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Performance Evaluation of Up-flow Anaerobic Sludge Blanket Reactor and Aerobic Digestor of Raj Brewery, Bhairahawa, Nepal

by

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The undersigned certify that they have read, and recommended to the Institute of Engineering for acceptance, a thesis entitled " Performance Evaluation of Up-flow Anaerobic Sludge Blanket Reactor and Aerobic Digester of Raj Brewery, Bhairahawa, Nepal" submitted by Amish Joshi in partial fulfillment of the requirements for the degree of Master of Science in Technology and Innovation Management .

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ABSTRACT

Large amount of wastewater is produced from brewery plants which must be treated before discharging into the environment. This research aims to study the chemical oxygen demand removal efficiency of the UASB technology and the aerobic digestor and estimate the biomethane potential that could be generated from the brewery wastewater by using UASB reactor. During the study, it was found that an average of 11 Nm^3 of methane was generated daily by the UASB plant at 48 hours hydraulic retention time and at volumetric loading rate of 84 m^3. The methane yield was found to be around 0.14-0.16 m^3/kg COD removed. The COD value at the influent ranged from 165 to 3950 mg/l and the COD value at the effluent ranged from 121 to 2230 mg/l after digestion in the UASB reactor. During the observation period, the overall efficiency of the UASB reactor in terms of COD removal was found to be 52.5 %. The efficiency of the UASB reactor in terms of COD removal fluctuated from 4% to 83.64 %. The concentration of VFA was found to be 86 to 1457 mg/l. The alkalinity was found to be 400 to 1540 mg/l. The VFA to alkalinity ratio was found to range from 0.14 to 2.46. The VFA/ alkalinity ratio was found comparatively higher during observation period, which hindered the operation of plant at optimal level. The COD removal efficiency of the aerobic treatment plant ranged from 22 % to 95 % during the observation period and the average efficiency was found to be 78.5%. The average pH, BOD, COD and TSS value of treated wastewater from the effluent treatment plant were found to be 7.82, 37.94 mg/l, 100.93 mg/l and 21.33 mg/l respectively and within the disposal guidelines set by Government of Nepal. Financial Evaluation of the UASB Reactor was also conducted and the investment was found profitable provided that the plant is operated at its full capacity i.e. 350 m^3 per day.

Hence, UASB technology appears to be cost effective, environmentally friendly and promising technology for treating brewery wastewater, which produces large amount of wastewater and contains high organic materials.

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LIST OF ACRONYMS AND ABBREVIATIONS

AD	Anaerobic Digestion
BMP	Bio Methane Potential
BOD	Biochemical Oxygen Demand
CH_4	Methane
CIP	Cleaning in Place
COD	Chemical Oxygen Demand
ETP	Effluent Treatment Plant
FB	Free Board
GHG	Green House Gas
GLSS	Gas Liquid Solid Separator
hl	Hectoliters
HRT	Hydraulic Retention Time
IPCC	Inter-governmental Panel on Climate Change
IRR	Internal Rate of Return
LPG	Liquified Petroleum Gas
NPV	Net Present Value
OLR	Organic Loading Rate
TS	Total Solid
TSS	Total Suspended Solid
UASB	Up flow Sludge Blanket Reactor
VFA	Volatile Fatty Acid
VSS	Volatile Suspended Solid

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CHAPTER ONE: INTRODUCTION

1.1. **Background**

Brewery effluent is the liquid waste stream generated from brewery. The production of beer involves the blending of the extracts of malt, hops and sugar with water, followed by its subsequent fermentation with yeast. (Wainwright, 1998) From the brew house, bits of grain and hops are most obvious, but the waste stream also includes the dilute wort that is too weak in sugars to use in brewing. From the fermentation come yeast and beer washings from tank cleaning. All stages in brewing use cleaners, most commonly caustic soda (sodium hydroxide), acids such as phosphoric and nitric, and detergents and sanitizers, often containing chlorinated chemicals.

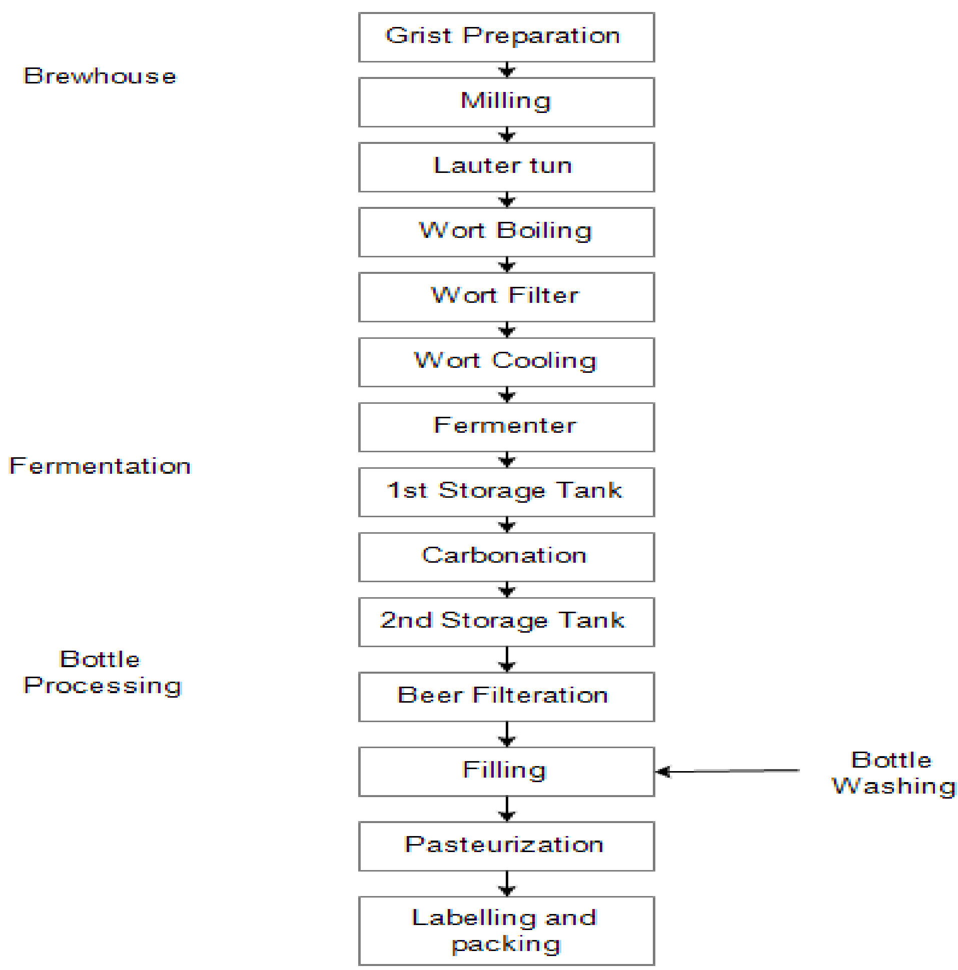

Figure 1. 1 Flow Diagram of a Typical Brewery Industry (Inyang,*et. al.*, 2012)

Production of beer includes blending and fermentation of maize, malt and sorghum grits using yeast, which requires large volumes of water as the primary raw material.

Traditionally, the amount of water needed to brew beer is several times the volume actually brewed. In brewing, the average water consumption of around 5 to 6 hectoliters per hectoliters beer is correlated to beer production for industrial breweries.(Perry and De Villiers, 2003). Large volumes of water are used by the industry for production of beer for two distinct purposes; as the main ingredient of the beer itself and as part of the brewing process for steam raising, cooling, and washing of floors, packaging, cleaning of the brew house during and after the end of each batch operation. (Inyang,*et. al.*, 2012)

Table 1. 1 Water Consumption Reported for the German Brewing Industry

Process step	**Water consumption (liters per liters of beer produced)**
Unfermented wort to whirlpool	2.0 (1.8– 2.2)
Wort cooling	0.0 (0.0– 2.4)
Fermentation cellar and yeast treatment	0.6 (0.5– 0.8)
Filter and pressure tank room	0.3 (0.1– 0.5)
Storage cellar	0.5 (0.3– 0.6)
Bottling (70% of beer produced)	1.1 (0.9– 2.1)
Barrel filling (30% of beer produced)	0.1 (0.1– 0.2)
Wastewater from cleaning of vehicles, sanitary use etc.	1.5 (1.0– 3.0)
Steam boiler	0.2 (0.1– 0.3)
Air compressor	0.3 (0.1– 0.5)
Total	**6.6 (4.9–12.6)**

(Source: Pollution Prevention and Abatement Handbook, 1998)

This brewery effluent stream is made up of the combined discharges of the brewing and packing sections, whose production rates vary independently of one another. The packing process produces a high flow, high pH, weak waste primarily composed of spilled beer and caustic bottle cleaning solutions, while the brewing process produces a low flow, neutral pH, and high strength alcohol-carbohydrate-protein waste. In general, the pH of the effluent is a function of production activities and may range from pH 7 – 12. However, within a few hours (7 – 16 hours) hydrolysis and anaerobic activity usually reduces the pH to about 4 to 8 since the effluent has a poor buffering capacity (Cronin and Lo, 1998).

The wastewater from brewery has high organic content i.e. BOD, COD, TSS etc, which has to be treated to bring down the levels of COD and BOD to be discharged into the environment. Biochemical Oxygen Demand (BOD) is the amount of oxygen that the bacteria take from the water when they digest the organic matter. Chemical Oxygen Demand (COD) is the amount of oxygen required for oxidation of organic and inorganic matter in the water sample. Total Suspended Solids are the residues that include both dissolved and suspended solids in a water sample.

A large number of technologies have been developed to achieve pollutant removal from wastewater. Both aerobic and anaerobic wastewater treatment systems are currently in use. They can be seen as complementary to each other, since in some situations anaerobic systems cannot fulfill the requirements of effluent quality.

The cheaper and the common treatment system used for treatment of spent wash is open lagoon, including anaerobic lagoon, facultative lagoon and aerobic lagoon. Although this system is sufficient to meet the disposal standards required by the environmental authorities, this method of treatment releases significant amount of greenhouse gases (GHG) into the atmosphere (Liu *et al.*, 2005). The organics in the wastewater undergoes anaerobic degradation in the open anaerobic lagoons and liberate biogas consisting mainly of methane (CH_4) and carbon dioxide (CO_2), which is released into the atmosphere. In fact, when methane is allowed to escape to the atmosphere, it has a global warming potential that IPCC estimates to be 21 times greater than that of the same volume of carbon dioxide (Brechet and Lussis, 2006). Another treatment system used for spent wash is anaerobic digestion. In terms of carbon footprint, anaerobic wastewater treatment is more advantageous, based on the relative efficiency of the aerobic system (Daud *et al.*, 2018). In case of effluent having low strength (BOD less than 300mg/L), aerobic process is favorable, as it generates less greenhouse gas. But, in case of wastewater having higher strength (BOD more than 300mg/L) anaerobic treatment is more beneficial (Cakir and Stenstrom, 2005). Anaerobic digestion is an attractive treatment strategy as it generates biogas, which can be used for process energy requirement in brewery industry, reduces the levels of BOD and COD in effluent for it to be discharged into the atmosphere and removes odour. In addition, energy recovery is essential for reducing the cost of manufacturing and the long-term sustainability of the brewing plant.

1.2. **Problem Statement**

Brewery plant produces a large amount of wastewaters that contains high concentrations of organic pollutants, low concentrations of nutrients and have large variations in these parameters (Huang and Hung, 1986). In particular, brewery effluent is generally characterized by high COD, BOD and TSS concentrations and wide variations in flow and strength (Le Clair, 1984). Therefore, brewery wastewater tends to be very difficult to treat due to wide variations in strength in terms of COD, pH and flow. If the brewery effluents are not properly treated or untreated, they can cause water pollution and spread foul odor around the plant. The wastewater from brewery has to be treated to bring down the levels of COD and BOD and to remove odour before being discharged into the environment. Various anaerobic treatment technologies can be applied to remove organic pollutants, odour and generate biogas which may be burned as additional energy resource.

Among the various anaerobic wastewater treatment technologies, up-flow anaerobic sludge blanket (UASB) reactors have achieved considerable success and these reactors have been applied to treat a wide range of effluents (Metcalf, 2003). The UASB process was developed by Lettinga and coworkers in the late 1970s (Metcalf, 2003). It is primarily used for the treatment of highly concentrated industrial wastewaters (Singh *et al.*, 2013); however, it can also be used for the treatment of low strength wastewater. As compared to aerobic technologies, anaerobic treatment systems such as UASB are being encouraged because of several advantages, including plain design, uncomplicated construction and maintenance, small land requirement, low construction and operating cost, low excess sludge production, robustness in terms of COD removal efficiency, ability to cope with fluctuations in temperature, pH and influent concentration, quick biomass recovery after shutdown, and energy generation in the form of biogas or hydrogen (Van Haandel *et al.*, 1994). Adoption of anaerobic wastewater treatment technologies like UASB reactor, which generates biogas from wastewater and removes organic pollutants and odour, is essential for the continued competitiveness of the brewery industries through generation of biogas.

There is no base line information which shows the performance of the brewery wastewater treatment plant both in biogas production and pollutant removal in Nepal. Hence, this study aims to evaluate the performance of Raj Brewery's UASB reactor in both removal of pollutants and methane production.

1.3. **Objectives**

1.3.1. Main Objective

To evaluate the performance of the UASB Reactor and the Aerobic Digestor in terms of pollutant removal from brewery wastewater at Raj Brewery Bhairahawa, Nepal

1.3.2. Specific Objectives

- To estimate the amount of bio methane generated from the brewery wastewater
- To evaluate the COD removal efficiency of the UASB reactor and the aerobic digestor.
- To determine the quality of treated water in terms of COD, BOD, TSS, pH value.
- To carry out the financial analysis of the energy recovery by UASB technology

1.4. **Limitations**

Only a limited data has been used to evaluate the bio methane potential using UASB technology and this study could not incorporate the performance of the UASB reactor under wide range of operating conditions due to time constraint. Also, only few samples of bio methane generated were measured and potential was determined based on those values.

CHAPTER TWO: LITERATURE REVIEW

2.1. **Spent Wash Generation in Brewery**

Production of beer includes blending and fermentation of maize, malt and sorghum grits using yeast, which requires large volumes of water as the primary raw material. Traditionally, the amount of water needed to brew beer is several times the volume actually brewed. In brewing, the average water consumption of around 5 to 6 hectoliter per hectoliter beer is correlated to beer production for industrial breweries.(Perry and De Villiers, 2003). Large volumes of water are being used by the industry for production of beer for two distinct purposes; as the main ingredient of the beer itself and as part of the brewing process for steam raising, cooling, and washing of floors, packaging, cleaning of the brew house during and after the end of each batch operation. The amount of wastewater that is being discharged from the industry after the production of beer, also contributes to this large volume of water (Simate *et al.*, 2011).

2.2. **Spent Wash Characteristics**

Table 2. 1 Average composition of brewery wastewater (Alvarado-Lassman et al. 2008; Simate et al. 2011; Akunna 2015)

Parameters	**Concentrations**
Chemical oxygen demand, COD (mgl^{-1})	1800–50,000
Biochemical oxygen demand, BOD (mgl^{-1})	1005–38,000
Ammonia–nitrogen (NH_3–N in mgl^{-1})	18–22
Total solids, TS (mgl^{-1})	50–6,000
pH value	3–12
Hydrogen (%)	6.98
Total phosphorus, TP (mgl^{-1})	4–103
Total Kjeldahl nitrogen, TKN (mgl^{-1})	20–600
Ammonium ion, NH_4-N (mgl^{-1})	13.3
Temperature (°C)	18–45
Sulfate, SO_4^{2-} (mgl^{-1})	20–50
COD to BOD ratio	1.667
Volatile fatty Acid, VFA (mgl^{-1})	1000–2500
Phosphates as PO_4^{3-} (mgl^{-1})	10–50
Total dissolved solids, TDS (mgl^{-1})	2020–5940
Total suspended solids, TSS (mgl^{-1})	550–3000

Organic component in brewery effluent (expressed as COD) is generally easily biodegradable as it mainly consists of sugar, soluble starch, ethanol, volatile fatty acids, etc. This is illustrated by the relatively high BOD/COD ratio of 0.6 – 0.7. (Driessen and Vereijken, 2003). The brewery solids (expressed as TSS) mainly consist of spent grains, kieselguhr, waste yeast and ('hot') trub. (Driessen and Vereijken, 2003). Brewery effluent pH levels are mostly determined by the amount and type of chemicals used at the CIP units (e.g. caustic soda, phosphoric acid, nitric acid, etc.). Nitrogen and phosphorus levels mainly depend on the handling of raw material and the amount of spent yeast present in the effluent. Elevated phosphorus levels can also be the result of phosphorus containing chemicals used in CIP unit.

2.3. **Treatment technologies for brewery spent wash**

Basically, wastewater treatment methods can be divided into three categories which are physical, chemical and biological wastewater treatment processes (Alao *et al.*, 2010). For almost all combinations of requirements in terms of effluent quality, land availability, construction and running costs, mechanization level and operational simplicity there will be one or more suitable treatment processes (Metcalf, 2003). The selections of specific unit processes depend not only on the nature of wastewater, including degradability and treatability by selected processes, but also on discharge requirements (Metcalf, 2003).

2.3.1. Physical Waste Water Treatment Process

Physical treatment is for removing coarse solids and other large materials, rather than dissolved pollutants. It may be a passive process, such as sedimentation to allow suspended pollutants to settle out or float to the top naturally. The physical units most commonly used in wastewater treatment include screening, grit removal, mixing and flocculation, sedimentation, clarification, aeration, and volatilization and stripping of volatile organic compounds (VOCs). These processes are mostly used at Pre-treatment stage. (Sincero and Sincero, 2002) (Olajire, 2012)

2.3.2. Chemical Waste Water Treatment Process

Chemical treatment processes are the processes used for the treatment of wastewater in which change is brought about by means chemical reactions. The principal chemical processes used for wastewater treatment include chemical coagulation, precipitation, disinfection and oxidation, ion exchange and others. This type of treatment mainly relies on addition of chemicals and is applied when the wastewater cannot be treated biologically. (Gillberg *et al.*, 2003) (Angassa, 2011).. A significant disadvantage of this treatment process is its additive. As a result, there is a net increase in the dissolved constituent and secondary pollutants in the wastewater (Huei, 2005). Besides that, another disadvantage of chemical treatment process is that the cost of most chemicals is related to the cost of energy. (Gillberg *et al.*, 2003)

2.3.3. Biological Waste Water Treatment Process

Due to its simplicity and flexibility biological wastewater treatment is the most utilized and the best economical solution for treatment of biodegradable wastewater. Organic components in brewery effluent are generally easily biodegradable as these mainly consist of sugars, soluble starch, ethanol, volatile fatty acids (Driessen and Vereijken, 2003). Biological treatment of brewery spent wash is either aerobic or anaerobic but in most cases a combination of both is used.

2.3.3.1. Aerobic Digestion

Aerobic digestion is the natural biological degradation and purification process in which bacteria that thrive in oxygen-rich environments break down and digest the waste. (Lee, 2011).

