International Journal of Current Engineering and Technology
E-ISSN 2277 – 4106, P-ISSN 2347 - 5161
©2014 INPRESSCO®, All Rights Reserved
Available at http://inpressco.com/category/ijcet

Research Article

Performance of UASB based Sewage Treatment Plant in India

Rinku Walia[A*], Pradeep Kumar[B] and Indu Mehrotra[B]

[A]Department of Civil Engg, Chandigarh University, Gharuan Distt Mohali -140413, India
[B] Department of Civil Engg., I.I.T. Roorkee, Roorkee- 247 667, India

Accepted 02 May 2014, Available online 01 June 2014, **Vol.4, No.3 (June 2014)**

Abstract

*In India and other developing countries, since early nineties, upflow anaerobic sludge blanket (UASB) reactors have come up in a big way for the treatment of sewage Sequence adopted: screens- grit chambers- UASB reactors followed by one-day detention pond (PP). Performance of PPs located at five STPs (27-70 ML/d) was evaluated over a period of one year from July 2004 to July 2005.The installation of these non-algal ponds reduced land requirement, but from treatment point of view it at best offered only removal of solids washed out of the UASB reactor. Total coliform count in the effluent from polishing ponds ranged from 10 ^{6} to 10 ^{9} MPN /100 mL is more than the maximum permissible limit of 10,000 MPN/100 mL (Foundation for Greentech Environmental Systems 2004)***.** *Suspended solids (SS) concentration in the effluent from polishing ponds ranged from 100 to140 mg/L which again exceeds the limit of Indian discharge standards. Effluent are devoid of oxygen and in reducing state (ORP: - 90 to -145) indicating immediate demand of O_2. The nutrient level is also high.*

Keywords: *Polishing ponds; Chemical oxygen demand; Wastewater; Anaerobic treatment*

1. Introduction

In India, where the government has felt a need to prevent pollution of its rivers and preserving natural resources, a major action plan has been formulated under which a good number of towns and cities have been identified by the National River Conservation Directorate under the Ministry of Environment & Forests (MoEF), Government of India. The objective of river action plan is to conserve the river water bodies. Within this framework, the Ganga Action Plan (GAP) was incepted and implemented in mid 80's. After the implementation of GAP in few states, Yamuna Action Plan (YAP) was formulated in early 1990 for the states of Uttar Pradesh, Haryana and Delhi where major part of Yamuna River flows.The treatment of sewage by UASB process is an attractive and appropriate option for developing countries since it involves low initial investment and low energy for operation, easier maintenance than conventional aerobic processes, and an energy recovery through the production of methane gas. However, the effluent quality from an anaerobic treatment unit in general, is not comparable with that of activated sludge process (ASP). It, therefore, indicates that the anaerobic process requires post treatment for the removal of residual organics, nutrients, and pathogens. The first ever full-scale UASB based sewage treatment plant was set-up in India at Kanpur in 1989 with a capacity of 5ML/d (Draaijer et al., 1992). Success at Kanpur led to construction of a number of UASB based STPs in north India at Saharanpur (38 ML/d), Ghaziabad (56 and 70 ML/d), Noida (27 and 34 ML/d), Yamunanagar (10 and 25 ML/d), Karnal (40ML/d), Panipat (10 and 35 ML/d), Sonipat (30ML/d), Gurgaon (30 ML/d), Faridabad (20, 45 and 50 ML/d), and Agra (78 ML/d) etc. after 2000. Sequence of treatment units is the same at all the plants i.e. screens, grit chambers, UASB reactors and polishing ponds. von Sperling et.al(2005) investigating the performance of polishing ponds treating effluents from UASB reactors inferred that the shallower pond had a higher BOD removal coefficient than deeper ponds. Sato et al. (2006) evaluated the performance of 15 full-scale UASB reactors and polishing ponds installed in India under yamuna action plan. The observations indicated that the polishing ponds were unable to produce effluent that meets the discharge standards. The limitation of the project was that they were results of one-time sampling. The objective of the present project is to find the status of polishing ponds in India and to trace the fate of pollutants.

