START-UP GUIDELINES

DEFINITION OF START-UP

Start-up of anaerobic reactors can be divided into two different categories, (1) Primary start-up and (2) Secondary start-up. In case of primary start-up the inoculum seed is not adapted to the waste. It has to undergo a selection, which radically alters the species distribution of the microbial population. The secondary start-up is most favorable in which the inoculum seed is already adopted to the substrate and the biomass only needs to grow in order to cope with the organic overload.

Start-up can be defined as the period of transient operation beginning when the process is started and lasting until full load steady state conditions are reached. The steady state conditions mentioned is a pseudo-steady state condition. High loading rates can only be achieved if high concentrations of active biomass are maintained within the reactor i.e., high microbial growth rates and good sludge settleability are the main conditions to achieve a successful start-up [Brunetti *et al*., 1983]. Thus, proper start-up methods are necessary to develop granular sludge with higher settling velocity, hence to maintain higher Solid Retention Time (SRT), and to develop sludges with maximum methanogenic activity to have maximum substrate conversion rate.

Different researchers have defined the start-up based on the parameters such as, methanogenic activity [Zeeuw *et al*., 1983, Lettinga *et al*., 1993b]; based on steady state achieved in effluent COD concentration and gas production [Gnanadipathy *et al*., 1993, Fang and Chui, 1993]; and based on volumetric COD removal rate [Lettinga and Hulshoff, 1991]. Basically in all the cases the duration of start-up was a time needed to achieve steady state performance for the reactor.

In UASB reactor in the start-up phase of operation the aim is to develop good quality granular sludge so as to meet the advantages mentioned earlier; and to achieve maximum COD reduction efficiency at high loading conditions. Thus, granulation of biomass and high COD reduction efficiency is an indication of successful start-up of the process. It has been the point of investigation in the last decade, and extensive studies have been done in this direction. Shortening of the start-up time along with good granulation to sustain higher loading rates is one of the key parameters to increase the effectiveness of this process. The start-up and granulation depend upon numerous parameters like inoculum characteristics and quantity, environmental parameters such as pH, temperature, and nutrients availability in the wastewater, and reactor hydrodynamics and geometry of the reactor, etc.

Type of Inoculum Sludge

The presence of bacterial culture and carrier materials for bacterial attachment is essential for the initiation and stimulation of sludge aggregation [Hulshoff and Lettinga, 1986]. Digested sewage sludge is most commonly used as the seed for granulation. Relatively easy and fast reactor start-up is possible with this type of seed sludge. The good inoculum digested sludge is characterized by low residual methanogenic activity (< 0.6 kg CH_4-COD/m^3.d) as well as good settleability (SVI, 50 mL/g VSS) after wash out of the colloidal fraction [Zeeuw and Lettinga, 1983]. With this type of sludge a long enough biomass retention time is possible to enable development of granular sludge devoid of support particles.

The digested sewage sludge with total solids less than 40 kg TS/m^3 usually has higher methanogenic activity than thicker types with total solids greater than 60 kg TS/m^3. Sludge with concentration of 30 to 40 kg TS/m^3 exhibit the highest methanogenic activity [Zeeuw and Lettinga, 1983]. However, the thicker types are more preferred, since a longer sludge retention time could be maintained [Hulshoff and Lettinga, 1986]. With thinner types of sludges, excessive expansion of sludge bed may result in washout of sludge, and a longer time may be required for sludge granulation. Inoculated digested sludge concentrations of 10 to 20 g VSS/L in the reactor region is recommended for thicker sludge type [Hickey *et al*., 1991b], and about 6 g VSS/ L for thinner type of digested sludge.

Start-up with out any seed material is possible for raw sewage [Barbosa *et al*., 1989, Lettinga *et al*., 1993b]. Long start-up is necessary in this case. The start-up time required in this case was reported to be 6 to 12 weeks.

Start-up and granulation is possible with inoculum sludge other than digested sewage sludge. Activated sludge also has enough methanogenic bacteria and can be used as an alternative to digested sewage sludge [Wu *et al*., 1987, Guyot *et al*., 1990]. Successful cultivation of granules using digested sludges, activated sludge, cow manure have been reported for variety of wastewater over a wide temperature range from 20 to 55^{o}C [Hulshoff *et al*., 1983a, Wiegant and Man, 1986, Wu *et al*., 1987, Manjunath *et al*., 1989, Campos *et al*., 1986, Peng and Jin, 1993].

