Journal of Environmental Sciences Vol.16, No.2, pp.194—198, 2004

ISSN 1001—0742
CN11—2629/X

Article ID: 1001-0742(2004)02-0194-05 **CLC number**: X703; X793 **Document code**: A

Performance evaluation of up-flow anaerobic sludge blanket (UASB) reactor for treatment of paper mill wastewater

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Abstract: The present study deals with the performance evaluation of the UASB reactor under varied organic loading rate(OLR) for the treatment of paper mill wastewater. The sludge granulation process started after 120 days from the start-up period. Sludge granules size was found to be 0.8 mm at OLR of 1.72 kgCOD/(m^3·d), which reached maximum size of about 1.0 to 1.2 mm at OLR of 2.1 kgCOD/(m^3·d). At the end of initial OLR of 1.0 kgCOD/(m^3·d) the VSS concentration was 12.86 gVSS/L, which got increased to 38.05 gVSS/L at the end of an OLR 2.1 kgCOD/(m^3·d). Most of the times VFA recorded were well within the limit of VFA reported in anaerobic fermentation process. Many times the pH observed was between 6.5 and 7.8, which is more favorable for any anaerobic process. It is also found that pH within the reactor increases along with the height of reactor. The total maximum biogas production was found to be 0.40 L/gCOD removals at OLR of 2.1 kgCOD/(m^3·d) and the maximum BOD removal at this stage was observed to be 90%.

Keywords: UASB; biogas; anaerobic digestion; sludge loading rate; organic loading rate

Introduction

In recent years energy considerations and environmental concerns have increased the interest in direct anaerobic treatment of industrial wastes. The anaerobic method of waste treatment offers under the present circumstances a number of significant advantages with little serious or insuperable drawbacks over other treatment methods. Conventional waste management technologies commonly adopted in tropical climates are not only expensive but also warrant exact operation and maintenance requirements. Most of the developing countries suffer from severe environmental problems, shortage of energy and resources. These countries urgently need simple, inexpensive and integrated environmental protection system, which combine wastewater treatment with recovery and reuse.

Biological treatment of wastewater basically reduces the pollutant concentration through microbial coagulation and removal of non-settleable organic colloidal solids. Organic matter is biologically stabilized, so that no further oxygen demand is exerted by it. Efficiency of any of the biological treatment processes is basically dependent on available active microbial population in the reactor, type of arrangement provided for contact of pollutant with the biomass and contact time provided for the microbial action. The interest in anaerobic liquid wastewater treatment processes in practice is sharply increasing all over the world.

In late 70's that a process was developed which due to its simplicity, low cost, high treatment rate and efficiency could compete with the aerobic processes. In Netherlands efforts has been made towards the development of a more sophisticated anaerobic treatment process, suitable for treating low strength wastes and for applications at liquid detention times of 3—4 h. The effort resulted in a new type of UASB process in Holland by Lettinga *et al*. (Lettinga, 1980).

Various studies regarding the assessment of suitability of UASB in wastewater treatment have been reported on bench, pilot and full-scale installations. Many researchers have studied the treatability of different types of wastewater (Craveiro, 1986; Ciftci, 1993; Hideki, 1996; Yeu, 1996; Richard, 1997; Gong, 1997; Habets, 1991; Michael, 1997).

Brewery wastewater was effectively treated in UASB with soluble COD and BOD removal efficiencies of 89.1% and 91.3% (Yeu, 1996). A two-phase UASB system was studied by Shin *et al*. (Shin, 1992) for high rate treatment of concentrated distillery wastewater, with loading rates up to 44 kgCOD/(m^3·d) which results in removal of 80% of influent COD, with gas production of 16.5 L/(L·d). Herbert *et al*. (Herbert, 1997) have studied the anaerobic degradation of benzoate and cresol isomers in sulphate rich wastewater. Herbert and Fang *et al*. (Herbert, 1995) studied the performance and sludge characteristics of UASB process treating propionate rich wastewater. Rajamani *et al*. (Rajamani, 1995) reported COD removal efficiencies of about 60% and TOC removal efficiencies of 65%—70% at a loading rate of 3—4 kgCOD/(m^3·d) on treating tannery wastewater using lab scale UASB. Paperboard mill effluent was successfully treated at loading rate of 20 kgCOD/(m^3·d) with HRT 2.5 h in UASB reactor, 70% of COD removal were reported (Habets, 1985).

