Performance Evaluation & Upgradation of UASB Technology used for the Treatment of Sewage Generated from Lucknow City

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Abstract— Over the recent years, sewage treatment is becoming an issue of paramount importance for cities and towns as governments are not only giving emphasis to treat wastewater in order to protect their resources but also paying stress to the concept of reuse & recycling of waste waters to reduce burden on fresh water resources. During the past few decades, several new sewage treatment technologies have been developed and are being adopted in many developing countries particularly in India. In the current scenario in India, the treatment issue is dominant and receiving due attention these days. However, public authorities have to think twice before making substantial investments where environmental issues could not be given priority due to financial constraints. Therefore this study is therefore performed with a key objective to evaluate the working performance of 345 MLD Upflow Anaerobic Sludge Blanket (UASB) technology based plant at Bharwara, Gomti Nagar Lucknow by analyzing the physico-chemical parameters to perform design analysis of water treated through UASB technology. The study also tries to upgrade the UASB technology by suggesting recommendations for efficient management of waste water reaching the inland water bodies through daily generated municipal sewage.

Key words: UASB, Sewage, Performance Evaluation, Dechlorination, Lucknow, India

I. Introduction

Sewage treatment is not a new proposition. Throughout history people have devised systems to make getting and using water more conveniently. Nevertheless, it was not until the late 19th century that it became possible to treat the sewage by chemically breaking it down through the use of microorganisms and removing the pollutants. During the past two decades UASB technology is being adopted in many developing countries particularly in the South-East Asian region including India. The UASB process was developed by Gatze Lettinga in the late 1970's at the Wageningen University (The Netherlands). The concept was born out of the recognition that inert support material for biomass attachment was not necessary to retain high levels of active sludge in the reactor. The main features for achieving granular sludge development was to maintain an upward-flow regime in the reactor selecting for microorganisms that aggregate and secondly to provide for adequate separation of solids, liquid and gas, preventing washout of sludge granules.

UASB reactor units are constructed out of concrete or other watertight material that can be designed in a circular or rectangular way. It has no special media since the sludge granules themselves act as the 'media' and stay in suspension. In UASB technology wastewater is pumped from the bottom into the reactor where influent suspended solids and bacterial activity and growth lead to the formation of sludge. The sludge blanket is comprised of microbial granules (1 to 3 mm in diameter), i.e., small agglomerations of microorganisms that, because of their weight, resist being washed out in the upflow. The microorganisms in the sludge layer degrade organic compounds. As a result, gases (methane and carbon dioxide i.e. biogas) are released. The rising bubbles mix the sludge without the assistance of any mechanical parts. Upstream velocity and settling speed of the sludge is in equilibrium and forms a locally rather stable, but suspended sludge blanket. Sloped walls deflect material that reaches the top of the tank downwards. The clarified effluent is extracted from the top of the tank in an area above the sloped walls. A gas-liquid-solids separator (GLSS) separates the gas from the treated wastewater and the sludge. After several weeks of use, larger granules of sludge form which, in turn, act as filters for smaller particles as the effluent rises through the cushion of sludge. Because of the upflow regime, granule-forming organisms are preferentially accumulated as the others are washed out. A high solid retention time (SRT) of 30-50 or more days occurs within the unit. No mixers or aerators are required. The gas produced can be collected and used if desired. Anaerobic systems function satisfactorily when temperatures inside the reactor are above 18-20°C. Excess sludge is removed from time to time through a separate pipe and sent to a simple sand bed for drying.

II. Site Analysis

The present study is concentrated at latitude-longitude extent of 26.85°N and 80.92°E which includes the location of UASB Bharwara Sewage Treatment plant Gomti Nagar, Lucknow. The plant receives sewage from total Trans-Gomti side including Indira Nagar, Gomti Nagar and Sitapur road areas conveying sewage which is sanctioned under Gomti Action Plan Phase-II. It has the Capacity to treat 345 MLD waste water through length of trunk and branch sewer lines of around 860 km. The whole Sewerage network of Lucknow city comprises 26 major drains which used to directly drain the raw sewage into the Gomti before these STPs came up. Out of these 26 drains 22 have been proposed to be directed to the Bharwara STP.

The Bharwara UASB reactor is a methanogenic digester which is evolved from the anaerobic clarigester. It uses an anaerobic process whilst forming a blanket of granular sludge which suspends in the tank. Wastewater flows upwards through the blanket and is degraded by the anaerobic microorganisms. The upward flow combined with the settling action of gravity suspends the blanket with the aid of flocculants. The blanket begins to reach maturity at around 2 months. Small sludge granules begin to form whose surface area is covered in aggregations of bacteria. In the absence of any support matrix, the flow conditions create a selective environment in which only those microorganisms, capable of attaching to each other, survive and proliferate. Eventually the aggregates form into dense compact biofilms referred to as "granules". The summarized detail of the plant is being given in table 1.

