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Study of Biogas Generation in Treatment of Distillery Wastewater by UASB Method

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***Abstract*—Distillery industry represents an important segment of the world economy is amongst the highly polluting industries. One of the most important environmental problems faced is management of distillery wastewater. Industrial processes create a variety of wastewater pollutants; which are difficult and costly to treat. The production and characteristics of spent wash (SW) are highly variable and dependent on feed stocks and various aspects of the ethanol production process. The spent wash is acidic (pH 3.94 - 4.50) dark brown, chemical oxygen demand (COD) (i.e., 80,000– 100,000 mg/l) and biological oxygen demand (BOD) (i.e., 30,000–50,000mg/l)[1]. If it is discharged to water-receiving bodies without treatment, it may damage the aquatic system. Apart from causing water pollution, unpleasant odor of effluent spreads several kilometers around the distillery. The untreated/partially treated effluent if discharged in the land makes it infertile. Environmental issues have become one of the important factors controlling the growth of distillery industries. Therefore, it is very necessary to investigate the efficient and cost-effective processes to treat SW.**

The study investigates the effectiveness and energy conservation potential of an Up-flow anaerobic sludge blanket (UASB) reactor treating distillery's spent wash

Keywords—Distillery Spent Wash; BOD; COD; UASB

I. INTRODUCTION

World energy demand is increasing rapidly and about 88% of this demand is found in fossil fuels, generating a lot of interest in renewable energy alternatives. In this context, biogas will play an important role in the future. Biogas is a versatile source of renewable energy that can be used to replace fossil fuels in heat and power production, and can also be used as fuel for vehicles. Biogas produced from anaerobic digestion of wastes contains a large amount of methane, typically 60%, having a high calorific value. Moreover, the composition is usually 40% carbon dioxide with traces of hydrogen sulphide and water vapor [2]. Biogas use also reduces the greenhouse gas emissions since methane contributes directly to global warming.[3]

One of the method used for treating distillery wastewater, is the application of UASB reactor (Up-flow anaerobic sludge blanket) which is very effective. The UASB process was developed in the late seventies in the Netherlands. UASB technology was introduced in India in late eighties during the Ganga Action Plan (GAP). A set of pilots were installed at Kanpur initially for treatment of a mix of sewage and tannery effluent. This development took place when a strong need for an appropriate "low cost" technology was felt subsequent to the experience of conventional aerobic technology based sewage treatment plants (STPs) where running cost was perceived to be unaffordable. At that point of time, UASB, which was still an evolving technology was positioned as an affordable option with potential for 'resource recovery'. Energy and environmental pollution are the most discussed topics of the day, the former; energy is in short supply and the latter environmental pollution in abundance. It is therefore the endeavor of mankind to not only efficient use energy and reduce hazards of pollution, but treat the pollutants to generate energy

II. COMPONENTS OF UASB REACTOR

The UASB reactor has four major components 1) sludge bed, 2) sludge blanket, 3) gas solid separator and 4) settlement compartment. The sludge bed is a layer of biomass settled at the bottom of reactor. The sludge blanket is the suspension of sludge particles mixed with gas produced in the process. Many factors have been found to affect the efficiency of UASB reactor such as temperature, wastewater composition, mixing, pH, OLR, and toxicity. The UASB process received its popularity because of its effectiveness and short hydraulic retention time. The key to its success has been the spontaneous formation of small 'granular' bacterial pellets (granules) in the reactor. These pellets settle readily to the bottom of the reactor. Thus wastewater can be pumped relatively quickly through this reactor without loss of bacterial granules. Therefore smaller reactors can be used that cost less than standard anaerobic digesters and treat effectively large volumes of wastewater[4].

UASB reactor is most effective and has the following unique features:

- Low energy requirement
- Less operation and maintenance cost
- Lower skill required for operation/supervision
- Less sludge production

Potential for resource recovery through generation of electricity from biogas and utilization of stabilized sludge as manure.

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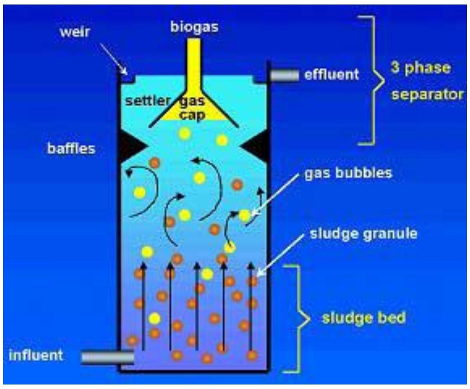

Fig. 1. Essential Components of UASB Reactor

III. ANAEROBIC DIGESTION PROCESS IN UASB REACTOR

There are four phases of anaerobic digestion in an UASB reactor:

1) *Hydrolysis*, where enzymes excreted by fermentative bacteria convert complex, heavy, un-dissolved materials (proteins, carbohydrates, fats) into less complex, lighter, materials (amino acids, sugars, alcohols).

