Biofuel Generation from Grass

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Abstract— *Almost quarter region of Indian terrain is covered by grasslands. Grass being a low maintenance perennial crop is in abundance. Farmers are well acquainted with its nature, yield and storage. The aim of this paper is to study and identify the applicability of grass as a source of bio fuel. Anaerobic break down is a well-recognized technology. This process is vital for harnessing bio fuel from grass. . Grass is a lignocellulosic material which is fibrous and can readily cause problems with parts in motion. Further, it also has a tendency to float. This paper also deals with the ideal digester configuration for biogas generation from grass. Intensive analysis of the literature is studied on the optimum production of grass storage in accordance with bio digester specifications. Subsequent to this two different digester systems were designed, fabricated, analyzed. The first setup was a double stage wet continuous arrangement usually known as a Continuously Stirred Tank Reactor (CSTR). The next was a double stage, double phase system implementing Sequentially Fed Leach Beds using an Upflow Anaerobic Sludge Blanket (SLBR-UASB). The above methodologies were carried for the same feedstock acquired from the same field. Examination of grass silage was undertaken using Biomethane Potential values. The outcomes portrayed that the Continuously Stirred Tank Reactor system produced about 450 liters of methane per Kg of volatile solids, at a detention period of 48 days. The second method involving Leach Beds produced about 340 liters of methane per Kg of volatile solids with a detention period of 28 days. The results showcased that CSTR when designed exclusively for grass proved to be extremely efficient in methane production. The SLBR-UASB has significant potential to allow for lower detention times with significant levels of methane production. This technology has immense future for research and development in India in terms utilizing of grass crop as a non-conventional source of fuel.*

Keywords— Biomethane Potential values, Upflow Anaerobic Sludge Blanket, Continuously Stirred Tank Reactor, Bio digester specifications.

INTRODUCTION

Energy is a critical input for economic growth and sustainable development in both developed as well as in developing countries. The world's energy requirement for transportation is met from non-renewable fossil fuels. However the sharp rise in crude oil prices has fastened the urge for alternative energy sources that are renewable and non-polluting[5]. After 70 years of research, grassland scientists have concluded that grass could be efficiently used as bioenergy feedstock for cellulosic ethanol production, direct combustion for heat and electrical generation apart from its conventional uses. This paper also talks about the characteristics of the grass silage used as feed stock, process description, operational procedures and options available for pretreatment.

I. CHARACTERISTICS OF GRASS SILAGE

The inlet substrate for the digester system was baled grass silage. The silage comprised of homogenous perennially available ryegrass. The grass was cut at early mature stage, as experiments showed that maximum efficiency was achieved at early mature age. Subsequently it was field wilted for 24 hours which assisted in moisture reduction before the process of baling. The bales were wrapped by adopting polythene stretch-film. Further it was stored for duration of five weeks. For experimental purpose small square bales of 25 kg were prepared [2]. The silage was macerated to average particle size of 20 mm by adopting a mobile macerator.

Table: 1 Inlet parameters of the silage

Parameter	Unit	Inlet Value
Dissolved Solids (D.S)	**%**	**30.65**

Volatile Solids (V.S)	**%**	**92.45**
pH		**4.3**
Lactic Acid	**$g\,kg^{-1}$ D S**	**26.95**
Propionic Acid	**$g\,kg^{-1}$ D S**	**0.26**
Acetic Acid	**$g\,kg^{-1}$ D S**	**3.92**
Butyric Acid	**$g\,kg^{-1}$ D S**	**1.43**
Volatile Fatty Acids	**$g\,kg^{-1}$ D S**	**5.61**
Oil	**$g\,kg^{-1}$ D S**	**3.3**
Carbon	**% DS**	**43.03**
Hydrogen	**% DS**	**5.82**
Nitrogen	**% DS**	**1.61**

II. PROCESS DESCRIPTION

There is a massive potential for the on-farm digesters which uses grass silage as a bioenergy feedstock, especially in India where major portion of agricultural land is under grass. The biogas generated on site can be effectively used as a source of combined heat, power or as transportation fuel[10]. Conventional digesters may not be used effectively as they are not designed for high solid contents i.e. 92%

Various digester configurations are selected which use various approaches such as one-stage or two-stage digesters, wet or dry/semi-dry digesters, batch or continuous digesters, attached or non-attached biomass digesters, high-rate digesters and digesters with combination of different approaches.

