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# Study of Anaerobic digestion of Brewery Spent Grains (December 2006)

Jatunarachchi T.S.S., Senaratne A.U. and De Alwis A.

***Abstract*** *- Beer brewing is a biotechnological process whereby agricultural products such as barley and hops are converted to beer by control of biochemical reactions in malting, mashing and fermentation. Breweries produce significant amounts of solid and liquid wastes from the production process. About 200 g of brewery wet spent grains and 11 Litres of wastewater are discharged per Litre of beer produced. The spent grains are disposed in a wet state with 70 % - 80 % moisture content. In this state spent grains deteriorate fast and becomes mouldy within hours, and unless controlled and properly managed, cause problems to the environment. Because solid waste that comes from the brewery industry is mainly organic in nature and highly biodegradable, it is quite suitable for anaerobic digestion. The objective of this study was to ascertain possibility of treating brewery spent grains in the process of anaerobic digestion and it was achieved by carrying out a series of experimental trials using spent grains as the feed substrate and varying process conditions in a high-rate digester unit. Study indicates that the anaerobic digestion of brewery spent grains could be accomplished with careful control of the process by adjusting certain parameters such as pH, temperature and volatile acid concentration. It could be further shown that the degradation of brewery solid waste generate substantial quantity of biogas with methane content around 65 % i.e. burnable gas. Experimental trials using high rate reactor showed that the maximum gas yield of brewery waste was 0.596* $m^3$*/kgVS added under mesophilic condition. This means very high degree of degradation with the substrate showing amenability to the anaerobic digestion process. The study thus indicates the potential for recycling of this waste stream as an energy stream back into beer production process.*

*Key words*— **Anaerobic digestion, Bio energy, Biogas, Brewery Spent Grains, Organic solid waste, Solid waste management.**

## 1. INTRODUCTION

Anaerobic digestion technology is an old technology. But the interest in anaerobic bioconversion processes had been rekindled due to increasing cost of fuel with rapidly depleting fossil fuel sources and devastating environmental impacts by the extensive use of fossil fuels. Anaerobic fermentation produces biogas. In this process, microorganisms in an oxygen free environment decompose organic substances. Many developed and some developing countries use this technology as a means of managing solid organic waste and use the biogas produced in cooking and generating electricity, thus replacing a part of conventional energy requirement. Among biological waste treatment options, anaerobic digestion is frequently the most cost-effective due to its higher energy recovery and its limited environmental impacts, especially with respect to the green house effect. Anaerobic treatment of industrial effluents has gained success over the past two decades mainly due to its low costs, compact construction, production of energy through biogas, and low surplus sludge production, which result in favorable economics [1]. Besides generating biogas for energy use, the process destroys pathogens and produces stabilized material which is about 40 % - 60 % by weight feedstock and that can be used as a soil conditioner [2].

Beer industry uses standard basic processes and raw materials. Brewing of beer is essentially a batch process that uses malt from barley, hops, water and yeast as the main raw materials. In addition, non-malted cereals such as corn and rice are often used as adjunct with barley malt, for economic reasons and as they aid producing a lighter product. The number of brewing batches per day is usually decided according to the production requirements.

Main byproducts of the brewing industry are wet spent grains, yeast, spent hops and insoluble protein resulting from the brewery process. In most countries brewery spent grains and yeast are commonly used as livestock feed. However, their usage is often constrained by transportation cost, and the freshness of the material, as both brewery spent grains and yeast will degrade within 24 hrs and become mouldy. In some other countries brewery solid waste is dried before using as livestock feed. But drying is energy intensive thus expensive. Therefore, land-filling of brewery solid waste is common except for some quantities sold as animal feed. No studies performed on the anaerobic digestion of brewery spent grains were reported in the literature.

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T. S. S. Jatunarachchi is a Senior Lecturer attached to the Department of Mechanical Engineering, The Open University of Sri Lanka, P.O.Box 121, Nawala, Nugegoda 10250, Sri Lanka. (phone: +94-11-2853777 Ext.265; Fax: +94-11-2822737; e-mail: tssaj@ou.ac.lk), corresponding author.

Dr. A. U. Senaratne Presently Managing Director of Clean Technologies (Pvt).Ltd. 28/1, Byrde Place, Kirallapone, Colombo 6, Sri Lanka. Sri Lanka. He is a principal consultant to Acwa Services Ltd., U.K.,CAP technologies Ltd., U.K. and Clean Flow Inc. Philippines.(phone: +94-11-2501029; Fax:+94-11-2502934 e-mail: cleantec@slt.lk).

Dr. Ajith De Alwis is the Head of the Department of Chemical and Process Engineering, Faculty of Engineering, University of Moratuwa, Moratuwa, Sri Lanka. (phone:+94-11-265081; fax:+94-11-2650622; e-mail: ajith@cheng.mrt.ac.lk).

