Performance Evaluation of Modified UASB Reactor for Treating Bakery Effluent

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Abstract

The bakery industry is a polluting industry. Over 50% of the world population depends on bakery products for sustenance. The industry produces highly biodegradable waste stream with BOD of 1800 - 3000 mg/l and COD of 5500 - 7000 mg/l. This study investigated the effect of Hydraulic Retention Time (HRT) and Organic Loading Rate (OLR) on the performance of an Upflow Anaerobic Sludge Blanket Reactor (UASBR) in treating the bakery effluent stream. The flow rates of the experiments were 7.20, 14.40, 21.60, 28.80 and 36.00 l/day which corresponded to HRT of 3.47, 1.74, 1.16, 0.87 and 0.69 days respectively. In order to evaluate the performance of UASB reactor, the process parameters viz., volumetric loading rate, organic loading rate and biogas generation were studied as response. The maximum chemical oxygen demand (COD) removal efficiency of 83.1% was achieved for the operating conditions of OLR at 0.037 kg COD/kg VSS. day and HRT at 3.47 days.

Keywords: Anaerobic, bakery wastewater, high rate, upflow anaerobic sludge blanket reactor, UASB.

INTRODUCTION

Environmental issue is a critical factor for industrial competitiveness. Hence, a common framework is set for industrial commitment on environmental protection by individual consumers and society. Redesign the process, recover the by-products or reuse the effluents are some of the possible actions towards an eco-efficient strategy. However, a crucial point here is the ability to protect natural ecosystems from polluted wastewater. Hence, a wastewater treatment plant that maximizes removal efficiency
and minimizes investment and operation costs is a key factor. For treating the industrial wastewater, anaerobic reactors have been used predominantly with high COD removal efficiency (Chen et al., 2008, Chan et al., 2009). In this regard, anaerobic system of Upflow Anaerobic Sludge Blanket (UASB) reactor is proved to be effective in treating both high-strength industrial wastewater as well as low-strength synthetic wastewater (Kida et al., 1994, Franklin 2001, Rajeshwari et al., 2000). Such anaerobic system of treatment has become popular around the world for treating to the high range of BOD in industrial effluent streams with cost economy and environmental protection (Lettinga et al., 1999, Vanlier 2008).

The bakery industry is a significant nourishment enterprise. Traditionally, bakery products are categorized as bread and bread roll products, pastry products (e.g., pies and pasties), and specialty products (e.g., cake, biscuits, doughnut, and specialty breads). Wastewater in bakeries is primarily generated from cleaning operations including equipment cleaning and floor washing. The wastewater has major components of high loading, fluctuating flow and it contains rich oil and grease, flour, sugar and yeast. Bread crumbs and other dry materials are swept off the floor and treated as solid waste. Cake, sweet goods, doughnut, and pie shop operations generate the highest strength liquid wastes. Pans and trays must be washed and greased after each baking resulting in a discharge that contains large quantities of grease, sugar, flour, fruit-filling materials and detergents. [Yim et al., 1975]. The Bakery wastewater lacks of nutrients and hence, disposal of the bakery’s wastewaters by biological treatment is a difficult problem.

The transformation of complex macromolecules present in wastewater into biogas requires the mediation of several groups of micro-organisms. Four different phases are distinguished in the overall conversion process, which are shown in the schematic diagram.

![Fig.1 Schematic Diagram of Anaerobic Process](image-url)
**Upflow Anaerobic Sludge Blanket Reactor**

Upflow Anaerobic Sludge Blanket (UASB) process is a type of anaerobic processes used for the treatment of wastes having high COD.

The UASB reactor is by far the most widely used high rate anaerobic system for anaerobic wastewater treatment, which was developed by Gatze-Lettinga and his group at the University of Wageningen in the Netherlands. This process combines high rate treatment efficiency with low construction and maintenance costs.

![Fig.2 Schematic Diagram of UASB Process](image)

**Manufacturing Process of Bakery**

The principles of baking bread have been established for several thousand years. A typical bakery process is illustrated in Fig. 3. The major equipment include miller, mixer/kneading machine, bun and bread former, fermentor, bake ovens, cold stage, and boilers. The main processes are milling, mixing, fermentation, baking, and storage. Fermentation and baking are normally operated at 400°C and 1600°C – 2600°C, respectively. Depending on logistics and the market, the products can be stored at 40°C – 200°C. Flour, yeast, salt, water, and oil/fat are the basic ingredients. The bread improver (flour treatment agents), usually vitamin C (ascorbic acid), and preservatives are included in the commercial bakery production process.