S. No.	UNITS	No.	DIMENSION
1.	Inlet Chamber	1	20mx9mx4m SWD
2.	No. of stream proposed	3	115 mld capacity each
3.	Distribution Chamber	3	8.8mx7.5mx2m SWD
4.	Screen (mechanical)	6	2 nos for each stream+1 standby
		+3 standby	6mx1.8mx1m SWD
	(manual standby)	3	1 no. for each stream 6mx2.8mx8m SWD
5.	Grit chamber(mechanical)	6	2nos working for each stream
	(manual standby 50%)	3	1 no for each stream divided in 2 channels of 9.5mx4.6mx7m SWD
6.	Parshall Flume	3no	1 for each stream 10mx1.5mx1.5m SWD
7.	Division box	3 no	12.8mx2.5mx2.25m SWD
8.	Division Box 2A	12 no	4 no for each stream 6.85mx2mx2.25m SWD
	Division Box 2B	60 nos	20 nos for each stream 3.6mx1.5mx1m SWD
9.	No. of UASB reactor 11.50 mld capacity each	30 nos	32mx28mx4.6m SWD (2 sets of 5 reactor in each stream)
10.	Feed pipe(75 mm dia) HDPE	6720 pipes	224 pipes/reactor(4 sqm. Per pipe)
11.	HRT at average flow		8.5 hrs
12.	HRT at peak flow		5.6 hrs
13.	SRT		35 days
14.	Gas holder	3.Nos	17.5m SWD & 3.50m SWD
15A	Pre aeration tank	3 nos	29.6x13.5x3 SWD
B	Surface aerators in pre aeration tank	6nos	2nos of 30 HP in each stream(fixed type)
16A	Polishing pond compartment	3 nos	1 no for each stream140mx140mx3m SWD
B	Floating aerator for compartment no. 1	18 Nos	6 nos surface aerator of 50 HP for each stream
17.	Polishing pond compartment no 2	3 nos	550mx140mx1.5m SWD
18.	Chlorine contact tank	3 nos	60mx20mx2m SWD
19.	Chlorination	3 nos	50kg/hr Booster pump 20 m^3/hr@6kg/cm^2
20.	Sludge Concentration		65 kg/m^3
21.	Total sludge generation(wet)		1812m^3/day
22.	Total sludge generation (dry)		100 tonnes/day
23.	Sludge sump	3 nos	1no. for each stream 9.85mx6.80mx1.0m SWD
24.	Sludge pump	18 nos (9W+9S)	68m3/hr at 35m head
25.	Sludge drying beds	106 nos	27mx27m
26.	Sludge cycle		10 days
27.	Filtrate water sump	2 nos	10mx7.5mx1.0m SWD
28.	Filterate water pump	4 nos	40m^3/hr.18m head
29.	Total power requirement of STP		1500 KVA
30.	Effluent pipe	1500m	2400mm dia RCC Pipe
31.	Dual fuel engine for bio gas utilization	2 nos	850 KVA each
32.	Gas flaring system	2 nos	Aspiration type pre mixing burner 6 m above GL.
33.	Estimated cost of work		
	(a)	Original	Rs.10422. lacs
	(b)	Revised	Rs.16971. lacs

Table 1: Summarized details of the Bharwara UASB plant

III. REVIEW OF LITERATURE

An extensive literature review was carried out by referring standard journals, reference books and conference proceedings. The major work carried out by different researchers can summarized as follows:

Abhishek Koul and Siby John (2015)[1] study presents a life cycle cost based approach to evaluate the performance of the treatment plants based on UASBR, SBR and MBBR, operating under similar conditions. In the study, attempt was made to generate a rational basis for comparison of STPs based on SBR, UASBR and MBBR.

Hina Rizvi et *al* (2015)[2] studied the upflow anaerobic sludge blanket reactors seeded with cow dung manure (UASBCD) and activated sludge of a dairy wastewater treatment plant (UASBASDIT) to treat raw domestic wastewater of medium strength. The study found that the UASBCD reactor required a period of 120 days to start up and UASBASDIT reactor, sludge bed was stabilized in a period of 80 days.

