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Potential of Recalcitrant Effluent to Generate Biogas by Up-flow Anaerobic Sludge Blanket and Mechanical Vapour Recompression (MVR) -A Case Study

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Research Article

Keywords: Biomethanation, Anaerobic treatment, Up-flow Anaerobic Sludge Blanket (UASB), Mechanical Vapour Recompression (MVR), Distillery spent wash (DSW).

Posted Date: April 19th, 2021

DOI: https://doi.org/10.21203/rs.3.rs-394660/v1

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Abstract

The spent wash generated in the distillation process has very high organic content like biochemical oxygen demand (BOD) and chemical oxygen demand (COD), which are treated to curtail the levels of COD and BOD. Day by day the rules and legislation are stringent and mandatory for disposal of distillery spent wash. Anaerobic treatment is the primary treatment widely adopted to generate biogas. To find out the potential of recalcitrant effluent a case study of the full-scale operating biomethanation plants at Sanjivani, SSK Ltd, Kopargaon, (M.S), India and Spectrum Renewable Energy Pvt. Ltd. (SREL) Warnanagar (M. S.), India was incorporated. Up-flow Anaerobic Sludge Blanket treatment was implemented to generate the biogas. Sanjivani distillery industry, Kopargaon has a COD removal efficiency of 70–72% with specific biogas generation of 0.5 m^3/ kg COD removal, and total biogas generated is 38000 Nm^3/d. Mechanical Vapour Recompression (MVR) is the cutting-edge technology executed to convert distillery spent wash into useful by-products such as biogas, clean water, and organic manure.

1. Introduction

India is one of the developing countries which establishing textile industries, paper industry, steel industries, a huge number of sugar and distillery industries which helps to development of the nation (Wagh and Nemade et al., 2015). In the economic development of the country, sugar industries play a prominent role (Shadmehr and Mirsoleimani et al., 2019). Sugar molasses is the by-product of the sugar industry and is a raw material for the distillery industry to manufacture the alcohol, rectified spirit (Wagh and Nemade et al., 2019). Alcohol distilleries based on sugarcane molasses comprised one of the highly polluted industrial sectors. Effluent generated during the manufacturing of alcohol; the rectified spirit is known as the spent wash. Spent wash is an intense dark color highly cumbersome, complex, recalcitrant effluent having very high total dissolved and suspended solids. For the production of 1L of alcohol 10–15 L of wastewater (Spent wash) is generated (Sahu, and Mazumdar et al., 2019). The billions of liters of spent wash are generated from the distillery industries which have adverse impacts on the environment and surrounding (Wagh and Nemade et al., 2015). The aqueous dark brown spent wash is highly acidic, complex, extremely organic, very high COD and BOD cumbersome effluent (Wagh and Nemade et al., 2017). Spent wash contains a significant amount of organic matter and plant nutrients (Wagh 2019]. It also comprises Ca, K, S, Mg, and acidic effluents rich in organic carbon, with a substantial quantity of P, N, micronutrients like Mn, Fe, Cu, Zn, and sucrose fructose (Wagh and Nemade et al., 2019). In India, the molasses-based distillery industry is one of the most polluting industries contributing nearly six times the effluent produced by the entire population of India (Gonder and Balcioglu et al., 2019). So, the central pollution control board (CPCB) listed distillery industries as a red category Industries (Wagh and Nemade et al., 2015). Several technologies such as coagulation, electrocoagulation, electrooxidation, electro-flotation, Membrane bioreactor, ozone, Fenton, advanced oxidation process (AOP), aerobic and anaerobic technology attempts were made to treat distillery spent wash cost-effectively (Goren and Kobya et al., 2020; Wagh and Nemade et al., 2018; Espinoza and Soto et al., 2020; Almaguer and Cruz et al. 2021;

Myburgh and Aziz et al., 2019; Pirsaheb and Moradi et al., 2020; Fito and Tefera et al., 2019; Mohtashami and Shang et al., 2019; El Nemr and Hassaan et al., 2018; Ravindra khose, Wagh et al., 2017; Wagh and Nemade et al., 2020). Anaerobic digestion offers potential energy recovery through the generation of biogas and is a relatively stable process for medium and high-strength aqueous organic effluents (Esmaeel and Seied et al., 2020). Apart from reducing a load of wastewater (BOD, COD), the methane produced from the anaerobic system can be used as a fuel for a partial or complete substitute for oil and coal. Aerobic processes were very popular till the late 1960's, for the biological treatment of industrial wastewaters (Wagh and Nemade et al., 2020). Anaerobic processes are designed to retain the biomass in the system either as suspended growth reactors (Contact/UASB reactors) or immobilized biofilm attached to the supporting medium as fixed-film reactors (anaerobic filter) and hybrid reactors (Wagh and Nemade et al., 2018). Anaerobic biotechnology has emerged globally as an alternative to conventional aerobic biological treatment methods for handling high-strength process wastewaters (Danial, and Abdullah et al., 2017). The individual treatment technology is not proven to more effective to convert distillery spent wash into valuable products. Hence it is an urgent need to rectify and resolve the problem of distillery effluent treatment in a cost-effective manner to minimize the pollution loads and the recycle of manufactured water in distillery unit operations. In the present paper, Sanjivani SSKL, Kopargaon, Maharashtra, India implemented the Up-flow Anaerobic Sludge Blanket (UASB) to generate the biogas. This paper also insights Mechanical Vapour Recompression (MVR) technology implemented for Spectrum Renewable Energy Pvt. Ltd. (SREL) Waranagar, Maharashtra, India. MVR is a novel technology for processing distillery spent wash. Technology meets the three prerequisites such as zero liquid discharge (ZLD), cost-effectiveness, and around 90% water recycled and reused.

