From Water and Wastewater.com

Ask Tom! Column

Methods for UASB Reactor Design

Guest article by Nguyen Tuan Anh

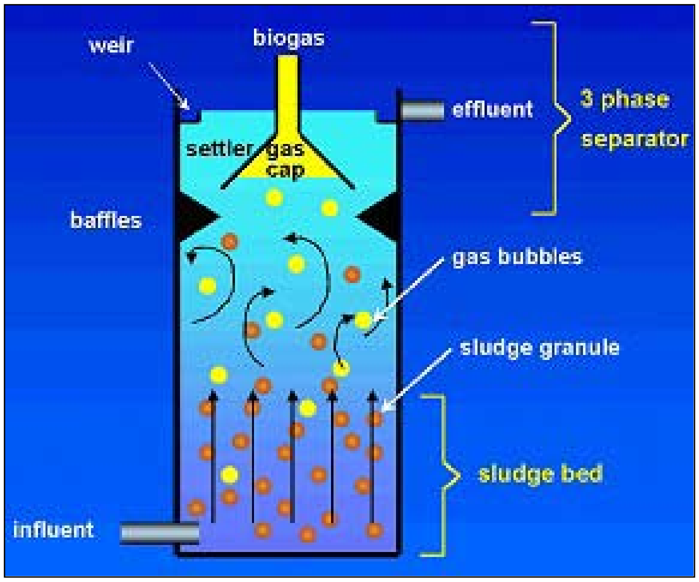

Figure 1. Essential Components of an UASB Reactor (courtesy: http://www.uasb.org/discover/agsb.htm)

Introduction

Anaerobic treatment is now becoming a popular treatment method for industrial wastewater, because of its effectiveness in treating high strength wastewater and because of its economic advantages.

Developed in the Netherlands in the late seventies (1976-1980) by Prof. Gatze Lettinga - Wageningen University, UASB (Upflow Anaerobic Sludge Bed) reactor was originally used for treating wastewater from sugar refining, breweries and beverage industry, distilleries and fermentation industry, food industry, pulp and paper industry.

In recent times the applications for this technology are expanding to include treatment of chemical and petrochemical industry effluents, textile industry wastewater, landfill leachates, as well as applications directed at conversions in the sulfur cycle and removal of metals. Furthermore, in warm climates the UASB concept is also suitable for treatment of domestic wastewater.

In recent years, the number of anaerobic reactors in the world is increasing rapidly and about 72% consist of reactors based on the UASB and EGSB technologies.

Anaerobic Processes in the UASB Reactor

There are 4 phases of anaerobic digestion in an UASB reactor

- *Hydrolysis,* where enzymes excreted by fermentative bacteria convert complex, heavy, un-dissolved materials (proteins, carbohydrates, fats) into less complex, lighter, materials (amino acids, sugars, alcohols...).
- *Acidogenesis,* where dissolved compounds are converted into simple compounds, (volatile fatty-acids, alcohols, lactic acid, CO_2, H_2, NH_3, H_2S) and new cell-matter.
- *Acetogenesis,* where digestion products are converted into acetate, H_2, CO_2 and new cell-matter.
- *Methanogenesis,* where acetate, hydrogen plus carbonate, formate or methanol are converted into CH_4, CO_2 and new cell-matter.

Specifics of the UASB Reactor

When comparing with other anaerobic reactors, we conclude that the differences as well as the specifics of an UASB are existence of granules sludge and internal three-phase GSL device (gas/sludge/liquid separator system)

Granules sludge: In an UASB reactor, anaerobic sludge has or acquires good sedimentation properties, and is mechanically mixed by the up-flow forces of the incoming wastewater and the gas bubbles being generated in the reactor. For that reason mechanical mixing can be omitted from an UASB reactor thus reducing capital and maintenance costs. This mixing process also encourages the formation of sludge granules.

