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Assessment of the Treatment of Textile Mill Effluent Using UASB Reactor

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This study was designed to evaluate the feasibility of the treatment of actual textile mill effluent using a upflow anaerobic sludge blanket (UASB) reactor. The main objective of this study was to generate design aids; in terms of organic loading rate (OLR), hydraulic retention time (HRT) versus chemical oxygen demand (COD) and colour removal in the textile effluent using a UASB reactor at neutral pH and constant mesophilic temperature. The COD, colour and total suspended solids concentration of the textile wastes used in the study were analyzed as 5440 mg/l, 3280 mg/l, 2320 units and 955 mg/l, respectively. The UASB reactor was started up by gradually increasing the OLR from 0.2 kg-COD/m^3-day to 2.6 kg-COD/m^3-day in order to prevent an organic shock to the reactor. Similarly, the hydraulic retention time (HRT) was slowly reduced from 58 h to 8 h to prevent the wash-out of sludge from the reactor. It was observed that more than 80% of COD and colour could be effectively removed at an OLR of 2.2 kg-m^3/d and HRT of 20 h. At optimum operating conditions, the effluent volatile fatty acid concentration was observed to be 430 mg/l. The average biogas production observed during this study was 0.34 l/g-COD$_{removed}$ and it was composed of 58% methane. During the course of maturity of granular sludge, its effective size and settling velocity were observed to increase exponentially as $0.261e^{0.051x}$ and $1.91e^{0.017x}$ respectively. The overall observed biomass yield (Y_{obs}) for the experimental period was calculated as 0.049 g-VSS/g-COD$_{rem}$. This study suggests that the use of a UASB reactor for textile mill effluent is a fairly feasible and viable option.

Key words: anaerobic digestion; textile mill effluent; neutral pH; COD; biogas; design parameters; constant temperature; OLR; HRT

Pakistan is facing acute water deficiency, its water resources have been declining day by day on account of diversified environmental and erroneous water management issues. The available water is being contaminated at a deplorable rate owing to the dumping of untreated domestic and industrial effluent together with agricultural/surface runoff into the receiving waterways. Clean drinking water is therefore only accessible to 18% of its population and the rest of the population are getting polluted drinking water, as designated by the required WHO standards (PCRWR 2005). Moreover, it is an admitted truth that Pakistan has a deficient energy sector despite the fact that it has ample potential for its production. The energy supply deficiency also applies to the electricity sector. Bio-gas is however playing a key role in this sector, which is approximately equal to 37% of the total energy production. Since, it's the most cost-effective and environmentally friendly source of energy, it requires more awareness and consideration for it to undertake the resolution of the energy crises

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by the latest developed techniques of bio-gas generation, especially by converting wastes into energy (Arshad & Hashim 2010). As a result of this, not only the energy dilemma could be worked out but the problem of disposing the untreated domestic and industrial wastes can also be resolved.

At present, there are numerous textile mills contributing significantly to the country's Gross Domestic Production (GDP) as the backbone of its economy. Textile manufacturing is however, one of the most polluting industries, it liberates heavily polluted effluent. Approximately 600 m^3 of wastewater is discharged from the textile mills for each kg of textile production. Wastewater contains more than 1000 mg/l of chemical oxygen demand (COD) in addition to a variety of dyes that impart unaesthetic colour to the receiving water courses (Pak-EPA 1999). The release of coloured compounds into the environment is extremely obnoxious because they destroy aquatic life by affecting photosynthesis; moreover, several dyes and their breakdown products are toxic and mutagenic to life (Somasiri *et al.* 2010; Paulo Igor *et al.* 2010). Consequently, textile waste management is an essential operation towards protection of the environment.

Although the available physical and chemical wastewater treatment techniques are fairly effective, they become expensive when applied on a larger field scale. Therefore, biological treatment techniques are considered as viable options for waste management, especially for developing nations (Bhatti *et al.* 1996; Savant *et al.* 2005; Arshad *et al.* 2008). The biological treatment methods are primarily of two kinds, aerobic process and anaerobic process. Due to the larger energy and nutrition input requirements of the aerobic process, comparatively more importance is given to anaerobic digestion. The utilization of anaerobic digestion which is fairly cheaper in operation, is certainly one of the most excellent wastewater treatment alternatives left for the various types of domestic and industrial effluent all over the world (Lettinga *et al.* 1980; Schellinkhout 1993). The basis of its recognition around the globe is its simple procedure, technical feasibility, cheaper running and maintenance cost, proficient treatment of high-strength wastes etc. The treatability of actual textile waste at a mesophilic temperature range using the UASB reactor still seems to be unconvincing and doubtful, as the available studies do not precisely indicate the effects of organic loading rate (OLR) and hydraulic retention time (HRT) on the COD and colour removal efficiency of the reactor (Isolina *et al.* 2010; Kaan *et al.* 2009; Sreekanth *et al.* 2009; Sarayu *et al.* 2009; Ilter *et al.* 2010).