2) *Acidogenesis*, where dissolved compounds are converted into simple compounds, (volatile fatty-acids, alcohols, lactic acid, CO2, H2, NH3, H_2S) and new cell-matter.

3) *Acetogenesis*, where digestion products are converted into acetate, H2, CO2 and new cell-matter.

4) *Methanogenesis*, where acetate, hydrogen plus carbonate, formate or methanol are converted into CH4, CO2 and new cell-matter. The main methanogenic reactions are:

Substrate	Reaction	
Acetate	$CH_3COOH \rightarrow$	$CH_4 + CO_2$
Hydrogen	$4H_2 + CO_2 \rightarrow$	$CH_4 + 2H_2O$
Methanol	$CH_3OH \rightarrow$	$3CH_4 + CO_2 + 2H_2O$

IV. FACTORS INFLUENCING UASB PROCESS

Development of anaerobic process technology is dependent on a better understanding of the factors that are associated with the stability of the biological process involved. Following environmental factors of primary importance to anaerobic process are:

1) *pH, Acidity and Alkalinity* **:** Methanogenic Microorganism is susceptible to minute changes in the pH values. Optimum pH ranges of 6.9-7.2, 6.4-7.2 and 6.6-7.6, have been reported favorable for the methane bacteria, which cannot tolerate fluctuations. The non-methanogenic bacteria do not exhibit such strong sensitivity for environmental condition and are able to function in a range of pH 5-8.5. The pH maintained inside the reactor due to the process result from the interaction of CO_2-bycarbonate buffering system and volatile acids- ammonia formed by process. It is necessary to prevent the accumulation of acids to a level which may become inhibitory to the methane bacteria. For this, it is important that there should sufficient buffering present in the reactor, which may prevent the reactor souring.

2) *Temperature:* As in all biological processes, anaerobic processes are affected by temperature. Generally speaking, the higher temperature, higher is the Microorganism's activity until and optimum temperature reached. A further increased of the temperature beyond its optimum values results in decreased activity. Anaerobic processes comprising sludge digestion and gas production can take place over a wide range of temperature (4-60 ^{0}C). Once an effective temperature range is established small fluctuations can result in a process upset. The optimum temperature for growth of anaerobic microorganism is between 35 and 40 ^{0}C for mesophilic range and about 55 for the thermophilic range [5]. Although anaerobic digesters have been reported to operate at substantially lower temperature such as 20 ^{0}C, anaerobic growth under these conditions is slow and difficulties in the start-up of reactors have been reported. In situations where reactor operating temperature is low, start-up will be beneficiated if initiated at approximately 35 ^{0}C.

3) *Nutrients:* Though anaerobic processes produce less sludge and thus require less nitrogen and phosphorus for biomass growth, many industrial wastewater may lack sufficient nutrients. .Thus, the addition of nitrogen and/or phosphorus may be needed. Normally for digestion of non or partly acidified wastewater N and P are required in the following ratios:

COD biodegradable : N :P = 300 :5 : 1

4) If N and P are not present in the influent in these amounts, additional N and P have to be added. Lack of nutrients will decrease the COD removal efficiency and sludge growth. Micronutrients like ammonium molybdate, nickel, chloride etc. should also be added to increase the activity of the sludge.

5) *Inhibitory Substances*: Proper analysis and treat ability studies are needed to assure that a chronic toxicity does not exists for waste water treated by anaerobic processes. At the same time, the presence of a toxic substance does not mean the process cannot function. Some inventory and low enough loading, the process can be sustained. Toxic and inhibitory inorganic compounds of concern for anaerobic processes are Sodium, Potassium, Calcium, Ammonia Sulphide, Copper, Nickel, Zinc etc.

V. PERFORMANCE STUDY OF LAB SCALE UASB MODEL

For the study, reactor of volume 10 Litres was designed and fabricated as per the guidelines given by Lettinga & Hulshoff [6].

