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Evaluation of the performance of integrated bioreactors for anaerobic digestion of organic wastes to biogas

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Abstract
The evaluation of the performance of an integrated bioreactor was carried out using organic municipal waste as the substrate. The test rig of the coupled bioreactor was designed and fabricated for experimented studies of anaerobic digestion of organic fraction of municipal waste. The first module up-flow bioreactor (UASB), has volume of 76 liter, the second module which was designed as twin in bioreactor with central dispensing unit has a total void volume of 76 liters. The test rig has a control panel which can be switch off and on from the experiment the maximum biogas yield was obtained in OLR_3 module 11 with 1577 ml/stp followed by OLR_1 module 1 with 1572 ml/stp. The least was noticed from the twin reactor OLR_2 module 11 with 895 ml/stp. The accumulative biogas yield and R-values obtained show close agreement between observed and theoretical postulate.

Keywords: integrated bioreactor, anaerobic digestion, biogas

Introduction

Biogas generation is one of the most efficient and effective options among the various other alternative source of renewable energy currently available. It is produced through anaerobic digestion processes where the consortia of microorganism convert complex organic matter into a mixture of methane and carbon dioxide. The anaerobic digestion of biomass requires less capital compared to other renewable energy sources such as hydro, solar and wind energy [1]. In order to get optimal performance from these renewable energy, various protocols followed in the design of these bioreactor depending on the input feed materials, scale of operations and other biochemical and engineering requirements. Similarly, the success and failure of any bioreactor depends upon a careful consideration of all the relevant inputs which cut across many disciplines e.g. sciences and engineering [2, 3]. The biogas production has a direct consequence with the characteristics of the feedstock as well as the operating condition of the process. Sometimes the feed stock itself can contain inhibitors, such as high concentration of cation and phenolic compound and atimes toxic compounds which are not initially present in the feed but produced by the dissolution of digester material during the anaerobic digestion process. The feed stock (i.e. nutrients, pH, buffer capacity and inhibitory compound) and operating condition (i.e. temperature and OLR influence directly on the performance of microorganisms. Also increase in temperature can lead to increase in the solubility of the soluble compound with the optimal pH 6.5-8.0 [4]. The buffer capacity is an important factor in resistance to pH change where the main buffer in anaerobic digester bicarbonate (HCO_3) with PKa of 6.3 and the main generated acid are VFA's with an aggregate PKa of 4.8 [5]. The studies have shown that higher OLR's will reduce COD removal efficiency in waste water treatment [7]. However, the gas production increase with OLR until a stage when methanogen are limited in their conversion. OLR is related to substrate concentration and HRT, thus a good Balance between these two parameters has to be obtained for good digester operation [10].

The difference in substrate for biogas generation have led to search for a more efficient and optimal condition for a digester design with associated improvement in theoretical and flow dynamics [11].

For instance, CSTR recretor is widely used in industrial scale biogas production and waste water treatment unit. If has successfully applied to anaerobic digestion of energy crops and food residues [8].

The UASB reactor concept relies on the establishment of dense sludge bed in the bottom of the reactor, in which the biological process take place [9].

Abbreviation and nomenclature

ORL: Organic loading rate (mg/L)
HRT: Hydraulic retention time (t)
UASB: Upflow Anaerobic Sludge
CSTR: Continous Stirred Tank Reactor
MOSW: Municipal Solid Organic Waste
COD: Chemical Oxygen Demand (mg/L)
PRODA: Project Development Institute
OFMSW: Organic fraction of Municipal Solid waste
TOC: Total Organic Carbon
VFA's': Volatile Fatty Acids
BOD: Biochemical Oxygen Demand

Materials and Methods

Organic waste (OW) was obtained by careful segregation of waste from central market in Owerri, Imo State. The construction of bioreactor integrated test rig was performed at the workshop complex of Project Development Institute (PRODA) Enugu under the engineering research, development and production department in accordance with Standard specifications. The

PRODA workshop provided the equipments and technical expertise for the fabrication work.

Determination of Feed Parameter

Physical parameter such as Nitrogen and crude Protein, crude fibre, total organic carbon (TOC) Carbohydrate content, volatile fatty acids, volatile solids, Ash content, Moisture contents, Biochemical Oxygen Demand (BOD) Alkalinity, Density and Chemical Oxygen demand (COD) were performed in order to characterize the feed slurry. All chemical and reagents used in this determination were analar grade unless otherwise stated.

