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PERFORMANCE OF THE 5 MLD UASB REACTOR FOR SEWAGE TREATMENT AT KANPUR, INDIA

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ABSTRACT

The present paper describes the performance of a 1200 m^3 UASB reactor treating 5000 m^3 municipal waste water per day at Kanpur, India. The reactor was constructed in three parallel compartments of 600, 300 and 300 m^3 respectively to study the influence of various design and operational parameters on process performance. The 600 m^3 compartment is the reference unit. In one of the 300 m^3 compartments the effluent overflow gutters are provided with baffles to prevent overflow of floating material. The other 300 m^3 compartment is provided with a double amount of inlet pipes at the bottom of the reactor to assess the effect of a more dense distribution of the influent.
The start-up of the reactor was carried out without addition of seed sludge since the influent contained the necessary seeding material.
Data collected over a period of twelve months showed that there was an average reduction in COD, BOD, and TSS concentrations of respectively 74,75, and 75 % at a hydraulic retention time of 6 hours. Excess sludge production was 0.2 kg TSS/m^3 waste water, having 60-70 percent ash. It could be dried in six days on open sludge drying beds. The biogas yield was 0.05 to 0.10 m^3/kg COD removed. The gas had 75 to 80 percent methane. Also during winter time the treatment efficiency and process stability remained good. The compartment provided with baffles showed better removal efficiencies for COD, BOD, and TSS than the other compartments. A double number of inlet points did not show an increase in removal efficiency. A density of one inlet point per 3.7 m^2 is sufficient to provide a properly distributed influent in the reactor.

KEYWORDS

Anaerobic sewage treatment; UASB system; full scale; biogas production; treatment performance; municipal waste water.

INTRODUCTION

In 1985 the existing bilateral development cooperation sectors between India and the Netherlands were expanded with an additional sector, Environmental Protection and Management. Also around that time the Government of India was in the process of formulating the Ganga Action Plan. The Ganga Action Plan aims to prevent pollution of the river Ganga with a view to make the river water amongst others suitable for

religious bathing. The main elements of the Ganga Action Plan are interception of natural drains and sewers which have outfalls to the river and construction of sewage treatment facilities.
Since in the Netherlands there was substantial advancement in the field of clean environmental technologies, the Ganga Project Directorate requested the Government of the Netherlands to provide technical assistance for two towns along the Ganga, i.e. Kanpur and Mirzapur.

Kanpur is predominantly an industrial town with textile mills and tanneries. The Indo-Dutch project covers the Jajmau area in Kanpur which has about 150,000 inhabitants and a cluster of about 150 tanneries along the river Ganga. Mirzapur has about 130,000 inhabitants and cottage level brassware and carpet weaving industries.

In the recent past the Upflow Anaerobic Sludge Blanket (UASB) technology has been developed in the Netherlands for treatment of industrial waste water (Lettinga et al, 1980; Jans et al, 1986). A few years ago this UASB concept was also applied for domestic waste water under temporate conditions (Lettinga et al, 1982; Man et al, 1986) and under tropical conditions in Cali Colombia with Dutch sponsoring (Velsen et al, 1985, 1988). The results were so promising that the Ganga Project Directorate requested the demonstration of the UASB technology under Indian conditions in Kanpur. Based upon the results of this demonstration plant, full scale plants could thereafter be constructed in Kanpur and Mirzapur.
To assess the lay out of the full scale UASB treatment plants at Jajmau and Mirzapur and to optimise specific design criteria, the first phase of the project included the construction and operation of a 5 mld UASB module for domestic sewage treatment as well as a 10m^3 UASB pilot plant for treatment of tannery waste water. These plants have been in operation since April 1989.
The main objectives of the 5 mld plant were :

- to demonstrate the UASB process under Indian conditions,
- to optimise the design criteria for further extension of the UASB treatment system in Jajmau as well as in Mirzapur,
- to assess the treatment efficiencies,
- to set-up operation and maintenance guidelines in the form of an Operation and Maintenance manual,
- to train plant operating personnel on operation and maintenance aspects of a UASB treatment plant.