2. Study area and sampling location

The UASB based STPs selected for present study were 27 and 34 ML/d at Noida, 56 and 70 ML/d at Gaziabad, and 38 ML/d at Saharanpur. STPs location is shown in Fig. 1 and their detail are presented in Table 1. Grab samples were collected monthly from STPs at Saharanpur (S-38 (29°58´ N, 77° 23´ E), Ghaziabad (G-70 & G-56 28° 4´N, 77° 28´ E) and Noida (N-34 & N-27 28°38´ N, 77°12´ E). A general schematic flow diagram of the combined UASB-PP (polishing pond) system with sample location

*Corresponding author **Rinku Walia** is working as Associate Professor, **Pradeep Kumar** and **Indu Mehrotra** as Professor

Table 1 UASB Based STPs: Design Parameter

Parameters	Installed capacity and locations				
	27 ML/d Noida	**34 ML/d Noida**	**38 ML/d Saharanpur**	**56 ML/d Ghaziabad**	**70 ML/d Ghaziabad**
Sample Name	N-27	N-34	S-38	G-56	G-60
Average operating capacity (ML/d)	24.7	32.1	30.4	42.3	60.3
Start of operation	April 2000	Oct. 2001	Mar. 2000	July 2002	July 2002
Design parameters					
COD (mg/L)	450	450	600	450	450
BOD (mg/L) (5 d, 20^0 C)	200	200	200	200	200
SS (mg/L)	400	400	400	400	400
Sewage temp. (^{0}C)	15	15	15	15	15
UASB reactors					
Numbers	3	4	4	4	4
Dimensions, L x W x D, (m^3) (each)	24 x 28 x6.1	24 x 24 x6.25	28 x 24 x6.05	32 x 32 x 6.10	32 x 40 x 6.38
Effective depth, (m)	5.55	5.9	5.55	5.6	5.88
Effective volume of reactors (m^3)	≈ 11200	≈ 13600	≈ 15000	≈ 23000	≈ 30000
HRT (at average flow), (h)	9.9	9.6	9.4	9.8	10.3
Polishing Ponds					
Numbers	2	2	2	2	2
Surface area, L x W, (m^2) (each)	110 x120	237.4 x55.1	12700	180 x120	190 x144
Effective depth, (m)	1.6	1.3	1.5	2	1.75
Total volume of ponds, (m^3)	42000	34000	38000	86000	96000
HRT (at average flow), (d)	1.6	1	1	1.5	1.4
Sludge drying beds					
Numbers	10	16	20	24	16
Dimensions, L x W, (m^2), (each)	385	13.4 x22.7	25 x14	30 x15	35.5 x23.6
Depth of sludge application, (m)	0.3	0.3	0.3	0.3	0.3

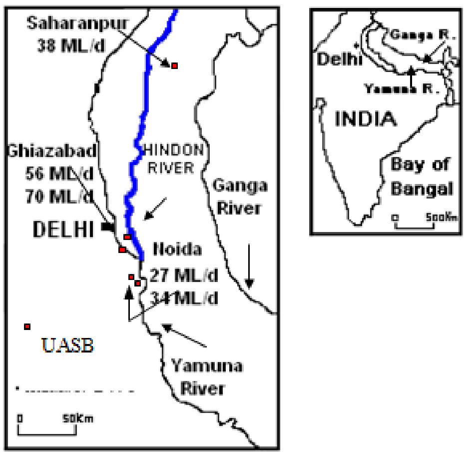


Fig. 1 Locations of investigated STPs with their treatment capacities

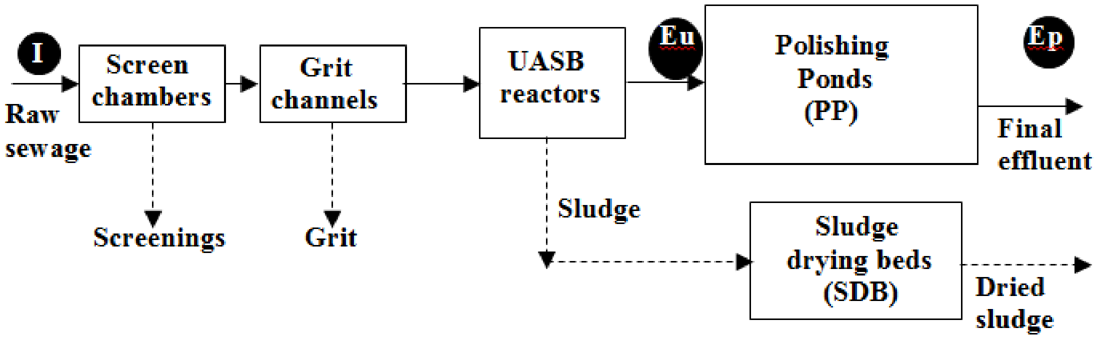


Fig. 2 Schematic flow-diagram of UASB based STP. (Sampling locations, I, Eu and Ep are shown in circles)

