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ORIGINAL PAPER

Recycle in upflow anaerobic sludge blanket reactor on treatment of real textile dye effluent

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Abstract The discharge of textile wastewater containing dye in the environment is varying for both toxicology and esthetical reasons as dyes impede light penetration, damage the quality of the receiving streams. Upflow anaerobic sludge blanket reactor with anaerobic digester sludge treating starch wastewater has been used to investigate the removal efficiency of chemical oxygen demand (COD) and colour of textile dye wastewater. In this study, the starch and textile dye wastewater was mixed at 70 and 30%, respectively, and the experiments were carried out with recycle of treated wastewater at different percentage as 10, 20, 30 and 40. Maximum removal of COD and colour was 96% and 93.3%, respectively, at 30% recycle. At various OLR and HRT, the maximum removal of COD, colour was 95.9%, 93% at 6.81 kg COD/m^{3}d and 96%, 93% with 24 h of HRT. The maximum production of biogas at 24 h of HRT with 30% recycle was about 355 l/d. The Volatile fatty acid/Alkalinity ratio of methanogenic reactor was found to be 0.049–0.053. The result provided evidence, the starch and dye wastewater have wide variation in their characteristics was treated on combination, this new technology supports the effective utilization of starch waste in destruction of dye.

Keywords Recycle ratio · Colour removal · Acidogenic · Methanogenic · UASB

Introduction

Industrialization is vital to a nation's economy because it serves as a vehicle for development. However, there are associated problems resulting from the introduction of industrial waste products into the environment. Textile industry, which is one the largest water consumer in the world, produces the effluents that contain several types of chemicals such as dispersants, leveling agents, acids, alkalis, carriers and various dyes (Cooper 1995). Colour is one of the most obvious indicators of water pollution and discharge of highly coloured synthetic dye effluents can be damaging the receiving water bodies (Nigam et al. 1996). The release of coloured compounds into water bodies is undesirable not only because of their impact on photosynthesis of aquatic plants but also due to the carcinogenic nature of many of these dyes and their break-down products (Weisburger 2002). Therefore, it is necessary to treat completely these types of wastewater before releasing to environment. In addition, textile industry wastewater presents the additional complexity of dealing with unknown quantities and varieties of many kinds of dyes, as well as low BOD/COD ratios, which may affect the efficiency of the biological decolourization. Physico-chemical treatment methods are the least desirable owing to their high costs and generation of secondary pollutants. On the other hand, biological treatment methods are attractive due to their cost effectiveness, diverse metabolic pathways and versatility of microorganisms (Banat et al. 1996; Singh et al. 2004; Mendez-Paz et al. 2005; Van der Zee and Villaverde 2005; Pandey et al. 2007). Among the anaerobic processes,

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Upflow Anaerobic Sludge Blanket (UASB) reactor has been widely used to treat variety of industrial and domestic wastewaters all over the world. One common feature offered by all the high-rate processes is their ability to provide high Solid Retention Time (SRT) in relation to Hydraulic Retention Time (HRT). High biomass concentration is maintained in a reactor with relatively low treatment time. Generally more resistant to toxic compounds as the result of structure of formed granular sludge with good settling velocities and mechanical strength, and suitable for the treatment of wastewater containing xenobiotic and recalcitrant compounds, and it promotes adaptation of bacteria to the presence of toxic compounds, and as well as it can be used for treatment of wastewater previously considered unsuitable for anaerobic treatment (Somasiri et al. 2006). The aim of this study is to decolourize the real textile wastewater containing combined dye using starch industry effluent as co-substrate in hybrid biphasic UASB reactor with different ratios of recycling the effluent from methanogenic reactor.

Table 1 Characteristics of wastewaters

S.No.	Parameters[a]	Textile dye effluent	Sago effluent
1	pH	12.8	4.5
2	Total suspended solids	420.0	640.0
3	Total dissolved solids	3,520.0	1,200.0
4	Chlorides	1,520.0	400.0
5	Sulphates	180.0	123.0
6	BOD	175.0	2,400.0
7	COD	1,600.0	6,000.0