Facultative waste stabilization pond sludge was also reported to be a suitable inoculum source for the UASB reactors treating a low strength domestic wastewater [Gnanadipathy *et al*., 1993]. Flocculent sludge from an anaerobic rotating biological contactor reactor can also be used for successful start-up of the reactor [Yan *et al*., 1993].

Bottom sediments of polluted ditch and sludge from septic tanks may also be used as seed material [Grin *et al*., 1983]. Even raw sewage and fresh cow manure are among the options [Wiegant *et al*., 1985a,b, Wiegant *et al*., 1986, Souza, 1986].

If granular sludge from existing UASB reactor is used as seed material, it is superior to digested sewage sludge. The start-up process with granular sludge may be faster, depending on the nature of the wastewater and characteristics of the sludge [Hulshoff *et al*., 1983a, Maat and Habets, 1987, Cao *et al*., 1992, Hajipakkos, 1992, Goodwin *et al*., 1992]. If the UASB reactor is seeded with granular sludge adapted from other full scale plants with similar wastewater composition, the full organic load can be injected very quickly [Hacks, 1985] or even from the start depending on the volume of inoculum granular sludge used. Thus, the start-up time can be reduced from several months to less than a day [Maat and Habets, 1987]. But when, the granular sludge is not available for similar characteristics of the wastewater, and even if available the cost of granular sludge is much higher, then it is necessary to go for primary start-up procedure, which may be cheaper than adopting granular sludge.

Problem may arise when the granular sludge is exposed to wastewater that has a very different composition and strength from that on which the granular sludge was originally cultivated [Hall and Jovanovic, 1982, Kudo *et al*., 1991]. The characteristics of the sludge may be expected to change in this case and secondary start-up becomes necessary [Peng and Jin, 1993].

Addition of small amount of crushed granular sludge in to the digested sludge seed can significantly enhance the development of granular sludge [Hulshoff *et al.*, 1983a,b, Hulshoff and Lettinga, 1986]. It can sharply increase the methanogenic activity. However, too large an amount of crushed granular sludge, greater than 15 % of the total seed material, will have no obvious beneficial effect although a smaller amount (less than 8 %) clearly enhances granulation. Addition of granular activated carbon to the basic non-granular seed sludge also found to have enhancing effect on granulation process and the reactor performance [Morgan *et al.*, 1991b].

Start-up of reactor: the required amount of inoculum should be added in the reactor depending on the desired sludge loading rates. The amount of inoculum required is generally about 30% of the reactor volume [Hickey *et. al.*, 1991]. While adding the inoculum care should be taken for minimum exposure of inoculum sludge with air. The start-up of the reactor, after addition of inoculum, should be preferably carried out at medium substrate concentration (1000 to 3000 mg/L) to allow high hydraulic loading rates. The organic loading rate during start-up should be preferably between 2 and 3.5 kg COD/m^3·d and sludge loading rate should be between 0.15 and 0.25 kg COD/ kg VSS.d [Ghangrekar *et. al.*, 1996]. With these loading conditions proper granulation of biomass in the reactor is expected with low SVI and higher settling velocity of a sludge for better retention. Once proper granulation of biomass is achieved in the reactor the loading to the reactor can be increased in steps to match with designed loading conditions. The OLR should, if possible, be increased by decreasing only HRT instead of increasing COD concentration [Campos and Anderson, 1992]. This allows washout of poor sludge and improves mixing in the reactor. The predetermined level of COD concentration, if greater than 3000 mg/L, should be achieved in steps only after granules have been formed in the reactor. The step increase in loading should be selected in such a way that it should not cause shock loading to the reactor. The step increase in loading can be 1.5 to 2 times earlier loading or the increment in OLR can be about 2 kg COD/m^3.d and increment in SLR can be 0.1 to 0.2 kg COD/ kgVSS.d [Lema *et. al.*, 1991], whichever is minimum.