Since the upflow anaerobic sludge blanket (UASB) reactor is the most common type of anaerobic digestion generally employed for industrial effluent treatment (Arshad *et al.* 2009), this study was designed using a single-stage UASB reactor to investigate the treatment feasibility of textile wastewater under anaerobic conditions. The main objective of this study was to investigate the effects of design parameters like OLR and HRT on the treatability performance of the reactor under steady state conditions of neutral pH and constant temperature.

MATERIALS AND METHODOLOGY

Experimental UASB Reactor

Owing to prior knowledge and the ample advantages of the UASB reactor, it was decided to utilize a UASB reactor for the study. The reactor was fabricated using acryl resin with a total effective volume of 4.5 l, together with a thermostatic casing to maintain steady temperature inside the reactor. The reactor was also equipped with a gas solid separator (GSS) and a mixing apparatus (turbine shaped, 3.81 cm × 7.62 cm) to facilitate the appropriate confluence of substrate and biomass (Arshad & Hashim 2010). A methodical illustration of the UASB reactor is shown in Figure 1.

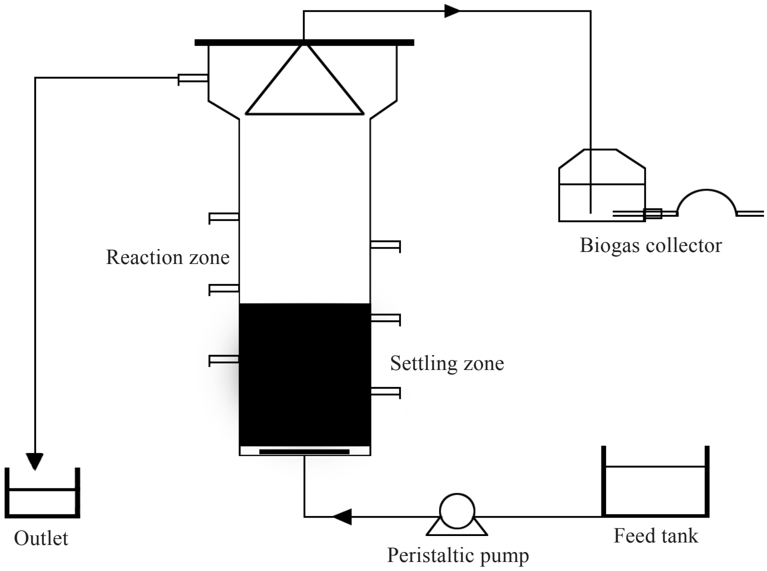

Figure 1. Methodological illustration of the UASB reactor.

Substrate and Nutrients

Actual effluent from the nearby textile mills was used in the study. Nitrogen and Phosphorous were added in the form of $(NH_4)_2SO_4$ and KH_2PO_4 in accordance with the COD:N:P ratio of 550:5:1. The stock solution of trace nutrients containing ferric chloride, zinc sulphate, copper sulphate etc. was added at a concentration of 1.0 milliliter per litre of the feed solution to the reactor (Bhatt 1995; Arshad *et al.* 2009). The wastewater characteristics of the textile mill used in the study is shown in Table 1.

Seed Sludge

About eighty percent volume of the reactor was filled with seeded sludge, which had been fully acclimatized with the substrate during the initial 20–22 days of typical laboratory procedures (Littinga *et al.* 1984; Arshad *et al.* 2010). The characteristics of the seeded sludge at the start up of the reactor are shown in Table 2. The seeded sludge provided 42 grams of volatile suspended solids (VSS). The loading rate was increased stepwise in order to avoid organic loading shock. HRT was also monitored and observed. Mixing was done twice a day.

Operational Conditions

Temperature. The temperature was kept constant at 28°C–30°C during the course of the study period, almost analogous to that of the actual effluent of the textile mill.

pH. A neutral pH was sustained by adding an external buffer solution ($NaHCO_3$) to the feed solution of the reactor.

