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Comparative Study on Startup Performance of UAHR and UASB Reactors in Anaerobic Treatment of Distillery Spentwash

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ABSTRACT: In this paper, startup performance of Upflow Anaerobic Hybrid Reactor and Upflow Anaerobic Sludge Blanket reactors in anaerobic treatment of distillery spentwash has been studied under identical conditions of operation. Various effluent characteristics like pH, Electrical Conductivity, Chemical Oxygen Demand, Biochemical Oxygen Demand and Total Solids and other process parameters like biogas production and methane per cent in biogas were studied until the attainment of steady state. The startup of the reactors has been completed and steady state condition attained on 25th day of reactor operation in UAHR and 34th day in UASB reactor. The treated effluent characteristics of both reactors were fairly steady after attaining the steady state condition. The pH of treated effluent during steady state condition was almost neutral for both reactors even though the influent had an acidic pH. The maximum COD, BOD and TS removal efficiencies were as high as 79.60%, 87.39% and 69.96% in UAHR as compared with UASB of 72.98%, 81.34% and 66.23%, respectively during the steady state period. The maximum volumetric gas production of 149 L m^{-3} produced more in UAHR than in UASB reactor during steady state condition. The population of total anaerobic bacteria and methanogenic bacteria also more as that of the other parameters in UAHR than in UASB reactor and it were 55.2 x 10^3 ml^{-1} and 40.0 x 10^2 ml^{-1} respectively in UAHR. It is found that from an overall assessment the UAHR has proved superior in its performance compared to the UASB reactor during the startup process.

Key words: Upflow Anaerobic Hybrid Reactor, Upflow Anaerobic Sludge Blanket reactor, startup performance, Steady state condition, biogas production

INTRODUCTION

Distilleries are listed at the top in the "Red Category" industries having a high polluting potential by the Ministry of Environment and Forests (MoEF), Government of India (Tewari *et al.,* 2007). The spentwash discharged from the molasses based distilleries contains all the ingredients found in the molasses except fermentable sugar which may create many environmental pollution problems (Pazouki *et al.,* 2008). It is considered as a very high strength wastewater having very high COD and BOD_5 with low pH and dark brown color (Goel and Chandra, 2003). This dark brown colored efûuent, when discharged into water bodies without proper treatment, deûles the natural ecosystem (FitzGibbon *et al.,* 1998). Problems like adequate treatment and disposal of distillery spentwash and the development of new water sources for irrigation can be related and solved using the proper technologies. Anaerobic treatment is an accepted technology for the treatment of distillery spentwash and various high rate reactor designs have been tried at pilot and full scale operation. Anaerobic digestion is an attractive primary treatment for distillery spentwash due to its reputation as low energy consumption, less sludge production, high organic loading rate (OLR) can be applied, environment friendly and socioeconomically acceptable technology (Acharya *et al*., 2008).

The high rate reactor most widely used for the treatment of several type wastewaters, in particular distillery spentwash is Upflow Anaerobic Sludge Blanket (UASB) reactor (Saleh and Mahmood, 2004). The success of the UASB reactor can be attributed to its capacity to retain a high concentration of sludge and efficient solids, liquid and gas phase separator. Hybrid reactors are developed as advancement to the UASB reactor by incorporating some modification into UASB reactor from other single-stage reactors. In these reactors biomass of bacteria is allowed to attach to inert film apart from suspended flocs or granules. Thus the

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biomass held in all over the reactor reduces the pollution load of substrates. Since its conception, this hybrid reactor has been studied by many researchers and found to be efficient in treating dilute to medium strength wastewaters (Ramjeawon *et al.,* 1995, Bardiya *et al.,* 1995, Banu *et al.,* 2006, Gupta *et al.,* 2007 and Kumar *et al.,* 2008). However, the quantitative information on the process performance of this reactor for the high strength industrial wastewaters needs to be explored. This modified configuration is yet to find its large-scale application owing to paucity of information on its performance for different types of industrial wastewater. Hence, the present study was undertaken to compare the startup performance of UAHR and UASB reactor for treating distillery spentwash and the better performance of the UAHR is highlighted, based on critical assessment of the effluent characteristics monitored until the attainment of steady state condition.

