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SEWAGE TREATMENT BY UASB-REACTOR. OPERATION RESULTS AND RECOMMENDATIONS FOR DESIGN AND UTILIZATION

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ABSTRACT

A 120 m^3 UASB reactor for domestic wastewater treatment was designed and built, based upon results obtained through the operation of a 106 L pilot unit. This system was operated for four years for demonstration and technology development purposes. The results obtained in the first year of operation were already previously presented.
After this period, some modifications were carried out aiming at design and operation and maintenance and facilities improvement. This was followed by a continuous 2-year operating period. In this work are presented some of the results obtained in this second phase of operation, with hydraulic retention times ranging from 5 to 15 h, resulting in an effluent with 50 to 150 mg COD.L^{-1} and 40 to 85 mg BOD.L^{-1}. Some criteria are presented, together with the experience acquired in the development of this technology from the pilot reactor phase. During this period, several lectures and discussions about the system were held in relation to its use, operation and efficiency, leading to considerations about the advantages and convenience of this choice, by establishing a comparison between it and other wastewater treatment processes.

KEYWORDS

Anaerobic treatment; sewage treatment; domestic sewage; UASB reactor; design; operation; post-treatment.

INTRODUCTION

It has been noticed in Brazil, mainly concerning the field of domestic sewage treatment, that the lack of basic sanitation has been mentioned as one of the main causes of infectious disease transmission. This fact, added to inadequate nutrition of lower income population, led to frightening infant mortality rates. This situation has been noticed in both large cities and small ones. In the search for alternatives for sewage treatment, several options should be evaluated to enable the establishment of sewerage and treatment systems adequate to the national reality, under reasonable costs.

It should be considered in this evaluation:

. operational and structural simplicity
. low cost
. low land requirements
. treatment efficiency to attain good effluent quality

Most widely used options for wastewater treatment

Septic tanks may be used when sewage quantity is small. The system composed of a septic tank followed by anaerobic filter provides an effluent with about 140 mg $COD.L^{-1}$ operating with a hydraulic retention time (HRT) of 1.5 days (Vieira and Alem, 1983). However, they are recommended only for flowrates up to 75 $m^3.day^{-1}$, corresponding to 500 inhabitants (NBR-7229/ABNT).

The techniques of sewage application to the soil as a fertilizer or the usage of stabilization ponds for larger flowrates may be recommended when there is enough land available. Stabilization ponds operate at high hydraulic retention times (15 to 20 days) providing an effluent with BOD lower than 40 $mg.L^{-1}$ and, in some cases, significantly removing pathogenic microorganisms (CETESB, 1989).

In case of limited land availability, aerobic treatment systems like the conventional activated sludge process, extended aeration or oxidation ditches may be used. Although being very expensive and requiring the use of electromechanical devices for aeration and mixing, these processes are very efficient,providing an effluent of about 20 mg $BOD.L^{-1}$ when properly operated. In the case of the conventional activated sludge process an additional system for stabilization of the primary and secondary sludges must also be provided.

UASB reactors were developed for concentrated wastewater treatment (Lettinga et al., 1980). After studying their applicability to stillage treatment (Souza and Garcia Jr., 1986) CETESB's technical staff also tested them for domestic wastewater treatment. This resulted in the development of a pilot reactor of 106 L capacity treating domestic sewage, that was operated for 2 years with good results (Vieira, 1984), leading to the design and installation of a 120 m^3 system destined to evaluate the real applicability of this technology (Vieira and Souza, 1986). Other parallel works have also proposed its utilization for diluted wastewater treatment, enabling the development of compact anaerobic systems (Lettinga et al., 1983; Schellinkhout et al., 1985; Jewell, 1985). These systems are simple and economical, not demanding any electromechanical equipment or energy input for aeration and mixing, besides being composed of a single unit. The UASB reactor treating domestic sewage provides an effluent between 40 to 80 mg $BOD.L^{-1}$ thus being an important option to be considered,depending on specific conditions of system requirements and receiving body characteristics. Table 1 illustrates a comparison between land requirements for the aforementioned systems (CETESB, 1989).

