Original Research Article

The Biogas Production from Brewery Waste: A Case Study for Tanzania Breweries Company Limited (Arusha-Branch)

Abstract

Beverage and Food processing industries are extremely large consumers of energy and bio-waste producer worldwide. Due to its high concentration of organic compounds, which imposes a high biochemical oxygen to the waste's breakdown, disposal from these companies in the environment increases the risk of inconvenience to the ecosystem. In this context, the brewing industry's production phases included the fermentation of vegetable feedstock such as barley malt, hops, and grains that produces a variety of by-products. Fermented malts, hops, yeast and water which used for the beer production caused waste materials that are disposed as organic wastes. Experimentally the waste as anaerobic digestion feed was assessed. The idea was to support the environment by utilizing alternative energy using the bio-waste from the brewery industry. Samples from the Tanzanian Breweries Company Limited (TBL) Arusha branch were taken to the CAMARTEC biogas plant. The wastes in form of sludge were investigated for anaerobic digestion. The findings of this study showed that waste from the brewing sector may be converted into environmentally acceptable solutions to be used as a biogas.

Keywords: *Feedstock, Organic waste, Digester Plant, Biogas, and alternative Energy*

1. Introduction

The use of fossil fuels as the main source of energy caused several economic and environmental challenges (Felix & Gheewala 2012). Traditional energy sources such as firewood, animal dung, crop wastes, and paraffin are used by many rural communities in underdeveloped countries but these traditional methods are often expensive and not eco-friendly (Demirbaş 2006). Biogas is a combustible gas composed primarily of methane, carbon dioxide, and trace gases. It is an environmentally friendly and alternative energy source that can replace coal and firewood. Biogas production via anaerobic digestion has

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significant advantages over other forms of bio-energy because of the reduction in carbon dioxide and other emissions (Chowdhury et al. 2020). An investigation into the utilization of anaerobic digestion in the treatment of industrial waste was conducted in this study, although it still requires creative technology and development (Adekunle & Okolie 2015).

Anaerobic Digestion (AD) is a biological process that includes a consortium of microorganisms treating and stabilizing organic matter in the absence of oxygen that can be considered into four major steps: Hydrolysis, Acidogenesis, Acetogenesis, and Methanogenesis (Lourinho et al. 2020). The hydrolysis stage is an extra-cellular process in which polymeric compounds organic matters are broken down into soluble oligomers and monomers. Hydrolysis of these compounds into smaller units is the first step in the AD process. Since fermentative bacteria seem unable to directly adsorb complex organic polymers into their cells. Hydrolysis is a necessary step before acidogenesis (Zamri et al. 2021). Hydrolysis is often considered as rate-limiting step in the AD of particulate feedstock such as lignocellulosic biomass, because digestible hemicelluloses are covered as health of insoluble lignin and because of the crystalline nature of cellulose (Parawira et al. 2005).

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Acidogenesis phase includes sugars, LCFAs, glycerol, and amino acids that are used by fermentative microorganisms to produce carbonic acids such as acetic acid, propionic acid, butyric acid, and other short chain volatile fatty acids. (Vavilin et al. 2008). Glycerol, on the other hand, is converted into acetate by acidogenesis, while LCFAs are converted into acetate and H_2 by acetogenic bacteria via the -oxidation process (Meegoda et al. 2018). Acidogenesis is the most rapid reaction in the anaerobic food chain. At low hydrogen pressure and high pH, acetate is discovered to be the primary fermentation product. Acidogenesis is frequently a faster step in the anaerobic transformation of complex organic matter in liquid phase digestions. (Rivas-García et al. 2020).

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The degradation of monosaccharides (glucose) can manifest in different pathways which leads to the emergence of different products such as VFA, as shown in Table 1.

