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Dynamic Simulation and Modelling of Methane Production Process for Habesha Beer Waste Water Treatment Process Using Aspen Plus Software

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Abstract: Brewery production process is one of the biggest economical sources in Ethiopia, there are different brands in beer industry in the country, such as Dashen, Balageru, Heineken, and Habesha Brewery Company, in such factories the modern technology treatment was performed in Habesha brewery. All beer industrial processes require large amounts of water and produce significant amounts of wastewater. Cleaner production is having an impact on these industries and today they are looking forward to zero discharge. In Habesha brewery, the generation of wastewater is coming under all departments, such as from brew house, filtration utility, and packaging rooms. The composition of brewery waste water effluent was sulphate, H_2S, CO_2, sugar, and methane, etc. Habesha Brewery has given value highly the quality, taste, and drinkability of their beer. Production of methane from waste water during the treatment process was not applied in Habesha brewery industry due to the low treatment of methane and lack of technology to recover methane as an energy source. Through anaerobic digestion of organic waste materials provides an alternative environmentally friendly renewable energy. Methane production from digestion of brewery wastewater was improved using chemical methods, using aspen plus dynamics simulation the model of methane production recovery system was modelled, and brewery waste was taken into the reactor in its own behavior was evaluated under atmospheric conditions, 25°C, 30°C & at 1 atmosphere. For all substrates, total solids, biological oxygen demand, chemical oxygen demand, temperature, total nitrogen, total phosphorus, and pH were measured before and after digestion. Wastewater by volume was taken fully into the digester. All measured physico-chemical parameters of the sample substrate significantly varied before and after anaerobic digestion. Methane was measured for all samples periodically starting from the effluent was started. In all substrates. Assessment of cumulative methane production revealed that the substrate at a temperature 30°C, pH 6.5 (0.0013 hl /0.008 hL sample of waste water) and after 4 days sample 25°C, PH 7.5 (0.001625 hL/0.008 hL sample) showed the highest Methane production and the lowest was in the last day volume waste water, 35°C temperature and pH of 6 (0.00125 hL/0.008 hL sample of waste water). The results indicated that the methane amount was affected by H_2S, CO_2, sugar, and other behaviors of brewery waste water effluent during the digestion process.

Keywords: Temperature Behaviors, Dynamic Simulation, Waste Water, Methane, Hydrogen Sulfide

1. Introduction

Beer requires these ingredients for brewing: properly prepared cereal grain (usually barley), hops, pure water, and brewer's yeast. Each ingredient can affect flavor, color, carbonation, alcohol content, and other subtle changes in the beer. Grains are carefully stored and handled to promote the highest quality. [7]

Hops are a form of cultivated perennial hemp, and the useful portions of the vine, the sticky cones, are developed from the blooms, which are used as flavorings, aroma, and preservative agent (antioxidants). The four main raw materials of beer are malt, yeast, water and hops. The malts are milled in every brewery process with sparging water at 30°C. After milling of the malt changed into grist [10]. This grist was in a mash tun cooked for the change from simple sugar for the preparation of wort. After the production of wort in this stage with different enzymes such as beta-amylase and alpha-amylase was denatured at a temperature of 78 degrees centigrade in the Lauter tun, the separation of spent grin from wort was applied with its own different constraints [6]. The wort boiling process was processed with the temperature of wort kettle around 96 degree centigrade in Habesha brewery Share Company due to highland area problem. In after all the process taken, there was filtration of beer from different wastes such as haziness, surplus yeast [1]. The packaging department was also ready for filling of each bottle with its own cleaning procedures. After all processed engaged, there was a complete cleaning process for each equipment with chemicals, caustic soda, hot water, and fresh water. After all cleaning process, the waste water was sent to the equalization tank and flowed into the sedimentation process [13]. Waste water treatment refers to the process of removing pollutants from water previously employed for industrial, agricultural, or municipal uses. The techniques used to remove the pollutants present in wastewater can be broken in to biological, physical, chemical, and energetic. Techniques to make the sewage harmless before it is disposed. Anaerobic degradation of organic matter is a complex process carried out by multiple microbial populations interacting in a food web; referred as bio-methanisation, it is a natural process that occurs in the absence of air. [3]. It involves the biochemical decomposition of complex organic materials by various biochemical processes with the release of energy-rich biogas and production of nitrous effluents. Biogas is produced when bacteria degrade biological materials in the absence of oxygen, during anaerobic digestion [8].

1) Waste water from the plant is collected in the collection pit (tank).
2) The solid parts of the waste were separated by a rough screen.
3) Some additives like sodium chloride and hydrochloric acid are added to waste water to neutralize the PH in the equalization tank, until the PH of waste water are in set point 6- 8.
4) Small solids that pass from a rough screen were separated by the fine screen separator.
5) Methane gas is formed in USAB (unflow, anaerobic, sludge and blanket), in this case the process is anaerobic and chemical degradation is performed when the methane was not collected after the production of methane simply thrown into atmosphere.
6) Sludge and water were mixed in the buffer tank for the treatment process. [1].

2. Material and Methods

2.1. Physical Waste Water Treatment Methods

Among the first treatment methods used are physical unit operations, in which physical forces are applied to remove contaminants. Physical methods remove coarse solid matter, rather than dissolved pollutants. It must be done in a passive process, such as sedimentation to allow suspended pollutants to settle out or float to the top naturally. In general, these methods have yielded little success; most often resulting in incomplete contaminant removal and/or separation. Sedimentation has been found to be unsatisfactory even with the addition of coagulants and other additives.