[a] All values except pH are mg/l

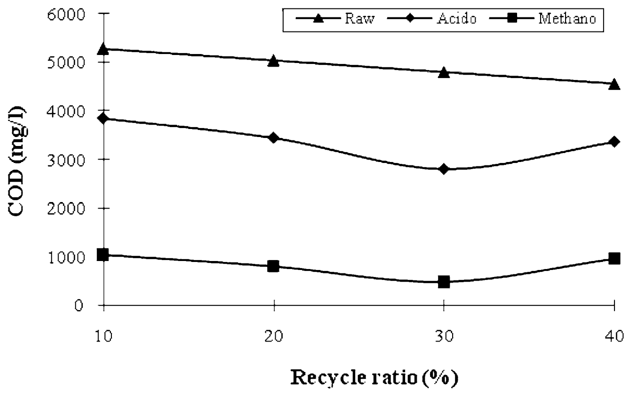

Fig. 1 COD at different recycle ratio

Materials and methods

Biomass

The methanogenic granular sludge with unknown microorganisms used in this experiment was procured from the anaerobic digester treating tapioca starch effluent of M/s Perumal SAGO factory, Salem, Tamil Nadu, India. Before loading the reactor, granular sludge was clearly washed, filtered through a fine mesh to reduce all the inorganic mineral contents. The volatile suspended solids content of the sludge was then estimated about 60,000 mg/l (APHA-AWWA-WPCF 2005).

Wastewater

The real untreated wastewater of starch industry and textile dye industry was collected from Sago factory and textile dyeing industry, Salem, Tamil Nadu, India. Totally ten wastewater samples were collected from each industries for duration of three months and the mean values of the parameters have been tabulated in Table 1. The complete analysis of the wastewater was carried out according to standard methods APHA-AWWA-WPCF (2005).

Experimental setup

In order to study the operational and performance characteristics of UASB reactor, a hybrid bi-phasic Upflow Anaerobic Sludge Blanket (UASB) reactor was fabricated. The acidogenic and methanogenic reactors are fabricated with 1:4 volumetric ratios. The first phase is an acidogenic reactor (300 mm inner diameter and 820 mm height) was made up of plexi-glass with working volume of 56 l and second phase is a stainless steel methanogenic reactor (350 mm inner diameter and 2,400 mm height) with working volume of 230 l. First the untreated real effluent was fed into the acidogenic reactor and secondly from acidogenic to the methanogenic reactor. Sampling ports were provided at a equal spacing of 400 mm from the bottom of the reactor to the top. On the top of the reactor, gas deflection was attached. The Gas–Liquid-Solid Separator (GLSS) consisted of an inverted conical funnel at top of the water column for the collection of biogas. In addition to the GLSS arrangement, a packed medium consisting of a PVC spirals size of 26 mm, surface area 500 $m^2 m^{-3}$ and void ratio 87% has been provided for a height of 200 mm locating at 1,770 mm from the bottom of the reactor. The spiral will retain the biomass in addition to giving polishing effect to the effluent. The sludge granules trapped in GLSS and the spiral will return to the reactor as soon as the gas entrapped inside the granules is released. Biogas generated was measured using wet gas flow meter. After stabilizing the reactor, studies were conducted under the steady state conditions. At steady state of the bioreactor performance parameters like COD, pH, colour removal were relatively constant (<10%). The reactor was operated at effluent recycle mode. The influent feed of the reactor consists of 70% of real sago wastewater and 30% of real textile dye effluent and operated at 24 h HRT. The treated effluent from methanogenic reactor was recycled at 90:10, 80:20, 70:30 and 60:40 ratios (70/30 mixing of sago and textile dye: recycle of methanogenic outlet).

Start-up phase

About 50% of both acidogenic and methanogenic reactors were seeded with previously screened and washed digester sludge treating the starch effluents. The reactor was operated at room temperature and the feed solution was led into the reactor at the required rate in an up flow mode using a Variable Speed Pump (Miclins VSP 50). The initial COD of starch effluent was 6,000 mg/l organic loading rate (OLR) was 1.44 kg COD m^{-3} d^{-1} with hydraulic retention time (HRT) of 24 h. Ammonium chloride and potassium dihydrogen phosphate were added to maintain a COD:N:P (macro nutrients) ratio of 300:10:1 so as to maintain balanced nutrients in the feed for the growth of microorganisms. To improve settling characteristics trace amount of cobalt chloride, nickel chloride, zinc chloride, barium chloride and boron all of analytical grade were added (Lettinga et al. 1985) once a week as suggested by Henze and Harremoes (1983).

