spent Wash-A study on Upflow Anaerobic fixed film Bioreactor. Bioresources Technology (2020) Vol.99, pages 4621-4626.

Agdag O. N, Sponza D.T, (2021), Anaerobic/aerobic treatment of municipal landfill leachate in sequential two-stage up-flow sludge reactor . (UASB)/completely stirred tank reactor (CSTR) system. Process . Biochemistry, 40(2):895-902.

Agumuthu, P. (2020) Specific Biogas production and role of packing medium in the treatment of rubber thread manufacturing industry waste water. Bioprocess and Biosystems Engineering. Vol 21, NO.2 P. 151-144.

Akepati, S.R. (2019) Upflow Anaerobic Sludge Blanket Reactor. Department of Biotechnology and Environmental Science, Thapar University, Patiala [Punjab]-147004. www.scribd.com/doc/31521347/upflow-Anaerobic-sludge-Blanket- reactor.

Akiribami, J.F.K., llori. M.O., Oyebisi, T.O., Akinwumi .I. O., Adeoti,O.(2021): Biogas energy use in Nigeria: Current state Future prospects and policy implications, Renewable and sustainable energy Reviews 5: 97-112.

Ann R.G and Oyebisi, T.O. (2021): role of packing medium in the treatment of rubber thread manufacturing industry waste water. Biochemistry, 40(2):895-902.

Atiqullah M., Hassan M.M., Chaudhry A.S., (2021), Multi-substrate analysis of carbon and nitrification in an up-fiow packed bed bio-film reactors, International Environmental Studies, 49, 31

Babaee, A., Shayegan, J. (2020), Effect of organic loading rate [OLR] on production of methane from anaerobic digestion of vegetable waste. World renewable energy congress (2020)-Sweden.

Bal, A.S., and Dhagat, N.N.; (2021) Up flow Anaerobic sludge Blanket Reactor- a Review. Indian J.Environ Health; (2021), pages 1-82.

Bahl, B.S., Bahl, Arun, and Tuli, G.D; (2018), Essentials of Physical Chemistry. [Revised Edition]. India: S.Chand and Company p17

Bhandari, V.B. (2017), Design of Machine Elements 3rd Edition. Tata ; McGraw Hill Education Private Limited, 7 West Patel Nagar, New Deltii 110008, chapt 1, pg 338.

Barol, A.P, Klasson, K.T., Ridenour, W., Holland, J. (2020), Effect of mixing in anaerobic digester on conversion of farm waste to methane in 1001 upflow bioreactor. 27th symposium on Biotechnology for fuel and chemicals. Paper No.5-53.

Borole B.F. , Beer, F.P, and Johnston, E.R (2019) Mechanics of materials Me Graw-Hill Book Company Inc. Edition 1 2019. Pg 590.

Bidgas technology and utilization chengdu seminar (2019). Sichuan Province office of Biogas Development, China Biogas Newsletter. No. 2, October, Bombay, India [2019].

Bonviliani. P., Ferrari, M.P., Duros, E.M. and Oregas, J.A (2016), Theoretical and Experimental study of the Effects of Scale- up on Mixing Time for a stirred Tank Bioreactor. Brazilian Journal of Chemical Engineering. Vol.23 No.1 Sao Paulo Jan.Mar.2006.

Borole, A.P, Klasson, K.T, Redevour, W., Holland, J., Karim, K., Al- Dahhan, M.H. (2019), Methane production in a 100-1 upflow bioreactor by anaerobic digestion of farm waste. Applied Biochem Biotechnol, 2019 Spring, 129-132: 88-96.

Budiyorfu M.N., Budiyono, Widiasa, I.N, Johari, S, Sunarso (2019), The kinetics of Biogas Production Rate from cattle manure in Batch mode. International Journal of chemical and Biomolecular Engineering, 3:39-44.

Budiyorfu M.N., Budiyono, Widiasa, I.N, Johari, S, Sunarso (2019), The kinetics of Biogas Production Rate from cattle manure in Batch mode 120-130: 87-99

Buzzini, A.P., Pires, E.C. (2017), Evaluation of an Upflow Anaerobic Sludge Blanket Reactor with partial Recirculation of Effluent used to treat wastewaters from pulp and paper plants. Bioresource Technology (2017), Volume: 98, Issue 9, Pages 1838-48. ISSN: 09608524. DOI:10.1016/j.biortec.2006.06.030,pubMed ID:17008086.