2.2. Chemical Waste Water Treatment Methods

Different chemicals must be added to the brewery wastewater to alter the water chemistry. Chemical pretreatment was involved with pH adjustment or coagulation and flocculation. The acidity or alkalinity of wastewater affects both wastewater treatment and the environment. Low pH indicates increasing acidity while a high pH indicates increasing alkalinity [4]. The pH of wastewater needs to remain between 6 and 9 to protect organisms. Waste CO_2 must be used to neutralize caustic effluents from clean-in-place (CIP) systems and bottle washers. The waste CO_2 could also were used as a cheap acidifying agent because during fermentation this gas was produced and recycled for decreasing the pH of alkaline wastewaters before the anaerobic reactor, thus replacing the conventionally used acids [18]. Neutralization with H_2SO_4 and HCl acids was usually not recommended because of their corrosive nature and sulfate and chloride discharge limitations, which added to the cost of effluent treatment operations [11]. Coagulation and flocculation are physicochemical processes commonly used for the removal of colloidal materials or color from water and wastewater. In water and wastewater treatment, coagulation implies the step where particles are destabilized by a coagulant, and that includes the formation of small aggregates by Brownian motion (per kinetic coagulation). On the other hand, the subsequent process in which larger aggregates (flocks) are formed by the action of shear is then known as flocculation. After small particles have formed larger aggregates, the colloidal material could be then be easily removed by physical separation processes such as sedimentation, flotation, and filtration [16].

2.3. Anaerobic Treatment Methods

The applicability of anaerobic treatment for municipal sewage (mixed sludge and wastewater) depends strongly on the temperature of the sewage. The activity of mesophilic anaerobic bacteria is at its optimum at 35°C. At lower temperatures, bacterial activity decreases, which results in lower treatment performance. According to the present technology development, combined anaerobic sewage treatment is feasible without heating at sewage temperatures above 15°C. Speaking of this type of technology, in addition to appropriate sewage temperatures, a further precondition for effective anaerobic treatment are the organic loading and nutrient content of the wastewater [19]. A comparison of investment and operation costs of different treatment systems shows that, given the high availability of land and thus low land costs, and not considering small environmental and climatic effects, pond systems at first appear to be a more economical solution. The simplest anaerobic systems were lagoons and CSTR reactors. [12]. as these reactors have no special sludge retention system, the sludge retention time is equal to the hydraulic retention time. As a result, the suspended biomass concentration is very dilute and consequently the biological treatment capacity is limited. These systems are mainly applied as sludge digesters and hardly suitable for treating waste water: The anaerobic contact process is a CSTR with an external separation unit to return a part of the sludge [15].

Anaerobic: COD+H_2O → CH_4+CO_2+anaerobic biomass.

Mixing is done by means of mechanical agitators or biogas blowers. Because of the flocculent and dilute nature of the anaerobic sludge, these systems operate at relatively low volumetric loading rates and are less suitable for low concentrated industrial effluents like brewery effluent. Anaerobic filters (AF) use carrier material for sludge retention on which the biomass is supposed to grow. As fixation to the carrier is often limited, suspended flocculent sludge still largely contributes to the capacity of such reactors [9].

2.4. Dynamic Simulation of Methane Production Process

In Habesha Brewery Company, the methane was not collected after treatment of waste water because of the not well installed model of the plant. The methane and other gas such as H_2S and CO_2 compounds were not collected directly after they smoked into the atmosphere by using fuel as heat source to breakdown such compounds into small compounds. The methane is produced in the anaerobic digestion system with the following plant model as shown in Figure 1. In the waste with this decomposition mechanism, the main output was H_2S, CO_2, and methane is produced, but the main aim was how to separate such compounds from methane. The modelling process is used to separate such components by using aspen plus v 10 software for the dynamic simulation process [5]. The following dynamic process was used for the purification of methane after the production process from beer waste water. Aspen Plus software was used for such modelling and dynamic simulation process for the entire plant installation. The distillation column was used for separation and purification of methane based on its own boiling and cooling point of each component [14].

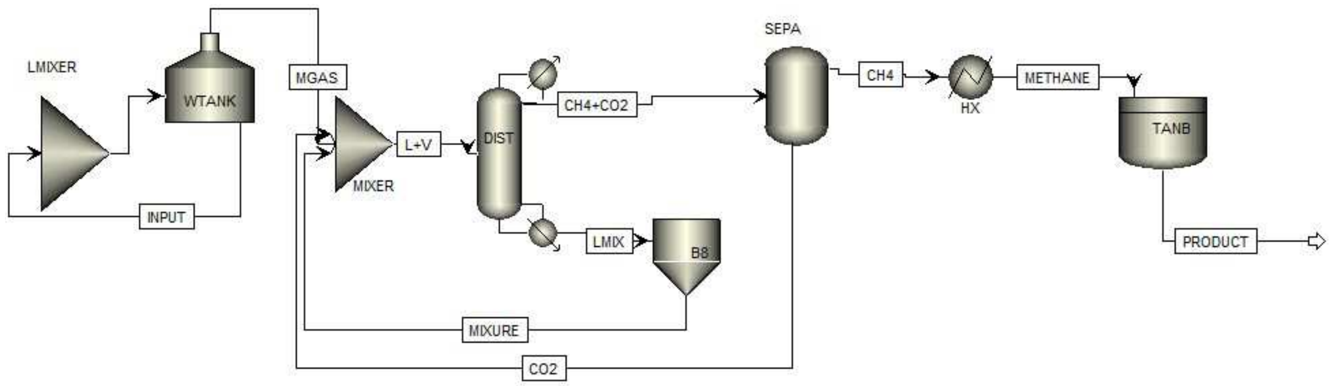

Figure 1. *Dynamic Simulation of Methane Production process with Aspen plus Software.*