The local legislation requirements for domestic effluent treatment systems must also be taken into account.

In Brazil, the State and Federal legislations classify and quantify the parameters for surface water quality which cannot be altered, and even define Emission Standards for the discharge of treated effluents into these waters. Concerning five-day Biochemical Oxygen Demand (BOD) for instance, the legislation determines a maximum concentration of 60 $mg.L^{-1}$ or a minimum removal of 80%. In order to meet specific requirements of legislation, post-treatment system for disinfection and/or additional removal of organic matter and nutrients may be necessary.

MATERIALS AND METHODS

System description

The UASB reactor treatment system installed at CETESB/São Paulo is fed with sewage collected by the local treatment plant. The reactor net capacity is 120 m^3, and it's built of carbon steel, internally lined with epoxy paint. It consists of a cylindrical tank with a frustum conical settler on its top. The general arrangement and main dimensions are shown in Figure 1.

TABLE 1 - Comparison between estimated land surface requirements for several option of sewage treatment

System	Served Population (inhab)	Per Capita Contribution ($L.inhab^{-1}.d^{-1}$)	Approximate Land Surface Required ($m^2.inhab^{-1}$)
Soil Application			
irrigation	7,000	150	22.5 to 87.0[1]
overland flow	7,000	150	7.5 to 22.5[1]
infiltration	7,000	150	0.3 to 10.5[1]
Stabilization Pond			
single facultative	1,000 to 50,000	150	2.6[1]
anaerobic+facultative	1,000 to 50,000	150	2.3[2]
aerated+sedimentation	1,000 to 50,000	150	0.4[2]
Septic Tank			
+infiltration ditch	500[3]	150	4 to 6[1]
+anaerobic upflow filter	500[3]	150	0.3[1]
Oxidation Ditch	1,000 to 50,000	150	0.2[4]
Conventional System			
act.sludge+an.digestion.	over 10,000	150	0.03[5]
		250	0.05[5]
UASB Reactor	over 1,000	150	0.01 to 0.11[6]
		250	0.02 to 0.12[6]

1. Land surface for safety, circulation, etc. not included.
2. Including estimate of 30% of the area for circulation, slope crests, etc.
3. 500 inhabitant maximum population (NBR-7229).
4. Drying beds included.
5. Considering mechanical sludge drying.
6. The lowest value considers mechanical sludge drying; the highest, drying beds.

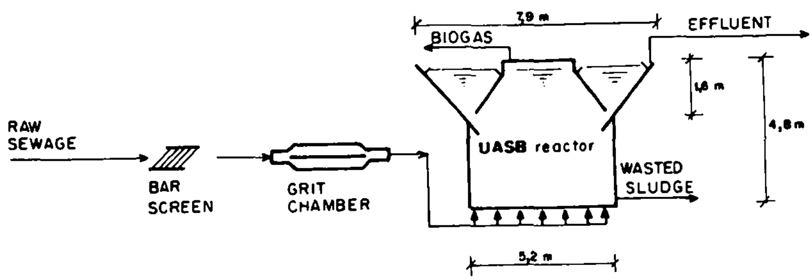

Fig. 1. General layout for the domestic sewage treatment system with 120 m^3 UASB reactor.

System monitoring

Flowrate measurement and control was effected initially by continuous monitoring with an automatic ultrasonic flowmeter type Manning UX-100 and later by hourly measurements with a V-notch weir. Influent and effluent characteristics were determined from composite samples taken for BOD, COD (Chemical Oxygen Demand), TSS (Total Suspended Solids), acidity and alkalinity determinations, four times a week, during 24 hours each. pH and temperature are measured hourly. The other system parameters were measured at least once a week. All analyses were conducted according to Standard Methods (1985). Gas production was measured with a mechanical gas meter, type LAO MG-2 or MG-6. Both gas composition and individual organic volatile acids were determined by means of gas chromatography (Vieira and Souza, 1981). Microscopic observations of the sludge were carried out following a methodology developed at CETESB Laboratories (Rech et al., 1991). The operational conditions are shown in Table 2. The necessary manpower for system operation and monitoring was about 1 to 2 persons.