Cail, R.G. and Barford, J.P (2016), Mesophilic semi-continous Anaerobic Digestion of Palm oil Mill Effluent. Biomass, vol.7t Issue 4, 1985, pages 287-295.

Chawler, K.K (2019), Composite Materials, Science and Engineering, 2nd Edition. Springer Science and Business Media Inc. Chapter2, PP38.

Cibrorowski, P.(2020): Anaerobic Digestion in the Diary Industry. Minnesota pollution control Agency, Air Innovation conference. www.epa.qove.

Cruazon, B. (2020), History of Anaerobic Digestion chHp://web.pdc.edu/- cruzan/The Magic of Methane/History of AD. Bio.Eng., 67 [3], 334-40.

Dalis, D., Anagnostidis, K., Lopez, A., letsiou, Land Hartmaan, L. (2014), Anaerobic Digestion of Total Raw Olive-Oil waste water in a two-stage pilot-plant [up~flow and fixed-Bed Bioreactors]. Bioresource Technology 57. (2023) 237-243.

Dennis, A. and Burke, P,E. (2021), Diary Waste Anaerobic Digestion Handbook. Environmental

Energy company 6007 Hill Street Olympia, WA 98516. Pg21.
Dickey, D.S., Bittorf, K.J., Ramsey, C.J. and Johnson, K.E. (2014), Understanding flow patterns in Glass-line Reactors. www.cepmagazine.org.www.acusim.com/paper/Glass 110421.

Drury, W.J. (2016), Modelling of Sulphate Reduction in Anaerobic Solic Substrate Bioreactors for Mine Drainage Treatment. Environmental Engineering Department, Montana Tech., 1300W. Park St, Butte MT 59701-8997. Mine Water and Environment. International Mine Association. (2006), www.IMWA.info.
Evans, J. (2020) Centrifugal pump efficiency. Pump-flow solutions (An Engineering software Business Inc) 4529 Intelco. Loop SE, Lacey, WA 98503-5941. U.S.A
Fedalla G.M and Hartmaan, L. (2020), Centrifugal pump efficiency. Pump-flow solutions (An Engineering software Business Inc] 3468 Intelco. U.S.A
Feng Z.D and Anagnostidis, K. (2018), Anaerobic Solic Substrate Bioreactors for Mine Drainage Treatment Edited by Kazutisa, Miyamoto, Osaka University, Osaka, Japan.
FAO Agricultural services Bulletin-128. (2020), Renewable Biological ' systems for Alternative Sustainable Energy Production, Edited by Kazutisa, Miyamoto, Osaka University, Osaka, Japan.
FAO (2020), FAO Irrigation and Drainage Paper, Rome, FAO Vol.59, pages 4721-4726. Ferguson.
T, and Mah, R. (2016).Methanogenic bacteria in anaerobic digestion of biomass [eds D.P Chynoweth and R. Issacson],Elsevier Applied Science, London, Uk, Pages 49-63
Ferguson, T. and Mah, R. (2016), Methanogenic Bacteria in Anaerobic Digestion of Biomass, Journal Bacteriol 179:3; pp49.
First Microbiology Reader (2016). Automation in microbiology. What is Bioreactor? http://www.bionewsonline.eom/o/ what is Bioreactor.htm.
Fischer, J.R., Lannoti, E.I. and Durand, J. (1999) Anaerobic Digestion of Animal Waste . C.R.C. Press Inc. PP129-141.
Forster, C.F. & Wase, D.A.J. (2020). Anaerobic treatment of dilute wastewaters using a upflow sludge Blanket Reactor. Environmental pollution series A, Ecological and Biological Volume 31, Issue I, May 2016, pages 57-66.
Fukuda, R., Tokumura, M., Znad, H.T., and Kawase, Y. (2019). Vapour Generation from the impellers in Boiling stirred Tank Reactors. 13th European Conference on Mixing, London, 2019.
Gerardi, M.H. (2019). Waste Water Microorganisms. Waste Water Microbiology Series. Copy right© 2006, John Wiley & Sons inc. [Chapter 1, pg 3].
Ghosh, P., Samanta, A.N., and Ray S.(2011) Kinetics Bases on Mechanism of COD Reduction for industrial Effluent in Fenton process. International of Chemical Technology, 3;26-36.
Grady, C.P.L, Daigger, G.T.Jr. and Lim, H.C. (1999). Biological wastewater Treatment 2nd Edition,CRC Press. Revised and Expanded. Marcel Dekkar,1999 -Technology and Engineering. Gramer,
M.J., Poeschi, D.M, Conroy, M.J., Hammer, B.E (1999). Effect of Harvesting Protocol on performance of a Hollow Fibre Bioreactor. Biotechnol Bio.Eng., 65 [3], 334-40.
Gunnerson,C.G., Stuckey, D.C.(2013):Anaerobic digestion - Principle and Practice for biogas systems. UNDP project management report No.5, the world Bank, Washington DC. Pg 178
Hayes, T.D., Jewell, W.J., Dell'Orto, S., Fanfoni, K.J., Leuschen, A.P and Shermon, D.F.(2022). Anaerobic Digestion of Cattle Manure/ Handout First International Symposium on Anaerobic Digestion. University College, Cardiff, Wales