At present brewery industry is one of the fastest growing industries in Sri Lanka. The total quantity of beer produced in the year 2004 is 48,394,870 litres [3]. According to the data obtained from the Ceylon Brewery Ltd. Sri Lanka, it has been calculated that 200 g of wet spent grains and 11 litres waste water are generated per litre of beer produced [4, 5]. Then the quantity of wet spent grains generated per day is 26520 kg and discharged volume of liquid waste is 1458 x $10^3$ litres per day. Thus, the amount of solid and liquid wastes generated is considerable, and this could lead to significant environmental problems. This paper describes feasibility studies on the anaerobic conversion of brewery spent grains into biogas, as it makes environmental and economic sense to explore the option of anaerobic digestion for this mainly organic brewery waste.

## 2. ANAEROBIC DIGESTION -PROCESS FUNDAMENTALS

Anaerobic digestion is a process by which almost any organic waste can be biologically converted in the absence of oxygen. This extremely complex anaerobic decomposition process requires specific environmental conditions and different bacterial populations. For simplicity, the process can be characterized as a sequential four-stage process comprising of hydrolysis, acedogenesis, acetogenesis, and methenogenesis [5].

### *Hydrolysis*

Hydrolytic bacteria begin to breakdown the high molecular weight carbohydrates, proteins and fats that are often insoluble by enzymatic action into soluble polymers.

### *Acedogenesis*

Acid forming bacteria convert the soluble polymers into a range of organic acids (lactic, formic, acetic, butyric and propionic acids), alcohols (ethanol, butanol) hydrogen and carbon dioxide.

### *Acetogenesis*

The third stage involves the degradation of volatile fatty acids, such as propionic and butyric, to acetic acid and hydrogen. This process is performed by acetogenic bacteria.

### *Methanogenesis*

Methanogenesis is the terminal step where methane escapes from the system, allowing the digestion process to proceed to completion. The methanogenic stage is continued by methanogenic bacteria which breakdown the acetic acid into even simpler molecules; water, carbon dioxide and methane, remove ordour and produce biogas. It is the final stage, which is perhaps most sensitive to inhibition, because these methanogenic bacteria are highly sensitive to the Oxygen concentration in the system. Their inactivity depends on an increasing fatty and acetic acids concentration within the environment, consequently lowering pH, whose measure, in a well-balanced system has to range between 7 and 8 [6].

When the process is in balance, these separate steps occur simultaneously at approximately equal rates. The process of anaerobic digestion can be broadly regarded as consisting of two stages, acid production and acid removal. The overall rate of reaction is controlled by the second stage, namely the conversion of volatile acids into methane and carbon dioxide gases. During the process of digestion, a variety of compounds is produced as intermediate and end products. If there is an imbalance in the digestion, the intermediate products accumulate. These intermediate products are either acidic or basic and affect the pH of the system. A common cause of failure in anaerobic digestion process is imbalanced acedogenesis.

## 3. EXPERIMENTAL SETUP AND PROCEDURE

### *Characteristics of Wet Spent Grains*

In this study, brewery spent grains obtained from Ceylon Brewery Ltd. Nuwara Eliya, Sri Lanka and having compositional analysis as given in Table1[4], were used as digester substrate. At the time of this study, the average solid waste generated from this brewery was estimated to be about five tones per batch. [4].

**Table 1. Dried spent grains – nutrient analysis (dry basis)**

| Component | Percentage |
|---|---|
| Moisture | 4.5 |
| Oil | 7.5 |
| Protein | 21.5 |
| Fiber | 16.5 |
| Carbohydrate | 46.0 |
| Ash | 4.0 |

Table 2 gives results of the analysis for some relevant characteristics of wet spent grains (moisture content 76%) used in this study. Average values for said characteristics were determined for well-mixed samples of wet spent grains in triplicate by using standard methods.

**Table 2. Analysis of wet spent grains**

| | |
|---|---|
| Total Nitrogen (mg/g wet solid) | 0.403 |
| Phosphorus (mg/g wet solid) | 0.099 |
| Sulphur content (g/g wet solid) | 0.6 |
| Chemical Oxygen Demand (COD) (g/g wet solid) | 0.3257 |
| % Total Solid content (TS) | 23.73 |

Supplemental nutrients are sometimes needed in biological treatment systems to balance the nutritional requirements for bacterial growth. Often Nitrogen and Phosphorus are the major elements found to be limited in nutrient deficient wastes. From the results of the feed characteristics, ratio of COD to Nitrogen (N) to Phosphorus (P) was calculated as 300 : 0.37 : 0.09. But for an efficient anaerobic digestion the substrate should have a COD: N: P ratio of 300 :5 :1 [5]. Comparison of ratios shows a nutritional deficiency in the substrate, requiring attention in feed preparation. It was decided to remedy this situation by supplementing the substrate with phosphorous and nitrogen to obtain the correct nutrient balance, with calculated amounts of ammonoim sulphate [$(NH_4)_2SO_4$] 21.02 mg per l of digester slurry and di-sodium phosphate [$Na_2HPO_4$] 10.03 mg per l of digester slurry.

Sulphur content is another important parameter as sulphur in the feedstock may contribute to the production of hydrogen sulphide. But the analysis showed that the sulphur content in the spent grains is significantly low.

