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Energy Recovery from "Spent Wash" of Alcohol Distillery: A Case Study of Carew & Co. Ltd.

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Abstract: Wastewater generated from distillery industry, known as the "spent wash," is one of the most important factors for environmental degradation. The wastewater is highly concentrated, characterized by high chemical oxygen demand (COD) (up to 80–100 kg O_2/m^3), low pH (up to 4.38), high biological oxygen demand (BOD), phosphorus, ammonia, metal ions like copper and iron, as well as complex organic materials such as lignin, yeast cells, protein, etc. One of the methods of management of distillery spent wash is anaerobic fermentation with the production of biogas, which is an alternative source of energy beyond fossil fuel. This study mainly focuses on analysis of the production rate of biogas by batch anaerobic fermentation process, quantification of biogas with respect to spent wash feed, and energy recovery from spent wash. The energy found in this study was equivalent to 7.535 W-h, per litre of spent wash. This study suggests that spent wash from distillery industry can be fermented to produce biogas, which will serve as an alternative source of energy and address energy crisis and environmental degradation issues.

Keywords: *distillery industry, spent wash, anaerobic fermentation, chemical oxygen demand, biological oxygen demand.*

1. Introduction

Energy demand is rapidly increasing worldwide. Statistically, in 2000 and 2019 world's total energy consumption were 27,417TWh and 43,849TWh respectively which indicates 60% increase in consumption with respect to 2000 [1]. As for environmental pollution concerns, the European Union aims to reduce total greenhouse gas emissions in developed countries up to 80-95% by 2050 [2]. Likewise, for growing energy demand, exploration of alternative source for energy is mandatory. It is found that total biofuel consumption increased around 900% from 2000 to 2019 [1]. The factors that initiates the need for switching towards renewable and alternative energy sources are energy prices, population increase and climate change issues [3]**.** And for these reasons, renewable sources of energy are considered as one of the emerging sources of energy.

Use of biogas as renewable fuel source for vehicles is growing in Sweden as well as in Switzerland, and there is rising demand in other countries, including Austria, France Spain, Germany, USA, China and India [4]. By utilizing biogas for the electricity production, huge amount of greenhouse gas emissions are reduced [5]. Distillery effluent wastewater contains large quantities of soluble organic matter and plant nutrients [6]. So, the residual organic content can be used as fertilizer after anaerobic treatment. The pH level, nutrient level, etc. also meets the amendment of soil after treatment.

On the other hand, alcohol distilleries are extensively growing due to widespread industrial applications of alcohol in pharmaceuticals, food, perfumery, etc. It is also used as an alternate fuel. With the highly increasing demand of alcohol, highly polluted wastewater is being generated having musty odor and dark brown color. As for example, the Carew & Co produce more than 150,000L of effluent per day for producing ethanol and spirit. The pollution load of these waste streams and large amount of spent wash being discarded directly to the environment make the alcoholic beverage industry a highly polluting one. [7]. It can damage river water quality. The concentration of inorganic substances such as nitrogen, potassium, phosphates, calcium, sulphates is also very high [8]. The unpleasant odor of the effluent is due to the presence of skatole, indole and other sulphur compounds, which are not effectively decomposed by yeast during distillation [9].

The four main phases in manufacturing alcohol in distilleries are feed preparation, fermentation, distillation, and packaging [10]. Ethanol can be produced from a variety of biomass sources, but their utility as feedstock is determined by their cost, availability, carbohydrate content, and ease of conversion to alcohol [11]. Sugar crops account for over 61 percent of global ethanol production [12]. Proper sugar content can be obtained from molasses. It is then complemented with a nitrogen source that can be assimilated, such as ammonium sulphate or urea. If necessary, it is further augmented with phosphate. Sulphuric acid is used to lower the pH of the fermentation broth to below 5. Fermentation is carried out with an active culture of *Saccharomyces cerevisiae*. In the fermented mash, ethanol can accumulate up to 8%–10% by volume. After the yeast sludge is discarded, the fermented mash is distilled, fractionated, and rectified. Spent wash [13] is the leftover portion of the fermented mash that emerges as a liquid effluent.

Spent wash disposal into the environment is hazardous as it has a high pollution load. High COD, total nitrogen, and total phosphate level of the effluent may lead to eutrophication of natural water bodies [14]. It also has adequate levels of micronutrients such iron, zinc, copper, manganese, boron, and molybdenum [15]. Colored components of the spent wash impede sunlight penetration in rivers, lakes, and lagoons, lowering photosynthetic activity and dissolved oxygen concentrations and harming aquatic life [16]. Disposing distillery spent wash on land is also detrimental to the environment. It impedes seed germination by diminishing soil alkalinity and manganese availability [14].