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Table 1: Estimated of the Different Products from Glucose Degradation during Acidogenesis Process

S/No.	Products	Reaction

1	Acetate	$C_6H_{12}O_6 + 2H_2O \rightarrow 2CH_3COOH + 2CO_2 + 4H_2$
2	Propionate+Cetate	$3C_6H_{12}O_6 \rightarrow 4CH_3CH_2COOCH + 2CH_3COOCH + 2CO_2 + 2H_2O$
3	Butyrate	$C_6H_{12}O_6 \rightarrow CH_3CH_2CH_2COOH + 2CO_2 + 2H_2$
4	Lactate	$C_6H_{12}O_6 \rightarrow 2CH_3\ CHOHCOOH$
5	Ethanol	$C_6H_{12}O_6 \rightarrow 2CH_3CH_2OH + 2CO_2$

The acetogenesis stage is crucial for the successful production of biogas. In contrast to fermentative bacteria, acetogens are obligatory symbiotic bacteria that live in close proximity to methanogens. (Fu et al. 2018). Acetogens are slow-growing organisms that are sensitive to changes in organic loads and environmental conditions, requiring lengthy reaction times. Acetogenic bacteria can be divided into hydrogen producing acetogenic bacteria and homoacetogenic production bacteria (Mu 2003). In anaerobic digestion, acetogenic bacteria convert VFAs and alcohols into acetate, hydrogen, and carbon dioxide, which are then used by methanogens to fuel their metabolism (Szewczyk & Bukowski 2008).

Propionate is mostly converted into acetate, carbon dioxide, and hydrogen during acetogenesis via the methylmalonyl-COA route. Table 2 shows examples of VFA degradation reactions.

Table 2: Fatty Acids Degradation Reactions

S/No.	Substrate	Reaction
1	Propionate	$CH_2CH_2COOH + 2H_2O \rightarrow CH_3COOH + CO_2 + 2H_2$
2	η-butyrate	$CH_3CH_2COOH + 2H_2O \rightarrow 2CH_3COOH + 2H_2$
3	i-butyrate	$CH_3(CHCH_3)\ COOH + 2H_2O \rightarrow CH_3COOH + 2H_2$
4	η-valerate	$CH_3CH_2CH_2CH_2COOH + 2H_2O \rightarrow CH_3COOH + CH_3 + CH_3CH_2COOH + 2H_2$
5	i-valerate	$CH_2(CHCH_2)\ CH_2COOH + CO_2 + 2H_2O \rightarrow 3CH_2COOH + H_2$

Sources: Pind et al., (2003)

In methanogenesis stage, the fermentation products such as acetate and H_2/CO_2 are converted to CH_4 and CO_2 by methanogenic archaea which are strict obligate anaerobes. Other

methanogens could also grow on one-carbon compounds the same as formate, methanol, and methylamine. Two groups of methanogens are involved in this process, the acetoclastic methanogens which are responsible for splitting acetate into methane and carbon dioxide (Szewczyk & Bukowski 2008). Normally, Methanosaeta and Methanosarcina, dominates in anaerobic digesters depending upon the type of waste and digester (Dworkin et al. 2006). The second group is the hydrogenotrophic methanogens that hydrogen and carbon dioxide produced methane from H_2/CO_2, whereas only a few species of methanogens are believed to be capable of utilizing acetate as a substrate (Macintosh 2019). However, estimated that stoichiometric ratio about 70% of the methane formed in anaerobic digesters which derived via the acetate pathway. The hydrogen pathway is more energy yielding than the acetate pathway, and is normally not rate limiting (Angelidaki et al. 2011). Table 3 shows the reactions that occur throughout the methanogenesis stage.

Table 3: Reactions related to methanogenesis stage

S/No.	Substrate	Reactions
1	Acetoclastic Methanogenesis	$CH_3COOH \rightarrow CH_4 + CO_2$
2	Hydrogenotrophic Methanogenesis	$4H_2 + CO_2 \rightarrow CH_4 + 2H_2O$
3	Accetate Oxidation	$CH_3COOH + 2H_2O \rightarrow 4H_2 + 2CO_2$
4	Homoacetagenesis	$4H2 + CO_2 \rightarrow CH_2COOH + 2H_2O$

The factors affecting anaerobic digestion processes include environmental factors such as temperature, VFAs, pH and alkalinity, inhibitors/nutrient and water content (Mao et al. 2015). Biological and anaerobic processes are affected by temperature. This includes the physical-chemical properties of all components in the digester as well as the thermodynamic and kinetic behaviour of the biological processes. The AD process can occur at a range of temperatures, including psychophilic (11-25 °C), mesophilic (35-40 °C), thermophilic (50-55 °C), and hyperthermophilic (55 °C), with mesophilic and thermophilic drawing the most attention. (Mu et al. 2006). There is a direct relation between the process temperature and the hydraulic retention time (Mahdy et al. 2019). Stability of the temperature is crucial for AD

process. In practice, the temperature of process is selected according to the type of feedstock used. The AD process functions within a pH range from 6.5 to 8 where in the microbial consortium it can replicate and so degrade the available substrates. The pH value in the AD process increases when there is ammonium accumulation (Calli et al. 2005). VFAs are precursors for methane production but accumulation may inhibit methanogenesis as a result of the drop in pH (Nges et al. 2012).