2. Alcohol Manufacturing And Spent Wash Generation Process

In sugar mills, the cane is crushed and the juice obtained is clarified, filtered, evaporated, and centrifuged to get sugar. The main by-products of sugar production are bagasse and molasses. Bagasse is a solid fibrous material and is a valuable by-product with a calorific value of 3000 kcal/kg (moisture 47–50%) and used as boiler fuel (Sica and Carvalho et al., 2020). Molasses is the syrupy liquid substance remaining after the separation of sugar crystals. It is a heavy viscous liquid with several constituents dissolved in water-sugar like sucrose, glucose, fructose, and other reducing substances, carbohydrates as gums and starch, ash as carbonates, sulphates, nitrogenous compounds like proteins, amino acids, glutamic acid, waxes, and sterols. It is utilized as the feedstock for the manufacture of alcohol in distilleries (Biradar 2003). Ethyl alcohol can be produced from molasses, by fermentation. Distillery molasses is first diluted to 10–15% sugar and then acidified with sulfuric acid to pH 4-4.5 (David and Arivazhagan et al., 2015). It is supplemented with nitrogen and phosphorus nutrients and seeded with yeast in batch fermenters. After fermentation for 30 to 40 hours at 35–37°C, the broth will contain 7 to 10% (w/v) ethanol (Gengec and Kobya et al., 2012). The beer then enters a three-column distillation system to yield a final concentration of 95 % (v/v) of ethanol (Kobya and Gengec et al., 2012; Prajapati and Chaudhari et al., 2015). The first distillation unit is a stripping column, which separates the bulk of the alcohol as an overhead product and an aqueous bottom product containing all the other constituents as a waste stream (spent wash) (Premalatha and Sankaran et al., 2014). The overhead stream containing alcohol, some water, and aldehydes passes through heat exchangers and condenser to aldehyde's columns where the low boiling point impurities such as aldehydes are separated as an overhead product. The bottom stream then flows to the third column i.e., rectifying column where alcohol is obtained as the desired final product (Santal and Singh et al., 2013). Figure.1 shows a schematic of the molasses fermentation and distillation units. In the continuous process, yeast is recycled and fermentation and distillation stages are coupled to get a continuous supply of fermented beer for the distillation column (Yadav 2012). The advantage of the process is that a high active yeast cell density initiates the fermentation rapidly and the alcohol yield is also much higher compared to the batch process (Salehin and Ahmed et al., 2021). The biostill process is one of the commercial continuous processes, in which the molasses flow rate to the fermenter is controlled at a constant flow rate to maintain the sugar and alcohol concentrations in the broth at 0.2% (w/v) or lower and 6–7% (v/v) respectively (Okewale and Adesina et al., 2019). Only about 10% of molasses are utilized in the processes and the major remaining part ends as effluent in the process (Srivastava et al., 2020). The wastewater generated from the process technology mostly consists of distillery spent wash, also yeast culture sludge, and flooring washings (Ryabov and Tugov et al., 2020). The resulting spent wash is highly colored and high in total solids and organic matter Table 1 gives the average characteristics of spent wash generated from batch process. The dark (black/brown) color of spent wash is caused by the presence of several constituents of molasses during processing. Some color constituents are naturally present as plant pigments and some are formed during sugar processing (caramel and melanoidin). There are four major classes of compounds contributing to the color of molasses (Bourtsalas and Huang et al., 2020).

Untreated spent wash disposed into the water bodies can cause eutrophication, odor, aesthetics, and degradation of aquatic ecosystems. The application of the spent wash on land for irrigation purposes can lead to high soil salinity and groundwater contamination. It is always desirable to use the wastewater in the process if possible or try to recover some valuable by-products rather than treating it for mere disposal entailing significant capital and recurring costs. various alternatives available for spent wash treatment and their suitability in meeting the prescribed standards. Land disposal through irrigation being a common practice in our country, its environmental implications are also discussed.

3. Treatment Technology

Anaerobic digestion process deeds the capability of numerous inhabitants of microorganisms to achieve different steps in a degradation treatment process to breakdown bulky organic molecules to water (H_2O, (CO_2) carbon dioxide, and methane (CH_4). This process provides chemical building blocks for the growth and maintenance of the bacterial population. A wide range of microbial species are responsible for the above conversions and each reaction is catalyzed by a distinct group of bacteria/ enzymes.

STEP 1: In Step 1 hydrolysis reactions are carried out by a group of hydrolytic bacteria, which convert complex organics into simpler molecules utilizing extracellular hydrolytic enzymes. Until recently this hydrolysis step was not accorded significant attention mainly because of the complexity of the reactions.

Recently this process has been shown to be potentially rate-limiting apart from the traditionally acknowledged slow methane formation step.

STEP 2: Step 2 is mediated by a general class of acidogenic bacteria that ferment monosaccharides and amino acids to acetic, propionic, butyric, and valeric acids generally termed as volatile fatty acids (VFA). The acetic acid formation is the most preferred since it offers the bacteria with the largest energy yield for growth and it provides the substrate for the acetoclastic methane formers as shown in Step 4.