The COD test is widely used as a means of measuring the polluting strength of domestic and industrial waste. There is a relation between COD and methane ($CH_4$) production. The amount of methane gas produced per unit of COD converted under anaerobic conditions at 35° C is 0.40 l $CH_4$/gCOD [1]. Therefore, the theoretical quantity of methane that can be produced from the anaerobic digestion of brewery spent grains based on the COD load is 3455 x $10^3$ l/d. If this quantity is converted to biogas considering 65% of methane in biogas then the theoretical quantity of biogas that can be generated is 5315 x $10^3$ l/d.

### Digester Substrate Preparation

There are several physical methods such as cutting, grinding or shredding of the feedstock to increase the surface area for enzymatic attack. Since most common digester feeds are only 40 -60 % degradable, substantial increase in gas yield could be achieved if the substrate could be adjusted to have its maximum degradability [5]. In this study the feed substrate used was fresh brewery spent grains having TS content of 23.73% which make it unsuitable for efficient digestion. Therefore, the digester feed slurry was prepared by blending known quantities of wet spent grains with water to make the desirable TS content. The blending of the spent grains was done in a household blender for 3 min to break big pieces of spent grains and to make the slurry.

### Digester Operation

There are numerous designs for anaerobic digesters; they can be categorized as low rate reactors and high rate reactors. Experimental trials were carried out using á Laval CMF 100 high rate laboratory reactor of 7 l volume, as shown in Fig.1.

The reactor is equipped with a blade stirrer agitation system, control unit, jacket for precise temperature control and a gas-tight cover with openings for feeding, mixing, gas extraction, and temperature and pH measurements. The digestion vessel is manufactured with special glass and provided with a hemispherical bottom for efficient agitation with low speed of the agitation system and a visible scale on the inside vessel for level adjustment. The agitator system is magnetically coupled to the motor and the mixing speed can be varied from 5 – 1500 revolution per minute (rpm). The control unit can control parameters such as the velocity of the agitator and temperature.

### Gas Collection and Measurements

A battery-operated Triton –WRC low flow rate gas volume meter was used to measure the volume of gas produced per day. The produced gas was first sent through a ferric chloride solution and then sent through the gas meter. The use of ferric chloride solution is to prevent hydrogen sulphide gas entering into the gas meter together with the produced gas. To check the burnability, gas was collected into a plastic bottle by the water displacement method and the burnability was tested by applying a flame and where a clear blue flame originated indicate burnability of produced gas.

### Gas Analysis

The methane percentage and carbon dioxide percentage of the produced gas were measured using the LFG 10- Land fill gas analyzer which has an in-built pump to take the sample gas from standard pipes or via a probe. The output from the detectors are processed and displayed for each gas as the concentration of gas present in the mixture. Content of hydrogen sulphide was measured using dragger tubes. The test tube method is an accurate and simple method of determining the hydrogen sulphide concentration in biogas. Gas is introduced to the dragger tube and the concentration of the hydrogen sulphide can be directly read as ppm.

### Analysis of Total Volatile Acid Concentration

In all trials the concentration of total volatile acid of digester liquor was monitored regularly as this gives a good indication of the reactor performance. Volatile fatty acid concentration is a critical measure of the digester performance. It clearly indicates the interface between the acid formers and methane formers. An increase in volatile fatty acid will precede a decrease in gas production, methane content and finally a low pH. Accumulation of volatile fatty acid concentration greater than 250 mg/l can be toxic towards the digester process[5]. Volatile acid concentration was determined by the standard method (504 B) of steam distillation.

### Mixed Liquor pH Control

The pH of the digester slurry was measured by using pH meters. Monitoring and controlling the mixed liquor pH near neutrality by neutralization or by suspending feeding can allow recovery of failing digesters and allow the digester to operate at optimal rates. A pH range of 7 – 8 is usually tolerated but a slight alkalinity is preferred so that the risk of acidic failure is eliminated. During the project trials, the mixed liquor pH had to be controlled, and at some instances, by adding sodium carbonate ($Na_2CO_3$) to maintain the pH value in the above range.

**Fig. 1. High rate reactor.**

## 4. DIGESTER SET UP AND PHYSIO-CHEMICAL ANALYSIS

The suitability of brewery spent grains to anaerobic digestion was tested in the high rate reactor shown above, by carrying out six trials with varying initial operating conditions. Process conditions of six trials are presented in Table 3.

