# TREATMENT OF MUNICIPAL SEWAGE THROUGH UPFLOW ANAEROBIC SLUDGE BLANKET (UASB) TECHNOLOGY

(Abstracted from Wastewater Treatment for Pollution Control and Reuse, by Soli J Arceivala & Shyam R Asolekar)

## 1.0 INTRODUCTION

In the last 2 or 3 decades, over 500 Upflow Anaerobic Sludge Blanket (UASB) units have been built in the world for treating high BOD industrial wastes. Over 40 plants exist in India. Since 1982 their use has been extended to include typical municipal sewage, which has relatively low BOD of only 200-300 mgl which has increased their use in many developing countries in warm climates. Its use has spread worldwide as an important treatment method.

## 2.0 TYPICAL ARRANEMENTS

A typical arrangement of a UASB type treatment plant for municipal sewage would be as follows:

1. Initial pumping
2. Screening and degritting
3. Main UASB reactor (having a sludge blanket and settler)
4. Gas collection and. handling
5. Sludge drying bed
6. Post-treatment facility (optional, depending on final effluent standards).

The raw municipal sewage flow coming to the plant is first screened and grit is removed. The flow is then taken to a distributing inlet chamber from where several vertical pipes take the flow down the UASB reactor of 4.5 to 5 m in depth (for BOD values around 200-300 mg/l) and release it uniformly in the lower part of the reactor allowing it to rise at a desired velocity up to the outlet which is at the upper periphery of the unit. Fig.1

In the UASB process, the whole waste (not just the sludge) is passed through the anaerobic reactor in an upflow mode, with a hydraulic retention time (HRT) of only about 8-10 hours of average flow. The upflowing sewage forms millions of small ‘granules’ or particles which are held in suspension and provide a large surface area on which organic matter can attach and undergo biodegradation. A high solid retention time (SRT) of 30-50 or more days occurs within the unit. No mixers or aerators are required, thus conserving energy and giving very low operating costs.

The gas produced can be collected and used if desired. Anaerobic systems function satisfactorily when temperatures inside the reactor are above 18°-20°C. Thus, in most parts of India temperature is no problem.

Excess sludge is removed from time to time through a separate pipe and sent to a simple sand bed for drying. The nutrients, nitrogen and phosphorus are not removed but are, in fact, conserved in the process and to that extent, make the irrigational use of the effluent more valuable The basic approach to design is the same regardless of whether low BOD municipal sewage or high BOD agro-industrial wastewaters are to be treated.

This approach is explained below.

## 3.0 APPROACH TO DESIGN

The UASB design has to be tailor-made to suit the wastewater characteristics with regard to certain parameters like BOD, COD, pH, alkalinity, TSS and VSS as well as other items which may prove toxic, such as sulphates-sulfides heavy metals and ammonia. It is also important to know two other wastewater characteristics: the temperature range (which affects solids-retention time), and the flow fluctuations (which affect the upflow velocity).

**Size of reactor:** Generally, UASBs are considered where temperatures in the reactors will be above 20°C. Between 20° to 26°C, a solids retention time (SRT) of around 30 to 38 days in India gives a stabilized sludge for disposal on open sand beds. At equilibrium conditions, the sludge withdrawn daily has to be equal to the sludge produced daily.

The sludge produced daily depends on the characteristics of the raw waste water since it is the sum total of:

(i) the new VSS (volatile suspended solids) produced as a result of BOD removal, the yield coefficient being assumed as 0.1 g / VSS/g BOD removed,

(ii) the non-degradable residue of the VSS coming in the inflow assuming that 40 per cent of the VSS are degraded and residue is 60 per cent, and

(iii) ash received in the inflow, namely TSS-VSS mg/1.

The sum total of the above three components gives the total solids produced per day and therefore the total sludge that must be withdrawn from the system at equilibrium conditions at steady state conditions:

SR T =Total sludge present in reactor, kg /Sludge withdrawn per day,
= 30 to 50 days, or more depending on temperature

It is important to achieve the desired SRT value at the prevailing temperature.
Another parameter is the hydraulic retention time (HRT) which is given by:
HRT = Reactor volume $m^3$ / Flow rate, $m^3$/ hr
= 8 to 10 hrs or more at average flow

The reactor volume has to be so chosen that the desired SRT value is achieved. This is done by solving for HRT from the SRT equation assuming: (i) depth of reactor, (ii) the effective depth of the sludge blanket, and (iii) the average concentration of sludge in the blanket (often taken as 70 kg/m$^{)}$.