MATERIALS & METHODS

Substrate

The untreated distillery spentwash was collected from a molasses based distillery located at Vellore, M/s. Bhavani Distilleries and Chemicals Limited, Tamil Nadu, India. The major characteristics of the spentwash are given in Table 1. Two types of Laboratory scale reactors *viz.,* the Upflow Anaerobic Sludge Blanket (UASB) reactor and Upflow Anaerobic Hybrid Reactor (UAHR) were made of 4 mm thick clear acrylic sheet to study the relative performance of both reactors under similar operating conditions. The volume of the reactors was 16.75 L and 19.25 L for UASB reactor and UAHR respectively. The reactors had a Gas-Liquid-Solid [GLS] separator installed at the top of the reactor. The hybrid reactor is a modified version of the UASB system with PVC frill sheet as the solid support and combines the merits of the UASB and fixed film reactors (Lettinga, 2001). The reactors details along with dimensions are given in Table 2 and schematics of UASB reactor and UAHR are illustrated in Fig.1 and Fig. 2 respectively. The feed from the container was pumped into the reactors through the inlet of each reactor by means of peristaltic pumps (Watson Marlow). The reactors were operated simultaneously using the same feed.

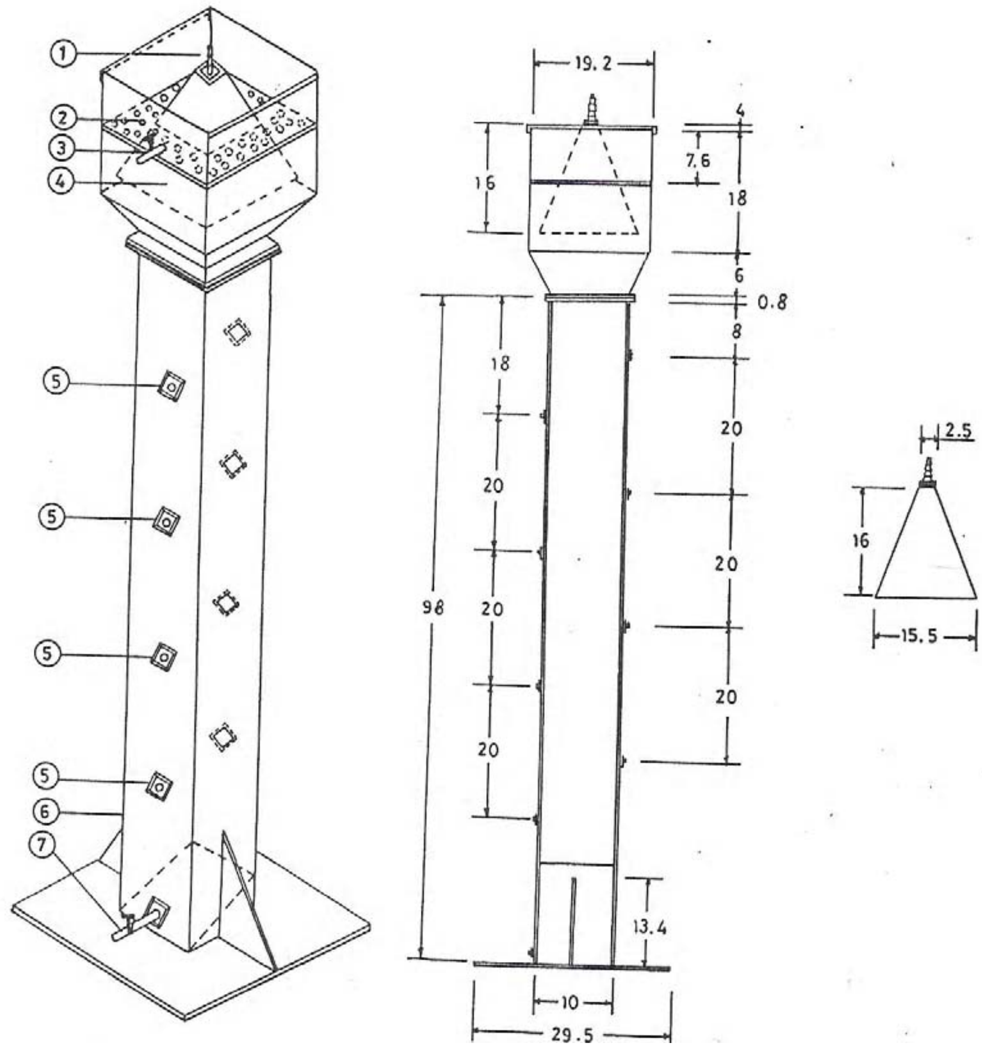
Table 1. Characteristics of raw distillery spentwash

