Influence of Advanced Settling Zone on COD Removal Efficiency of UASB Reactor Treating Dairy Wastewater

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Abstract - *This study focuses on the importance of anaerobic wastewater treatment method for the dairy industry. As India ranks first in milk production, need for treatment of dairy wastewater generated daily is of great importance. As anaerobic treatments generate less sludge compared to aerobic systems, it has a lot of scope for dairy wastewater treatment which contains biologically degradable organic matter. As a bonus anaerobic treatment generates gas which can be used as a fuel for cooking or other household applications. Various reactor models have been suggested for this over the years. This study focuses on upflow anaerobic sludge bed reactor or commonly known as UASB reactor. An innovative new design of gas-liquid solid (GLS) separator is proposed and the reactor of capacity 7.2 liters is commissioned for pilot scale study purposes. Dairy wastewater was obtained from Katraj Dairy Dhankawadi Pune. The plant was operated for approximately 55 days including the time for startup. The successful startup evident by the formation of healthy granules took 36 days. After a successful startup, the reactor was operated with a constant organic loading rate of 1200 mg/lit with a hydraulic retention time of 7 days. The efficiency of the reactor was measured in terms of total COD removed. A maximum COD removal efficiency of 79% was obtained with the formation of a healthy granular anaerobic sludge blanket inside the reactor. This blanket then showed increased methanogenic activity. The modified GLS separator design allowed higher flow rates without flooding the reactor. This will help to create high rate UASB reactors with lower retention times and increased methanogenic activity with a very little production of sludge.*

Key Words: **UASB reactor, GLS separator, dairy wastewater, COD removal, methanogenesis.**

1. INTRODUCTION

According to the economic survey 2015-16, India ranks first in milk production. During the year 20014-15 India produced an annual output of 146.3 million tones which accounts for 18.5 % of world production. The per capita availability of milk in India was 294 grams per day in 2014-15. This highlights the vast dairy network in India in urban as well as suburban regions. This also indicates the huge amount of wastewater generated by the dairy industry. Most of the dairy wastewater comprises of water used for washing & cleaning, quality control and byproducts of whey, cheese etc. It is rich in biodegradable organic content which when disposed of directly in natural resources, damages aquatic and land ecosystem [1].

An average dairy industry generates about 1 to 2 liters of wastewater per liter of processed milk which may increase up to 10 liters [2]. With all the environmental sanctions imposed by the government to control pollution, effluent from every industry needs to be treated before adding it to the natural water resources. The general guidelines given by the Indian Central Government are as follows:

TABLE I: Central Pollution Control Board's consent limits for industrial effluents [3].

Sr. No.	Sample	Limit
1	Chemical Oxygen	250 mg/l
2	Total Suspended	100 mg/l
3	BOD at 3 days $27^{0}C$	100 mg/l
4	pH	5.5 - 9.0
5	Oil & Grease	10 mg/l
6	Total metal	10 mg/l

There are different types of wastewater treatment methods which can be used for treating industrial effluents. These are mainly divided into two categories as aerobic and anaerobic. The aerobic treatment uses aerobic bacteria which degrade the effluent in presence of oxygen whereas anaerobic treatment uses anaerobic bacteria which work in absence of oxygen. Facultative bacteria which show both aerobic and anaerobic properties can be used in either treatment processes. Dairy wastewater being rich in biodegradable organic content can be reduced easily and more efficiently using anaerobic treatment. Anaerobic treatment has various advantages over traditional aerobic treatments as follows [4]:

- It has less production of sludge.
- No aeration is required.
- Energy in the form of methane can be generated.
- It can handle higher loading rates.
- Anaerobic sludge has a higher shelf life.

Various anaerobic treatment technologies have been in use for a long time. Septic tanks are the most commonly found anaerobic reactors in many villages. These are very efficient in treating high strength wastewaters. As a bonus, they produce methane gas which can be used as a fuel for cooking. As observed by McCarthy, these techniques are being used from as early as 1881 [5]. Over the years, many modifications have been proposed for anaerobic reactors to increase their efficiency and range of applications.

Anaerobic reactors can be classified on the basis of the distribution of microorganisms as granule and biofilm reactors. Hybrid reactors incorporating both the techniques are also in use for optimal results.

In this study, a granular reactor called upflow anaerobic sludge bed reactor or UASB is used for treating dairy wastewater. A modified design is proposed to optimize the performance of the reactor.

2. UASB Technology

Upflow anaerobic sludge bed reactor or UASB reactor was first proposed by Lettinga & Hulshoff in the Netherlands in 1970. Since then a lot of modifications have been suggested by various scientists. Hybrid technologies combining UASB reactors with others are also found to be more effective. In India 16 full-scale UASB reactors were commissioned by the government as part of Yamuna River Action Plan in 2003 [6]. However, to meet the standards set by National River Conservation Directorate (NRCD) of India, post-treatment methods in the form of polishing ponds were used in Yamuna river basin.