Held, C. Wellacher, M., Robra, K., Gubitz, G.M. (2019). Two stage Anaerobic Fermentation of Organic of Organic Waste in CSTR and UFAF-Reactors, 81[1], 19-24. Retrieved from http://www.ncbi. nim.gov/pubMed/11708753.

Ho, J., and Sung, S. (2019). Methanogenic activities in anaerobic membrane bioreactor [AnMBR] treating synthetic Municipal waste water. Bioresource Technology 101 (2019) 2191-2196

Holler A.U, and Trosch Water S (2020) Kinetics of Biogas Production Rate from Cattle Manure in Batch mode International Journal of Mechanical Engineering p.3, p. 39-44.

Hoffmann O.U, Hojnacki, A., Li, L, Kim, N., Markgraf, C., Pierson, D. (2018), Bio-digester Giobal case studies. D-Lab waste. p.13, p. 9-14

Hoffmann O.U, Hojnacki, A., Li, L, Kim, N., Markgraf, C., Pierson, D.(2020). Biodigester Giobal case studies. D-Lab waste. p.7, p. 33-40

Hu, W.C., Thayanithy, K., Forster, C.F. (2021), A kinetic study of the Anaerobic digestion of ice-cream wastewater. Process Chemistry, volume 37, Issue 9, 2002, pages 965-971.

Kale, S.P. (2020). Nisargruna Plant for Urban and Rural Waste Management, Energy Conservation, Better Environment and Restoration of soil fertility. Bio-Energy News. Volume 7, No.3, 13-16 (2020).

Kalia, a.K., (2020). Development and evaluation of a Fixed Dome plug flow Anaerobic Digester. Biomass 16 (2020) 225-235.

Kanwa, C.M. (2020). Biogas project, Technical Report. National Institute for Scientific and Industrial Research Zambia.

Karim et al. (2015). Optimization of Biogas Production for Maximum,Energy,Outputhttp://www.docstoc.com/docs/28954059/optimization-of- Biogas-Production-for maximum-Energy-Output-from.

Kukura,J.,Arratia P.C.Szalia,E.S. Bittorf k.J, andMuzzio,F.(2017). Understanding Pharmaceutical flows.Pharmaceutical Technology (2017). Available on Iine;www.acusim.com/papers/kukurapharmtech l pdf.

Khurma S. R , Kurmi, R.S. Gupa J.K (2022) A text book on Machine Design (S)units]. Urasia Publishing house [PVT] ftd. Ram Nagar, New Delhi-110055. Edition 2022, chapter 7, 224-260 .

Kumar Dhanasekharann.(2016). Design and Scale-up of Bioreactors using computer simulations. Bio-process international March 2016.www.fluent .com

Lau I.W.C and Fang H.H.P (2021). Effect of temperature shock thermophiiic granules. Water Resource 31, 2626-2632

Lay, J., Li, Y., Noike, T. (2017), Developments of Bacterial Population and Methanogenic Activity in a Laboratory-Scale Landfill Bioreactor. Water Research, vol 32, Issue 12, pages 3673-3679.