points are presented in Fig. 2. ORP of anaerobic samples was measured exsitu. Samples filled in the BOD bottles were monitored for ORP. Three sets of samples comprising of (i) influent (I) to UASB i.e. raw sewage, (ii) effluent (Eu) from UASB reactor, and (iii) effluent (Ep) from polishing pond (PP) were collected from each of the STPs and analyzed for COD, ORP, pH, TOC, NH_3, DO, BOD, SO_4^{2-} and S^{2-} as per Standard Methods for Water and Wastewater (APHA, 1998).

2.1 UASB Based STPs

A general schematic flow diagram of the combined UASB-PP (up-flow anaerobic sludge blanket-polishing pond) system is shown in Fig. 2. Main characteristics are summarized in Table 2. Same sequence is followed at all UASB based STPs. At STPs (S-38, G-70, G-56, N-34 and N-27) sewage reached after multistage pumping. It is primarily because of flat topography of the cities and presence of a number of water channels. At every stage, sewage is detained for a short period of time and is mixed in the sewage sump. It is finally collected at the main pumping station (MPS) just ahead of each STP. From MPS, it is pumped round the clock more or less at a uniform rate. It flows through the STP by gravity. Study was carried over a period of twenty one months (Aug. 2004 - Apr. 2006) covering different seasons. The combined (UASB-PP) systems were designed to handle 200 mg/L of influent biochemical oxygen demand (BOD, 3 day; 27 ^{0}C), and 400 mg/L of influent suspended solids (SS) for meeting the required Indian standards of 30 mg/L of BOD and 100 mg/L of SS in the final effluent. Sewage after preliminary treatment (screening and grit removal) is uniformly distributed at the bottom of UASB reactors. The UASB effluents are discharged to 1 to 1.6 day detention polishing ponds (PP) for tertiary treatment. Finally the effluents are discharged to nearby water bodies.

3. Analytical methods

The ORP was measured using an ORP electrode (Thermo Orion model) consisting of a reference electrode and a platinum band electrode built into one body. The electrode was rinsed with distilled water and calibrated with Zobells Solution before use (APHA, 1998). TOC concentration was determined by the Shimadzu TOC-5000A analyzer. Potassium phthalate and sodium carbonate/sodium bicarbonate were used as standards for the calibration of TOC and TIC respectively. DO was analyzed with Aqualytic OX 24 DO meter. The DO meter was daily calibrated with saturated air. Samples for COD, BOD and other parameters were analyzed as per Standard Method (APHA, 1998).

4. Results and discussion

4.1 Fate of pollutants in five STPs

Samples I, Eu and Ep were analyzed from five full scale UASB based STPs for COD, BOD, ORP, NH_4-N, SS, and total coliform to trace out the fate of pollutants and to assess the polishing treatment given after UASB. The histograms in Fig (3.1-3.4) give consolidated information on the characteristics of I, Eu and Ep of different STPs.

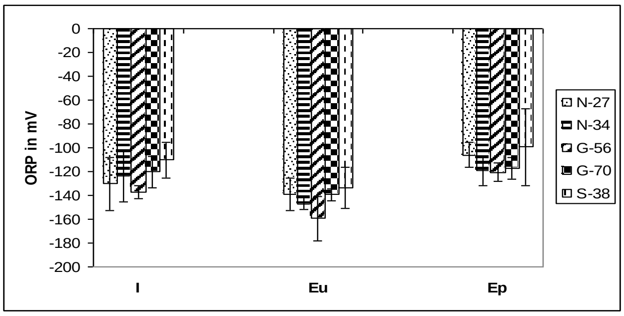


Fig. 3.1 Average ORP of i) raw sewage (I), (ii) UASB effluent (Eu) and (iii) Polishing pond effluent (Ep) for different UASB based STPs.