There are one of another technique to reduce COD concentration, as well as complex organic materials such as lignin, yeast cells, protein by utilizing this waste as raw material of biogas production. There is different technique involved in biogas generation like anaerobic lagooning, high-rate anaerobic reactor such as fixed film reactor, UASB reactor, fluidized bed reactor, batch reactor and aerobic system etc. [17] One of the methods of distillery spent wash utilization

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is anaerobic fermentation with the production of biogas which is an alternative source of energy after fossil fuel as the storage of fossil fuel is curtailed. Biogas produced from anaerobic digestion of wastes contains a large amount of methane, typically 50-65%, having a high calorific value. It can be used for the production of electricity, heat and power [18].

Conventional treatment processes of spent wash have a number of advantages, but consequently, more effective microorganisms that can decolorize effluent and can be used as the primary source of nutrients without considerable dilution are needed. Both color and COD can be removed using physicochemical treatment procedures. However, these systems have drawbacks such as excessive chemical consumption, sludge production with subsequent disposal issues, and high operational expenses [15].

1.1. Anaerobic Treatment Processes

A typical COD/BOD ratio of 1.8–1.9 indicates the suitability of the effluent for biological treatment [19]. Anaerobic treatment of distillery effluent is an accepted practice and various high-rate reactor designs have been tried at pilot and full-scale operations [20].

Anaerobic digestion is considered as a complex ecosystem in which methane and carbon dioxide are generated by physiological activities of a distinct groups of microorganisms. It has a strong degradation capacity for concentrated and refractory compounds. It generates very less sludge, uses less energy, and can be economic if considerable amount of biogas can be cogenerated [21]. These mechanisms, however, have been found to be susceptible to organic shock loadings, low pH, and anaerobic microbe growth rates, resulting in extended hydraulic retention durations (HRT).

Single-phase and bi-phase anaerobic systems are both viable. A biphasic system can optimize fermentation procedures of each stage in its own fermenter. As a result, the total process efficiency and kinetics are better than those of single-stage processes.

The treatment of distillery effluent in CSTR has also been reported in single and biphasic operations, with COD reductions up to 80–90% in 10–15 days [22]. To achieve an acceptable amount of deterioration, very high HRT values are required. Because of high HRT values, the CSTR approach for wastewater treatment is less feasible.[23]

In fixed film reactors, the biomass attachment is reinforced by a biofilm support structure (media).

The advantages of a fixed film reactor are ease of construction, absence of mechanical mixing, improved stability at increased loading rates, and the capacity to absorb toxic shock loads. After a period of deprivation, the reactors can swiftly recover [24].

In recent years, numerous categories of wastewater have been effectively treated using the Upflow Anaerobic Sludge Blanket (UASB) technique [25]. UASB reactor systems fall under the category of high-rate anaerobic wastewater treatment, making them one of the most widely used reactor designs for distillery wastewater treatment worldwide. The development of active and settleable granules is critical to the effectiveness of UASB [26]. The granules are made up of self-immobilized anaerobic bacteria into compact forms. This improves biomass settleability and results in effective bacteria retention in the reactor [27]. The UASB reactor design has several appealing qualities, including its independence from mechanical mixing of digester contents, the recycling of sludge biomass [28] and ability to cope up with perturbances caused by high loading rates and temperature fluctuations [29]. The UASB technology is well suited for high strength distillery wastewater only when the process has been successfully started and is in stable operation.

In the anaerobic fluidized bed reactor (AFB), the drag forces imposed by the up flowing wastewater keep the medium for bacterial adhesion and growth fluid. Sand with tiny particles, activated carbon, and other media are employed. Each medium provides a significant surface area for biofilm formation and growth whenever it is fluidized. It allows for a high reactor biomass holdup, also improving system efficiency and stability. Fluidized bed technology is an excellent anaerobic method for treating high-strength waste fluids because it promotes the transfer of microbial cells from the bulk to the surface, increasing the interaction between microorganisms and the substrate [30].

Batch reactor treatment for distillery wastewater has not been widely used. The reactor's potential, operating feasibility, and scale-up need to be investigated. In this study, an anaerobic sequencing batch reactor (ASBR) was used to explore the treatment of winery wastewater [31].