Lo, H.M., Kurniawan, T.A., Sillanpaa, M.E.T., Pai, T.Y., chiang, C.F., Chao, K.P., Liu, M.H., Chuang, S.H., Banks, C.J., Wang, S.C., Lin, K.C., Lin, C.Y., Lui, W.F., Cheng, P.H., Chen, C.K., Chiu, H.Y. and Wu, H.Y.(2019). (Modelling biogas production from organic fraction of MSW congested with MSW Ashes in Anaerobic Digesters. Bioresource Technology, vol 101, Issue 16, pages 6329-6335.

Madarnwar E.Y Alexandria, V.A. WEF (2019) Design of Wastewater Treatment Plants, 4th Ed., Manual of Practice No.8, Vol.3, Chaps. 17-24

Mahnert, P.and Linke, B. (2019). Kinetic study of Biogas production from Energy crops and Animal Waste slurry Effects of Organic Loading Rate and Reactor Size, Environmental Technology, vol.30, N0.1, Jan.2009, 93-99

Mahnet B.C., Link G. J and Jagadeesh, K.S. (2020) Proceedings of the International Conference on Biogas Energy Systems held at TERI, New Deihl. p. 22-23

Marques, I.P., Teixeira, A., Rodrigues, L, Martins, D.S and Novals, J.M. (2016). Anaerobic Treatment of Olive Mill wastewater with Digested Piggery Effluent Water Environment Research, Volume 70, No.5

Mc Naught, A.D, and Wilkinson, A (2020). IUPAC. Compendium of chemical technology, 2nd edition (the Gold Book). Blackwell Scientific Publications, Oxford. XML on-line corrected version: http://qoldbook.iupac.org (2023)

Monteith, A.D and Stephenson, J.P (2019), Mixing Efficiencies in Full Scale Anaerobic Digestion By Tracer Methods. Journal WPCF, Volume 53, No.1.

Mununga, L., Hourigan, K., Thompson, M. T and Johnson, S. (2020), Numerical investigation of discharge flow and circulation flow in an 'unbaffled mixing vessel agitated by a plain disc. 2nd International conference on Heat Transfer, fluid mechanics and Thermodynamics. Victoria fails Zambia. Paper NO.M21.

Namdev, P.K., Dunlop, E.H.O. Wanger, K. and Villeneuve, P. (1994), Role of Turbulence in Fermentations In: Gailndo, E., and Ramirez, O.T., eds. Advances in Bioprocess Engineering. Dordrecht, Kluwer Academic Publishers, 1994, pages 149-156.

Najafpour, G.O., Zinatizadeh, A.A.L, Mohammed, A.R., Isa, M.H and Nasroltehzadeh, H. (2016), High-Rate Anaerobic Digestion of Palrn oil Mill Effluent in an Upfiow Anaerobic siudge-fixed film Bioreactor. Process Biochemistry 41, 2006, 370-379

Nander S.F., Hajarnis, S. R. and Ranade, D. R. (2019), World J. Microbiol Biotechnol., Resource 2019, 17:295-408, p.10, p.350-351.

ODOE: Bioenergy in Oregon (2019), Biogas Technology. Available online: www.oreqon.gov/ENERGY/ Biomass/biogas.shtmi accessed:11th June 2023

Ofoefula R. M and Barky P.O (2018) New Technologies for Anaerobic Wastewater Treatment, Water Science Technology Vol. 18, No. 12, p. 14-53

Omer AM., Fadalla, Y. (2020):Biogas energy technology in sudan. Renewable energy 28: 499-507. Onkem, U./Liefke, E. (2019). Effect of total and partial pressureon aerobic microbial process. Bioprocesses and Engineering.vol.40/1989,137-169.

Poh P.D and Chong M.F (2018) Biological Nitrogen Fixation and Biogas Technology Tamil Nadu Agricultural University, Coimbatore, Pp. 162-165

Poh,-P.E and Chong, M.F. (2020). Development of Anaerobic Digestion Methods for Palm Oil Mill Effluent Bioresource Technology. Volume 100, Issue 1, 2009, pages 1-9.

Mixing Optimization and Solutions (2010). The use of Axial Fiow -Down-Pumping Agitators in Biological processes. ‘Webpage: http://www.postmixing.com/contact_us.htm.

Rajput, R.KF (1999) Heat and mass transfer [in S.I unit] S. Chand and Company Ltd, Ram Nagar, New DeIhi-110055 Multicolour.