2. Materials and Methods

2.1. Feed Material

The yeast from Tanzania Breweries Limited Company's Arusha branch was used as the feed material. Calories, protein, carbohydrate, dietary fiber, fat, potassium, phosphorus, calcium, sodium, niacin, iron, thiamine, riboflavin, and chromium are all found in yeast.

2.2. Biogas Plant

The biogas plant had a storage capacity of 1.8 m^3 of gas. The plant is divided into five major sections: the inlet section, where the feed stock is introduced to the plant, the bio-digester section, where the entire process of yeast digestion occurs, and the bio-digester, which contains four processes: hydrolysis, acidogenesis, acetogenesis, and methanogenesis. The third component is the expansion chamber, whose primary function is to preserve materials from the digester while also assisting in the balance of the plant's pressure. The fourth component was the outlet, which was responsible for releasing the digested matter. (Fig.1). It shows how compost was made from the plant's using a compost pit or bio-sturry pits.

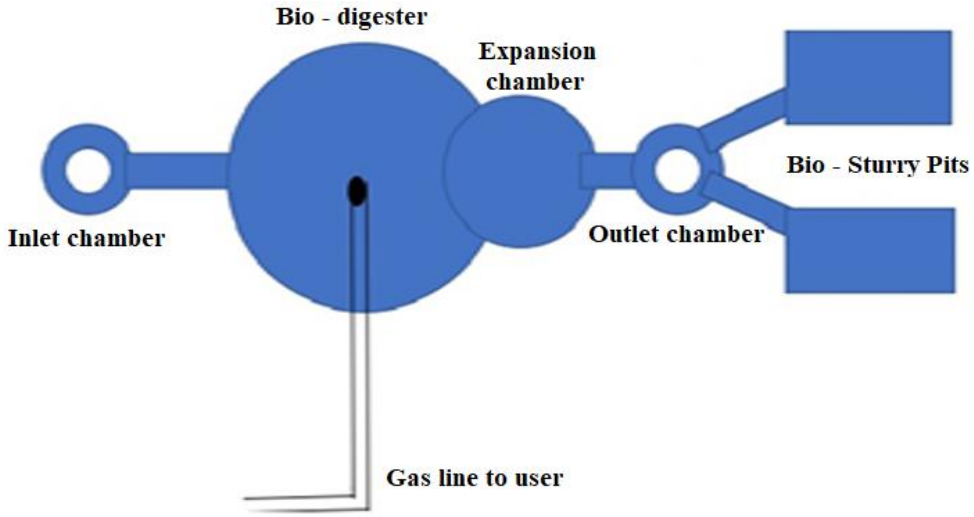

Fig.1.: Digester Plant Layout.

2.3. Experimental Setup

As illustrated in (Fig.2.) the experimental setup included a bio-digester, a pressure gauge for measuring and recording gas pressure linked inline to the gas flow meter, and another pressure gauge for measuring the pressure flow directed to the two (2) stoves to test the biogas's operating performance.