**Table 3. Process conditions of trials**

| Trial | Operating conditions | Feed slurry (wet solid %) | Feed Slurry TS % | Loading pattern |
|---|---|---|---|---|
| A | At 37° C, Mixing at 400 rpm | 4 | 1 | Intermittently |
| B | At 37° C, Mixing at 400 rpm | 4 | 1 | Intermittently |
| C | At 30° C, Mixing at 400 rpm | 59 | 14 | Daily |
| D | At 37° C, Mixing at 400 rpm | 59 | 14 | Daily |
| E | At 37° C, No mixing | 59 | 14 | Daily |
| F | At 30° C, No mixing | 59 | 14 | Daily |

Prior to starting the experiments, some anaerobic sludge required as the basic seed culture was prepared and heated first and then, allowed to mix thoroughly for 1 day. Then the required amount of prepared sludge and blended brewery wet solid was fed to the digester in the form of slurry. Feeding was done by removing a bung in the feed inlet and introducing the sludge and slurry into the digester. After the digester became stable, an amount of sludge equivalent to the feed volume was withdrawn at the time of feeding. Ultimate solid level of this sludge in terms of Suspended Solid (SS) in g/l was determined.

After setting up the digester it was sealed, and parameters such as pH, acid level, gas production rate, gas composition, gas burnability were monitored as the digestion progressed. For all the pilot trials, the same experimental set up and procedures were followed with variation in some operational parameters. Therefore, the trials were conducted one after the other because only one high rate reactor was available. The trials were run for more than two weeks, and terminated when the rate of gas production decreased.

Loading rates were calculated based on daily feed addition in Volatile Solids (VS) and represented in (gVS/ld). The effective volume of the digester was taken as 5 l. In first two trials (Trial A and Trial B) TS content of the feed slurry was adjusted to 1% and loading was done intermittently. In subsequent trials (Trial C, Trial D, Trial E and Trial F) TS content in the feed slurry was increased up to 14% while feeding was done on daily basis.

## 5. RESULTS AND DISCUSSIONS

In this study six trials were performed varying the operational conditions in order to investigate the suitability of anaerobic digestion to brewery spent grains. The criteria used for measuring success of anaerobic digestion process of spent grains were biogas production rate, gas yield, methane productivity and the percentage solid degradation. The data obtained from the experimental trials has been analysed and the results are presented below.

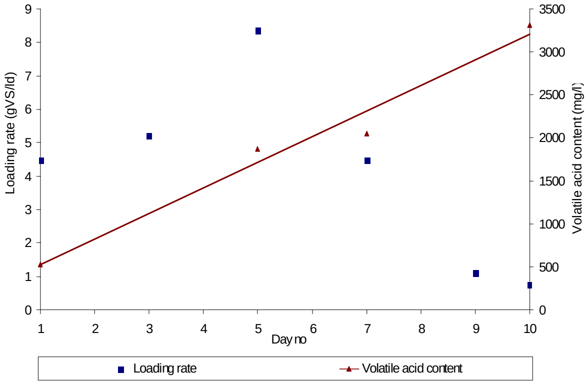

**Fig. 2. Variation of loading rate & total volatile acid content (Trial A).**

Before starting the trial A, the digester was initially inoculated with the seed culture taken from an existing digester in order to develop a sufficient bacterial culture. The trial A was started with the loading rate of 4.45 gVS/ld but with low percentage of TS (1%) in the feed slurry and went up to 8.37 gVS/ld on day 05. Loading was done intermittently as presented in Fig.2. and it shows that total volatile acid concentration gradually increased up to 3300 mg/l with this organic loading and produced gas contained more carbon dioxide than methane which was not burnable (Fig.3). Even though the loading rate was decreased up to 0.93 gVS/ld the pH value dropped significantly from 7.9 to 6.4 (see Fig.4). This means that anaerobic digestion is inhibited significantly owing to the build up of volatile fatty acids and the reason may be the sludge used was not properly acclimatized. This sign indicated that digester was unstable and experiment was terminated on day 10.