Another parameter considered in design is the organic loading on the solids in the reactor. The full depth of the reactor for treating low BOD municipal sewage is often kept at 4.5 to 5.0 m of which the sludge blanket itself may be 2.0 to 2.5 m depth. In this way, the organic loading remains within desired limits. For high BOD wastes, the depth of both the sludge blanket and the reactor may have to be increased so that the organic loading on solids may be kept within the prescribed range.
Once the size of the reactor is fixed, the upflow velocity can be determined from:

Upfow velocity m/hr =Reactor height / HRT, hrs

Using the average flow rate, one gets the average HRT while the peak flow rate gives the minimum HRT at which minimum exposure to treatment occurs. In order to retain flocculent sludge in reactor at all times, experience has shown that the upflow velocity should not be more than 0.5 m/hr at average flow and not more than 1.2 m/hr at peak flow. At higher velocities, carry over of solids might occur and effluent quality may be deteriorated. The feed inlet system is next designed so that the required length and width of the UASB reactor are determined.

The settling compartment is formed by the sloping hoods for gas collection. The depth of compartment is 2.0 to 2.5 m and the surface overflow rate kept at 20-28 m$^3$/m$^2$/day (namely about I to 1.2 m/hr) at peak flow. The flow velocity through the aperture connecting the reaction zone with the settling compartment is limited to not more than 5 m/hr at peak flow. Due attention has to be paid to the geometry of the unit and to its hydraulics to ensure proper working of the “Gas-Liquid-Solid-Separator “(GLSS)” the gas collection hood, the incoming flow distribution to get spatial uniformity and the outflowing effluent. Figures 2 (a) and (b) show details of gas separation and collection hoods and settler compartment. Sludge withdrawal and dewatering have also to be designed

## 4.0 USEFUL PARAMETERS FOR DESIGN

The following physical and process design parameters are useful in preparing the initial designs for UASBs for both municipal and industrial wastewaters.

### 4.1 Physical Parameters

A single module can handle 10 to 15 ML/day of sewage. For large flows, a number of modules can be provided to make up the total flow such that if one module is out of operation, the overload on each of the remaining modules will be a handleable fraction of the total inflow. Some physical details of a typical UASB reactor module are given below.

| | |
|---|---|
| Reactor configuration in plan | Rectangular or circular. Rectangular shape is preferred for larger sized units as the required number of gas domes at the top can be accommodated. However, structurally, it is more economical to construct a circular shape. |
| Depth, width or diameter | 4.5 - 5.0 m for sewage. More for stronger wastes To limit the length of inlet laterals to around 10 - 12 m facilitating uniform flow distribution and sludge withdrawal. This can affect overall size of a module |
| Length | As necessary (in the case of rectangular units). |
| Inlet Feed | Depending on topography, pumping arrangement and likelihood of chokage of inlet pipes, one can provide either gravity feed from top (preferred for municipal sewage or (ii) pumped feed from bottom through manifold fan laterals (preferred in the case of soluble industrial wastewaters. |
| Sludge Blanket Depth | 2-2.5 m for sewage. More depth is needed for stronger sewage or industrial waste to keep within desired organic loading. |
| Deflector/GLSS | This is a deflector beam which together with the gas hood (slope–60 degree) forms a 'gas-liquid-solid-separator' (GLSS) letting the gas go to the gas collection channel at top, while the liquid rises into the settler compartment and the sludge solids fall back into the sludge compartment. The flow velocity through the aperture connecting the reaction zone with the settling compartment is generally limited to about 5 m/hr at peak flow. |
| Settler Compartment | 2.0-2.5 m in depth. Surface overflow rate equals 20-28 m3/ m2/day at peak flow |
| Loss of head through Unit | 2- 3 m for gravity feed with distribution from top of UASB through the use of splitter boxes and weirs to divide and regulate the feed to each inlet channel and then to downtake pipe (see fig 1) |

In case of municipal sewage, it is very important to provide inlet arrangements which, if choked, can be readily detected by the operator and cleaned. The hydraulic distribution of the inflow also has to be carefully designed so that the whole floor area of the unit is equally covered by the inlet point.