Abdur Rahman Quaff, Sisir Mondal and Ashish Tiwari (2014)[3] carried out a review on development of anaerobic process and technology, involved for the treatment of domestic wastewater. The study highlighted the ability of small, UASB systems for increased use in the urban environment. Two main reasons behind the importance of this were generation of large volume of low-strength wastewaters, which are often disposed untreated due to high costs, and the potential of stabilizing the organic wastes by producing valuable energy byproduct.

Z. A. Bhatti, F. Maqbool, A. H. Malik and Q. Mehmood (2014)[4] studied to shorten the start-up time of up-flow anaerobic sludge blanket (UASB) reactor. In this study two different nutrients were used during the UASB start-up period, which was designed to decrease the hydraulic retention time (HRT) from 48 to 24 and 12 to 6 hrs at average temperatures of 25-34 ^{0}C. In the first stage, start-up was with glucose for 14 days and then the reactor was also fed with macro- and micronutrients as a synthetic nutrient influent (SNI) from 15 to 45 days as the second stage. The removal efficiencies of the chemical oxygen demand (COD) were 80% and 98% on the 6th and 32nd day of the first and second stage, respectively.

K.Kaviyarasan (2014)[5] studied the performance of UASB (Upflow Anaerobic Sludge Blanket) reactor for treating various industrial and domestic wastewaters at various operating conditions. The study found that the UASB reactors can be conveniently used for the treatment of tannery, distillery, food processing, metal mining, dairy, domestic wastewater etc. The performance of the reactor mainly depends on the OLR and HRT.

Abid Ali Khan et *al* (2014)[6] studied up flow anaerobic sludge blanket (UASB) based sewage treatment plants (STPs) of different cities of India. The study highlighted that presently 37 UASB based STPs were under operation and about 06 UASB based STPs are under construction and commissioning phase at different towns. The nature of sewage significantly varied at each STP.

Massimo Raboni, Renato Gavasci, and Giordano Urbini (2014)[7] conducted an experimental process designed for the treatment of the sewage generated by a rural community located in the north-east of Brazil. The process consists of a preliminary mechanical treatment adopting coarse screens and grit traps, followed by a biological treatment in a UASB reactor and a sub-surface horizontal flow phytodepuration step. The use of a UASB reactor equipped with a top cover, as well as of the phytodepuration process employing a porous medium, showed to present important health advantages..

Sandeep Kumar Gautam et *al* (2013)[8] carried out a conventional kind of monitoring study. The objective of the study was to assess and monitor the physicochemical parameters in wastewater at inlet and outlet of sewage treatment plant (STP) and also to study the effectiveness of the STPs.

Charu Sharma, S.K Singh (2013)[9] carried out evaluation for the techno-economical and environmental performance of STP based on advanced aerobic BIOFOR technology located in Delhi for handling and treating the domestic wastewater. The parameters which were monitored under the study included pH, Total Suspended Solids (TSS), Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Mixed Liquor Suspended Solids (MLSS), Total Coliform (TC) and Fecal Coliform (FC).

Mrunalini M. Powar et *al* (2013)[10] study found that UASB reactor is feasible for treating variety of wastewater and performance of UASB reactor gets affected by pH, HRT, OLR, temperature and volatile fatty acids (VFA) to alkalinity ratio. The study recommended that proper HRT should be provided to give sufficient contact time between wastewater and bacteria. For avoiding VFA accumulation in UASB reactor and for getting effective biogas production sodium bicarbonate alkalinity should be provided. VFA to alkalinity ratio should maintained between 0.5 - 0.8 for good performance of UASB reactor.

Mansi Tripathi and S. K. Singal (2013)[11] conducted a study to evaluate the performance of existing sewage treatment plants (STPs) in Lucknow City of India. In this study two approaches, evaluating the treatability performance and Life-Cycle Assessment (LCA) have been used to determine the plants efficiencies in the study. All the results have been interpreted graphically. The results of this study concluded that the UASB reactor is better than the FAB, however in terms of LCA the FAB seems to be more reliable.

Gangesh Kumar Kasaudhan *et* al (2013)[12] work is concerned with the detailed study of Asia's largest sewage treatment plant of 345 MLD capacity (based on Up flow Anaerobic Sludge Blanket reactor), installed at Bharwara, Lucknow, Uttar Pradesh, India. The design analysis of the sewage treatment plant has been carried out to comment on the adequacy of design and capacity.

R. Thenmozhi and R.N. Uma (2012)[13] studied the different treatment for waste water. The study designed a hybrid UASB rector involving both suspended and attached growth process by changing retention time in day for particular organic loading rate. The study found that this method effectively removed the BOD, COD and other parameters because of both suspended and attached growth process.