2.5. Mathematical Model

The combination of the proportional, integral, and derivative control modes as a PID controller. Many variations of PID control are used in practice. Next, consider the three most common forms [13].

$$P(t) = P_o + kc\,[e(t) + 1/\tau I \sum_0^t e(t) * dt + \tau D * de(t)/dt] \quad (1)$$

$$P(s)/E(s) = Kc\,[1 + (1/\tau I.S) + \tau D.S] \quad (2)$$

From the above relation, the waste water was sent in one hr. The given settling time duration was used for the flow rate of 6-9 hl of waste into the treatment plant. On in one week the amount of treated waste water was 750 hl, and the final effluent from this was 500 hl sent to the farmer for irrigation. The remaining 250 was in the treatment tank for safety and due to careful measurement.

The formulation is shown below:

$$P(s)/E(s) = Kc\,[1 + (1/\tau I.S) + \tau D.S]$$

$$=250[1 + (1/60min.S) + 60min.S] \quad (3)$$

$$250hl * d(C)/dt = 6hl/hr. * Ci - 4hl/hr. * Co \quad (4)$$

3. Results and Discussion

3.1. Habesha Waste Water Treatment Process

In Habesha brewery, the effluent after treatment was sent to the farmer framing places for agricultural production such as tomatoes, onion, and cabbage. From Figure 2, as shown below, the result of the treatment process of Habesha brewery waste water is treated with chemical and physical methods such as sedimentation, filtration, and addition of some chemicals. After all treatment process were applied, the water became purified and sent us effluent for the irrigation process. PH of all effluents would be between 6 and 8 due to acidity and basicity. The other silicate and sulphate content were also measured for extra treatment. The following figure indicated that the treatment process was applied with atmospheric pressure and temperature. Weekly amount of treated water effluent was 750 hl was given to the farmer for irrigation.

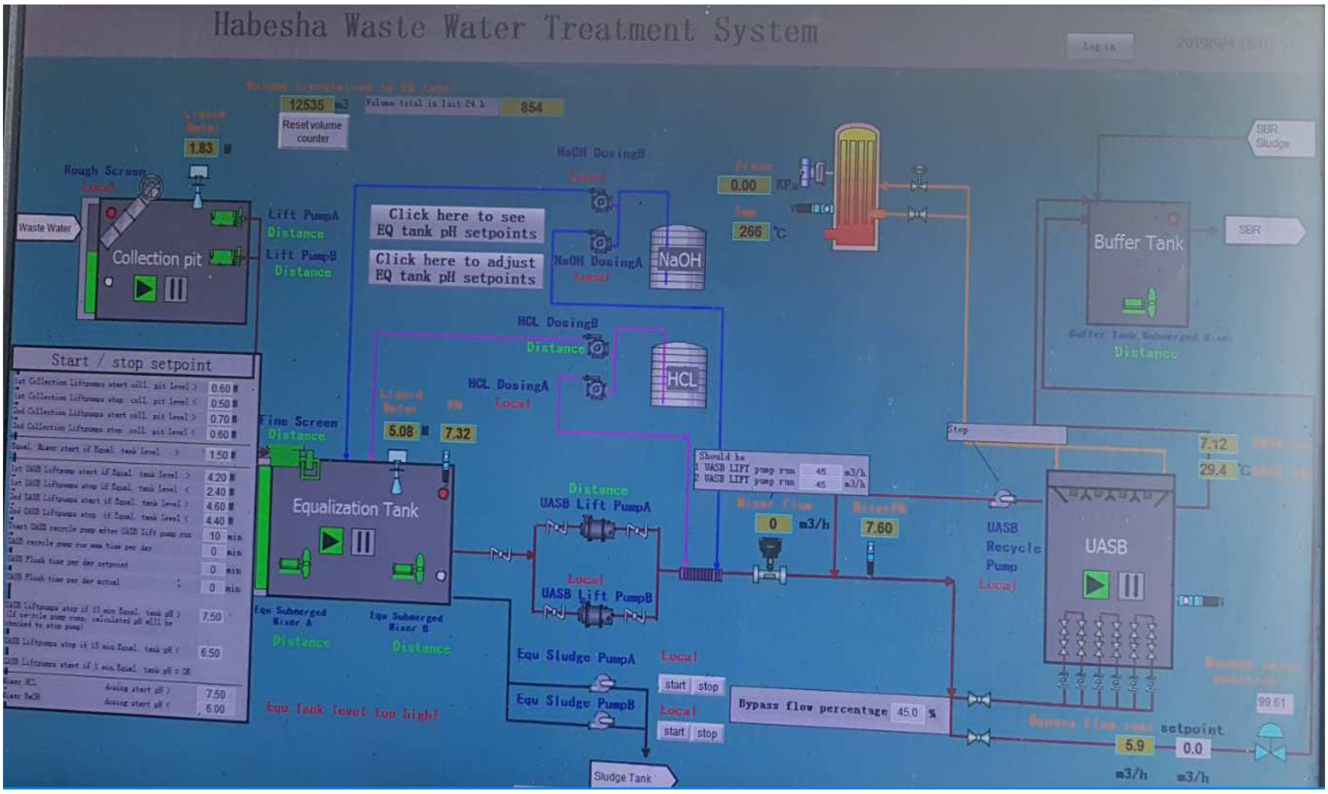

Figure 2. Waste water treatment process plant results of Habesha brewery.