## 4.2 Process Design Parameters

A few important process design parameters for UASBs are listed below for municipal sewage with BOD around 200 - 300 mg/l and temperatures above 20°C:

| | |
|---|---|
| Hydraulic Retention Time (HRT) | 8 - 10 hours at average flow (minimum 4 hours at peak flow) |
| Solids Retention Time (SRT): | 30 - 50 days or more |
| Length | As necessary (in the case of rectangular units). |
| Solids Blanket Concentration (average) | 15-30 kg VSS per m3 for municpal wastewaters. (About 70 kg TSS per m3). Higher values for industrial wastes. |
| Organic Loading on Sludge Blanket | 0.3-1.0 kg COD/kg VSS day (even up to 10 kg COD/kg VSS day for agro-industrial wastes) |
| Volumetric Organic Loading | 1 3 kg COD/m3 day for sewage (10-15 kg COD per $m^3$ day for agro-industrial wastes). |
| BOD /COD Removal Efficiency | Sewage: 75-85% for BOD, 74-78% for COD. Industrial wastes: 85-95% for BOD/COD |
| Inlet Points | Minimum I point per 3.7-4.0 $m^2$ floor area |
| Flow Regime | Either constant rate for pumped inflows or typically fluctuating flows for gravity systems. In the latter case, the peak and average flows must be known |
| Up flow Velocity | About 0.5 m/hr at average flow, or 1.2 m/hr at peak flow, whichever is lower |
| Sludge Production: | 0.15-0.25 kg TS per m3 sewage treated |
| Sludge Drying Time: | About seven days (in India). Normally, UASB sludge is easier to dry than conventional digested sludge |
| Gas Production | Theoretical 0.38 m3/kg COD removed. Actual 0.1- 0.3 m3 per kg. COD removed. |
| Gas Utilization | The method of use is optional (see text) 1 m3biogas with 75% methane content is equiv alentto 1.4 kWh electricity. |
| Nutrients Nitrogen and Phosphorus Removal | 5-10% only |

## 4.3 SULPHATES AND SULPHIDES

Sulphides require special attention in case of all anaerobic processes as they can lead to a lot of corrosion and other problems. Sulphides may come from industrial sources or be formed in the anaerobic units as a result of the reduction of sulphates present in the wastewaters. High sulphates may come from the original water supplies of the city or industrial wastes. They may also come from infiltration of brackish ground waters where sewers pass through such area. The extent to which sulphates (SO4) contained in the influent to the UASB are converted to sulphides (S) depends on various factors and removals can vary from 50-90 per cent or more. The sulphates so removed are converted to sulphides.

Sulphides formed equal one third of the sulphates removed, stoichiometrically. Sulphides ($S_2$) can be toxic above 100 mg/1, but are partly converted to $H_2S$, which is less toxic. Depending on the pH and dissociation constant at given temperature, the unionised $H_2S$ can be determined.

The free or unionized $H_2S$ fraction at pH 7.0 to 7.4 may be about 0.2-0.4 of the sulphides present and can be toxic to the process at about 250 mg/l for granular sludge (for dispersed sludge the limit is 50 mg/1) Gas production can then be diminished by about 50 per cent or more and the corresponding economy of the system also diminished. Sulphate reduction also consumes some COD and to that extent, less COD is available for gas production.

Sulphides tend to remain dissolved in the liquid phase if the COD/$SO_4$ ratio is less than 7-10, though ratios as low as 0.5 have been operated with, as long as $H_2S$ is less than 200 mg/l. When the COD/$SO_4$ ratio is higher than 10, the sulphide tends to get stripped from the liquid phase to the gas phase owing to the higher rate of gas production. The dissolved $S_2$- still remaining in the liquid phase goes out in the effluent. At pH 7.2, the residual sulphides may be about 25 % of the sulphides formed earlier; and will have an immediate oxygen demand at the rate of 2g of $O_2$ per 1 g of sulphides

This immediate oxygen demand has to be met by aerating the effluent as stated. This again reduces, to some extent, the economy of the UASB system. Discharge standards in India generally allow sulphides up to 2 mg/l in effluents to be discharged to surface waters and 5 mg/l to marine coastal waters.