When a culture of aerobic heterotrophic microorganisms is placed in an environment containing a source of organic material, the microorganisms will remove and utilize most of this material. During fermentation metabolism, these materials will be channeled into metabolic energy and oxidized to carbon dioxide, water and soluble inert material, providing energy for both synthesis and maintenance (life support) functions (Roš and Zupančič, 2002). The equation is given as below.

$$\text{Organic Materials} \xrightarrow{\text{heterotrophic}} \text{VFAs} + CO_2 + H_2O + CH_4 + \text{Energy} + \text{Residue}$$

(Seabloom and Buchanan, 2005)

Through the process of respiration, aerobic microorganisms can further transform the volatile fatty acids to carbon dioxide, water and additional energy (Lehninger, 1973) as shown in Equation below.

$$\text{Volatile Fatty Acids} + O_2 \xrightarrow{\text{aerobic microbe}} \text{Energy} + CO_2 + H_2O + \text{Residue}$$

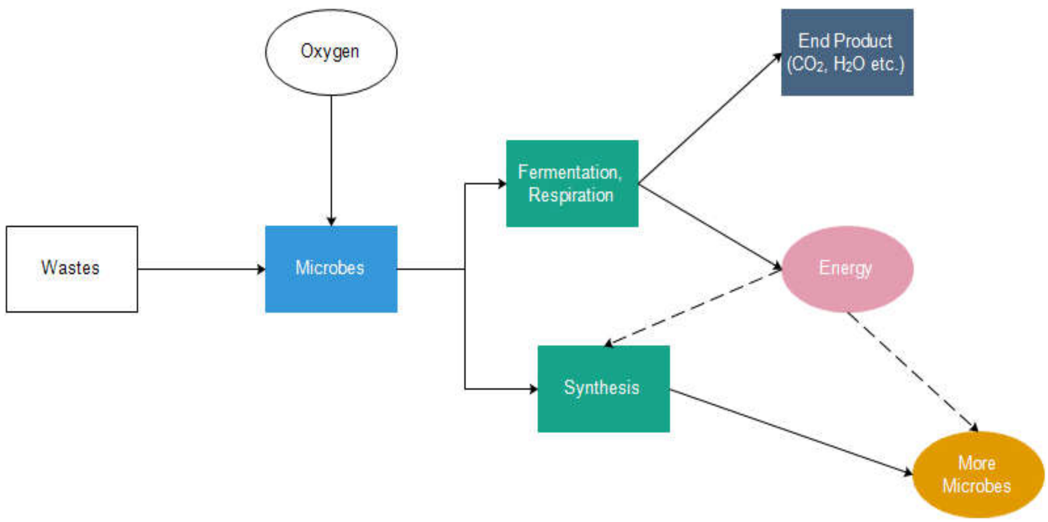

Figure 2. 1 Treatment technologies for brewery spent wash

2.3.3.2. Anaerobic Digestion

Anaerobic digestion is a biological process that happens naturally when microorganisms break down organic matter in environments without oxygen with concurrent production of biogas. During anaerobic digestion, organic matter is completely converted to carbon dioxide and methane. This involves four stages: hydrolysis, acidogenesis, acetogenesis, and methanogenesis (Obayashi and Gorgan, 1985). The anaerobic digestion process involves the complex metabolic interactions of three groups of bacteria (Obayashi and Gorgan, 1985):

1) fermentative bacteria hydrolyze the substrate polymers to single soluble compounds which are fermented to volatile acids, carbon dioxide, and hydrogen.

2) obligate H_2, producing acetogenic bacteria subsequently oxidize the propionate, butyrate, and longer-chain fatty acids to acetate, carbon dioxide and hydrogen.

3) methanogens utilize the acetate and hydrogen to produce methane.

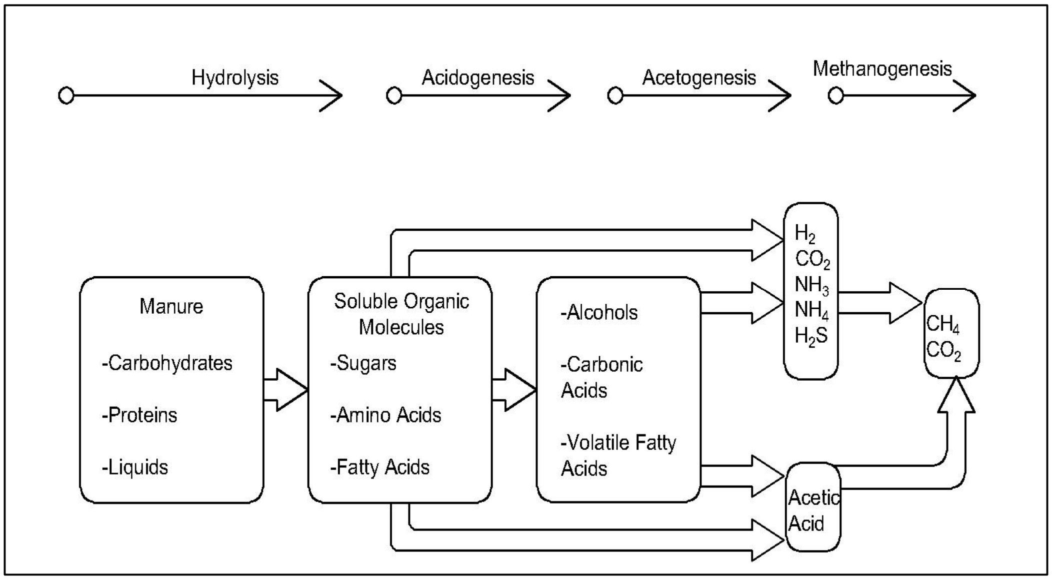

Figure 2. 2 Anaerobic Digestion Process (Girard *et al.*, 2013)

Approximately 70% of the total methane derives from acetic acid while the remaining 30% comes from the conversion of hydrogen and carbon dioxide. The stability of the anaerobic microbial ecosystem is very dependent on methanogenic activity, this activity being characterized by slow growth rates of microorganisms and great sensitivity to inhibition processes and environmental conditions such as pH (Stronach *et al.*, 2012). The ideal pH range for the growth of methanogens is between 6.8 and 7.2, but may vary among species (Stronach *et al.*, 2012).. It is essential that growth conditions are suitable for methanogenic bacteria to prevent the breakdown of the treatment process. The rate limiting step in methane fermentation involves the degradation of volatile fatty acids (VFA) such as acetic acid, propionic acid and butyric acid and others during methanogenesis since these acids begin to accumulate in digesters stressed by high organic loading rates, and/or short retention times and/or inhibitors.(Marchaim and Krause, 1993)

2.4. **Anaerobic Treatment**

In recent years, anaerobic treatment of industrial wastes has become increasingly popular due to energy costs and environmental concerns. (Lettinga *et al.*, 1980). The anaerobic treatment of wastewater has several advantages over aerobic treatment and few serious drawbacks. Lettinga et al., (1980) have listed some of the advantages and disadvantages of anaerobic wastewater treatment:

Advantages

1. low production of excess sludge
2. stable sludge produced which can easily be dewatered
3. low nutrient requirements
4. no energy required for aeration
5. methane is produced, which can be used as an energy source
6. very high loading rates can be applied under favourable conditions
7. active anaerobic sludge can be preserved unfed for many months

Disadvantages

1. anaerobic metabolism is a sensitive process which can be inhibited by environmental conditions such as the presence of specific compounds (eg. CN^-)
2. relatively long periods of time are required to start up the process due to the slow growth rate of anaerobic bacteria
3. anaerobic treatment is essentially a pre-treatment method and usually requires post-treatment to meet effluent standards
4. little practical experience has been gained with the application of the process to the direct treatment of wastewaters.

In recent years, there has been much research into the development of high rate anaerobic treatment processes for the treatment of a variety of wastewaters. Hulshoff Pol *et al.*, (1983) states that the basic conditions for a high rate anaerobic wastewater treatment are:

1) a high sludge retention and a high specific activity of the sludge

2) good contact between the sludge and the incoming wastewater

The UASB reactor system is a high rate anaerobic treatment system that has been reported to have achieved high treatment efficiencies at high loading rates. (Hulshoff Pol *et al.*, 1983).

2.5. **Types of Anaerobic Bioreactor**

2.5.1. High-Rate Waste Water Bioreactors

The successful application of anaerobic digestion technology to the treatment of industrial wastewater is critically dependent on the development and use of high-rate anaerobic bioreactors (Barber and Stuckey, 1999). This is because large volumes of effluent have to be treated and optimally designed bioreactors can decrease the treatment time and increase the treatment efficiency, leading to an overall lowering of the treatment cost. The application of high-rate reactors has enhanced the recognition of anaerobic digestion as a cost effective and efficient technology for environmental protection. High-rate reactors meet the following two conditions: (a) high retention of viable sludge under high organic loading conditions, and (b) good contact between biomass and incoming wastewater, resulting in reduced reactor size and low process energy requirements (Van Lier *et al.*, 2001) (Lettinga *et al.*, 1997)

The average growth rate of methanogens is much lower than that of acidogens; the overall rate of the bio-methanation process is controlled by the methanogenic step if the wastewater does not contain particulate matter. It has been observed that the rate of bio-methanation can be accelerated by enhancement of the rate of conversion of VFAs to methane by increasing the concentration of the methanogens in the reactor. This can be achieved by two methods: making the individual cells agglomerate to form sludge granules so that they have better settling properties and are not washed out of the reactor, or by making the cells grow while attached to an inert 'carrier' material which has a higher specific gravity than cells (Lettinga *et al.*, 1997) (Lettinga *et al.*, 1980).

High-rate bioreactors include the UASB, packed-bed and fluidized-bed reactors, based on the mechanism used to achieve biomass retention within the bioreactors (Figure 2.3).These bioreactors provide a high reaction rate per unit reactor volume thus reducing reactor volume and ultimately allowing the application of high volumetric loading rates (Korsak, 2008) (Barber and Stuckey, 1999).

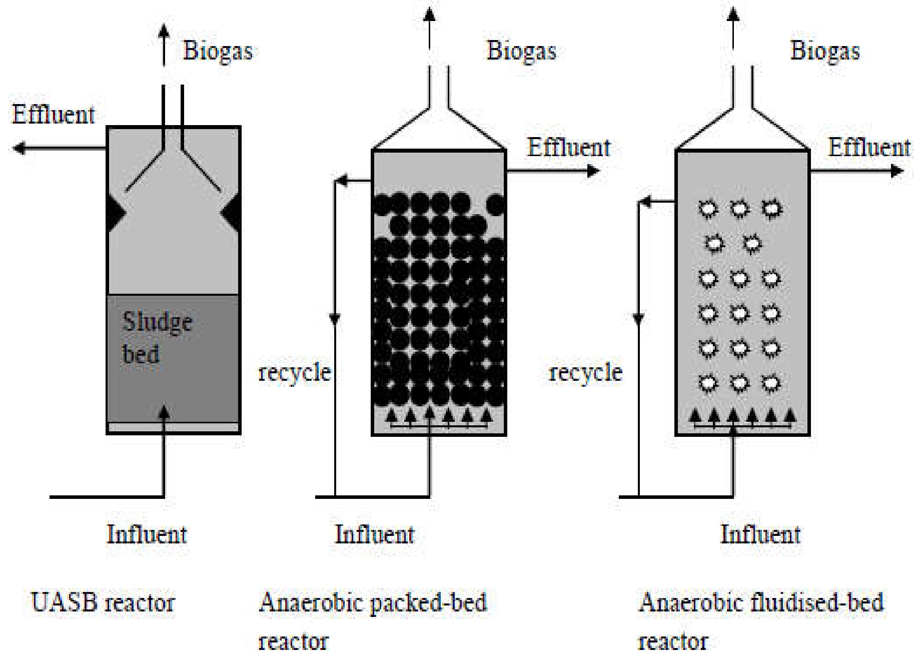

Figure 2. 3 Anaerobic Reactor Configuration (Parawira, 2004)

2.6. **Up-flow Anaerobic Sludge Blanket Concept**

The UASB concept was first conceived by Lettinga and his co-workers in the Netherlands in 1971. The first full scale application was realized in 1977, over five years after the first laboratory studies had been made. To date, over l00 full-scale UASB plants have been commissioned in the Netherlands and other Western European countries, Canada, USA, and the Far East (Hickey *et al.*, 1991).

In this process, the waste to be treated is introduced at the bottom of the reactor. The wastewater flows upward through a sludge blanket composed of biologically formed granules or particles and treatment occurs as the wastewater comes in contact with the granules. Lettinga et al., (1980) states that the main principle underlying the UASB concept is that anaerobic sludge inherently has superior flocculation and settling characteristics. Flocculation refers to the process by which fine particulates are caused to clump together into a floc. The floc may then float to the top of the liquid (creaming), settle to the bottom of the liquid (sedimentation), or be readily filtered from the liquid. Provided that the physical and chemical conditions for sludge flocculation are (and remain) favorable. Once this condition is met, the desired retention of the sludge depends mainly on an effective separation of the gas from the sludge and the liquid. This is accomplished in the UASB reactor by the gas-liquid-solid separator device (GLSS device) in the upper part of the reactor and by keeping mechanical mixing and/or sludge recirculation at a minimum (Lettinga et al., 1980).

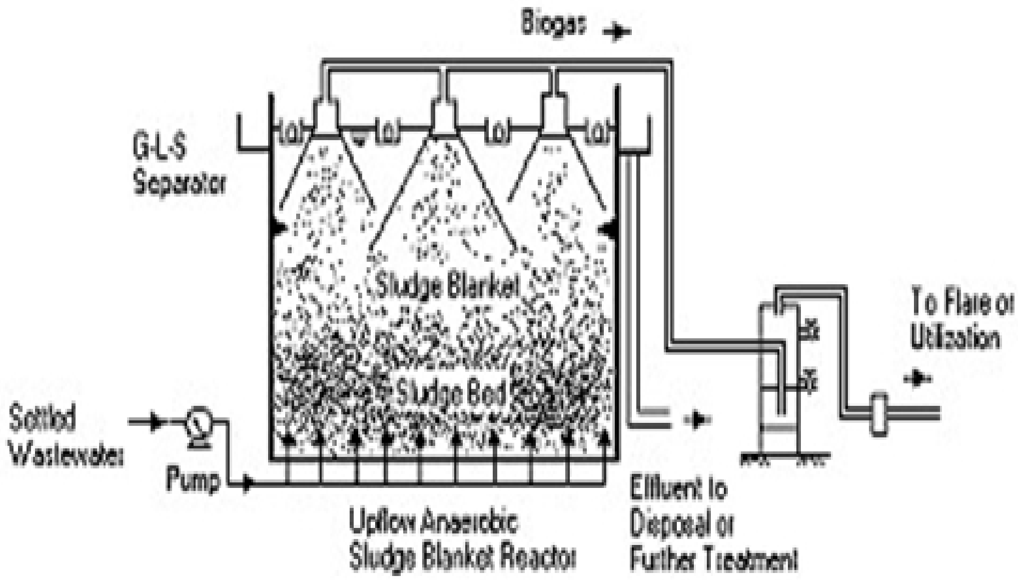

Figure 2. 4 Schematic Diagram of a UASB Reactor (Shirule *et al.*, 2013)

For a satisfactory operation of the GLSS device it is required to: a) achieve an effective separation of entrapped or attached gases from the sludge; and b) enable the sludge separated from the solution in the settler compartment to return to the digester compartment. The liquid-solids-gas separator consists of a cone, with its larger base either facing up or down, sealed to the reactor inner wall near the top of the reactor. The device achieves high sludge retention by creating a quiescent zone near the top of the reactor which helps rising sludge flocs form larger aggregates and sink back down. The sludge floes rise either by turbulence (due mainly to gas production) or flotation (Cronin and Lo, 1998).

High concentrations of biomass are retained in UASB systems, which allows the process to achieve high removal efficiencies at high volumetric COD loading rates. Weiland and Rozzi, (1991) reported that compared to other high rate anaerobic systems, UASB systems lead to the highest biomass accumulation with contents of up to 50 g VSS/l and should achieve removal capacities between 50 and 100 kg COD/m^3 /d at specific sludge loadings of 1-2 g COD/g VSS. ln addition, the UASB system is the only anaerobic system that can remove significant amounts of nitrogen (Wentzel *et al.*, 1994). Weiland and Rozzi, (1991) have compared the UASB system with other high rate anaerobic treatment systems in terms of its advantages and disadvantages:

Advantages

l. high removal capacity

2. short retention times

3. high COD removal efficiency

4. low energy demand

5. no need of support media

6. simple reactor construction

7. long experience in practice

Disadvantages

1. granulation process difficult to control

2. granulation depends on wastewater properties

3. start-up eventually needs granulated sludge

4. sensitive to organic shock loads

5. restricted to nearly solids-free wastewater

6. Ca^{++} and NH_4^+ inhibit granule formation

7. re-start can result in granule floating

2.7. **Start- Up of UASB Reactors**

Good results with the UASB reactor can be primarily attributed to the formation of a highly settleable and active sludge in the reactor. During the start-up of a UASB reactor, the biomass aggregates to form stable, compact, granules or pellets which may be up to 5 mm in diameter (Hulshoff Pol *et al.*, 1983). The development of a completely granulated sludge can be a lengthy process, but is considered vital to the success of the operation of the UASB reactor. This is due to the fact that granules settle well against the up-flow of waste to be treated; high biomass retention is possible at hydraulic loading rates which would cause a poorly flocculated sludge to wash out almost immediately (Hulshoff Pol *et al.*, 1983). These hydraulic effects are exacerbated by the degree of turbulence in the bed resulting from high biogas production rates which tends to assist washout of any but the most rapidly settling sludges (Hulshoff Pol *et al.*, 1983). Goodwin et al., (1992) found that although granules can eventually be formed from a diffuse seed sludge, reactors seeded with granulated sludge achieved high performance levels within a few days, while reactors seeded with diffuse sludge required start-up periods in excess of 60 days. Granulation can be seen to occur in three distinct phases; each phase characterized by different sludge concentration profiles in the reactor and differences in the nature of the sludge itself (Hickey *et al.*, 1991):

Phase one: the sludge bed expands as gas production increases and sludge concentration in the sludge blanket increases, at the same time, granules begin to form in the sludge bed and gradually grow.

Phase two: sludge concentration in the blanket continues to increase and washout of the inoculated sludge begins; consequently, the total amount of the sludge in the reactor drops to a minimum.

Phase three: the growth of granules exceeds the sludge wash-out rate and the total biomass in the reactor again increases. Sludge granulation is governed mainly by bacterial growth, and many factors influence the formation of granular sludge in UASB reactors. Such factors include the characteristics of the seed sludge, operational parameters, wastewater characteristics, and environmental factors (Lettinga *et al.*, 1980).

2.8. **Effect of Different Parameters on The Efficiency of UASB Reactor**

The efficiency of UASB reactors is regulated by a large number of factors including wastewater characteristics, acclimatization of seed sludge, pH, nutrients, presence of toxic compounds, loading rate, up-flow velocity, hydraulic retention time (HRT), liquid mixing, and reactor design that affect the growth of sludge bed (Foresti, 2002)(Zhang, Liu and Zhang, 2013)(Turkdogan-Aydınol and Yetilmezsoy, 2010)(Abma *et al.*, 2010).

2.8.1. Effect of Temperature

Temperature considerably influences the growth and survival of microorganisms. Anaerobic treatment is possible at all three temperature ranges (psychrophilic, mesophilic, and thermophilic); however, low temperature generally leads to a decline in the maximum specific growth rate and methanogenic activity (Singh *et al.*,, 2006) (Bodik *et al.*, 2000)(Azbar *et al.*, 2009). Methanogenic activity at this temperature range is 10 to 20 times lower than the activity at 35°C, which requires an increase in the biomass in the reactor (10 to 20 times) or operating at higher sludge retention time (SRT) and hydraulic retention time (HRT) in order to achieve the same COD removal efficiency as that obtained at 35°C.(Mahmoud, 2002) (Foresti, 2002).

It is argued that the decrease of temperature slows down the hydrolysis and decreases the maximum growth and substrate utilization rates (Lettinga *et al.*, 2001). Singh *et al.*, (2013) treated municipal wastewater using a UASB system under low temperature conditions and reported 70% COD removal at 11°C and 30 to 50% at 6°C(Singh *et al.*, 1996). Lew et al. found a gradual decrease in COD removal efficiency as the temperature was decreased (Lew *et al.*, 2011). They reported 82% COD removal at 28°C, 72% at 20°C, 68% at 14°C, and 38% at 10°C. Kalogo and Verstraete also found that COD removal efficiency at temperature in the range of 10–15°C was lower than that of efficiency at 35°C.(Kalogo and Verstraete, 1999)

Van Lier and Lettinga studied the effect of transient temperature rise on the performance of a UASB reactor containing mesophilic microorganisms.(van Lier and Lettinga, 1999) There was an increase in the methane production with an increase in the temperature due to the accelerated methanogenic activity. However, a sharp drop in the methane generation was noted at the reactor temperature exceeding 45°C because of a substantial decline in the activity of mesophilic granular sludge due to bacterial inactivation. Halalsheh et al. treated high strength sewage (COD = 1531 mg/L) using a UASB pilot plant under subtropical conditions. (Halalsheh *et al.*, 2005). The COD removal efficiencies were 62% and 51% in summer and winter, respectively, when the plant was operated at ambient temperature (18–25°C) and hydraulic retention time of 24 hours.

