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Performance evaluation of modified lab-scale UASB reactor with different OLR in treating synthetic wastewater

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Abstract - *UASB reactors are well known for their ability to treat high strength wastewater. In the present study, a modified lab-scale UASB reactor was evaluated for COD removal and theoretical biogas production in treating synthetic wastewater having COD 4900 mg/L. The reactor modification included a modified three-phase separator and a rope matrix. The spiral flow inside the reactor induced by the modified three-phase separator helped prevent biomass washout and also aided in mixing. The rope matrix provided near the bottom facilitated the attached growth inside the UASB reactor. Besides COD removal, changes in other parameters including pH, alkalinity, suspended solids, Conductivity and theoretical methane production were also observed for the varying OLR. The performance of the reactor was evaluated by varying the OLR with HRT ranging from 18 to 24 hours. Maximum COD removal of 87% and maximum theoretical methane production of 0.24015 m^3/Kg COD were obtained at an OLR 5.34 Kg COD m^{-3} d^{-1}. Further increase in OLR resulted in decreased performance of the modified reactor in terms of COD removal. The theoretical methane production value opens up the possibility of comparing theoretical values with practical methane production.*

Keywords: Modified UASB, synthetic wastewater, COD removal, OLR, theoretical methane production

1. INTRODUCTION

Anaerobic treatment has been used since the 1960s. Anaerobic treatment processes are advantageous over aerobic treatment processes in aspects like lesser sludge production, lesser power consumption and their ability to treat wastewater in a shorter period even with fluctuation in the concentration of pollutant in the influent. Up-flow Anaerobic Sludge Blanket (UASB) reactor is one of the high-rate anaerobic reactors that was developed by Lettinga and coworkers in the late 1970s in the Netherlands [1], [2]. The first developed UASB reactor was used to treat beet sugar refinery wastewater. The UASB reactor is simple with a three-phase separator to retain the solids and does not require any mixing device because of the mixing by the up-flow velocity of wastewater and gas bubbles produced due to the reaction inside the reactor. The typical up-flow velocity of the UASB reactor is 0.5 m/hr to 1.0 m/hr and the height to width ratio is 0.2 to 0.5. The UASB reactor is usually started with the sludge of about 10–30% of the reactor volume. The UASB reactor is capable of maintaining high solids retention time which makes the treatment more efficient [3]. UASB reactors were initially used to treat medium to high strength wastewaters. But recent advances focus on its use to treat domestic wastewater. Several researchers have recommended UASB technology for the treatment of sewage mainly in tropic and subtropical regions because of its ability to cope with fluctuations in temperature, pH, influent substrate concentration, quick biomass recovery after shutdown and energy generation in the form of biogas or hydrogen. This statement is particularly appealing in tropical countries because the temperature is optimum for maintaining the methanogens for better performance of the UASB process. These characteristics make UASB one of the popular treatment technologies [4]. The deviation and difference in approach in the use of UASB technology are mainly due to its advantages such as simple design, easy construction and operation, lesser capital investment, robustness in terms of COD removal efficiency and its potential to withstand fluctuations in loading [5].

The UASB reactor is an ideal reactor to treat organic wastewater but retaining the solids is important because washout of the granules results in decreased efficiency of the process. The reactor consists of three phases namely the liquid phase (wastewater to be treated), a solid phase (solids or biomass) and a gas phase (biogas generated). The biogas bubbles generated (containing a mixture of methane, carbon dioxide, and hydrogen sulphide) gets attached to the biomass and takes biomass along with the effluent [6]–[8]. The UASB reactor has been proven to be successful in treating a wide range of effluents from industries such as slaughterhouse, sugar, pulp and paper, dairy and tanneries. The UASB reactor has been proven to be effective in treating wastewater with high carbohydrate content. The uniqueness of the UASB reactor is that it does not require any support material for the sludge bed, and also, there is no need for external mixing. The mixing inside the reactor is taken care of by the up-flow velocity and gas bubbles produced inside the reactor.