M.I. Sudasinghe, L.W. Galagedara and E.R.N. Gunawardena (2011)[14] carried out a study to evaluate the performances of eight STPs representing different locations and management organizations such as government, private sector and community and to investigate the reasons for their performance. The methodology included a checklist survey with 109 performance criteria under five categories such as general, technical, physical, personnel and operational and maintenance, complemented by focus group discussion, formal and informal discussion and stakeholder interviews. The results showed that only two out of eight STPs studied performed well.

Takahashi, M. et *al* (2011)[15] investigated the treatment characteristics and sludge properties of an upflow anaerobic sludge blanket (UASB) process using a pilot-scale 1.15 m^3reactor. In this study the UASB, inoculated with digester sludge, was operated at a hydraulic retention time of 8 h at sewage with temperatures ranging from 10.6 to 27.7^{0}C for more than 1100 days. The study observed that the stable removal efficiencies for total CODCr and SS were 63 ± 13% and 66 ± 20%, respectively.

S.A. Habeeb et *al* (2011)[16] studied the up-flow anaerobic sludge bed UASB operation as well as the main parts of the reactor. The study specifically explained the correlations and compositions of sludge granule and believed that the extracellular polymer (ECP) is totally responsible of bacterial cell correlations and the formation of bacterial communities in the form of granules.

Sunny Aiyuk et *al* (2010)[17] study was conducted to find the performance and stability of a domestic sewage treatment system consisting of an upflow anaerobic sludge blanket (UASB) reactor. This study came up with a technical evaluation of using such a system to treat directly such wastewater containing high amounts of suspended solids (SS) in developing countries like Lesotho.

Nadeem Khalil, Rajiv Sinha, A K Raghav, A K Mittal (2008)[18] studied the overall implications of UASB technology in India. In this study institutional and technical aspects with special reference to the Yamuna Action Plan (YAP) were presented. It also presents the potential of UASB technology in other developing countries with its future within India as well based on the evaluation of life cycle cost (LCC).

P. Sankar Ganesh et *al* (2007)[19] studied the suitability of UASB reactors in treating low-strength (< 2000 mg/L COD) industrial wastewaters in general and dairy industry wash water in particular. The study found that the consistency of reactor performance even when COD loading is changed quickly over a wide range of values indicates the robustness of the system. The reactors appear capable of treating the wash waters with a high degree of consistency even when the influent strength may vary due to across-the-week flow variations and shock loads.

Baisali Sarkar et *al* (2006)[20] studied the dairy waste water by adsorption, coagulation and membrane separation process. In this study pretreatment was done by different coagulant as a organic, inorganic and polymeric. Coagulant method was done at various pH by using different dosage of coagulants which is continuously followed by activated charcoal treatment. Wastewater was then passed through cross flow reverse osmosis membrane system. The results revealed that colour and odour were are permanently removed and organic matter effectively removed.

A. Mirsepasi et *al* (2006)[21] studied two full-scale UASB reactors were investigated. Volume of each reactor was 420 m^3. Conventional parameters such as pH, temperature and efficiency of COD, BOD, TOC removal in each reactor were investigated. Also several initial parameters in designing and operating of UASB reactors, such as upflow velocity, organic loading rate (OLR) and hydraulic retention time were investigated.

A.A.Azimi and M.Zamanzadeh et *al* (2004)[22] studied UASB reactor for treating waste water in tropical regions. In this study two different temperatures of waste water were carried out at ambient temperature. It was observed that in colder period BOD_5, COD and TSS removal efficiency were 54, 46, 53% respectively and in warmer period it is about 71, 63 and 65% respectively.

Catherine N. Mulligani and Bernard F. Gibbs (2003)[23] study found that biological treatment of wastewater has been engaged successfully for numerous types of industries. Aerobic processes have been used expansively. However, large production of sludge is the main problem and methods such as bio filters and membrane bioreactors are being developed to combat this occurrence.

Nidal Mahmoud et *al* (2003)[24] studied different potential methods for waste water treatment and sludge stabilization including UASB in tropical countries. The study analyzed the performance of one stage UASB reactor comparing with UASB digester system for low temperature i.e 15^0 C at a HRT of 6 Hours. The study come across that UASB digester provide better separation efficiency and conversion than the one stage reactor and whatever sludge produced in UASB reactor is much more stabilized.

A.G. Brito et *al* (1997)[25] studied the UASB reactor for low strength of wastewater. The study analyzed the UASB for glucose base wastewater degraded by acidogenic bacteria in which common granular structure could not be observed. The study found that UASB process removed about 90 % glucose during the pre-acidification of the wastewater and enhanced the granulation process.