Over 300 full-scale UASB reactors have been built worldwide which most of them designed for treating wastewater from food, beverage, potato, starch and sugar processing industries (Lettinga, 1991). Very few researchers have tried to treat the pulp and paper mill wastewater adopting UASB reactor (Habets, 1991; Yan, 1995; Rintala, 1991).

Paper plays an increasingly important role in modern civilized society. Today paper is finding expanding outlets in the industrial sphere at the same time pulp and paper mill is one among the major polluters of the aquatic environment. These industries, if they discharge their effluents directly into the river, deplete the dissolved oxygen in the river, which may cause damage to flora and fauna. The lignin compound

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which imparts color to the effluent, are not easily biodegradable and hence imparts dark color to the receiving stream, which persists for long time and inhibit photosynthesis and assimilation capacity. Disposing on land cause blocking of soil pores, which leads to soil sickness. Hence, an attempt in the field of wastewater treatment especially the anaerobic technology being an energy recovery process would serve the dual goal of wastewater management.

1 Materials and methods

The UASB reactor used in this study is illustrated in Fig.1 of 9.45 L in volume. Reactor has been fabricated out of plexiglass, inlet and outlet ports were made up of brass. Two modules of the reactor, each of 600 mm length and 100 mm diameter are fabricated of plexiglass and fitted one above the other with the help of plexiglass plate flanges. Asbestos rubber washers are provided in between the flanges of the corresponding diameter to make the joints leak proof. Brass nozzles are fixed along the height of the reactor using based blocks of plexiglass attached to the surface. At the bottom similar brass ports were provided to act as inlets for wastewaters.

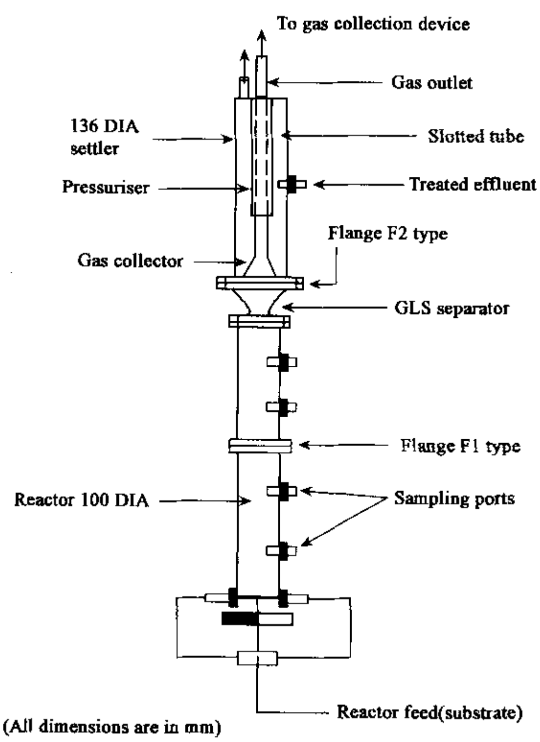

Fig.1 Fabricational details of the UASB reactor

The microbial seed culture was obtained from Kesare Sewage Treatment Works near Mysore, Karnataka, India. Paper mill wastewater brought from a typical Indian papermill, was used as substrate for the microbial culture. Laboratory study was conducted by continuously running the anaerobic reactor in a temperature-controlled chamber with a thermostat in-order to maintain the desired temperature of 35 ± 2℃. The reactor was seeded with 5 L of previously screened sewage sludge. After filling up of the reactor with feed solution, nitrogen gas was purged through the reactor for 2—3 min to reduce oxygen toxicity and micronutrients were added to improve the settling of sludge.