Sludge granulation is a complex process in UASB technology. But the performance of the UASB reactor in terms of COD removal depends on the granulation process [9]. About 60% of the full-scale anaerobic treatment processes utilize the UASB process out of which around half have been installed in tropic and subtropic regions. The efficiency of the UASB reactor process depends on the configuration and operating conditions of the reactor (such as pH, granulation, organic loading rate and height of the reactor, hydraulic retention time, mixing and temperature). The modification of the conventional UASB reactor configuration and use of UASB reactor in sequence with other treatment techniques or the use of UASB reactors in multiple stages for better performance is the recent research area in the field of anaerobic wastewater treatment [4]. The start-up of the UASB reactor which is considered to be the challenging aspect was about 90 days even when a pre-granulated sludge was used [10]. A hybrid UASB reactor with a rope matrix was developed to treat swine wastewater to achieve the advantages of both attached and suspended growth processes. The rope matrix was placed vertically along the height of the reactor such that there is no interference in the flow of wastewater. Also, the rope matrix comprising 18 parallel ropes each of length 65cm was installed in the mid-section to facilitate the attached growth [11].

Previous studies from the literature survey showed that modification to the conventional UASB reactor was attempted and hybrid UASB reactors were compared with conventional UASB reactors for pollutants removal. The modifications included the introduction of filter media for sludge retention, the addition of a second leach bed, the inclusion of membrane to the UASB reactor to form an anaerobic membrane bioreactor (AnMBR), provision of a slanted baffle for better mixing, provision of a mechanical stirrer in the reaction zone for good mixing, the addition of plastic filter rings to prevent sludge washout, provision of a modified three-phase separator to prevent sludge washout and provision of rope matrix to facilitate the attached growth inside the UASB reactor to improve the treatment efficiency [8], [11]–[17].

The present work aims in the evaluation of the wastewater treatment efficiency of UASB reactor with modifications in the conventional configuration. The modification includes the combination of the modified three-phase separator and the rope matrix. The objectives of the present work are

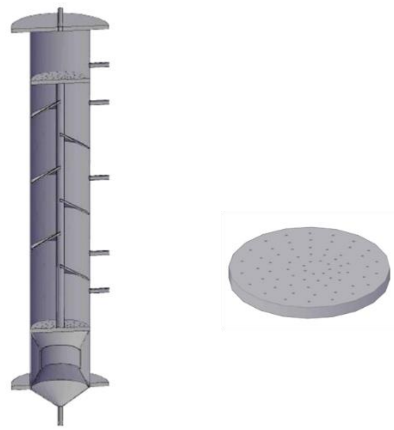
1. Evaluation of the influence of modified UASB reactor with a modified three-phase separator with the inclusion of attached growth using rope matrix on reduction of COD besides changes in pH, alkalinity, Total Suspended Solids and Conductivity with respect to varying OLR.

2. Determination of theoretical methane production with respect to varying OLR.

2. MATERIALS AND METHODS

2.1. Experimental UASB reactor setup

The UASB reactor used in the present work (Total volume of 17 L, total height of 1m and diameter of 15 cm) was made up of acrylic plastic (polymethyl methacrylate) with a hopper bottom. The reactor was provided with a modified three-phase separator which consists of six fan-shaped deflector plates arranged alternatively and fixed to the central shaft at a spacing of 5cm and at an inclination of 30^0 with the horizontal for facilitating spiral flow. Two perforated plates (2mm openings) were provided at the top and bottom to support the central shaft and to ensure the uniform flow of the feed into the reactor. The main aim of the modified three-phase separator was to retain the biomass within the reactor and to facilitate spiral flow for better mixing. In addition to the suspended growth process, the rope was used as the material for the attached growth process to improve treatment efficiency. The longitudinal section of the modified UASB reactor and the perforated plate used in the reactor for the present study are shown in Figure 1 (a) and (b).