OLR/HRT. The reactor was operated stepwise by gradually increasing the organic loading rates (OLR); starting from 0.2 kg-COD/m^3-day and getting it to the highest limit of 2.6 kg-COD/m^3-day during the course of study period. The HRT was however slowly reduced from 58 h to 8 h.

Monitoring and Analysis

pH, temperature, influent and effluent COD, volatile fatty acid (VFA) and gas production were monitored regularly, twice a week. Gas was collected over tap water saturated with NaCl. All analysis was carried out in accordance with standard laboratory techniques (AWWA 2005).

Table 1. Wastewater characteristics of the textile mill.

Parameters	Concentration
pH	8.5–9.1
Colour (units)	2320
COD (mg/l)	5440
BOD (mg/l)	3280
Total solids (mg/l)	2885
Total dissolved solids (mg/l)	1450
Total suspended solids (mg/l)	955
Total volatile solids (mg/l)	485

Table 2. Characteristics of seeded sludge.

Parameters	Value
Total solids (mg/l)	63.5
Total suspended solids (mg/l)	51.84
Volatile suspended solids (mg/l)	29.00
Colour	Blackish

RESULTS AND DISCUSSION

Start-Up of the Reactor

Since, pH and temperature are the most significant governing parameters for anaerobic digestion, extreme care was made during the course of study period to maintain them at an optimum level. Past experiences and literature reviews illustrate that a mesophilic range of temperature is the most suitable range for anaerobic conditions, as lower temperature inhibits microbial activities, while elevated (thermophilic) temperature gives rise to high endogenous death of microbes (Buhr *et al.* 1977; Switzenbaum *et al.* 1980; Kennedy *et al.* 1982; Henze *et al.* 1983; Grin *et al.* 1985). Therefore, the temperature was kept constant at a mesophilic range by placing water heating jackets around the reactor. The average temperature recorded during the course of the study period was 28°C–30°C. Likewise, neutral pH is considered to be the most appropriate range for anaerobic digestion (Bhatti *et al.* 1996). Consequently it was kept constantly at a neutral range, to attain maximum benefit from the process, by adding an external buffer solution of 0.03 M $NaHCO_3$, at the rate of 60 ml per litre, to the feed solution of the reactor (Arshad & Hashim 2010). The time course of pH during the study period is shown in Figure 2.

The reactor was started up in accordance to standard procedure and guidelines. The OLR was slowly raised from 0.2 kg-COD/m^3-d to 2.5 kg-COD/m^3-d and the HRT was gradually reduced from 2.8 d to 8 h to avoid any organic distress to the reactor. The treatability performance was also assessed during the course of the study period by observation of the concentration of VFA in the effluent of the reactor. VFA is one of the critical parameters which indicate the failure of the reactor to recover methane from the acetic acid. If the concentration of VFA exceeded 500 mg/l, the feed should be temporarily stopped to prevent further accumulation within the reactor or they could also be diluted by draining out part of the reactor fluid and adding some tap water (Riera *et al.* 1985; Mahadevaswamy *et al.* 2004). During this study, the average concentration of VFAs was observed to be 428 mg/l while its maximum value was observed to be 810 mg/l when the pH of the reactor dropped drastically to the acidic medium. The time course of VFA during the study period is shown in Figure 3.

Treatability Performance

During the course of the study period, the overall COD and colour removal efficiency of the reactor under varying OLR and HRT were carefully observed. Increases in the COD and colour removal efficiency were observed during every step of steady state conditions of the reactor under a given OLR or HRT. Previously, it had been reported that the HRT did not significantly affect decolourization especially from 24 h to 12 h (Paulo Igor *et al*. 2010) but during this study a sudden decrease in the reactor's efficiency was observed for every step of either increasing the OLR or decreasing the HRT. This might be due to the accumulation of