Since the sludge activity was initially low, lower feed concentration helped to control excessive volatile fatty acid (VFA) formation and guarded against excessive pH drop. The COD conversion efficiencies as well as gas production showed remarkable improvement after third day. On the thirty-first day the reactor showed signs of stability. After stabilizing the reactor, studies were conducted under the steady state conditions. At steady state of the bioreactor performance parameters like COD, pH, colour removal were relatively constant (<10%). The reactor was operated at effluent recycle mode. The influent feed of the reactor was in the ratio of 70% of real sago wastewater and 30% of real textile dye effluent. The optimum mixing ratio of synthetic textile dye and starch wastewater in bench scale reactor was already found by Senthilkumar et al. (2009). The treated effluent from methanogenic reactor was recycled at 90:10, 80:20, 70:30 and 60:40 ratios (70/30 mixing of sago and textile dye: recycle of methanogenic outlet).

Result and discussion

Effects of effluent recycle on COD removal

Figure 1 shows the COD concentrations of combined effluent of starch and textile dye with various recycling ratio of treated effluent. As the recycling ratio increases, the COD of inlet wastewater get decreased due to dilution of the feed. The reactor was fed with the COD range of 5,840–4,720 mg/l. The COD removal efficiency at various recycling ratios is shown in Fig. 2. There is a gradual increment of removal efficiency up to 30% of recycling after that it becomes almost stable. Recirculation generally improves the performance of the reactor (Van der Zee and Villaverde 2005). Effluent recycle will fluidize the sludge bed to have a sufficient contact between wastewater and sludge even at low organic loads and certainly will result in high treatment efficiency (Lettinga et al. 1985). As quoted by Van den Berg et al. (1981) and Lettinga et al. (1985) 96.7% of COD removal efficiency was achieved by 30% of recycling the effluent. The removal efficiencies of COD in acidogenic and methanogenic reactors are in the range of 28–43% and 79–96%, respectively (Fig. 2). The overall COD removal efficiency of 30% recycling was about 96.6% at HRT of 24 h. A maximum COD removal at a mixing ratio of 60% of synthetic starch wastewater and 40% of synthetic dye using bench scale reactor without recycle was about 96% (Senthilkumar et al. 2009). It is also evident that 30% of effluent recycle is the most optimum level (Fig. 2).

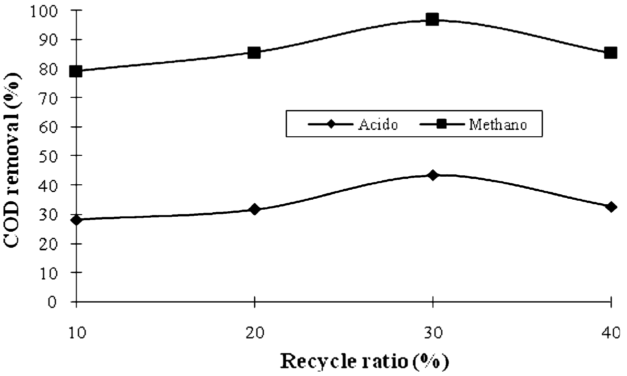

Fig. 2 Removal of COD at different mixing ratio

Effects of effluent recycle on color removal

The intensity of colour in the influent and outlets of acidogenic and methanogenic reactors were measured using UV-Vis Spectrometer at 600 nm was shown in Fig. 3. The optical density values of different recycle ratio for feed vary between 0.412 and 0.652. Figure 4 shows the removal efficiencies of colour in acidogenic and methanogenic reactor. The colour removal efficiency was in the range of 71–93.3% at 24 h HRT for various ratios of effluent recycle. Chinwetkitvanich et al. 2000 disclosed that the colour removal efficiency from three different real wastewaters was in the range of 36–71%, whereas, from synthetic wastewaters between 56 and 63% with synthetic tapioca starch as co-substrate in both the experiments using