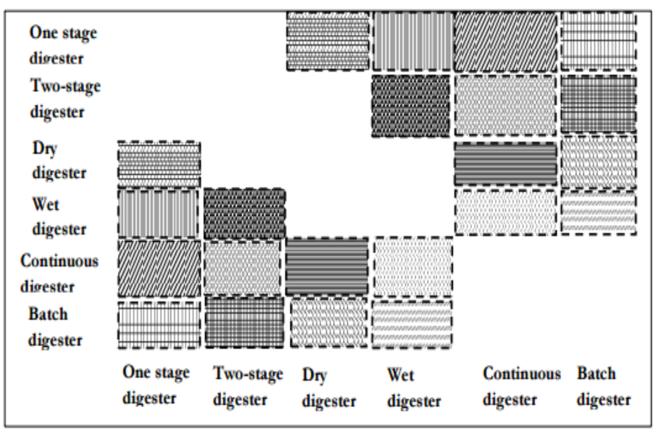

Figure : 1 Possible combination of various digester types

In one-stage digestion process, all the microbial activities of anaerobic digestion occur in one tank. However in two-stage digestion the microbial activities are separated. The second stage digestion allows storage of digestate and remedial gas collection. However when the microbial phases are segregated the hydrolytic and acidification phases may occur in the first reactor and acetogenesis and methanogenesis occur in the second reactor. The concept of using two stage digestion is used to gain optimization of the digestion process which will result in higher yield of biogas in smaller digesters. However the one-stage system is still popular at industrial scale because of the simplicity in operation, reduced costs and lesser technical problems. The one-stage process can be either operated in dry batch systems or wet continuous systems, whereas in the two-stage process, continuous and wet processes are preferred.

Fig: 2 Possible combination of various digesters.

Table : 2 Comparison of different digesters for high solid content feed stock.

Criteria	One-stage	Two Stage	Dry	Wet	Batch	Continuous	High rate Bio Reactor
Biogas production	Irregular and discontinuous	Higher and stable	Higher Less and irregular	Less and irregular	Irregular and discontinuous	Continuous	Continuous and higher
Solid content	10-40%	2-40%	20-50%	2-12%	25-40%	2-15%	<4-15%
Cost	Less	More	Less	More	Less	More	More
Volatile solids destruction	Low to high	High	40-70%	40-75%	40-70%	40-75%	75-98%
HRT (days)	10-60	10-15	14-60	25 – 60	30-60	30-60	0.5-12
OLR	0.7-15	10-15 for second stage	12 – 15	< 5	12-15	0.7-1.4	10 -15

III. DRY VERSUS WET DIGESTERS

Digesters which consists of 20-40% dry matter of the feedstock are termed as dry anaerobic digesters[3]. Similarly those with less than 20% dry matter are termed as wet digesters. Hence, a pre-treatment (i.e. pulping and slurrying) is required for grass silage in wet digesters. One-stage dry batch systems typically use a system whereby high solids content in feed-stock is entered into a vessel without any prior dilution. Recirculation of water/leachate is done accordingly.. However, Vertical CSTR (Continuously Stirred Tank Reactor) is the most commonly used configuration in most of the newly installed wet digesters. Parasitic energy demand for wet digesters is comparatively higher than for dry digester because of the requirement to dilute grass silage, pump slurries and mix reactors for the total retention time.

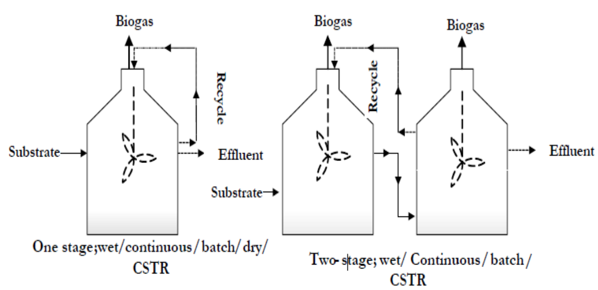

Fig: 3 Design variations in one stage and two stage digesters.

IV. BATCH VERSUS CONTINUOUS DIGESTERS

In batch digesters, the reactor vessel is initially loaded with raw feedstock for a given detention time (and inoculated with digestate from another reactor)[4]. It is then sealed and left until complete degradation takes place. On the other hand, in continuous digesters, the substrate is continuously and frequently fed either mechanically or by force of the newly entered substrate. In continuous digesters, plug flow, CSTR, anaerobic filters and UASB (Upflow Anaerobic Sludge Blanket) systems are commonly used whereas in batch digesters, one-stage, sequential batch and hybrid batch digesters are generally used. It can be concluded that batch digesters are more suitable for grass silage digestion due to dry solid contents (bailed silage has a solid content of 32%) and fibrous characteristics of grass silage and the reduction in demand of parasitic energy. This becomes even more advantageous when more than one batch digesters with different start up times are being used to guarantee a continuous yield of biogas.