STEP 3: Acetogenic bacteria convert propionic and butyric acids to acetic acid. Enrichment cultures of these bacteria indicate that they grow relatively slow even under optimum conditions of low concentration of hydrogen

STEP 4: This is the last step in the entire chain of events leading to the generation of methane. The formation of methane is postulated to occur by two mechanisms. The synthesis of methane takes place according to Eq. (1).

$CH_3COOH \rightarrow CH_4 + CO_2$ (1)

The bacteria catalyzing this reaction are slow-growing and control the pH value of the fermentation medium by the removal of acetic acid and the formation of carbon dioxide. They are responsible for most of the methane produced by the anaerobic digestion process (Wagh and Nemade et al., 2018). Methane generation (Step 4) can also occur According to Eq. (2) in the presence of hydrogen utilizing methane bacteria. These bacteria grow relatively rapidly with a minimum doubling time of six hours and they utilize the H_2 produced during the hydrolysis and carbon dioxide produced during acetogenesis to form methane and water.

$CO_2 + 4H_2 \rightarrow CH_4 + 2H_2O$ (2)

Distillery spent wash is a complex substrate having high COD (90,000–1,00,000 mg/L), BOD (45,000–50,000 mg/L) and low pH (4.2–4.5). The major constituents of distillery spent wash is carbohydrates, organic acids, proteins, nitrogenous compounds, and minerals. The anaerobic biological conversion of organic matter to methane is a complex multi-step process involving several groups of bacteria carrying out rather specific reactions shown in Fig. 2. Clostridium, Proteus, and peptococcus group of bacteria hydrolyze (Step 1) proteins to amino acids and sugars. Clostridium, acetovibrio celluliticus, and staphylococcus hydrolyze carbohydrates to amino acids and sugars. Also, lipids are hydrolyzed to amino acids, sugars, higher fatty acids, and alcohol by clostridium and syntrophomon as wolfei in the first step of the hydrolysis reaction of spent wash. During the fermentation process (Step 2) amino acids and sugars are converted to acetate by lactobacillus, escherichia, and staphylococcus, and intermediates (valerate, isovalerate, and butyrate) are formed due to the action of clostridium, eubacterium limosum. Zymomonas converts the amino acids to higher fatty acids and alcohol. Further in the third step intermediates are fermented to acetate and hydrogen by syntrophomonas wolfei and syntrophobacter wolfei. Finally, in the methanogenesis step (Step 4) acetate and hydrogen are converted to methane by a group of methanothrix, methanobacterium, methanosarcina and methanoplanus

3.1 Case study 1: UASB system at Sanjivani SSK Ltd. Kopargaon

Sanjivani (T) Sahakari Sakhar Karakhana Ltd, Kopargaon, Ahmednagar dist, Maharashtra has a 75 KLD capacity distillery based on sugarcane molasses and generates about 1060 m^3/d of spent wash. The company has installed four full-scale UASB (Up-flow Anaerobic Sludge Blanket) reactors for the primary biological treatment of spent wash for generating biogas. The technology adopted was based on the know-how of PAQUES, BV Holland represented by Western PAQUES Ltd, Pune, who pioneered the marketing of UASB technology for this application and commissioned several plants in the early nineties in India. Spent wash generated in the distillery is slightly acidic and dark-colored and also contains a large proportion of organic matter. The characteristics of raw spent wash feed to the reactors (diluted by recirculation) are given in Table 2.

A schematic of the anaerobic treatment plant at Sanjivani SSKL for generating biogas from distillery spent wash is shown in Fig. 3. Raw spent is first taken into an atmospheric cooling pit where it is mixed with the recirculated effluent from the UASB reactor. This helps in partial dilution of raw spent wash and to adjust the pH of feed to the bioreactors. The UASB reactor is a 6 m tall closed tank with 1.2 m granular sludge zone at the bottom. Wastewater is pumped from the cooling pit and introduced at the bottom of the reactor through a common header and a series of nozzles on lateral distributors. Raw spent wash moves upward through the sludge blanket zone and the anaerobic bacteria breaks down the organic matter to release methane gas and carbon dioxide. A three-phase mixture consisting of biogas-biomass and partially treated spent wash move upward in the reactor and a proprietary internal baffle arrangement separates the individual phases. Biogas leaves at the top towards a common manifold and the biomass is retained in the reactor by gravity while the clear liquid overflows from the top of the reactor for subsequent treatment. Technical specifications and process design aspects of the UASB system at Sanjivani SSKL are shown in Table 3. The table gives detailed information of special features: UASB reactor, biogas composition, steam generation, fuel-saving, capital cost.

The anaerobic treatment plant at Sanjivani SSKL has been in operation since 1992 and has given satisfactory performance with respect to gas generation and COD removal efficiency. Table 4 gives a summary of average weekly observations of feed COD, final COD, feed rate, and biogas generation rate. The average spent wash feed rate to the reactor during the observation period was 990 m^3/d with feed and the final COD values of spent wash are 100,000 and 29,000 mg/L respectively. The rate of biogas generation was 38,000 m^3/d with a 72% COD reduction. A graphical representation of the plant performance is shown in Fig. 4. The profile shows the concentration of feed COD entering the digester and the concentration of final COD in the treated effluent. The profiles also show the capability of the system to perform in a very stable manner despite fluctuating COD loading patterns (13–17 kg COD/ m^3.d). The actual biogas generation was 37,640 m^3/d, with a specific biogas generation rate of 0.54m^3/kg COD and 350 working days, compared to the designed biogas generation of 38,000m^3/d, with specific biogas generation of 0.5 m^3/kg COD based on 300 working days per year. Cost savings through the replacement of the coal by biogas as fuel for steam generation has been estimated to be Rs 380 lakhs per annum.