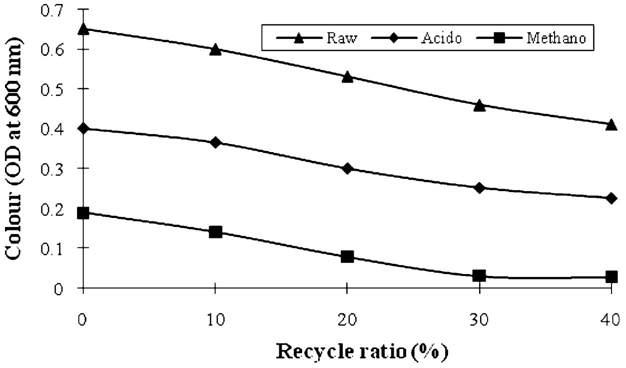

Fig. 3 Colour at different mixing ratio

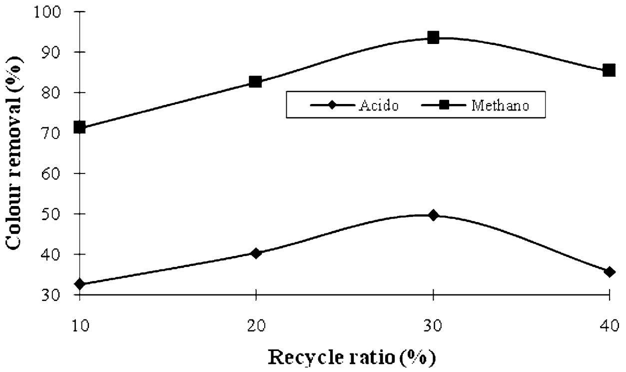

Fig. 4 Removal of colour at different mixing ratio

two-stage UASB reactor of 3 l capacity in 12 h HRT. In this study, the colour removal efficiency from real dye bath wastewater was about 93.3% with real sago effluent as co-substrate using hybrid UASB reactor system of 230 l capacity in 24 h HRT.

Influence of pH

Methanogenic microorganisms are more susceptible to even a minute changes in the pH values. The pH values of raw effluent, acidogenic and methanogenic reactor effluent for various recycle ratios at 24 h of HRT are shown in Fig. 5. Influent pH values ranges between 6.3 for no recycle and 6.5 for effluent recycle, whereas, the pH values were vary optimum ranges of 6.8–8.0 for both stage of reactors. Specifically for methanogenic reactor effluent pH increased and remained between 7.8 and 8.0. Optimum pH ranges of 6.0–7.2, 6.4–7.2, and 6.6–7.6 have been reported to be favorable for the methane bacteria, which cannot tolerate the fluctuations (Cheremisinoff and Morress 1976; Dugan 1977; Jayantha and Ramanujam 1996). The pH maintained inside the reactor, due to the process results from the interaction of the carbon dioxide-bicarbonate buffering system and volatile acids-ammonia formed by the process (Bisselli 1975). It is necessary to prevent the accumulation of acids, to a level, which may become inhibitory to the methane bacteria. In this study, sufficient buffering was present in the reactor, which prevents the reactor souring.

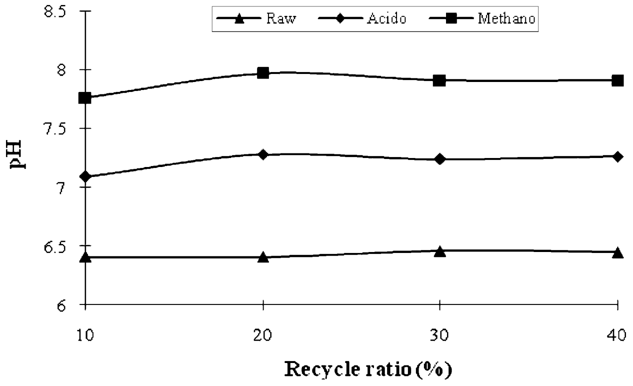

Fig. 5 pH at different recycle ratio

Influence of volatile fatty acid (VFA)/Alkalinity ratio

Figure 6 shows the volatile fatty acid (VFA)/Alkalinity ratio for both acidogenic and methanogenic reactors for different percentage of effluent recycle at 24 h of HRT. The effluent volatile fatty acid (VFA)/Alkalinity ratio of the acidogenic reactor was more or less equal to 1 which demonstrates the proper functioning of acidogenic species in the anaerobic process. Similarly, the volatile fatty acid (VFA)/Alkalinity ratio of methanogenic reactor ranges between 0.049 and 0.053. It reveals that throughout the experimental period volatile fatty acid accumulation was under control and the reactor was under stable condition. In a stable reactor, volatile fatty acid content will be low in proportion to the available alkalinity. Simpson (1960) reported that the volatile fatty acid (VFA)/Alkalinity ratio must be very low range for stable anaerobic digester. Even though a little accumulation of volatile fatty acid was observed in increased dye concentrations, the detected