A. Design Details of Lab Scale UASB Reactor

The laboratory scale anaerobic filter reactor was constructed from transparent polyacrylic column. The column had an inside diameter 11.42cm and height of 97.59cm with a working volume of 10 lit. The reactor had a new three phase separation system, made of one deflector plate attached to central axis and inclined at 55°. The feeding system of the reactor was designed in such a way that the inlet end opens towards the bottom of the reactor, which allows feed to first

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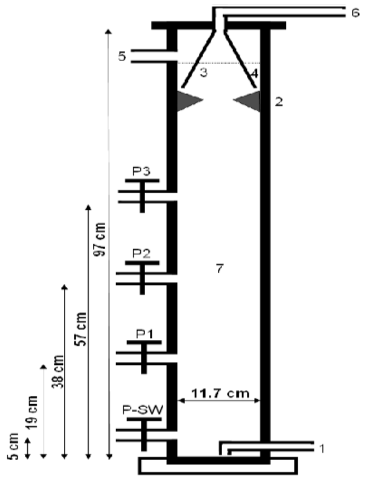
strike at the bottom and then get evenly distributed while rising upwards in a hopper bottom.

Sampling port were provided at the depth of 19 cm, 38 cm and 57 cm from the base plate and were named as Port No. 1, 2, and 3 respectively. Sludge washing port had been provided at 5 cm above the base of reactor. Gas collector being an important part in UASB so it was carefully designed according to the norms specified in the literature. The angle of inclination of faces of collector was kept 55º. Acrylic pipe of 1 cm internal diameter and 1.5 cm external diameter was attached to the gas collection cone and was further joined to gas collection pipe.

The filter was operated at 37ºC temperature. The 200 watt bulbs were used to maintain the temperature inside the filter at 37ºC. This is the optimum temperature for mesophilic bacterial growth.

TABLE I. DESIGN DETAILS OF UASB REACTOR

Sl No	Details	Unit	Scale of operation
1	Capacity of reactor	m^3	0.01
2	Reactor configuration	-	Circular
3	Building material	-	Acrylic
4	Height	m	0.9759
5	Bottom surface area	m^2	0.01
6	Depth of digestion zone	m	0.7807
7	Depth of setting zone	m	0.1952
8	Types of wastewater	-	spent wash
9	Sampling probes from bottom I	m	0.19
	II	m	0.38
	III	m	0.57
10	Sludge washing port	m	0.05



1 -Feed Inlet
2 -Gas Deflector
3 -Gas Collector
4 -Settling Compartment
5 -Effluent Outlet
6 -To Gas Collector
7 -Digester Compartment
P -Sampling Ports (P1,P2,P3)
P-SW- Sludge Washing Port

Fig. 2. Design Details of Lab Scale UASB

The UASB reactor consists of a biological reaction zone and a sedimentation zone. The lower portion of the reactor maintains the biomass necessary for digestion. In this zone, the organic compounds in the influent are converted to methane and carbon dioxide as the flow passes upwards through a bed of highly active sludge. The necessary mixing in the system is carried out by the gas generated. The inverted cone acts as gas solid separator where the sludge is separated and the gas is released to the gas collector. The sloping bottom provided below the inverted cone allows the gas to pass through the gas solid separator only. Thus a quiescent zone, called the settler, is maintained in the space outside the inverted cone and inside the outer walls of the reactor. This zone allows the separation of solids from liquid phase. The solid particles flocculate and settle to the lower portion of the reactor slipping down from the sloping bottom below the inverted cone. For good functioning of settler, the settling properties of the sludge are important. For efficient functioning of UASB reactor, it is necessary to ensure that the influent is distributed uniformly at the bottom of the reactor, the bio gas generated is separated effectively and the dispersed sludge particles formed in the sludge blanket and which tend to escape along with the effluent are separated in a quiescent zone within the reactor where they can settle and return again into the digestion compartment.

B. Source of Biomass

The reactor was inoculated with active sludge from an anaerobic reactor at the Niphad Sugar Factory wastewater treatment plant (Niphad, Nashik). The acclimatization of the sludge was carried out in the reactor, until the COD percent was approximately 60 to 70%.

C. Wastewater Feed

The wastewater feed was collected from the Yeshwant Sahakari Sakhar Karkhana, Theur (Pune). The wastewater composition varying with the COD between 90000 to 100000 mg/lit and pH is between 3.5 to 4.5. The influent was fed to the lower part of the filter, which distributed the flow in upward direction.