This paper describes the results obtained during the monitoring period which took place from April 1989 up to October 1990 and provides information regarding the design and application of this promising technology for sewage treatment in developing countries.

THE UASB CONCEPT

Anaerobic digestion in fact is a mineralization process, converting biodegradable organic compounds into methane and carbon dioxide, and leaving in the aqueous solution compounds like ammonia, sulphide, phosphate.

In the UASB concept treatment is carried out in an upflow reactor with a feed inlet distribution system at the bottom of the reactor and a gas-solids-separator (GSS) at the top. The waste water is evenly distributed over the reactor bottom and flows upward through a bed of anaerobic sludge. During passage through the sludge bed suspended solids are entrapped and biodegradable material is consequently digested. Dissolved organics are removed from the solution by the anaerobic bacteria and converted into biogas and for a small fraction in new bacterial biomass. The biogas provides a gentle mixing in the sludge bed, therefore no mechanical mixing is required. In the upper part of the reactor the produced biogas is collected in the GSS from were it withdrawn. The water-sludge mixture enters a settling compartment where the sludge can settle and flow back into the digestion compartment. After settling the treated water is collected in gutters and discharged. A salient feature of the UASB concept is that anaerobic flocculant or granular type of sludge inherently has or will attain good settling properties provided the process is operated in the proper way during the reactor start-up.

DESCRIPTION OF THE 5 MLD UASB TREATMENT PLANT

The layout and an overview of the UASB treatment plant are given in Figure 1.a and 1.b respectively.

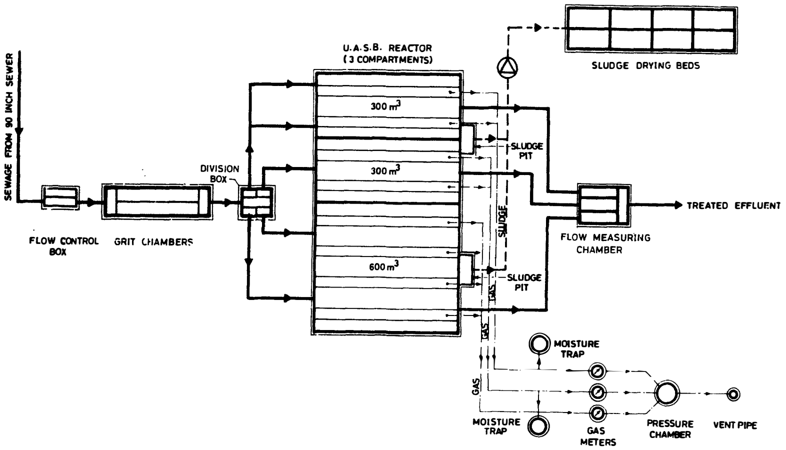

Fig. 1.a. Layout of the UASB plant.

The waste water is supplied by the Jajmau pumping station and arrives under pressure at the UASB plant site. The system consists of a flow control box for the approximate flow regulation followed by a grit chamber to remove grit particles. In the grit chamber also screens and sieves are provided to prevent coarse materials from entering the reactor. From the grit chamber the sewage flows into the division box, where the sewage is proportionately distributed over the three compartments of the UASB reactor. Sewage enters the UASB reactor through distribution boxes. These boxes have a by-pass valve for the exact regulation of the flow into the reactor. From these distribution boxes the sewage is distributed over the bottom of the reactor through a system of feed inlet pipes.

The effluent flow is measured in the measuring chamber. The biogas produced from the sewage is measured by three wet-test gasmeters, one for each compartment. Sludge can be discharged by gravity into the sludge pits from where it is pumped to the sludge drying beds.