S.No.	Parameters	Concentration*
1	pH	4.20
2	EC (dSm^{-1})	40.80
3	Total dissolved solids (mg/L)	92800
4	Total suspended solids (mg/L)	28220
5	Total solids (mg/L)	121020
6	BOD (mg/L)	56970
7	COD (mg/L)	122000
8	Nitrogen (mg/L)	3460
9	Phosphorus (mg/L)	2130
10	Potassium (mg/L)	17360
11	Calcium (mg/L)	4200
12	Magnesium (mg/L)	2500
13	Sulphate (mg/L)	3280

* Mean of three samples

Table 2. The dimension of the UASB reactor and UAHR

Particulars	UASB	UAHR
Total height of the reactor	125 cm	125 cm
Height of the bottom portion of the reactor	100 cm	100 cm
Height of the GLS, housing and gas collector assembly	25 cm	25 cm
Height of the GLS assembly	18 cm	18 cm
Cross section of sludge bed	10x10 cm^2	10x10 cm^2
Cross section of the gas collector assembly	19x19 cm^2	23x23 cm^2
Volume of the digester	16.75 L	19.25 L
Settler volume [above the bottom portion of reactor-c/s.10X10 cm^2]	7.150 L	9.650 L
The slope of the GLS settler bottom [inclined wall]	53°	53°
No. of acrylic mesh kept in the hybrid reactor	-	2
Diameter of holes in acrylic mesh	-	1 cm