The produced gas was collected through the top of the column by a water displacement method. Control parameters routinely measured were flow rate and composition of the effluent, flow rate and methane content of biogas, pH, COD, volatile fatty acid of the effluent

D. Gas Collection

Gas production was collected and measured by a water displacement method. The volume of produced gas was measured everyday as a volume of distilled water replaced in gas collector, which was connected to the filter. The gas analysis was done by using Gas Chromatography Instrument.

E. Analytical Procedure

Sample from the reactor influent, sampling port, and effluent were collected periodically for analysis of COD, VFA, alkalinity, acidity, suspended solids, VSS and pH, temperature, methane gas according to standard methods [7].

VI. REACTOR PERFORMANCE

The UASB reactor was operated for a period of 16 weeks and data was collected periodically for analysis of COD, VFA, alkalinity, acidity, suspended solids, VSS, pH, temperature and methane gas.

During initial start-up of the reactor in Jul 09 about 0.003 m^3 of digested sludge from an anaerobic reactor at the Niphad Sugar Factory waste water treatment plant was used as the inoculums. In the first stage of operation, the acclimatization of seed sludge was carried out in the reactor by feeding diluted waste water and gradually increasing the effluent load to 100%, until the COD reduction percent was approximately 60% to 70% in 16 weeks.

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The pH was maintained in the range of 6.5 to 7.5 by addition of lime to the influent. Sufficient nutrients are required for optimal bacterial granulation in the reactor. DAP and Urea are used as secondary nutrients. Other parameters like temperature, alkalinity, VFA, TDS, TSS were also monitored for the optimal growth and conversion process in the anaerobic reactor.

Fig. 3. Experimental Set-up of UASB reactor with gas collection arrangement

A. Gas collection in UASB

Fabrication of gas collection system in UASB reactor consists of three parts: aspiratory bottle filled with distilled water, displacement bottle and gas collection cone. Gas formation takes place in the main frame of UASB reactor. It is then collected by the gas collection dome. Gas then passes through rubber pipeline in to the aspiratory bottle which is having distilled water. This distilled water is displaced from aspiratory bottle to displacement bottle because of the high pressure of gas coming from UASB reactor. Gas is collected by the gas collection cone, which is connected to aspiratory bottle at the top.

B. Performance of UASB reactor

Laboratory studies were carried out to assess the feasibility of UASB for treatment of wastewater from Distilleries for a period of sixteen weeks. The data was collected periodically and recorded for analysis of various parameters which are discussed in subsequent paragraphs.

1) COD Removal: Efficiency of COD removal is observed 60.43% at an organic loading rate of 9.2 Kg COD/m³.d. The UASB system exhibited the satisfactory performance of organic loading rate as low as 5.63 Kg COD/m³.d. COD reduction values Increases from 23,233 mg/liter to 55,600 mg/liter in 16 week.

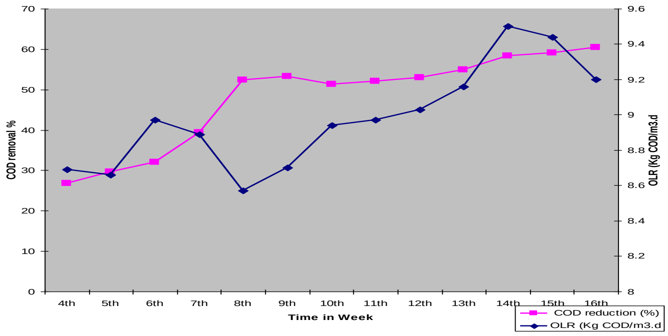

Fig. 4. COD Removal Efficiency and OLR Against Time

2) BOD Reduction: The BOD reduction is around 50% in the 10th week at 85% dilution

TABLE II. BOD REDUCTION VALUES IN Mg/L

Sl. No.	Week	Dilution (%)	Unit	BOD value		% BOD Reduction
				Inlet	Outlet	
1	2nd	50%	mg/L	46,880	-	-
2	4th	75%	mg/L	42,380	37,587	11.30
3	6th	80%	mg/L	44,777	38,380	14.28
4	8th	85%	mg/L	49,880	34,749	30.33
5	10th	85%	mg/L	47,332	23,515	50.31
6	12th	90%	mg/L	46,432	23,646	49.07
7	14th	90%	mg/L	42,789	22,207	48.10
8	16th	95%	mg/L	40,000	20,000	50

Note: - Inlet sample without dilution is 47,574 mg/L of BOD.

3) Reactor Temperature: The reactor temperature has an important effect on the growth rate and the activity of bacteria. The reactor has been operated in the temperature range of 36 to 40 ºC which is suitable for mesophilic methanogenic bacteria.