2.8.2. Effect of Hydraulic Retention Time

The upflow velocity is directly related to Hydraulic retention time (HRT) and plays an important role in entrapping suspended solids. A decrease in upflow velocity entails an increase in HRT, which boosts suspended solids' (SS) removal efficiency of the system (Van Haandel *et al.*, 1994; Liu *et al.*, 2010; Rajakumar *et al.*, 2011). The COD removal efficiency of a UASB reactor also decreases at elevated upflow velocity because higher upflow velocity reduces the contact time between sludge and wastewater in addition to smashing of sludge granules and resultantly higher washout of solids(Mahmoud, 2002; Leitão, 2004; Nkemka and Murto, 2010). However, some scientists reported no distinct effect of HRT on the treatment efficiency of UASB reactor(Vieira and García, 1992; Halalsheh, 2002). The difference of opinion in scientific community is attributable to the difference in the reactor design, operating procedures, and range of HRT. Flow rate is also a key operational parameter that maintains the hydraulic retention time. In UASB process, if diameter of reactor will be too large then it may cause liquid channeling in the reactor leading to insufficient contact between the substrate and biomass. Therefore, large reactor will result in decreased biogas production and sludge washout due to insufficient mixing within the reactor. In contrast, comparatively more height may promote substrate mixing leading to proper contact of substrate with microorganisms resulting in more organic matter degradation and formation of biogas (Peña *et al.*, 2006).

2.8.3. Effect of Organic Loading Rate

OLR is the main parameter significantly affecting microbial ecology and functioning of UASB process. UASB reactor is preferred for its potential to treat wastewater having low content of suspended solids and gives higher methane yield (Shahperi *et al.*, 2016). The OLR can be changed by varying the COD concentration of influent, flow rate, HRT and volume of the reactor in accordance with the following relationship.

$$\text{OLR} = \frac{\text{Q X COD}}{\text{V}} = \frac{\text{COD}}{\text{HRT}} \qquad \text{.... 2.1}$$

where

OLR = Organic loading rate (kg COD/m^3d)

COD = Total chemical oxygen demand of influent (kgCOD/m^3)

Q = flow rate (m^3/d)

V = reactor volume (m^3)

HRT = Hydraulic retention time (days)

The reactors seeded with granular activated sludge can give high performance within a brief startup period and can also adapt quickly to increase of OLR (Kalyuzhnyi *et al.*, 1996). The effect of OLR on the performance of a UASB reactor depends on a number of factors which sometimes have a dissimilar effect, mostly contradictory, on the performance of UASB reactor(Leitão, 2004). Researchers have reported an increase in the efficiency of high rate anaerobic reactors with increasing OLR (Ren *et al.*, 2009). However, that increase is up to a certain OLR, beyond which there occurs sludge bed flotation and excessive foaming in the gas-liquid-solids separator (GLSS); therefore a range of optimum OLR is usually recommended for a given temperature range and wastewater (Farajzadehha *et al.*, 2012). Seghezzo operated pilot-scale UASB reactors with OLR of 0.6 kgCOD/m^3·day (HRT of 6 hours and COD influent = 153 mg/L) and achieved maximum 63% COD removal efficiency at a low temperature of 17°C.(Seghezzo, 2004). Higher than optimal OLR results in the accumulation of biogas in the sludge bed forming gas pockets that ultimately cause sludge flotation (Kalyuzhnyi *et al.*, 1996).

According to Leitao, as OLR is dependent on wastewater strength, up-flow velocity, and volume of reactor, it is thus also dependent on the applied HRT. Therefore, impact of OLR on reactor performance is not simple, as it is dependent on other parameters, which have opposing effects on the removal efficiency of UASB.(Leitão, 2004)

2.8.4. Effect of pH

The pH of an anaerobic reactor is especially important because methanogenesis process can proceed at a high rate only when the pH is maintained in the range of 6.3–7.8 (Casserly and Erijman, 2003). In the case of domestic sewage, pH naturally remains in this range because of the buffering capacity of the acid-base system (carbonate system), and addition of chemical is not required (Van Haandel *et al.*, 1994). Improvement in both hydrolysis and acidogenesis rates is achieved when treating domestic wastewater using anaerobic reactor and pH 7 provides an optimal working environment for anaerobic digestion resulting into more than 80% TOC and COD removal (Zhang *et al.*, 2005)

2.8.5. Effect of Granulation

In UASB reactor, long HRT have been found disadvantageous for the development of granular sludge (Batstone *et al.*, 2005; Ren *et al.*, 2009). In contrast, very short HRT lead to washout of biomass. Both situations are unacceptable for achieving optimum results from UASB reactor. Even though granulation has been considered essential for successful treatment of domestic wastewater in UASB reactors, these reactors are found to be effective even without granules. The high performance of the UASB reactor is based on the formation of an active sludge in the lower part of the reactor. The development of sludge bed occurs by the accumulation of incoming suspended solids and bacterial growth under specific conditions, due to the natural aggregation of bacteria in flocs and evolution of granules in the form of layered structure (Tay and Yan, 1996; Fang, 2000). These granules are not washed out from the reactor during operation of UASB. The diameter of the granulated sludge particles has been found in the range of 1.0 to 3.0 mm(Chou and Huang, 2005; Veronez *et al.*, 2005; Vlyssides *et al.*, 2008; Yetilmezsoy and Sakar, 2008). The granular suspensions have greater settling velocities (20–80 mh^{-1}) as compared to upflow velocities (0.1–1.0 mh^{-1}). Therefore, substantial quantity of biomass can accumulate in the reactor. Consequently, a high sludge loading rate (SLR) could be applied (up to 5 $gCODgVSS^{-1}day^{-1}$) with a relatively short HRT, less than 4 hours (Kalyuzhnyi *et al.*, 1996). Formation of activated sludge is important, in either granular or flocculent form, in the reactor which ensures adequate removal efficiency even at high OLR (Shahperi *et al.*, 2016).

2.8.6. Effect of Volatile Fatty Acids

In an anaerobic digestion system, there are two major groups of bacteria, which can either coexist or inhabit separately. The first group degrades organic matters and releases VFAs. Then the second group of micro-organisms converts these VFAs to methane and carbon dioxide. Organic acids formed during the digestion process are immediate products. The system equilibrium is disturbed if the volatile organic acids are produced more than they are utilized. Higher acid concentration results in the alkalinity reduction and consequently leads to pH drop.

VFA and alkalinity together are the good indicators for evaluating the process stability of the anaerobic reactor since total alkalinity reflect both levels of VFA and bicarbonate, and under unstable conditions increased VFA reduce bicarbonate resulting in constant total alkalinity (Somasiri *et al.*, 2006). If the ratio of VFA to alkalinity exceeds 0.8, the inhibition of methanogens occurs and process failure is apparent, increase above 0.3 to 0.4 indicate system instability and a proper ratio is between 0.1 to 0.2 (Zhao and Viraraghavan, 2004). The optimum ratio of VFA to alkalinity should be less than 0.3 or 0.4. (Sanchez *et al.*, 2005).

2.9. **Up-flow Anaerobic Sludge Blanket System**

Currently there are several anaerobic reactor configurations that take advantage of anaerobic granules. The up-flow anaerobic sludge blanket (UASB) reactor is often utilized in industrial and municipal wastewater settings. The UASB reactor is one of the most common anaerobic digestion systems currently in use (Nelson et al., 2012). In the UASB reactor contains a blanket of granular sludge which is kept in suspension by the upward flow of wastewater into the system. The density of anaerobic granules in a UASB reactor needs to be large enough to resist the shear stress supplied by the hydraulic up-flow of the influent and the biogas. Excessive hydraulic loadings in a UASB can lead to the washout of biomass with the effluent (Bal and Dhagat, 2001). The UASB reactor requires a gas-liquid-solid separation device, which occupies between 16 and 25% of the reactor volume (Hashemian and James, 1990). This device must be properly operated and maintained to achieve the maximum treatment efficiency. Blockages in the gas separator compartment of the UASB can result in failure to separate solids from the effluent (Hashemian and James, 1990). Improper alignment of effluent weirs can also result in hydraulic short circuiting and reduced treatment efficiencies in the UASB (Heffernan *et al.,* 2011). The sludge bed height of a UASB reactor needs to be controlled to prevent it from extending above the entrance of the gas liquid separator, thus increasing the potential to discharge solids with the effluent. The UASB reactor also requires an operator to control the sludge bed height in the reactor by appropriately discharging granular sludge (Heffernan *et al.,* 2011).

2.10. **UASB System and Effluent Treatment Plant at Raj Brewery**

The UASB reactor at Raj Brewery is located at Hakui, Bhairahawa. The effluent treatment plant at Raj Brewery has a treatment capacity of 350 kiloliters per day consisting of equalization tank, buffer tank, a UASB reactor and a post wastewater treatment plant. The plant receives waste water from the brewery itself. The various components of effluent treatment plant and their functions is as follows:

- Screen Chamber

The effluent from the brewery and bottling plant is first screened in a screen chamber. Screen chamber separates large floating objects on water/from water and prevents those objects from entering the treatment plant and also safeguard against damage to any pumps, pipes and other equipment.

- Oil and Grease Trap

Oil and grease trap remove the oil and grease present in the brewery effluent after they are screened through the chamber. The oil and grease trap dimensions at Raj Brewery is 2.0 m x 1.2 m 1.0 m. with a capacity of 2.4 m^3.

- Equalization Tank

The equalization tank collects effluent that comes at widely fluctuating rate from oil and grease trap and helps to maintain the desired flow rate to downstream process. It also makes the effluent from oil and grease trap homogenous. The dimensions of equalization tank at Raj Brewery is 6.0m x 5.0m x 3.0m + FB with a capacity of 90.0 m^3.

- Buffer Tank/UASB Feed Tank

Buffer tank receives brewery effluent from the equalization tank with fluctuation in pH value. The brewery effluent is treated in this tank before it is fed into the UASB reactor. pH is maintained around 7 in this tank by adding NaOH if the effluent is acidic and by adding HCl if the effluent from brewery is basic. The dimension of the buffer tank at Raj Brewery is 5.0 m x 1.8 m x 3.0m + FB with a capacity of 27.0 m^3.

- UASB Reactor

It is the reactor where effluent from the buffer tank is treated at the bottom of the reactor. Sludge blanket composed from biologically formed granules are present at the bottom of the reactor. As effluent passes through this blanket, it is digested anaerobically releasing biogas. The reactor is cylindrical with internal diameter of 6.7 meters and height of 5.5 meters. The capacity of the UASB reactor is 193.8 m^3.

- Primary Clarifier

It receives effluent from the UASB tank. The main function of the primary clarifier is to separate the solid and liquid particles from the effluent. The surface loading rate of the primary clarifier is 1.0 m^3/m^2/hr. and the dimension of the tank is ϕ4.8 m with a height of 2.5m.

- Aeration Feed Tank

Aeration feed tank collects the effluent from the primary clarifier and feeds it to the aeration tank. Its dimensions are 3.0m x 3.0m x 3.0 m +FB with a capacity of 27.0 m^3.

- Aeration Tank

The dimensions of aeration tank are 8.0mx 6.0m x 4.6m +FB with a capacity of 220.8 m^3. Inside aeration tank air and water comes in close contact to remove dissolved gases and dissolved metals through oxidation.

- Secondary Clarifier

The function of the secondary clarifier is to separate the solid and liquid particles from the effluent after aerobic digestion in the aeration tank. Its dimensions are ϕ5.3m with a height of 2.5 m and surface loading rate of 0.8 m^3/m^2/hr.

- Clear Water Tank

It collects the water particles that has been separated by the secondary clarifier. The tank capacity is 36.0 m^3 with dimensions of 4.0m x 4.0m x 3.0m + FB.

- Treated Water Tank

The clear water is treated with hypochloride and is passed through multi-grade filter and activated carbon filter to further purify and reduce the odor in the water.

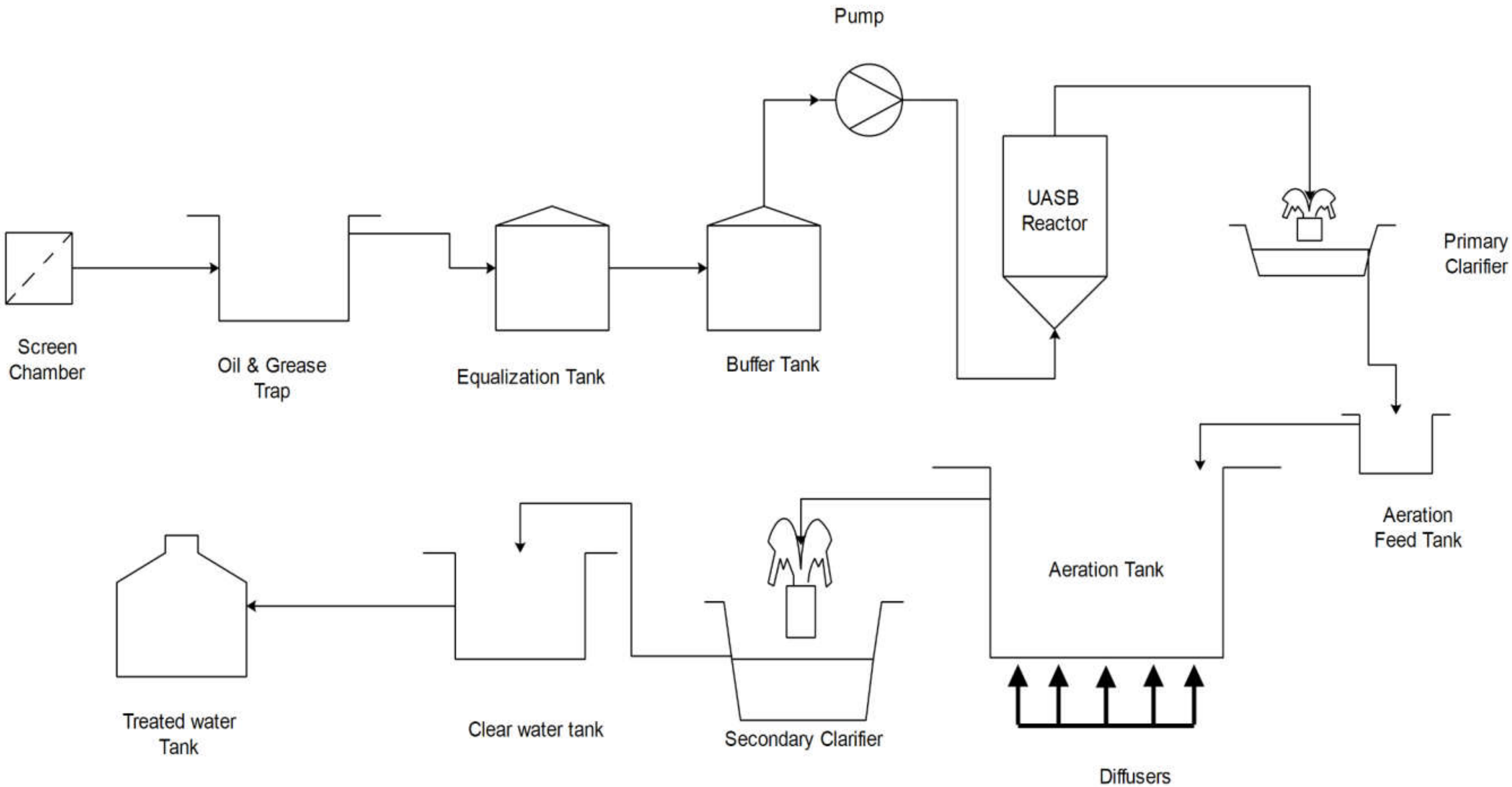

Figure 2. 5 Schematic Diagram of ETP at Raj brewery

2.11. **Findings of some relevant papers on wastewater treatment using UASB**

- Draaijer et al (1992) showed that there was an average reduction in COD, BOD and TSS concentration of 74, 75 and 75% respectively at a hydraulic retention time of 6 hours. The biogas yield was 0.05 to 0.10 m^3/kg COD removed. The gas had 75 to 80% methane. Also, during winter time the treatment efficiency and process stability remained good (Draaijer *et al.*, 1992)
- Goodwin & Stuart (1994) studied the anaerobic digestion of a liquid waste product from the malt whisky industry, in a UASB reactor and the investigation revealed that the COD reduction efficiency was 90% at an OLR of 15 kg COD/ m^3.d with a retention time of 2.1 days (Goodwin and Stuart, 1994).
- Pathe et al (1995) studied the performance of UASB reactor in the treatment of sugar mill effluent. It has been reported that more than 90% COD could be removed at lower loadings up-to 13 kgCOD/m^3d and about 80% COD up to 25 kg COD/m^3d at HRT ranging from 4 - 24 hours. The methane content in the biogas was in the range of 70% -74%. (Pathe *et al.*, 1995).
- Joo – Hwa Tay & Yue – Gen Yan (1996) studied the brewery wastewater treatment in UASB reactor. The UASB performed stably with soluble COD and BOD removal efficiency of 89.1% and 91.3% respectively under Volumetric Loading Rate of 12.2 g COD /L.d and HLR of 4 hrs (Yan and Tay, 1996).
- Subramaniam & Sastry (1998) reported that brewery mill wastewater, using Upflow Anaerobic Sludge Blanket Reactor, treated for COD removal from 72.1% to 87% for the COD loading rates varying from 1.33 to 16 kg COD / m^3/ d. (Subramaniam & Sastry, 1998)
- Blonskaja et al (2003) studies of two-stage anaerobic treatment for distillery waste, the HRT ranging from 10 to 19 days at loading rates of 2.5– 5.1 kg COD/ m^3d in the first stage, and upto 20–39 days, corresponding to loading rates 0.6– 2.5 kg COD/m3d in the second stage. The treatment efficiencies (COD removals) achieved was 54 and 93% in the first and second stage, respectively. (Blonskaja *et al.*, 2003)
- Parawira (2004), studied in an opaque beer factory for anaerobic brewery wastewater. The average COD reduction was 57% and total & settleable solids reduction was 50% & 90% respectively with HRT of 24 hrs. (Parawira, 2004)

- Parawira et al (2005) conducted a study on industrial anaerobic treatment of beer brewery wastewater on a full-scale UASB reactor seeded with activated sludge and reported a COD removal efficiency of 57% with a hydraulic retention time of 24 hrs. (Parawira *et al.*, 2005)
- Hampannavar and Shivayogimath (2010) studied the treatment of sugar waste water and reported that maximum COD removal efficiency of 89.4% was achieved. The COD removal rate linearly increased with increase in OLR. UASB design is feasible to treat sugar industry wastewater efficiently upto an OLR of 16 gCOD/Ld with a COD removal efficiency of 89% at much lower HRT of 6 h. The ratio of VFA to alkalinity was varied between 0.19-0.33 during the treatment. When the OLR increased to 24 gCOD/Ld, the VFA to alkalinity ratio reached a value of 0.7 indicating, system instability; During that period alkalinity dropped to 1251 mg/L as CaCO3. (Hampannavar and Shivayogimath, 2010)
- Sankar Ganesh *et al.* (2012) studies on treatment of low-strength effluents by UASB reactor and its application to dairy industry wash waters and reported that the reactors achieved treatment efficiency of the order of 75 to 85% and were able to withstand shock-loads without adversely affecting the treatment efficiency. (Sankar Ganesh *et al.,* 2012)

CHAPTER THREE: RESEARCH METHODOLOGY

The basic methodology of the research work is as follows:

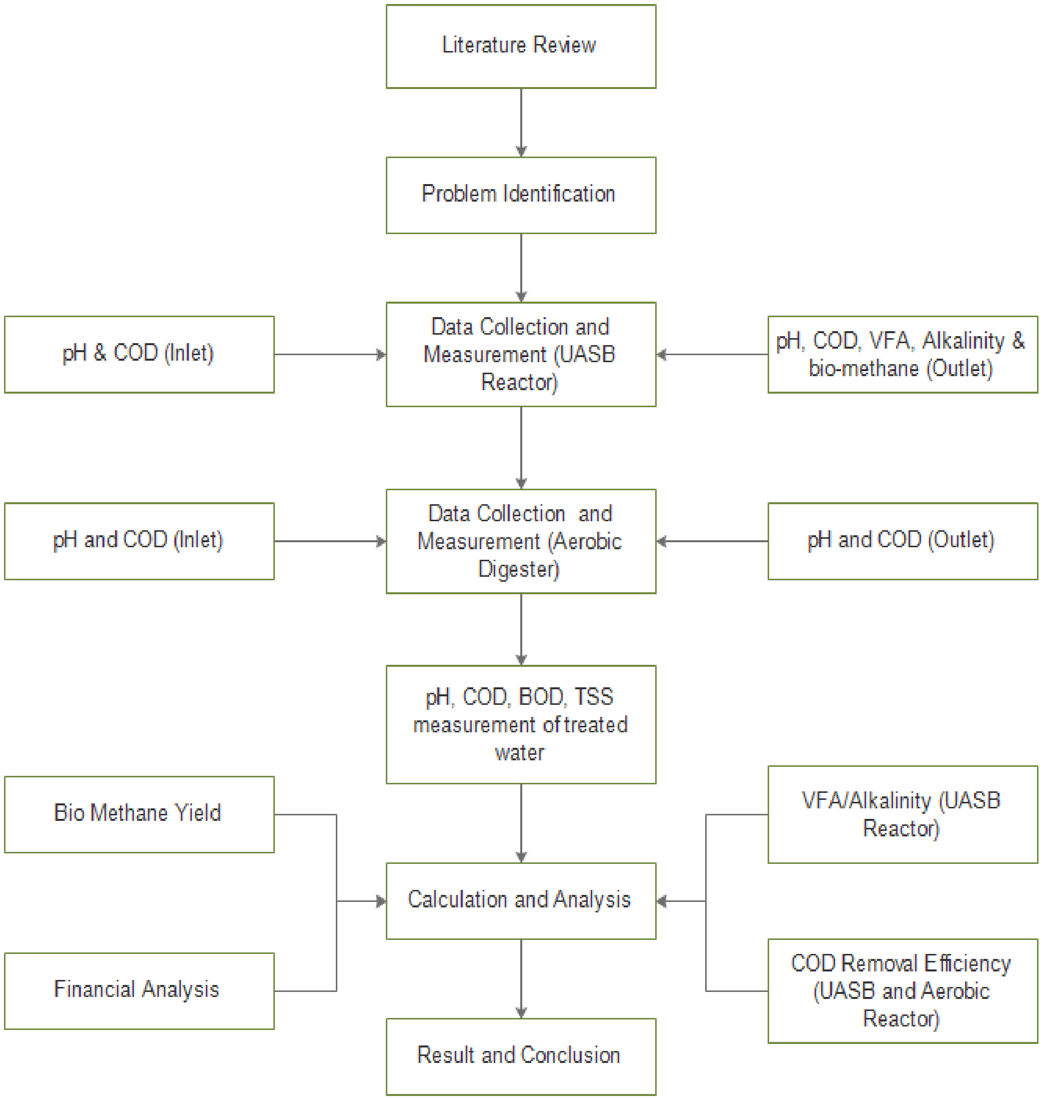

Figure 3. 1 Methodology Flow Chart

3.1. Literature Review

Literature review comprises of reviewing the existing national as well as international journals, reports, articles, documents and analyzing the standard protocol suitable in context of Nepal. Similar research works done globally were reviewed from international journal articles and their conclusions were analyzed.

3.2. **Data Collection**

Data collection was carried out from primary as well as secondary sources including both qualitative and quantitative data types. The effluent treatment plant at Raj Brewery was used as primary source of data. Data regarding the various parameters during operation of ETP plant were collected by direct interviews with concerned personnel during field visit. Up-flow Sludge Blanket Reactor for Effluent Treatment of Raj Brewery selected for study was located at Hakui, Bhairahawa. Raj Brewery has a beer production capacity of 100,000 hl per annum. The Effluent Treatment Plant has a design effluent treatment capacity of 350 Kiloliters per day. The brewery receives waste water from the various sections of brewery itself.

3.3. **Reactor Configuration**

The flow rate of effluent inside the UASB reactor was maintained at around 3-4 m^3/hr during the study period. The hydraulic retention time was maintained at around 48 hrs. Both the feed buffer tank and the reactor were maintained at ambient temperature. The organic loading rate varied widely during the study period as the waste concentration in terms of COD and BOD varied and the flow rate of effluent from brewery also varied.

3.4. **Sample Collection**

Samples of wastewater from the brewery effluent and after treatment in the UASB reactor and after post treatment in the aerobic digestor were collected on a daily basis using a sterilized plastic bottles and transported to the laboratory facilities at the plant for physiochemical analysis within 48 hours.

3.5. **Waste water Analysis**

Brewery wastewater samples and samples after treatment were analyzed for parameters such as Total suspended solids (TSS), pH, Chemical oxygen Demand (COD), Biochemical Oxygen Demand (BOD), Volatile Fatty Acids (VFAs), alkalinity. The performance of the UASB reactor and post treatment aerobic digestor were also assessed on the basis of COD removal. The quality of the treated water was also compared with the standard values.

3.5.1. pH

pH is the measure of hydrogen ion concentration. pH during the study was measured using a pH meter. The pH meter measures the difference in electrical potential between a pH electrode and a reference electrode.

3.5.2. Total Suspended Solid

TSS are solid materials, including organic and inorganic, that are suspended in the water. These would include silt, plankton and industrial wastes.

Total suspended solids (TSS) is that portion of the Total Solids that are retained on a no-ash glass fiber filter disc of approximately 0.45 mm pore size. The wetted and weighed filter disc is placed in a filtering apparatus and a suction is applied. A measured volume of wastewater is passed through the filter. The filter containing the residue is then dried in an oven for one hour at 103 to 105°C. The sample is then cooled and weighed. The difference in weight of the dry filter before and after solids passed through is the TSS milligrams (mg) of suspended solids per liter (l) of wastewater filtered.

Calculation

$$\text{Total Suspended Solid (TSS)} = \frac{a-b}{c} \times 10^{6} \quad \ldots\ldots 3.1$$

Where, a = Weigh of disk + solid, (g)

b = Weight of empty disk, (g)

c = Volume of sample used (mL)

3.5.3. Biochemical Oxygen Demand

BOD is the amount of oxygen that the bacteria takes from the water when they digest the organic matter. The BOD values during the study were measured with Hach BOD Trak II Tester by taking direct physical measurement of the oxygen consumed by a sample waste water.

A measured sample of wastewater is placed in one of the amber bottles on the apparatus and the bottle is connected the instrument. Above the water sample is a quantity of air, which contains 21 percent oxygen. Over a period of time, bacteria in the waste water consume dissolved oxygen to oxidize organic matter present in the sample. The air in the closed sample bottle replenishes the used oxygen, resulting in a drop-in air pressure in the sample bottle. The BOD Trak Apparatus measures the drop in pressure and displays results directly as mg/L BOD. During the test period (usually five days) the sample is continually agitated by a magnetic stirring bar. Carbon dioxide is produced by the oxidation of organic matter and must be removed from the system so that the pressure difference observed is proportional only to the amount of oxygen used. This is accomplished by the addition of a few crystals of lithium hydroxide in the seal cup of each sample bottle. The electromagnetic stirring mechanism provides adequate agitation to effectively maintain rapid transfer of oxygen from the liquid sample to the air above.

3.5.4. Chemical Oxygen Demand

COD represents the oxygen requirement of a sample for oxidation of organic and inorganic matter. COD does not require five days procedure as required for BOD. COD was measured using Hach COD Kit during the study.

The Chemical Oxygen Demand (COD) test uses a strong chemical oxidant in an acid solution and heat to oxidize organic carbon to CO_2 and H_2O. COD test involves an acidic oxidation with potassium dichromate. A measured amount of Potassium dichromate is added to the sample waste water. The acidified sample is then boiled for 2 hours, cooled and the amount of dichromate is measured by titration with ferrous ammonium sulphate and the oxidizable matter is calculated in terms of oxygen equivalents. When dichromate is used as oxidizing agent, the principal reaction may be represented in the general way by the following unbalanced equation:

$$(C_aH_bO_c) + Cr_2O_7^{--} + H^+ \longrightarrow Cr^{3+} + CO_2 + H_2O \qquad ..... 3.2$$

Organic matter

During experiment, excess dichromate concentration is determined by titrating it with ferrous ammonium sulfate (FAS). The reaction is given by:

$$6Fe^{2+} + Cr_2O_7^{2-} + 14\ H^+ \longrightarrow 6Fe^{3+} + 2Cr^{3+} + 7H_2O \qquad ...... 3.3$$

3.5.5. Volatile Fatty Acid

VFAs are the intermediate produced during the anaerobic digestion of organic matters. Acetic acid is the most abundantly produced volatile acid formed as an intermediate during the anaerobic treatment of almost all varieties of organic matter. Distillation method was used to determine the VFA in the waste water samples during the study.

200 ml Waste water samples is centrifuged for 5 minutes and the supernatant liquor is collected. 100 ml of supernatant liquor is placed in a 500 ml distillation flask, 100 ml distilled water, 4 or 5 glass beads and 5 ml H2SO4 are added to the liquor. The contents are well mixed, so that acid does not remain on the bottom of the flask. The flask is connected to a condenser and distilled at the rate of about 5ml/min. 150 ml of distillate is collected in a 250 ml conical flask and titrated with 0.1 N NaOH, using phenolphthalein indicator. The end point is the first pink coloration that persists on standing for a short time. (APHA, 2005)

The volatile acids are determined using the relationship

Volatile acids, mg/l (as acetic acid) = $\frac{ml\ NaOH\ x\ N\ x\ 6000}{ml\ sample\ x\ f}$ …… 3.4

Where:

N = Normality of NaOH, and

f = recovery factor during distillation

3.5.6. Alkalinity

Alkalinity of a water is its acid-neutralizing capacity. Titration method was used to determine the alkalinity of the waste water samples during the study.

Hydroxyl ions present in a sample as a result of dissociation or hydrolysis of solutes react with additions of standard acid. Alkalinity thus depends on the end-point pH used. (APHA, 2005). Following procedure is used to measure alkalinity according to APHA (2005).

Collect 50 mL water sample, add 3 drops of phenolphthalein indicator, titrate the 50 mL sample with 0.02N sulfuric acid to pH 8.3 and estimate phenolphthalein alkalinity

(Eq. 3.5.6.1) (phenolphthalein indicator will change color, from pink to clear, at pH 8.3)

Phenolphthalein Alkalinity (in mg/L as CaCO3) = (A1×N × 50000) / V ……3.5

Where: A1 = volume of sulfuric acid used in mL;

N = normality of acid used to titrate;

V= volume of sample used in mL

Use the same sample. Add 3 drops of bromcresol green indicator. Titrate the 50 mL sample with 0.02N sulfuric acid to pH 4.5 and estimate total alkalinity (bromcresol green indicator will change color, from blue to yellow, at pH 4.5). Amount of acid used at this moment starting from step1 (i.e., A2) is used to react with the hydroxide, carbonate, and bicarbonate and it constitutes of total alkalinity (Eq. 3.5.6.2):

Total Alkalinity (in mg/L as CaCO3) = (A2×N ×50,000) / V ……… 3.6

Where: A2 = volume of acid used in mL starting from step 1 (i.e., A2>A1);

3.6. **Estimation of Pollutant Removal Efficiency**

The pollutant removal efficiency of UASB and ETP plant were measured using the equation 3.6 below.

Removal Efficiency = $\frac{C_{inf.} - C_{eff.}}{C_{inf.}}$ X 100 % ……….. 3.7

Where,

Cinf. = Influent values and

Ceff. = effluent value

3.7. **Estimation of Methane Gas Potential**

The chemical oxygen demand (COD) is an indicative measure of the amount of oxygen that can be consumed by reactions in a measured solution. The mass of O_2 required to convert organic matter to CO_2 and H_2O is the oxygen demand of the organic matter and for that 2reason, it can be applied to estimate the CH_4 yield of biomass substrate. Anaerobic digestion takes place in the absence of O_2:

$OM + heat \rightarrow CH_4 + CO_2 + H_2O + energy$

This method is based on the assumption that 1 mole of methane requires 2 moles of oxygen to oxidize carbon to carbon-dioxide and water.

$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O + heat$

We can use chemistry to calculate the unit mass for each constituent in methane combustion (Equation 3). Unit masses must balance on both sides of Equation 3. Putting numbers to the equation:

16g + 2 X 32g = 44 g + 2 X 18 g

The mass of one mole of methane is 16g. The 2 moles of O_2 have a mass of 64g. So, each gram of methane represents 4 grams of COD (64g/16g = 4g). Under normal conditions (1 atmosphere pressure and 0°C) 0.25 grams of CH_4 take up a volume of 350 ml. Based on a theoretical amount of 0.35 1 methane produced per gram COD removed, COD equivalent of the total methane gas produced could be calculated.

3.8. **Biomethane Measurement.**

The methane production was measured by water displacement setup. A tube was used to connect the gas outlet pipe from reactor to an inverted cylinder of known volume immersed in a 3 M KOH solution to absorb CO_2 and H_2S. Methane produced was collected in the cylinder which allowed volumetric methane measurements at atmospheric pressure.

3.9. **Financial Analysis**

Financial analysis was conducted by using Net Present Value (NPV) method, Internal Rate of Return (IRR) method and Payback (PB) period method of using these technologies was calculated to study the feasibility of bio-methane generation from brewery wastewater. Assumptions needed for financial analysis were made from market study and literature reviews of similar research work.

3.9.1. Net Present Value

The process of translating a future payment into a value at present is called discounting. The value at present of a future payment is called the present value (PV). And, the interest rate used to do the discounting is called the discount rate. The net present value (NPV) is the difference between the sum of the present value of future cash flows and the initial investment.

If PV is the present value, F is the future payments, and r is the discount rate. Then

$$PV = \frac{F}{1 + r}$$

To obtain the formula for the case where the payment is two years in the future, the discounting should be done twice so that the corresponding formula for NPV would be:

$$NPV = \frac{F}{(1 + r)^2} - I$$

Where, I = initial Investment

Similar reasoning implies that the net present value of a payment made in n years in the future would be:

$$NPV = \frac{F}{(1 + r)^n} - I$$

Likewise, the Net Present Value of a series of payments made in several different years can be obtained by extending the aforementioned formula.

$$NPV = \sum_{k=0}^{n} \frac{F}{(1 + r)^n} - I$$

3.9.2. Internal Rate of Return

Internal Rate of Return (IRR) gives the annual return for any capital investment. It is the discount rate for which the NPV of net benefit (benefits minus costs) is zero. Internal rates of return (IRRs) are of two types – financial and economic. Financial rates of return (FIRR) are calculated only by considering private benefits and private costs, while economic rates of return (EIRR) are calculated by considering social benefits and social costs. FIRR refer to the internal rates of return from user's point of view while

EIRRs refer to the internal rates of return from economic point of view. However, IRR itself does not, on its own, provide a criterion for selection of projects. It also has to be compared with market rate of interest, or social rate of interest. In this case, the following decision rule can be applicable:

- Select a single project if IRR is greater than market rate of interest or social discount rate; and
- In case of more than one project, rank the projects in descending order of IRR values and select the projects for which IRR are greater, subject to fund availability.

3.9.3. Pay Back Period

In general, the simple PB period can be calculated with the following:

$$PB = \frac{Investment\ cost}{Annual\ cash\ inflow}$$

Where, the annual cash inflow represents the difference between the annual revenue stream and the annual costs stream. This parameter is usually used for giving an initial evaluation of the time required to recover the investment.

When cash inflows are uneven, the cumulative net cash inflow for each period should be calculated and then following formula for payback period is used:

$$Payback\ Period = A + \frac{B}{C}$$

Where, A is the last period with a negative cumulative cash flow; B is the absolute value of cumulative cash flow at the end of period a; C is the total cash flow during the period after A.

CHAPTER FOUR: RESULTS AND DISCUSSION

4.1. Spent Wash Characterization

During the study period, wide variation in brewery effluent in terms of pH, BOD and COD was observed. The brewery effluent pH varied from 5.17 to 10.1. the wide variation in pH value was due to chemicals used at the CIP units such as caustic soda and due to batch processing nature of brewing industry. The variation in brewery effluent concentration of COD and BOD was 339 - 4110 mg/l and 199 – 2420 mg/l respectively during the observation period. The average value of COD during the study period was around 1493 mg/l. Also, wide variation in the brewery waste water composition was observed as it depends upon the activities and practices of the brewery plant. The characteristics of brewery effluent calculated during the study is shown in the Table 4. 1 below.

Table 4. 1 Brewery Wastewater characteristics

Characteristics	Packing Section	Brewing Section	Inlet UASB	Outlet UASB
Average Discharge (m^3/hr.)	3 to 4			
pH	8.03 - 10.1	5.17 - 7.72	5.58 - 11.46	6.18 – 8.56
BOD (mg/l)	199 - 1780	1220 - 2420	99- 2370	73- 1338
COD (mg/l)	339 - 2968	2034 - 4110	165 - 3950	121 - 2230

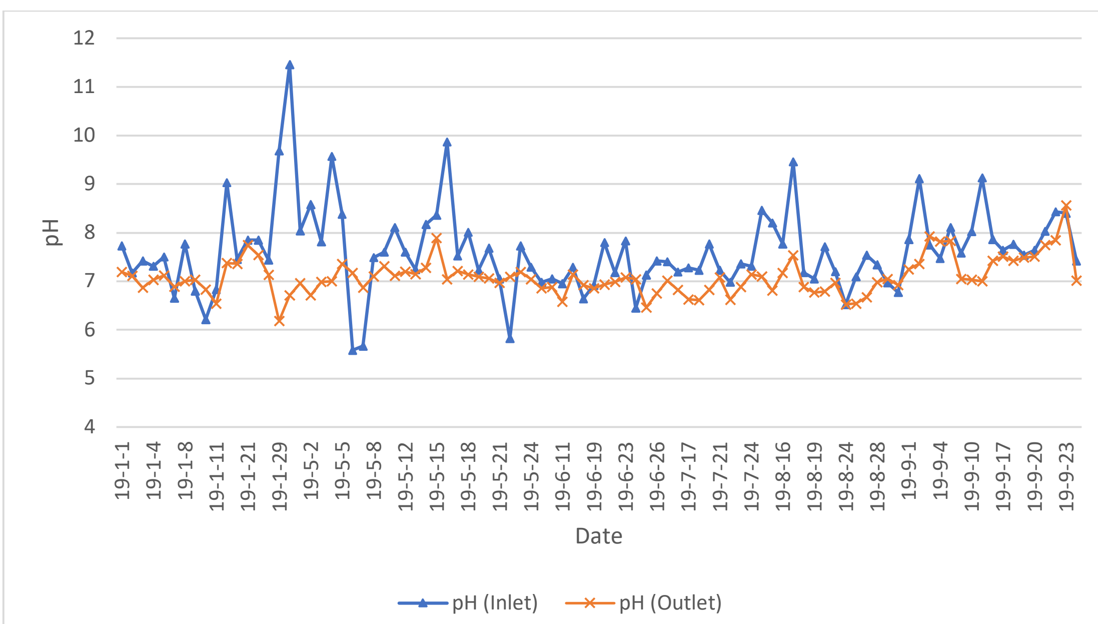

Figure 4. 1 pH variation at inlet and outlet of UASB reactor

The pH of an anaerobic reactor is especially important because methanogenesis process can proceed at a high rate only when the pH is maintained in the range of 6.3–7.8 (Casserly and Erijman, 2003). The pH variation at the inlet and outlet the UASB reactor is shown in Figure 4.1. The pH value ranged from 6.18- 8.56 during the study.

Figure 4.2 shows the COD values in mg/l before and after digestion in the UASB reactor with 48 hours HRT during the study. The COD value at the UASB inlet ranged from 165 to 3950 mg/l and the COD value at the outlet of UASB Reactor ranged from 121 to 2230 mg/l.