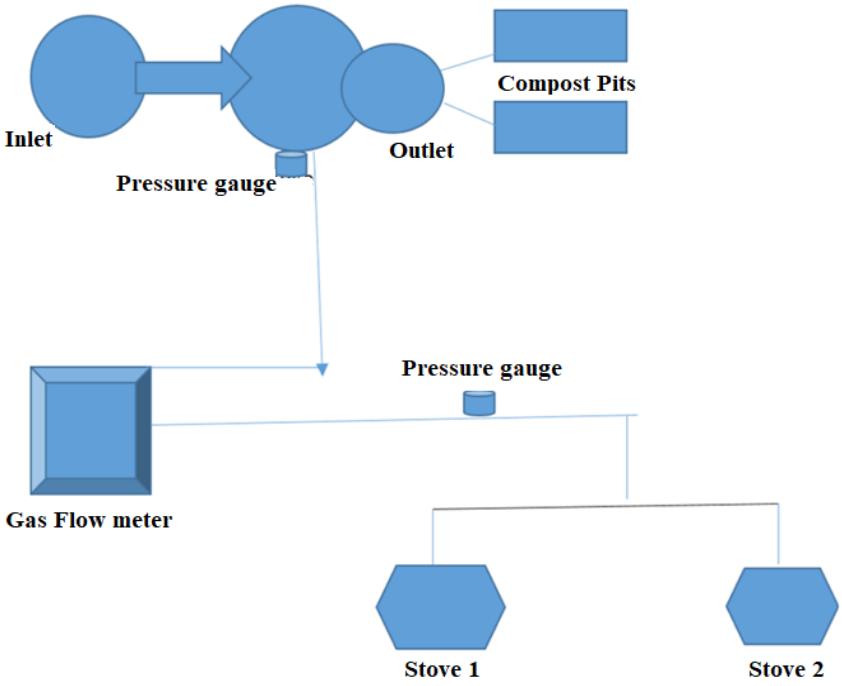

Fig.2. Experimental Setup.

2.4. Instrumentation and Measurements

Several instruments were utilized to gather various measurements during the experiment, as follows:

i. *Gas Flow Meter* was used to determine the amount of gas utilized daily in the kitchen through stove sets.

ii. *Hydrogen Sulphide Analyzer* was used to determine the level of sulphur in the system (biogas).

iii. *pH Meter* was used to check out the pH of inlet feedstock and the outlet bio-slurry.

iv. *Pressure Gauge* was used to determine the pressure of the gas produced within the system.

v. *Thermometer* was used to determine the inside and ambient temperature required to support anaerobic processes.

vi. *Methane Analyzer* was used to determine methane content of biogas.

3. Results and Discussion

3.1. General Procedures

The biogas plant was fed brewery yeast material for this study. The digester initially contained cow dung, but after 60 days, the cow dung was replaced with yeast, and the hydraulic retention period of 60 days was chosen because the substrates contain significantly more solid material and nitrogen. The medium consistence of brewery residues was 20% solid content and 80% water. The test was conducted in March 2018.

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3.2. Data Collection

The parameters such as gas pressure in kPa, volume of gas utilized daily in litres, temperature in ℃, methane concentration in parts per million (ppm), hydrogen sulphide in ppm and pH was measured and recorded every day. Feeding rate was 120 litres of brewery yeast at interval of three days, this was done to check the possibility of yeast consistence in gas production that was proved to be viable. Data were collected using various instruments and devices such as a gas flow meter, hydrogen sulphide analyzer, pH meter, pressure gauge, thermometer, and methene analyzer. Data collected on a daily basis included pressure, methane content, pH of the inlet and outlet, sulphur content of the gas, gas produced and consumed daily, and the amount of slurry overflew, which averaged 80 litres per day or per 3-days?.

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3.3. Data Analysis

The collected data has been analyzed daily to check for any changes, and the methane level in yeast as a feedstock has reached up to 90%. The plant's specific size reached 6 m^3, and its maximum pressure was 8.5 kPa, which was recorded every morning, indicating a good flow in the plant. The sulphur level in the biogas content was 135 kPa, and the temperature ranged between 20 and 30°C. The gas quality has improved, with low levels of other gases such as carbon dioxide and nitrogen. Because the amount of gas generated was very high, roughly 1000 litres during 4 hours, the user can use up to 1000 litres of gas in the kitchen and wait for comparable amount of gas to be produced in this digester for the following 4 hours.

3.4. Biogas Production and Its Constituents

Yeast has proven to be an excellent feedstock in this investigation. The gas output, which grew to 9 kPa, as well as the methane content of the gas, which increased to 90% of the total biogas, have both improved significantly. There has also been a shift in the pH of the feedstock and the pH of the slurry produced after fermentation, indicating higher purity of gas produced by yeast. where the feedstock (4.5-6) is more acidic and the slurry produced during the process is more basic, but the pH test has been moved from 8.3 to neutral 7.9.