Experimental

The integrated bioreactors comprises of three couple bioreactors namely up-flow (UASB), Twin vessel bioreactors and a continuous stirrer tank reactor. All the reactor vessels including the central dispenser, have cylindrical configuration. The rig had an overhead feeder tank which feed substrate slurry. An electric pump delivers the slurry from the reservoir to the feed tank. Thereafter, the substance slurry is fed into all the bioreactors by gravity while opening valves x4, x5, x5, x6 and x6. The closure of valves x3, x4, x6, x7, x8 and x9 configures the rig into three experimental modules 1, 11 and 111 each of which is capable of independent operation and observation. Each module of the bioreactor rig has a sampling port, a vent gas and provision for attachments of sensors for temperature and gas pressure monitoring device. Module 1 and 11 bioreactor each have additional meters pump for recirculation.

Initialization of the Integrated Bioreactors

In order to prepare the internal bioreactor environment for aerobic digestion, the test rig of bioreactor were fed full with a solution of 5 liters mild liquid soap (morning fresh) in 245 liters of distilled water. The soap solution filled the entire void space in the reactors and the feed tank. The system was allowed to run 24-hours continuously to allow dissolution of unwanted oil and chemicals in the reactors subsequently, the system was discharge of its content by opening the effluent valve outlet x3, x7 and x9.
The process was repeated with 250 liters of distilled water to flush out the soap contents in the system. Finally, the system was once again fed full, with actual substrate as specified then runs four (4) days to prepare the reactors for biochemical activities this way, the system was freed of substance that could impair reactor performance.
The experiment were carried out in triplicate for each of three sub system module 1,11 and 111 each with bioreactors of differing substrate flow and mixing feature. The experimental module operated aerobically under merophilic temperature of 37% and data average of measure of has volume generated for each reactor recorded six hourly.