Despite numerous additional research on other approaches, as discussed above, the study with batch anaerobic process is insufficient to make any further decisions about its use in commercial or large-scale applications. Hence, this technology was selected for research in order to explore probable options in the renewable energy sector.

2. Materials and Methods

2.1 pH adjustment and Reactor setup

As the pH of spent wash was 4.38 which was too low to grow microorganisms involved in anaerobic fermentation, 2M NaOH was used to adjust the pH in 6.7.

For batch reaction process, 4L pH adjusted spent wash and 100gm cow dung as inoculum were added in a 5L bottle. After that, an agitator at 400-500 rpm speed was set-up and the bottle was made airtight to inhibit air insertion.

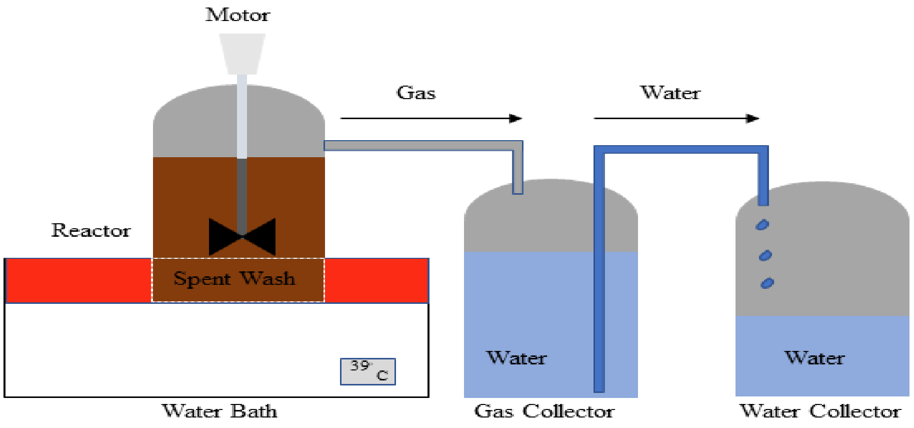

Figure 1: Experimental setup.

2.2 Gas and water collector setup

There were two hose pipes, one for gas collection from reactor to gas collector and another one for displaced water collection from gas collector to water collector. The pipe between two collectors was adjusted in such a way that both sides of this pipe was dipped in water, hence air could not enter into the reactor by back flow. Then the reactor was taken into a water bath to maintain a temperature of 39 degree centigrade as shown in figure 1.

2.3 Energy estimation for produced biogas

After producing biogas, the focus of this study was to estimate the total energy and power generation from the treated waste.

Total biogas produced and total power recovery can be calculated by following equations.

- Total methane content (mole)= Total biogas production (mole)×methane percentage /100
- Power generation from produced methane (KW h/L spent wash) = heat content (KW h /mole CH_4) × total produced methane (mole) / spent wash volume (L)

3. Results and Discussion

The produced gas was collected every day from gas collector after day 1 from run . Overall production of gas per liter of spent wash was 1.28L. Figure 2, shows that during the first two days, the production was not enough but after three days it showed a peak production which was 58.1% more at day 3 than day 2 and increasing trend was continued till day 4.

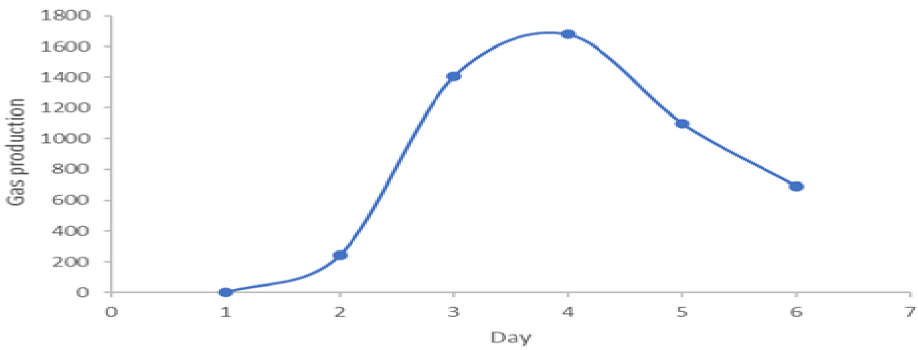

Figure 2: Gas production from batch process of anaerobic Fermentation.