The ORP of the raw sewage (I) ranging from -100 to -130 mV was decreased in UASB reactor (Fig. 3.1). The DO was found to be zero. Samples having ORP ≤ 50 mV are devoid of DO. DO value equal to zero does not define the reductive capacity of the sample. The same however can possibly be described by ORP. The ORP of the Eu varied from to -130 to -160 mV. Even after detention in ponds for 1 to 1.6 days ORP remained between -100 to -120 mV i.e. on exposure to air, the increase in ORP was marginal. Such a wastewater is likely to exert an immediate oxygen demand (IOD) on the receiving water body and disturb aquatic ecosystem of the river water. The immediate oxygen demand may be due to the presence of reducing agents such as S^{2-} or Fe^{2+}. According to the Indian guidelines the DO of the river water should not fall below 4 mg/L after the disposal of effluents. DO however remain zero in the polishing ponds. Anaerobic system becomes aerobic when the condition defined by the Eq. (1) is satisfied i.e.

Reaeration > Deoxygenation

$$k_a \text{ Deficit} > k_b \text{ BOD} \quad (1)$$

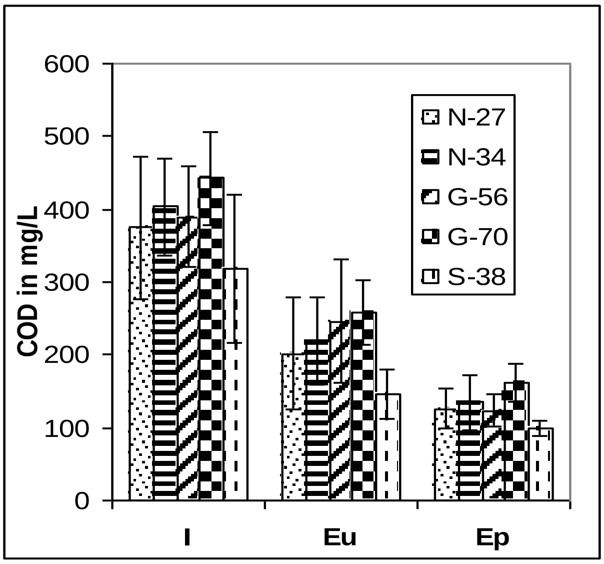
$$\text{Deficit} = \text{DOs-DO}$$

$$\text{or} \quad \text{BOD} = \frac{k_a}{k_b}\text{DOs};(\text{DO}=0 \text{ in PPs}) \quad (2)$$

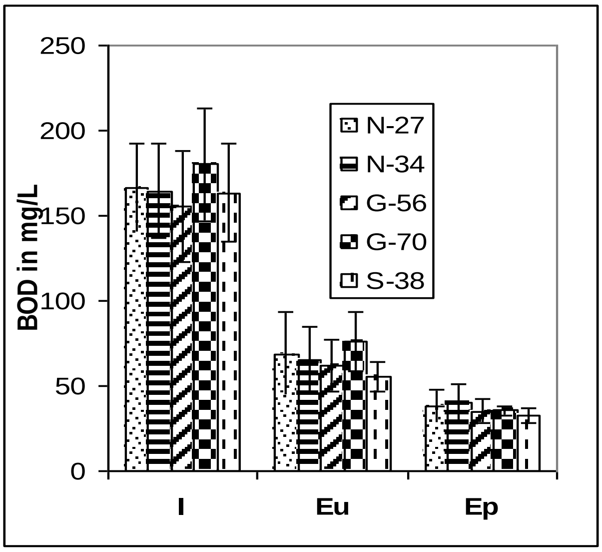
where

k_a & k_b are the rate constant for reaeration and BOD exertion (river deoxygenation constant) in time^{-1} (Thomann & Mueller, 1987).

At a given temperature DOs is constant and the ratio of k_a/k_b depends on the nature of water body and oxygen demanding waste. For ponds and sluggish water bodies the k_a is 0.1 d^{-1} whereas k_b is 0.1 to 0.3 d^{-1} for domestic wastewater (Davis and Cornwell, 1991). Implying that polishing ponds will be aerobic only if BOD is reduced considerably i.e reduced BOD ≤ DOs i.e. ~9 mg/L .The other alternative is to increase the ratio of k_a to k_b by mechanical aeration, the system would be aerobic even at higher BOD.



(a)



(b)

Fig. 3.2 (a-b) Average COD and BOD of i) raw sewage (I), (ii) UASB effluent (Eu) and (iii) Polishing pond effluent (Ep) for different UASB based STPs.