During start-up, the reactor was fed with sewage for about 60 d and later the paper mill wastewater was fed with 30%, 60%, 75% and 100% dilution. The reactor was operated and monitored for a period of 100 d. The pH, COD of both influent and effluent was measured daily. The BOD of the effluent was measured twice for each loading rate after attaining the steady state. Biogas production and VFA of effluent were determined daily.

2 Results and discussion

2.1 Sludge development and granule formation

The sludge concentration in the reactor are of the chief factors to evaluate the performance of the reactor which could not be determined accurately as the sludge bed was found to expand and contract due to entrapped or rising gas bubbles, and the internal circulation of the reactor contents due to up-flow velocity and the gas induced huogarly. In the present study during the initial OLR of 1.0 kgCOD/(m^3 · d), the growth of the sludge was not much significant, this may be due to washout of sludge, which afterwards got improved. The behavioral pattern is given by the ratio of VSS to TS as shown in Fig.2. From Fig.2 it is evident that at the end of initial loading of 1.0 kgCOD/(m^3 · d), the concentration of VSS was 12.86 gVSS/L, which got increased to 38.05 gVSS/L at the end of OLR of 2.1 kgCOD/(m^3·d). The profiles of VSS determined along the height of the reactor at various OLR's are shown in Fig.3.

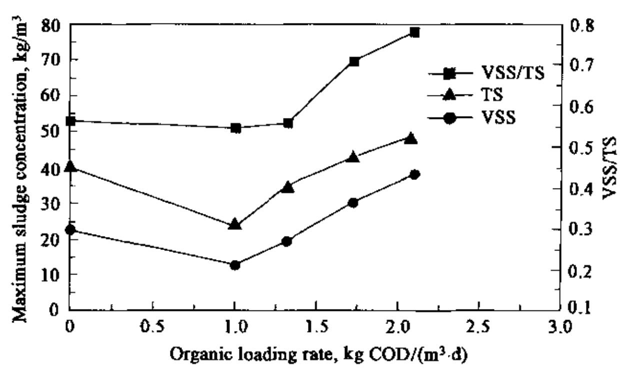

Fig.2 Maximum sludge concentrations in the reactor at different OLR

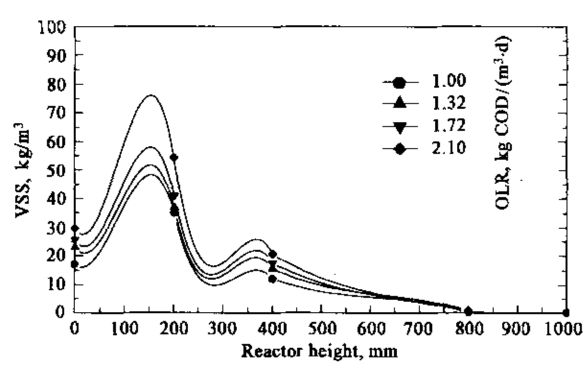

Fig.3 Variation of VSS along the height of the reactor

The granulation of the seeded sludge is shown to be substrate dependent and it may not occur at all for certain specific substrates. Pol *et al*. (Pol, 1983) have reported that granulation did not occur with mixed VFA as substrate with high ammonium concentration(1000 mgNH_4-N/L). Further, for some wastewaters, such as cheese whey, granular sludge did not develop with non-granular sludge as seed but when inoculated with granular sludge, the granules were intact and well maintained(Yang, 1993). However during the present study, the granulation process started after 120 d from the start-up period. During the treatment of distillery spent wash using UASB reactor, the granulation process started after about 55 d from the start-up period showed interesting patterns(Suneeth, 1998).

Lettinga *et al*. (Lettinga, 1980), Pol *et al*. (Pol, 1983), Pette and Versprille(Pette, 1981) have reported that the granules were varying between 0.5—5 mm sizes with an average size of 1—3 mm predominating. These findings were for different types of wastewaters. In the present study some of the granules were found to be small particulate of about 0.3 to 0.8-size mm(150 d from start-up at OLR of 1.72 kgCOD/(m^3·d), which reached maximum size of about 1.0 to 1.2 mm at OLR of 2.1 kgCOD/(m^3·d).