3.2. Methane Production Process with Anaerobic Digestion

When activated sludge is kept in an aerobic environment, specialized bacteria were developed that used the excess sludge as a source of organic matter for fermented metabolic processes. The end products of the fermentation were mainly methane and carbon dioxide. The overall conversion process of complex organic matter into methane and carbon dioxide must be divided into four steps: hydrolysis, acidification, acetogenesis, and methanogensis. In an aerobic digester, the four processes occur simultaneously. When the anaerobic digester performs properly, the conversion of the intermediate products (i.e., the products of the first three steps) is virtually complete, so that the concentrations of these are low at any time. In the hydrolysis process, macro molecules like proteins, poly saccharides, and fats that compose the cellular mass of excess sludge are converted into molecules with a smaller molecular mass that are soluble in water: peptides, saccharides and fatty acids. The hydrolysis or solubilisation process is carried out by exo enzymes excreted by fermented bacteria. Hydrolysis is a relatively slow process and generally limits the rate of the overall anaerobic digestion process. [2]. From Table 1, acetogenesis, the products of acidification are converted into acetic acid, hydrogen, and carbon dioxide by acetogenic bacteria. The first three steps of anaerobic digestion are often grouped together as acid fermentation. It is important to note that in the acid fermentation, no organic material is removed from the liquid phase [7]. It is transformed into a form suitable as substrate for the subsequent process of methanogensis. By using methanogensis bacteria, acetic acid is changed to methane and carbon dioxide. [17].

3.3. *Anaerobic Digestion Decomposition Production Process*

Anaerobic digestion process is an acidogenesis or acidification, a process that results in the conversion of hydrolyzed products into simple molecules with a low molecular weight, like volatile fatty acids, acetic-, propionic and butyric acids, alcohols, aldehydes and gases like CO_2, H_2 and NH_3. There are always bacteria present that will scavenge the oxygen whenever it is available. The presence of these bacteria is important to remove all oxygen that might be introduced into the system, the acetogenic bacteria are able to metabolize organic materials down to a very low PH of around 4.

Table 1. *Experimental results of methane from the company.*

No	Method	Compounds					
		Fatty acids	Amino acids, sugars%	Propionate Butyrate%	Acetate%	Hydrogen%	Methane%
1	Anaerobic dig	39	21&40	20	35	19	70
2	Hydrolysis	34	5	--	23		--
3	Acidogenesis	34			11		--
4	Acetogenesis			--	23	11	--
5	methanogensis				70	30	30

3.4. Dynamic Simulation Modelling of Methane Production from Effluent

Among biological treatment systems, one can distinguish between anaerobic (without oxygen) and aerobic (with air/oxygen supply) processes. Anaerobic treatment is characterized by biological conversion of organic compounds (COD) into biogas (mainly methane 70-85 vol% and carbon dioxide 15-30 vol% with traces of hydrogen sulphate). Methane was produced from the experimental results taken from Habesha beer company 0.008 hl sample with temperatures of 25°C, 30°C, and 35°C and 1 atm. For four days. The result was 0.001625 hl, 0.0013 hl, 0.00125 hl, respectively. During aerobic treatment (air), oxygen is supplied to oxidize the COD into carbon dioxide and water. Both biological processes produce new biological biomass. The dynamic process was applied to the optimization process of methane from the effluent of treated water in Habesha Brewery Company. Simulation process modelling was applied by Aspen Plus software. In beer wastewater, the COD has its own components, such as sucrose, CO_2, H_2S, ethanol, water, sulphate, silicate, sulfate, and methane.