The UASB reactor has a volume of 1200 m^3. The treatment capacity is 5000 m^3 per day. The module is divided into three separate compartments of 600 m^3, 300 m^3, and 300 m^3 respectively. The main purpose of dividing the reactor in three compartments is to test the applicability of certain design concepts in order to optimise the design for further extension of the UASB system. The three compartments of the first 5 mld UASB module differ one from another in the following way.

Compartment 1: This compartment has a volume of 600 m^3 and is the reference unit.

Compartment 2: This compartment has a volume of 300 m^3. The effluent overflow gutters are provided with baffles to prevent the overflow of floating material. In this way the formation of a floating layer can be assessed. Furthermore, it provides the possibility to assess the effect of retaining floating material on the treatment efficiency.

Compartment 3: This compartment has a volume of 300 m^3 and is provided with a double amount of feed inlet points at the bottom to assess the effect of a more dense distribution of waste water.

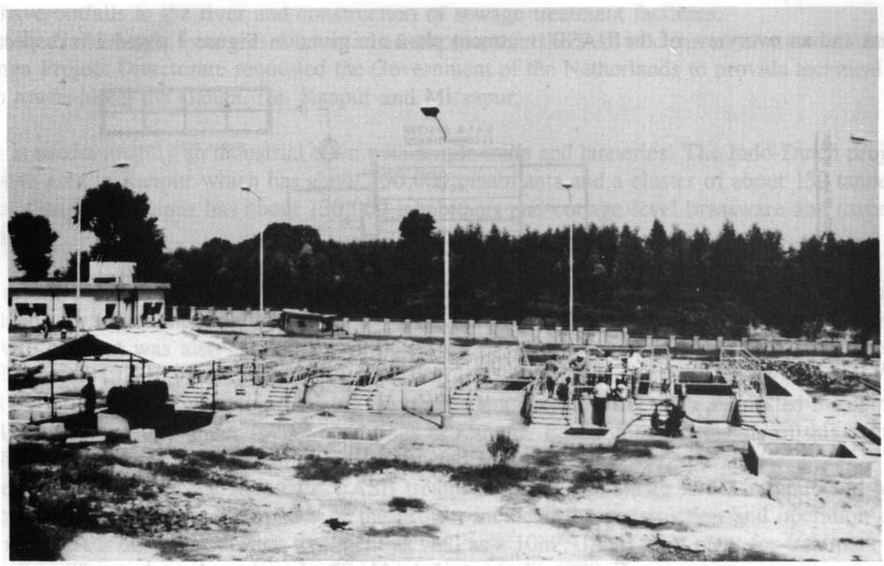

Fig.1.b. Overview of the UASB plant

MONITORING PROGRAMME

The operation of the plant was divided into a start-up phase and steady state operation. The start-up was carried-out without the addition of seed sludge, since the influent sewage contains the necessary seeding material. During start-up, the emphasis on operation is to collect the sludge that is present in the influent sewage to improve the sludge quality, and to eventually reach a steady-state condition. The plant was started up with its nominal loading rate at a hydraulic retention time of 6 hours. The start-up can be divided into three steps:

Step 1: Sludge accumulation

The aim of the sludge accumulation step is to fill the reactor with sludge. This is achieved by feeding the sewage to the reactor. The sludge in the sewage settles in the reactor.

Step 2: Sludge improvement

The sludge quality is improved by stopping the feeding of the plant for approximately 2 weeks. The undigested organic material in the accumulated sludge degrades and the settling properties and methanogenic activity improves.

Step 3: Blanket formation

In this last step of the start-up the sludge bed grows to its maximum height and the settling characteristics are further improved till steady state conditions are achieved.

Under steady-state conditions the UASB reactor achieved its typical characteristics, namely high Biological Oxygen Demand, Chemical Oxygen Demand, and Total Suspended Solids reduction rates at low hydraulic retention times. Once the steady-state operating condition was reached the three compartments were monitored to assess the treatment efficiencies with respect to the influence of baffles and a double number of feed inlet pipes.