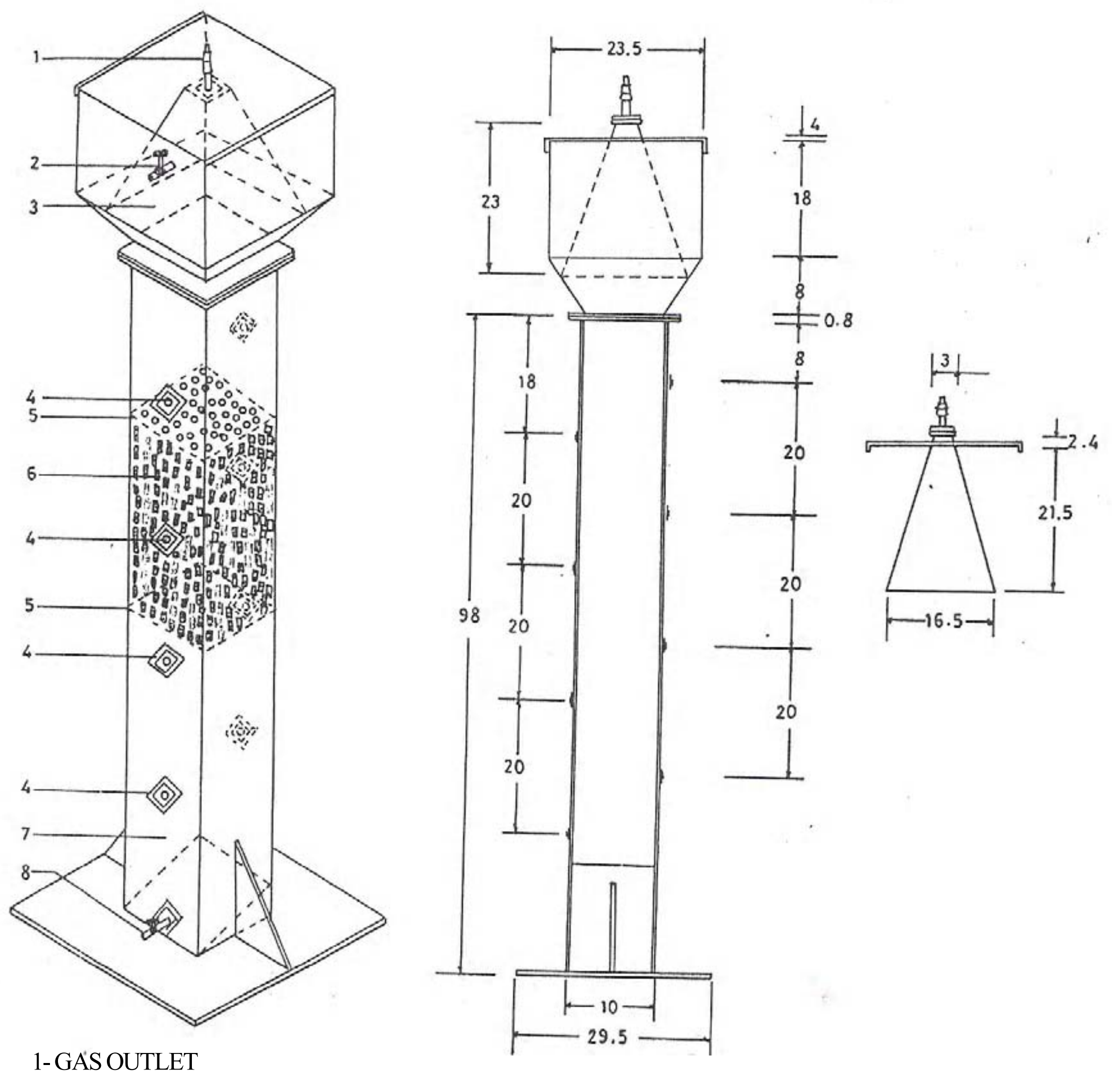


1- GAS OUTLET
2- EFFLUENT OUTLET
3- GAS SOLID SEPERATOR (GSS)
4- SUPPORT FOR GAS SOLID SEPERATOR (GSS)
5- SAMPLING PORT
6- 4mm ACRYLIC SHEET UASB
7-WASTE WATER INLET

Fig. 1. Design details of Upflow Anaerobic Sludge Blanket reactor

The reactors were seeded with the anaerobic consortia developed in the laboratory by enrichment of anaerobic sludge from an ongoing reactor and cow dung slurry along with distillery spentwash.The seeding was done by mixing equal volume of enriched consortium and distillery spentwash and replacing one third of the mixture with fresh distillery spentwash at four days interval. After four cycles, the replacement of two third of the mixture was done and after the completion of the second cycle regular feeding of the distillery spentwash was done. This was done for proper acclimatization of anaerobic consortia with distillery spentwash.

Successful commissioning of the reactors is known as commencing of reactor startup. The reactor startup is very important, as it will have an impact on continuous and efficient operation without any system failure. After seeding, during initial startup period the



1- GAS OUTLET
2- EFFLUENT OUTLET
3- GAS SOLID SEPERATOR (GSS)
4- SAMPLING PORT
5- ACRYLIC MESH
6- PLEATED PVC RING (12 mm dia)
7- 4 mm ACRYLIC SHEET HYBRID REACTOR
8-WASTE WATER INLET

Fig. 2. Design details of Upflow Anaerobic Hybrid Reactor

reactors were fed continuously with the distillery spentwash at 10 days HRT, which corresponds to the OLR of 11.75 kg COD m^{-3} day^{-1} and 11.45 kg COD m^{-3} day^{-1} for UASB reactor and UAHR, respectively. The distillery spentwash having pH range of 3.80 to 4.20 was used as feed without neutralization and any pretreatment.

Influent and treated effluent samples were routinely analysed for pH, electrical conductivity, COD, BOD and total solids according to Standard Methods for Examination of Water and Wastewater (APHA, 1992). Biogas production was measured by using water displacement method and methane per centage was measured by Gas Chromatography, with thermal conductivity detector (TCD) having 'Porapak Q' column by setting the oven temperature at 80 ^{o}C to 100 ^{o}C, injector temperature at 100 ^{o}C to 200 ^{o}C, detector temperature at 120 ^{o}C and using nitrogen as carrier gas at a flow rate of 30 ml min^{-1}.

Total anaerobic bacteria and methanogenic bacteria present in the reactors were enumerated by using roll tube technique (Hungate, 1957). The samples were serially diluted in bicarbonate (0.5%) dilution buffer with 0.0001% of resazurin to control the redox potential. The total anaerobic bacteria were enumerated on modified Hungate's medium (Hungate, 1957). Simultaneously total methanogens were enumerated using the medium of Mah (1980).