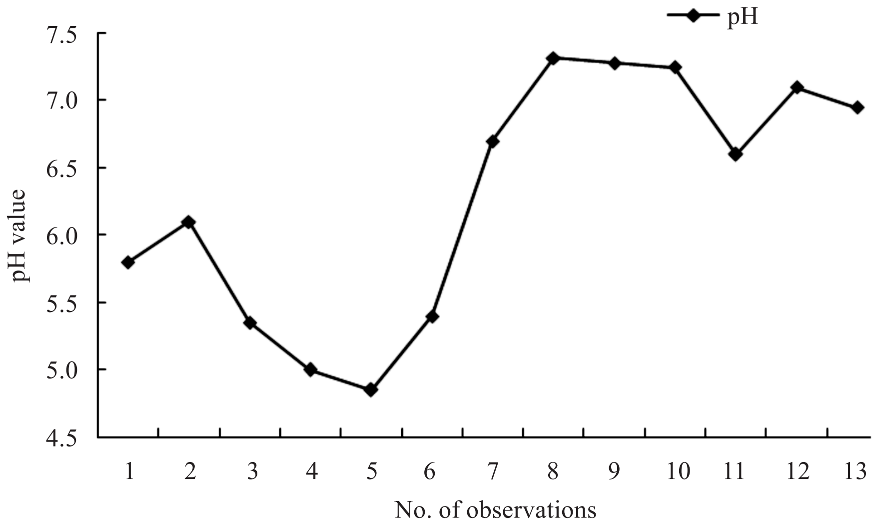

Figure 2. Time course of pH during the study period.

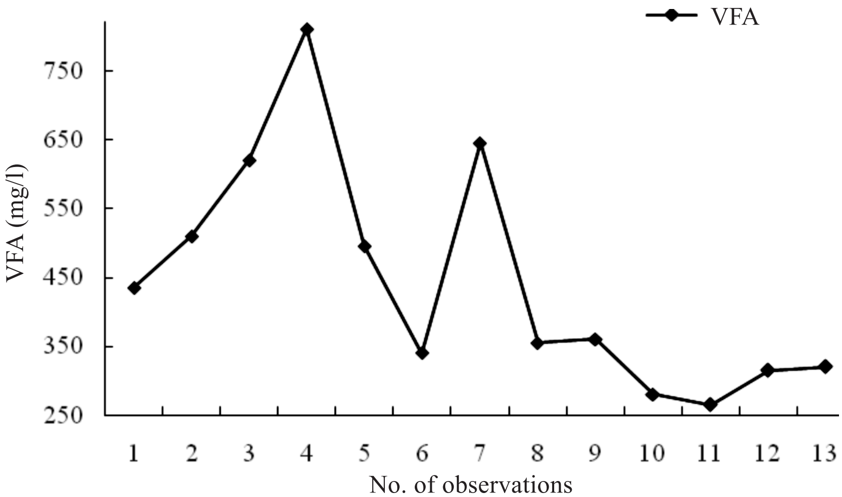

Figure 3. Time course of VFAs during the study period.

excessive VFA in the reactor at these operating conditions. The effects of OLR and HRT on the COD and colour removal efficiency of the reactor are illustrated in Figures 4–7.

The results acquired illustrate that lower OLR and higher HRT favour the treatability performance of the reactor. It was observed that corresponding to optimum conditions, i.e. OLR of 2.2 kg-m^3/d and HRT of 20 h, the COD and colour removal efficiency of the reactor were more than 82% and 79%, respectively. Almost comparable treatability performance has been reported earlier while working on the textile mills effluent under anaerobic conditions (Somasiri *et al.* 2010; Wijetunga *et al.* 2008). In fact, the data acquired from this study presents practical guidelines for the design of a UASB reactor for textile mill effluent at various OLRs and HRTs.

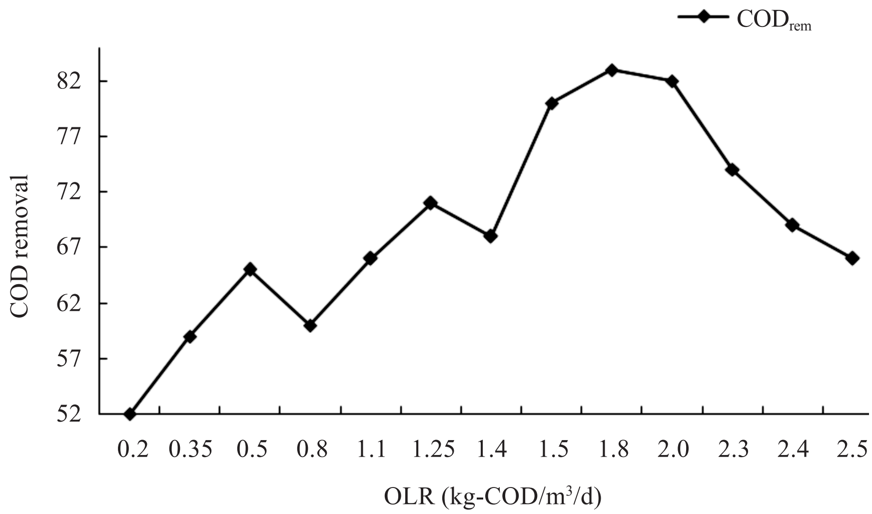

Figure 4. Effects of OLR on COD removal.