In compartment number 2 the performance was tested under changing flow conditions by the introduction of a day/night rhythm. To study the effect on the treatment performance one compartment was also operated at a higher hydraulic retention time of 12 hours. To assess the reactor performance at lower temperatures the plant was monitored during the winter period of December 1989 and January 1990.

The monitoring consisted of daily routine and periodical intensive sampling. Each time after changing the process parameters, e.g. day/night rhythm or hydraulic retention time, the treatment process had to reach a new steady state. The daily routine monitoring was carried out to follow the performance of the treatment process during this phase as closely as possible. More intensive sampling was carried out once the system approached a new steady state, in order to assess more accurately the effect on critical process parameters. In this way a close monitoring of the plant was possible, while limiting the number of analyses to an acceptable level.

Influent and effluent were analyzed for: temperature, pH, COD-total, COD-filtered, TSS, Volatile Suspended Solids, BOD-total, BOD-filtered, Volatile Fatty Acids, alkalinity, Total Kjeldahl Nitrogen, P-total, sulphate, sulphide, chromium, and chloride. The sludge was analyzed with respect to TSS, VSS, methanogenic activity, dewatering ability, drying characteristics, sludge settleability, and trivalent chromium content. The biogas was analyzed with respect to methane, carbon dioxide, and hydrogen sulphide contents.

OPERATIONAL ASPECTS

Compartment number 1 of the plant was started up in April 1989. Within another month the remaining two compartments were started up. All the compartments were started up by simply filling them with sewage. Within a few weeks a considerable amount of sludge had accumulated in the reactor compartments. It appeared that there was no need to add external seed sludge for start up purposes.

The main parameters to assess the quality of sludge are the increase in ash content and increase in gas production. By the beginning of August 1989, the desired sludge blanket was formed. Around the middle of August the sludge discharge pumps got clogged due to presence of plastic pieces in the influent. This problem was overcome by improvements in the screening. After a few more teething troubles a steady state situation was reached by the end of September 1989.

In November, the filtering capacity of the sludge blanket decreased due to accidental excess removal of sludge which resulted in a higher turbidity and darker colour of the effluent. By the middle of December the required amount of sludge was again retained and performance of the reactor improved.

In December 1989 the COD, BOD and TSS concentrations of the influent increased up to values as high as 759 mg/l COD, 270 mg/l BOD, and 629 mg/l TSS. These high values were due to an increase in the discharge of tannery waste water in the sewerage system during the winter months when the tanneries have their highest production. In the months of February and March 1990 the sewage concentrations decreased gradually but were still at a high level.

For two periods of about four weeks in November, December 1989 and February 1990 compartment Number 2 was operated on a day/night rhythm. The average hydraulic retention time was kept at 6 hours, but the flow at day time was 1.5 times the average flow.

PERFORMANCE OF THE PLANT

In Table 1 the average COD, BOD and TSS concentrations and the temperature of the domestic sewage over the period September 1989 - October 1990 are given. In Table 2 a comparison of the average performance of the three compartments during stable operating conditions in the period from September 1989 - October 1990, at an HRT of 6 hours is given.

A graphical presentation of the performance of compartment number 2 based on weekly averages is given in Figures 2, 3 and 4 for respectively COD-total, BOD-total and TSS. A graphical presentation of the cumulative frequency distribution of the effluent COD, BOD and TSS data of compartment number 2 for the period from September 1989 - October 1990 is presented in Figure 5. A COD balance of compartment 2 for the period from September 1989 - October 1990 is presented in Figure 6.

In Table 3 the sludge characteristics are presented. There were no significant differences in the characteristics and growth of sludge from the three compartments. In Table 4 the biogas production and quality are given. There were no significant differences in the biogas production and quality from the three compartments.

TABLE 1. Average Composition and Temperature of Domestic Sewage.