(a) (b)

Figure -1: (a) longitudinal section of the UASB reactor, (b) Perforation plate

The rope matrix was fitted near the bottom of the reactor using another hollow cylinder with a height of 5 cm along with inclined plates both at the top and bottom of the hollow cylinder. This isolates the knots from the reaction zone. The rope matrix consisted of two horizontal rows orthogonal to each other fitted one above the other at a distance of 5 cm. The total length of the rope provided including the knots was 70 cm. The rope matrix was fitted near the bottom of the reactor to facilitate the attached growth near the sludge bed. A valve for biogas collection was provided at the top four sampling valves were provided along with the height of the reactor and a valve for the effluent collection was provided above the sampling valves. A peristaltic pump was used to feed the wastewater from the bottom of the reactor.

2.2. Characteristics of wastewater

Synthetic wastewater was used for the study. The wastewater was prepared so that it reflected the characteristics of effluent from the sugar industry. Sugarcane juice was used to prepare wastewater because 1 ml of raw sugarcane juice makes 1500 mg/L of COD. Synthetic wastewater was prepared by adding chemicals to tap water in a prescribed dosage depending on the desired COD. The composition of the wastewater was sugar (10 mg/L), ammonium chloride (10 mg/L), magnesium sulphate heptahydrate (50 mg/L), ferric chloride hexahydrate (3 mg/L), calcium chloride monohydrate (0.4 mg/L), potassium chloride (60 mg/L) and di-ammonium phosphate (10 mg/L) [18]. The characteristics of the synthetic wastewater are given in Table 1. The COD of the prepared wastewater is 4900 mg/L.

Table -1: Characteristics of synthetic wastewater

Characteristic	Value
pH	7.07
Conductivity	124.3 mS/cm
Turbidity	125 NTU
Alkalinity	1150 mg/L
Total suspended solids	1840 mg/L
Chemical oxygen demand	4900 mg/L

2.3. Operating conditions

The performance of an anaerobic process depends mainly on its operating conditions. The main parameter that influences the operating conditions of the reactor is the influent COD. The OLR and HRT recommended for the UASB reactor based on the influent COD concentration have been given by Arceivala [19] which is shown in Table 2. The expected COD removal efficiency is 80–90% and 75–85% at a COD range of 750–3000 mg/L and 3000–10000 mg/L respectively with HRT of 6–24 hours. This proves that the UASB reactor is suitable for medium and high strength wastewater. The efficiency was maintained at 70–75% even when low strength wastewater was used. This satisfactory performance of the UASB reactor provided an initiation for an approach towards its application in the treatment of low strength wastewaters where the major aim is substrate removal. Even though the performance of the UASB reactor in terms of COD removal is good (70–75%), the biogas production will be less when operated with low strength wastewater than when operated with high strength wastewater [9]. This is because high strength wastewater contributes to greater biogas production. The recommended operating conditions for the UASB reactor with respect to influent COD and the corresponding expected efficiency of the reactor are given in Table 2.

Table-2: Recommended loading for UASB reactors

Influent COD (mg/l)	OLR (kg [COD] $m^{-3}d^{-1}$)	SLR (kg [COD] kg VSS^{-1} d^{-1})	HRT (hr)	Liquid Up-flow Velocity (m/h)	Expected Efficiency (%)
<750	1-3	0.1-0.3	6-18	0.25-0.7	70-75
750-3000	2-5	0.2-0.5	6-24	0.25-0.7	80-90
3000-10,000	5-10	0.2-0.6	6-24	0.15-0.7	75-85
>10,000	>10	0.2-1	>24	0.15-0.7	75-80

The modified UASB reactor was operated by varying the OLR and HRT but with a constant COD. The influent substrate concentration was maintained constant at 4900 mg/L and the HRT was varied from 18 to 24 hours (18, 19, 20, 21, 22, 23 and 24 hours). The corresponding OLR are 6.533, 6.189, 5.88, 5.6, 5.345, 5.113 and 4.9 Kg COD $m^{-3}d^{-1}$ respectively. The corresponding up-flow velocities are 0.044, 0.042, 0.040, 0.038, 0.036, 0.035 and 0.033 m/hr respectively. The operational parameters were chosen as recommended based on the influent COD [19]. The expected COD removal efficiency of the UASB reactor for this operating condition is 75–85% as far as Table 2 is concerned.