Number and growth rate of microorganism growth are crucial factors to increase gas production. During the first two days there was not enough microorganism to produce maximum amount of gas but with passage of time the growth and number of microorganisms were increased to its optimum position to produce maximum amount of gas on day 4. But after peak result, it showed a downfall of gas production, 53% decrease at day 5 compared to day 4 as the death rate of the microorganisms was more than growth rate.

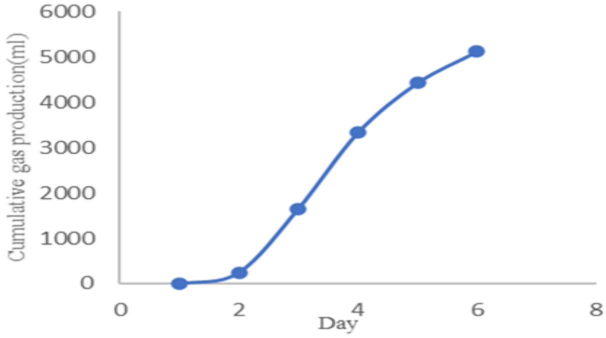

Figure 3: Cumulative gas production

Figure 3 represents the total gas produced in cumulative way, which was 5.1L after 6 days of production. The gas composition analysis was conducted by by Gas Chromatograph (GC) (Model 2014, Shimadzu, Japan). In GC analysis, following conditions were used for the methane, nitrogen, and carbon dioxide content measurement: column temperature – 60^0 C, pressure – 375 kPa, and gas flow rate – 55 ml/min). The result found from this analysis is shown Table 1. This experiment was conducted in anaerobic batch process and [32] process was ran by up flow anaerobic sludge blanket (UASB) method. For this reason the composition may vary in CH_4 and CO_2 contents from the reference values.

Table 1: Comparison analysis of biogas composition

Gas Components	**Study values (%)**	**Reference values [32] (%)**
CH_4	53	57
CO_2	30	23
N_2	15	15.6
Others	2	4.4

3.1. Methane production and energy estimation

For conversion of biogas units from L to K mole, ideal gas law was used which states that pressure times volume is equal to mole times gas constant times temperature in Kelvin unit.

- Total biogas production (mole NTP)

  = 5.1L * (1 atm) / (0.0821 L atm K^-1 mole^-1 * 298K)

  = 0.2085 mole NTP.

- Total methane content (mole)

  = 0.2085 mole biogas * 53 % CH_4 / 100

  = 0.11 mole CH_4

  To calculate heat production capacity of produced bio-methane from biogas, it was required to know the heat of combustion of per mole methane which is 889.2 kJ/mole and thus 0.247 KW h/ mole [33].

- Power generation from produced methane (W h/ L spent wash)

  = 0.11 mole CH_4 * 0.247 KW h/ mole / 4L spent wash

  = 7.535 W h/ L spent wash.

From Table 2 it can be seen that the COD as well as nitrogen [35] is much higher, which mean s higher C/N ratio, as substrate to produce sufficient amount of microorganism as well as biogas found from experiment. The data obtained here might be analoguous to sugarcane distillery plant.
As Carew and Co. Ltd. produce 160,000L/day spent wash, it is a huge opportunity to produce large volume of biogas which can meet one of the largest portions of gas necessity in Bangladesh.

Table 2: Characteristics of untreated and anaerobically treated distillery effluent [34]

Parameters (mg L−1)	**Values for distillery effluent**
pH	3.0–4.5
BOD5	50,000–60,000
COD	110,000–190,000
Total solid (TS)	110,000–190,000
Total volatile solid (TVS)	80,000–120,000
Total suspended solid (TSS)	13,000–15,000
Total dissolved solids (TDS)	90,000–150,000
Sulphate	7500–9000
Phosphate	2500–2700

4. Conclusion

As the energy problem is rising day by day globally and in Bangladesh, the need for alternate renewable energy source is growing day by day to fulfil the current demands. Furthermore, environmental problems are also increasing day by day and it is on its way to become one of the major threats to our flora and fauna, and hence it is urgent to reduce wastes to save the world. Reusing the waste and converting it into value-added products is a great way to reduce wastes. This study focuses on treatment of spent wash from Carew and Co. Ltd. and it was found that 53% CH_4 and 30% CO_2 was obtained after anaerobic treatment of spent wash and power equivalent to 7.535 W h was obtained from per Litre spent wash. From this experiment, it can be understood that biogas generation from distillery spent wash is a source for energy recovery as well as environmental conservation. This can save water bodies from pollution and can contribute to national energy grid to cover up a portion of our energy scarcity.

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