The COD and BOD concentration after UASB ranged from 145-250 mg/L and 55-75 mg/L respectively [Fig. 3.2 (a-b)]. COD of Ep ranged from 100 to 160 mg/L. The removal of BOD and COD in UASB reactors was ~ 60 and 45% respectively. BOD removal was inferior as compared with 72% at Kanpur STP (Draaijer et al. 1992), and 63% at Mirzapur STP (Hammad 1996), which served as the model for constructing the fifteen STPs. The concentration of sulphates and sulfides in sewage has been found to vary from 40 to 367 mg/L and 1 to 31 mg/L respectively. The reasons for low efficiency can be due to high fraction of particulate COD (30 to 60%); COD consumed in sulfate reduction and due to incorporation of industrial wastewater into the municipal sewage. The removal of BOD, however in polishing ponds was ~ 40-50 % i.e the BOD of Ep (32-40 mg/L) is high enough to render it aerobic (Eq. 2). In about 50 % of the data, BOD of the final effluent i.e Ep was above 40 mg/L which is not in compliance with the discharge limit of 30 mg/L prescribed by Indian Standards. This could be due to several reasons. According to Sato et al. (2006) it is due to the incorporation of industrial wastewater into the municipal sewage. The other reason is that the effluent from UASB as well as polishing ponds is having negative ORP. The inherent anaerobicity of wastewater is still there even after 1 to 1.6 day detention in polishing ponds. The anaerobicity can be removed by simple aeration (Arceivala 1999).

The BOD analyzed after UASB can be considered as superficial BOD as it is the sum of actual carbonaceous BOD and immediate oxygen demand (which is created due to reducing environment measured as –ve ORP). Draaijer et al. (1992) also observed somewhat higher BOD and this was attributed to sulphide in the UASB effluent, which was oxidized during BOD analysis, resulting in higher BOD.

The TSS concentration in the polishing ponds varied from 100 to 140 mg/L (Fig.3.3). The TSS removal ranged from 34-48 % in UASB reactor and polishing ponds. High concentrations of SS in the Eu are largely due to the washout of sludge. Sludge washout is generally as a result of too much sludge being accumulated in the reactor, low temperature, a high flow velocity, vigorous gas production, and other factors. The periodic desludging of the excess sludge from UASB reactors can improve the quality of Eu. This would also reduce accumulation in PP eventually improving the quality of Ep.

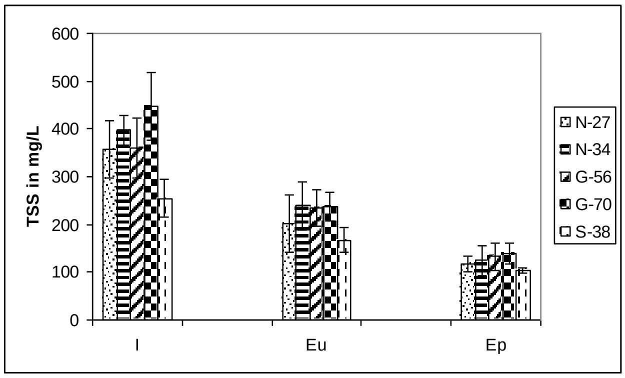
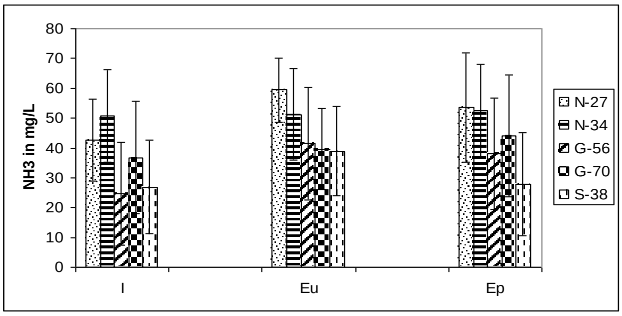
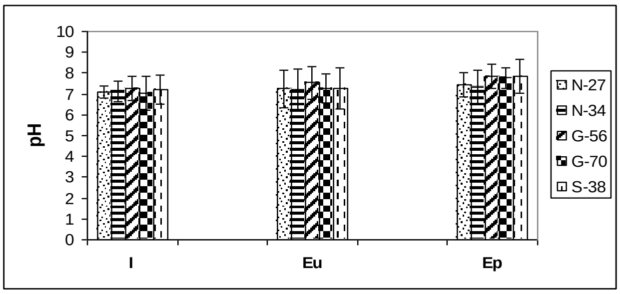


Fig 3.3 Average TSS of i) raw sewage (I), (ii) UASB effluent (Eu) and (iii) Polishing pond effluent (Ep) for different UASB based STPs.