Possibilities of conversion of sulphides into elemental sulphur from anaerobic effluents high in sulphides have been successfully explored and provide interesting opportunities for by product recovery of sulphur where sulphates/sulphides are in high enough concentration in raw wastewater. This approach appears more favourable to follow than aerating the effluent. It can also be used to treat exhaust gases.

## 4.5 GAS PRODUCTION AND COD BALANCE

Theoretically, gas produced at 25°C and 1 atm - 0.38 $m^3$ per kilogram of COD removed. However, since COD is removed in various ways as shown below, the effective gas production may be only 0.10-0.3 $m^3$ per kilogram of COD removed. About 15 L biogas is produced per day per population equivalent. Biogas has about 70-80 per cent methane content, on an average. In energy terms, 1 $m^3$ biogas with 75 per cent methane content is equivalent to 1.4 kWh electricity.

Only a part of the biogas formed in the UASB is available for energy purposes, with the rest staying dissolved in the wastewater and passing out with the effluent.

Typically, in terms of COD balance, about 80 per cent of the COD is removed in process, while the balance 20 per cent COD goes out with the effluent. Out of the 80 per cent COD removed in the process, (23 + 23.5) per cent is accounted for by the gas produced, whereas nearly 31 per cent is the COD of the sludge. A relatively small percentage of the COD is consumed in sulphate reduction. If sulphates in the influent are high, this percentage can be quite high, and to that extent, less gas would be produced

## 4.6 GAS RECOVERY

Gas recovery is optional, though normally favoured in view of its fuel value and fears of global warming. In case of high BOD industrial waste, gas recovery is generally desirable, but in case of municipal systems, the gas production may be relatively small and the fuel value of the gas may or may not justify the expenditure and complexity of having a proper gas recovery arrangements with a gas-tight dome on top of the reactor, gas scrubbing (to remove $H_2S)_1$ gas piping, metering, storage and conveyance to place of usage. Also, in most parts of India, the temperatures of digester contents do not fall so low as to need gas for UASB heating. If gas is collected but not used, a flare may be installed to burn the biogas. It also helps avoid odour nuisance from any $H_2S$ present in the gas.

If at all gas recovery is to be practiced for municipal installations, it would be wiser to find bulk consumers of gas nearby and sell them the surplus gas directly rather than try to produce electricity.

The economics and desirability of the whole gas recovery question has therefore to be carefully reviewed in each individual case. Generally, in terms of operating costs, the UASB process is cheaper to operate than usual conventional processes for municipal plants, even when the income from gas recovery is neglected.

## 7.8 NUTRIENTS

Removal of nitrogen can hardly be expected from an anaerobic unit like the UASB. Anaerobic units are unable to remove any Kjeldahl nitrogen (TKN) by means of oxidation. Some organic nitrogen is converted (further reduced) to ammonia-nitrogen (NH-N). Total nitrogen removal of less than 5-10 per cent may be expected from UASB (Alaerts et al., 1990). This is no problem where irrigational use is to be made of the treated effluent. However, for surface water discharge, TKN (as NH3) has to be limited to 100 mg/1 in India, and post-treatment after UASB has to be designed for it, if necessary.

Phosphorus removal is also relatively small in a UASB (less than 3 per cent). However, both nitrogen and phosphorus are very useful to retain in the effluent where irrigational use is made.

## 7.9 TOXICITY

Toxicity in a UASB is reported to come from the following, which may be present in high enough concentrations in industrial wastes. Municipal wastewater, which is predominantly domestic in character, generally presents no problem because of relatively low concentrations in the waste.