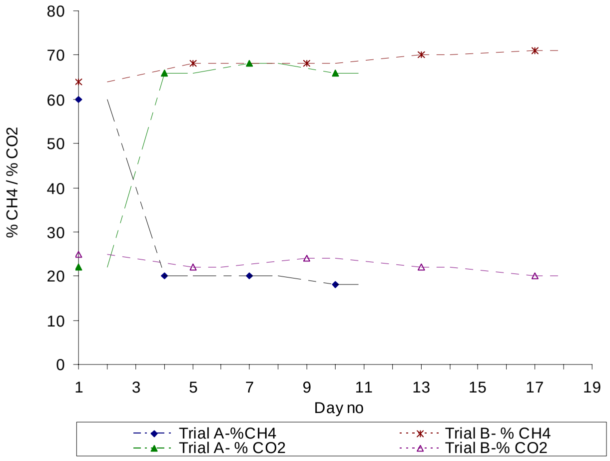

**Fig. 3. Gas composition (trial A & trial B).**

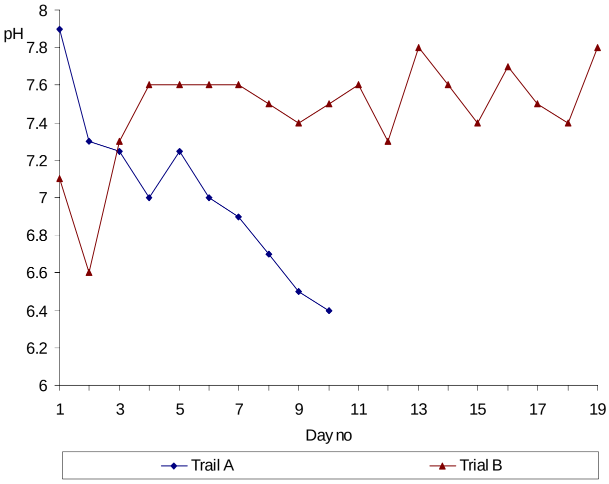

**Fig. 4. Variation of mixed liquor pH (trial A & trial B).**

Therefore, the trial B with same operating conditions started using properly acclimatized sludge and it was decided that, to prevent acid concentration increasing, feeding has to be started in very dilute condition. Therefore, the trial B was started with reduced rate of organic loading, 0.3 gVS/ld, and then, loading rate was gradually increased as shown in the Fig. 5. This procedure made it possible to obtain stable conditions within the digester. The burnable gas obtained throughout the experiment showed these stable conditions and it can be seen from the Fig. 3 & Fig. 4. According to Fig. 4 the pH value initially 7.0, dropped over the first two days to 6.5 but eventually stabilized above 7 for the remaining digestion period. Also Fig. 5 indicate that the volatile acid level gradually decreased with digestion time and ultimately it reaches 192 mg/l. Such a drop of the volatile acid level gives a good indication of stable condition within the digester.

The next trial C was carried out using the acclimatized sludge taken from the trial B, and similarly when conducting rest of the (i.e. D, E, & F) the acclimatized sludge was taken from the previous trial as the initial seed culture. The percentage of TS in the feed slurry was increased up to 14 and organic loading was done on daily basis. The operational conditions of these trials were varied as described in the Table 3 and the digester performance was examined. It was decided to carryout these trials initially with low loading rate and then to gradually increase the loading rate (see Fig. 6) while monitoring the stability of the digester. As a result of this controlled digestion process, a considerable increase of burnable gas production could be seen.

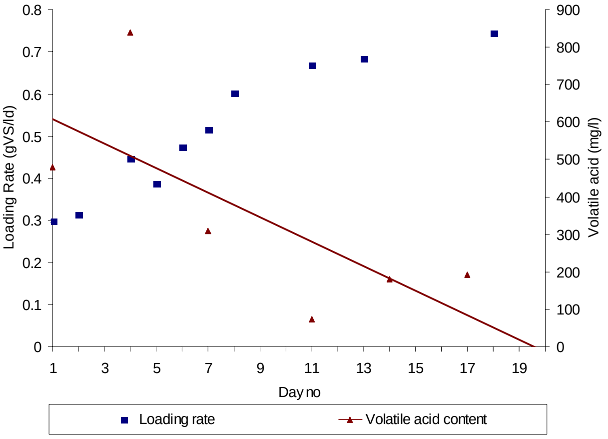

**Fig. 5. Variation of loading rate & volatile acid content (trial B).**

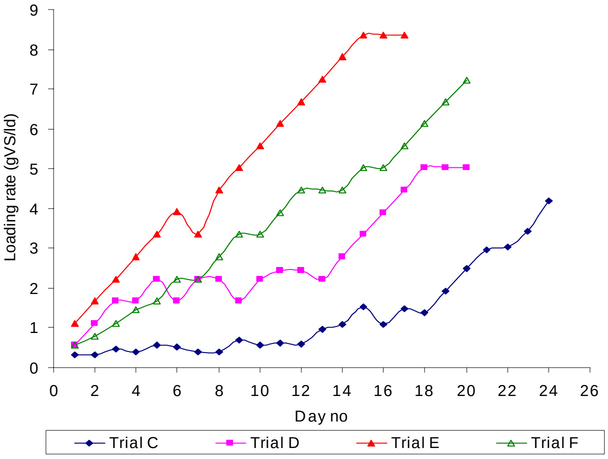

**Fig. 6. Variation of loading rate with time for trials C,D,E,F.**

Digester performance data shown in Table 4 clearly revealed that the methane content of the biogas generated from the reactors of last four trials was in the range of 56 - 69% while carbon dioxide content was within 25 - 31% and concentration of hydrogen sulfide in the produced biogas was less than 120 ppm. However, the mixed liquor pH varied slightly between 7.5 and 7.8, and it was in the range considered as optimum for methanogenesis. The concentration of volatile acid varied within the range of 57 – 744 mg/l. As shown in Fig. 7 volatile acid profile varied slightly under different conditions whereas in trial E total volatile acid remained below 400 mg/l showing optimum conditions within the digester.