2.4. Start-up of the UASB reactor

The start-up of an anaerobic process is a complicated and challenging process. It determines the effectiveness of the process and depends on many factors such as feed wastewater characteristics, operating conditions, and reactor seeding [9]. Reactor start-up is an important process. The reactor is said to have achieved start-up when sludge granulation occurs and when the sludge attains stability to treat the incoming wastewater to maximum efficiency. Once the start-up of the reactor is attained which results in a good quality granular sludge, then the reactor will be capable of handling higher loading rates and can achieve a steady state in a short period [20]. Cow dung comprising organic matter and a heavy population of microbes, collected from the nearby locality was used as seed sludge. The MLSS concentration of the cow dung was 7 g/L and the pH was 8.18. Wet sludge of 2.7 Kg was added and half the designed loading was fed to the reactor during the start-up and was gradually increased to achieve the operating loading. The temperature was maintained at 37°C (mesophilic range) during the full operational period. If the temperature is below 30°C the anaerobic digestion decreases at a rate of 11% per degree Celsius decrease [21]. The greater the granulated solids inoculated to the reactor, the greater the loading rate that can be treated effectively by the reactor [22].

2.5. Analytical procedures

Chemical oxygen demand (COD), pH, Conductivity, Turbidity, Alkalinity and Total suspended solids (TSS) were analysed. The analytical procedures were performed by standard methods for the examination of water and wastewater [23]. The theoretical methane production and the corresponding biodegradability index for the operational OLR were determined.

3. Results and Discussion

3.1. Effect of OLR on COD removal

The performance of the UASB reactor is assessed by its COD removal efficiency. This is because COD removal can be considered a major factor associated with reactor performance. After the start-up of the reactor is attained, the reactor was operated with an OLR range of 4.9 to 6.53 Kg COD $m^{-3}d^{-1}$ with a constant substrate concentration with HRT varying from 18 to 24 hours. The up-flow velocity was varied from 0.033 m/hr to 0.044 m/hr during the operation period. For each OLR, the reactor was operated until it attained a steady state. Figure 2 shows the effect of COD, TSS and alkalinity removal with respect to varying OLR. The COD removal efficiency showed an increasing trend with an increase in OLR up to 5.34 Kg COD m^{-3} d^{-1} after which it started to decrease with a further increase in OLR. Thus, the removal of COD with respect to OLR can also be viewed in an aspect that increasing HRT increases COD removal. When HRT was increased from 18 to 22 hours, the UASB reactor showed an increased COD removal efficiency. When further increased beyond 22 hours, the reactor performance showed a decline in the COD removal efficiency. The increase in HRT reduces the mixing inside the reactor because of the decreased up-flow velocity. The rope matrix was provided near the bottom of the reactor orthogonal to the influent direction in a way that does not obstruct the influent wastewater flow. The matrix provided a good surface for the attachment of microorganisms due to its rough surface and also provided some resistance to the up-flow velocity making sure that the influent comes in contact with the attached microorganisms. The increasing COD removal with increasing HRT may be due to the presence of rope matrix which aids in providing a surface for attachment of microorganisms and improving the degradation of the influent substrate by facilitating the contact of influent wastewater and microorganisms. Lowering of HRT below 22 hours increases the up-flow velocity and may cause the detachment of the sludge particles from the rope matrix thus affecting the contact of the influent substrate and the sludge, thus reducing the COD removal and biomass washout. This increasing trend of COD removal was found to be in accordance with that stated by Trnovec and Britz [24], the reactor being operated with OLR 2.28 to 10.95 Kg COD $m^{-3}d^{-1}$ and the maximum COD removal efficiency was 96% at an OLR of 4.36 Kg COD $m^{-3}d^{-1}$ after which it started to decrease. A UASB reactor was fed with synthetic wastewater at a wide variety of OLRs between 3.4 and 44.9 Kg COD $m^{-3}d^{-1}$. At OLRs below 11 Kg COD $m^{-3}d^{-1}$, the COD removal efficiency remained above 98%. At higher OLRs the removal efficiency was reduced but remained above 96%. However, at this higher OLR range, the time taken to reach the maximum efficiency was up to three times as long as that at the lower OLR range [25]. In the present study, temporary disturbances such as large gas bubble formation and sludge floatation were observed immediately after an OLR shift. These results show that the UASB reactor is capable of coping with a wide range of OLR and the results of the present study resemble the results of the previous study. The increase in OLR can be associated with a decrease in HRT. The increasing HRT contributing to the lack of mixing may also be the reason behind the decreasing trend of COD removal efficiency [26]. The decreased COD removal at minimum OLR and corresponding maximum HRT may be due to inadequate contact of granules with influent wastewater and also the low activity of the granules [3].