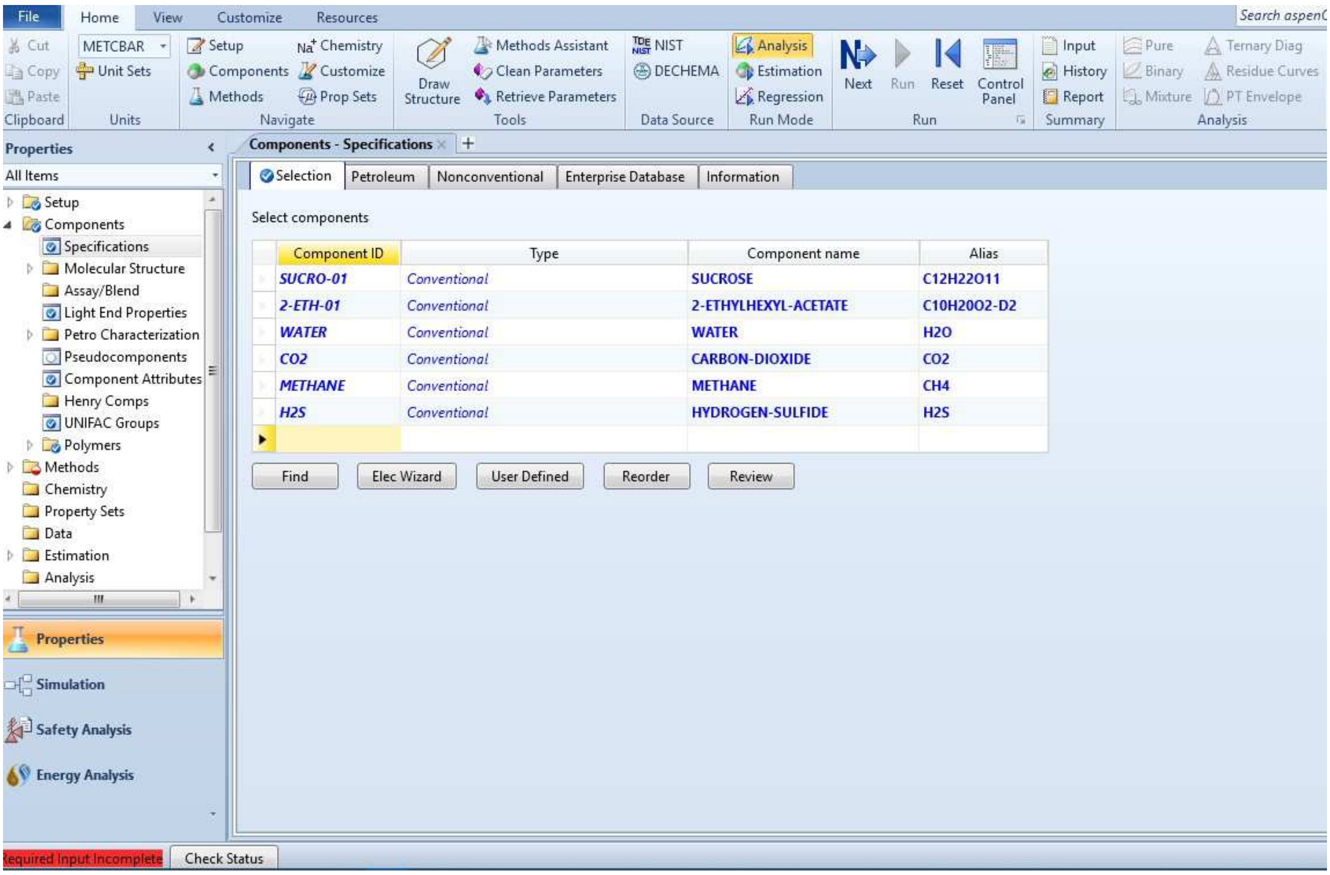

Figure 3. *Compound identification for simulation modeling process.*

From the above Figure 3, during the waste water treatment, the above component was identified for anaerobic digestion system in aspen plus software for modeling and simulation process for the production of methane process, due to the highly composition recovered in the waste water concentration and the mole amount was a highly significant impact on the simulation modelling process.

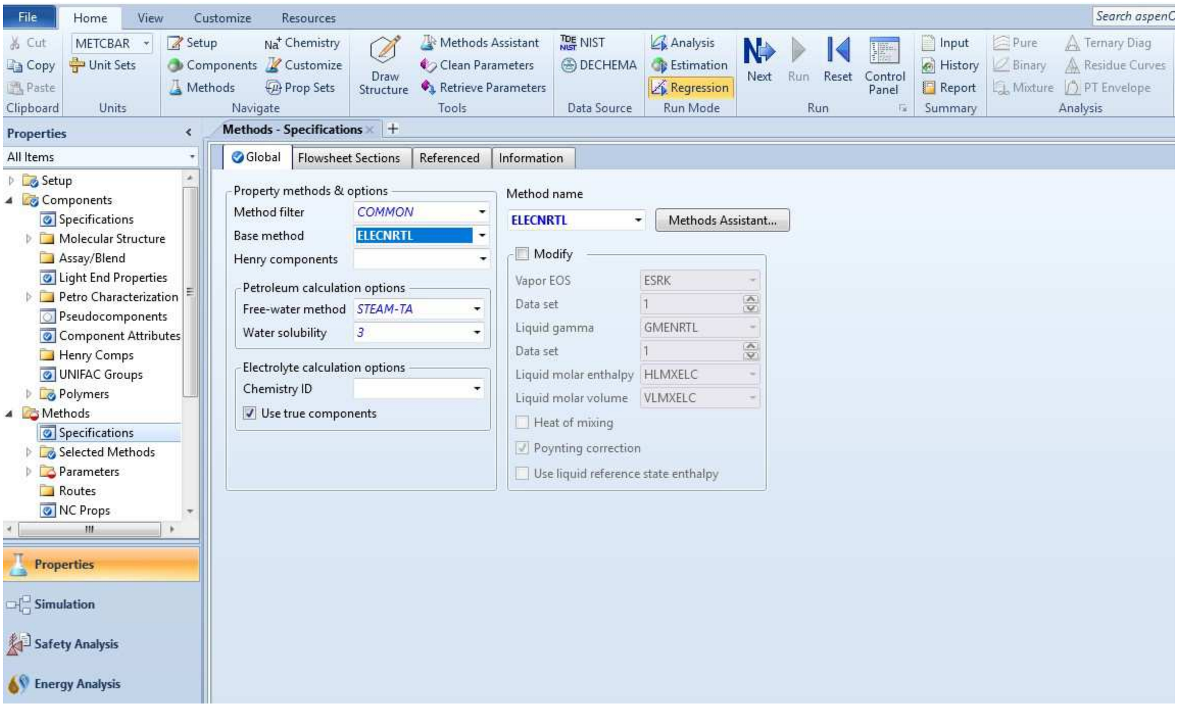

Figure 4. *Base method selection for simulation modelling & production process.*

From the above Figure 4, in aspen plus software v 10 ELECNRTL method was selected because the electrolysis process was applied for methane production to break down the bond. From Figure 5 as shown below, the electrolyte nonrandom two-liquid (ELECNRTL) was suited for the purification process of methane with anaerobic decomposition process.