L. Florencio et *al* (1995)[25] evaluated the effect of methanol concentration and inorganic carbon on the competition between acetogens and methanogens for methanol. In this study eight upflow anaerobic sludge blanket reactors were operated continuously with different levels of sodium bicarbonate at variable methanol loadings.

Jules B. van Lier et *al* (1993)[27] studied the UASB reactor on the basis of thermophilic high- rate system. The study aimed to find result by effect of temperature on the conversion rate of volatile fatty acid (VFA) by thermophilic methanogenic sludge grown under different condition.

Erik Ten Brummerler et *al* (1985)[28] developed an UASB reactor by raising sludge retention time by natural immobilization to find out high rate anaerobic digestion phenomenon for upflow anaerobic sludge blanket reactor. The study observed that high-rate anaerobic digestion can be applied in upflow anaerobic sludge blanket reactors for the treatment of various wastewaters.

IV. METHODOLOGY

To evaluate the performance of UASB plant physico-chemical parameters of temperature, pH, biochemical oxygen demand (BOD_5), chemical oxygen demand (COD) and total suspended solids (TSS) of the inlet and outlet points of the treatment units were selected and analyzed for conformity with the standard values. Consequently, the design analysis of Volumetric hydraulic loading (VHL), Organic loading rate (OLR), Upflow velocity and removal efficiencies of biochemical oxygen demand (BOD_5) and chemical oxygen demand (COD) through empirical equations were calculated to compare the values obtained to check for variation in the actual values obtained through tests.

V. DATA COLLECTION AND ANALYSIS

The samples were collected at inlet and outlet points of the treatment units and analyzed as outlined in the standard methods for the examination of water and wastewater (APHA, 1999).**[29]** The samples were collected in plastic sample bottles of 500 ml each and rinsed with the effluent water at the sampling points. Inlet samples consisted of raw waste water entering the UASB plant through the inlet chamber while the outlet water consisted of treated water from the plant which is being released into the Gomti River.

Both ambient air temperature and wastewater temperature of the sewage were recorded at the time of sampling.

The samples were mostly collected between 10:30 AM and 11:20 AM. The parameters of influent and effluent were monitored two times every month (fortnightly) for over a period of four months i.e from May 2015 to August 2015.

A. Temperature

The mean, maximal, and minimal recorded temperatures of the influent water were 29.8^{0}C, 31.4^{0}C and 28.6°C, respectively. While the effluent mean, maximal, and minimal recorded temperatures were 30.7^{0}C, 32.6^{0}C and 29.4°C. Thus the recorded temperatures of the influent and effluent were between 29.2°C to 32.6°C which was found optimal for the growth of bacteria and optimal anaerobic digestion. The temperature of the raw sewage is typical of the local tropical climate value is maintained quite well during the whole treatment process. This represents a particularly favorable condition for achieving high treatment efficiencies for the UASB process.

B. pH

The waste water reaches the inlet chamber with pH between 7.1 and 8.3, in the alkaline range. This alkaline characteristic may have been caused by the presence of detergents, and by the food leftovers, which consist of minerals. A significant drop in pH was observed in the streams reaching the distribution chamber, being between 6.97 and 7.8, due to the formation of acetate, with consequent release of hydrogen. There was also the degradation of solids, increasing the nitrogen content. Since most of the total nitrogen was in the form of ammonia (NH_3), an increase in the concentration of N_2 took place, due to the disruption of nitrogen-hydrogen bonds of the ammonia, forming thus H_2 and H_3O^+, reducing the pH of this unit. After the distribution chamber, the effluent reached the UASB reactor, which presented a better hydrolysis and acidification, and the pH remained between 6.8 and 7.8.

In most of the monitoring, the UASB reactor operated with a mean pH of 7.7 reaching the UASB reactor and the mean pH value of effluent water was reported to be 7.3, which is within the optimum range for growth of microorganism producers of methane.

C. Biochemical Oxygen Demand (BOD_5)

The performances of UASB reactor in treating the BOD5 showed considerable fluctuations. The removal efficiency of the BOD5 first decreased but was then increased and remained fairly stable until the last sampling. The cause of this observance can be attributed to the declining pH of water in almost all of the reactors. The decrease in the pH shows that acidogenesis and acetogenesis processes might have already occurred, therefore, the organic matter was converted into volatile fatty acids and the pH further inclined towards the acidic side. The accumulation of the volatile fatty acids in the reactor could have caused obstruction in the methanogenesis process and would then have affected the organic removal efficiency. It can be stated that the amount of the BOD5 removed by the microorganisms in the reactor increased with increase in the influent BOD5 concentration. The substrate enters the cell of a microorganism through diffusion in which the molecules from higher solute concentration move to the lower solute concentration. Therefore, an increase in substrate concentration, would have readily allowed the entrance of substrate in the microorganisms cells, as BOD5 allowance.