With the further decrease in HRT below 22 hours, the up-flow velocity increases and the contact time between wastewater and granules decreases resulting in decreased performance of the reactor. The maximum COD removal was found to be 87% at an OLR of 5.34 Kg COD $m^{-3}d^{-1}$ and the corresponding HRT was 22 hours, which is nearly similar to the removal efficiency of 91% at an OLR of 5.6 Kg COD $m^{-3}d^{-1}$ in a study conducted by Borja [27]. This shows the ability of the modified UASB reactor to perform successfully up to an OLR of 5.34 Kg COD $m^{-3}d^{-1}$, beyond which flotation of sludge bed and accumulation of inorganic substances in the effluent occurs, reducing the performance of the UASB reactor in terms of COD removal. The increase in the dissolved solids due to increased loading contributes to the effluent COD. The UASB reactor showed a COD removal efficiency that ranged from 67–87% during its operation.

The COD removal efficiency of the modified UASB reactor used in the present study is better when compared with the COD removal of 85% at HRT 22 hours within the organic loading range 2.7–10.8 Kg COD $m^{-3}d^{-1}$ and the maximum removal at an OLR of 3.2 Kg COD $m^{-3}d^{-1}$ and 61% at an OLR of 3.5 g COD/litre reactor day with an HRT of 3.37 day by using hybrid UASB reactors [8], [11].

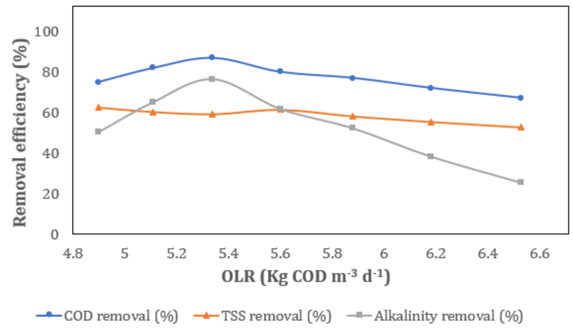


Figure-2: Effect of OLR on the removal of parameters (COD, TSS and Alkalinity)

The better performance may be due to the provision of a modified three-phase separator and the combined effect of the attached and suspended growth process in treating the wastewater. The attachment of the biomass with the rope matrix might have contributed to the stability of the modified UASB reactor in terms of COD removal (67–87%) and steady theoretical methane production (0.185–0.24 m^3/Kg COD digested) which is discussed in section 3.4. Also, this study is consistent with the expected efficiency of 75–85% given by Arceivala [19]. A modification to the conventional configuration has yielded a similar performance when compared with the previous studies.