Fig.3. shows the methene rise corresponding to pH at inlet and outlet.

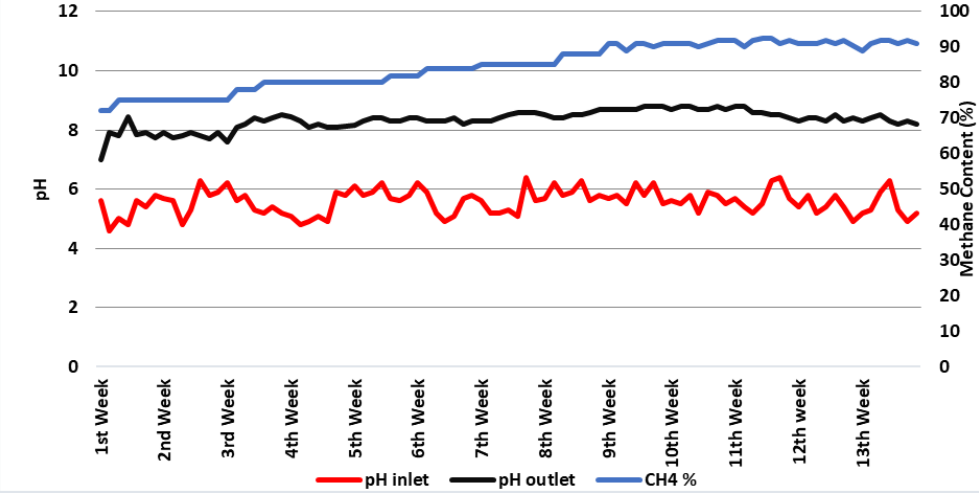

Fig.3. Methene Rise Corresponding to pH Inlet and Outlet.

The temperature has no effect on the pressure that is created; it has been observed that the temperature of the digester and the temperature of the surrounding area are always the same. The temperature had no effect on the gas output in the digester, as shown in (Fig.4.).

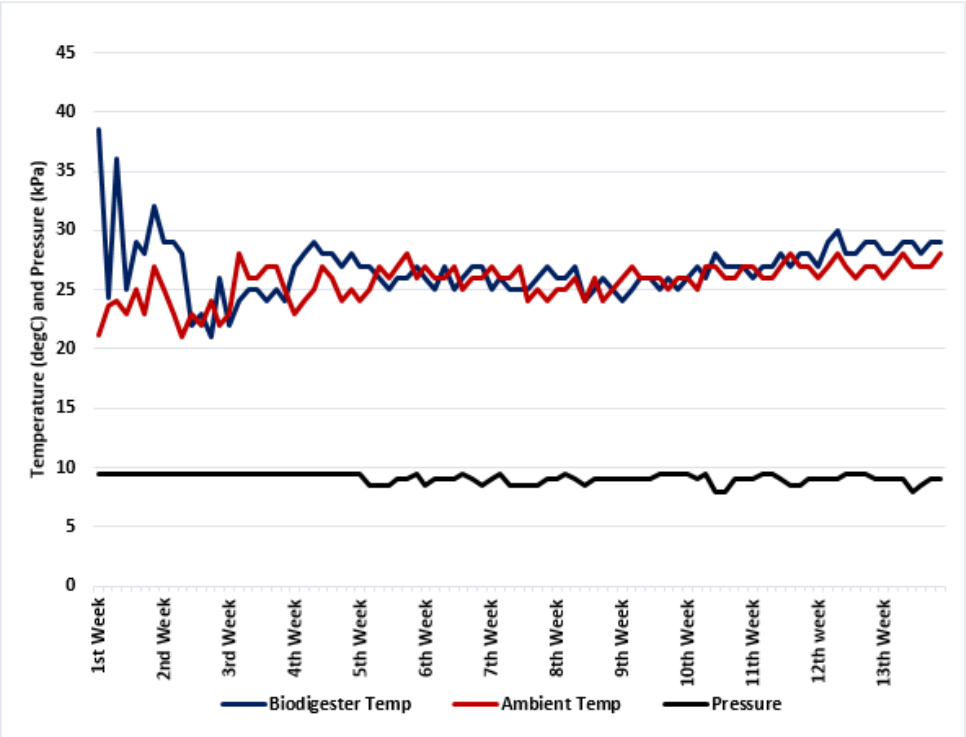

Fig.4. Effects of Temperature Variation to the Pressure of the Plant.