3.2 Case study 2: Spectrum Renewable Energy Pvt. Ltd. (SREL) Warnanagar

The SREL has installed an MVR project at Warnanagar Maharashtra, India. Warna Sugar Mill, having a crushing capacity of 10,000 metric tons/day. The plant processes the 1m^3 of Reactor effluent and converts it into useful bioproducts such as clean water and organic manure (Clean water-800 L and Organic sludge-200 kgs). The plant runs on the Mechanical Vapor Recompression (MVR) technology and the condensate was cooled by exchanging its temperature with the incoming feed through a heat exchanger. The working of the (MVR) evaporator is based upon the recycling of heat (Fig. 5).

- Biomethanated distillery spent wash was feed by the feed pump with the help of the feedstock heat exchanger and into the circulating stream. Table 5 illustrate the characteristics of biomethanated spent wash Feed to MVR. The feedstock heat exchanger was implemented to heat the biomethanated distillery spent wash by transferring functional heat from the boiling condensate to the cooler feed.
- The recirculation pump circulates biomethanated distillery spent wash from the separation tank through the essential heat exchanger, to the orifice plate, and back into the separation tank. The dormant heat from the compressed vapor is transferred to the biomethanated distillery spent wash through the main heat exchanger.
- In MVR, biomethanated distillery spent wash heated with steam and the generated vapor were compressed and sent to a heat exchanger where it is condensed, providing pure water at the outlet. Evaporation is an energy-intensive process that requires more energy in the form of steam to heat the effluent.
- The developed MVR based Evaporator recovers clean water by concentrating spent wash and reducing its mass/volume to negligible, which provides an environmentally friendly and sustainable solution.

- MVR evaporator does not require a boiler and external steam input for operation and is capable of generating clean water for reuse at very minimal cost and energy. The module is developed using Low-Temperature Evaporation technology for recycling distillery spent wash in to clean water. Plate type Falling Film Evaporator is used in the system which is based on Plate type heat exchangers instead of conventional tube heat exchangers. The use of Plate Packs increases heating surface density to a much higher level and makes it compact in size and weight as compared to conventional evaporators. The condensate is cooled by exchanging its heat with the incoming feed through a heat exchanger. The net blow down from the system remains almost negligible and the condensate is reused back into the factory process. Table 6 illustrate the detail information of biogas production and steam generation. The product uses a unique technology to separate water from the raw effluent through low-temperature evaporation from 250°C to 65°C. The operation eliminates the need for any conventional heating sources and is at low ΔT with low power consumption, which is lower than any water treatment technology currently available. The technology is developed to use clean water we get after the treatment process back into the plant to diminish tube well and stream water consumption. The product is designed for separating 85–99% of excess water from the spent wash, which in turn, concentrates into discharge fluid. This concentrated discharge fluid can be sent for further drying or be used as manure.

3.3 Advantages of MVR

- As the MVR system is based upon the evaporation system pollution control problem is zero as the system not required a boiler.
- The surrounding area is not highly polluted.
- Very less power consumption as compared to the conventional treatment technology as the system not required boiler, steam cooling, condensation unit.

3.4. Limitation of MVR

- Before applying distillery spent wash to MVR technology need to minimize total solid present in the DSW.
- MVR technology get blocked due to very high BOD, COD and total solids.
- For excellent working of MVR Primary treatment such as anaerobic is must for DSW.

4. Conclusion

The anaerobic treatment plants at Sanjivani, SSK. Ltd. Kopargaon, Ahmednagar, Maharashtra, India, are in operation since the last three-decade and have given a satisfactory performance concerning gas generation and COD removal efficiency. The summary of the performance of the system shows the COD removal efficiency of 70-72% with specific biogas generation of 0.5 m3/ kg COD removal. The cost-saving through the replacement of the coal biogas as fuel for steam generation has proved to be profitable with a payback period in the plants. The quality of effluent provided by anaerobic treatment will not be sufficient to meet the discharge requirement and require additional treatment. Most of the distilleries as secondary treatment aeration process followed by clarifiers are used. The aerobic processes are capable of reducing 90% of BOD and generate biogas is about 18,000-22,000 m3/d. Hence recalcitrant effluent has the potential to generate biogas by anaerobic treatment technology.

Mechanical Vapor Recompression (MVR) treatment technology can assist to recover the condensate for cleared recycle, as well as release it into groundwater whereas instantaneously recuperating biogas and biofertilizer, thus promising useful products and zero waste into the environment. MVR is a zero-liquid discharge (ZLD) distillery spent wash scrubbing treatment technology that can have a profound impact on the sugar molasses-based distillery industry across India. Therefore, MVR is a cost-effective and better Return on investment (ROI) generating treatment technology, providing water in plenty for manure and for recycling. MVR is an innovative energy efficacy rejuvenation key that supports financial and eco-friendly sustainability. A long-standing problem of the complex cumbersome recalcitrant distillery spent was resolved by MVR. Technology converting harmful spent wash into useful, eco-friendly by-products. MVR has a significant opportunity to expand renewable energy portfolio and meet sustainable development and environmental footprint.