Anaerobic: COD + H_2O → CH_4 + CO_2 + anaerobic biomass. CSTR reactor type is used for the methane generated from waste water in the treated effluent.

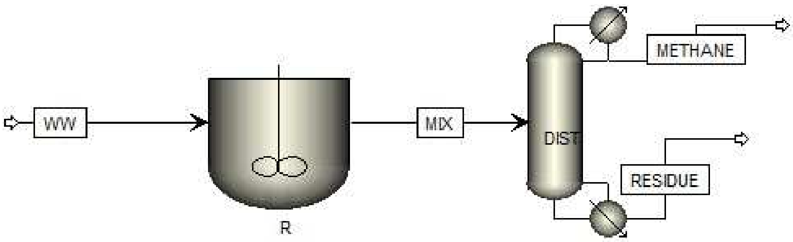

Figure 5. *Aspen plus model & simulation result of methane production process.*

3.5. Performance Evaluation of Controller Effect on the Simulation Process

The controller effect is one of the tools for measuring the quality of each constraint in the production process.

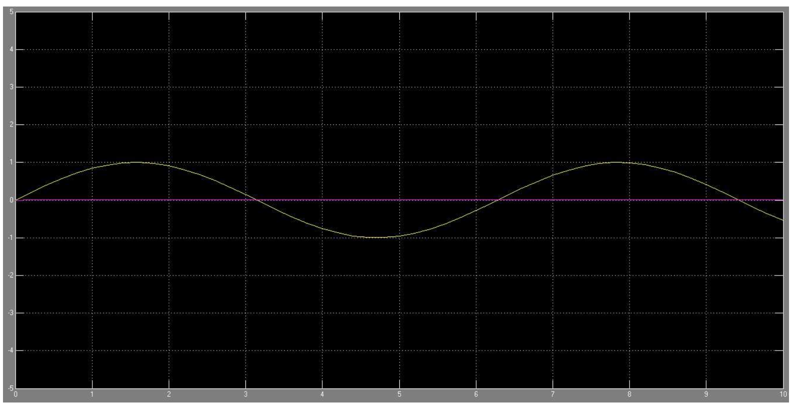

Figure 6. *Controller effect for evaluation of methane.*

From the above Figure 6, the result of methane production simulation was identified with the controller effect after the production starts in 10 min. The process would stable with the normal point of view, the effect indicated that after 10 min. The peak was reduced from the maximum range of fluctuation into +or – 9% error due to the input of sulfide and the silicate amount was highly impacted on the production process.

3.6. Residues of Waste Water Composition

After the digestion system, the residue graph was identified for each component of water sucrose, with its own mole fraction. At atmospheric pressure and temperature. From the above Figure 7, the mole fraction of sugar content and ethanol has a direct relation to waste water of water at 25°C.

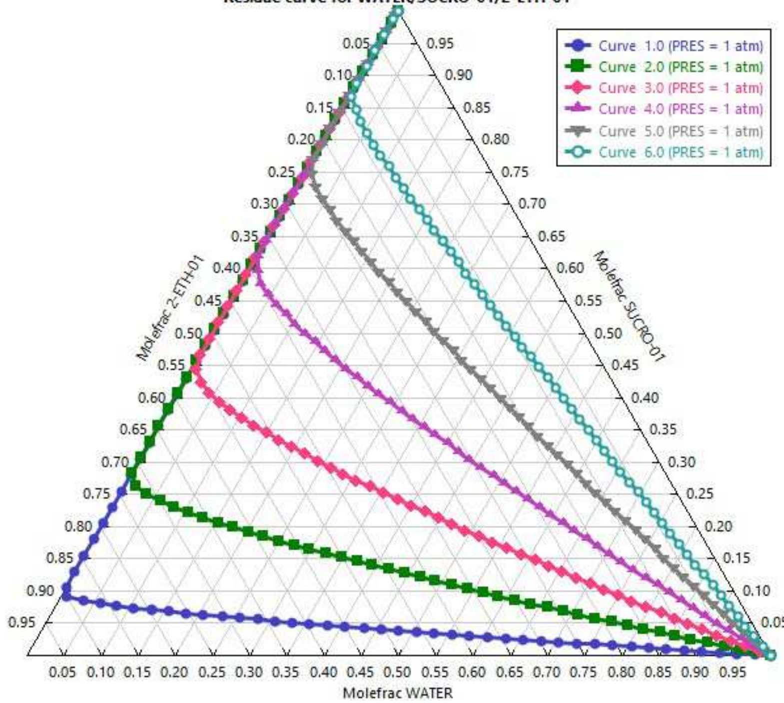

Figure 7. *Residue result relations in the waste water before treatment process at atmosphere pr.*