3.5. Utilization of Biogas from Yeast for Cooking

The drop in pressure while using the gas by the stove was observed, revealing that the stove consumed up to 300 litres of gas in 30 minutes and the pressure dropped from 9 kPa to 2 kPa, resulting in a cooking time of 180 minutes and a total of 1800 litres of gas consumed, which is a normal circumstance depending on the stove control and much gas was used when allowed to flow, while it was not properly used and occurs when the knob is full, which is a normal circumstance as shown in (Fig.5.).

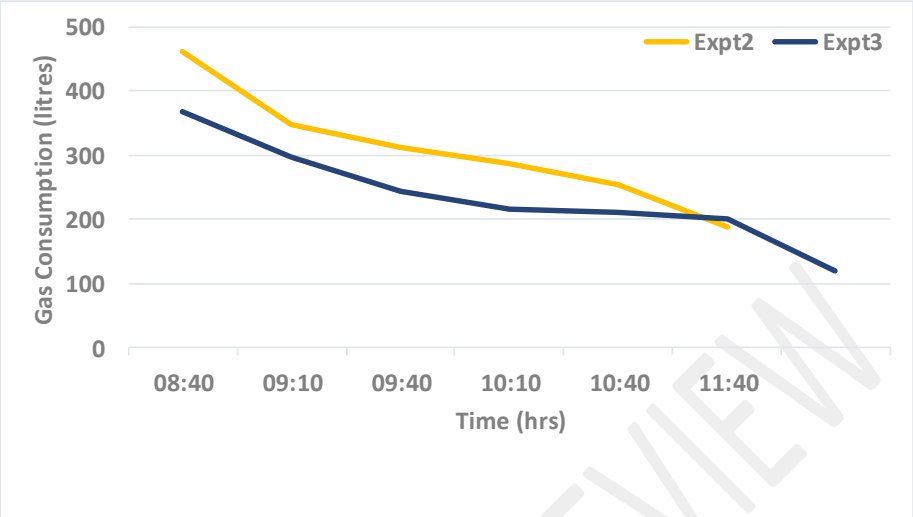

Fig.5. Gas Consumption Corresponding to Time Used.

When the stove was opened to half way the gas utilized was less and more time was available for cooking as shown in (Fig.6.).

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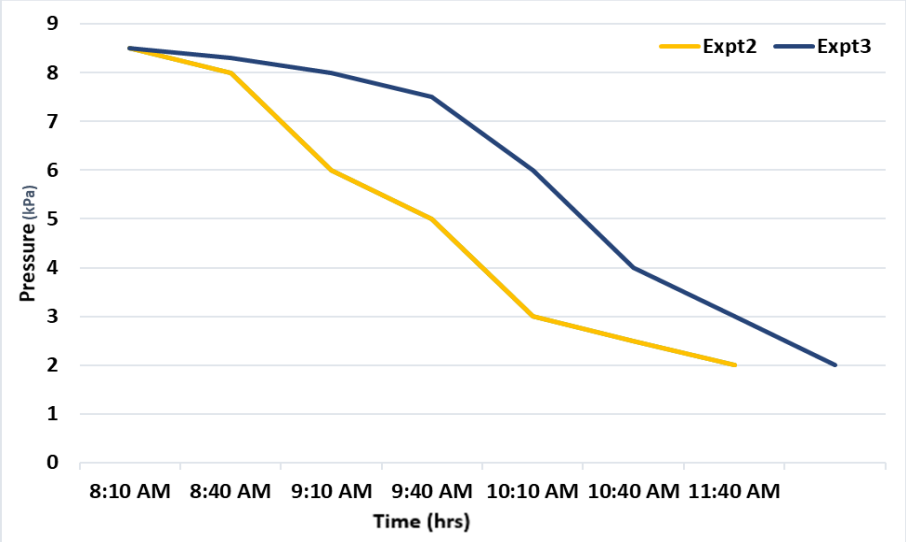

Fig.6. Pressure Drop while Utilizing the Gas.