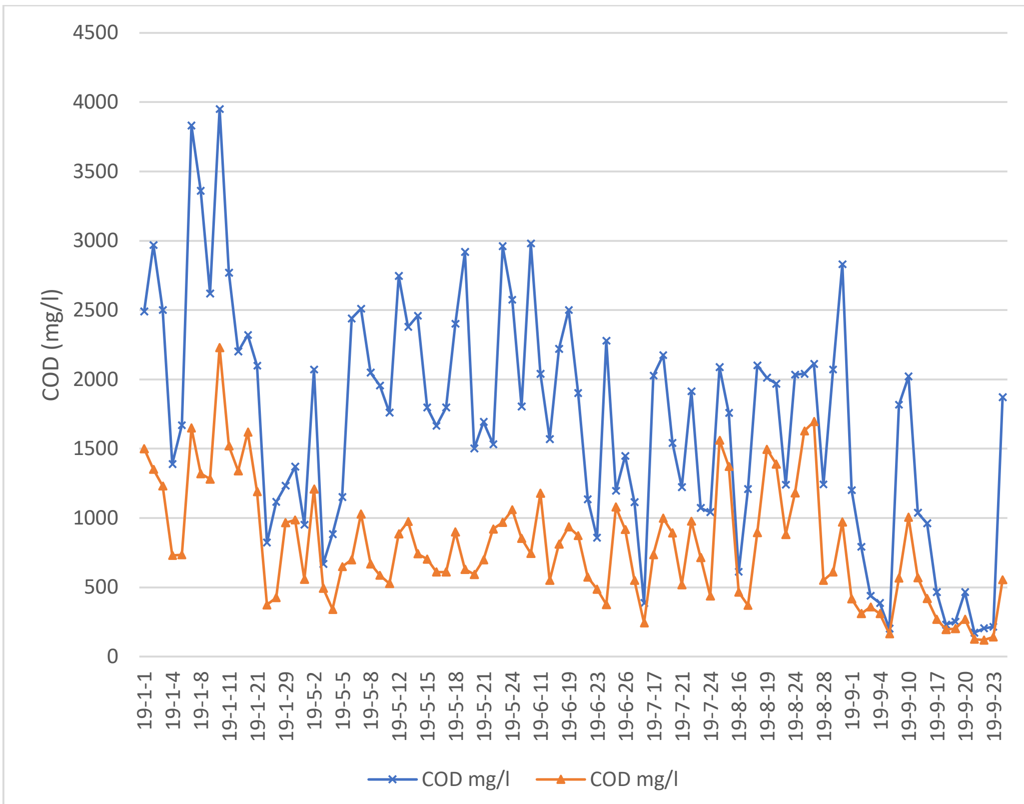

Figure 4. 2 COD values before and after anaerobic digestion in UASB Reactor

4.2. **Theoretical Bio Methane Potential**

Figure 4.3 shows the theoretical values of the methane gas generated based on the COD conversion by the UASB reactor. The average theoretical methane gas generation during the study period was calculated to be 26.2 Nm^3 per day. The maximum theoretical bio methane gas generated on a day was 67.3 Nm^3. Later actual bio methane generated was measured.

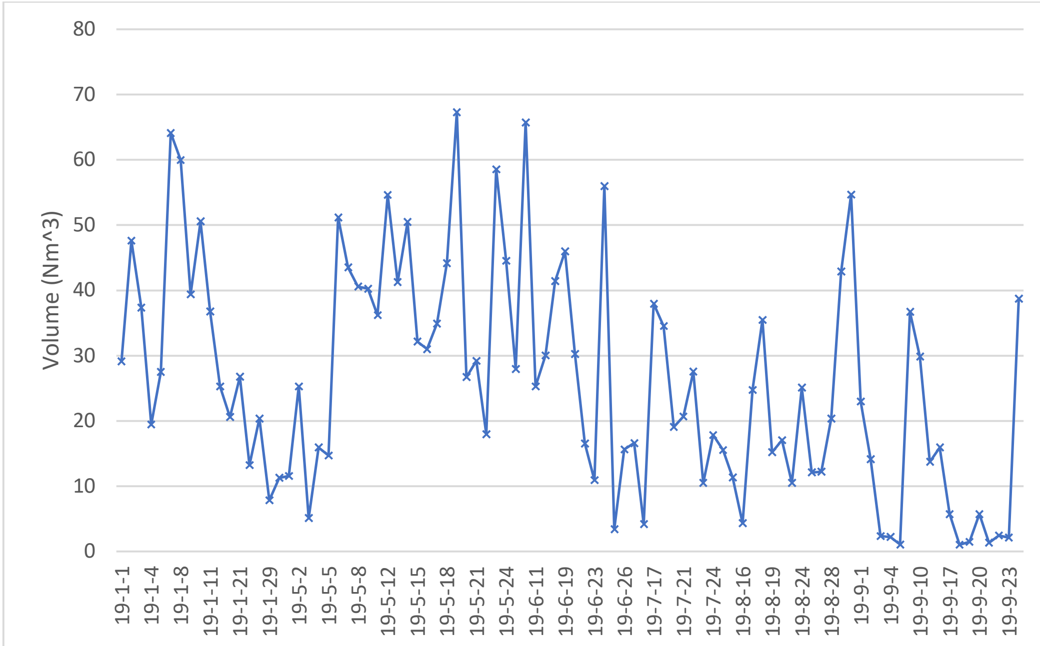

Figure 4. 3 Theoretical Volume of Methane Generated Daily in Nm^3

4.3. **Actual Biomethane Potential**

Based on the sample measurement of the biomethane generated, the actual biomethane yield was found to be 0.14-0.16 m^3/kg COD removed. The actual biomethane generated is shown if Figure 4. 4.

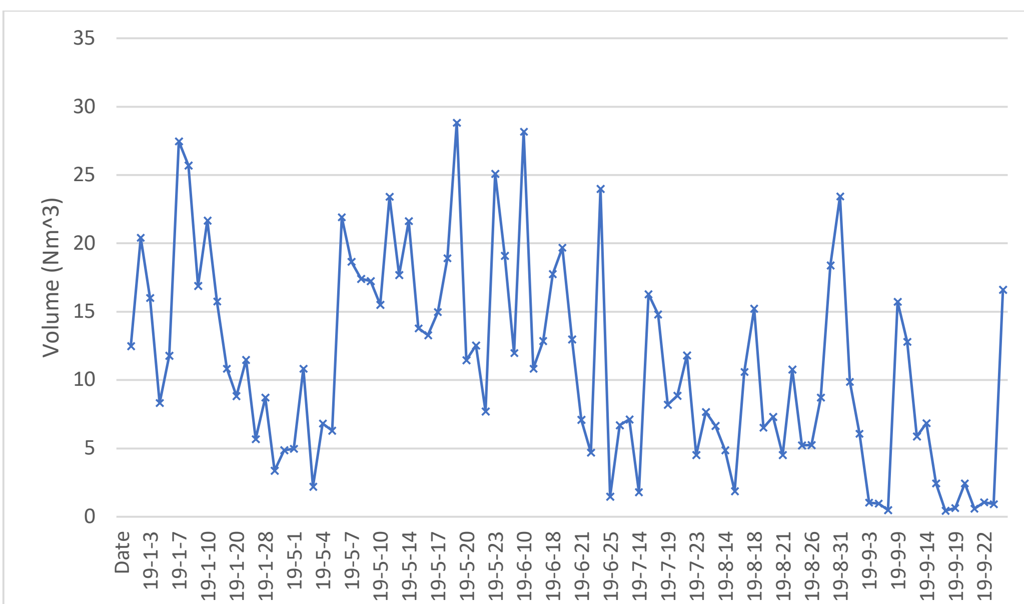

Figure 4. 4 Actual Biomethane Generated Daily (Nm^3)

The organic loading rate varied widely during the study period as the waste concentration in terms of COD and BOD varied and the effluent generation from brewery also varied. The average organic loading rate was 0.85 kg COD/ m^3.d. The variation in organic loading rate is shown in Figure 4.5.

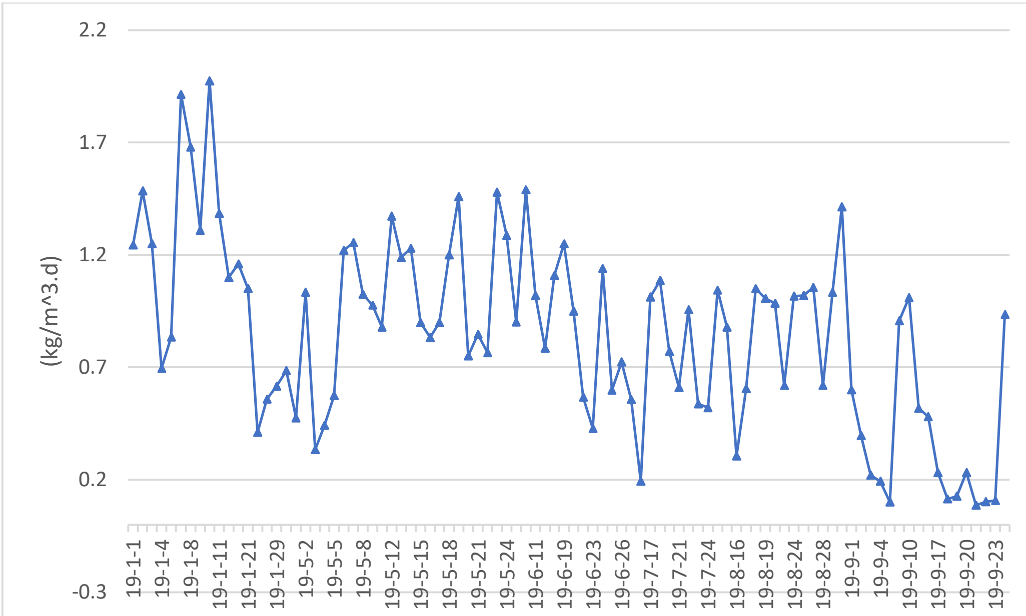

Figure 4. 5 Variation in Organic Loading Rate

4.4. **COD Removal Efficiency of UASB Reactor**

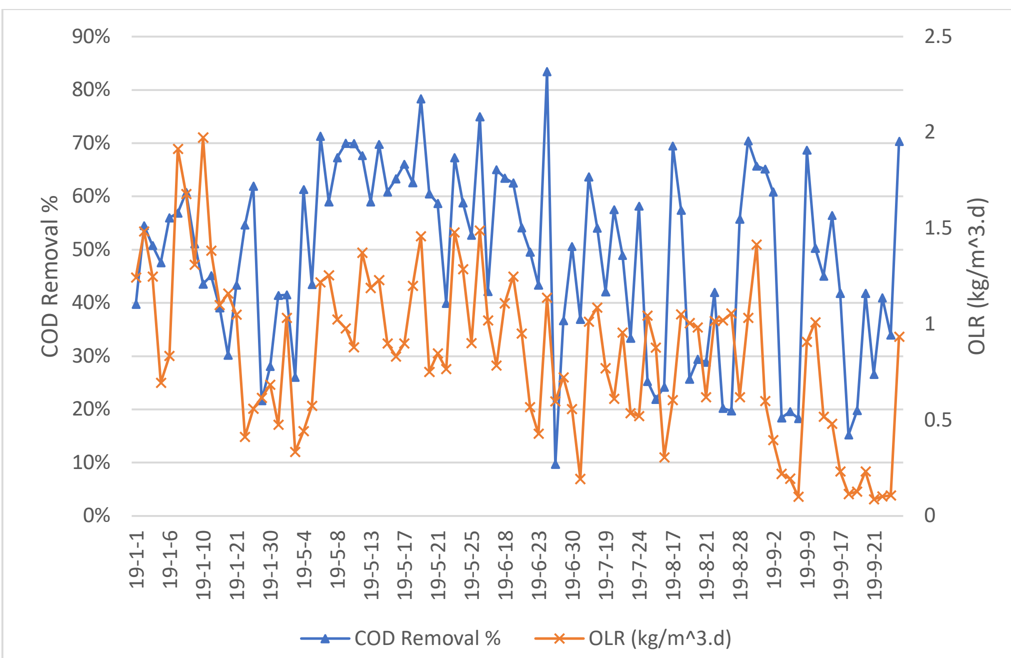

Figure 4. 6 COD Removal Efficiency (UASB) at various OLR

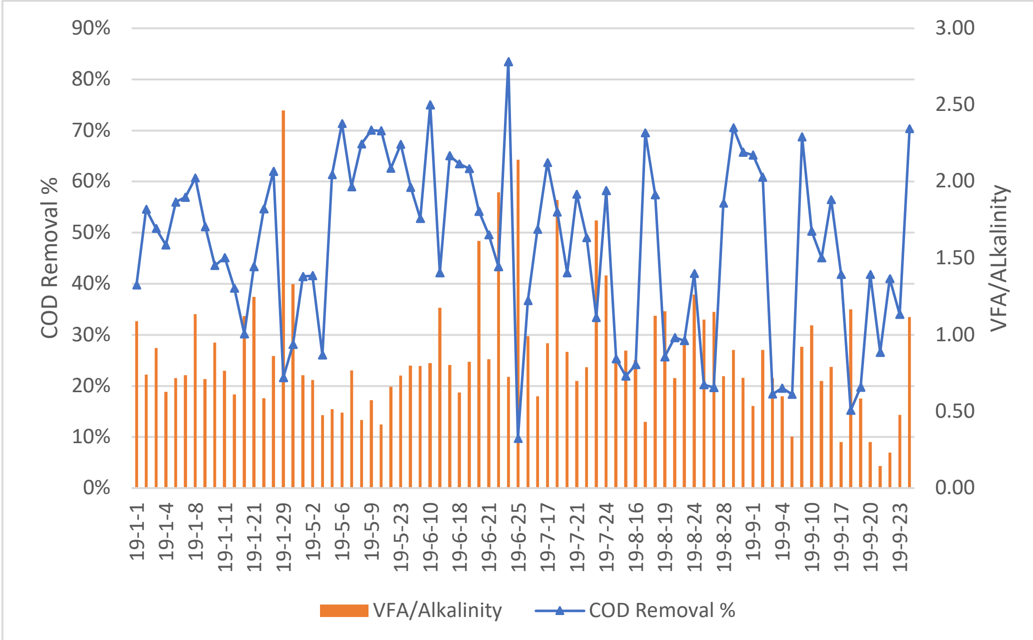

Figure 4. 7 COD Removal Efficiency (UASB) at various VFA/Alkalinity

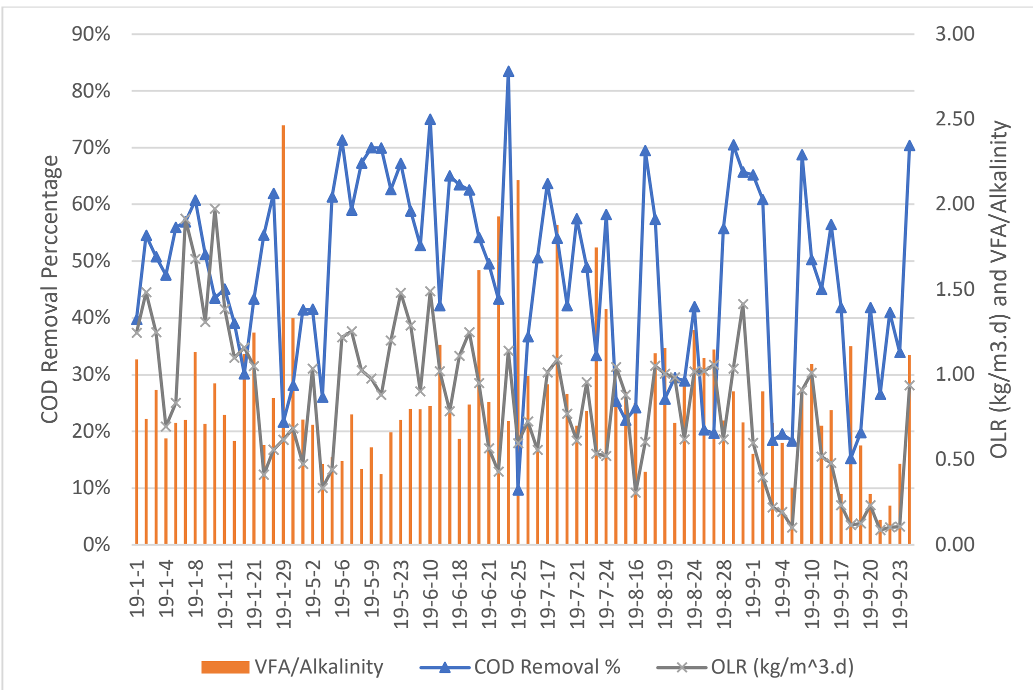

Figure 4. 8 COD Removal Efficiency (UASB) at various OLR and VFA/Alkalinity ratio

The COD removal efficiency of UASB reactor at various organic loading rate and at various VFA/Alkalinity ratio is shown in Figure 4.8. The COD removal efficiency of the UASB reactor at 48 hours HRT ranged from 4.0 % to 83.64 % during the observation period. The lowest efficiency was observed at OLR of 0.46 Kg/m^3.d and VFA/Alkalinity ratio of 1.19. The highest efficiency was observed at OLR of 1.12 Kg/m^3.d and VFA/Alkalinity ratio of 0.7.

During the observation period, the overall efficiency of the UASB reactor in terms of COD removal was found to be 51.5 %. The lower efficiency observed during the period can be attributed to various factors such as lower organic loading rate value due to variation in activities and operation of brewery plant as well as the high VFA to alkalinity ratio.

The VFA, alkalinity and VFA/alkalinity ratio during the observation period is shown in Figure 4.9. The concentration of VFA was found range from 86 to 1457 mg/l. The alkalinity was found to range from 400 to 1540 mg/l. The VFA to alkalinity ratio was found to range from 0.14 to 2.46.

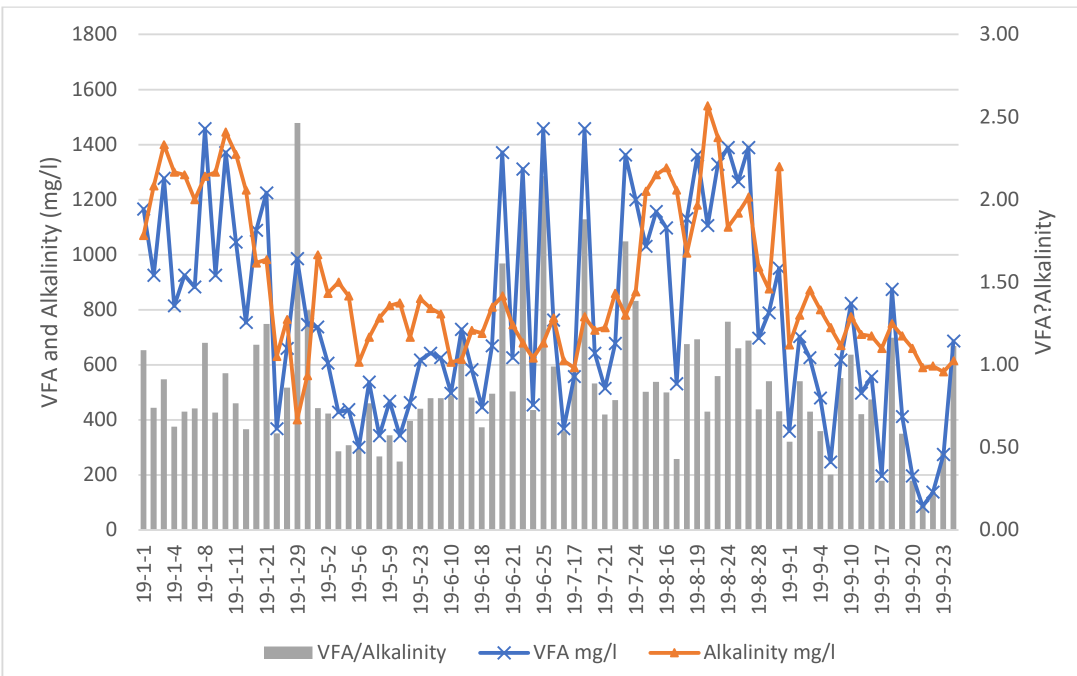

Figure 4. 9 VFA, Alkalinity and VFA/ Alkalinity

The brewery wastewater characteristics and the efficiency of the UASB reactor observed from the study and from various literature is shown in the Table 4.2. The COD removal efficiency of the UASB reactor from this study was found to be lower than that of other literature mentioned in Table 4.2. One of the reasons behind lower efficiency of the UASB reactor was high VFA to alkalinity ratio. The optimum ratio of VFA to alkalinity should be less than 0.3 or 0.4. (Sanchez *et al.*, 2005). The VFA to alkalinity ratio of the UASB reactor was found to be higher than 0.4 for most of the time during the observation period, causing instability of UASB reactor.