3.2. Effect of OLR on pH and alkalinity removal

Figure 3 shows the variation of effluent pH and conductivity with varying OLR. No chemical was added to the reactor for maintenance of pH and alkalinity. The effluent pH was in the range of 6.6 to 7.2 throughout the study thus adequate for a favourable condition. The pH shows a decreasing trend with an increase in OLR up to an OLR of 5.345 Kg COD m^{-3} d^{-1}. This decrease in pH indicates the increase in the production of VFA due to the partial conversion of influent COD to methane. pH is one of the most important factors in the operation of an anaerobic reactor and it is well known that microbial activity is high in the pH range of 6.8 to 8.5. pH and VFA are very important parameters that determine the stability of anaerobic digestion processes. Anaerobic digestion takes place in three steps namely hydrolysis, acidogenesis and methanogenesis. pH influences these steps thus affecting the performance of the reactor. pH below 5.75 and alkalinity below 1200 mg/L indicate digester trouble [28]. Also, the bicarbonate alkalinity required for a stable operation of an anaerobic digester is between 1000 and 3000 mg of $CaCO_3$/L [29]. The pH range of 6.8 to 7.4 proves to be the optimum condition for the methanogens, but a pH range of 6.4 to 7.8 is necessary to maintain adequate activity [30]. Therefore, if the reactor goes out of the 6 to 8 range, then the activity of the methanogens is reduced and this causes a negative effect on the reactor performance. As the organic loading increases further, accumulation of hydrogen may take place which decreases the effluent pH and the activity of the methanogens. The decreased activity of the methanogens affects the COD removal efficiency because a portion of COD is being converted to methane during operation.

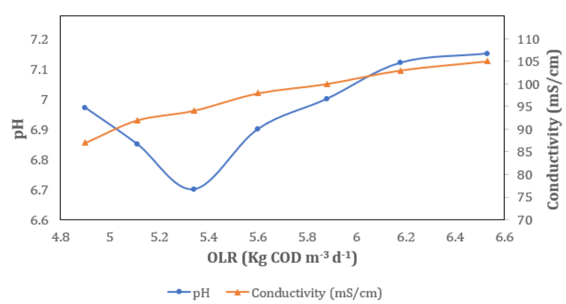


Figure-3: Variation of effluent pH and conductivity with respect to OLR

Also, conversion of ammonium into free ammonia may take place due to the increase in pH. This will cause a negative impact on the reactor performance because free ammonia is toxic to the microorganisms. The alkalinity of the influent is 1150 mg/L. Alkalinity removal efficiency follows a similar trend as that of COD removal with increasing OLR. This is because alkalinity is related to pH, and the state of the reactor can be assessed sensitively by the VFA-total alkalinity ratio [10]. The operating condition of the UASB reactor can be expressed in terms of the VFA-total alkalinity ratio. Alkalinity removal increased with an increase in OLR achieving a maximum removal of 76% at an OLR of 5.34 Kg COD m^{-3} d^{-1} and decreased with a further increase in OLR.