Table : 3 Strength and weaknesses of various digesters.

Type of digester	Strength	Weakness
	Simpler design	Higher retention time
ONE STAGE DIGESTER	Less technical failure	Foam and scum formation
	Low cost	
	Efficient substrate degradation owing to recirculation of digestate	Complex and expensive to build and maintain
TWO STAGE DIGESTER	Constant feeding rate to second stage	Solid particles need to be removed from second stage
	More robust process	
	Less susceptible to failure	
DRY DIGESTER	Higher biomass retention	Complex handling of feedstock
	Controlled feeding	Mostly structured substrates are used
	Simpler pre-treatment	Material handling and mixing is difficult
	Lower parasitic energy demands	
WET DIGESTER	Good operating history	Scum formation
	Degree of process control is Higher	High consumption of water and energy
		Sensitive to shock loads
		Short-circuiting
BATCH DIGESTER	No mixing, stirring or Pumping	Channeling and clogging
	Low input process and mechanical needs	Larger volume
	Cost-effective	Lower biogas yield
CONTINUOUS DIGESTER	Simplicity in design and Operation	Rapid acidification
	Low capital costs	Larger VFA (Volatile Fatty Acid) production
HIGH RATE BIOREACTORS	Higher biomass retention	Larger start-up times
	Controlled feeding	Channeling at low feeding Rates
	Lower investment cost	
	No support material is needed	

V. OPERATIONAL PROCEDURES-

A. pH range-

The most appropriate pH range for anaerobic digestion is 6.8-7.2. Below a pH of 6.6, there will be a decrease in methanogenic population. Excessive alkalinity can also result in the failure of the process by disintegration of microbial granules. pH values for the first and second stage of two-stage two-phase digesters vary accordingly[9]. In the first stage of a grass digester the pH should be maintained between 4.0 and 6.5 and a pH of 7 in the second digester.

B. Temperature

Generally, increases in temperature result in increase in solubilisation because xylan, the major component of hemicellulose in grass, is unstable at high temperatures. Hence short-chain fragments are formed as a result of increased temperature, resulting in higher biological suitability of substrate for microbes. The problem associated in using thermophilic temperature conditions in the digester is the high demand for parasitic energy. Therefore, if two-stage and two-phase digestion is used, then the first stage should be operated at thermophilic temperatures and the second stage should be operated at mesophilic temperatures in order to hasten the grass hydrolysis and finally the methane yield.

C. Particle Size

Particle size affects the methane yield appreciably because of the increased availability of surface area for fiber degradation through hydrolyzing enzymes and bacteria. Methane yield can be increased by reducing the size of the particles to a range of 3 mm – 0.4 mm.

D. Retention time

Experimentally it has been observed that 80-85% of biogas is produced in the first 18 days of a total of 30 days digestion period. It was also proposed that a period of 2-3 weeks as an optimum HRT for lignocellulosic substrates[1].

VI. PRE-TREATMENT

A combination of different pre-treatment approaches along with various operational procedures is required for optimum cost-effective pre-treatment manipulation accompanied with minimum parasitic energy demand.Pre-treatment also focuses to avoid any excessive formation of inhibitory byproducts which includes furfural, hydroxymethyl furfural, and levulinic acid. For lignocellulosic substrates, economically viable and operationally efficient pretreatment options are steam and lime based pretreatment, liquid hot water (LHW), and ammonia-based pretreatments.It has been observed that with proper pre treatment the quantity of Methane produced can be improved significantly.

VII. PHYSICAL PRE-TREATMENT

Physical or mechanical pretreatments increase the pore-size of grass silage by releasing the intercellular components.
. With increase in the pore size, the hydrolysis of hemicelluloses occurs at a faster rate, which results in further accelerating the cellulose hydrolysis along with lignin degradation. However drying is not favourable after pretreatment because this can result in the collapsing of pore structure, which further reduces hydrolyzable substrates in the digester.