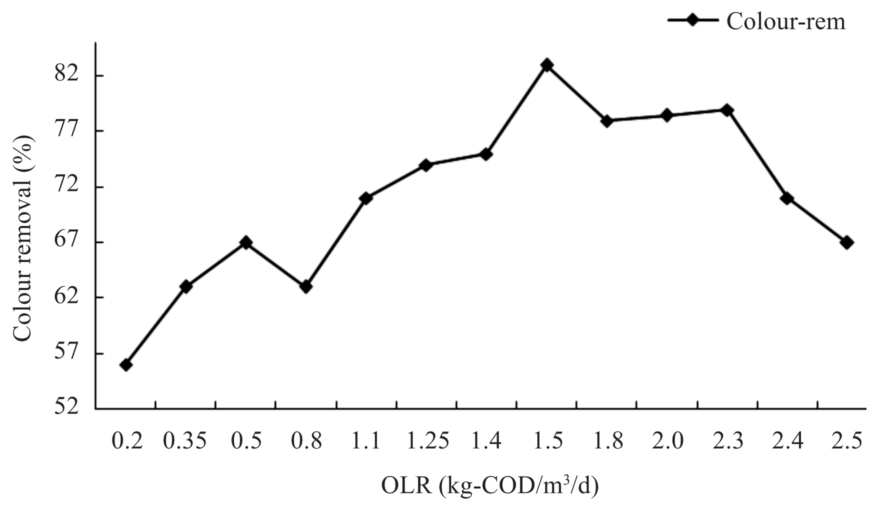

Figure 5. Effects of OLR on colour removal.

Treatment assessment of different studies conducted on various types of waste using a UASB reactor is shown in Table 3. This evaluation demonstrates the effectiveness of a UASB reactor for the treatment of textile wastes analogous to the pulp and paper mill wastes, sugary wastes etc. The slightly lower treatment efficiency of the UASB reactor for the textile mill effluent, as was also evident from this study, might be due to the existence of a high proportion of material which were not susceptible to anaerobic digestion in the wastes that were used.

Bio-gas Production

Figures 8 and 9 illustrate the amount of biogas production and the methane composition observed during the course of the study period. It was noticed that the amount of biogas production varied linearly with the HRT. The higher the HRT, the more would be the biogas

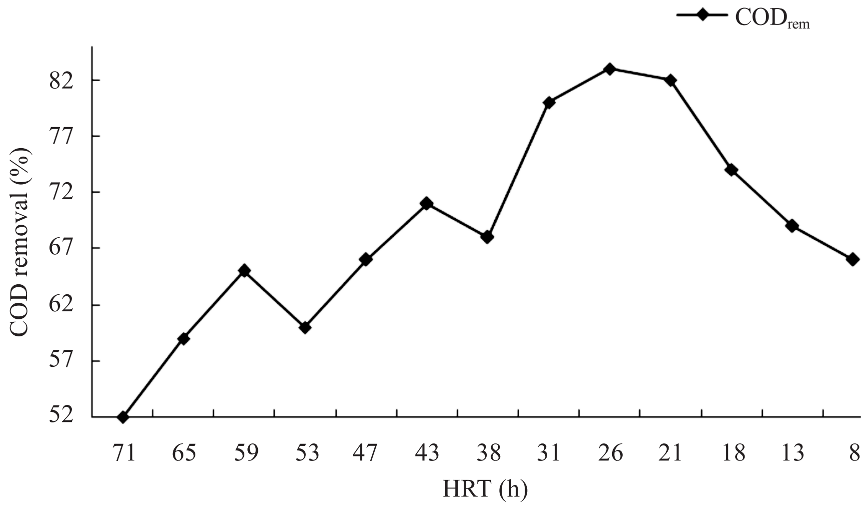

Figure 6. Effects of HRT on COD removal.