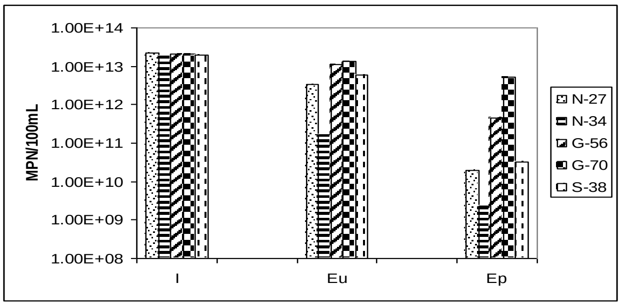
The ammonia concentration in different STPs is presented in Fig. 3.4(a). The nutrient removal in the polishing ponds can proceed through physical and chemical processes, governing factor being pH. At pH values exceeding 9, ammonia predominates in the gaseous (NH_3) form and thus nitrogen is removed by ammonia desorption. At high pH, considerable removal of phosphate can also be achieved due to the formation of poorly soluble phosphates that can precipitate, e.g. apatite. Data collected over a period of one year indicates ammonia removal ranging from 0-9%. pH of the polishing ponds Ep ranged from 7.3 to 7.85 (Fig.3.4 b) and nitrate was also found to be low. The observation was in line with the facts found by Sato et al. (2006). It, therefore, implies that neither the ammonia stripping nor the nitrification takes place in polishing ponds. There is no energy input for turbulence and consequently there is no reareation of wastewater in the PP. Reaeration through algal growth or photosynthesis is also not facilitated for a simple reason that a minimum of 3 days detention is required for algal growth (Bal and Dhagat 2001). The hydrolysis of organic nitrogen apparently controlled the concentration of ammonia in the PP rather than the removal of ammonia by algae, ammonia stripping or nitrification.



(a)



(b)



(c)

Fig. 3.4 (a-c) Average ammonia, pH and Total coliform of (i) raw sewage (I), (ii) UASB effluent (Eu) and (iii) Polishing pond effluent (Ep) for different UASB based STPs.

Unlike, activated sludge and oxidation pond process, the reduction of MPN coliform is insignificant in UASB. MPN concentration in different STPs is presented in Fig. (3.4c). MPN in polishing pond effluents ranging from $5X10^3$ to $24X10^{12}$ is more than the maximum permissible limit of $10X10^3$ MPN/100 mL. According to Pearson et al. (1987) at a pH value of 9 or more, FC die-off in WSPs is accelerated; and other parameters such as light, temperature and susceptibility to toxic substances may also act synergistically with pH. Von Sperling et al. **(**2005) concluded that the removal of E coli and helminth eggs in UASB- polishing pond systems in Brazil is due to high DO and pH which in turn are due to intense photosynthetic activity. The effluent Ep from polishing ponds was devoid of DO and anaerobic in nature (as indicated by negative ORP values). Post treatment provides in polishing ponds of one day detention are not meeting the required standards. Out of these, the regulation regarding indicator organism (faecal matter) is considered to be the most serious as it has emerged recently apart from sustainability, monitoring and O&M issues. Besides the typical quality parameters of BOD, suspended solids and DO which have a direct impact on the quality of receiving water body/environment, the pathogens are known to have a direct impact on the public health. The intestinal pathogens and coliform are obligate anaerobes and unlike in an activated sludge plant, their die off rate in UASB environment is low.

Recognizing this aspect and in view of wider application of the anaerobic technology, the Ministry of Environment and Forests has proposed inclusion of Faecal Coliform as one of the quality parameters in the national discharge standards for STP effluents. The suggested desirable and maximum permissible limits for Faecal Coliform are 1000 and 10,000 MPN/100 ml respectively. However, adequate post-treatment removing faecal matter and residual organic & solids load has always been an issue, which needs to be attended. Other post-treatment options like constructed wetlands, newly developed attached growth aerobic system, lagoons are to be investigated for their suitability after UASB. Institutional strengthening and involvement of local urban minor bodies for the operation of assets is another important issue. The engineers of Jal Sansthans (operating agencies under YAP) have little prior experience or knowledge of the STPs created under the project. The agencies are plagued by institutional and financial crisis, barely managing the current services. There was a need for comprehensive and systematic training for specific target groups under YAP.