RESULTS & DISCUSSION

The variation in pH during the startup period of the reactors is shown in Fig. 3. The pH of the treated effluent gradually increased from 4.46 and 4.52 respectively of UASB reactor and UAHR on the initial start up period to 7.42 and 7.50 respectively for UASB reactor and UAHR on the end of the startup period. Achieving neutral pH level in the treated effluent was the indication of healthy anaerobic environment and satisfactory methanogenic activity. The overall performance of the reactor during the start up was more satisfactory. It is known that the selection of seed material plays a crucial role in minimizing the time required for initial granulation and biofilm establishment (Salkinoja-Salonen *et al.*, 1983). Rising of pH occurred during the startup period in both reactors but in UAHR highest pH of 7.50 was attained on 25th day of reactor operation compared to UASB reactor in which 34 days were required to attain the highest pH of 7.42. In steady state period, the effluent pH values stabilized at the range of 7.30 to 7.50 and 7.40 to 7.82 for UASB reactor and UAHR, respectively. Good buffering capacity in the reactors and higher microbial activity are responsible for the increase in pH. Generally, the rise in pH is due to the oxidation of organic acids to CO_2 and the reaction between the CO_2 and basic compounds to form carbonates and bicarbonates (Pant and Adholeya, 2007). Banu *et al.* (2006) achieved a neutral pH (7.5 to 7.9) in the treatment of sago wastewater using Hybrid Upflow Anaerobic Sludge Blanket (HUASB) reactor.

The COD level of the feed was 108.30 to 118.56 g/L. During the startup of the reactors the decrease in the level of COD was observed in the effluent after biomethanation. Continuous feeding of the reactors resulted in the gradual decrease of the COD reaching 31.24 g/L on the 34th day and 22.80 g/L on the 25th day of the startup period for UASB reactor and UAHR, respectively. In UASB reactor, the COD removal efficiency gradually increased from 3.51 per cent on the initial start up period to 72.98 per cent on the end of the startup period. Similarly, the COD removal efficiency in UAHR also gradually increased from 5.76 per cent on the initial start up period to 79.06 per cent on the end of the startup period (Fig. 4). The better performance of reactors might be due to better granulation and biofilm establishment. The high COD reduction accomplishment of reactors can be attributed to the development of an active microflora in the reactors. While treating ice cream wastewater, Hawkes *et al.* (1995) found that the poor performance of UASB reactor was due to poor formation of granules in the

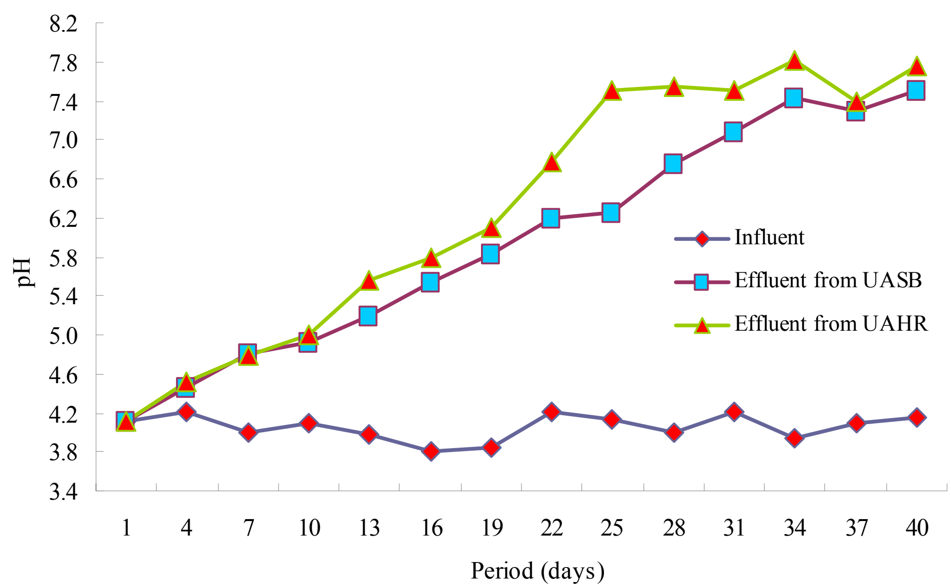


Fig. 3. Variation of pH during startup period of UASB reactor and UAHR

reactor. Proper granulation is thus required for effective treatment of wastewater (Goodwin *et al.,* 1990). In this present study, better performance of reactors with 72.98 and 79.06 per cent (for UASB reactor and UAHR respectively) were achieved, perhaps due to better granulation in response to OLR of 11.75 kg COD m^{-3} d^{-1} and 11.45 kg COD m^{-3} d^{-1} respectively for UASB reactor and UAHR. It is also true that granulated anaerobic sludge would have been best obtained during the startup period of reactors seeded with anaerobic consortia developed in the laboratory, as observed by previous workers (Lettinga *et al.,* 1992; Souza *et al.,* 1992).