3.3. Effect of OLR on suspended solids and conductivity removal

UASB reactors are capable of removing suspended solids and this also contributes to the removal of COD. The removal mechanism of solids is quite complicated and depends on many parameters namely operating conditions (HRT, OLR and up-flow velocity), influent wastewater characteristics and the sludge bed characteristics. The removal of solids by biological processes has been reported whereas the physical and chemical mechanisms of solids removal are scarcely reported. Figure 2 shows the trend of solid removal efficiencies with varying OLR. TSS in the influent was 1840 mg/L and the removal efficiency varied from 51–61%. The TSS removal of the modified UASB reactor is nearly constant for the varying OLRs. The maximum removal efficiency was 61% at an OLR of 4.9 Kg COD $m^{-3}d^{-1}$ its corresponding HRT being 24 hours. The reduction in suspended solids in the effluent may also be due to the hydrolysis of the solids present in the wastewater. The up-flow velocity plays a major role in the removal of TSS. The up-flow velocity increases the rate of collision between sludge particles and thus ensures adequate mixing inside the reactor and improves solids removal. On the other side, the increase in the up-flow velocity results in the suspension of the sludge bed causing the detachment of the trapped solids from the sludge bed. Even though it is construed that lower HRT lowers the removal of solids, there is also evidence that HRT is an inadequate parameter for describing solids removal in up-flow reactors [31]. The sludge bed characteristics play a major role in determining the removal of solids because they act as a filter trapping the solids within the reactor, reducing the solids in the effluent. Turbidity is also the measure of the solids in the wastewater. The turbidity of the influent is 125 NTU. Turbidity of the effluent increases as a result of sludge bed agitation due to decreasing HRT. The smaller sludge particles which float due to the greater up-flow velocity increase the effluent turbidity, thus affecting the reactor performance. The maximum removal of turbidity is similar to TSS removal and is achieved at an OLR of 4.9 Kg COD $m^{-3}d^{-1}$ and the corresponding turbidity of effluent is 56 NTU.

The variation in conductivity of the wastewater after treatment in the UASB reactor was also observed. The conductivity of the influent was 124.3 mS/cm. Figure 3 shows the variation of conductivity with varying OLR. The conductivity of the effluent follows an increasing trend with increasing OLR. The conductive ions come from dissolved solids and inorganic materials. The major ions causing salinity include chloride, sodium, magnesium, calcium and bicarbonate. This may be the reason for the increasing trend of conductivity. An increase in pH and alkalinity may be the cause for the increase in the conductivity of the effluent. The increase in the effluent conductivity at greater OLR may be due to the decreased performance of the UASB reactor at greater OLRs. The increase in inorganic materials and dissolved solids in the effluent are contributed by the increasing OLR and decreased HRT. This is in accordance with the reduced COD removal efficiencies with increasing OLR, justifying the presence of dissolved solids in the effluent. Thus, the increasing trend of conductivity in the effluent indicates the presence of dissolved solids in the effluent. Hence pH and alkalinity may be considered the major factors in determining the conductivity of the wastewater.

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3.4. Sludge characteristics and theoretical methane production

The MLSS concentration of the seed was 7 g/L during operation. During the operation of the reactor, MLSS concentration increased to 28 g/L, and the test results are similar to that reported by Farajzadehha [26]. The granule sizes also affect the reactor performance in terms of specific methanogenic activity (SMA) [24]. The SMA values for the sludge granule size ranges of 1.5–1.7 mm, 0.7–1.0 mm and 0.1–0.2 mm were 0.28, 0.26 and 0.16 g COD/g VSS.d respectively. Also, the reactor performance was good with seed sludge of size 1.5–1.7 mm. This shows that sludge granulation has a major impact on the determination of reactor performance and biogas production. Synthetic wastewater was fed into the reactor without any external nutrition addition. Temperature also influences the sludge granulation process (mesophilic and thermophilic range). Biogas production is an important factor because the performance of the reactor is based on the fraction of methane produced. The theoretical methane production at laboratory conditions is computed for the operating OLR using equation (1) [32].

$$\text{BMP} = \frac{\eta_{CH_4} RT}{P \; VS_{added}} \qquad (1)$$

Where,

BMP – Biochemical Methane Potential, R – Gas constant (R = 0.082 atm L/mol K), T – Temperature of glass bottle (308 K), VS_{added} – Volatile solids of the substrate (g/L), P – Atmospheric pressure (1 atm), η_{CH_4}- Amount of molecular methane determined from equation (2) (mol/L).

$$\eta_{CH_4} = \frac{COD}{64\,(g/mol)} \qquad (2)$$

The maximum theoretical biogas production has been worked out to be 0.35 m^3/Kg COD digested at Standard Temperature Pressure (STP). In the present study, the maximum value of theoretical methane production is 0.24015 m^3/Kg COD at an OLR of 5.34 Kg COD $m^{-3}d^{-1}$. The theoretical methane production remains almost the same with an increase in OLR. The theoretical methane production and biodegradability index for the varying OLR are given in Figure 4. Sludge granulation also affects biogas production. The biogas produced by the UASB bioreactor consisted of 67% methane whereas the biogas produced by the modified UASB bioreactor (with an additional sludge bed supported by a multi-perforated metallic plate without blocking the hydrodynamic flux) consisted of 80% methane [12].