Table 4. 2 Reported Brewery Wastewater Characterization from The Literature and The Efficiency of the UASB Reactor at Raj Brewery, Bhairahawa

Parameter	This study	(Parawira *et al.*, 2005)	(Ahn, Min and Speece, 2001)	(Díaz *et al.*, 2006)	(Abimbola *et al.*, 2015)
pH	5.17 – 10.1	3 -6.3	6.3 – 6.9	7.2	4.6 – 7.3
COD (mg/l)	339 - 4110	8240- 20000	910 - 1900	4000	1096 - 8926
COD Removal %	51.5	57	80	80	79

4.5. **Aerobic Digestor**

The brewery waste water needs to be treated further after digestion in the UASB reactor before they are discharged into the environment as the level of BOD, COD, TSS and other particles are considerably high from environmental perspective. The effluent from the UASB reactor is further treated aerobically to bring the BOD, COD, TSS and other particles to a safe level.

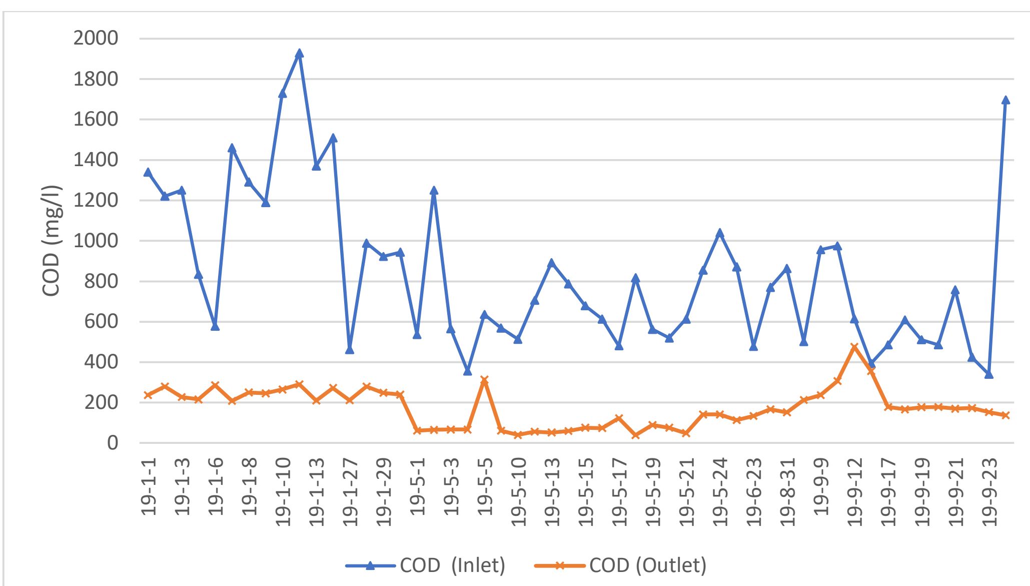

Figure 4. 10 COD at the Inlet and Outlet of Aerobic Reactor

Figure 4. 10 shows the COD values in mg/l before aerobic digestion in the aeration tank and after aerobic digestion and treatment. The COD value at the influent ranged from 340 to 1930 mg/l and the COD value of the treated water in the aerobic digester ranged from 38 to 475 mg/l.

4.6. **COD Removal Efficiency of Aerobic Digestor**

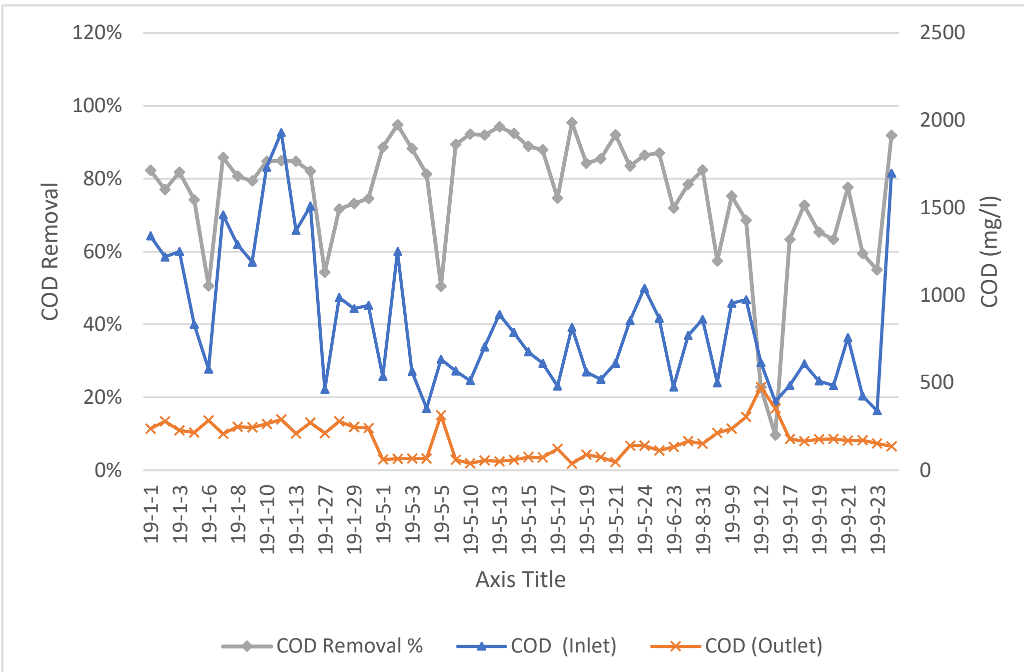

Figure 4. 11 COD Removal Efficiency of Aeration Tank

The daily COD removal efficiency of aerobic digestion and treatment plant is shown in the Figure 4.11. The COD removal efficiency ranged from 22 % to 95 % during the observation period. The COD values of the effluent from the aerobic digestor was fairly consistent. During the observation period, the overall efficiency of the aerobic treatment plant in terms of COD removal was found to be 78.5 %.

4.7. **Treated Water**

The post treated water is further treated with hypo-chloride and is passed through multi-grade filter and activated carbon filter to further reduce organic matter, suspended solids and odor in the water.

Figure 4.12, 4.13, 4.14 and 4.15 shows the pH, BOD, COD, TSS values of the treated water against the discharge guidelines for waste water before it is discharged to the environment. All those values were within the limit set by Government of Nepal regarding the wastewater discharge.

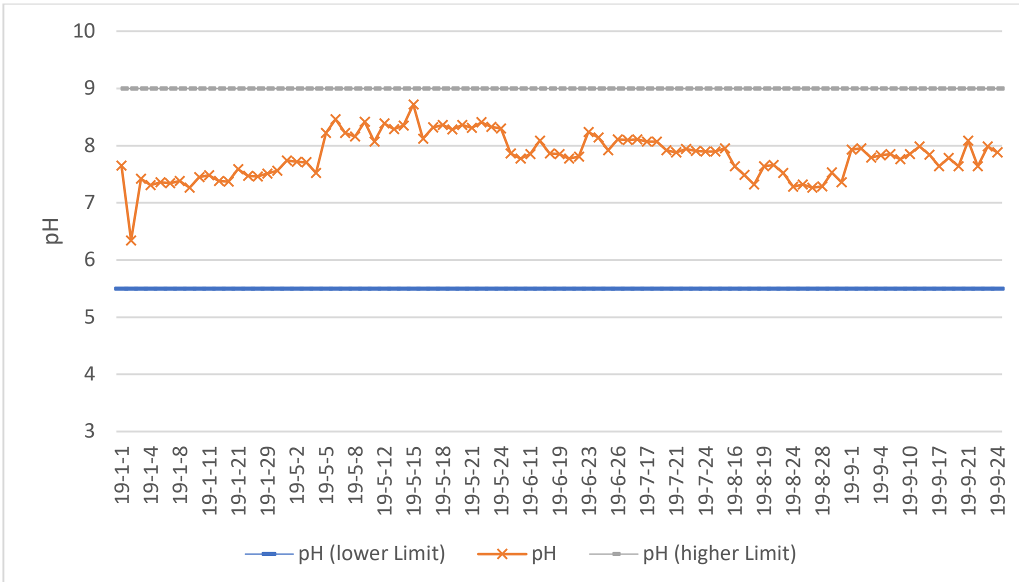

Figure 4. 12 pH Value of Treated Water against Guidelines Values

The pH value of treated water was found to be within the range (5.5 – 9.0) as specified by the Government of Nepal.

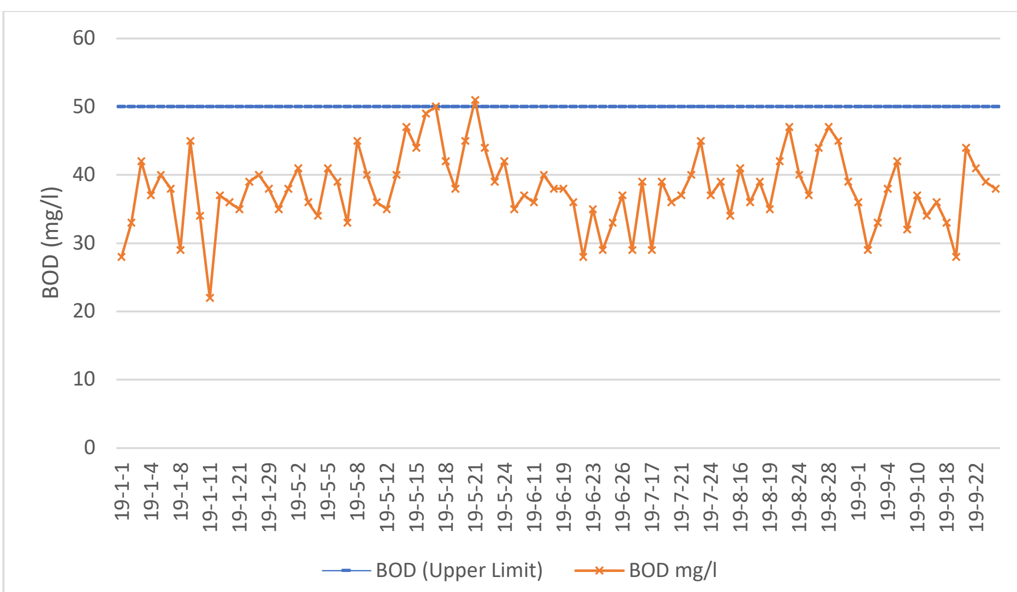

Figure 4. 13 BOD Value of Treated Water against Guidelines Values

The BOD value of treated water was also within the limit (< 50 mg/l) specified by Government of Nepal during almost all the samples measured as shown in Figure 4.13.

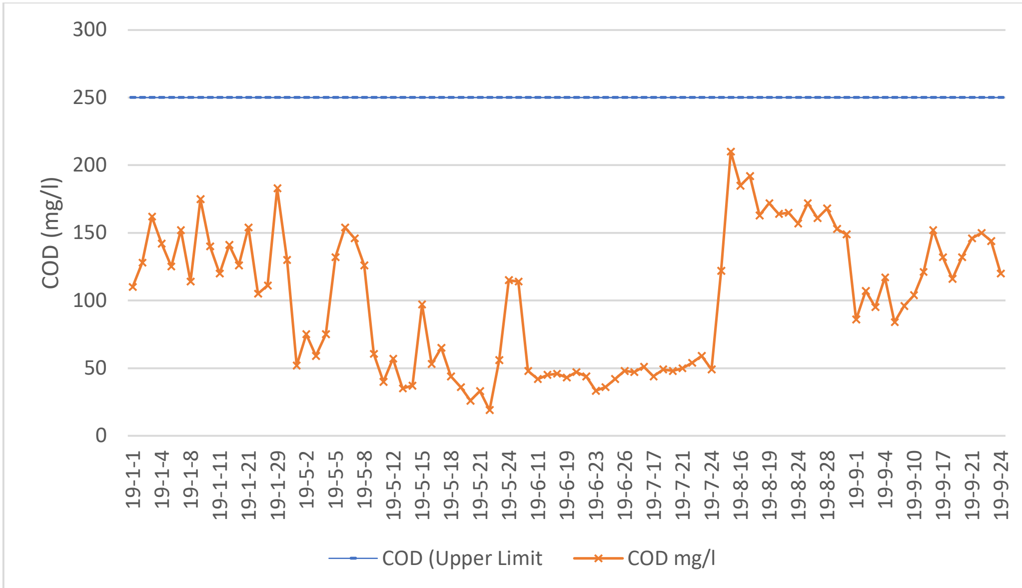

Figure 4. 14 COD value of treated water against discharge guideline value

The COD value of treated water was also within the limit (< 250 mg/l) specified by Government of Nepal.

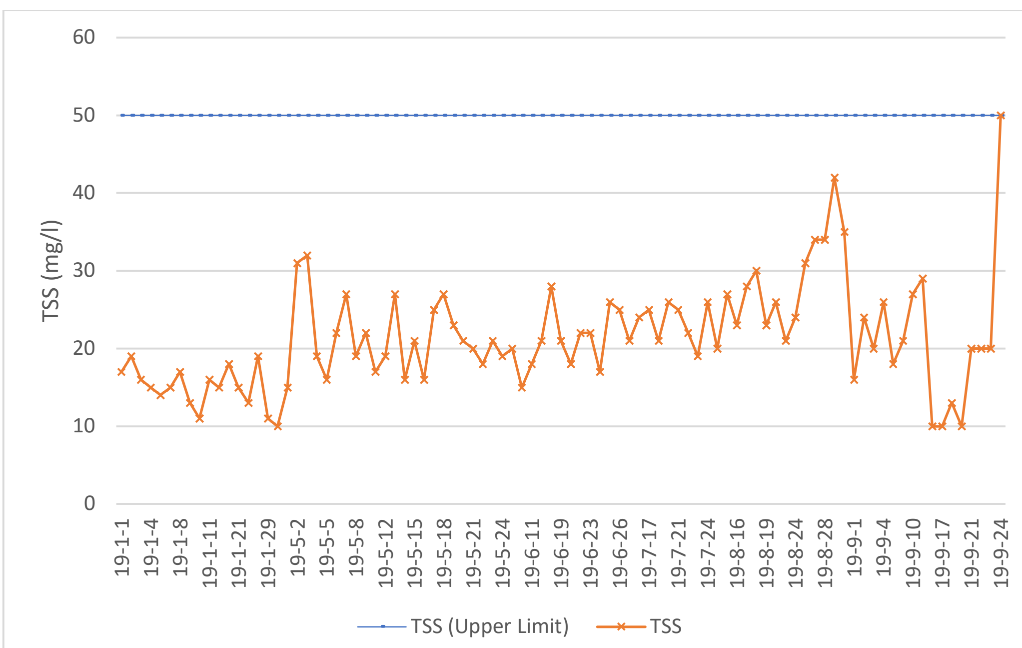

Figure 4. 15 TSS value of treated water against discharge guideline value

The TSS value of treated water was also within the limit (< 50 mg/l) specified by Government of Nepal.

Table 4. 3 Comparison of Treated Wastewater against Discharge Guidelines (GoN, 2010)

Parameters	Unit	Standard Value (GoN)	This study
pH		5.5 to 9.0	6.34- 8.72
Biochemical Oxygen Demand for 5 days at 20 °C	mg/l	< 50	22 -51
Chemical Oxygen Demand	mg/l	< 250	19 -210
Total Suspended Solids	mg/l	< 50	10 - 50

4.8. **Financial Analysis**

Financial analysis includes calculation of Net Present Value (NPV), Internal Rate of Return (IRR) and Payback (PB) Period of investments made on the UASB reactor. The financial analysis has been done by taking into consideration Capital cost, Operating and Maintenance cost, cost of manpower, power requirements, and cost of chemicals. and income earned from the UASB Reactor. Capital cost included the cost of screen, grit chamber, wastewater treatment facility and other necessary facilities. Repair costs for civil work, mechanical and electrical equipment are estimated annually as a certain percentage multiplied by capital cost.

- The capital cost of the plant was estimated to be around NRs. 4 Million. (Sato *et al.*, 2007)
- The annual repair cost for civil work was calculated at 0.5% of the capital cost for UASB. (Sato et al., 2007)
- Likewise, the annual repair cost for mechanical and electrical equipment was calculated at 3% of the capital cost. (Sato et al., 2007).
- The annual power cost, was estimated to be about NRs. 85,000 without further increment. (Khalil et al., 2008)
- The annual labor cost was estimated to be about NRs. 25,000 with 5% annual increment. (Khalil et al., 2008)
- The annual chemical cost was estimated to be about NRs. 35,000 with 2.5% annual increment respectively. (Khalil et al., 2008)

- The economic life of plant and annual rate of interest have been considered as 30 years and 12% respectively. (Khalil et al., 2008).
- This research assumes a straight-line depreciation starting from the first year of operation.
- The total income generated by the plant is about NRs. 1.4 million annually considering the biomethane generation daily and assuming that the UASB reactor is operating at its full capacity i.e. UASB reactor treats 350 kiloliters effluent daily. The production capacity of UASB plant is equivalent to 2.85 LPG cylinders per day on the basis of calorific value.

Based on the above assumptions, a discounted cash flow (DCF) analysis was conducted for 30 years and Net Present Value (NPV) was calculated at the discount rate of 12 %.

NPV for the UASB plant was calculated to be around NRs. 2.1 million. Similarly, the internal rate of return for the UASB plant was calculated to be around 19 %. The payback period was calculated to be around 6 years.

From the above financial analysis, it can be supported that energy recovery from the brewery spent wash is viable at Raj Brewery, provided that the UASB reactor is operated at its full capacity.

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CHAPTER FIVE: CONCLUSION AND RECOMMENDATIONS

5.1. Conclusion

From this study the following conclusions were made:

- The amount of bio-methane that is generated from brewery spent wash was calculated to be around 11 Nm^3 per day at 48 hours HRT and volumetric loading rate of 84 m^3 under various organic load. The methane yield was found to be around 0.14-0.16 Nm^3 per kg of COD removed. The amount of bio-methane that is generated, if the UASB reactor operates at full capacity i.e. if it treats 350 m3 of waste water daily, is 47 Nm^3.
- The overall efficiency of the UASB reactor in terms of COD removal was found to be 52.5 % at 48 hours HRT. The COD removal efficiency of the UASB reactor at 48 hours HRT ranged from 4.0 % to 86.34 %. The overall COD removal efficiency of the aerobic treatment plant was found to be 78.5 %. The COD removal efficiency of the aerobic treatment plant ranged from 22 % to 95 %.
- The average pH, BOD, COD and TSS value of treated wastewater from the effluent treatment plant were found to be 7.82, 37.94 mg/l, 100.93 mg/l and 21.33 mg/l respectively and within the disposal guidelines set by Government of Nepal.
- A discounted cash flow (DCF) analysis was conducted for 30 years. Net Present Value (NPV) for UASB technology was calculated at the discount rate of 12 % and it was found to be NRs. 2.1 million. The IRR and payback period were calculated to be 19 % and 6 years respectively.

5.2. Recommendations

- The bio methane potential was estimated with a hydraulic retention time of 48 hours. The bio methane potential can be estimated by varying the hydraulic retention time and other parameters to get a better understanding of bio methane potential under various conditions.
- The biomethane generation volume was estimated based on the measurement of volume of limited biomethane samples generated during the study. A gas flow meter could be installed to monitor the actual gas generation values.

- The gas generated at Raj Brewery was flared to atmosphere. The gas generated could be utilized as boiler feed or in other processes to recoup the energy from the waste.
- The UASB reactor at Raj Brewery was operated at ambient temperature. Temperature control device could be installed in the reactor to maintain the temperature at optimal level for better performance.
- The VFA/alkalinity ratio of the UASB reactor was found to be high for longer period of time. The ratio could be brought to an optimal value for efficient operation of the UASB reactor.
- The treatment of brewery spent water through UASB technology offers several environmental benefits. It not only reduces the GHG gas emitted in the atmosphere due to capturing of methane but also reduces the consumption of other fuels. It also reduces the organic contents in the wastewater and produces treated water which could be used for irrigation. Hence, UASB technology in combination with aerobic treatment could be adopted by brewery and other industries, which produces large amount of wastewater, for mitigating problems caused by wastewater.

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Annex I - Effluent Treatment Plant

SIMA LABS PVT. LTD.
Sophisticated Industrial Materials Analytic Labs Pvt. Ltd.