Toxicity in anaerobic systems may be: (i) pH-related, or (ii) immediate, or (iii) concentration- related, as shown below:

**1. pH-related toxicity**

Ammonia, VFA and sulphides are prominent members of this group as they dissociate in water depending on pH and their dissociation constant. In their undissociated form, they are toxic at the following concentrations:

| | |
|---|---|
| Ammonia | 1000mg/1 |
| VFA (volatile fatty acids) | 1000 mg/l |
| Dissolved sulphides | 50 (dispersed sludge) to 250 mg/1 (granular sludge) (as unionized H2S) |
| 2) Immediate toxicity | |
| Chlorinated compounds (CCI4, CH;Cl, CH,CI2) | I mg/1 or less |
| Cyanides | Highly toxic, but adaptation possible |
| Formaldehydes | 50-100 |
| Oxygen | Toxic to methane formers |
| 3) Concentration-related | |
| Heavy metals | 1-10 mg/1 bu generally precipitated as non-toxic metal sulphides and may cause sludge disposal problems (Aharnmed et al., 1998). |

**7.10 PLANT COMMISSIONING AND OPERATION**

Generally, two to three months time is needed to build up a satisfactory sludge blanket without the addition of 'seed' sludge from a working UASB. A shorter time is needed if seeding is done. During the start-up period, chemical oxygen demand (COD) removal in the UASB gradually improves as sludge accumulation occurs. This may be called the sludge accumulation phase. The end of the sludge accumulation phase is indicated by a sludge washout. At this time, the reactor is

shut down to improve the quality of the sludge. This may be called the sludge improvement phase. After sludge improvement, blanket formation starts. Once the blanket is formed, again some surplus sludge washout could occur and in order to get stable operation, one has to thereafter keep removing the excess sludge periodically. The excess sludge so removed can be sent directly to the sludge drying bed. No separate digestion is needed.

The sludge accumulated in the UASB is tested for pH, volatile fatty acids (VFA) alkalinity, COD and SS. If the pH reduces while VFA increases, do not feed new material until the pH and VFA stabilize. If on any day, it is observed that the VFA: Alk ratio is less than 1:2, one should stop feeding for the day and add bicarbonate alkalinity to bring the ratio to 1:2.

The daily operation of the UASB requires minimum attention. No special instrumentation is necessary for control, except where gas conversion to electric power is practiced. As stated, surplus sludge is easy to dry over an open sand bed. The reactor may need to be emptied completely once in five years, while any floating material (scum) accumulated inside the gas collector channels may have to be removed every two years to ensure free flow of gas (DHV and Haskonings, 1993).

## 7.11 POST-TREATMENT REQUIREMENTS

Some form of post-treatment is generally required after an UASB. Where 75-80 per cent BOD removal is adequate to meet effluent discharge standards, further treatment may be required only to give slight aeration to the effluent to destroy anaerobicity. In such a case, a simple cascade‘ type post-treatment may b adequate. The same effect may be obtained in the effluent flowing through a long enough open channel to an irrigation area, or by the provision of a short detention algal oxidation pond if land is available. In India, irrigation standards (BOD< 100 mg/l] are generally conveniently met by UASBs when followed by some aeration as above. The standards for discharge to creeks can also be met.

When stricter effluent standards have to be met (as for river discharge), some better form of post-treatment may become necessary. The design of a proper post-treatment system is important for the success of any project involving an anaerobic step. Post-treatment required may be given in various forms to meet effluent discharge standards. A few typical methods are listed in Table below and may be used singly or in combination depending on site-specific requirements.

**Typical post-treatment methods of UASB**

| | | |
|---|---|---|
| 1 | Provision of cascades or holding of effluent in a short detention algal oxidation pond with or without aeration. | To drive off odorous gases, (sulphides) destroy anaerobicity, and catch any solids carry over that may occasionally occur. |
| 2 | Aerobic biological treatment (e.g. aerated lagoon, activated sludge, extended aeration). | To reduce sulphides, suspended solids, BOD/ COD and nutrients (nitrogen and phnsphnru). |
| 3 | Chemical treatment | To remove sulphides, adjust pH. reduce suspended solids, BOD/COD and nutrients (phosphorus). |
| 4 | Oxidation ponds (three cells in series) | To eliminate helminths and reduce pathogen-,etc. |
| 5 | Duckweed ponds | To reduce suspended solids, BOD/COD and nutrients (phosphorus). |