D. Chemical Oxygen Demand (COD)

The COD variations in the UASB reactor influent and effluent are shown in table 2. The average COD concentration of the UASB influent was reported to be 206 mg/l whereas the average effluent COD concentration was reported to be 48 mg/l

E. Total Suspended Solids (TSS)

Fluctuations were observed in the TSS removal efficiency, as shown in table 2. The fluctuations in the value of the TSS removal efficiency can be attributed to have occurred due to the accumulation of solids inside the reactor. Therefore, as more solids started accumulating in the reactor and were not carried over into the effluent, higher removal efficiency values were obtained and the effluent seemed to be much clearer. Furthermore during a certain time, the unstable accumulations were carried over into the effluent and, thus smaller removal efficiencies and higher turbidity levels were obtained.

In a research conducted on UASB systems, Aiyuk et al.[30] have also found that the sludge bed can act as filter for the suspended solids and thereby increasing their specific residence time. Therefore, the UASB reactor may achieve high TSS removal at relatively short Hydraulic Retention Times (HRTs). However, the accumulation of suspended solids in the sludge bed can provoke the displacement and dilution of the active cells.

S. No.	Date	Influent					S. No.	Effluent				
		pH	Temp. ^{0}C	TSS (mg/l)	BOD (mg/l)	COD (mg/l)		pH	Temp. ^{0}C	TSS (mg/l)	BOD (mg/l)	COD (mg/l)
1.	15/05/2015	7.1	28.6	298	116	214	2.	6.9	29.4	27	29	50
3.	31/05/2015	7.7	29.2	202	98	204	4.	7.5	29.9	22	26	49
5.	15/06/2015	7.9	29.7	233	105	210	6.	7.3	30.1	25	27	51
7.	30/06/2015	7.2	29.6	205	99	197	8.	6.8	30.3	23	26	47
9.	15/07/2015	8.2	30.2	245	110	211	10.	7.8	31.6	26	27	52
11.	31/07/2015	7.8	31.4	196	92	199	12.	7.1	32.6	20	24	45
13.	15/08/2015	7.6	30.4	212	102	207	14.	7.3	31.7	23	26	49
15.	31/08/2015	8.3	29.5	200	97	205	16.	7.7	30.5	21	25	43
	mean	**7.7**	**29.8**	**224**	**102**	**206**		**7.3**	**30.7**	**23**	**26**	**48**

Table 2: Results of wastewater quality parameters for the 16 samples collected at Bharwara UASB plant

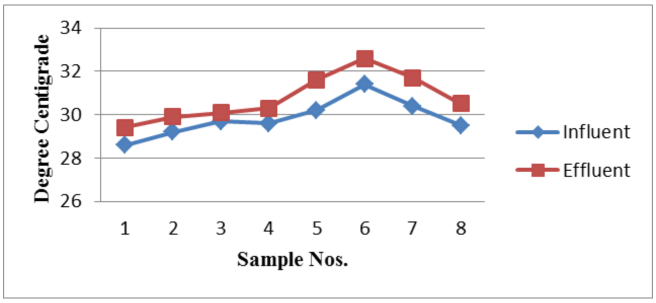

Fig. 1: Temperature Variation b/w influent and effluent of the Bharwara UASB plant