VIII. CHEMICAL PRE-TREATMENT

Chemical pretreatment results in increasing the surface accessibility for enzymes and bacteria by decreasing the cellulose crystallinity[8]. In chemical pretreatment, use of NaOH, NH4OH, or a combination of both to grass fiber increases the potential of methane yield significantly. Acid pretreatment can also be preferred for grass silage because of the enhanced degradation of xylan (the major component of hemicellulose) in acidic environments.Formic acid can be used as ensiling method, but it also serves as chemical pretreatment. Acid pretreatment should be preferred in the first phase of a two-phase process such as the leach bed in a SLBR-UASB, because of the methanogenesis process occurs in the second phase of the UASB unit which can regulate any possible incoming inhibitory compounds.

A. Biological pre-treatment

Biological pretreatment provides a very cost-effective solution in comparison to other pretreatment options but it requires specific parameters to work efficiently. For example, treatment with cellulase enzyme during the preparation of silage resulted in increased degradation of plant cell wall constituents which were more susceptible to bacterial decomposition. Also, addition of cellulose enzymes facilitate the breakdown of the component of structural carbohydrates during ensiling which resulted in improved degradation during silage fermentation[6]. Considering the use of inoculants it has been proposed that heterofermentative bacteria are more effective in comparison to homofermentative bacteria for efficient anaerobic digestion. The reason behind is that they facilitate the production of intermediates for methanogens. Other benefits include the reduction in quantity of digestate and reduced parasitic energy demands. The use of the filamentous fungi, especially white-rot fungi, has been studied by virtue of its potential to degrade lignin.

IX. START-UP PROBLEMS

Initially problems of foam formulation and clogging were observed. Basically foams are formed when the reactors are fed at loading rates which is beyond the capacity of the bacterial population. Collection of big chains of fatty acids within the reactor results in foaming. It is observed that initially due to very high loading, significant foaming was observed. The foaming can be controlled by reducing the loading rate, by using water holding cups to backwash the gas pipes.

Clogging was observed due to considerable quantity of the coarse particles. As a result of which the nozzles of sprinkling heads were choked which further resulted in irregular and weak sprinkling.

Initially for the first 84 days of operation less methane was produced due to the problem of clogging and foam formulation. Later

X. RESULTS AND DISCUSSION

Methane Generation-

The methane generation is evaluated in 2 set ups.

Experimental set up 1- Here the system is analysed during the first 60 days of operation (Day 1-60). The system is fed with approximately 3.5 Kg of grass silage in each bed to attain a life cycle of 5 days, resulting in overall HRT of 30 days.

The methane generation was 305 L CH4 kg-1 VS added for the first 30 day cycle. However, this increased to 314 L CH4 kg-1 VS added for the next (second) 30 day cycle. The average is then considered as 310 L CH4 kg-1 VS

Experimental Set up 2-

The set up was analysed from Day 61-120. As a result of addition of the second pump, there was a significant increment in methane production i.e. 339 L CH4 kg-1 VS added in the first cycle of 30 days and 344 L CH4 kg-1 VS added in the next (second) cycle of 30 days. The average is taken as 341 L CH4 kg-1 VS added.

A.UASB Efficiency-

The UASB efficiency is calculated by the formula-

UASB efficiency (%) = 100 × COD in – COD out /COD

Where,

COD_{in} is the COD flowing into the UASB

COD_{out} is the COD leaving the UASB.

Thus,

Efficiency in Experimental Setup-1 = 90 %and

Efficiency in Experimental Setup-2 93%

B.Dry solid removal efficiency

Experimental Setup-1: With a retention time of 30 days the dry solids removal efficiency varied from 68 % to 71% averaging 69%.[7]

Experimental Setup-2**:** In the second experimental scheme, the DS removal efficiency increased from 72% to 74% averaging73% (Figure 6.2c).

C. Volatile solid removal efficiency

Experimental Setup-1-**:** The volatile solids removal efficiency varied slightly from 70 % to 71% with average value of 70.5 %
Experimental Setup-2**:** The Volatile solids removal efficiency increased from 74% to 77% with average value of 75%

D. UASB granule structure

The average size of the granule observed was 2.55 mm. It was proposed that the size of granule will be more than 2 mm when the UASB will be fed at high organic loading rate. Also large granules remove COD more efficiently, typically converting 95% of COD is converted to methane while the remaining 5% is converted to biomass. The shape of the granules varied with the operating conditions but usually a spherical shape was dominant.

XI. CONCLUSION

Thus it is concluded that grass silage can be effectively used as a clean and pollution free energy source. It is observed that with proper pre treatment the generation of biogas can be optimized. Also the various measures to be taken during the initial period of commencement, helps in proper execution of the process. For a country like India whose much portion is covered with grasslands, such simple and effective technologies can be exclusively used to meet the significant demands of energy.

XII. REFERENCES

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