		COD	BOD	TSS
No. of analyses		164	65	140
Average	(mg/l)	563	214	418
Standard deviation	(mg/l)	164	47	157
Temperature	(°C)		20-30	

TABLE 2. Average Effluent Quality and Reduction in COD, BOD and TSS

		COD Compartment no.			BOD Compartment no.			TSS Compartment no.		
		1	2	3	1	2	3	1	2	3
No. of analyses		164	163	164	65	65	64	135	140	140
Average	(mg/l)	178	149	169	66	54	61	130	107	134
Standard deviation	(mg/l)	54	44	51	17	18	19	65	76	67
Reduction	(%)	68	74	70	69	75	72	69	75	68

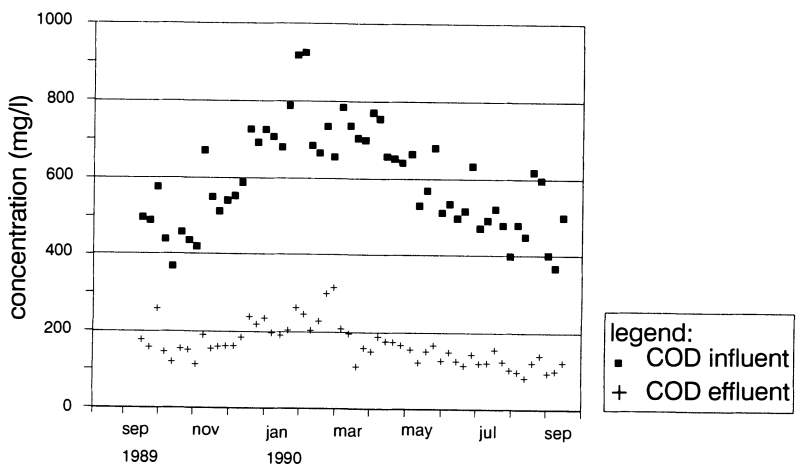

Fig. 2. Compartment number 2, COD influent and effluent values.

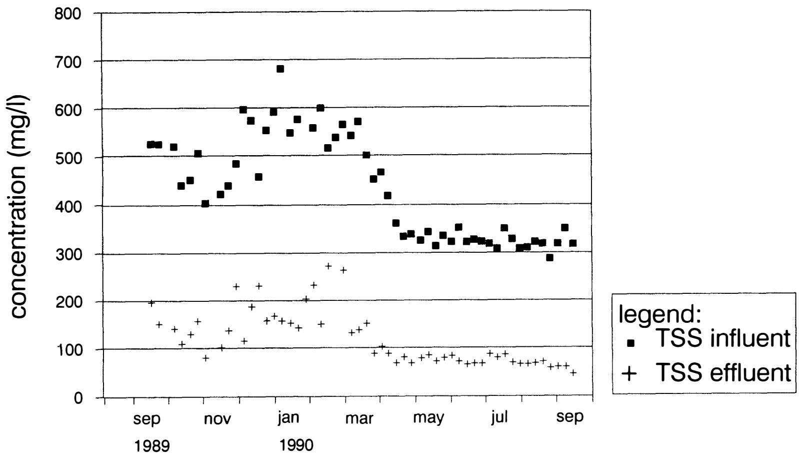

Fig. 3. Compartment number 2, BOD influent and effluent values.