TABLE 2 - Basic operating conditions (Mean ± Standard Deviation and Range)

Period (days)	Ambient Temperature (°C)	HRT (hours)
9 to 3	19±3 (12 to 27)	14.5± 2.2 (12.1 to 21.8)
37 to 72	18±3 (10 to 24)	11.0± 2.4 (9.2 to 23.1)
93 to 145	21±3 (14 to 29)	8.8± 1.7 (7.5 to 16.4)
146 to 164	22±3 (15 to 30)	7.2± 0.6 (6.9 to 10.6)
170 to 180	22±2 (17 to 29)	7.0± 0.1 (6.8 to 7.2)
228 to 248	25±2 (19 to 30)	7.5± 0.8 (6.8 to 10.7)
253 to 262	28±1 (22 to 32)	6.1± 0.1 (5.9 to 6.3)
269 to 339	25±2 (18 to 32)	6.2± 0.6 (5.6 to 12.5)
340 to 382	21±3 (12 to 28)	5.1± 0.2 (5.0 to 6.1)
432 to 472	18±2 (10 to 25)	4.4± 0.2 (4.0 to 4.9)
493 to 516	22±4 (14 to 31)	5.0± 1.0 (4.0 to 7.2)

RESULTS AND DISCUSSION

The results presented here were obtained throughout 2 years of tests, startup and operation, beginning in 1989. The results obtained in the other phases were already published. (Souza and Vieira, 1986, 1987; Vieira et al., 1987a, 1987b; Vieira, 1988).

Sewage characteristics

The averages and ranges calculated from sewage parameters measured throughout each different period of HRT studied are shown in Table 3.

TABLE 3 - Main influent characteristics (Mean ± Standard Deviation and Range)

HRT (hours)	COD ($mg.L^{-1}$)	Filtered COD ($mg.L^{-1}$)	BOD ($mg.L^{-1}$)	TSS ($mg.L^{-1}$)	Sulfate ($mg.L^{-1}$)
14.5	400±64	171±34	255±68	not determined	not determined
	(317 to 523)	(139 to 253)	(166 to 397)	(-----)	(-----)
11.0	403±68	156±37	249±64	182±48	not determined
	(213 to 538)	(84 to 227)	(118 to 372)	(70 to 260)	(-----)
8.8	407±61	151±20	253±51	195±70	32±7
	(213 to 595)	(96 to 189)	(182 to 351)	(109 to 408)	(12 to 43)
7.2	459±84	160±17	255±53	219±57	77±131
	(322 to 561)	(139 to 184)	(187 to 367)	(148 to 315)	(6 to 443)
7.0	374±31	139±10	237±35	192±64	88±120
	(340 to 406)	(126 to 152)	(196 to 272)	(125 to 285)	(31 to 302)
7.5	194±65	96±31	105±54	91±39	34±8
	(113 to 331)	(58 to 172)	(58 to 234)	(50 to 164)	(24 to 52)
6.1	188±37	96±21	104±18	67±11	21±9
	(133 to 228)	(77 to 129)	(73 to 117)	(56 to 84)	(7 to 32)
6.2	258±50	115±29	157±48	113±43	24±9
	(164 to 350)	(57 to 164)	(68 to 241)	(48 to 212)	(7 to 52)
5.1	307±63	120±28	198±46	149±72	25±13
	(199 to 477)	(50 to 155)	(134 to 310)	(40 to 352)	(11 to 73)
4.4	285±63	130±38	181±48	236±164	23±6
	(211 to 406)	(77 to 211)	(119 to 233)	(44 to 512)	(4 to 33)
5.0	393±76	155±31	208±40	207±60	25±11
	(316 to 479)	(111 to 187)	(139 to 263)	(155 to 240)	(17 to 57)

Effect of HRT on reactor performance

For an HRT range of 5 to 15 hours, it was found that the organic removal efficiency did not vary appreciably, having maintained a value of about 60% for COD (Figure 2), 70% for BOD and 70% for TSS, with effluent quality varying between 80 to 150 mg $COD.L^{-1}$ and 40 to 85 mg $BOD.L^{-1}$. The reactor performance has decreased only in a period of high influent sulphate concentration (Figure 3).