CERT ISO 9001

RAJ BREWERIES KATHMANDU	Project No.	P - 860
	Prepared By	Poonam
EFFLUENT TREATMENT PLANT - 350 KLD	Revision	1

UNIT LIST

S.No	UNIT	QTY.	SIZE / CAPACITY	MAKE / MOC	TYPE	PURPOSE	SCOPE	DRAWING / DATA SHEET
1	CIVIL							
1.1	BAR SCREEN CHAMBER	1 No.	Size : 1.2 m x 1.2m	Civil Structure	Tank	For removal of Fine & coarse particles	Client	Architectural Drawing
1.2	OIL & GREASE TRAP	1 No.	Size : 2.0 m x 1.2m x 1.0m SWD+FB Capacity: 2.4 m^3	Civil Structure	Tank	For Trapping Oil and Grease	Client	Architectural Drawing
1.3	EQUALIZATION TANK	1 No.	Size : 6.0 m x 5.0m x 3.0m +FB Capacity: 90.0 m^3	Civil Structure	Tank	For Equalization of Wastewater.	Client	Architectural Drawing
1.4	BUFFER/UASB FEED TANK	1 No.	Size : 5.0 m x 1.8m x 3.0m +FB Capacity: 27.0 m^3	Civil Structure	Tank	For maintaining of pH of waste water	Client	Architectural Drawing
1.5	UASB REACTOR	1 No.	Flow : 350 m^3/day Capacity : 193.8m^3 Dia : 6.7m Height : 5.5m	Civil Structure	Tank	For anaerobic digestion of the waste water	Client	Architectural Drawing
1.6	PRIMARY CLARIFIER	1 No.	Size : Dia : 4.8m ; Height : 2.5 m Surface Loading : 1.0 m3/m2/hr	Civil Structure	Tank	For the separation of solid and liquid from the effluent	Client	Architectural Drawing
1.7	AERATION TANK FEED SUMP	1 No.	Size : 3.0 m x 3.0 m x 3.0 m - F.B Capacity : 27.0 m3	Civil Structure	Tank	For feed it effluent to aeration tank	Client	Architectural Drawing
1.8	AERATION TANK	1 No.	Size : 8.0 m x 6.0 m x 4.6 m + F.B Capacity : 220.8 m3	Civil Structure	Tank	For aerobic digestion of the waste water	Client	Architectural Drawing
1.9	SECONDARY CLARIFIER	1 No.	Size : Dia : 5.3 m ; Height : 2.5 m Surface Loading : 0.8 m3/m2/hr	Civil Structure	Tank	For the separation of solid and liquid from the effluent	Client	Architectural Drawing
1.10	CLEAR WATER TANK	1 No.	Size : 4.6 m x 3.0 m x 3.0 m + F.B Capacity : 36.0 m3	Civil Structure	Tank	For collection of clear water	Client	Architectural Drawing
1.11	TREATED WATER TANK	1 No.	Size : 5.0 m x 4.0 m x 3.0 m + F.B Capacity : 60.0 m3	Civil Structure	Tank	For Collection of Treated water	Client	Architectural Drawing

Annex II - ETP Analysis

Equilization Tank		Buffer Tank		UASB Outlet				Aeration Feed Tank			Aeration Tank		Secondary Clarifier					Clear water Tank	Treated Water						
pH	COD mg/l	pH	COD mg/l	pH	COD mg/l	FVA mg/l	Alkalinity mg/l	pH	COD mg/l	BOD mg/l	pH	MLSS mg/l	pH	COD mg/l	TSS mg/l	Turbidity NTU	Ammonia mg/l	FRC mg/l	pH	BOD mg/l	COD mg/l	TSS mg/l	FRC mg/l	Turbidity NTU	Volume m^3
-	-	7.73	2490	7.19	1500	1165.7	1070	6.85	1340	-	7.6	1830	7.66	237	20	15	0.72	0.6	7.65	28	110	17	0.3	8.3	118.86
-	-	7.17	2970	7.11	1350	925.71	1250	7.18	1220	-	7.64	1840	7.67	280	28	16.7	0.9	0.7	6.34	33	128	19	0.4	7.2	125.85
-	-	7.42	2500	6.87	1230	1277.1	1400	7.04	1250	-	7.5	3990	7.55	228	20	16.8	0.837	0.7	7.42	42	162	16	0.4	10.3	120.17
-	-	7.31	1390	7.03	729	814	1300	7.17	834	-	7.57	1900	7.58	215	23	12.8	0.13	0.7	7.31	37	142	15	0.4	6.4	114.5
-	-	7.5	1670	7.12	735	925.71	1290	7.02	577	-	7.63	1920	7.68	285	18	19.6	0.11	0.7	7.36	40	125	14	0.5	7.5	128.1
-	-	6.65	3830	6.89	1650	882.86	1200	6.96	1460	-	7.62	1850	7.68	208	25	18.4	0.18	0.7	7.34	38	152	15	0.4	5.1	153.6
-	-	7.77	3360	7	1320	1457.1	1285	7.08	1290	-	7.61	1760	7.68	250	21	18.3	0.18	0.7	7.38	29	114	17	0.5	3.4	165.3
-	-	6.8	2620	7.03	1280	925.71	1300	6.98	1190	-	7.45	2040	7.61	245	27	12.1	0.18	0.6	7.26	45	175	13	0.5	10.3	167.2
-	-	6.21	3950	6.83	2230	1371.4	1445	6.91	1730	-	7.38	2120	7.52	265	18	11.7	0.13	0.7	7.45	34	140	11	0.4	10.5	164.96
-	-	6.83	2770	6.54	1520	1045.7	1365	5.42	1930	-	7.3	2282	7.33	290	34	15.3	0.13	0.7	7.48	22	120	16	0.3	14.6	163.12
-	-	9.03	2200	7.38	1340	754.28	1235	7.34	1370	-	7.54	2360	7.49	210	42	14.6	0.19	0.7	7.38	37	141	15	0.3	12.8	182.42
-	-	7.45	2320	7.36	1620	1088.6	970	7.25	1510	-	7.58	1820	7.59	272	-	-	-	0.6	7.37	36	126	18	0.4	7.55	116.1
-	-	7.85	2100	7.74	1190	1225	982.5	7.07	1020	-	7.47	1860	-	-	-	-	-	0.6	7.59	35	154	15	0.4	8.6	60.023
-	-	7.85	824	7.54	374	368.57	630	7.69	462	-	7.62	2030	7.67	211	27	15.6	0.09	0.7	7.47	39	105	13	0.5	9.4	134.37
-	-	7.44	1117	7.13	425	660	765	6.65	988	-	7.89	1990	7.4	280	24	10.7	0.12	0.7	7.46	40	111	19	0.4	15.8	169.49
-	-	9.68	1233	6.18	966	985.71	400	6.78	923	-	7.37	1960	7.37	248	30	10.4	0.1	0.7	7.51	38	183	11	0.5	12.7	172.85
-	-	11.46	1370	6.71	985	745.71	560	7.18	943	-	7.38	1830	7.37	240	24	11.4	0.082	0.7	7.56	35	130	10	0.4	14.6	156.8
		8.04	952	6.96	558	737.14	1000	7.1	536	-	7.54	-	7.58	61	-	43	-	0.7	7.74	38	52	15	0.4	5.6	43.137
		8.58	2070	6.71	1210	606	860	7.45	1250	-	7.29	1300	7.28	65	10	8.86	0.39	0.6	7.72	41	75	31	0.4	5.7	64.495
		7.81	668	6.99	494	428.57	900	7.77	565	-	7.64	1400	7.64	66.4	30	4.48	0.034	0.7	7.71	36	59	32	0.4	5.4	84.909
		9.57	884	7	342	437.14	850	7.91	355	-	7.62	1450	7.63	66.5	10	4.84	0	0.7	7.52	34	75	19	0.4	8.5	20.124
-	-	8.38	1150	7.36	650	-	-	8.16	635	-	7.81	-	7.92	314	-	4.84	-	-	8.22	41	132	16	0.3	3.33	67.75
-	-	5.58	2440	7.17	700	300	610	8.12	514	-	8.02	1100	8.09	-	35	12.8	-	-	8.46	39	154	22	0.2	2.26	69.29
-	-	5.67	2510	6.87	1030	537	700	7.79	894	-	7.84	1050	7.89	-	20	5.57	-	-	8.22	33	146	27	0.2	1.43	60.91
-	-	7.49	2050	7.1	670	342.85	770	7.84	681	-	7.86	1250	7.92	-	-	2.89	-	-	8.16	45	126	19	0.2	1.37	71.71
-	-	7.6	1955	7.31	586	467.14	815	8.07	568	-	7.94	-	7.99	60.3	-	3.48	-	-	8.42	40	60.5	22	0.2	3.5	71.225
-	-	8.11	1760	7.11	529	342.86	825	7.9	513	-	7.69	1080	7.76	40	-	2.75	-	-	8.07	36	40	17	0.4	1.7	56.834
-	-	7.6	2745	7.2	887	-	-	8.03	705	-	8.07	-	8.12	56.3	-	3.7	-	-	8.39	35	57	19	0.2	1.75	91.156
-	-	7.24	2380	7.15	976	-	-	7.95	891	-	8.17	-	8.18	51.5	-	2.78	-	-	8.29	40	35	27	0.2	1.65	79.73
-	-	8.17	2460	7.28	743	-	-	7.99	787	-	8.06	-	8.15	59.6	-	4.51	-	-	8.35	47	37	16	0.4	2.22	74.453
-	-	8.36	1798	7.89	704	-	-	8.42	678	-	8.45	1430	8.45	75.5	-	4.85	-	-	8.72	44	97	21	0.2	1.5	71.285

Equilization Tank		Buffer Tank		UASB Outlet				Aeration Feed Tank			Aeration Tank		Secondary Clarifier					Clear water Tank	Treated Water						
pH	COD mg/l	pH	COD mg/l	pH	COD mg/l	FVA mg/l	Alkalinity mg/l	pH	COD mg/l	BOD mg/l	pH	MLSS mg/l	pH	COD mg/l	TSS mg/l	Turbidity NTU	Ammonia mg/l	FRC mg/l	pH	BOD mg/l	COD mg/l	TSS mg/l	FRC mg/l	Turbidity NTU	Volume m^3
-	-	9.87	1664	7.04	610	-	-	7.96	613	-	7.83	-	7.89	73.8	-	5.02	-	-	8.12	49	53	16	0.2	3.09	86.524
-	-	7.52	1798	7.21	610	-	-	8.08	481	-	8.02	1480	8.01	122	-	5.67	-	-	8.32	50	65	25	0.4	1.65	67.643
-	-	8.01	2400	7.14	898	462.86	700	8.03	817	-	8	1550	8.03	37.8	-	5.13	-	-	8.36	42	44	27	0.2	1.53	67.598
-	-	7.23	2920	7.09	631	-	-	7.86	562	-	7.94	1465	7.97	88.6	-	8.86	-	-	8.28	38	36	23	0.2	2.57	83.9
-	-	7.68	1502	7.06	593	-	-	7.84	519	-	7.98	1580	8.05	75.4	-	6.57	-	-	8.36	45	26	21	0.2	0.86	78.078
-	-	7.05	1694	6.97	700	-	-	7.82	613	-	7.98	1650	8	48.7	-	6.29	-	-	8.31	51	33	20	0.2	0.91	85.849
-	-	5.82	1532	7.09	920	-	-	7.75	756	-	8	1680	-	-	-	-	-	0.3	8.41	44	19	18	0.4	1.4	78.162
-	-	7.73	2960	7.19	969	617.14	840	8.03	855	-	8.29	1750	8.23	141	-	28.9	-	-	8.33	39	56	21	0.2	5.85	77.328
-	-	7.29	2575	7.04	1060	642.86	805	7.91	1040	-	8.15	1820	8.19	141	40	27.8	-	-	8.3	42	115	19	0.4	7.4	100.39
-	-	6.98	1804	6.86	853	625.71	785	7.55	871	-	7.72	1950	7.78	113	-	18.5	-	-	7.86	35	114	20	0.5	9.2	86.299
-	3380	7.05	2980	6.88	745	497.14	610	7.73	485	-	7.5	1580	-	-	-	-	-	-	7.77	37	48	15	0.4	2.1	70.35
-	2736	6.95	2040	6.58	1180	728.57	620	7.36	865	-	7.52	1540	7.51	-	-	9.7	-	-	7.85	36	42	18	0.4	1.4	60.18
7.63	1730	7.29	1570	7.14	549	582.86	725	7.73	464	-	7.49	1300	7.45	-	-	11.2	-	-	8.09	40	45	21	0.5	1.8	54.69
5.33	2700	6.64	2220	6.92	812	445.71	715	7.65	542	-	7.6	1310	7.56	-	-	4.84	-	-	7.86	38	46	28	0.5	1.7	60.01
6.37	2960	6.92	2500	6.86	937	668.57	810	7.55	676	-	7.58	1400	7.67	-	-	4.2	-	-	7.85	38	43	21	0.5	1.9	58.56
10.09	1578	7.8	1902	6.93	872	1371.4	850	7.53	833	-	7.71	1240	7.68	-	-	4.42	-	-	7.77	36	47	18	0.5	2	58.80
7.94	1124	7.18	1136	6.99	573	625.71	745	7.64	665	-	7.91	1280	7.88	-	-	4.39	-	-	7.81	28	44	22	0.4	1.8	80.96
8.46	808	7.83	858	7.08	486	1311.4	680	7.7	477	-	7.92	1350	7.93	134	-	13.3	-	-	8.24	35	33.2	22	0.3	2.87	80.20
5.21	4100	6.45	2280	7.04	377	454.28	625	7.71	376	-	7.91	1420	7.87	-	-	8.04	-	-	8.14	29	36	17	0.2	4.1	70.66
8.69	2968	7.13	1196	6.46	1080	1457.1	680	7.28	848	-	7.81	1380	7.85	-	-	9.34	-	-	7.92	33	42	26	0.5	3.5	88.70
9.48	1634	7.42	1448	6.75	917	762.86	770	7.44	1050	-	7.87	1400	7.88	-	-	10.8	-	-	8.11	37	48	25	0.5	3.9	74.00
-	-	7.4	1114	7.01	550	368.57	615	7.67	503	-	7.92	1450	8	-	-	15.7	-	-	8.1	29	47	21	0.4	1.91	67.53
8.35	339	7.19	387	6.82	244	-	-	-	251	-	7.87	1360	-	-	-	3.95	-	-	8.11	39	51	24	0.4	2.5	69.86
-	-	7.28	2027	6.63	736	557.14	590	7.7	424	-	7.77	1250	7.78	-	-	5.08	-	-	8.07	29	44	25	0.2	1.28	71.556
-	-	7.23	2174	6.61	999	1457.1	775	7.74	839	-	7.78	1440	7.87	-	-	5.02	-	-	8.07	39	49	21	0.2	0.89	99.088
-	-	7.77	1541	6.82	892	642.85	725	7.48	837	-	7.81	1210	7.88	-	-	8.97	-	-	7.92	36	48	26	0.4	3.4	79.28
-	-	7.23	1222	7.08	519	514.29	735	7.72	484	-	7.76	1140	7.69	-	-	4.03	-	-	7.88	37	50	25	0.4	2.5	80.122
9.73	1742	6.98	1914	6.62	977	677.14	860	7.55	636	-	7.79	1100	7.81	-	-	10.1	-	-	7.94	40	54	22	0.2	1.9	87.179
-	-	7.36	1073	6.88	715	1362.9	780	7.81	626	-	-	-	-	-	-	-	-	-	7.91	45	59	19	0.2	0.88	87.069
-	-	7.31	1043	7.14	436	1200	865	7.71	495	-	-	-	7.76	-	-	11	0.05	-	7.9	37	49	26	0.2	1.3	83.654
-	-	8.46	2089	7.1	1561	1030	1230	7.19	1429	-	7.83	1580	7.84	224	10	16.5	7.5	-	7.9	39	122	20	0.8	10.3	121.54
-	-	8.2	1759	6.81	1373	1157.1	1290	7.38	1465	-	7.64	1620	7.88	210	20	19.4		-	7.95	34	210	27	0.5	8.5	123.48

Equilization Tank		Buffer Tank		UASB Outlet				Aeration Feed Tank			Aeration Tank		Secondary Clarifier					Clear water Tank	Treated Water						
pH	COD mg/l	pH	COD mg/l	pH	COD mg/l	FVA mg/l	Alkalinity mg/l	pH	COD mg/l	BOD mg/l	pH	MLSS mg/l	pH	COD mg/l	TSS mg/l	Turbidity NTU	Ammonia mg/l	FRC mg/l	pH	BOD mg/l	COD mg/l	TSS mg/l	FRC mg/l	Turbidity NTU	Volume m^3
-	-	7.77	612	7.17	464	1097.1	1315	7.84	742	-	7.78	1640	7.84	210	28	17.6	0.438	-	7.64	41	185	23	0.7	6.9	146.84
-	-	9.46	1210	7.53	369	531.43	1235	6.78	451	-	7.99	1790	7.97	199	34	18.7	0.686	-	7.49	36	192	28	0.5	8.3	146.75
-	-	7.18	2102	6.88	895	1131	1005	6.34	496	-	7.81	-	7.99	188	-	16.4	0.56	-	7.32	39	163	30	0.6	6.4	134.34
-	-	7.05	2012	6.77	1495	1362.9	1180	6.86	1207	-	7.57	1500	7.61	183	10	12.8	0.44	-	7.64	35	172	23	0.7	7.1	148.2
-	-	7.71	1969	6.79	1389	1105.7	1540	7.12	1357	-	7.52	-	7.49	192		12.5	0.44	-	7.66	42	164	26	0.5	7.6	154.82
-	-	7.2	1240	6.97	882	1328.6	1425	6.89	970	-	7.52	2060	7.52	175	20	18.5	0.74	-	7.52	47	165	21	0.3	4.7	153.9
-	-	6.52	2035	6.52	1181	1388.6	1100	6.84	704	-	7.52	-	7.52	-	-	21.6	0.859	-	7.28	40	157	24	0.7	3.2	121.15
-	-	7.09	2041	6.54	1628	1265	1150	6.32	1427	-	7.4	1800	7.49	184	36	17.4	0.49	-	7.32	37	172	31	0.3	6.1	121.26
-	-	7.54	2112	6.67	1696	1388.6	1210	6.41	1711	-	7.27	1850	7.15	165	29	16.3	0.35	-	7.26	44	161	34	0.6	5.3	125.59
-	-	7.34	1241	6.98	548.9	697	955	6.69	598.9	-	7.28		7.26	158		16.3	0.33	-	7.29	47	168	34	0.3	8.8	58.359
-	-	6.97	2070	7.05	611	788.57	875	6.81	770	-	7.32	2040	7.42	166	44	18.3	0.369	-	7.53	45	153	42	0.5	4.2	116.96
		6.77	2830	6.92	970	950	1320	6.76	864		7.43	1900	7.5	152	39	15.7	0.685		7.36	39	149	35	0.4	8.9	112.66
-	-	7.86	1200	7.25	418	360	672	7.71	573	324	7.8	1450	-	-	-	-	-	0.4	7.93	36	86	16	0.2	8.86	132.15
9.88	712	9.11	792	7.36	310	702.85	780	7.56	462	-	7.82	1640	-	-	-	-	-	0.5	7.95	29	107	24	0.2	5.1	117.98
9.69	506	7.75	440	7.92	359	625.71	872	6.68	474	-	7.66	1340	-	-	-	-	-	0.5	7.79	33	95	20	0.2	4.3	104.17
8.03	377	7.47	388	7.82	312	480	800	7.46	432	296	7.94	1650	-	-	-	30.1	20	0.5	7.83	38	117	26	0.2	3.9	91.44
8.16	583	8.11	202	7.83	165	246.72	735	7.25	501	-	7.85	1550	7.89	213	50	35.8	>20	0.4	7.85	42	84	18	0.3	4.1	0.00
5.17	2034	7.58	1816	7.05	568	617.14	670	6.78	955	-	7.74	1570	7.89	237	80	39.9	>20	0.3	7.76	32	96	21	0.2	4.7	34.26
7.02	2015	8.02	2021	7.03	1005	822.85	775	7.53	975	-	7.95	1510	8.02	306	60	38.7	>20	0.4	7.85	37	104	27	0.3	5.1	54.07
8.04	1234	9.13	1037	7	570	497.14	710	7.74	615	-	7.85		8	475		25.9	>20	0.5	7.99	34	121	29	0.3	8.6	40.00
7.72	1211	7.86	962	7.42	419	557.14	705	8.06	393	-	8.21	1430	8.26	355	30	45.2	20	0.4	7.84	36	152	10	0.3	5.3	111.51
-	-	7.64	464	7.51	270	197.1	660	7.24	485	-	7.8	1490	7.91	178	70	32.8	20	0.6	7.64		132	10	0.3	6.7	129.31
		7.76	230	7.42	195	874.28	750	7.36	608		7.61	1270	7.84	166	30	29.4	>20	0.5	7.78	33	116	13	0.3	4.2	12.426
		7.54	253	7.49	203	411.42	705	6.65	510		7.64	1510	7.73	177	80	21.1	>20	0.5							
		7.64	464	7.51	270	197.1	660	7.24	485		7.8	1490	7.91	178	70	32.8	20	0.6	7.64	28	132	10	0.3	6.7	17.262
		8.03	173	7.74	127	85.74	590	6.19	758		7.57	1480	7.68	170	50	29.6	16	0.5	8.09	44	146	20	0.2	22.3	23.238
		8.43	205	7.84	121	137.14	595	7.4	424		7.62	1520	7.72	172	70	28.2	15	0.6	7.64	41	150	20	0.1	19.5	48.693
		8.4	215	8.56	142	274.28	575	7.77	340		7.82	1470	7.94	153	40	26.5	10	0.7	7.99	39	144	20	0.3	21.4	65.278
		7.42	1872	7.01	555	685.71	615	7.53	1697		7.48	1440	7.46	137	60	22.2	13	0.6	7.88	38	120	50	0.4	14.1	101.98