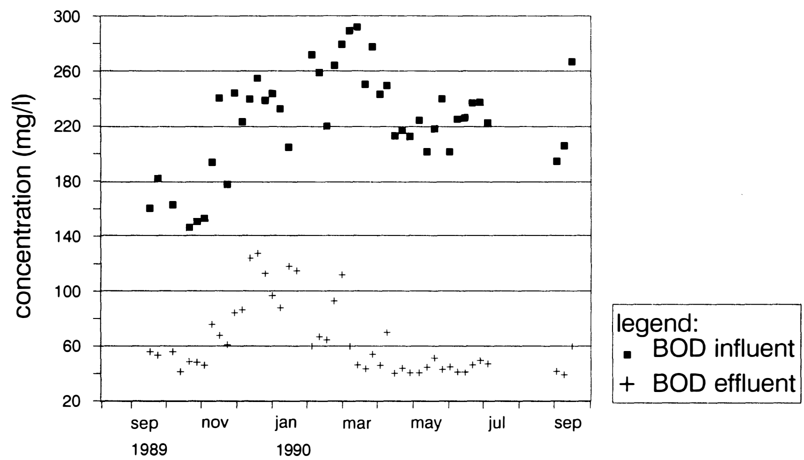

Fig. 4. Compartment number 2, TSS influent and effluent values.

EVALUATION OF THE RESULTS

The overall performance of the reactor was satisfactory with respect to COD, BOD, and TSS removal efficiencies. However, the standards for discharge on surface water (BOD 30 mg/l, TSS 50 mg/l) could not be met. In order to meet these standards a post-treatment is needed.

Compartment number 2 provided with baffles to prevent floating material from overflowing into the effluent gutters showed better efficiencies for COD, BOD and TSS removal if compared with the other compartments as can be seen in Table 2. It was found that specially when the sludge concentrations in the reactor were very high, sludge wash-out was to a large extent prevented by the baffles. Compartment number 3 which was provided with a double density inlet system showed comparable removal efficiencies with the reference compartment no. 1. It appeared that 1 inlet point per 3.7 m^2 was sufficient to provide a properly distributed influent and there is no need for a higher density of inlet points in the case of treatment of domestic wastewater.

It was observed that the treatment efficiencies remained constant irrespective of the decrease in temperature during wintertime. Furthermore, during about 3 weeks in January 1990 when the sewage temperature decreased to 20 °C, there was a clear decline in gas production. The biogas production increased rapidly again when the sewage temperature went up, indicating that there was no change in the sludge quality with respect to methanogenic activity, but merely a temporary temperature effect. As soon as the waste water temperature increased again in February 1990 the biogas production increased consequently.

The sludge profiles reveal that in the bottom part of the reactor high concentrations of suspended solids are maintained throughout the whole investigation period. At higher levels in the reactor the suspended solids concentration is lower but constant over the height. The amount of suspended solids retained in the reactor can very likely be somewhat increased by discharging excess sludge at a higher level. Based on the sludge stability tests, the ash contents of the sludge and the absence of mal-odour, it can be concluded that the excess sludge is well stabilized. Furthermore, the sludge settleability during the whole investigation period remained satisfactory. The sludge drying characteristics are excellent.

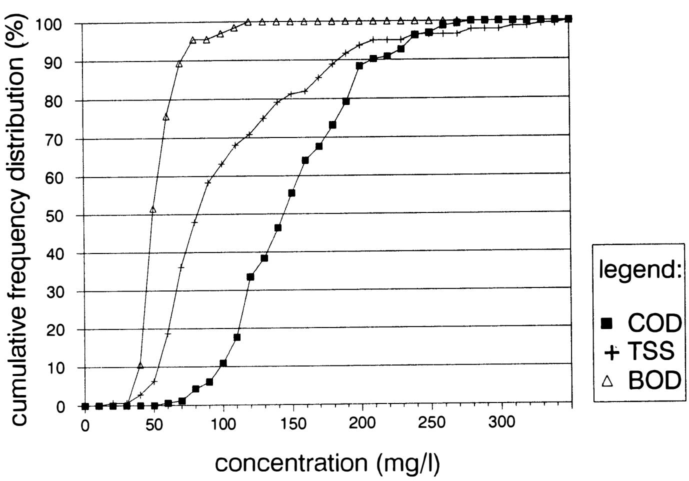

Fig. 5. Compartment number 2, cumulative frequency distribution of the effluent COD, BOD and TSS.