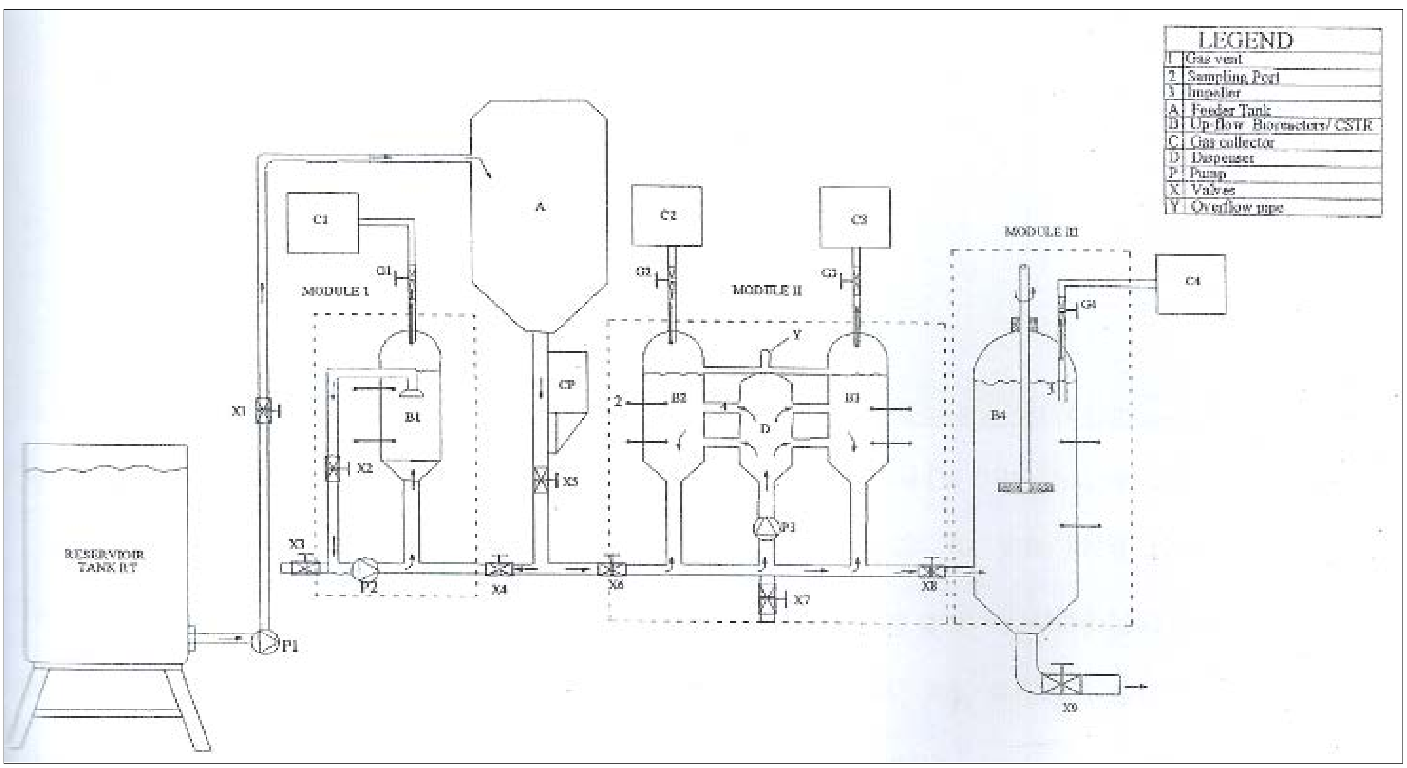

Fig 1: Schematic diagram of the system of integrated bioreactor

Result of Discussion

The result of methane yield are presented in the tables below.

Table 1: Methane yield as power function and seventh order

Organic loading rate (OLR)	Module	Functional equation
OLR_1	1	$Y = 8.4\ 10x\ X\ 7\text{-}4.5 \times 10^{-3x6+0.1x5-1x4+7.5x3-29x2+72X+0.35}$ (RS = 0.9987)
	11	$Y = 7.2x10\text{-}^{5x6+4.7x10-3x5\ 0,11x4+1.3x3+8.9x2+4x0.03}$ (R2) = 9998)

	111	Y = 1.5X10^{-2} 1.1x2+23x-2.7 (R2=9986)
OLR$_2$	1 11 111	Y = 73 x10-2x3-2.5x2+31x+1.1 (R2=9989) Y=3.6x10-3x4=0.19x3 R2=0.9712 Y= 3.8x10-8x4+0.19x3+3.6x+1.5 (R2=0.9813)
OLR$_3$	1 11 111	Y=3.6x10-2x3-2x2+28x+51 (R2=0.9970) Y=8.5x10-2 X3-3.2x2+38x+21 (R2=0.9012) Y=2.5x105x7-1.8x10-2x5-75x4-6.2x3+81x ($R^{2=0.9989}$)

Table 2: Methane yield for each bioreactor modules for the period of 14 days

		Cumulative Methane Yield
OLR$_1$	1	1577 ml/stp
	11	1194ml/stp
	111	1248ml/stp
OLR$_2$	1	1248ml/stp
	11	895.96 ml/stp
	111	990ml/stp
OLR$_3$	1	1348 ml/stp
	11	2577 ml/stp
	111	1459 ml/stp

The result of methane yield presented in table 1 shows that OLR3 for module 11 twin reactor had highest methane yield of 2577ml/stp followed by OLR$_1$ model 1 with 1572 ml/stp. The comparatively higher methane gas generated by module 11 twin reactors was probably due to the integrated flow and the scale of mixing pattern. This contrasted with substrate flow observation in module 1 upflow bioreactor which showed partial separation of substrate [10] reported that adequate mixing is essential to transfer substrate and maintain uniformity in the reactor in order to prevent solid deposition and scum formation. For the module 111 CSTR, insufficient mixing of substrate was probably the main cause of the low biogas yield [11] reported that in spite of the existence of a variety of impeller design there was hardly any one of them sufficiently versatile to perform all the functions of mechanical agitation in a digester thin was corroborated by experimental investigation carried out by [5] in which it was shown that combination of impellers produced more efficient performance in bioreactors.

The table 2: showed methane yield expressed as a power series where the R-values indicate agreement between observed experimental point and fitted theoretical construct. The representive of OLR$_1$ module 3, all module 2 and OLR$_3$ module I aid 2 fitted into group whose power series order is below five (5) lower R_2 values which means a higher disparity between the experimental and theoretical value.

Recommendation

The work present an attractive option for the treatment of organic fraction of municipal solid waste (OFMSW). Biogas is produced from organic waste and the residue can be applied directly as organic fertilizer. The system of these bioreactor configuration was able to achieve 95% conversion efficiency of OFMSW in terms of methane yield. Therefore this new bioreactor system is good option to obtaining higher methane yield. It also introduces a bioreactor scale up option which relies on a multi vessel concept rather than single vessel enlargements with attendant mixing problems. However, the following modifications are recommended to improve the overall efficiency of the twin reactor concept.

- To avoid occasional explosive gas collection from the reactor, it is recommended that a pressure relief value of about 1.3 bar be connected to the gas collection device.
- There is need for further work to investigate rigorously the turbulence characteristics in fluid flow in this work using state of the arts methods such as particles image velocimetry and computational fluid dynamics software in order to characterize module 11 twin bioreactors.

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