Annex III - UASB Reactor COD Removal & VFA/Alkalinity Ratio Calculations

Buffer Tank (Inlet)		UASB Outlet				Calculations		
pH	COD (mg/l)	pH	COD (mg/l)	VFA (mg/l)	Alkalinity mg/l	COD Removal	VFA/ Alkalinity	Volume of CH_4 (Nm^3)[1]
7.73	2490	7.19	1500	1165.7	1070	39.76%	1.09	12.47
7.17	2970	7.11	1350	925.7	1250	54.55%	0.74	20.41
7.42	2500	6.87	1230	1277.1	1400	50.80%	0.91	16.00
7.31	1390	7.03	729	814.0	1300	47.55%	0.63	8.33
7.5	1670	7.12	735	925.7	1290	55.99%	0.72	11.78
6.65	3830	6.89	1650	882.9	1200	56.92%	0.74	27.47
7.77	3360	7	1320	1457.1	1285	60.71%	1.13	25.70
6.8	2620	7.03	1280	925.7	1300	51.15%	0.71	16.88
6.21	3950	6.83	2230	1371.4	1445	43.54%	0.95	21.67
6.83	2770	6.54	1520	1045.7	1365	45.13%	0.77	15.75
9.03	2200	7.38	1340	754.3	1235	39.09%	0.61	10.84
7.45	2320	7.36	1620	1088.6	970	30.17%	1.12	8.82
7.85	2100	7.74	1190	1225.0	982.5	43.33%	1.25	11.47
7.85	824	7.54	374	368.6	630	54.61%	0.59	5.67
7.44	1117	7.13	425	660.0	765	61.95%	0.86	8.72
9.68	1233	6.18	966	985.7	400	21.65%	2.46	3.36
11.5	1370	6.71	985	745.7	560	28.10%	1.33	4.85
8.04	952	6.96	558	737.1	1000	41.39%	0.74	4.96
8.58	2070	6.71	1210	606.0	860	41.55%	0.70	10.84
7.81	668	6.99	494	428.6	900	26.05%	0.48	2.19
9.57	884	7	342	437.1	850	61.31%	0.51	6.83
8.38	1150	7.36	650	-	-	43.48%	NA	6.30
5.58	2440	7.17	700	300.0	610	71.31%	0.49	21.92
5.67	2510	6.87	1030	537.0	700	58.96%	0.77	18.65
7.49	2050	7.1	670	342.9	770	67.32%	0.45	17.39
7.6	1955	7.31	586	467.1	815	70.03%	0.57	17.25
8.11	1760	7.11	529	342.9	825	69.94%	0.42	15.51
7.6	2745	7.2	887	-	-	67.69%	NA	23.41
7.24	2380	7.15	976	-	-	58.99%	NA	17.69
8.17	2460	7.28	743	-	-	69.80%	NA	21.63
8.36	1798	7.89	704	-	-	60.85%	NA	13.78
9.87	1664	7.04	610	-	-	63.34%	NA	13.28
7.52	1798	7.21	610	-	-	66.07%	NA	14.97
8.01	2400	7.14	898	462.9	700	62.58%	0.66	18.93

[1] Bio-methane yield 0.14 – 0.16 Nm^3/kg COD

Buffer Tank (Inlet)		UASB Outlet				Calculations		
pH	COD (mg/l)	pH	COD (mg/l)	VFA (mg/l)	Alkalinity mg/l	COD Removal	VFA/ Alkalinity	Volume of CH_4 (Nm^3)[1]
7.23	2920	7.09	631	-	-	78.39%	NA	28.84
7.68	1502	7.06	593	-	-	60.52%	NA	11.45
7.05	1694	6.97	700	-	-	58.68%	NA	12.52
5.82	1532	7.09	920	-	-	39.95%	NA	7.71
7.73	2960	7.19	969	617.1	840	67.26%	0.73	25.09
7.29	2575	7.04	1060	642.9	805	58.83%	0.80	19.09
6.98	1804	6.86	853	625.7	785	52.72%	0.80	11.98
7.05	2980	6.88	745	497.1	610	75.00%	0.81	28.16
6.95	2040	6.58	1180	728.6	620	42.16%	1.18	10.84
7.29	1570	7.14	549	582.9	725	65.03%	0.80	12.86
6.64	2220	6.92	812	445.7	715	63.42%	0.62	17.74
6.92	2500	6.86	937	668.6	810	62.52%	0.83	19.69
7.8	1902	6.93	872	1371.4	850	54.15%	1.61	12.98
7.18	1136	6.99	573	625.7	745	49.56%	0.84	7.09
7.83	858	7.08	486	1311.4	680	43.36%	1.93	4.69
6.45	2280	7.04	377	454.3	625	83.46%	0.73	23.98
7.13	1196	6.46	1080	1457.1	680	9.70%	2.14	1.46
7.42	1448	6.75	917	762.9	770	36.67%	0.99	6.69
7.4	1114	7.01	550	368.6	615	50.63%	0.60	7.11
7.19	387	6.82	244	-	-	36.95%	NA	1.80
7.28	2027	6.63	736	557.1	590	63.69%	0.94	16.27
7.23	2174	6.61	999	1457.1	775	54.05%	1.88	14.81
7.77	1541	6.82	892	642.9	725	42.12%	0.89	8.18
7.23	1222	7.08	519	514.3	735	57.53%	0.70	8.86
6.98	1914	6.62	977	677.1	860	48.96%	0.79	11.81
7.36	1073	6.88	715	1362.9	780	33.36%	1.75	4.51
7.31	1043	7.14	436	1200.0	865	58.20%	1.39	7.65
8.46	2089	7.1	1561	1030.0	1230	25.28%	0.84	6.65
8.2	1759	6.81	1373	1157.1	1290	21.94%	0.90	4.86
7.77	612	7.17	464	1097.1	1315	24.18%	0.83	1.86
9.46	1210	7.53	369	531.4	1235	69.50%	0.43	10.60
7.18	2102	6.88	895	1131.0	1005	57.42%	1.13	15.21
7.05	2012	6.77	1495	1362.9	1180	25.70%	1.15	6.51
7.71	1969	6.79	1389	1105.7	1540	29.46%	0.72	7.31
7.2	1240	6.97	882	1328.6	1425	28.87%	0.93	4.51
6.52	2035	6.52	1181	1388.6	1100	41.97%	1.26	10.76
7.09	2041	6.54	1628	1265.0	1150	20.24%	1.10	5.20
7.54	2112	6.67	1696	1388.6	1210	19.70%	1.15	5.24
7.34	1241	6.98	548.89	697.0	955	55.77%	0.73	8.72
6.97	2070	7.05	611	788.6	875	70.48%	0.90	18.38

Buffer Tank (Inlet)		UASB Outlet				Calculations		
pH	COD (mg/l)	pH	COD (mg/l)	VFA (mg/l)	Alkalinity mg/l	COD Removal	VFA/ Alkalinity	Volume of CH_4 $(Nm^3)^1$
6.77	2830	6.92	970	950.0	1320	65.72%	0.72	23.44
7.86	1200	7.25	418	360.0	672	65.17%	0.54	9.85
9.11	792	7.36	310	702.9	780	60.86%	0.90	6.07
7.75	440	7.92	359	625.7	872	18.41%	0.72	1.02
7.47	388	7.82	312	480.0	800	19.59%	0.60	0.96
8.11	202	7.83	165	246.7	735	18.32%	0.34	0.47
7.58	1816	7.05	568	617.1	670	68.72%	0.92	15.72
8.02	2021	7.03	1005	822.9	775	50.27%	1.06	12.80
9.13	1037	7	570	497.1	710	45.03%	0.70	5.88
7.86	962	7.42	419	557.1	705	56.44%	0.79	6.84
7.64	464	7.51	270	197.1	660	41.81%	0.30	2.44
7.76	230	7.42	195	874.3	750	15.22%	1.17	0.44
7.54	253	7.49	203	411.4	705	19.76%	0.58	0.63
7.64	464	7.51	270	197.1	660	41.81%	0.30	2.44
8.03	173	7.74	127	85.7	590	26.59%	0.15	0.58
8.43	205	7.84	121	137.1	595	40.98%	0.23	1.06
8.4	215	8.56	142	274.3	575	33.95%	0.48	0.92
7.42	1872	7.01	555	685.7	615	70.35%	1.11	16.59
				Overall Efficiency		52.56%		
Average Methane Generation daily @ volumetric loading rate of 84 m^3/day								11.23

Annex IV - Aerobic Digestor COD Removal Calculations

Aeration Feed Tank			Aeration Tank Outlet		COD Removal (%)
pH	COD mg/l	BOD mg/l	pH	COD mg/l	
6.85	1340	-	7.66	237	82.31%
7.18	1220	-	7.67	280	77.05%
7.04	1250	-	7.55	228	81.76%
7.17	834	-	7.58	215	74.22%
7.02	577	-	7.68	285	50.61%
6.96	1460	-	7.68	208	85.75%
7.08	1290	-	7.68	250	80.62%
6.98	1190	-	7.61	245	79.41%
6.91	1730	-	7.52	265	84.68%
5.42	1930	-	7.33	290	84.97%
7.34	1370	-	7.49	210	84.67%
7.25	1510	-	7.59	272	81.99%
7.07	1020	-	-	-	NA
7.69	462	-	7.67	211	54.33%
6.65	988	-	7.4	280	71.66%
6.78	923	-	7.37	248	73.13%
7.18	943	-	7.37	240	74.55%
7.1	536	-	7.58	61	88.62%
7.45	1250	-	7.28	65	94.80%
7.77	565	-	7.64	66.4	88.25%
7.91	355	-	7.63	66.5	81.27%
8.16	635	-	7.92	314	50.55%
8.12	514	-	8.09	-	NA
7.79	894	-	7.89	-	NA
7.84	681	-	7.92	-	NA
8.07	568	-	7.99	60.3	89.38%
7.9	513	-	7.76	40	92.20%
8.03	705	-	8.12	56.3	92.01%
7.95	891	-	8.18	51.5	94.22%
7.99	787	-	8.15	59.6	92.43%
8.42	678	-	8.45	75.5	88.86%
7.96	613	-	7.89	73.8	87.96%
8.08	481	-	8.01	122	74.64%
8.03	817	-	8.03	37.8	95.37%
7.86	562	-	7.97	88.6	84.23%
7.84	519	-	8.05	75.4	85.47%
7.82	613	-	8	48.7	92.06%
7.75	756	-	-	-	NA
8.03	855	-	8.23	141	83.51%

Aeration Feed Tank			Aeration Tank Outlet		COD Removal (%)
pH	COD mg/l	BOD mg/l	pH	COD mg/l	
7.91	1040	-	8.19	141	86.44%
7.55	871	-	7.78	113	87.03%
7.73	485	-	-	-	NA
7.36	865	-	7.51	-	NA
7.73	464	-	7.45	-	NA
7.65	542	-	7.56	-	NA
7.55	676	-	7.67	-	NA
7.53	833	-	7.68	-	NA
7.64	665	-	7.88	-	NA
7.7	477	-	7.93	134	71.91%
7.71	376	-	7.87	-	NA
7.28	848	-	7.85	-	NA
7.44	1050	-	7.88	-	NA
7.67	503	-	8	-	NA
-	251	-	-	-	NA
7.7	424	-	7.78	-	NA
7.74	839	-	7.87	-	NA
7.48	837	-	7.88	-	NA
7.72	484	-	7.69	-	NA
7.55	636	-	7.81	-	NA
7.81	626	-	-	-	NA
7.71	495	-	7.76	-	NA
7.19	1429	-	7.84	224	84.32%
7.38	1465	-	7.88	210	85.67%
7.84	742	-	7.84	210	71.70%
6.78	451	-	7.97	199	55.88%
6.34	496	-	7.99	188	62.10%
6.86	1207	-	7.61	183	84.84%
7.12	1357	-	7.49	192	85.85%
6.89	970	-	7.52	175	81.96%
6.84	704	-	7.52	-	NA
6.32	1427	-	7.49	184	87.11%
6.41	1711	-	7.15	165	90.36%
6.69	598.89	-	7.26	158	73.62%
6.81	770	-	7.42	166	78.44%
6.76	864		7.5	152	82.41%
7.71	573	324	-	-	NA
7.56	462	-	-	-	NA
6.68	474	-	-	-	NA
7.46	432	296	-	-	NA
7.25	501	-	7.89	213	57.49%
6.78	955	-	7.89	237	75.18%

Aeration Feed Tank			Aeration Tank Outlet		COD Removal (%)
pH	COD mg/l	BOD mg/l	pH	COD mg/l	
7.53	975	-	8.02	306	68.62%
7.74	615	-	8	475	22.76%
8.06	393	-	8.26	355	9.67%
7.24	485	-	7.91	178	63.30%
7.36	608		7.84	166	72.70%
6.65	510		7.73	177	65.29%
7.24	485		7.91	178	63.30%
6.19	758		7.68	170	77.57%
7.4	424		7.72	172	59.43%
7.77	340		7.94	153	55.00%
7.53	1697		7.46	137	91.93%
			Overall Efficiency		78.54 %

Annex V - Financial Analysis

A. Initial Investment Cost and others in (NRs.)

Capital Cost of Plant	4,000,000.00
Maintenance Cost	140,000.00
Labor Cost	25,000.00
Power Cost	85,000.00
Cost of Chemicals	35,000.00

Particulars	**Value**	**Unit**	**Reference**
Calorific Value of Methane	55.00	MJ/kg	http://www.world-nuclear.org/information-library/facts-and-figures/heat-values-of-various-fuels.aspx
Daily Methane Production	47	Nm^3	
Density of Methane	0.71	Kg/N	
Daily Energy Generation	1,845.69	MJ	
Calorific value of LPG cylinder	46	MJ/Kg	http://www.world-nuclear.org/information-library/facts-and-figures/heat-values-of-various-fuels.aspx
Mass of LPG cylinder	14.2	Kg	
Total Calorific Value of a Cylinder	653.2	MJ	
No of LPG Equivalent Cylinders	2.83		
Income Earned Per Day @ NRs. 1350 per cylinder	3,814.58	NRs	http://www.noc.org.np @ 1 November 16, 2019
Income Earned Per Year	1,392,320.	NRs	

B. Operating Cost

Year	Maintenance Cost (NRs.)	Labor Cost (NRs.)	Energy Cost (NRs.)	Cost of Chemicals (NRs.)	Depreciation (NRs.)	Total (NRs.)
1	140,000.00	25,000.00	85,000.00	35,000.00	400,000.00	685,000.00
2	147,000.00	26,250.00	85,000.00	35,875.00	360,000.00	654,125.00
3	154,350.00	27,562.50	85,000.00	36,771.88	324,000.00	627,684.38
4	162,067.50	28,940.63	85,000.00	37,691.17	291,600.00	605,299.30
5	170,170.88	30,387.66	85,000.00	38,633.45	262,440.00	586,631.98
6	178,679.42	31,907.04	85,000.00	39,599.29	236,196.00	571,381.75
7	187,613.39	33,502.39	85,000.00	40,589.27	212,576.40	559,281.45
8	196,994.06	35,177.51	85,000.00	41,604.00	191,318.76	550,094.33
9	206,843.76	36,936.39	85,000.00	42,644.10	172,186.88	543,611.13
10	217,185.95	38,783.21	85,000.00	43,710.20	154,968.20	539,647.56
11	228,045.25	40,722.37	85,000.00	44,802.96	139,471.38	538,041.95
12	239,447.51	42,758.48	85,000.00	45,923.03	125,524.24	538,653.27
13	251,419.89	44,896.41	85,000.00	47,071.11	112,971.81	541,359.22
14	263,990.88	47,141.23	85,000.00	48,247.89	101,674.63	546,054.63
15	277,190.42	49,498.29	85,000.00	49,454.08	91,507.17	552,649.97
16	291,049.95	51,973.20	85,000.00	50,690.44	82,356.45	561,070.04
17	305,602.44	54,571.86	85,000.00	51,957.70	74,120.81	571,252.81
18	320,882.56	57,300.46	85,000.00	53,256.64	66,708.73	583,148.39
19	336,926.69	60,165.48	85,000.00	54,588.06	60,037.85	596,718.08
20	353,773.03	63,173.75	85,000.00	55,952.76	54,034.07	611,933.61
21	371,461.68	66,332.44	85,000.00	57,351.58	48,630.66	628,776.36
22	390,034.76	69,649.06	85,000.00	58,785.36	43,767.60	647,236.79
23	409,536.50	73,131.52	85,000.00	60,255.00	39,390.84	667,313.85
24	430,013.33	76,788.09	85,000.00	61,761.37	35,451.75	689,014.55
25	451,513.99	80,627.50	85,000.00	63,305.41	31,906.58	712,353.48
26	474,089.69	84,658.87	85,000.00	64,888.04	28,715.92	737,352.53
27	497,794.18	88,891.82	85,000.00	66,510.24	25,844.33	764,040.57
28	522,683.89	93,336.41	85,000.00	68,173.00	23,259.89	792,453.19
29	548,818.08	98,003.23	85,000.00	69,877.33	20,933.91	822,632.54
30	576,258.98	102,903.39	85,000.00	71,624.26	18,840.51	854,627.15

C. NPV and IRR Calculation

Year	**Initial Investment** (NRs.)	**Net Cash flow** (NRs.)	**Cumulative cash flow** (NRs.)
0	4,000,000.00	(4,000,000.00)	(4,000,000.00)
1		707,320.50	(3,292,679.50)
2		738,195.50	(2,554,484.01)
3		764,636.12	(1,789,847.89)
4		787,021.20	(1,002,826.69)
5		805,688.51	(197,138.18)
6		820,938.75	623,800.57
7		833,039.04	1,456,839.62
8		842,226.16	2,299,065.78
9		848,709.36	3,147,775.14
10		852,672.94	4,000,448.08
11		854,278.55	4,854,726.63
12		853,667.23	5,708,393.86
13		850,961.28	6,559,355.14
14		846,265.87	7,405,621.00
15		839,670.53	8,245,291.53
16		831,250.46	9,076,541.99
17		821,067.68	9,897,609.67
18		809,172.11	10,706,781.78
19		795,602.41	11,502,384.19
20		780,386.89	12,282,771.08
21		763,544.14	13,046,315.22
22		745,083.71	13,791,398.92
23		725,006.64	14,516,405.57
24		703,305.95	15,219,711.51
25		679,967.02	15,899,678.53
26		654,967.97	16,554,646.50
27		628,279.93	17,182,926.43
28		599,867.31	17,782,793.74
29		569,687.96	18,352,481.69
30		537,693.35	18,890,175.04
		NPV	2,103,003.10
		IRR	19%