2.2 COD removal efficiency

Fang and Chui (Fang, 1993) reported that the COD removal efficiency of a UASB reactor was mainly dependent on the COD loading rate, and was sensitive to either the hydraulic retention time or the wastewater COD level alone. In the present study the daily variation of influent COD values and effluent COD for different OLR during the start-up period is shown in Fig. 4. The efficiency of COD removal rate increases with increasing in organic loading rate. The removal efficiency increased from 70% at OLR of 1.0 kg COD/(m^3·d) to 84.46% at an OLR of 2.1 kgCOD/(m^3·d) which may further increase the COD removal efficiency with increasing OLR. It was observed that, for every step there was marked increase in the COD removal efficiency after reaching steady state under that OLR. However at each increase in OLR, there was sudden reduction in COD removal efficiency temporarily, which gradually got increased later. This could be due to abrupt increase in the VFA resulting in reduction of operating pH. Fig.5 shows the variation of COD along the height of the reactor. The maximum COD concentration was observed at 200 mm height.

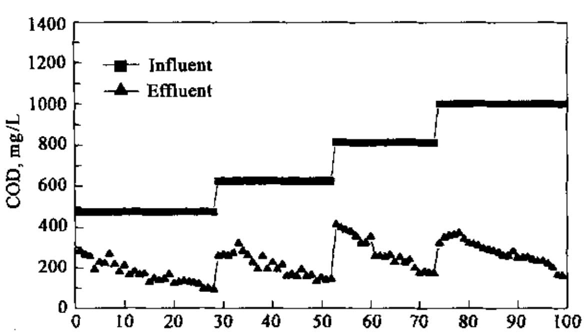

Fig.4 Variation of COD in influent and effluent during the operating period

2.3 Sludge loading rate

Fig. 6 shows the sludge loading rate (SLR) corresponding to different OLR during operating days. It shows a minimum of 0.076 gCOD/(gVSS·d) to start with, at an OLR of 1.0 gCOD/(L·d) which increased to a maximum value of 0.16 gCOD/(gVSS·d) at an OLR of 2.1 gCOD/(L·d). Unlike the aerobic process, the cell yield in anaerobic process is slow. Hence, the SLR normally increases with increase in OLR. Lettinga *et al*. (Lettinga, 1980) have reported SLR values in the range of 0.5 to 1.1 gCOD/(gVSS·d) for beat sugar, 1.0 to 1.4 gCOD/(gVSS·d) for potato processing wastes, 1.1 to 1.8 gCOD/(gVSS·d) for alcoholic wastes and 2.3 gCOD/(gVSS·d) for VFA bound substrates. Jayantha and Ramanujan(Jayantha, 1995) have reported a value of 1.6 gCOD/(gVSS·d) at the OLR in the range of 3.5 to 4.8 gCOD/(L·d) for distillery spent wash. The SLR was in the range of 0.55 to 0.58 gCOD/(gVSS·d) for OLR in the range of 10 to 12 gCOD/(L·d) during operating a molasses solution(Manjunath, 1987).