Declarations

Funding Section:

No funding was obtained for this study.

Disclosure statement:

No potential conflict of interest was reported by the authors

Authors' contributions:

1. Manoj Pandurang Wagh: Collecting the data, analysis, manuscript writing
2. Pravin Dinkar Nemade: Guidance.
3. Ashok Biradar: Suggestion.

Acknowledgment:

The authors would like to express sincere thanks to Dr. Mohan Rao Chairman of Spectrum Renewable Energy Pvt. Ltd. (SREL) Waranagar, Maharashtra, India.

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Tables

Table 1. Characteristics of spent wash generated from continuous processes.

Parameters in (mg/l) except	Initial Value
pH	3.45
Chemical Oxygen Demand (COD)	115271
Total Dissolved Solids (TDS)	92587
Total Suspended Solids (TSS)	14658
Sulphate	7921
Chloride	8115
Hardness	2760
Calcium	2498
Magnesium	1289

Table 2. Average Characteristics of Distillery Spentwash across UASB System (Sanjivani SSKL., Kopargaon)

Parameter (mg/L)	Raw Spentwash	UASB Feed	UASB Effluent
pH	3.5-4.0	6.1-7.1	7.5-7.7
Temperature ℃	90-100	25-29	32-33
TS	1,00,000	80,000-90,000	70,000-80,000
TSS	4,000-12,000	4,000-5,000	3,000-2,500
BOD	45,000-50,000	30,000-40,000	5,000-5,500
COD	1,00,000-1,20,000	70,000-80,000	20,000-22,000
Sulphate	4,000-5,000	4,000-5,000	2,000-2,500
Chlorides	5,000-6,000	5,000-5,500	5,000-5,500
Potassium	6,000-8,000	5,000-6,000	5,500-6,000
Sodium	1,000-1,200	600-800	600-800

Table 3. UASB Reactor System at Sanjivani SSKL., Kopargaon

UASB REACTOR	
Number of reactors	4
Reactor diameter, m	22.5
Sludge blanket zone, m	1.2
Total height, m	6
HRT, d	9
Specific biogas generation, Nm^3/kg CODr	0.5
COD reduction, (%)	71
Total biogas generation, Nm^3/d	38,000
BIOGAS COMPOSITIONS, (%)	
CH4	60-62
CO2	35-37
H2S	1.5-2.5
Calorific value, kcal/Nm^3	5500
Energy value, kcal/d (38000 x 5500)	$209x10^6$
STEAM GENERATION	
Boiler efficiency, (%)	80
Steam enthalpy (@ 10 kg/cm^2), kcal/kg	660
Steam generated from biogas, MT/d ($209x10^6$ x 0.8) x 10^{-3}/660	253.33
FUEL SAVING	
Steam from one MT of coal, MT	4
Equivalent coal saving per day (253.33/4), MT/d	63.33
Coal price, Rs. /MT	2,000
Saving in coal costs with biogas as fuel, Rs. /d (63.33 x 2000)	1,26,600
Number of working days per year	300
Saving per year, Rs.	380,00,000
Capital cost of biogas plant	Rs.439,00,000

Table 4. Performance of UASB system at Sanjivani SSK, Bio-gas Plant

Week	Feed rate (m^3/ d)	Feed COD (g/L)	Final COD (g/L)	COD reduction (%)	Specific biogas generation, (Nm^3/kg COD removal)	Gas generation (Nm^3/d)
1	938	102	29	72	0.51	34942
2	947	102	29	72	0.53	36971
3	949	103	30	71	0.51	34771
4	955	101	28	72	0.52	35914
5	1054	100	28	72	0.50	37714
6	938	98	29	70	0.54	34942
7	824	98	29	70	0.54	30500
8	1029	98	28	71	0.53	38142
9	947	99	28	72	0.55	36971
10	1056	102	29	72	0.50	38400
11	1012	101	29	71	0.51	37428
12	901	101	28	72	0.50	32857
13	824	98	28	71	0.53	30500
14	938	99	29	72	0.53	34900
15	873	102	29	72	0.52	33115
16	960	101	29	71	0.50	34242
17	950	99	28	72	0.54	36514
18	978	104	31	70	0.53	37820
19	1027	99	30	70	0.55	39600
20	997	101	30	70	0.55	38900
21	1004	101	30	70	0.56	39600
22	917	98	31	68	0.63	39300
23	1030	96	31	68	0.57	38071
24	1054	98	30	69	0.55	39600
25	1054	97	30	69	0.58	40750
26	1043	98	28	71	0.56	40800

27	1086	101	30	70	0.53	40800
28	830	98	30	69	0.52	29392
29	1018	100	29	71	0.56	40400
30	1052	102	29	72	0.53	40800
31	1045	99	29	71	0.56	40800
32	1049	102	30	71	0.54	40800
33	947	100	28	72	0.57	39287
34	1025	99	29	71	0.57	40800
35	1040	102	28	73	0.52	40200
36	860	101	30	70	0.59	36220
37	1050	99	30	70	0.56	40800
38	1045	103	29	72	0.51	39800
39	1040	99	30	70	0.57	40800
40	1056	100	30	70	0.55	40800
41	1040	101	30	70	0.54	39900
42	1042	98	30	69	0.58	40800
43	1060	102	29	72	0.53	40800
44	920	97	29	70	0.58	36300
45	830	102	30	71	0.48	28800
46	920	103	30	71	0.49	33171
47	1053	103	29	72	0.49	38400
48	1056	100	29	71	0.51	38400
49	1056	100	29	71	0.51	38400
50	1030	100	29	71	0.53	38400
51	1056	100	29	71	0.51	38200
52	1056	99	29	71	0.55	40800
Average	**990**	**100**	**29**	**71**	**0.54**	**37641**

