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Aerobic Granulation Technology – An Improvement over Activated Sludge Process

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***Abstract*—Conventional activated sludge process plants requires a large footprint because of the poor settling characteristics of the activated sludge. Aerobic granulation technology is proved to an effective and economic technology to overcome the drawbacks of conventional activated sludge process like low organic loading rates and long settling time. Aerobic granulation was experimented in a laboratory model of sequencing batch reactor with high organic loading rates and low settling times. Very good performance was observed with organic loading rate of 6 kg of COD/m3.d and with a settling time of 5 min. Aerobic granules of 2.4 mm size and sludge volume index of 26 ml/g were developed at optimum conditions. A removal efficiency of 98% was observed for chemical oxygen demand. The experimental study proved that aerobic granulation technology is a more effective and economic technology for the treatment of wastewater compared to conventional activated sludge process.**

***Keywords*—Activated Sludge Process, Aerobic Granulation, Organic Loading Rate, Sequencing Batch Reactor, Settling Time.**

I. INTRODUCTION

Solid-liquid separation is the basic idea of all types of water and wastewater treatment systems. Biological treatment of wastewater employs the use of microorganisms in the processing and cleansing of wastewater. Many microorganisms are able to metabolize a variety of organic and inorganic substances that are present in wastewater. Biological wastewater treatment takes advantage of this property and supports it with various nutrients and aeration. The types of bacteria utilized in wastewater processing can be categorized based upon their necessity or intolerance of oxygen to survive. Aerobic microbial communities have several specific advantages. They have large free energy potentials, enabling a variety of often parallel biochemical mechanisms to be operated.

In activated sludge process, treatment of wastewater is based on providing intimate contact between wastewater and biologically active sludge. The activated sludge is obtained by settling sewage in presence of abundant oxygen so as to be supercharged with favourable aerobic microorganisms [1]. The activated sludge which is made to settle in the secondary sedimentation tank is flocculant in nature. These biosolids have relatively poor settling characteristics, which in turn demand large area for the settling units. Hence conventional wastewater treatment plants based on activated sludge process require a large footprint. To overcome the disadvantages of a conventional wastewater treatment plant, biomass has to be grown in a compact form, like granular sludge. This eliminates the use of the large settling tanks and allows much higher biomass concentrations in the reactors. This leads to the concept of biogranulation.

Biogranulation includes anaerobic and aerobic granulation processes. Anaerobic granulation has been well documented for decades. In spite of the wide scale applications, anaerobic granulation technology has some drawbacks. Treatment of low strength organic wastewater and removal of nitrogen and phosphorus are not efficient using anaerobic granulation technology. Other drawbacks include the need for a long start-up period, a relatively high operation temperature and unsuitability for low strength organic wastewater. Hence the research has been devoted to the development of aerobic granulation technology to overcome the above drawbacks [2]. Intensive research in aerobic granulation started in late 90s. Although Mishima and Nakamura [3] developed aerobic granules with good settling properties in upflow sludge blanket reactor, aerobic granulation has since been reported in Sequencing Batch Reactors (SBRs) by many researchers after 1996 only [4-7].

The aerobic granules have several advantages over conventional activated sludge flocs. These include a strong and compact microbial structure, improved settling ability and higher biomass retention. The efficiency of biomass retention in SBRs is a function of the settling characteristics of the microbial aggregates. As granular sludge settles much faster than activated sludge flocs, higher biomass retention can be achieved within a more condensed settling process. Because of their ability to retain biomass, aerobic granules are capable of handling significantly higher organic loading rates (OLRs) compared to conventional activated sludge systems [8].

To date, most research on aerobic granulation has been done in SBRs. The SBR method of wastewater treatment has received considerable attention because it is compact, easy to operate and maintain, and capable of eliminating nutrients. The SBR is a fill – and - draw (batch) activated sludge system in which the characteristics of operation can be varied by controlling the time period of each cycle. The system is operated in a cyclical manner, with each cycle consists of filling, aeration, settling, and decanting [9]. The SBR process is flexible in that the operational time applied to a cycle can be readily varied according to operational needs including hydraulic loading, economic efficiency of power requirements, or treatment levels for target contaminants [10].