4.2 Correlation of ORP with other Parameters

Oxidation-reduction potential (ORP) of a particular system depends on the ratio of the concentration of oxidant to the reductants. Carbon of organics acts as electron donor as well as electron acceptor. Reduction in COD is via biotransformation of organics to methane or methane COD. The anaerobic zone represents conditions where SO_4^{2-} is reduced to sulfide and organic material is reduced to CH_4 . The variation of sulphate, sulfide and ORP is graphically presented in Fig. 4. Sulphate reduction and sulfide increase was observed in all STPs. During anaerobic biodegradation in UASB reactor organic matter and sulphate are converted to methane and sulphide respectively. Methane producers have been found to be competitive at COD/SO_4^{2-} ratio of 1.7 to 2.7 (Choi and Rim, 1991). The dissolved sulphide in the effluent has an immediate oxygen demand at the rate of 2 g of oxygen (O_2) per g of sulphide. The concentration of sulphates and sulfides in sewage has been found to vary from 40 to 367 mg/L and 1 to 31 mg/L respectively. Sulphates reduced in UASB and marginally increased or decreased in PP. The sulphides or bisulphides of Eu are reduced in Ep. The sulphide reduction in PP can be due to oxidation of sulphide to sulphate. At pH ranging from 7.0 to 7.85, S^{2-}exists as HS^- and H_2S. H_2S can escape during the fall of Eu into PP. If H_2S or $S^{2-}$is oxidized to SO_4^{2-}then the sulphate concentration should increase in Ep. The increase in sulphate has been observed in N-27 and S-38. The stripping of H_2S appears more probable than oxidation. The escape of sulphide will reduce COD; whereas sulphides in Eu will demand oxygen.

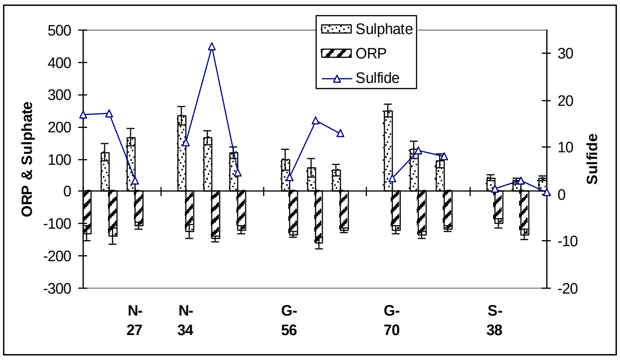


Fig. 4 Variation of ORP, Sulphate and Sulfide

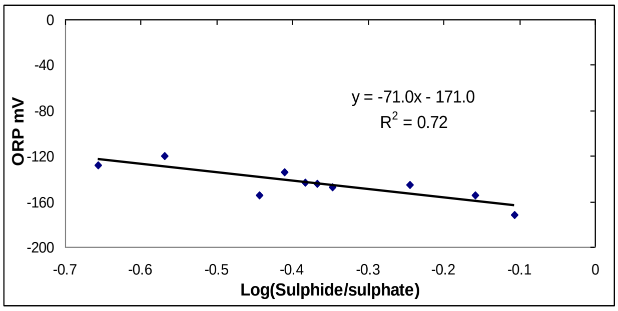


Fig. 5 Variation of ORP with the ratio of sulphide and sulphate

An attempt has been made to correlate ORP with Log SO_4^{2-}/S^{2-} system (Fig.5). In UASB, SO_4^{2-} is an electron acceptor and organics are electron donor [Eq.3.1-3.2], where as in case of PP, S^{2-} is electron donor and oxygen is an electron acceptor [Eq. 4.1-4.2]. The intercept E^o of -171 mV has been taken as an empirical constant for $SO_4{}^{2-}/S^{2-}$ redox reactions in both UASB and PP. The value however is more close to the standard potential given by Eq. 3.3 than Eq. 4.3. It further suggests that H_2S is desorbed rather than oxidized.