Table 5. Characteristics of Biomethanated spent wash Feed to MVR

Parameters in (mg/l) except	Initial Value
pH	7.4
Chemical Oxygen Demand (COD)	24000
Biochemical Oxygen Demand (BOD)	11800
Total Suspended Solids (TSS)	7500
Total Dissolved Solids (TDS)	22420
Total Solids	299920
Volatile Solids	13540
Sulphate	980
Potassium	1420

Table 6. Mechanical Vapour Recompression (MVR) Technology at SREL

Parameters	Value
Molasses available	25000 MT
No of working days	100
Fuel need to distillery	17000 L
Fuel cost	17000 x 35 = Rs 5,95,000/-
Alcohol production	65000 L/day
Fuel cost on alcohol	Rs 9.15 /L of alcohol
Biogas production	12000 M^3/day
If 75 % recovery	9000 M^3/day
Steam generation	9000 x 6.6 =59.4 MT
Saving	59.4 x100 =5940 L
Fuel saving cost /day	5940 x 35 = Rs 2,07,900/-

Figures

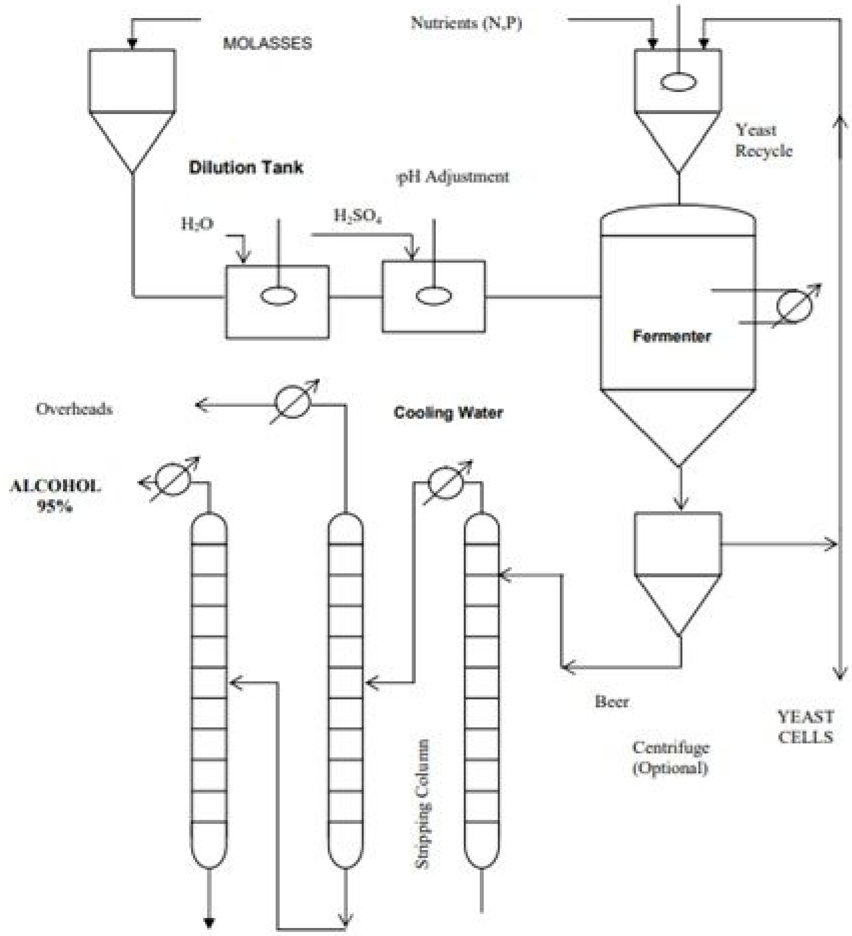

Figure 1

Flow sheet for alcohol manufacture by molasses (sugarcane) fermentation and distillation