Flour made from wheat contains a higher contents of protein and gluten. Yeast is used to introduce anaerobic fermentation, which produces carbon dioxide. Adding a small amount of salt gives the bread flavor, and can help the fermentation process to produce bread with better volume as well as texture. A very small quantity of vegetable oil keeps the products soft and makes the dough easier to pass through the manufacturing process. Another important component in production is water, which is used to produce the dough. The ratio of flour to water is normally 10:6. Good bread should have a certain good percentage of water. Vitamin C, a bread improver,
strengthens the dough and helps it rise. Preservatives such as acetic acid are used to ensure the freshness of products and prevent staling. During the manufacturing process, 40°C – 50°C hot water mixed with detergents is used to wash the baking plates, molds, and trays. Baking is normally operated on a single eight-hour shift and the production is in the early morning hours.

![Diagram of Bakery Industry Production Process]

**Fig. 3 General Production Process Diagram of Bakery Industry**

**Sources of Wastewater**

The bakery industry is one of the largest water users in Europe, United States and in India. The daily water consumption in the bakery industry ranges from 10,000 to 300,000 gal./day. More than half of the water is discharged as wastewater. Confronting expanding stringent wastewater release directions and cost of pre-treatment, more pastry kitchen makers have swung to water protection, clean innovation and contamination counteractive action in their creation forms.

The wastewater from cake plants has higher strength than that from bread plants. The pH is in acidic to impartial extents, while the 5-day biochemical oxygen request (BOD₅) from a couple of hundred to a couple of thousand mg/L, which is substantially higher than that from the domestic wastewater. The suspended solids (SS) from cake plants are very high. Grease from the bakery industry is generally high, which results from the production operations. The waste strength and flow rate
are very much dependent on the operations, the size of the plants, and the number of workers. The wastewater from cleanup has low strength and it mainly contains flour and grease. On the other hand, cake production generates higher strength waste, which contains grease, sugar, flour, filling ingredients, and detergents.

**Bakery Wastewater Treatment**

Bakery wastewater lacks nutrients; the low nutrient value gives BOD$_5$ : N : P ratio of 284 : 1 : 2. Hence, extra nutrients must be added to the system to obtain better biological treatment results. The existence of oil and grease also retards the mass transfer of oxygen. The toxicity of excess detergent used in cleaning operations can decrease the biological treatment efficiency. Therefore, the pre-treatment of wastewater is always needed. Bakery industry waste is nontoxic. It can be divided into liquid waste, solid waste, and gaseous waste. In the liquid phase, there are high contents of organic pollutants including chemical oxygen demand (COD), BOD$_5$, as well as fats, oils, and greases (FOG), and suspended solid (SS). Wastewater is normally treated by physical, chemical, and biological processes. Table 1 shows the wastewater characteristics in the bakery industry.

<table>
<thead>
<tr>
<th>Type of bakery</th>
<th>pH</th>
<th>BOD$_5$ (mg/L)</th>
<th>SS (mg/L)</th>
<th>TS (mg/L)</th>
<th>Grease (mg/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bread plant</td>
<td>6.9-7.8</td>
<td>155-620</td>
<td>130-150</td>
<td>708</td>
<td>60-68</td>
</tr>
<tr>
<td>Cake plant</td>
<td>4.7-8.4</td>
<td>2240-8500</td>
<td>963-5700</td>
<td>4238-5700</td>
<td>400-1200</td>
</tr>
<tr>
<td>Variety plant</td>
<td>5.6</td>
<td>1600</td>
<td>1700</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Unspecified</td>
<td>4.7-5.1</td>
<td>1160-8200</td>
<td>650-13430</td>
<td>-</td>
<td>1070-4490</td>
</tr>
</tbody>
</table>

**METHODOLOGY**

A laboratory model of the Upflow Anaerobic Sludge Blanket Reactor with necessary mixing cum equalization tank, having an effective capacity of 25 litres was fabricated and used for this study.

Synthetic bakery wastewater, simulating the typical characteristics of bakery wastewater, was daily prepared with necessary chemicals and nutrients for conducting the experimental study.

Experiments were conducted at different prefixed but varying and operating conditions. Experiment was conducted for five different concentrations of influent substrate (COD), at five different hydraulic loading rates by adjusting the speed.
of the peristaltic pump after required calibration of the pump.