A typical operation of a UASB reactor involves wastewater entering in called as influent and treated water leaving out called as effluent. A sludge bed of anaerobic bacteria is present inside the reactor which is used to degrade the complex organic matter in wastewater. Gas generated during the process is collected at the top of the reactor. A recycle of effluent to the reactor may be provided to enrich the sludge bed increasing its degradation capacity.

A typical biological and chemical degradation process in UASB reactor is carried out in four stages i.e. hydrolysis, acidogenesis, acetogenesis and methanogenesis [7]. Hydrolysis breaks down complex molecules into simple sugars, amino acids and fatty acids releasing hydrogen which can be used by methanogens present in the sludge. Acidogens and acetogens further digest the simple hydrolysed molecules during acidogenesis and acetogenesis respectively. In methanogenesis, as a terminating stage of anaerobic digestion, all the smaller constituents are converted to methane, carbon dioxide and water.

3. Materials and Methods

3.1 Configuration of reactor

A 7.5-liter cylindrical UASB reactor was commissioned for the experimental study. Advanced settling zone is proposed for a faster settling of granules inside the reactor. For this two concentric cylindrical pipes of varying diameter are used. Smaller diameter pipe is connected with larger one using inverted funnel-like arrangement. These inverted funnels act as Gas Liquid Solid (GLS) separator. The sudden expansion in the diameter of upper pipe inhibits the upflow velocity of influent and allows the granular sludge to settle at much larger velocity creating a suspension zone or blanket in the middle of the reactor. A peristaltic pump was obtained from AMSPA Nigdi Pune for dosing purposes with a flow range of 0.05 to 20 ml/minute. Because of the positive displacement properties of the peristaltic pump, no air was able to enter the reactor through influent and anaerobic conditions were maintained.

Gas generated in the reactor was collected at the top using water displacement method. A U tube assembly was employed at the effluent outlet to prevent the escape of gas generated during the operation of the reactor.

Fig. 1 Modified UASB reactor

3.2 Operation of reactor

The UASB reactor was inoculated with anaerobic sludge specially designed for dairy wastewater. Wastewater was obtained from Katraj Dairy, Dhankawadi, Pune. The reactor was operated from August to October 2015 with ambient temperatures in the range of 27 to 32^{0}C. During startup of the reactor, feed wastewater was introduced at a constant flow rate of 500 ml/day. Successful startup of UASB is evident by the appearance of granules inside the reactor. Granules formation can be enhanced by adding natural polymers like Moringa Oleifera seeds water extract and also by adding commercial & synthetic polymers [8]. After successful startup and stabilization, UASB was operated continuously at a constant organic loading rate of 1200 mg/liter to achieve maximum COD removal efficiency. Once the maximum removal efficiency is achieved, keeping organic loading rate constant, hydraulic retention time was reduced gradually to find out the maximum permissible upflow velocity for sufficient COD removal.

3.3 Analytical methods

All the experimental parameters like COD, BOD, pH, TSS, temperature, etc. were calculated using standard methods. BOD of wastewater was calculated at 3 days and 27^{0}C. TSS was calculated using an electric oven. COD was calculated using closed reflux method. For closed reflux method, a sample with high organic content was diluted with suitable dilution factor. Automatic electronic temperature indicator was inserted inside the reactor to monitor the temperature continuously. Influent wastewater flow rates were directly controlled by a peristaltic pump with LED display.

4. Results and discussion.

4.1 Composition of dairy wastewater

Dairy wastewater was obtained from Katraj Dairy Dhankawadi Pune. The composition of wastewater was calculated on the day it was obtained. Freshly procured dairy wastewater was found to have following properties:

TABLE 2: Dairy wastewater composition

Sr. No.	Parameter	Value
1	pH	7.2
2	TSS	290 mg/lit.
3	Temperature	26^{0}C
4	BOD at 5 days	1012 mg/lit.
5	COD	1428 mg/lit.

All the analysis was done using standard APHA methods. The last day effluent characteristics of wastewater were found to be as follows:

TABLE 3 Effluent wastewater characteristics

Sr. No.	Parameter	Value
1	pH	7.2
2	Temperature	29^0 C
3	COD	249 mg/lit.

4.2 Startup of reactor

UASB reactor was inoculated using anaerobic sludge procured from the laboratory. It was operated continuously. Dairy wastewater contained high quantity of fats which later converted into fatty acids. This led to an increase in acidity which may be inhibitory to the anaerobic operation. However, $NaHCO_3$ was added to maintain the alkalinity. Stabilization of UASB was evident by the formation of granules on day 36 of the experiment. These granules were lifted up by the gas molecules. When they collide on GLS separator, coagulated sludge starts to settle whereas gas will escape to the top. This motion creates a suspension zone inside the reactor which was found to be enriching for the sludge activity. To speed up the start-up of the reactor, a pre-treated sludge can be procured from a functioning anaerobic water treatment unit. After achieving the stabilization, influent wastewater was fed into the reactor to achieve maximum organic matter removal efficiency.