Effect of sulphate concentration on reactor performance

Domestic sewage is prone to be affected by fluctuations in its composition, caused by discharges of wastes containing substances of toxic or inhibiting effects over the microorganisms. A typical case is that which occurs when sulphate is discharged in the sewerage system. The resulting sulphide emission causes problems in the anaerobic digestion of wastewaters containing sulphate and sulphide. The sulphate reducing bacteria inhibit the activity of the methanogenic bacteria competing for the same substrate (acetate and hydrogen). Besides this, sulphide has a toxic effect on the anaerobic digestion (Buisman et al., 1990; Figueiredo et al., 1991). In these studies we have observed peak sulphate concentrations of about 400 mg $SO_4^{2-}.L^{-1}$ (with HRTs of 7.2 and 7.0 h) that resulted in a general decrease of 10% for COD, BOD and TSS removal (Table 5), and adversely affected effluent quality (Table 4).

Effect of low strength sewage on reactor performance during the rainy season

During the rainy season, the removal efficiency decreases due to a decrease in influent COD concentration. However a better effluent quality is also observed during this season, with conditions of HRT 7.5 and 6.1 h (Figure 3 and Table 4). In this instance an effluent COD of about 85 mg.L^{-1} has been recorded.

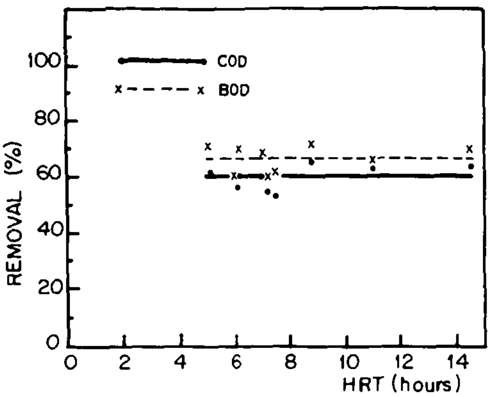

Fig. 2. Average BOD and COD removals for the tested conditions

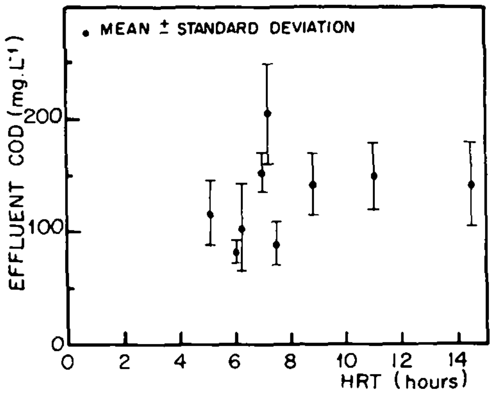

Fig. 3. Effluent COD for the tested conditions

TABLE 4 - Main effluent characteristics (Mean ± Standard Deviation and Range)