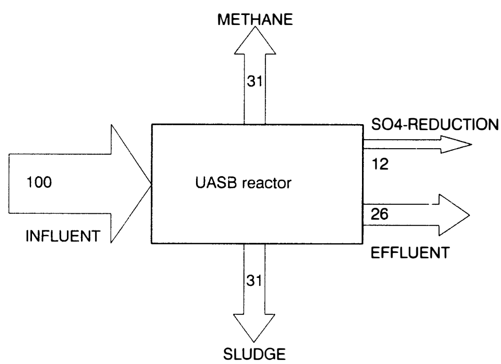

Fig. 6. COD balance of compartment number 2.

TABLE 3. Sludge characteristics.

Parameters		
Growth	(kg TSS/m3)	0.2
	(kg TSS/kg TSS in)	0.4
Sludge age	(days)	28
Ash content	(%)	60 - 70
On-site methanogenic activity	(kg COD/kg VSS.day)	0.06
Sludge methanogenic activity (lab)	(kg COD/kg VSS.day)	0.20
Stability	(ml CH4/kg VSS)	65
Chromium content	(mg Cr/kg TSS)	6700
Dewatering and drying	after six days (g TSS/kg)	300 - 500

TABLE 4. Biogas production and quality.

Parameters		
Biogas yield	(m3/kg COD rem.)	0.05 - 0.10
	(m3/m3 waste water)	0.025-0.030
H_2S	(vol. %)	0.5
CO_2	(vol. %)	5.0
CH_4 estimated	(vol. %)	75 - 80
N estimated	(vol. %)	14 - 19

There are relatively large fluctuations in COD, BOD, and TSS concentrations of the sewage as can be seen in Figures 2,3 and 4. These fluctuations are to a large extent caused by the cluster of 150 tanneries in the Jajmau area. It appeared that during the period from November up to March the tanneries are running at full production capacity, thereby discharging a considerable amount of concentrated industrial wastewater in the municipal sewer system. During other periods production in the tanneries is stopped almost completely.

Besides the COD, BOD and TSS loads, the tannery wastewater also contributes considerably to the sulphate load of the sewer system. From Figure 6, representing the COD balance, it can be seen that about 12 % of the influent COD was used for sulphate reduction. Both sulphate reducing bacteria and methane producing bacteria use volatile fatty acids as substrate. This substrate competition results in a somewhat lower biogas production.
The sulphide which is formed by reduction of sulphate is not measured in COD analyses of the UASB effluent. It is stripped as H_2S during the destruction at very low pH which is part of the COD analyses method. However, sulphide is oxidized during BOD analyses of the UASB effluent, resulting in somewhat higher BOD effluent data. This explains the only slightly higher BOD removal efficiency when compared to the COD removal efficiency, despite the fact that the UASB system is a biological system, which in general is capable of a high degree of conversion of biodegradable material.

CONCLUSIONS

1. Start-up of the UASB reactor without the use of seeding material is successful and can be achieved in a period of about 10 weeks.

2. Anaerobic treatment of sewage by using the UASB concept is feasible with satisfactory COD, BOD, and TSS reductions of respectively 74, 75, and 75 percent at a hydraulic retention time of 6 hours with respect to the prevailing conditions in India. The process stability of the system is good.

3. The compartment provided with baffles showed a better performance with respect to BOD, COD and TSS removal.

4. A density of one inlet point per 3.7 m^2 is sufficient to provide a properly distributed influent.

5. The produced excess sludge has excellent dewatering and drying characteristics and is well stabilized. Within 6 days this sludge dries on sludge drying beds and the cakes can be removed manually.

6. During winter time the treatment efficiency and process stability remains good. There occurred a temporary lower biogas production due to a lower sludge methanogenic activity for a period of about 3 weeks.

7. In order to meet the Indian discharge standards for surface water discharge post-treatment is required.

Based on the performance of the 5 mld UASB plant a 14 mld full scale UASB plant is being implemented at Mirzapur, which has a post-treatment system consisting of a pond with one day retention time.

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