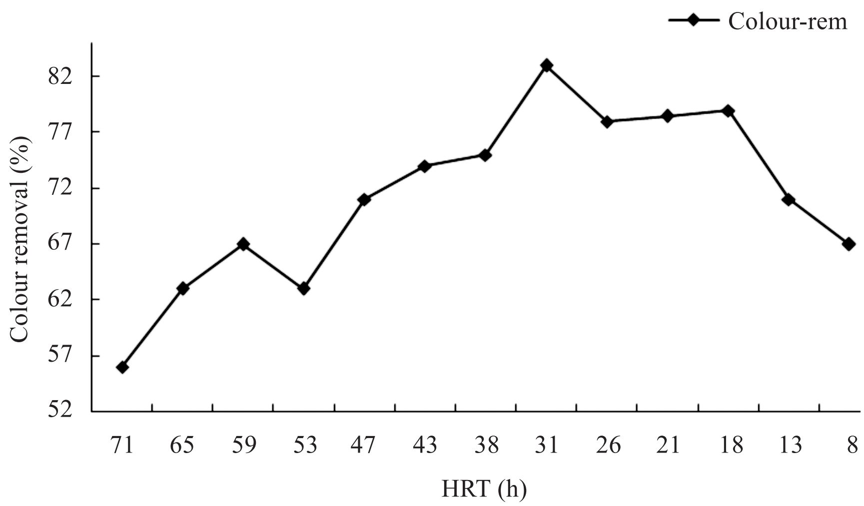

Figure 7. Effects of HRT on colour removal.

Table 3. Treatment assessment of the UASB reactor using various types of waste.

Substrate	Removal efficiency	ORL/HRT	Reference
Domestic effluent	COD = 85%	OLR = 1.8 kg-COD/m^3-d	Arshad *et al*. 2008
NSSC pulping effluent	Lignin-COD = 38%	OLR = 2.75 kg-COD/m^3-d HRT = 38 h	Arshad *et al*. 2009
Paper mill effluent	COD = 64%	OLR = 2.14 kg-COD/m^3-d	Arshad & Hashim 2010
Sugar mill effluent	COD = 70%	OLR = 2.1 kg-COD/m^3-d HRT = 16 h	Arshad *et al*. 2010
Textile mill effluent	COD = 82% Colour = 79%	OLR = 2.2 kg-COD/m^3-d HRT = 20 h	This study

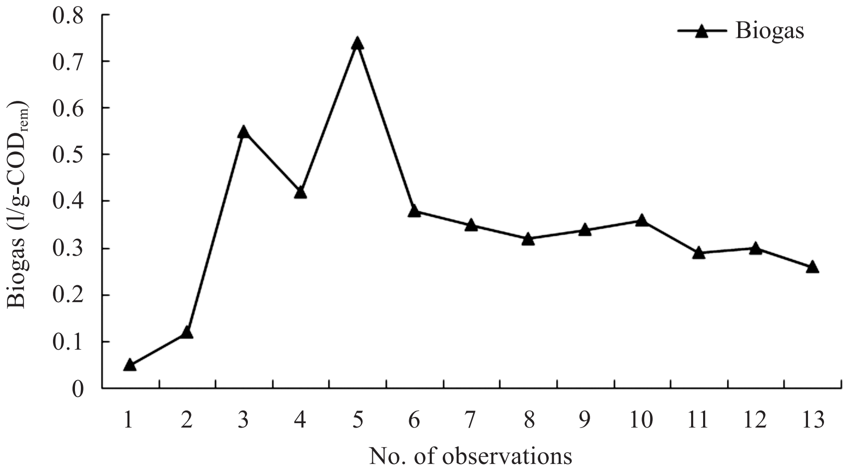

Figure 8. Amount of biogas production.