HRT (hours)	COD (mg.L^{-1})	Filtered COD (mg.L^{-1})	BOD (mg.L^{-1})	TSS (mg.L^{-1})
4.5	142 ± 37 (92 to 227)	93 ± 21 (76 to 135)	77 ± 20 (56 to 115)	not determined
11.0	149 ± 30 (72 to 184)	85 ± 22 (45 to 135)	84 ± 22 (55 to 128)	45 ± 19 (10 to 85)
8.8	142 ± 27 (92 to 198)	75 ± 16 (49 to 117)	72 ± 17 (47 to 106)	49 ± 23 (12 to192)
7.2	206 ± 46 (143 to 273)	121 ± 19 (92 to 143)	101 ± 32 (34 to 139)	74 ± 33 (38 to118)
7.0	152 ± 18 (126 to 170)	91 ± 11 (80 to 109)	73 ± 17 (59 to 101)	45 ± 9 (34 to 62)
7.5	89 ± 20 (50 to 129)	45 ± 17 (21 to 77)	40 ± 9 (26 to 50)	34 ± 14 (14 to 54)
6.1	83 ± 10 (73 to 97)	45 ± 15 (25 to 50)	42 ± 10 (29 to 53)	24 ± 8 (12 to 32)
6.2	103 ± 39 (26 to 216)	54 ± 21 (26 to 111)	47 ± 22 (8 to 118)	37 ± 16 (6 to 58)
5.1	117 ± 29 (73 to 186)	50 ± 17 (21 to 77)	58 ± 14 (38 to 100)	49 ± 21 (18 to 78)
4.4	189 ± 44 (106 to 236)	100 ± 33 (53 to 164)	111 ± 33 (65 to 153)	105 ± 112 (20 to372)
5.0	280 ± 25 (246 to 304)	110 ± 26 (98 to 145)	121 ± 32 (83/to 166)	78 ± 49 (20 to125)

Table 5 - Average operating results

HRT (hours)	14.5	11.0	8.8	7.2	7.0	7.5	6.1	6.2	5.1
Gas yield									
($m^3_{STP}.kg^{-1}COD_{appl}$)	0.08	0.08	0.10	0.10	0.11	0.17	0.12	0.13	0.12
($m^3CH_{4STP}.kg^{-1}COD_{rem}$)	0.09	0.09	0.11	0.12	0.12	0.25	0.15	0.15	0.13
Estimated f									
(kgCODappl.kg^{-1}TSS.day^{-1})	---	0.07	0.09	0.19	0.12	0.05	0.08	0.12	0.19
Wasted Sludge									
(kgTSS.day^{-1})	4.5	20.7	26.9	31.1	24.0	16.6	11.0	8.0	6.4
Estimated Sludge Age (days)	---	49	33	16	30	48	51	39	27
Sludge yield									
($kgTSS.kg^{-1}COD_{appl}$)									
- Wasted Sludge	---	0.20	0.20	0.17	0.16	0.22	0.12	0.07	0.04
- Wasted Sludge plus effluent losses	---	0.31	0.32	0.33	0.28	0.40	0.25	0.21	0.20
Removal (%)									
- COD	64	63	65	55	59	54	56	60	62
- Filtered COD	77	79	81	74	76	77	76	79	84
- BOD	70	66	72	60	69	62	60	70	71
- TSS	---	75	75	66	76	62	64	67	67
COD/Sulfate mean ratio	---	---	12.7	6.0	4.3	5.7	9.0	10.8	12.3

Sludge loss

After about 400 days of operation, the system's performance decreased, culminating in the complete loss of all of its sludge. (Table 4, for conditions of HRT of 4.4 and 5.0 h).

It was found later that it was caused by the failure of the steel effluent outlet pipe, that was placed inside the reactor, on this bottom.

Microscopic observations of the sludge

During all the periods studied after start-up, granules were observed. Their overall dimensions did never exceed 2 mm however, with a round or ellipsoidal format. The microscopic observations made possible the identification of the main bacteria present in the sludge. A predominance of methanogenic bacteria of the genus *Methanothrix* was observed, besides others from the following probable genus: *Desulfovibrio*, *Desulfobulbos* and *Clostridium*, among others.

RECOMMENDATIONS FOR DESIGN CRITERIA

Taking into account the experience acquired and based upon criteria already defined before (Souza, 1986) some design parameters are thereby recommended, which are also in agreement with the ones described by Lettinga and Pol (1991).

HRT

As the domestic sewage has a relatively low organic load, the limiting design parameter is the hydraulic load. For average flows, an HRT of above 6 hours is recommended.