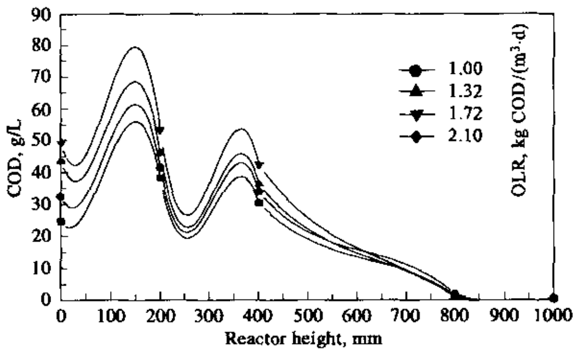

Fig.5 Variation of COD along the height of the reactor

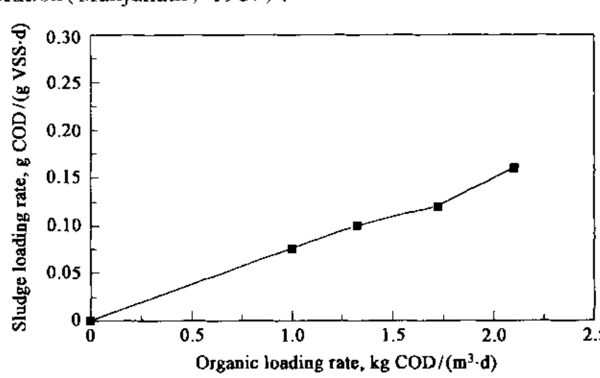

Fig.6 Variation of sludge loading rate during different OLRs

2.4 pH and VFA levels

The concentration of volatile fatty acids is one of the major controlling parameters in anaerobic digestion. The wastewater generated from paper mill industries had a pH level in the range of 7.0—7.3, which is an optimum range for good methanogenesis. Reduction of the influent pH below 6 results in the accumulation of VFA with the reduction in efficiency. In the present study the pH and VFA concentration of the reactor effluent was measured every day. These recorded values of pH and VFA are presented in Fig. 7. If the VFA exceeds above 500 mg/L, the feed into the reactor should be stopped for a short duration to avoid further accumulation of VFA inside the reactor. In the present study, the VFA in the effluent was well within the limit of VFA reported in anaerobic fermentation process (< 500) (APHA, 1995). Riera *et al*.(Riera, 1985) have controlled the accumulation of VFA by draining out some part of the high VFA fluid and replacing it with tap water.

The minimum and maximum pH recorded during the paper mill wastewater treatment were found to be 6.5 and 7.8 while those for VFA were 27 mg/L and 130 mg/L, respectively. At times, maintenance of a higher influent pH would result in neutralization of the VFA formed. Further, variation of pH along the height of the reactor is presented in

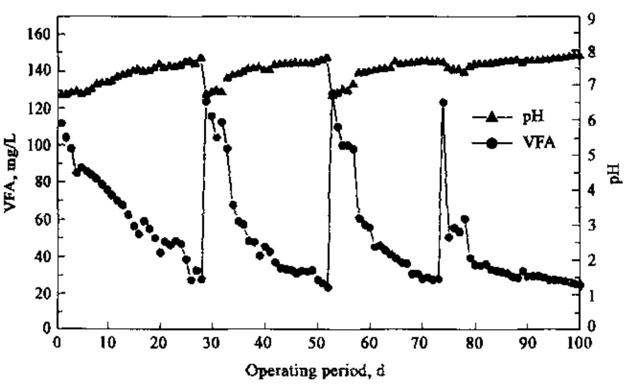

Fig.7 Variation of effluent VFA and pH during the operating period

Fig.8. From this figure it is evident that pH with in the reactor increased along the height of the reactor. Fig. 9 depicts the variation of COD removal efficiency with effluent VFA during the operating period. It was found that the COD removal efficiency increased with decrease in VFA concentration. In the conventional anaerobic digestion literature, an ultimate limit of 2000 mgVFA/L has been specified beyond which the microbial activity in the reactor stops and the reactor becomes struck.