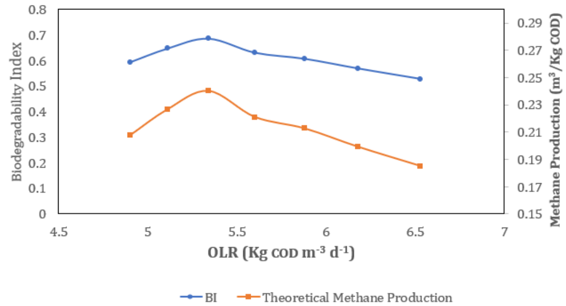

Figure-4: Theoretical methane production and biodegradability index for the varying OLR

A previous study by Meza-Gordillo [13] using a modified UASB reactor with a dual sludge bed showed a COD removal efficiency of 91%, production of methane increased by 15.76% and the methane content in the biogas increased by 13% than the conventional UASB reactor. The biodegradability of the influent wastewater can be expressed by a unitless quantity known as the biodegradability index (BI). A biodegradability index is a number that indicates the ability of the substance to become inert after being broken down into innocuous products by the action of microorganisms. The higher the numerical value, the more quickly the substance will degrade. The BI relates the biochemical methane potential and the maximum methane production. Based on the biochemical methane production (BMP) the biodegradability index (BI) can be obtained using equation (3) [13].

$$\text{BI} = \frac{BMP}{350\,\frac{mL\,CH_4}{g\,COD}} \qquad (3)$$

Where,

350 is the theoretical volume of methane per gram of COD removed at standard temperature and pressure (T = 273 K, P = 1 atm).

Based on the biochemical methane potential the biodegradability index of the modified UASB reactor is calculated and the variation in BI with respect to varying OLR is given in Figure 4. As BI is the same measure of BMP the variation is identical with the maximum biodegradability index (BI) of the reactor being 0.686 at OLR 5.34 Kg COD $m^{-3}d^{-1}$ with the corresponding HRT being 22 hours. The Biodegradability Index (BI) indicates the degradation ability of the wastewater. In the present study, the calculated BI of the synthetic wastewater was 0.686. This indicates that the wastewater used may be more suitable for physico-chemical treatment processes. But still, its treatment using a modified UASB reactor yielded a maximum COD removal of 87% at OLR of 5.34 Kg COD $m^{-3}d^{-1}$.

4. CONCLUSION

The present study shows that synthetic wastewater of COD around 5000 mg/L gives better results in terms of COD removal using a modified up-flow anaerobic sludge blanket reactor at an OLR of 5.34 Kg COD $m^{-3}d^{-1}$ the corresponding HRT being 22 hours. The COD removal ranged from 67 to 87 % at OLRs ranging from 4.9 to 6.533 Kg COD $m^{-3}d^{-1}$, the maximum removal being 87% at OLR of 5.34 Kg COD $m^{-3}d^{-1}$. Also, the maximum theoretical methane production occurred at the same OLR. The theoretical methane production value opens up the possibility of comparing these values with practical methane production. The decrease in the performance of the modified UASB reactor with a further increase in OLR beyond 5.34 Kg COD $m^{-3}d^{-1}$ was due to the reduction in contact time between the sludge and incoming wastewater because of the shorter HRT. The spiral flow inside the reactor helped prevent biomass washout. Also, the rope matrix provided near the bottom of the reactor aided in the provision of a surface for the attachment of granules thus enhancing the contact of wastewater and sludge granules. Hence this study proves that the modified UASB reactor is better for the treatment of high strength wastewater.

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