Overflow Rate (O.R.) in the settler

It is fundamental that the biomass be retained in the internal settler to assure its maintenance in the reactor. An O.R. of 0.7 $m^3.m^{-2}.h^{-1}$ is recommended for raw domestic sewage. For peak flowrates this must be below 1.3 $m^3.m^{-2}.h^{-1}$.

Reactor height

An overall useful height for domestic sewage between 4.0 and 4.8 m for the reactor, and between 1.5 and 1.6 m for the settler have proved to be effective.

Upflow velocity in the reactor

The feeding distribution effect and gas production must provide good mixing conditions in order to enable an adequate contact between the substrate and the biomass as well as help in sludge granulation. The liquid flow plays an important role in the resulting mix, since the gas production from domestic sewage is relatively low. On the other hand, high upflow velocities should not be used in order to avoid the loss of solids from the reactor. It is recommended as average design criteria to keep the upflow velocity lower than 1.0 $m.h^{-1}$ in the reactor body.

Internal settler

The inside settler must only effect the separation between the solid and liquid phases, avoiding organic matter transformation on its walls. Therefore, these must have a slope steeper than 50°. In order to enable the return of settled sludge back to the reactor body, the settler inlet must be properly designed so that in this region the velocity must be lower than 5$m.h^{-1}$ at the average flow. Asymmetric flow conditions must be avoided. In order to improve effluent quality by means of floating material removal, the installation of baffles about 20 cm deep is suggested.

Gas deflectors

Deflectors must be designed in order to avoid gas bypass to the settling area and lead it to one or more gas chambers. It is suggested a minimum overlap of 20 cm be used between the settler wall and the deflector to avoid gas losses. The velocity profile at the settler inlet should be as symmetrical as possible.

Gas collectors

The gas released in the process must be directed to one or more gas chambers on top of the reactor. In order to avoid scum build-up, the gas velocity must be high. On the other hand, it cannot be excessive in order to avoid dragging solids to the gas outlets. A value of $1m^3$ $gas_{STP}.m^{-2}.h^{-1}$ should be kept. The provision for manholes for inspection and eventual scum removal is also recommended.

Inlet distribution system

As noted before, by having a small gas production the domestic sewage does not contribute significantly for the mixing conditions in the UASB reactor. It is thus important to plan a homogeneous influent distribution in the bottom of the reactor in order to prevent the development of stagnation areas and short circuits in it. A distribution system with as many feeding chambers as inlet points is recommended, in order to provide each of them with the same flow. In order to avoid dragging air through the reactor piping, this system must be installed on top of the reactor and have a good hydraulic design.

It is important to provide for:

- an inlet point each 1 or 2 m^2 of reactor surface;
- a height of 20cm from inlet point to reactor bottom;
- the non-utilization of internal division devices (manifolds), in order to facilitate the detection and solution of clogging problems.

Temperature control

The installation of heating devices is not required if weather conditions enable ambient temperature to be maintained above 15°C. The process velocity is enhanced in the mesophilic range between 30 and 40°C. On the other hand, below 10°C it steadily decreases and its use in this condition without heating has not yet been proved viable, although research has been done to reach it (de Man et al., 1988). An economical evaluation of a system partially heated by its own biogas is also recommended.

Reactor shape and building materials

The reactor shape depends on the building material selected. Rectangular reactors are usually built of concrete masonry, whereas circular ones are made of metal, fibreglass or plastic. When system modulation is needed, rectangular reactors provide advantages by allowing the use of single walls between units.

The selection of building material basically depends on its availability, means of building, and on-site system installation cost.

The internal settler on rectangular reactors is usually rectangular. Depending on project demands and ease of installation, they can be circular or rectangular in the case of circular reactors. Settlers can be covered or uncovered. The uncovered ones are more economical and easier to maintain; however, they can present odor and corrosion problems in the settling walls due to oxidation of H_2S to H_2SO_4.

In order to minimize inspection and maintenance requirements, it is suggested to avoid the location of structural parts subject to mechanical stress or leakage inside the reactor.