II. MATERIALS AND METHODS

A. *Experimental Set-up and Operation*

A column type SBR with an effective volume of2 liters was used for the experiment. The internal diameter and the effective height of the reactor were 6.5 cm and 60.3 cm respectively. Influent was admitted from the bottom and the effluent was withdrawn from the middle port by two peristaltic pumps. Thus the volume exchange ratio was kept as 50%. Air was introduced from the bottom through a porous stone diffuser, maintaining a superficial air velocity of 3.0 cm/s. The reactor was operated in successive cycles of 4 hours, which is comprised of 5 min for feeding influent, 225 min for aeration, 5 min for settling, and 5 min for effluent withdrawal. The cyclic operation was controlled by a micro controller AT89C51. Schematic of the SBR is shown in Fig.1.

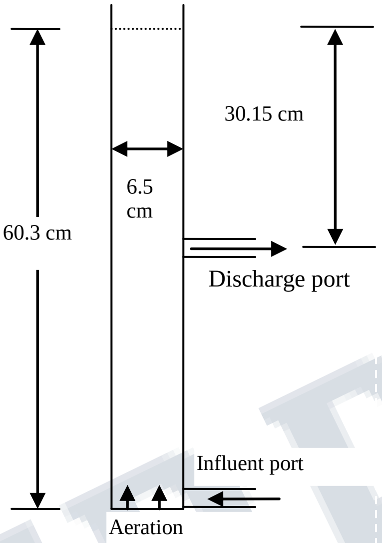

Fig. 1. Schematic of the Column SBR

B. *Influent and Seed Sludge*

The synthetic wastewater consisted of sodium acetate as the sole carbon source was used for the study. The composition of the feeding solution including micro-nutrients was adopted from Tay et al. (2002) [11]. It gives a total influent chemical oxygen demand (COD) of 2000 mg/l and an organic loading rate of 6 kg COD/(m3.d).

The seed sludge was collected from the activated sludge processing unit of the Petrochemical Division of Fertilizers And Chemicals Travancore (FACT) Limited, Cochin, and Kerala. The reactor was started with 750 ml of seed sludge.

C. *Analytical Methods*

Determination of COD, mixed liquor volatile suspended solids (MLSS), mixed liquor volatile suspended solids (MLVSS) and SVI as per standard methods [12]. Samples from the reactor were collected and analyzed for pH, COD, MLSS, and MLVSS daily and SVI on alternate days. pH and the dissolved oxygen (DO) concentration were monitored using a pH meter (Cyberscan pH-510) and DO meter (Cyberscan DO-110) respectively.

III. RESULTS AND DISCUSSION

A. Operation under various OLRs

Three different OLRs and settling times were tried in separate trials. Three OLRs were studied as 3, 6, and 9 kg COD/(m3.d) corresponding to influent COD concentrations of 1000, 2000, and 3000 mg/l in trial 1, 2 and 3 respectively. All other operating parameters except influent COD concentration and hence OLR were kept constant for these trials.

High fluctuations in effluent COD (CODe) were observed during the start-up period, but steadier conditions were observed after 20 days. Tiny granules were appeared in the reactor by 28th day of operation. At this stage the settling of the sludge became faster. The granules slowly grew in size and reached an average size of 1.8 mm. The reactor was operated for 45 days, in which the last 10 days showed percentage COD removal efficiency (CODre) of 95% to 96%. Hence the reaction was assumed to attain a steady state.

In the trial 2, The reactor was fed with CODi of 2000 mg/l (OLR = 6 kg COD/(m3.d)) and operated for 36 days. Steady conditions were achieved by around 28th day and a better CODre was also achieved (97.9%) towards the end of operation. Appearance and development of the granules were at a faster rate with an average final size of 2.4 mm. Trial 3 was conducted with CODi of 3000 mg/l (OLR = 9 kg COD/(m3.d)). Compared to the first two trials, trial 3 showed more fluctuations in CODe, and hence in COD removal efficiency too. The granules were grown to a size of less than 1 mm only.