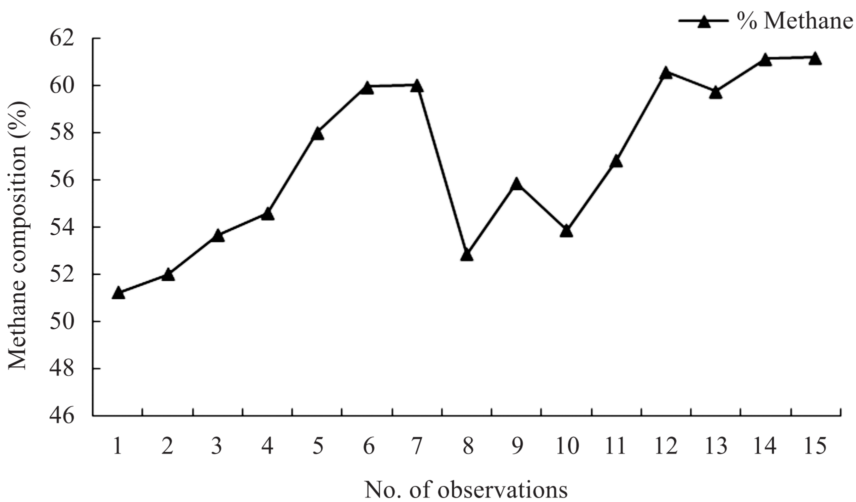

Figure 9. Methane composition of the biogas.

production and vice-versa; and that might be due to the fact that the lower HRT promoted the wash-out of sludge from the reactor, which ultimately affected the biogas generation. In addition, the low mixing of the biomass and the substrate also reduced the biogas production.

The main constituents of the biogas as reported earlier were methane and carbon dioxide that were produced during anaerobic digestion (Bhatti *et al*. 1996; Mahadevaswamy *et al.* 2004). A small proportion of the biogas was H_2, if the reactor was not functioning properly, due to the existence of hydrogen-producing acetogens that provided adverse operational conditions for the conversion of VFA to acetate rather then to methane.

The average gas production observed during the study was 0.34 l/g-$COD_{removed}$ that nearly resembled the theoretical value of 0.35 l/g-$COD_{removed}$ (Arshad *et al*. 2010), but the percentage composition of methane was comparatively low, i.e. 57.88% (Bhatti 1995, Arshad *et al.* 2009) which indicated the presence of recalcitrant substances in the textile waste. As the granules had not matured during the initial study period, the amount of biogas observed during that stage was comparatively lower, i.e. 0.08 l/g-COD_{rem}-d composed 52% of methane.

Sludge Characteristics

The sludge character is an important factor in evaluating the treatability performance of the reactor. The seeded granular sludge that was dark brownish in colour at the start-up period became grayish-dark in colour after a few weeks of the process. The effective size and settling velocity of granular sludge during the course of the study period is shown in Figures 10 and 11, respectively. The figures illustrate that the effective size and settling velocity of the granular sludge gradually increased during the course of digestion until they were entirely mature. The equations obtained from the data are shown below:

Granular size development

$$y = 0.261e^{0.051x} \tag{1}$$

Settling velocity improvement

$$y = 1.91e^{0.017x} \tag{2}$$

At the initial period of the study, the enhancement in the effective size of sludge was comparatively lower, which was mainly due to the wash-out of sludge from the reactor. The effective size of granular sludge previously reported varied from 0.3 mm–5 mm for different types of waste (Pol 1983; Mahadevazwamy *et al.* 2004). In this study, the average effective size and settling velocity of the granular sludge were observed to be 0.38 mm and 2.17 cm/s, respectively. The smaller granule size observed was mainly due to the shorter period of the study and the employment of an insignificant OLR.

The mean ash content of the granular sludge was observed as 10.12%, which decreased to 8.84% at the end of study period. The MLSS concentration and the VSS/MLSS ratio of the granular sludge were recorded at 56 400 mg/l and 0.81 mg/l, respectively. The overall observed biomass yield (Y_{obs}) for the experimental period was calculated as 0.049 g-VSS/g-COD_{rem} by using the following equation:

$$Y_{obs} = \sum X / \sum S \tag{3}$$

Where,
$\sum X$ = total biomass produced, g-VSS and
$\sum S$ = Total substrate removed, g-COD

This value of Y_{obs} was almost one-tenth of the typical activated sludge process (Bhatti *et al.* 1996). Thus, it was consistently shown by means of this study that anaerobic digestion produced comparatively less sludge than the aerobic process.