**Table 4. Digester performance data**

| Parameter (unit) | | Trial C | Trial D | Trial E | Trial F |
|---|---|---|---|---|---|
| pH | Initial | 7.8 | 7.73 | 7.73 | 7.7 |
| | Final | 7.72 | 7.7 | 7.63 | 7.5 |
| Volatile acid (mg/l) | Mini. | 144 | 360 | 57 | 288 |
| | Max. | 576 | 741 | 360 | 744 |
| $H_2S$ (ppm) | Mini. | 110 | 90 | 100 | 110 |
| | Max. | 120 | 100 | 110 | 120 |
| $CH_4$ % | Initial | 65 | 65 | 65 | 56 |
| | Final | 69 | 68 | 67 | 64 |
| $CO_2$ % | Initial | 30 | 29 | 30 | 30 |
| | Final | 25 | 28 | 31 | 30 |
| Total VS loaded (g) | | 124 | 270 | 416 | 352 |
| Total Gas production (l) | | 51 | 119 | 248 | 120 |
| Gas yield (l/g $VS_{added}$) | | 0.411 | 0.440 | 0.596 | 0.340 |

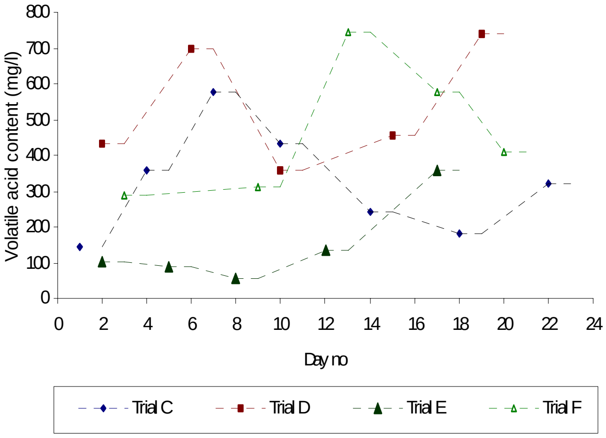

**Fig. 7. Variation of volatile acid concentration with time for trials C to F.**

The gas production data are more indicative of the degree of stabilization of feed substrate, than any other measurable parameters in the system. Therefore, it is important to consider the rates at which the gas is produced. Fig.8 shows the biogas production during anaerobic digestion of brewery waste at different process conditions. In all the trials, rate of gas production was quite low during the initial period of testing. This is because a longer acclimation period is necessary to produce more efficient methenogens, which convert brewery waste to methane.

When comparing Fig.6 and Fig.8, it is evident that the biogas production rate increased with the increase in organic loading rate. The highest production of gas could be obtained from the trial E, and it indicated that stable gas production could be achieved even with higher loading rates. Comparing cumulative gas production data for trials B C,D,E, F presented in Fig. 9, clearly showed that the last four trials gave the best performance and feasibility of using spent grains for anaerobic digestion. Gas production data also shows that the gas production of trial B where feeding was intermittent with low TS content in the feed slurry, was fairly low as compared to trials C, D, E, F. It revealed that daily or continuous feeding patterns together with fairly high solid concentration in the feed slurry are also necessary to maintain the steady digestion process.

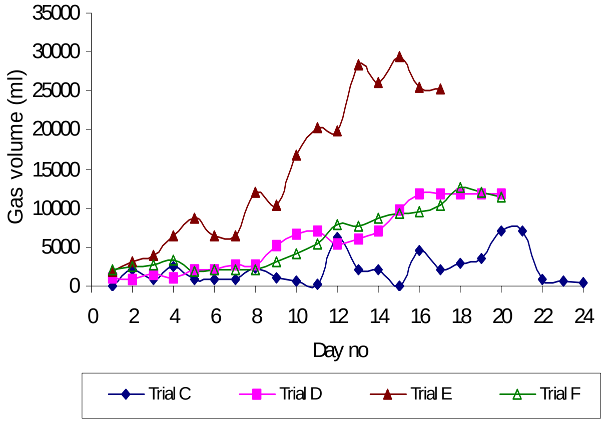

**Fig. 8. Variation of gas production with time for trials C to F.**

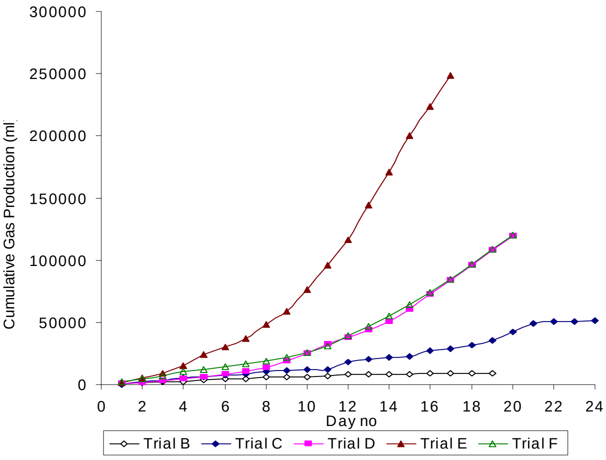

**Fig. 9. Cumulative volume of gas production for trials B to F.**

**Table 5. Analysis of digester slurry**

| Parameter (unit) | | Trail C | Trail D | Trail E | Trail F |
|---|---|---|---|---|---|
| Day No. operated | | 24 | 20 | 17 | 20 |
| Loading rate (g VS/ ld) | Initial | 0.55 | 0.31 | 0.55 | 1.11 |
| | Final | 7.25 | 5.58 | 5.02 | 8.36 |
| Substrate concentration (gVS/l) | Initial | 24.8 | 54 | 83.2 | 70.4 |
| | Final | 10.19 | 22.62 | 28.53 | 49.1 |
| Inoculums SS (g/l) | | 53.13 | 47.24 | 41.64 | 55.1 |
| Ratio of Substrate to inoculums | | 1:2.1 | 1:0.87 | 1:0.5 | 1:0.78 |
| % solid degradation | | 58.9 | 58.1 | 65.7 | 30.3 |