**EXPERIMENTAL SETUP**

The experimental setup consists of UASB reactor made of acrylic material with a cylindrical portion having 60 cm height and diameter of 20 cm, whose top widens to accommodate a gas liquid solid separator (GLSS) as shown in Fig.4. The reactor is fed with the influent tank by means of a peristaltic pump of Miclin’s make and Model PP-20. The influent to the reactor is at its bottom and the reactants move from the bottom to the gas liquid solid separator at the top where the gas gets separated and collected in a gas collector. The reactor is provided with sampling ports at zones viz., hydrolysis, acidogenesis and methanogenesis in the reactor. The influent tank is provided with an agitator to ensure proper mixing of the wastewater. The treated effluent from the top of the reactor is obtained by overflow through the launder provided at the top of the reactor. The physical dimensions of the reactor model were assessed using an empirical approach for an effective reactor volume of 9 liters with an overall volume of 25 litres. The design approach was made on the basis of influent flow rate, hydraulic retention time, upward velocity, influent COD and Organic Loading Rates. The physical dimension and process parameters of the experimental model of UASBR is presented in the Table 2.

![Diagram of Laboratory Experimental Setup for UASBR – 25 Litres](image-url)
Table 2: Up flow Anaerobic Sludge Blanket Reactor- Experimental Model

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total volume of the Reactor, lit</td>
<td>25</td>
</tr>
<tr>
<td>Height of the Reactor, cm</td>
<td>69</td>
</tr>
<tr>
<td>Effective height of the Reactor, cm</td>
<td>60</td>
</tr>
<tr>
<td>Effective diameter of the Reactor, cm</td>
<td>20</td>
</tr>
<tr>
<td>Diameter of the reactor at top, cm</td>
<td>36</td>
</tr>
<tr>
<td>Diameter of the GLSS at Top, cm</td>
<td>7.2</td>
</tr>
<tr>
<td>Diameter of the GLSS at Bottom, cm</td>
<td>17</td>
</tr>
<tr>
<td>Total height of the GLSS, cm</td>
<td>9</td>
</tr>
<tr>
<td>Diameter of the influent &amp; Effluent Pipes, cm</td>
<td>1</td>
</tr>
<tr>
<td>Width of the Launder, cm</td>
<td>2.5</td>
</tr>
<tr>
<td>Peristaltic Pump [Miclin’s make]</td>
<td>PP-20 Model</td>
</tr>
<tr>
<td>Influent Flow rate, liter/day</td>
<td>7.2, 14.4, 21.6, 28.8 &amp; 36</td>
</tr>
<tr>
<td>Influent COD, mg/l</td>
<td>3264, 4178, 5214, 6360 &amp; 7228</td>
</tr>
<tr>
<td>Volumetric Loading Rate, Kg COD/m³.day</td>
<td>0.875 to 10.62</td>
</tr>
<tr>
<td>Organic Loading Rate, Kg COD/ kg VSS. day</td>
<td>0.037 to 0.423</td>
</tr>
</tbody>
</table>

Operating Variables

The experiment was carried out on two major operating parameters viz., influent flow rate and influent COD. The dependent variables of the operating parameters are Hydraulic Retention Time and Organic Loading Rate. The experiment was run for bakery waste streams. The observations were made on operating the model on continuous mode for the parameters such as influent COD, effluent COD and VSS in the sludge blanket. The experimental operating conditions and observations were correlated and following interpretations for Volumetric Loading Rate (Kg COD/m³.day) and Organic Loading Rate (Kg COD/ kg VSS. day) were made for studying the performance of the model.

Characterization of Bakery Effluent

The sample was drawn from M/S Casino Bakery which is located at Chidambaram. The experiment was started with samples drawn from the said industry and biomass acclimatization was achieved, with partial introduction along with domestic wastewater, on reaching the process stabilization. The biomass acclimatization was assessed with an average removal of COD at 70 to 74%. On the basis of the analyzed values, the synthetic characteristics of the bakery effluent was drawn for
running the experiment continuously. In order to standardize the experiment, synthetic effluent was used for the experiment. The synthetic wastewater was prepared using bakery powder juice, as an average value of one gram powder that caused 2200 to 2400 mg/l of COD. The Chemical Composition Synthetic Waste water of bakery is presented in Table 3.