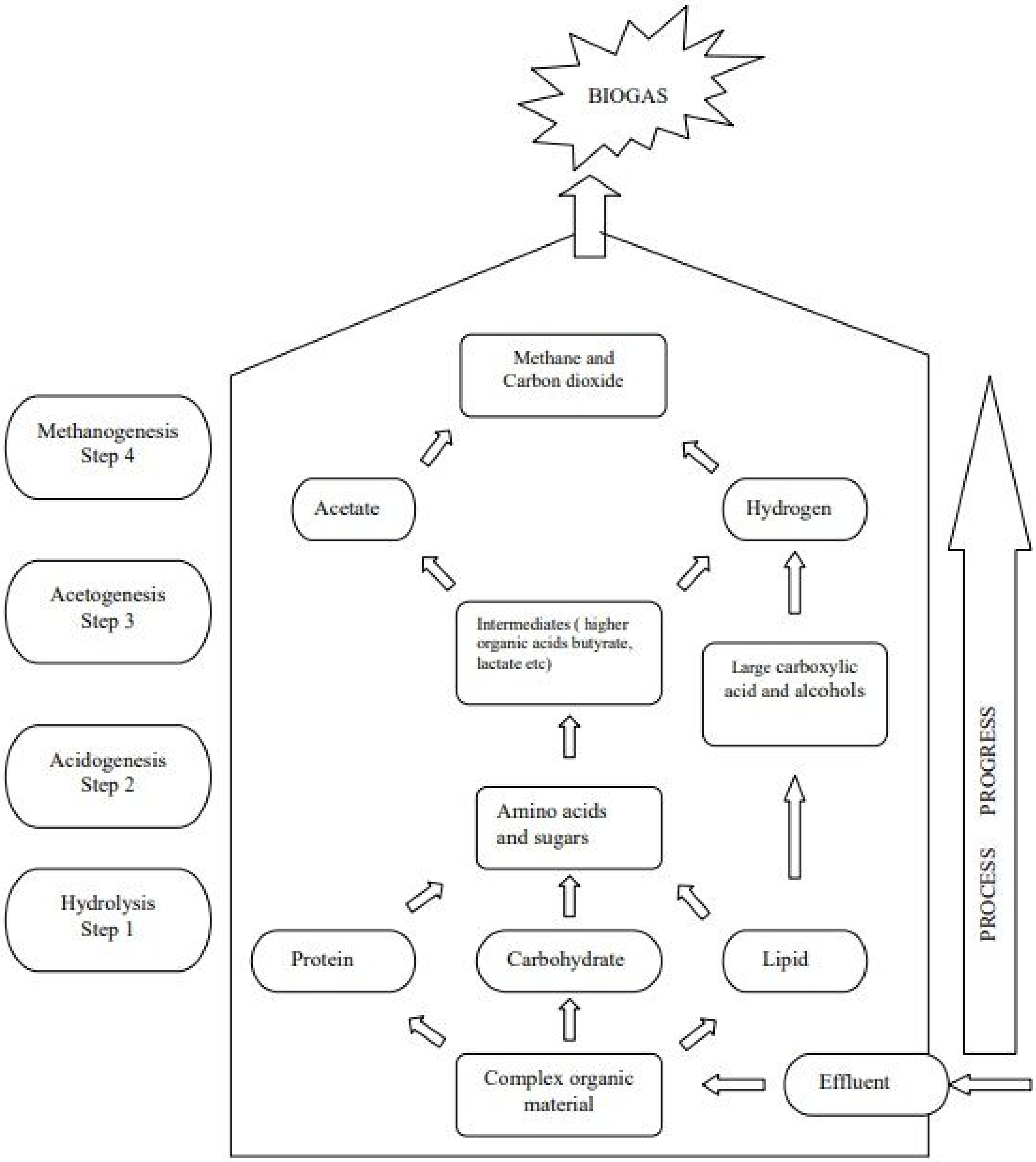

Figure 2

Biochemical reaction steps in anaerobic digestion system

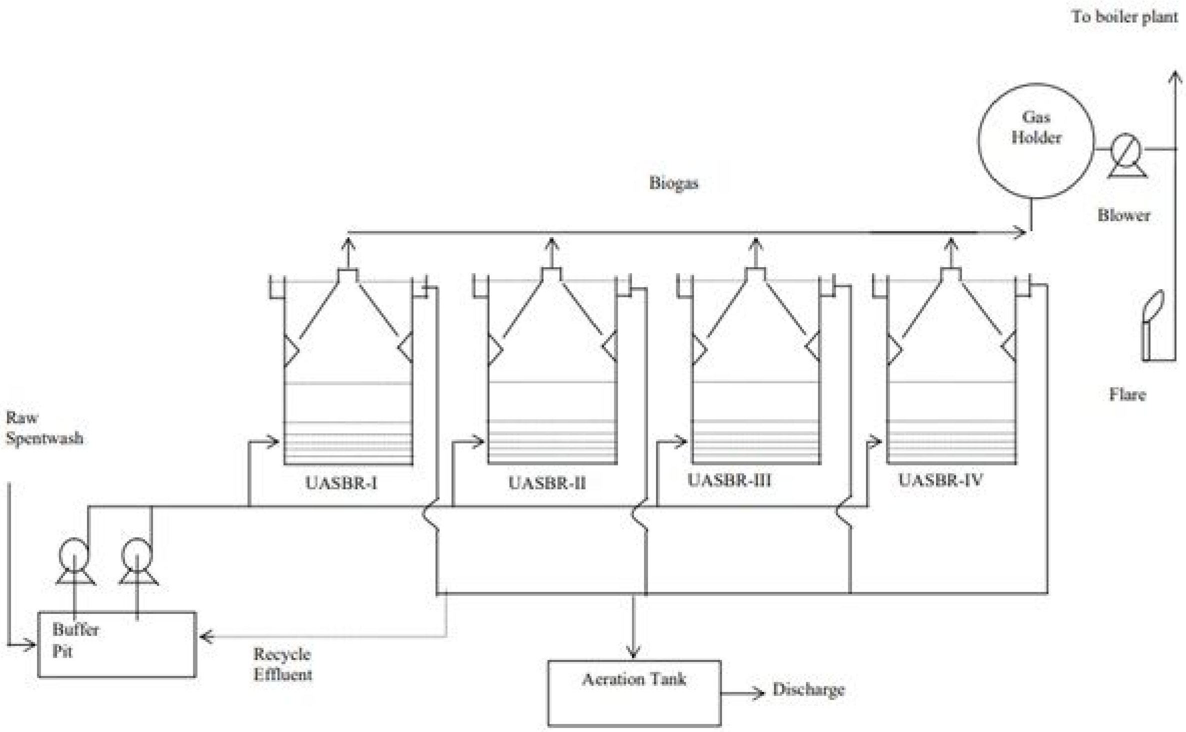

Figure 3

Schematic of UASB System (Sanjivani SSKL, Kopargaon)