The BOD of feed ranged from 42.48 to 49.25 g/L. In both reactors, decrease in the level of BOD was observed in the treated effluent during the startup period and it reached 8.74 g/L (on the 34^{th} day) and 6.17 g/L (on the 25^{th} day) respectively for UASB reactor and UAHR. The BOD removal efficiency increased gradually from 7.21 and 8.54 per cent respectively for UASB reactor and UAHR from the initial start up period to 81.34 and 87.39 per cent respectively for UASB reactor and UAHR at the end of the startup period (Fig. 5). As the anaerobic microbial population gradually developed in the reactor and due to the stabilization of the consortium, the bioconversion rate is improved with enhanced substrate utilization. Hence the BOD removal efficiency also increased and reaches a maximum of 81.34 and 87.39 per cent respectively for UASB reactor and UAHR.

The variation in TS of the influent and treated effluent of the reactors during the startup period are shown in Fig. 5. The TS of feed range was 119.60 to 121.48 g/L. In UASB reactor, TS recorded was 40.46 g/L on 34^{th} day and in UAHR it was 36.38 g/L on 24^{th} day. The TS removal efficiency increased from 2.37 to 66.23 per cent and 3.88 to 69.96 per cent for UASB reactor and UAHR respectively from initial start up period to the end of the startup period. The change in pH from acidic to neutral facilitates the proper growth of the bacterial population which in turn results in the increased TS reduction (Hickey *et al.,* 1991).

Biogas production rates are the most important indicators of reactor performance for anaerobic reactors. Both reactors experienced increases in biogas production during the startup period. The biogas production efficiencies of the reactors are presented in Table 3. The mean daily biogas production was 0.65 L and 1.25 L respectively for UASB reactor and UAHR on third day and steadily increased to 26.95 L on 34^{th} day and 33.84 L on 25^{th} day of the startup period for UASB reactor and UAHR, respectively. The increased biogas production was due to the development of proper methanogenic consortium development and sequential conversion of metabolic products developed at different stages of anaerobic digestion. It indicated steady state condition of the process.

The methane content of biogas was initially 44.2 and 47.6 per cent respectively for UASB reactor and UAHR and steadily increased to 60.0 per cent on 31^{st} day in UASB reactor and 62.6 per cent in UAHR on 25^{th} day of the startup period. The low methane content of the reactors during initial stages was possibly due to the low pH (less than 7) of the liquid phase. At acidic conditions, the CO_2 is less soluble in water. When the pH is on the alkaline condition, more CO_2 would have been absorbed in the liquid phase giving out a more methane rich biogas. Morgan *et al.* (1990) also has reported such correlation between the pH and methane content.

Biogas yield The biogas yield, defined as the amount of biogas produced for a given quantity of organic matter removed as a result of the activity of the anaerobic microorganisms, for both reactors are summarized in Table 3. Generally, the biogas yield in both reactors exhibited as increasing trend from initiation to end of the startup period. In UASB reactor, biogas yield were 203, 422 and 191 L/kgof TS, BOD and COD removed respectively at the steady state period. Similar to UASB reactor, the biogas yield in UAHR were 207, 453 and 204 L/kgof TS, BOD and COD removed respectively at the steady state period. In this present study, biogas yield of the reactors are comparable with specific biogas yield reported by other researchers (Shin *et al.,* 1992; Bardiya *et al.,* 1995 and Jimnez *et al.,* 2003).

The population of total anaerobic bacteria and methanogenic bacteria were monitored during the anaerobic process both in UAHR and UASB to elucidate the process and correlated with the reduction in pollution load, rate of biogas production etc. In both reactors, increase in population of total anaerobic bacteria and methanogenic bacteria were observed during the startup period. After completion of initial startup period, the population of total anaerobic bacteria and methanogenic bacteria were almost remained as stable (30.1×10^3 ml^{-1} - 48.2×10^3 ml^{-1} and 34.7×10^2 ml^{-1} - 57.4×10^2 ml^{-1}, respectively) in both reactors during entire period of study. This is an indication for stable operation of the reactors. Jetty *et al.* (2004) also reported that the anaerobic and methanogenic bacterial population in synthetic chemical wastewater treatment using hybrid reactor were 43.5×10^5 ml^{-1} and 16×10^5 ml^{-1} respectively. The population of total anaerobic bacteria and methanogenic bacteria also more as that of the other parameters in UAHR than in UASB reactor and it were