### 7.11.1 Post-treatment Ponds and Lagoons

In the case of municipal sewage, where sulphides are not expected to be a special problem and the final effluent is to he used for irrigation, the flow from an anaerobic unit can he treated in a simple algal oxidation pond of short detention (about half to one day) to provide some aeration and also settle some solids that may occasionally overflow from the anaerobic unit. Algal growth cannot he expected at pond detention times less than the multiplication rate of algal cells, which is 2 to 2.5 days at $20^0$ C. Thus, pond detention time would have to be kept to about 2.5 days if algal growth to meet the oxygen demand of the effluent is desired. Moreover, the presence of sulphides above 4.5 to 6 mg/l in the effluent would deter algal growth altogether, even if detention time was adequate from the point of view of cell growth rate. Thus, in some cases, a short detention, mechanically aerated lagoon for post-treatment may need to be considered rather than an algal pond.

## 7.12 SOME PROS AND CONS IN THE USE OF UASB

1. Capital Costs: The capital cost of the UASB system for low BOD municipal sewage is more or less of the same order as that of activated sludge extended aeration process which makes the cost relatively high compared to the effluent quality expected from it, namely 75-85 per cent BOD removal against 93 per cent in activated sludge and 97 per cent in the case of extended aeration. The cost of the UASB system may be even higher if much post-treatment is required for meeting discharge standards. BOD removal of only 75 to 85 per cent makes the UASB a good and economical form of intermediate treatment, such as that required prior to land irrigation in India. The flow sheet remains simple and devoid of moving machinery

2. Operating Costs: The low operating power cost of UASB makes it worthwhile to be considered, especially in developing countries where power costs are high, and/or power supply is not dependable. Because of low operating costs, the UASB is today the cheapest method of municipal sewage treatment, especially when complicated post-treatment is not needed. Its main advantage is its almost zero power requirements for BOD reduction, and its low land requirement.

If power failure occurs, the process does not suffer since it is already anaerobic in nature and little electrical equipment is involved. Provision of captive power supply for only initial pumping of raw sewage can keep the whole plant operational at all times. This is a great advantage in many parts of India where regular power cuts occur. Moreover, with minimal equipment, their repair and maintenance is also simplified.

The benefit from power saving is so substantial that even if no gas recovery is done, the UASB becomes cheaper than other processes in terms of the 'present worth' method of comparison of capital and operating costs.

3. Wastewater and Sludge Quality: The inflowing quality of the raw wastewater and its fluctuations must be carefully considered before a UASB is adopted. The following factors should be kept in mind:

- Saline water infiltration into sewers laid in coastal areas and/or presence of certain industrial wastes can bring in sulphates into the inflow, which, in the anaerobic atmosphere of the UASB, can be reduced to the highly corrosive and toxic form of sulphides as stated earlier. The sulphides in the effluent would need to be aerated to convert back to sulphates before discharge. This would be a set-back.
- Certain heavy metals present in industrial wastes can retard biological action in UASBs or get precipitated as metal oxides in the UASB making sludge disposal difficult.
- Inflow fluctuations can give corresponding fluctuations in upflow velocities leading to some solids carry over in effluent. In some cases, this may need prior 'equalization' of the-inflow. However, equalization must be achieved without any aeration of the wastewater, as oxygen is toxic to anaerobic processes.

4. Corrosion: The corrosion potential of anaerobic systems is a major negative point and makes it important to choose the right construction materials. Otherwise, corrosion can ruin a UASB in no time. The use of M-20 grade concrete, FRP, PVC, HDPE and such other materials in strategic parts of_the UASB is essential, although it increases the construction cost substantially.

Conclusion: Wherever it is feasible to provide the UASB, it is the least demanding process on resources in terms of land, energy and finances. The facultative aerated lagoon, on the other hand, is somewhat lower in initial capital cost, but requires both more power and land than the UASB. In India, power supply is short and must be conserved for sustainability. Land also needs to be conserved especially since sewage treatment requires very valuable land in the vicinity of cities.