As per the data shown in the Table 4 & 5 all four digesters behaved quite similarly. For the analysis, only trials C, D, E, and F were considered as the performance of the trials A and B were significantly lower. The results did not show a significant effect of mixing in the digesters (trials C & D). Impact of mixing on anaerobic digestion of animal waste has been studied by researchers and they show that when thicker manure slurry (10%) was fed, mixing improved the biogas production whereas no significant effect of mixing or mode of mixing under the studied experimental conditions with 5% manure slurry [7]. Further, they mentioned that the role of mixing becomes more important with an increase in TS concentration in the feed slurry [7]. However, performances of trials D and E in which the digesters were operated at 37 °C temperature, are quite better than that of other trials.

Table 6 presents the summary of calculated average steady state data for the last four trials.

**Table 6. Biogas production rates, Methane yield, and Methane productivity of the trials C, D, E, F**

| Trial | VS loading (g/ld) | Biogas production rate (l/ld) | Gas yield ($l/gVS_{added}$) | Methane productivity ($l\ CH_4/\ gVS_{consumed}$) |
|---|---|---|---|---|
| C | 1.03 | 0.425 | 0.411 | 0.698 |
| D | 2.7 | 1.19 | 0.440 | 0.758 |
| E | 4.89 | 2.91 | 0.596 | 0.907 |
| F | 3.52 | 1.20 | 0.340 | 1.120 |

The biogas production rates, methane yield and methane productivity obtained from the study trials are described in the Table 6. Methane productivity is defined as the volume of methane produced per unit weight of the VS consumed [7].The results showed that, as the slurry loading increased the biogas production rate also increased. The highest biogas production rate could be observed from trial E. In trial F, though the trial was carried out at ambient temperature and without having mixing showed the highest methane productivity. That can be explained as, since trial F was the last trial conducted, the sludge used (taken from the trial E) were properly acclimatized. Therefore, the results suggested that the digester system should be allowed to have time interval sufficient for development of microorganism rich environment in order to achieve the optimum conditions. Reference [8] stated the effect of microbial acclimation on anaerobic treatability of broiler and cattle manure and described that an increase amount of biogas and methane content was seen in trials which used acclimated culture. Therefore, based on the results of this study pre-acclimation is strongly recommended in order to increase the efficiency of digestion process.

As the anaerobic digestion process proceed, volatile solids concentration of the solids reduces with the production of biogas. Solid mass balance calculations were done and percentage solid degradation for last four trials are presented in Table 5. The percentage solid degradation results of trials C,D,E,F indicate that the percentage volatile solids reduction were in the range 30 – 66 As illustrated in Fig.10 the trial E gave the highest percentage solid degradation compared to other trials.