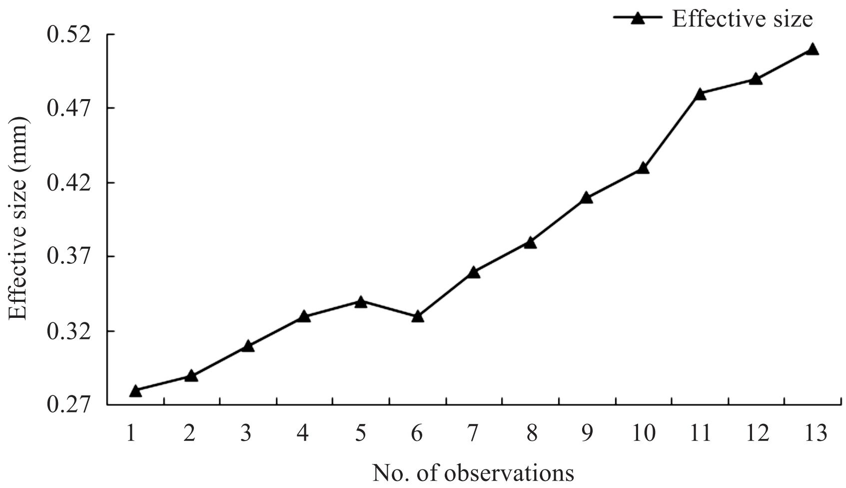

Figure 10. Effective size of the granular sludge.

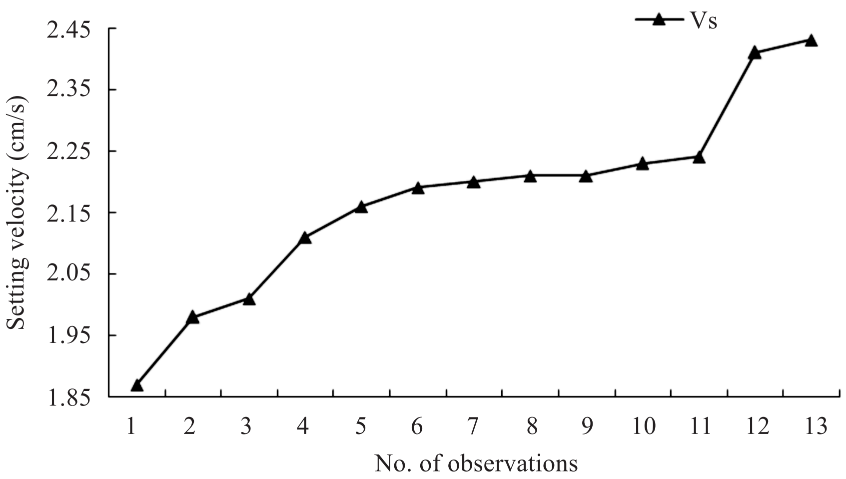

Figure 11. Settling velocity of the granular sludge.

CONCLUSION AND RECOMMENDATION

From the results of this study, the following conclusions were drawn:

- The textile industry's waste management was a serious environmental concern that should be tackled appropriately. Due to the limited energy and resources crises being faced by the developing world, anaerobic digestion was one of the best options available for the precise management of various kinds of waste including effluent from textile mills.
- The wastewater being released from textile industries, which was of high-strength, alkaline and coloured in nature, was quite feasible for anaerobic digestion. The COD, BOD, TDS, TSS and colour concentration values of the textile mill effluent were

5440 mg/l, 3280 mg/l, 1450 mg/l, 955 mg/l and 2320 units, respectively.

- More than 80% of the COD and colour could be removed from textile effluent at an OLR of 2.2 kg-m^3/d and HRT of 20 h.
- Sustaining neutral pH by adding an external buffer solution $NaHCO_3$ to the reactor, the VFA of the effluent concentration could possibly be kept at less than 430 mg/l.
- An average gas production of 0.34 l/g-$COD_{removed}$ could be obtained from the textile mill effluent by using a UASB reactor at constant neutral pH and mesophilic temperature.
- The lower methane composition of the biogas generated during the study, i.e. 57.88% reveal the presence of recalcitrant substances in the textile mill effluent.
- The effective size and settling velocity of the granular sludge enhance exponentially through their development, i.e. $0.261e^{x0.051}$ and $1.91e^{x0.017}$, respectively.
- The mean ash content, MLSS concentration, VSS/MLSS ratio of the granular sludge was 10.12%, 56 400 mg/l and 0.81 respectively, while the overall biomass yield (Y_{obs}) was calculated as 0.049 g-VSS/g-COD_{rem}.

Treatability of textile effluent in a single-stage UASB reactor at neutral pH and mesophilic temperature is a highly feasible, cost-effective and reliable technique. A long-term comprehensive study is required to study the exact behaviour of textile effluent under anaerobic conditions using variable operating conditions. The nature and concentration of recalcitrant material in the textile effluent and their overall impact on anaerobic digestion needs to be evaluated.

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