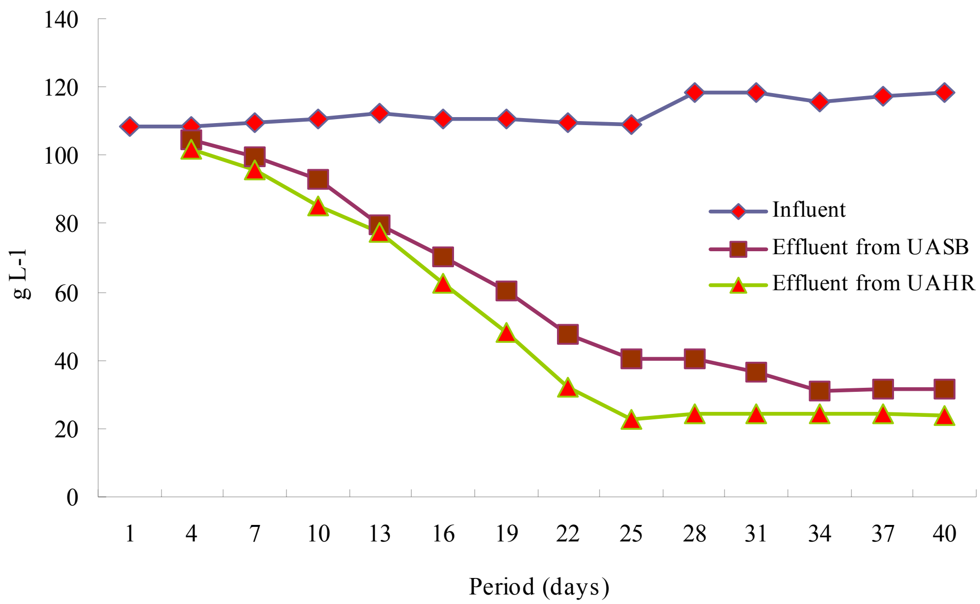


Fig. 4. Variation of COD during startup period of UASB reactor and UAHR

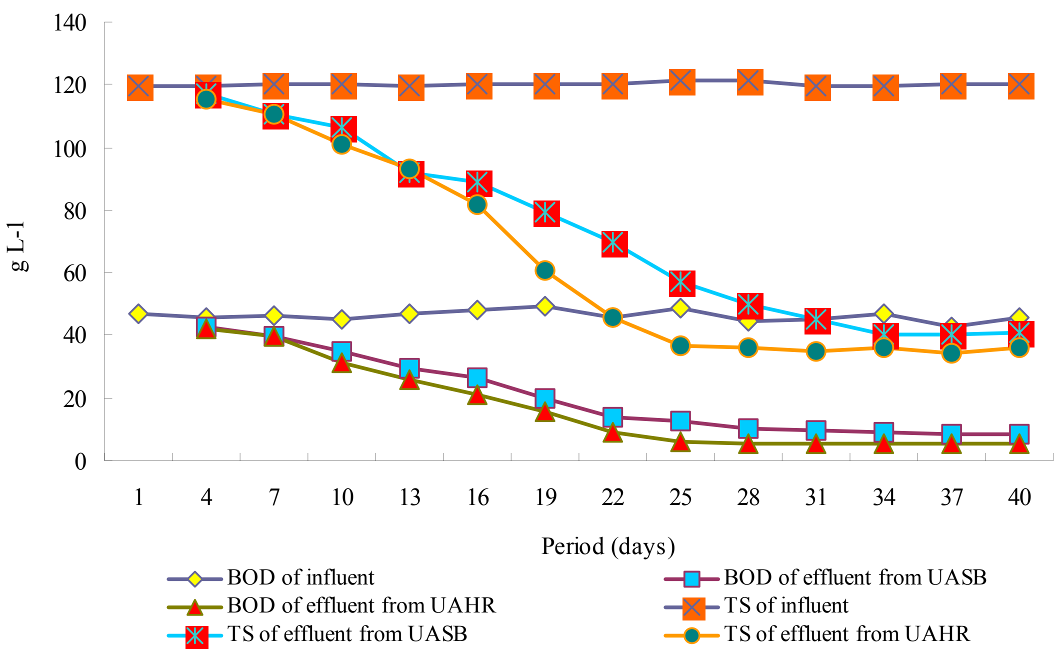


Fig. 5. Variation of BOD and TS during startup period of UASB reactor and UAHR

Table 3. Biogas production during startup of UASB reactor and UAHR

Period (day)	UASB reactor				UAHR			
	Total biogas production (L d^{-1})	Biogas (L/kg of TS removed)	Biogas (L/kg of BOD removed)	Biogas (L/kg of COD removed)	Total biogas production (L d^{-1})	Biogas (L/kg of TS removed)	Biogas (L/kg of BOD removed)	Biogas (L/kg of COD removed)
1	-	-	-	-	-	-	-	-
4	0.65	137	118	102	1.25	140	166	104
7	2.15	136	187	126	3.52	188	262	127
10	4.87	210	283	161	8.69	229	339	178
13	6.94	150	245	127	11.96	232	298	178
16	9.01	170	253	134	17.23	230	332	186
19	11.08	162	226	132	22.50	196	347	188
22	13.15	156	247	127	28.77	200	408	193
25	15.22	142	252	133	33.84	207	411	204
28	18.90	157	331	145	34.16	208	453	188
31	22.36	179	379	163	34.65	212	454	191
34	26.95	203	422	191	33.80	209	426	192
37	27.80	207	483	193	34.76	210	484	194
40	27.46	207	440	189	34.90	216	449	192

55.2 x 10^3 ml^{-1} and 40.0 x 10^2 ml^{-1} respectively in UAHR. The higher population of total anaerobic bacteria and methanogenic bacteria in UAHR could be accounted to the hybrid design. The biomass could grow on the surface of the packing media as attached bio-layer where as it was in the form of suspended sludge bed zone (bottom unpacked zone) of the reactor.

The start-up period found in UAHR makes it superior than UASB reactor in terms of early adoption of the reactor in the field. The UAHR startup took 25 days while the UASB reactor took 34 days. Increase in pH was achieved during the startup period in both the reactors but in UAHR the highest pH was attained on 25th day of reactor operation compared to UASB reactor which attained on 34th day of reactor operation. The change in startup period between the two reactors might be due to reactor type, configuration, quantity of biomass, non-uniform distribution of biomass throughout the reactor height and suspended biomass entrapped in the media matrix (Weiland and Rozzi, 1991).

The overall trend of COD, BOD and TS of the effluent treated through UAHR has low than treated through UASB reactor. This meant that higher removal of COD, BOD and TS occurred in UAHR. The maximum COD, BOD and TS removal efficiencies were as high as 79.60%, 87.39% and 69.96% in UAHR as compared with UASB of 72.98%, 81.34% and 66.23%, respectively during the steady state period. The high performance of the UAHR could be accounted to the hybrid design which incorporated the UASB concept along with media packing. Cordobo *et al.