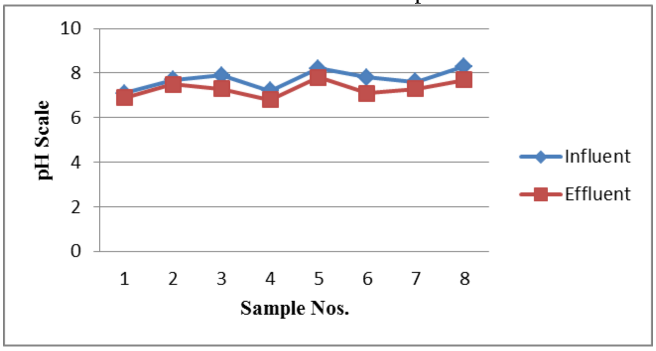

Fig. 2: pH Variation b/w influent and effluent of the Bharwara UASB plant

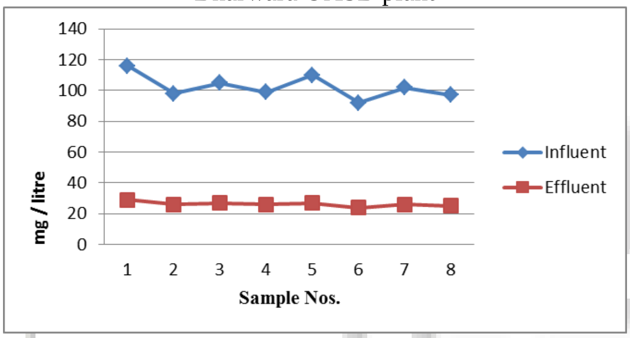

Fig. 3: BOD5 of influent and effluent of the Bharwara UASB plant

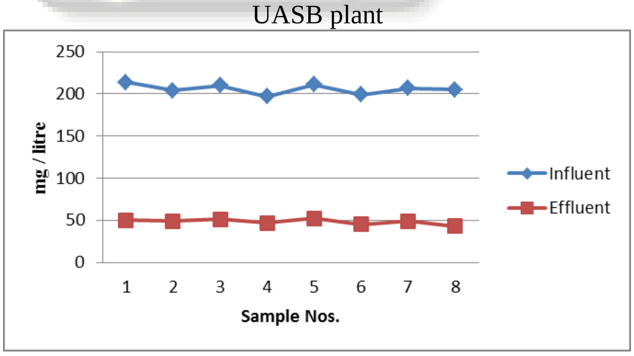

Fig. 4: COD of influent and effluent of the Bharwara UASB plant

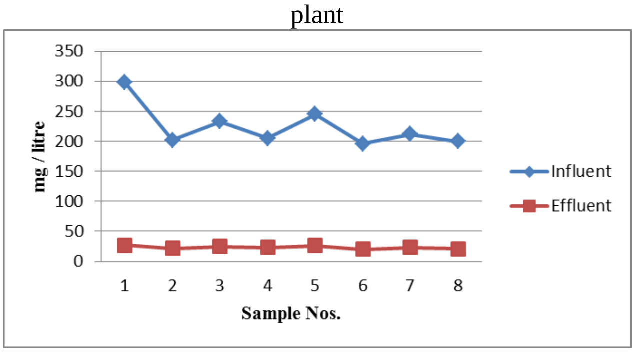

Fig. 5: TSS concentrations of influent and effluent of the Bharwara UASB plant

VI. DESIGN ANALYSIS

The design analysis of the UASB reactor was done against commonly used design equations and empirical formulas. The design equations and the typical values against which the design analysis was carried out according to Metcalf and Eddy, (2003)[31], Chernicharo, (2007)[32] and Marcos Von Sperling, (2007)[33]. The standard design considerations the design analysis of UASB is determined by the following steps:

A. Volumetric Hydraulic Loading (VHL)

The volumetric hydraulic load is the quantity of wastewater loaded per unit volume of the reactor per unit time. The hydraulic detention time is reciprocal of the volumetric hydraulic load. It is represented as:

Volumetric hydraulic loading (VHL) = Q/V

Where; VHL =Volumetric hydraulic load ($m^3/m^3.d$)

Q = Flow rate (m^3/d)

V= Total volume of the reactor (m^3)

t = V/Q

Where t is hydraulic detention time (d)

The total Volume of the UASB reactors was estimated as 123,648 m^3 which was found to be designed for HRT of 8.6 hrs. Volume of the digestion zone is 87879.6 m^3 and design HRT of the digestion zone is 6.1 hours. Design volumetric loading rate according to the equation was calculated as 3.9 m^3/m^3.d.

B. Organic Loading Rate (OLR)

Organic loading rate (OLR) indicates how many kilograms of organic dry solids are loaded per m^3 of digester volume and unit of time. The organic loading rate is important for the plant components and for the bacteria. If the organic loading rate is too high technical components like mixers or pumps could be damaged or need an earlier maintenance than calculated due to an overload.

The Organic loading rate of a reactor is calculated as:

Organic loading rate (L_v) = Q × So/V

Where: L_v= volumetric organic loading rate (kg COD/ m^3.d)

Q= flow rate (m^3/d)

S_o=influent substrate concentration kg COD/m/d)

V=total volume of reactor (m^3)

Where t is hydraulic detention time (d)

C. Upflow Velocity

The upflow velocity of a reactor was calculated as:

$V_{uf} = Q/A$

Where:

V_{uf} = upflow velocity (m/hr)

Q = flow (m^3/hr)

Upflow velocity in the UASB reactor for the design flow was calculated as 0.54 m/hour.

D. Efficiency of the UASB reactors

Efficiencies of the UASB reactors by empirical relations were estimated as:

$$ECOD = 100 \times (1- 0.68 \times t-0.35)$$

Where:

E = efficiency of UASB reactor in term of COD removal (%)

t = hydraulic detention time (hr.)