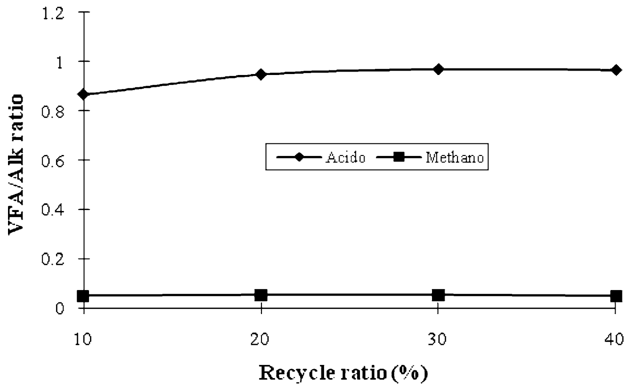

Fig. 6 VFA/Alkalinity at different recycle ratio

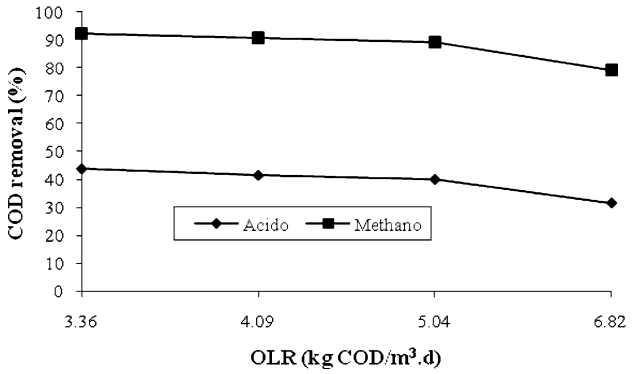

Fig. 7 Removal of COD at different OLR with recycle ratio

values of volatile fatty acid, alkalinity and pH showed that the values are in the range of desirable limits of anaerobic process (Somasiri et al. 2008).

Effect of organic loading rate (OLR)

Figures 7 and 8 illustrates the percentage removal efficiency of COD and colours at different organic loading rates with 30% of effluent recycle. The various OLRs are 3.36, 4.09, 5.04 and 6.81 kg COD/m^3 d for 36, 30, 24 and 18 h HRTs, respectively, with an Upflow velocity of 0.1 m/h. The COD and colour removal efficiencies in the methanogenic reactor were found to be higher of about 95.9 and 93%, respectively, at an OLR of 6.81 kg COD/m^3 d. Similarly, the COD and colour removal efficiencies in the acidogenic reactor were found to be 38.9 and 45.6%, respectively. Talarposhti et al. (2000) reported a maximum colour removal of 90% at OLR of 0.25 kg COD/m^3.d with an HRT of five days in two-stage anaerobic packed bed reactor. Torkian et al. (2004) achieved 85% of COD removal with an Upflow velocity of 0.9–1 m/h and organic loading rates of 14–25 kg COD/m^3 d.

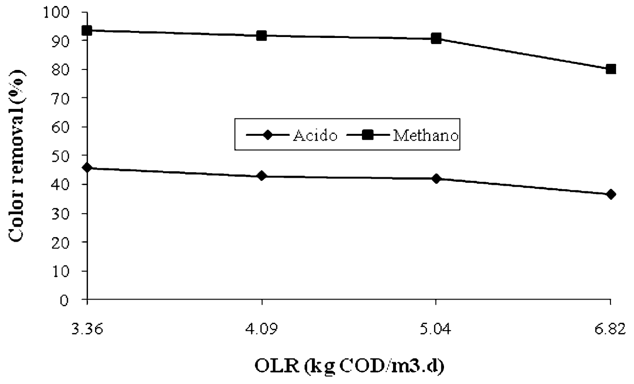

Fig. 8 Removal of colour at different OLR with recycle ratio

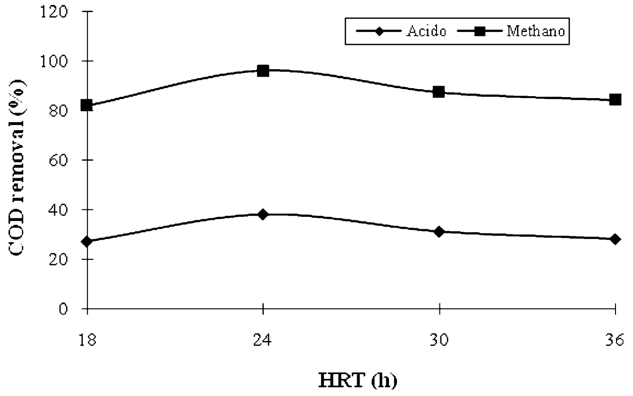

Fig. 9 Removal of COD at different HRT with recycle ratio

Influence of hydraulic retention time (HRT)