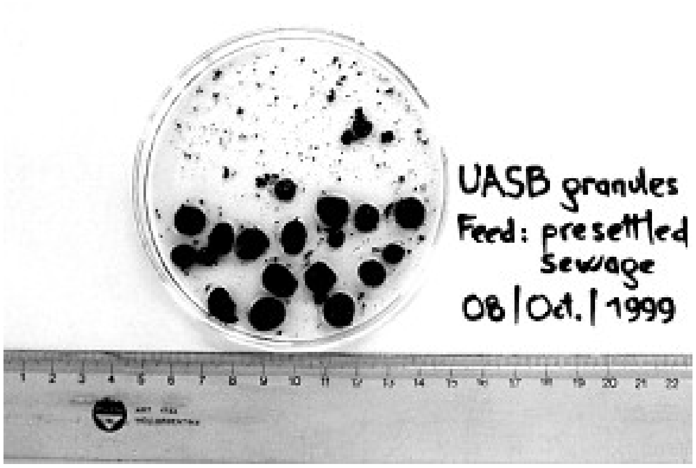

Figure 2. Shape and size of granules sludge

The sludge granules have many advantages over conventional sludge flocs:

- Dense compact bio-film
- High settle-ability (30-80 m/h)
- High mechanical strength
- Balanced microbial community
- Syntrophic partners closely associated
- High methanogenic activity (0.5 to 2.0 g COD/g VSS.d)
- Resistance to toxic shock

Internal three-phase GSL device: Installed at the top of the tank, the GSL device constitutes an essential part of an UASB reactor with following functions:

- To collect, separate and discharge the biogas formed.
- To reduce liquid turbulences, resulting from the gas production, in the settling compartment.
- To allow sludge particles to separate by sedimentation, flocculation or entrapment in the sludge blanket.
- To limit expansion of the sludge bed in the digester compartment.
- To reduce or prevent the carry-over of sludge particles from the system.

UASB Design

In general, there are two ways to design an UASB reactor

1. If input COD: 5,000 - 15,000 mg/l or more, the design method should be used based on Organic Loading rate, (OLR)
2. If input COD < 5000 mg/l, the design method should be calculated based on velocity.

Calculation UASB Tank Base on OLR

If input COD: 5,000 - 15,000 mg/l
with Organic loading rate ORL: 4 - 12 kg COD/m3.d
and Hydraulic retention time HRT: 4 - 12 h

COD treatment efficiency: E = (CODinput – CODoutput)/CODinput

In Calculation, Percent of COD removal is 75 - 85 %

Organic loading rate ORL = Q (CODinput – CODoutput) * 10^3

Volume of tank W = C * Q / OLR = (kg COD/m3 * m3/h) / (kg COD/m3.h)

C: concentration of COD in wastewater
Q: flow rate of wastewater

H (m) the height of tank can be calculated by: $H = H_S + H_{Se}$

The height of sludge layer Hs is: Hs = V * HRT

where Hs: the height of sludge layer area (main reactor)
and Hse: the height of sedimentation area
Where V = Velocity of flow 0.6 to 0.9 m/h
HRT = Hydraulic retention time (h)

In general, the height of sludge layer will be chosen in Table 1:

Table 1. Sludge Layer Height Selection

COD input	Sludge layer height
< 3000 mg/l	3 – 5 m
> 3000 mg/l	5 – 7 m

Note: Sludge layer is longer than sludge bed layer

The height of setting area $H_{Se} \geq 1.2$ m and

The area surface of an UASB tank (m2): A = HRT * Q / H

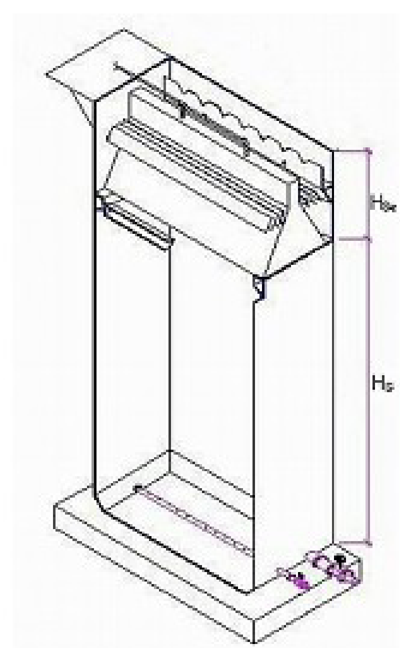

Figure 3. A typical model of an UASB design

Calculating an UASB Tank Based on Velocity

When input COD < 5,000 mg/l, using the method base on ORL is not effective in operation process because the granular sludge will be hardly formed. Therefore, the design criteria must be:

- Up-flow velocity V J 0,5 m/h.
- Hydraulic retention time HRT J 4 h
- Chosen in table 1, the height of sludge is Hs = 3 – 5 m
- The height of setting area HSe J 1.2 m

The volume of the UASB reactor: W = Q x HRT
The area of the UASB reactor: A = V / Q

GSL Separator Design

Slope of the separator bottom from 45 – 60°
Free surface in the aperture between the gas collectors: 15 – 20% of reactor area.
Height of separator from 1.5 – 2 m

The baffles to be installed beneath the gas domes should overlap the edge of the domes over a distance from 10 – 20 cm

Construct material: In the anaerobic conditions of an UASB reactor, there is a risk of corrosion in two main situations:

- Some H2S gas can pass the GSL separator and accumulate above the water level in the top of the reactor. This will be oxidized to sulphate by oxygen in the air to form Sulphuric Acid that will in turn cause corrosion of both concrete and steel.
- Below the water level: Calcium Oxide, (CaO), in concrete can be dissolve with by Carbon Dioxide, (CO2), in the liquid in low pH conditions.

To avoid these problems, the material used to construct the UASB reactor should be corrosion resistant, such as stainless steel or plastics, or be provided with proper surface coatings, (e.g. coated concrete rather than coated steel, plastic covered with impregnated hardwood for the settler, plastic fortified plywood, etc).

Operation

Operation criteria: The optimum pH range is from 6.6 to 7.6 The wastewater temperatures should not be < 5°C because low temperatures can impede the hydrolysis rate of phase 1 and the activity of methanogenic bacteria. Therefore in winter season, methane gas may be needed to heat the wastewater to be treated in the reactor.

Always maintain the ratio of COD : N : P = 350 : 5 : 1 If there is a deficiency of some of these nutrients in the wastewater nutrient addition must be made to sustain the micro-organisms. Chemicals that are frequently used to add nutrients (N, P) are NH4H2PO4, KH2PO4, (NH4)2CO3...

Suspended solid (SS) can affect the anaerobic process in many ways:

- Formation of scum layers and foaming due to the presence of insoluble components with floating properties, like fats and lipids.
- Retarding or even completely obstructing the formation of sludge granules.
- Entrapment of granular sludge in a layer of adsorbed insoluble matter and sometimes also falling apart (disintegration) of granular sludge.
- A sudden and almost complete wash-out of the sludge present in reactor
- Decline of the overall methanogenic activity of the sludge due to accumulation of SS

Therefore, the SS concentration in the feed to the reactor should not exceed 500 mg/l In phase 2 and 3 the pH will be reduced and the buffer capacity of wastewater may have to be increased to provide alkalinity of 1000 – 5000 mg/l CaCO3

Start-up: An UASB reactor requires a long time for start-up, e.g. from 2 – 3 weeks in good conditions (t > 20°C) and sometimes the start-up can take up to 3 – 4 months. In start-up process, hydraulic loading must be J 50% of the design hydraulic loading.

The start-up of the UASB reactor can be considered to be complete once a satisfactory performance of the system has been reached at its design load.

Note: Information provided at http://www.uasb.org/discover/agsb.htm is acknowledged in the preparation of this article.

About Our Author

Nguyen Tuan Anh

++++++++++++++++++++++++