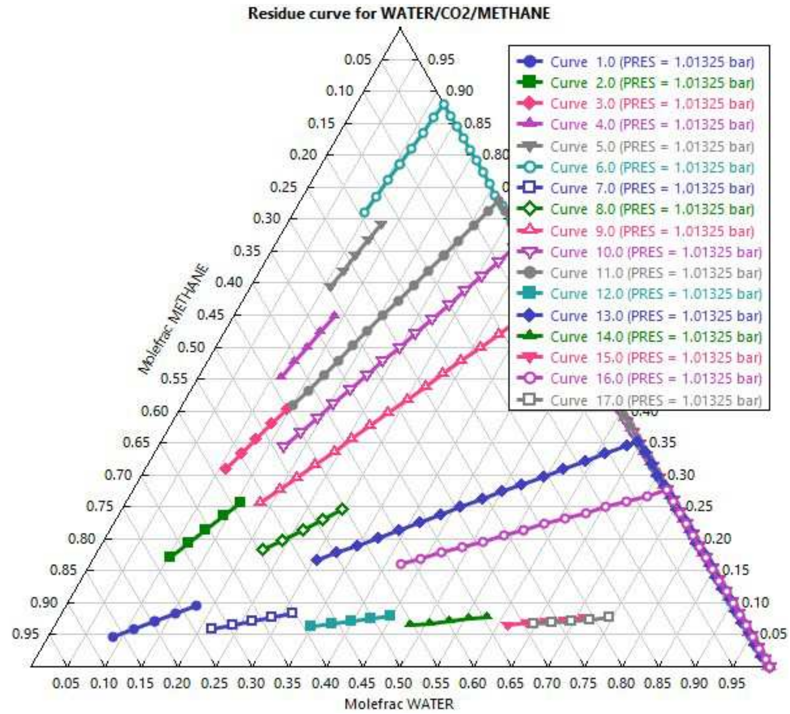

Figure 8. *Treated waste water composition experiment result.*

From the above Figure 8, the result composition was identified in the treated waste water, the result of methane was highly produced with small amount of carbon dioxide in the ration of treated water. The above figure indicated that the mole fraction of methane was highly increment with a small mole fraction of carbon dioxide, and this indicated that the purity of the methane is good. In the distillation, the separation process was measured with its own boiling point of methane and carbon dioxide in the heat exchanger, the glycol was opened below -2 degrees centigrade for the quality of methane and for the reduction of other gases. The methane amount is greater than 0.65 mole fraction in the ration of 0.85 mole fraction waste water with other gases included in atmospheric pressure.

3.7. Temperature Relation with Each of Waste Water Composition

In the waste water, the maximum amount of composition was sugar, ethanol, sulphate, nitrate, silicate, ammonia, hydrogen &sulfide, etc. The addition of bacteria in the waste water is advantageous for the breakdown of the bond of the above listed compounds without oxygen, and this process tends to for the production of methane and carbon dioxide gas and biomass. The following Figure 9, indicates that the result of waste water composition with increment of temperature. The amount of heat capacity needed for breakdown of the compounds.

The mole fraction of each component was identified on the graph of the result.

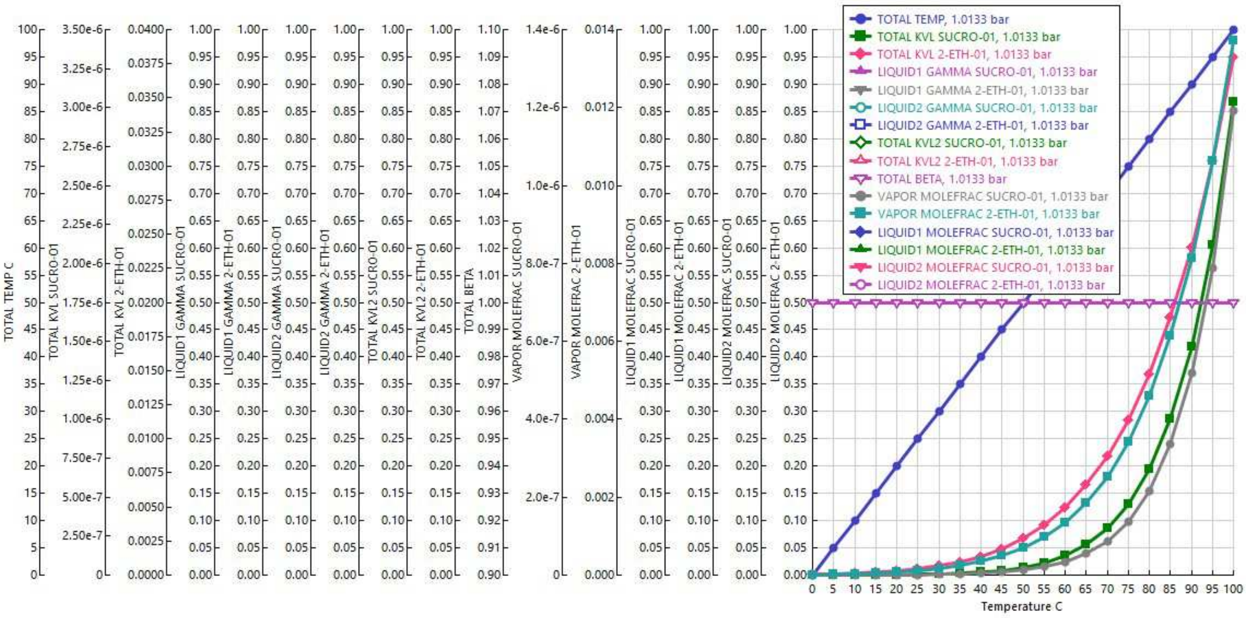

Figure 9. *The relationship of each component with temperature and heat capacity in treated waste water.*