Corrosion

The reactor must be protected with suitable coatings and paints against premature wear of the building materials. All the piping must be made of PVC or inert materials. Extra care must be taken of all the brittle points in the structure, such as welds, wall joints and contact points between materials of different electrochemical potential. The intervals between coating maintenance vary, the manufacturer's advice being important in this matter.

Odor

The development of small quantities of H_2S by anaerobic digestion causes unpleasant odors when this gas is emitted to the atmosphere. It is emitted from the effluent in the regions where turbulence occurs (settler troughs, final effluent outlets). In order to minimize this nuisance, it is suggested that the covering of the reactor and other critical points with lids be made of light material provided with water seals and, if possible, the venting of the emitted gas to an H_2S removal device. In case of the existence of inhabited area in the reactor zone, odor control systems must be utilized.

Reactor maximum volume/modulation

A significant amount of the costs of a collecting and treatment system is for the building of collecting and intercepting sewers. As the population density of a given region increases causing a rise of land area costs, the treatment systems have to be larger and larger and installed farther from the generating centres of sewage with a significant cost rise for collection and pumping. If possible, it's always desirable to design a treatment plant forecasting a modulation between 2 and 8 stages over a 20-year useful lifespan. The maximum recommended volume for each digester unit is 400 m^3 (Pol and Lettinga, 1989), because large volumes do not present any added advantages concerning structural aspects and operational/maintenance requirements.

Production and disposal of excess sludge

In every compact system of sewage treatment there is a build-up of excess sludge which needs to be separated, conveniently conditioned and disposed of. Despite the fact that the sludge production is smaller in a UASB reactor than in the aerobic processes, it must be carefully considered. CETESB research indicates a sludge production around 0.2 kg $TSS.kg^{-1}COD_{appl}$.

The sludge disposal is intermittently done. The operation periodicity is set according to the digester size. The discarded sludge should be taken to a suitable drying system (drying beds or mechanical system). In order to afford a more accurate evaluation of the overall sludge mass in the system as well as to provide a fine tuning of mass and volumes to be discarded, the installation of sampling points set at various heights in the reactor is recommended. The disposed sludge is still heavily contaminated by pathogenic microorganisms (Gasi et al., 1989) and it should be carefully handled to avoid the contamination of the operators.

Required preliminary treatment

Concerning the design and operation characteristics of the UASB reactor, for a better performance and reliability of the system, the setting of the following preliminary treatment is recommended:

. rough screening (before the pumping station)
. medium screening (7 to 12 mm)
. grit removal
. oil and grease removal (to reduce scum build-up)
. rotary or static screen (for high fibre quantity).

Byproducts destination and utilization

Effluent

The treated effluent may only be discharged into surface waters if its quality complies with the Emission Standards set by the State and Federal Legislations. In order to comply with the legislation (CETESB,1988), in case of the need for increased effluent quality, various complementary treatments already tested by several authors may be used. The main ones are listed below.

CHLORINATION: is a simple and economical process easy to install. It only promotes disinfection without additional organic matter removal. It may eventually develop chloroamines and trihalomethanes (THM) according to the concentrations applied (Gasi et al., 1987, 1988).

SLOW SAND FILTRATION: is a process which only promotes disinfection requiring large land area for its setting. It is often subjected to clogging and requires frequent maintenance and washing (van Buuren, 1988).

OZONATION: removes organic matter and promotes disinfection. It is technically the best system because of being quite compact and efficient in view of effluent improvement. On the other hand, it is quite expensive, requiring skilled labor and energy consumption for its operation. Some economical evaluations of the UASB reactor/ozonation show that, under certain conditions, it is competitive with the extended aeration activated sludge process besides having the advantage of providing decontaminated effluent (Gasi et al., 1990, 1991).

STABILIZATION PONDS: are large systems with high retention times, requiring large land areas for their implantation. They remove organic matter and allow good disinfection under retention times of about 30 days (CETESB, 1989). It is a good and simple solution which requires only little care for its operation if the land costs are not high and there is enough available.