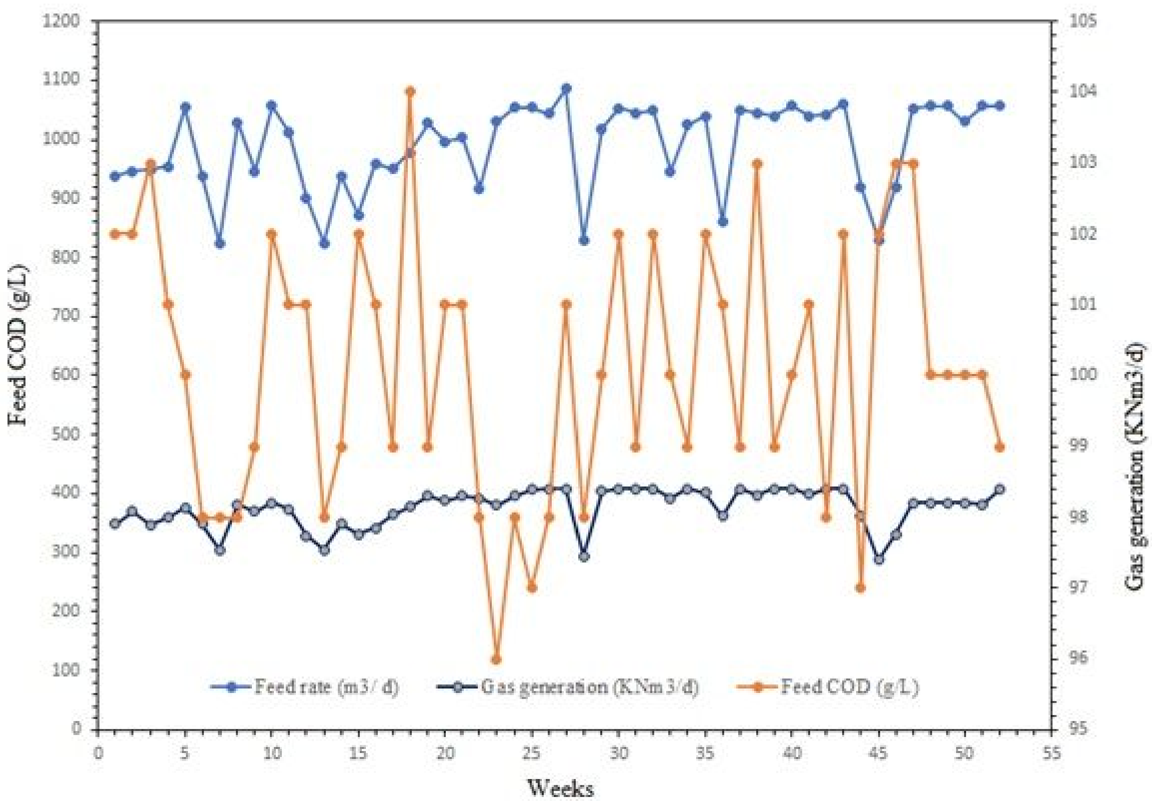

Figure 4

Profile of weekly average Feed and final COD values and biogas generation rates (UASB System, Kopargaon)

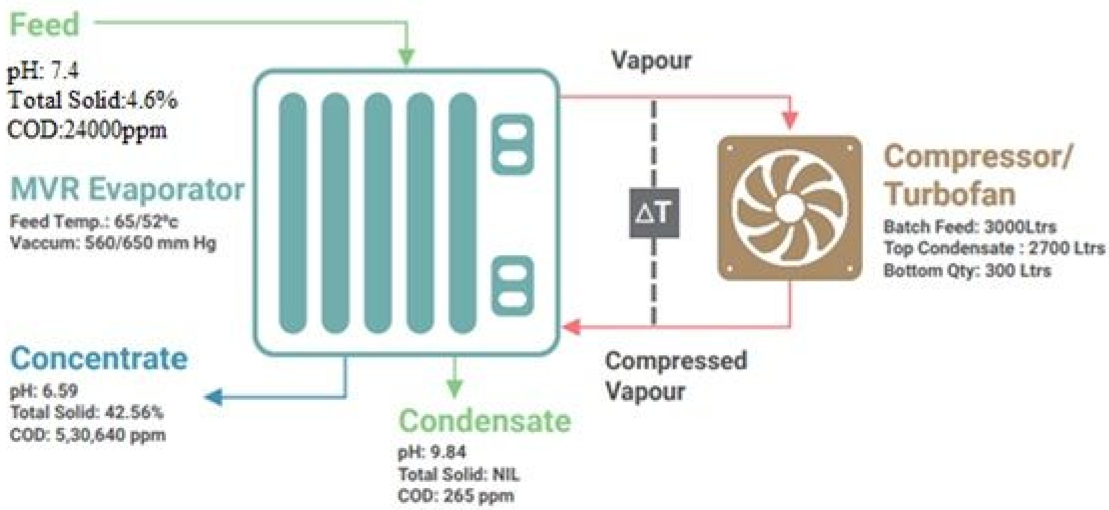

Figure 5

MVR Process for Biomethanated distillery spent wash