0.68 = empirical constant

0.35 = empirical constant

E BOD = 100 × (1 − 0.70 ×t-0.50)
Where:
E = efficiency of UASB reactor in term of BOD removal (%)
t = hydraulic detention time (hr.)
0.70 = empirical constant
0.50 = empirical constant

Treatment efficiencies of the UASB reactor, according to the empirical equations were calculated as 66% for COD and 74% for BOD.

The design analysis calculations which included volumetric loading are presented in the table 5.9. Volumetric hydraulic loading rates were slightly variable and ranged between 3.48 and 3.80 m^3/m^3.day and as a consequence the upflow velocity was also slightly varying from 0.55 to 0.62 m/hour.

Months	Volumetric hydraulic loading rate (m^3/m^3.d)	Volumetric organic loading rate (kg COD/m^3.d)	Upflow velocity (m/hr)	HRT (hr)
May	3.48	0.85	0.55	6.89
June	3.57	0.88	0.56	6.73
July	3.70	0.94	0.57	6.48
August	3.80	1.02	0.62	6.32

Table 3: Design analysis calculations for UASB reactor

Despite this, the treatment efficiencies were observed to be higher than the expected. Observed efficiencies were 75.9%-77.7% for COD and 74.0%-74.7% for BOD while expected efficiencies calculated according to the empirical formula equations were 64.3-65.3% and 72.1 -73.3% respectively.

Months	COD removal efficiency (%)		BOD removal efficiency (%)	
	Expected	Observed	Expected	Observed
May	65.3	**76.3**	73.3	**74.3**
June	65.1	**75.9**	73.0	**74.0**
July	64.6	**76.4**	72.5	**74.7**
August	64.3	**77.7**	72.1	**74.4**

Table 4: Efficiencies calculation for the UASB reactor

This indicates that the equations used were slightly underestimating the COD efficiency, which may be because of the differences in the characteristics of the sewage being treated.

VII. Conclusions

This investigation of the working performance of UASB plant located at Bharwara, Gomtinagar Lucknow observed that the maximum BOD_5 removal efficiency was 74.7%, while the maximum COD removal efficiency was 77.7% and the maximum TSS removal efficiency was 72%. The BOD_5 and TSS allowance values increased with the increasing influent concentrations. Generally, the reactor with 0.55 m h^{-1} upflow velocity performed relatively better than the reactors that involved other variants of the upflow velocities. This observance of comparatively higher value of the removal efficiency can be attributed to the assumption that slower upflow velocity will allow more time for the microorganisms to decompose the substrate in the wastewater.

There are few observations that can be used for the identification of the fluctuations in the removal efficiency. As the pH value tended to decrease and became more acidic, decline was observed in the BOD_5 removal efficiency. The reason for the decrease in removal efficiency can be that as more organic matter was decomposed into volatile acids, the pH value dropped to be more acidic which could have obstructed the methanogenesis process. The moderate value of the BOD_5 was observed as the pH value tended to be normal. However, small allowance efficiencies and high TSS values resulted in a cloudy effluent as due to the unstable upflow velocity, the ability to trap solids in the reactor was affected and small removal efficiency was obtained as if these solids were carried into the effluent. However, the treatment of the wastewater using the UASB reactor did meet the quality standard stated by enforcement agencies in India.

The following suggestions and recommendations can be made from this study:

- A large quantity of foam was observed at site during the visit in the final polishing ponds of the UASB reactor. Antifoaming agents should be used to control the foam formation in the polishing ponds.
- It was observed that all treated water is disposed into the Gomti River. The treated water may be used for industrial and irrigation purposes.
- Due to the inefficient sewerage network, highly diluted sewage is received at the Bharwara plant due to which there is insignificant biogas generation which could otherwise be used for power generation; hence, cost recovery.
- It was also observed that chlorination is being done for the removal of microorganisms from the waste water retrieved from polishing pond. The addition of Chlorine and its intermediates causes inactivation of pathogenic microorganisms. However, addition of chlorine for disinfection of water can produce many by-products that are carcinogen for human health and the free available chlorine reaching the Gomti River course may have detrimental effects on its aquatic fauna and flora. The study felt that removal of free available chlorine from the treated water is must and a preliminary investigation is made through use of hydrogen peroxide (H_2O_2) to dechlorinate the effluent.
- The operating agencies of the UASB plant are plagued by institutional and financial crisis, barely managing the current services efficiently. It should be more regularized for proper Operation & Maintenance of the plant.

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