In the case of gas utilization, pressure drops down and builds up, the observation has shown that the gas can be utilized for a specific period of time for a pressure drop to nearly 1.5 kPa and then it take up to 4 hours for pressure to build up again to its maximum level of 8.5 kPa. The trend has been demonstrated in various experiments, as shown in (Fig.7.).

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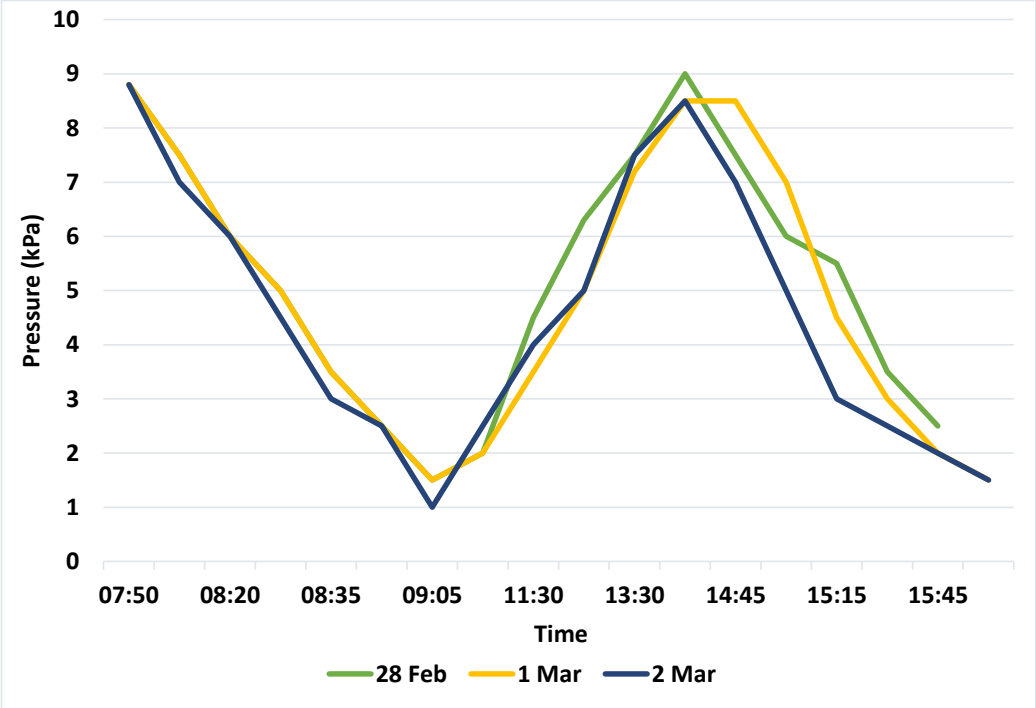

Fig.7. Pressure drop and pressure build up in particular time.

3.6 Biogas Stove

The biogas stoves as shown in Fig.8. (a) and (b), are installed in the kitchen at the household level for cooking purposes and are designed solely for biogas utilization.

(a) (b)

Fig.8. (a) Installed biogas stoves that are turned off when not in use. (b) Installed biogas stoves that are turned on when in use.

3.7. Feeding Yeast

Feeding frequency was managed to ensure yeast consistency and sustainability, and the findings revealed that you can feed the plant once for three days without feeding back while maintaining the rate of gas production. As shown in Table 4.

Table 4 Shows an average of 8 days of data from experiments on various knob openings, corresponding to time, volume, and initial pressure read during morning and afternoon.

Knob opening	Morning			Afternoon		
	Initial Pressure (kPa)	Volume used (litres)	Time (H:min)	Initial Pressure (kPa)	Volume used (litres)	Time (H:min)
Full	8.7	921	0:48	8.3	927	0:51
Half	8.7	1169	2:31	8.5	947	1:35
Min	8.7	935	2:46	8.3	942	2:01

The three-day feeding trend has not resulted in any major changes in the number of hours used in relation to the manner knobs were opened, as shown in (Fig.9.)