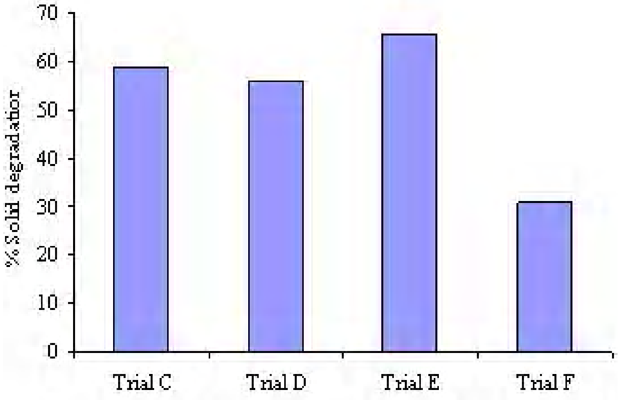

**Fig. 10. Percentage solid degradation of trials C to F.**

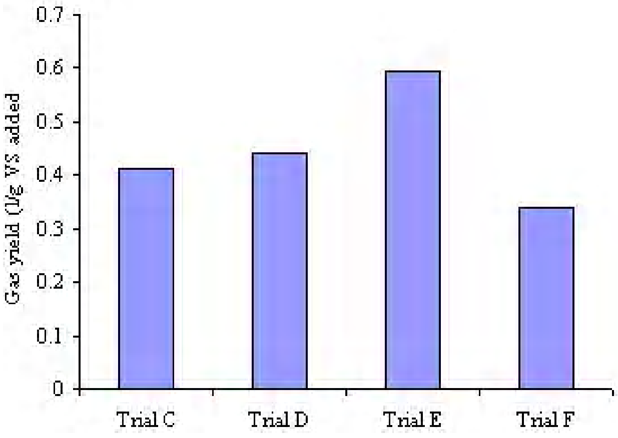

**Fig. 11. Variation of biogas yield of trial C to F.**

The values of gas yield (l of biogas produced per g of volatile solids applied) for trials C, D, E, F are presented in Fig. 11 and show that the highest gas yield, 0.596 could be obtained from trial E. But the gas yield for trial F was significantly lower than the trial E, the reason being, both mixing and heating were not provided for the process. Mixing of the digester contents offers several distinct advantages; the substrate supply and heat uniformly distributed, biological intermediate and end products are not allowed to accumulate and scum layer formation is reduced to a minimum, whereas keeping the digester at mesophilic region is also an important parameter as the reaction rate increases with the temperature. In the trials C and D the digesters were operated at same conditions (TS%, daily feeding and mixing) except in trial D that was operated at elevated temperature, made no difference in the gas yield as well as percentage solid degradation.

However, the maximum gas yield for brewery spent grains was found to be 0.596 $l/gVS_{added}$ for loading of 4.89 g/ld at 37° C. This value of gas yield compares well with the available gas yield data for other substrates in the literature. Some of the methane gas yield data for different substrates are given here. Methane yield for digestion of the organic fraction of pineapple waste is 0.29 l/gVS whilst fruit and vegetable mixture gave a yield of 0.36 l/gVS in the mesophilic region [9]. And also it has been reported that methane production potential of poultry slaughter house waste at a rate of 0.52 – 0.55 l/gVS$_{added}$ [10]. Also reference[10] mentioned that methane yield of 0.54 l/gVS$_{added}$ for source sorted organic fraction of municipal solid waste and a methane yield of 0.11 -0.24 l/gVS$_{added}$ for cattle manure under varying process conditions. Also it has been reported for distillery waste maximum biogas yield 7.14 l/l$_{\text{Distillary waste}}$ have been obtained for Biological Oxygen Demand (BOD) loading of 2.74 g/l at 50ºC digestion temperature [11].

According to these figures, a better digester performance was observed in trial E. This trial demonstrated that stable conditions of the anaerobic process could be achieved and maintained even without mixing. However, keeping the digester at mesophilic region is important as the temperature increases, the reaction rate constant increases. It can be observed that the digester operating conditions are optimized the process can be made economically sustainable. Thus the result suggested that a controlled feed procedure along with acclimated digester system is also necessary to maintain steady digestion.

Taken overall the study results show that anaerobic digestion of brewery spent grains is most successful at high temperature even without mixing. The combustion characteristics, the clear blue flame obtained from burning the gas generated is a good indication of the potential for energy generation. As mentioned, in Sri Lanka the generated quantity of brewery solid waste for the year 2004 is 26520 kg/d. As the %TS of wet spent grains is known, the TS content of this waste can be found as 6293 kg/d. It was assumed that VS content is 80% of that TS content, and then the total VS content of this generated solid waste can be calculated as 5034 kg/d. Since the gas yield was found as 0.596 l/gVS-$_{added}$ - if the organic fraction of this waste is made to produce biogas from the anaerobic digestion process, the estimated quantity of biogas is 3000x10$^3$ l/d and the energy equivalent of the produced gas is 71,700 MJ/d (Pure methane has an energy content of about 35.9 MJ/m$^3$ and 23.9 MJ/m$^3$ of energy in the biogas that include carbon dioxide [1]). Therefore, the electrical power that can be generated from this energy is 5 MWh/d considering the generator efficiency as 25%. The simple calculation presents an extremely optimistic picture to the brewery industry as what the answer indicates is that the electricity supply is shown to be achieved using this waste. The recovery of waste heat can also be used to produce process steam necessary for the brewing process and to heat the digester. The benefits of this study can be in identifying as process with twin possibilities. i.e. A process capable of acting as an environmental management tool as well as an energy generating potential for an industry.

## 6. CONCLUSION

The high content of starch (fermentable matter) of brewery waste indicates a potential for achieving a rapid and high level of biodegradation. Therefore, it is feasible and effective to apply the anaerobic digestion process to brewery spent grains. It was also found that the maximum gas yield of brewery waste at 37 ºC was around 0.596 l/gVS$_{added}$ at the loading rate of 4.89 g/ld. This value is somewhat higher when compared with the values reported in literature for other substrates. The theoretical biogas production was calculated as 5315x10$^3$ l/d based on COD loading and it was estimated that 3000x10$^3$ l/d biogas could be produced. Although the theoretical rate of gas production is obviously higher than the expected value, production of 3000x10$^3$ l/d can be achieved in practice. This means a very high degree of degradation, with the particular solid waste showing positive amenability to the anaerobic digestion process. Providing an environment having sufficient amount of microorganisms and other parameters controlled within the digester, is a must when adopting anaerobic digestion process for brewery spent grains. Thus, the anaerobic digestion has been shown to be a viable method of stabilization and volume reduction for brewery waste. Therefore, the study has been shown that this industry can benefit by waste utilization via recycling the energy content by the anaerobic digestion method.

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