Figures 9 and 10 shows HRT versus COD and colour removal at various HRTs such as 36, 30, 24 and 18 h. The COD removal in acidogenic reactor was in the range of 27–38% and in methanogenic reactor was 82–96% at different HRT for 30% effluent recycling. The maximum removal efficiency of COD was achieved at 24 h HRT. The colour removal efficiency for both acidogenic and methanogenic reactor was in the range of 32–46% and 83–93%, respectively. Senthilkumar et al. (2009) had reported that COD and colour removal efficiency was found to be maximum at 12 h HRT in bench scale study using synthetic wastewaters.

Biogas production

The biogas production at various percentage of effluent recycles at 24 h HRT was shown in Fig. 11. The biogas generation was decreased with increase of dye wastewater. The maximum production of biogas was measured about 355 l/d for 30% effluent recycle, whereas, the biogas production at 10, 20, and 40% was recorded as 158, 284 and

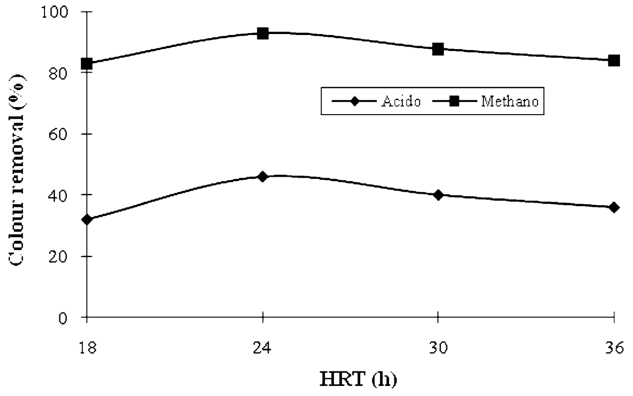

Fig. 10 Removal of colour at different HRT with recycle ratio

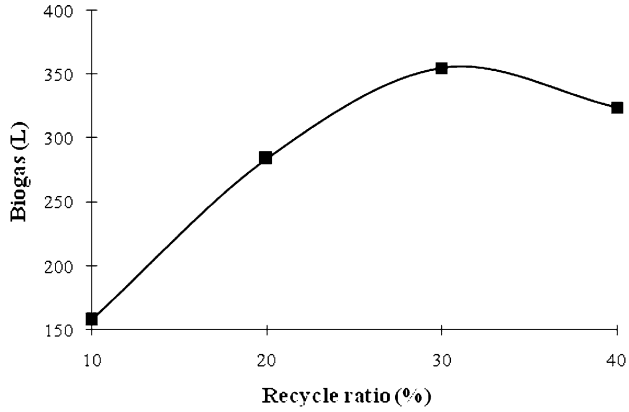

Fig. 11 Biogas production at different recycle ratio

324 l/d, respectively. Biogas production is directly related to COD stabilization, for example without biogas production minimal COD removal occurs (Gardy et al. 1999). Mustafa Isik (2004) reported the maximum biogas production of 180 ml/day when the COD was 2,026 mg/l.

Conclusion

Textile industry wastewaters are degraded and decolorized using starch industry wastewater as co-substrate in two-phase upflow anaerobic sludge blanket reactor. An effluent recycle ratio of 30% of methanogenic outlet was optimized. Overall COD and colour removal efficiency of 96 and 93%, respectively. The reactor was operated at several HRTs (36, 30, 24 and 18) and maximum COD and colour removal were obtained at 24 h HRT. The VFA/Alkalinity ratio was in the range of stable condition for the anaerobic reactors. The biogas production was 355 l/d at optimized condition. The two-phase pilot plant UASB reactor produces much less organic sludge comparable with present conventional physico-chemical treatment systems.

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