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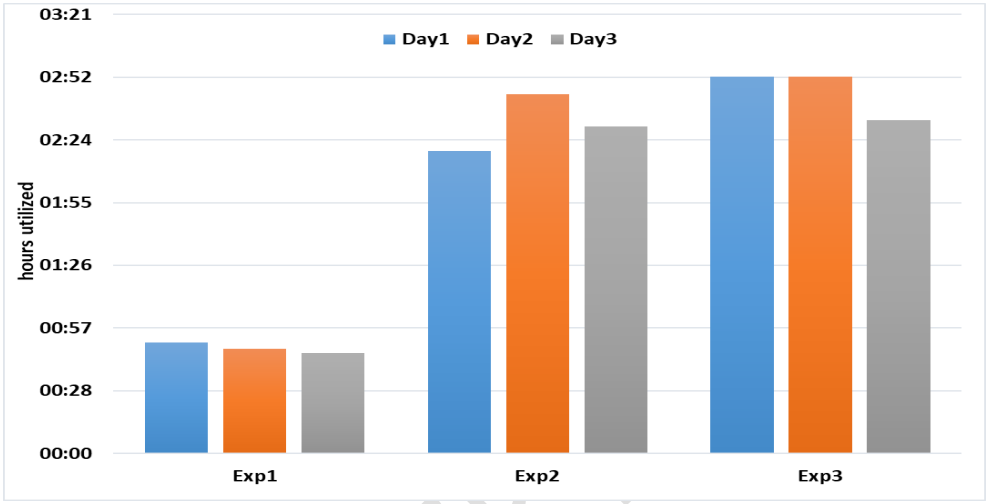

Fig.9. Feeding Interval to Number of Hours Used

The pressure created over the course of three days did not exhibit much variation. In three experiments of knob opening (full, half, and min), there was almost 8.5 kPa readings. This proves that you may feed the plant every three days and get the same pressure every day, as illustrated in (Fig.10.).

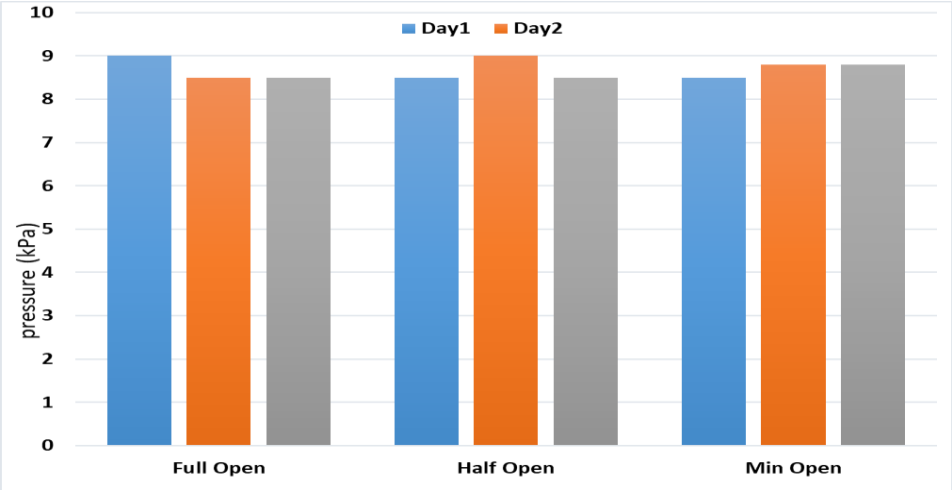

Fig.10. Feeding Interval to Pressure Consistence

4. Conclusion

In the case of biogas production, yeast as a feedstock has shown a lot of promise. The acquired results can assist Tanzanian Breweries Company Ltd (TBL) in developing future plans for the exploitation of yeast extracted from their factories in various zones across the country, as well as serving as a biogas energy source to provide additional benefits.

COMPETING INTERESTS DISCLAIMER:

Authors have declared that no competing interests exist. The products used for this research are commonly and predominantly use products in our area of research and country. There is absolutely no conflict of interest between the authors and producers of the products because we do not intend to use these products as an avenue for any litigation but for the advancement

of knowledge. Also, the research was not funded by the producing company rather it was funded by personal efforts of the authors.

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No data are given on the energy value of the biogas at 90% methane concentration.It should be about 32 MJ/m_3 or 45MJ/kg. No costing information is given for digester and stove. This should be given

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