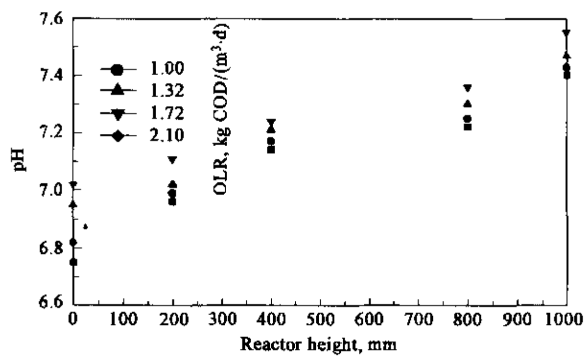

Fig.8 Variation of pH along the height of the reactor

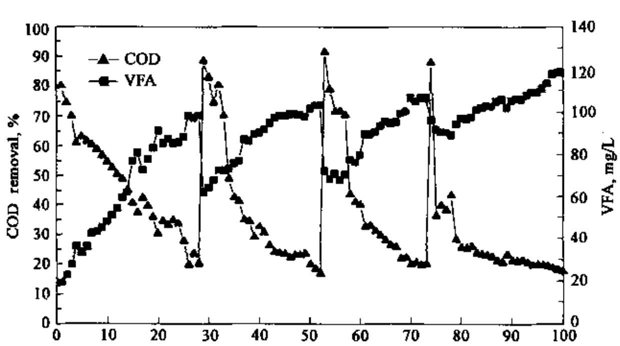

Fig.9 Variation of COD removal and effluent VFA during operating period

2.5 Gas production

Gas production is one of the key parameter indicating the health of a reactor. At low loading the gas production is less and the sludge bed expands due to entrapped and accumulated gas. The increase in gas production due to higher loadings brings about additional turbulence causing good mixing and consequently enhancing the sludge thickening. The gas entrapped in the bed is there by released and the expanded bed contracts. This phenomenon continues and the sludge bed height increases.

Due to the presence of viable microbial cells in the seed sludge for anaerobic treatment, biomethanation started immediately after feeding the raw paper mill wastewater into the reactor. At OLR of 1.0 kgCOD/(m^3 · d) the biogas production was found to be 0.15 L/g COD removal. It reached a maximum value of 0.4 L/g COD removal on the day 100 with OLR of 2.1 kgCOD/(m^3 · d). However, excessive gas production may result in washout of the sludge and disintegration of the granules formed and in turn depletion of the sludge bed may occur. The total biogas production on various operating periods is shown in Fig. 10 for different OLRs. Also, variation of biogas and VFA during the operating period shown in Fig. 11. Biogas production reached a maximum value of 0.4 L/g COD removal at 2.1 kgCOD/(m^3 · d). The biogas contained an average of methane of 69%, 27% of CO_2 and 1% to 1.5% H_2S.

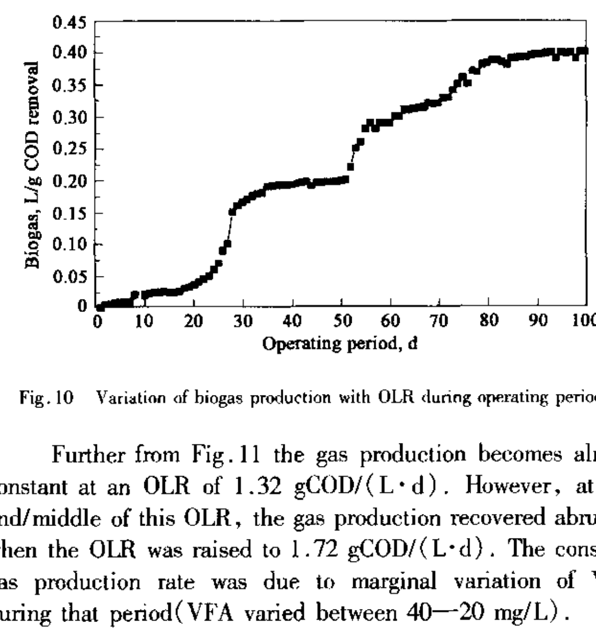

Fig. 10 Variation of biogas production with OLR during operating period

Further from Fig. 11 the gas production becomes almost constant at an OLR of 1.32 gCOD/(L · d). However, at the end/middle of this OLR, the gas production recovered abruptly when the OLR was raised to 1.72 gCOD/(L·d). The constant gas production rate was due to marginal variation of VFA during that period(VFA varied between 40—20 mg/L).