VII. BIOGAS PRODUCTION

The anaerobic digestion of organic material produces bio-gas which is mainly of methane and carbon-dioxide. The bio-gas is a well-recognized fuel gas with minimum air pollution potential. The amount of bio-gas released can vary over a wide range and depends on the concentration of biodegradable organic material and the biological activity in the reactor[8]. Maximum bio-gas production of 2500 ml/d was observed at OLR of 9.20 kg COD/m³.d.

TABLE III. PERFORMANCE OF UASB REACTOR & BIO-GAS GENERATION

Week	Average OLR(Kg COD/m3.d)	Average COD (mg/l)	Effluent (B)	Average COD reduction (%)	Average Bio-gas Production (ml/day)	Average Methane In %
1st	5.63	92,000	-	-	NR*	
2nd	7.56	91,890	-	-	NR*	
3rd	8.47	91,558	-	-	NR*	
4Th	8.69	88,889	65,300	26.53	NR*	
5Th	8.66	89,900	60,300	32.93	100	NR*
6Th	8.97	89,700	58,500	31.97	175	NR*
7Th	8.89	88,890	53,940	39.31	200	NR*
8Th	8.57	85,665	40,800	52.37	250	NR*
9Th	8.70	87,000	40,717	53.19	375	NR*
10Th	8.94	89,369	43,456	51.37	450	35
11Th	8.97	89,698	43,000	52.06	550	42
12Th	9.03	90,321	42,523	52.92	800	45
13Th	9.16	91,598	41,258	54.95	1000	50
14Th	9.50	94,985	39,552	58.35	1500	52
15Th	9.44	94,430	38,632	59.08	2100	56
16Th	9.20	92,000	36,400	60.43	2500	57

NR*- Not Recorded

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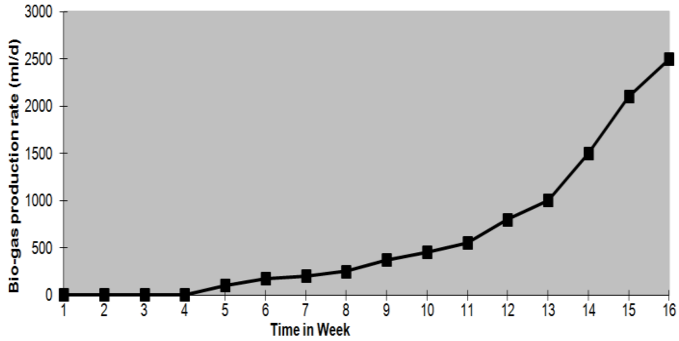

Fig. 5. Bio-gas Production Rate Against Time

Methane gas percent increased from 35 to 57%. In the 16th week gas analysis report showed 57% methane, 23% CO_2 & 20% of air.

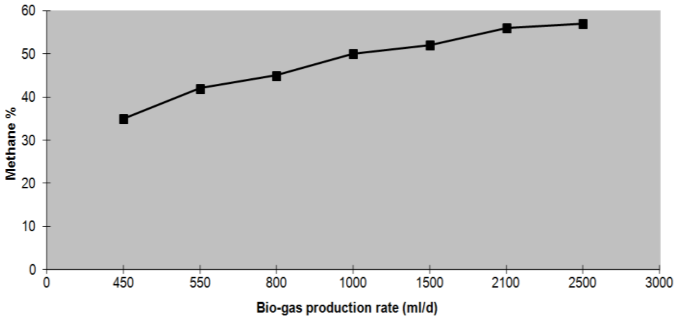

Fig. 6. Methane Percentage Against Bio-gas Production

VIII. CONCLUSION

The following conclusions are based on the findings in the work performed.

- The laboratory scale study indicates that the UASB process can be used for the anaerobic treatment of spent wash from the distillery .The data from the experimental study clearly show that a UASB reactor is able to handle varying influent loads and yet function efficiently.
- The organic loading rates up to 9.5 kg COD /m³.d were applied to the system without a decrease in the performance of the process.
- The removal efficiencies for total chemical oxygen demand (COD) is 60.43 which is within acceptable range for anaerobic treatment of distillery waste using the UASB reactor.
- The average temperature required for proper efficiency is in the range of 35 to 40°C and the reactor's average temperature was maintained at 37.58°C with the help of light bulbs.
- The methane gas formation has been achieved 57% and other gases 43% and if properly harnessed, could represent a potential source of energy for heating or electricity production.
- COD Influences the production of biogas, COD reduction goes on increasing the biogas production rate goes on increasing

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