The MLSS concentration of the seed sludge was 5050 mg/L. When the reactor was started with fresh influent, the MLSS concentration showed a slightly decreasing trend in all trials, and then gradually increased. These disturbances may be due to the struggle of the microorganisms to adjust with the new living conditions.

Sludge volume index (SVI) is an important property to test the settle ability of the sludge. The SVI of the seed sludge was 245 ml/g and showed the presence of fluffy flocs. The SVI of the reactor contents in all the three trials showed a decreasing trend. The minimum SVI observed were 31, 25.1, and 30.6 ml/g for trial 1, 2, and 3 respectively. Fig 2 and 3 show the variation of COD removal efficiency and SVI with applied OLRs.

Fluffy sludge has a small particle size and low density. Hence rate of settling will be low, resulting in a high SVI. The lower settling time provided in SBR, compared to that of conventional activated sludge process will eliminate very small suspended particles that are difficult to settle. Thus particles that can settle with in the allowed settling time will remain in the reactor, and particles with poor settle ability will be washed out [13].

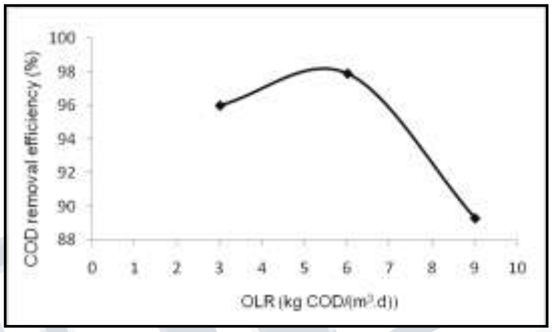

Fig.2. Variation of COD removal efficiency with OLR

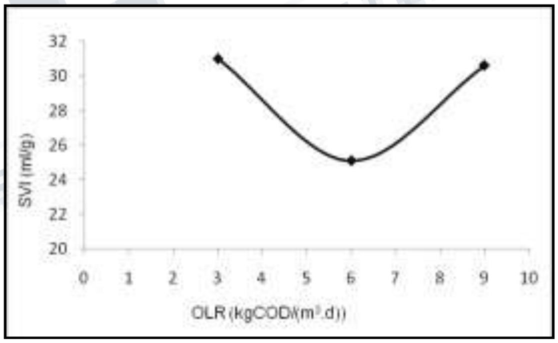

Fig. 3. Variation of SVI with OLR.

B. Operation under various Settling Times

Three different settling times (3 min, 5 min, and 10 min) were studied in three different trials (trial 4, trial 5, and trial 6 respectively). All other operating parameters except settling time were kept constant.

When the SBR was operated with settling time as 3 min, the MLSS was found to reduce considerably in the initial period of operation due to the wash out of poorly settle able sludge particles. The reactor could achieve a MLSS concentration above 2000 mg/l after two weeks only.

The granules were first visible on day 19, and soon after that MLSS showed a marked increase. Steady state was achieved on day 30 and the MLSS reached around 10000 mg/l towards the end of operation. When the settling time was increased to 5 min, the MLSS reach 7900 mg/l. Experiments with settling time as 10 min, formation and development of granules were delayed and they could not be get matured even after running up to 40 days. The MLSS also showed a drastic reduction towards the end of operation. The average size of the granules at three trials were 2.1, 2.4 and 1.1 mm (trial with settling time 3 min, 5 min and 10 min) respectively. The highest settling velocity (72 m/hr) was observed in trial 4.

The trial with settling time as 10 min resulted in a higher value of SVI (75 ml/g) and lower value of settling velocity (31.2 m/hr) compared to those obtained in other two trials. It can be concluded that a lower settling time favors a higher settling velocity. The variations of COD removal efficiency and SVI with settling time were graphically represented in Fig. 4 and 5 respectively.