4.3 Optimum COD removal efficiency

Influent dairy wastewater at a constant organic loading rate of 1200 mg/lit were continuously fed to the UASB reactor. The available sample was diluted to maintain constant organic loading rate. The efficiency of the reactor was calculated in terms of total COD removed. COD calculations were done daily. In this study, it was observed that initially early in the experiment, COD started to increase but once the anaerobes from the sludge media started to degrade the organic matter in wastewater, COD started to decrease gradually. Maximum COD degradation was observed on day 45 after the startup of UASB. The total COD removed at this stage was 79% with a hydraulic retention time of 7 days maintained at a flow rate of 1 lit/day.

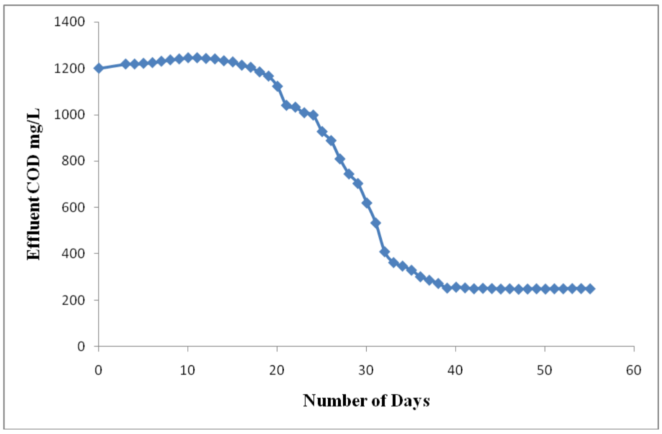

Fig. 2: Effluent COD per day

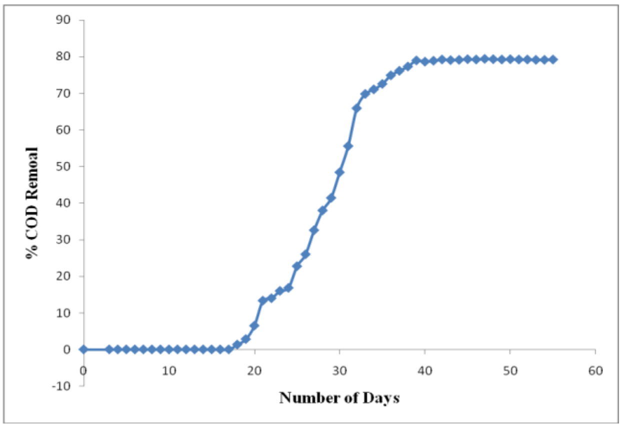

Fig. 3: % COD removal rate per day

Variation in pH was also observed initially during the operation. Initially pH of the system started to decline and created slightly acidic conditions inside the reactor. This would have caused an inhibitory action on the anaerobes present in UASB. To maintain alkalinity, $NaHCO_3$ was added to the reactor. The pH was usually maintained at 7.2 to 7.6.

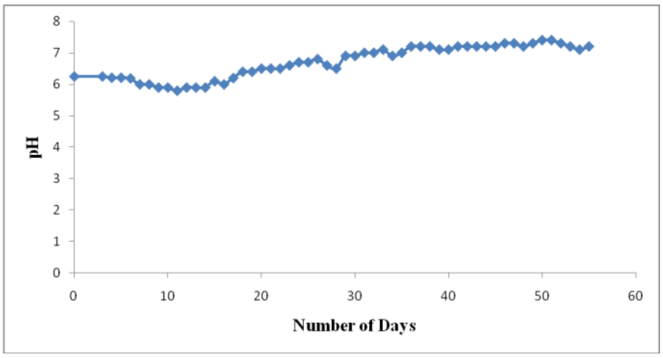

Fig. 4: Variation of pH during the operation of the reactor

4.4 Effect of improved GLS separator design

A venturimeter like design of GLS separator allowed higher flow rates up to 1.2 lit/hr without any sludge washout. This zone was observed to create more turbulence inside the sludge bed felicitating automatic mixing at higher velocities. Optimum reactor efficiency of 76% was obtained at hydraulic retention time as low as 4 hours. The increased turbulence also helped to maintain the temperature at 29 ^{0}C.

5. Conclusion

The proposed modified design of GLS separator provided more methanogenic activity during the experiment. The additional turbulence created was beneficial for mixing as well as mass transfer between various methanogens present in the sludge. The system was also found to maintain its own temperature within favorable limits.

Some issues with leakages were observed slightly during the experiment and maintaining anaerobic conditions inside the reactor was a task. Facultative bacteria can be used to deal with this problem. These bacteria can use whatever little air is leaked into the reactor, maintaining total anaerobic condition. With high rate capacity such reactors can be used effectively for low cost, low maintenance wastewater treatment units with economic feasibility as well.

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