* (1995) also reported an increased efficiency when the UAF was converted into hybrid type. Gupta *et al.* (2007) also obtained 5% of more COD removal efficiency in hybrid reactor compared to UASB reactor with an OLR of 8.7 kg COD m^{-3} d^{-1} at 5 days HRT while treating distillery spentwash. They attributed the higher performance of hybrid reactor to higher Sludge Retention Time (SRT) and plug flow pattern of hybrid reactor than UASB reactor having completely mixed flow pattern.

The mean daily biogas production and biogas yield were more in UAHR than in UASB reactor during the startup period. The maximum volumetric gas production of 149 L m^{-3} produced more in UAHR than in UASB reactor during steady state period. The better performance of UAHR than UASB reactor in biogas production could be due to retention of more of active biomass. In this study, total anaerobic and methanogenic bacterial population also more as that of the other parameters in UAHR than in UASB reactor. Gupta *et al.* (2007) reported that the floating media in UAHR effectively prevent the loss of sludge and also it works effectively in high shock loading.

CONCLUSIONS

In present study, the startup performance of UAHR and UASB reactor in anaerobic treatment of distillery spentwash investigated under the same substrate and similar operating conditions. The important conclusions are as follows:

- The treated effluent characteristics of both reactors with respect to pH, EC, COD, BOD and TS were fairly steady during the steady state condition showing good stability of the reactors.
- The maximum COD, BOD and TS removal efficiencies were as high as 79.60%, 87.39% and 69.96% in UAHR as compared with UASB of 72.98%, 81.34% and 66.23%, respectively during the steady state period.
- The mean daily biogas production and biogas yield were more in UAHR than in UASB reactor during the startup period. The maximum volumetric gas production of 149 L m^{-3} produced more in UAHR than in UASB reactor during steady state period.
- Further, the startup of the UAHR has been completed and steady state condition attained on 25th day whereas the UASB reactor attained steady state condition on 34th day of reactor operation. Hence from an overall assessment, the UAHR has performed better than the UASB reactor during the startup process for the distillery spentwash treatment.

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