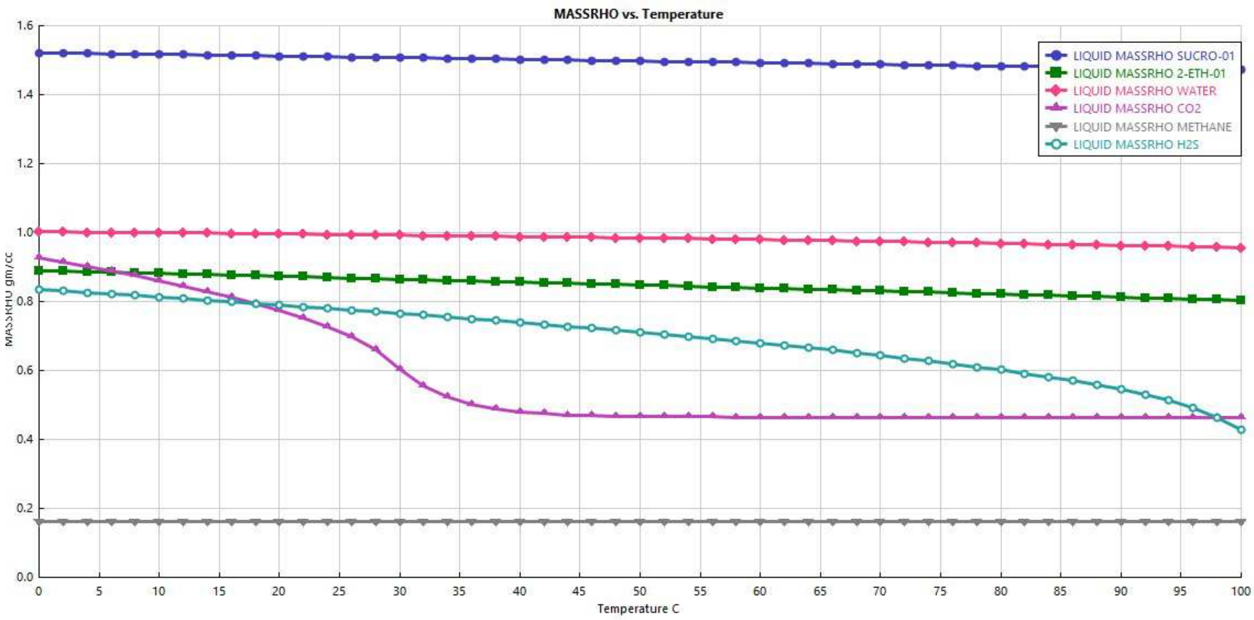

Figure 10. *Relationship of each compound with temperature and mass.*

From the above Figure 10, the result was identified for each compound with temperature difference at atmospheric pressure. The mass ratio of each compound to water was shown in the above figure. The liquid methane was decreased due to the increment of temperature with atmospheric conditions. The hydrogen sulfide maximum in small amount of temperature, decrement the point of hydrogen sulfide at 30°C, 0.75 with water ration. The liquid methane amount was around 0.17 with its own temperature increment.

4. Conclusion

During beer production, large quantities of waste water are generated from all brew plant equipment during the cleaning process. In waste water, there is a residue like surplus yeast is a residue containing high amounts of biodegradable organic matter, with a considerable potential for energy production through conversion to methane. The digestion of surplus yeast in existing anaerobic digesters for wastewater treatment would enable taking advantage of its energy potential with little investment. Co-digestion of yeast and brewery wastewater is feasible since no negative effects of joint digestion were observed during batch tests compared to the result of anaerobic digestion of Habesha brewery wastewater. The effluent improvements of methane yield with different methods within the optimum conditions in Habesha brewery. The result from the sample of 0.008 hl waste water was taken for investigation of three temperature zones 25, 30, 35°C at 1 atmospheric pressure. The result was 0.001625 hl, 0.0013 hl, 0.00125 hl, respectively. CSTR tank was used to enhance the anaerobic digestion of surplus yeast and waste water treatment process with the addition of bacteria for decomposition. Within 7 days period to send the effluent waste water treatment process, the PH was around 6-8, the effluent was around 750 hl. The other sulphate, silicate, nitrate, H_2S having no negative effects were observed when digesting the wastewater treatment process.

The dynamic simulation of methane production process with aspen plus software were to investigate the treatment of wastewater collected from the flow of brewery lines in the laboratory for modelling of methane production for energy source recycle in to boiler for steam production. The characteristics of the brewery wastewater used in this study confirm the findings from previous studies that have been conducted on brewery wastewater. The brewery wastewater used in this study indicated a wastewater quality that is high in organic constituents, which is highly biodegradable and one that were required to prior treatment before discharge into the environment to avoid pollution that may arise from methane and other chemicals.

The investigation has demonstrated that it is feasible to treat brewery wastewater using an anaerobic sequencing CSTR reactor without the need to enhance the activity of microorganisms in both sequencing reactions by providing supplementary inputs into the reactor. It was therefore concluded that the better performance was observed in the sequencing reactor.

Abbreviations

AF	anaerobic filter
CIP	cleaning in place
COD	chemical oxygen demand
CSTR	continuous stirred tank reactor
Distal	distillation column
DSTL	distillation
ELECNRTL	electrolyte nonrandom two liquids
Hl	hectoliter
HX	heat exchanger
L	liquid
Lmixture	liquid mixture
MGAS	methane gas
PID	proportional integral derivative
Sepa	separator unit
TankB	product collection tank B
USAB	unflow anaerobic sludge and blanket
V	vapor
Wtank	water tank
WW	waste water

Data Availability

The data used to support the findings of the study are included in the article.

Conflict of Interest

The authors declare that they have no competing interests.

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