ACTIVATED SLUDGE: UASB reactor/activated sludge composite systems allow an excellent organic matter removal, but require an additional stage for disinfection. Despite its high cost, the activated sludge system is very compact. There are systems which include the stabilization of excess sludge by a UASB reactor and nutrient removal by activated sludge system. These systems are regarded as promising, but are still being studied at CETESB.

ULTRA-VIOLET: because of the low contact time afforded by this process, the UASB reactor's effluent disinfection by means of ultra-violet radiation may be an interesting option. Its efficiency depends on the level of suspended particles and on the color of the effluent, which may cause efficiency losses.

Sludge

The most widely used method for excess sludge disposal in Brazil is in sanitary landfills. However, due to the exhaustion of available sites, this option will tend to be more and more limited in the future. Other options that may be used are:

. soil application as an agricultural corrective, if there are no pathogenic microorganisms and/or heavy metal contamination;
. use as raw material for liquid or solid organomineral fertilizers manufacturing (technology developed by IPT - Institute of Technological Research - SP - Brazil);
. utilization for lightweight aggregate or civil building block manufacturing.

These options or other ones that may become available in the future must be individually evaluated in order to make use of the most suitable one taking into account social, economical and cultural realities of the supported region.

Biogas

The production of useful biogas is about 0.1 $m^3_{STP}.kg^{-1}COD_{app}$ (14 $m^3_{STP}.(1,000\ inhab)^{-1}.day^{-1}$). Its approximate composition is:70% CH_4, 10% CO_2,20% N_2 and 1% O_2. The biogas differs in composition from that generated by concentrated effluent treatment systems or primary/secondary sludge stabilization, mainly in relation to high levels of nitrogen and low levels of carbon dioxide, rendering the current available technologies for its purification and compression for automotive utilization of little use.

Until now, the removal of an inert gas like nitrogen has only been possible by the employment of very expensive methods, like molecular sieves or cryogenic processes. Therefore, if no significant improvement in biogas purification occurs in the near future, its utilization as automotive fuel will remain uneconomical.

Another potentially interesting option consists in a primary purification aiming at H_2S removal and its distribution to nearby industries and/or housing districts as industrial or residential fuel. Besides this, the possibility of its utilization inside the treatment plant may be considered for heating or auxillary energy production purposes. In case there are no cost-effective uses for biogas utilization, it must be vented to a properly designed flare.

Cost evaluation

Various authors have discussed the cost for UASB systems. The main capital costs are:

.land;
.sewer and pumping;
.building materials;
.auxillary equipment like gas and liquid flow meters, instrumentation, etc;
.excess sludge drying and disposal devices.

As there is wide cost fluctuation in direct proportion to each one of the several alternative subsystems, large variations have been observed for the system's capital costs, ranging from US$ 13 (Collazos,1990) to US$ 30 (Vieira,1988) per inhabitant.

In the instances where complimentary treatment is needed or any biogas utilization is made, there will be a cost rise in direct proportion of the adopted system. However, when considering the need for sewage treatment for public health reasons, the by-products may be considered as a capital income to cover operational and maintenance costs, at least in a partial basis.

CONCLUSIONS

- The experience gained throughout the 5 years of the 120 m^3 reactor operation for domestic sewage treatment has allowed the mastering of the technology involved, enabling its application to full size treatment plants.

- Wastewater treatment by an UASB reactor operating in São Paulo city at room temperature with an HRT of 5 to 15 hours showed good results.

- The UASB reactor is a viable solution in Brazil for short term installation of effective treatment systems in order to achieve a general improvement of surface water quality, which is currently deteriorating due to raw sewage discharges, and also to get an improvement from the public health point of view. Effluent post treatment affords compliance with the local legislation for disinfection, additional organic load and nutrient removal.

- For better results, UASB reactor design must follow stringent design and dimensioning criteria. Besides this, its adequate operation and monitoring are important.

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