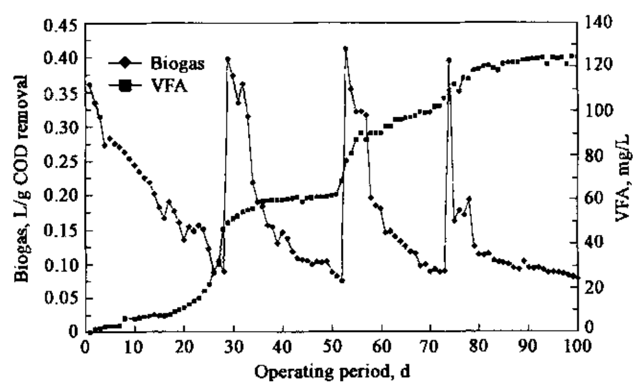

Fig. 11 Variation of biogas production and effluent VFA during operating period

2.6 BOD removal efficiency

Fig. 12 shows the variation of BOD removal with increasing OLR during the operating period. From this figure it is observed that there is steady increase in percent BOD removal reaching a maximum value of 90% at the OLR of 2.1 kgCOD/(m^3·d).

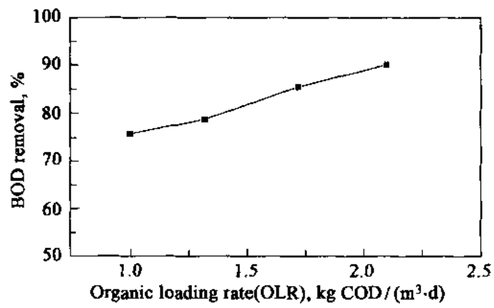

Fig.12 Variation of BOD removal efficiency with increasing OLR

3 Conclusions

In the present investigation performance evaluation of UASB reactor for the treatment of paper mill wastewater has been studied. It is observed that at the end of initial loading of 1.0 kgCOD/(m^3·d), the concentration of VSS was 12.86 gVSS/L, which got increased to 38.05 gVSS/L at the end of OLR of 2.1 kgCOD/(m^3·d). In the present study, the sludge granulation process started after 120 d from the start-up period. Sludge granule size was found to be 0.8 mm size (150 d from start-up) at OLR of 1.72 kgCOD/(m^3·d), which reached maximum size of about 1.0 to 1.2 mm at OLR of 2.1 kgCOD/(m^3·d). Further, to start with a maximum sludge loading rate (SLR) of 0.076 gCOD/(gVSS·d) was observed at an OLR of 1.0 gCOD/(L·d), which increased to a maximum value of 0.16 gCOD/(gVSS·d) at an OLR of 2.1 kgCOD/(m^3·d). Unlike the aerobic process, the cell yield in anaerobic process is slow. Hence, the SLR, normally increases with increase in OLR.

Concentration of VFA is one of the major controlling parameter in anaerobic digestion. In the present study, the VFA recorded was well within the limit of VFA reported in anaerobic fermentation process($<$ 500 mg/L). The minimum and maximum pH recorded during paper mill wastewater treatment was found to be 6.5 and 7.8, while those for VFA were 27 mg/L and 130 mg/L respectively. The maintenance of higher influent pH would result in neutralization of the VFA formed. Further, it is also observed that pH within the reactor increases along the height of the reactor.

In the present investigation, at low loading rates the gas production observed was less, during this period the sludge bed was expanded due to entrapped and accumulated gas. Later, the increase in gas production due to higher loadings brings about additional turbulence causing good mixing and consequently enhancing the sludge thickening. At OLR of 1.0 kgCOD/(m^3·d) the biogas production was found to be 0.15 L/g COD removal and it reached maximum value of 0.40 L/g COD removal on the day 100 at OLR of 2.1 kgCOD/(m^3·d). At this stage the biogas contained average methane of 69%, 27% of carbon dioxide and 1% to 1.5% of hydrogen sulphide. During the study period, the results of BOD values reveals that there is steady increase in percent BOD removal reaching a maximum value of 90% at an OLR of 2.1 kgCOD/(m^3·d).

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(Received for review November 15, 2002. Accepted June 23, 2003).