Table 3: Typical Characteristics of Bakery Effluent

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Concentrations</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
<td>6.05</td>
</tr>
<tr>
<td>Total suspended Solids, mg/l</td>
<td>1180</td>
</tr>
<tr>
<td>Total Dissolved Solids, mg/l</td>
<td>3600</td>
</tr>
<tr>
<td>Total Solids, mg/l</td>
<td>4780</td>
</tr>
<tr>
<td>BOD$_5$@ 20°C, mg / l</td>
<td>2250</td>
</tr>
<tr>
<td>COD, mg/l</td>
<td>5700</td>
</tr>
<tr>
<td>Nitrogen[N], mg/l</td>
<td>60 – 90</td>
</tr>
<tr>
<td>Phosphorus[P], mg/l</td>
<td>30 – 100</td>
</tr>
<tr>
<td>Grease, mg/l</td>
<td>96</td>
</tr>
</tbody>
</table>

Sample Collection

While collecting the sample, much care and observations are essential as the small quantity of sample gives the characters of whole wastewater. In the Bakery Industry, the hourly variations of different streams of flow and characteristics considerably varied throughout the day. Forty litres sample of wastewater were taken at a two hour intervals over a period of 24 hours and mixed according to their flow rates, then the integrated sample was used for analysis to find out various parameters.

RESULTS AND DISCUSSION

The performance of the UASBR model was studied in terms of its COD removal efficiency. The model was run for various combinations of influent COD and flow rate. Under each condition of operations, the following parameters of process were observed.

- Influent COD
- Effluent COD
• Concentration of solids in the Sludge Blanket Zone
• \( M^3 \) of gas per Kg.COD removal

The influent COD co-related with the flow rate and effective reactor volume for the valuation of Organic Loading Rate (kg COD applied/ Kg VSS in the Sludge Blanket Zone. day) and Volumetric Organic Rate (Kg COD applied/ effective volume of the reactor. day). The performance study for the Bakery waste stream was studied with the continued experiments with model run under continuous mode.

**Performance of the UASBR Model**

The UASBR model, through a completely mixed reactor by virtue of its granular sludge blanket, is essentially immobilizing the microbial culture to envisage very high mean cell residence time. The rising gas bubbles from the sludge blanket offers much required mixing. The solid concentration was observed as high as 57800 mg/l in the sludge blanket zone. The model was essentially brought to steady-state conditions of treatment using domestic wastewater after continual operation of the model for 2 months.

The feed effluent was drawn from the Bakery Industry for process acclimatization and steady state conditions of the model operation. The steady state condition of the model during the experiment using synthetic effluent was achieved over operation for two weeks. The experiment was run for specific conditions of operations and observations were made, with the model continuously operated for the specified time.

**Performance of Model for Treating Bakery Effluent**

The varying influent COD applied over the model were 3264, 4178, 5214, 6360 and 7228 mg/l. The varying influent flow rate applied over the model for each concentration of influent COD, were 7.20, 14.40, 21.60, 28.80 and 36.00 lit/day. The different flow rates of influent stream applied over the model were correlated with the specific volume of the reactor and it was found that in each flow rate conditions of the feed, the hydraulic retention time (HRT) was 3.47, 1.74, 1.16, 0.87 and 0.69 days respectively.

Under each conditions of model operation, influent COD, effluent COD, concentration of Volatile Solids in the Sludge Blanket Zone and amount of gas per kg COD removal were observed through suitable samples drawn and using standard methods of analysis. The graphical representations to assess the system performance for different operating conditions were drawn, using the observed values of the experiment. The system performance curves of UASBR for treating Bakery effluent are presented in Figs. 5 to 9.
The COD removal efficiency was found to vary from 53.4 to 83.10 % with respect to varied OLR of 0.037 to 0.423 kg COD/kg VSS.day and HRT of 0.69 to 3.47 days. The maximum % COD removal was found to be 83.10 % for the OLR of 0.037 kg COD/kg VSS.day and HRT of 0.69 to 3.47 days. The biogas generation was found to vary from 0.27 to 0.32 m³/kg COD removal with respect to varied OLR of 0.037 to 0.423 kg COD/kg VSS.day and HRT of 0.69 to 3.47 days.

In the Bakery Effluent treatment, the maximum efficiency of the UASBR was observed by COD removal at 83.10 %. The maximum concentration of VSS in the Sludge Blanket of the model was observed at 57800 mg/l. The maximum gas conversion ratio was assessed at 0.32 m³ of gas/kg of COD removal.
CONCLUSION

The experimental work on UASBR model for treating bakery waste stream was found to be successful with % COD removal of 83.1 % for the operating conditions of OLR at 0.037 kg COD/kg VSS.day and HRT at 3.47 days. It can, thus, be concluded that UASBR is one of the best options to treat bakery wastewater for the removal of about 83 % COD. UASBR requires downstream aerobic treatment systems to reduce COD further to meet the standards for disposal of the treated effluent.

REFERENCES