Ramasany, E.V., Gajalakshmi, S., Sanjeevi, R., Jithesh, M.N, Abbasi, S.A (2021). Feasibility studies on the treatment of diary wastewaters with upflow, anaerobic sludge Blanket reactors. Bioresources Technology, Vol.93, Issue2 pages 209-212

Ranade, V.V., Mishra, V.P., Deshpande, G.B Joshi, J.B (1999). Comparison of Axial flow impellers using a Laser Doppler Anemometer. Industrial Erig. Chem. Resource 31 [10], PP 2370-\ 2379.-

Ranade, V.V., Mishra, V.P., Saraph, V.S, DEshpande, G.B., Joshi, J.B (1999). Comparism of Axial flow impellers using a Laser Doppler Anemometer. Industrial Eng.Chem. Resource 31 [10], PP 2370-2379.

Sakar, S., Yetilmezsoy, K., and Kocak, E. (2019) Anaerobic Digestion Technology in Poultry and livestock waste treatment-a literature review. Waste management resource. February 2009, Vol.27 No.13-1

SANSED-PROJECT Final Report. (2019) Closing Nutrient cycles in Decentralized water Treatment Systems in the mehong delta. Report edited by: UK Arnold and Frank Greens. Project funded by: German federal ministry of education and Research (Bio BF]. Ref. No.:02-WD-0620 to 02-WD-0629 and Vietnamese Ministry of Science and Technology [MOST].

Sichuen G. G, Hajarnis, S. R. and Ranade, D. R. (2020), World J. Microbiol Biotechnol., p.10, p.350-351.

SKF General Catalogue 6000 EN (2019), Principles of Bearing Selection and Application. Printed in Germany on Environmentally Friendly paper page 306.

Smith, M.C., Neitzel, G.P.,Nerem R. Wick, T. (2017) dynamic fluid of Bioreactors. The George W. Woodruff school of Mechanical Engineering. http://www.Me.gatech.edu/Marc.smith.

Surha, C.S and Kandpal, T.C (1999). A Framework for the financial of Household Biogas Plantain India: ELSEVIER, Biomass Volume 23, Issue I, pages 39-53.

Suncteep.N. ,Dro nawat,.L, Kurt, S and Thomas,R.H (2022) Effect of impeller Geometry on Gas-Liquid Mass Transfer coefficient in Filament suspensions. Applied Biochemistry and Biotechnology Vol.63-65,No.1,363-373.

Theme, 4 international symposium on Bioreactor and Bioprocess Fluid Dynamics (1999), Bioreactor and Bioprocess Fluid Dynamics. Edinburgh, UK: 1-3 July ,1999. www.bhrgroup.co.uk/confsite/bio/home.htrn.

United Nations. (1999), Updated Guidebook on biogas development Energy Resource Development Services 1999, No.27, United Nations. New York, USA.

Updated guide book on Biogas Development, United Nations, New York, (1999). Energy Resources Development Series No.27, page 178

Uzodinma, E.G. and Ofoefule, A.U. (2018). Effect of Abattoir Cow Liquor Waste on biogas yield of some agro-industrial waste. Scientific Research and Essay vol 3 [10], PP 473-476.

Wu, J., Graham, L.J., and Mechide, N.N. (2006). Estimation of Agitator Flow Shear Rate. America/1 Institute of Chemical Engineers [AlChE] Journal. Volume 52, Issue 7, pages 2323-2332.

Young, J.C. and McCarthy, [1969]. Upflow Anaerobic Filter Process Reactor. Journal of water pollution control Fed., 41, pages 160-173

Yusuf, M.O.L, Debora, A., Ogheneruona, D.E (2020), Ambient Temperature Kinetic Assessment of Biogas Production from co-digestion of Horse and Cow Dung Res. Agr Engineering; Vol 57, N03: 97-104

Zheng, D., Angenent, L.T., Raskin, L (2020), Monitoring granule formulation in anaerobic upflow bioreactors using Oligonucleotide hybridization probes. Biotechnol Bioeng [2006].Pages 458-720

Zlokarnic, M, (2019). Stirring Theory and Practice. Verlag GmbH, D-69469 Weinheim. [Federal Republic of Germany] Chapt 1, pg 50.

Zwietering, M.H., Jongenburg I., Rombouts, P.M., Vant Riet, k.(2020). Modelling of the Bacterial Growth Curve. Applied Environmental Microbiology, 56: 1875-1881