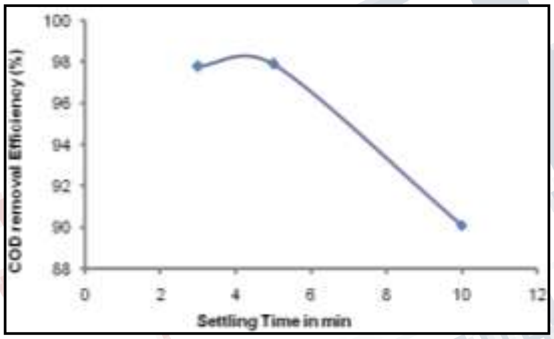

Fig. 4. Variation of COD removal efficiency with settling time

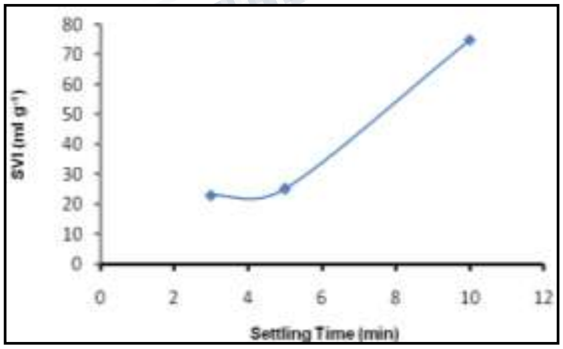

Fig. 5 Variation of SVI with settling time

Qin et al., (2004a, b) It is suggested that very weak selection pressure in terms of long settling time did not favour aerobic granulation and the settling time required for successful aerobic granulation would not be longer than 15 min [14, 15]. McSwain et al., (2004) and Adav et al., (2009) also concluded with experimental results that short settling times in SBR cycle select for fast settling granules and the initial mass wash-out and continual removal of flocs affects species selection during start-up and produces a less diverse but more stable population [16, 17].

C. Activated Sludge Process and Aerobic Granulation

Conventional sewage treatment plants based on activated sludge technology require a large footprint. This is caused by the relatively poor settling characteristics of activated sludge, resulting in low permissible dry solids concentrations in aeration tanks and in a low maximum hydraulic load of secondary sedimentation tanks [18]. Conventional suspended biomass reactors like activated sludge systems have specific drawbacks such as:

- low volumetric conversion capacity (0.5-2.0 kg of COD/m3.d) implying large reaction volumes;
- low sludge settling velocity with consequently large-sized sedimentation tanks [19].

Suspended biomass reactors with aerobic granules can overcome the above drawbacks to a good extent. Aerobic granules could be successfully developed with high strength wastewater (COD = 2000 mg/l) and higher organic loading rates (OLR = 6 kg of COD/m3.d). Very good COD removal efficiency also could be achieved with granules. Since these granules are of higher size (about 2.4 mm diameter) and density, settling time can be considerably reduced.

In the present study settling time provided was 5 minutes, instead of 1-2 hours in the case of conventional activated sludge process. Thus the area requirement is lowered very much. Under more controlled conditions, still higher OLRs can be applied with very good pollutant removal efficiency.

Because of the outstanding settling properties and sequential operation the use of a traditional or integrated settler is not necessary. Separation of sludge and effluent occurs within the reactor during a short settling phase. No long idle times due to sludge settling are required in these granulated sequencing batch reactors.

CONCLUSSION

Unlike conventional activated sludge systems, higher organic loading rates and shorter settling time could be achieved. When experiment was conducted, following conclusions were arrived:

- Aerobic granules could be developed successfully with OLR of 6 kg of COD/m3.d
- Aerobic granules developed have an average size of 2.4 mm.
- Aerobic granules developed have good settle ability and 5 min was found sufficient for the settling process
- Towards the end of the experiment, SVI reached a value less than 26 ml/g
- Very good COD removal efficiency, of the order of 98 % could be achieved

Aerobic granulation is proved to be an effective and economic technology for the treatment of wastewater.

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