E^o

$$\frac{1}{4}CH_2O+\frac{1}{4}H_2O \Rightarrow \frac{1}{4}CO_2 + H^+ + e^- \quad (-433mV) \qquad (3.1)$$

$$\frac{1}{8}SO_4{}^{2-} + \frac{9}{8}H^+ + e^- \Rightarrow \frac{1}{8}HS^- + \frac{1}{2}H_2O \quad (220mV) \qquad (3.2)$$

Overall reaction

$$\frac{1}{4}CH_2O + \frac{1}{8}SO_4^{2-} + \frac{9}{8}H^+ \Rightarrow \frac{1}{4}CO_2 + \frac{1}{8}HS^- + \frac{1}{2}H_2O \quad (-213mV) \qquad (3.3)$$

$$\frac{1}{8}HS^- + \frac{1}{2}H_2O \Rightarrow \frac{1}{8}SO_4^{2-} + \frac{9}{8}H^+ + e^- \ (-220mV) \qquad (4.1)$$

Overall reaction

$$\frac{1}{8}HS^- + \frac{1}{4}O_2 \Rightarrow \frac{1}{8}SO_4^{2} + \frac{1}{8}H^+ \quad (590mV) \qquad (4.3)$$

Conclusions

The effluent Ep from polishing pond with one-day detention was unable to meet effluent discharge standard of 30 mg/L of BOD_3 at 27°c. The BOD varied from 30 to 45 mg/L and Total coliform ranged from 10^6 to 10^9 MPN/100 mL. ORP & COD were found to vary from -100 to -160 mV and 95 to 450 mg/L respectively. Suspended solids (SS) concentration in polishing ponds ranged from 100 to140 mg/L.BOD can't be reduced to 30 mg/L in the polishing ponds because of the immediate oxygen demand or the negative ORP. The system would be aerobic only by increasing the ratio of k_a to k_b by mechanical aeration. The ORP of –100 to –160 mV found in UASB and polishing ponds is more close to the system where SO_4^{2-} is an electron acceptor and organics are electron donor.

References

APHA (1998), Standard methods for the examination of water and wastewater, 20th edition, American Public health association, Washington, DC.

Arceivala,S.J. (1999), Wastewater Treatment for pollution control, 2nd edition, Tata Mcgraw-Hill, New Delhi .

Bal, A.S and **.**Dhagat, N.N (2001)**,** Up flow Anaerobic sludge blanket reactor- A Review, *Indian J. Environ Health.*, Vol. 43,pp 1-83.

Choi, E. and Rim, J.M. (1991), Competition and inhibition of sulfate reducers and methane producers in anaerobic treatment , *Water Sci. Technol*., Vol.23,pp 1259-1264.

Davis, M.L and.Cornwell, D.A. (1991), Introduction to environmental Engineering, 2nd edition, Mc Graw-Hill, New York,.

Draaijer, H., Maas, J.A.W. , Schaapman, J.E.and Khan, A. (1992) , Performance of the 5 MLD UASB reactor for sewage treatment at Kanpur, India, *Water Sci. Technol.*, Vol. 25, pp123-133.

Foundation for Greentech Environmental Systems (2004), Case study on sewage treatment plants and low-cost sanitation under River action plans. New Delhi.

Hammad, S.M. (1996), Performance of a full scale UASB domestic wastewater treatment plant. *J. Inst. Public Health Eng. India*, 1, pp11-19.

Pearson, H.W., Mara, D.D., Mills, S.W. and Smallman, D.J. (1987), Physico-chemical parameters influencing faecal bacterial survival in waste stabilization ponds, *Water Sci. Technol.* ,31, pp129-139.

Sato, N., Okubo, T., Onodera, T., Ohashi, A.and Harada, H. (2006), Prospects for a self-sustainable sewage treatment system. A case study on full-scale UASB system in India's Yamuna River Basin, *Journal of Environmental Management*, Vol. 80, pp 198-207.

Thomann, R.V. and .Mueller, J.A (1987), Principles of Surface water Quality Modeling and Control, Harper and Row, Publishers, INC,.

Von Sperling , M., Bastos, R.K.X and. Kato, M.T (2005), Removal of E. coli and helminth eggs in UASB: polishing pond systems in Brazil, *Water Sci. Technol*., Vol. 51,pp 91-97.