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AEROBIC GRANULATION - AN ECONOMICALLY VIABLE OPTION FOR THE TREATMENT OF WASTEWATER

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ABSTRACT

Aerobic granulation technology is an improvement over conventional activated sludge process. Granulation in sequencing batch reactors leaves a small footprint, as separate settling units are not required. Aerobic granulation was experimented in a laboratory scale sequencing batch reactor with a short settling time of 3 min and organic loading rate as 6 kg chemical oxygen demand/(m^3.d). Compact and dense granules of excellent settling velocity of 72 m/hr were developed with a sludge volume index of 23 ml/g with in 5 weeks. A COD removal efficiency of 97.6 % was achieved in steady state. The possibility of a very short settling time was successfully proved by this experiment.

NOMENCLATURE

H Effective height of the column reactor D Internal diameter of the column reactor

L Distance of travel to reach the discharge port Vs Settling velocity
d Diameter of the particle
ρ_p Density of the particle and media respectively ρ Density of the media
μ Viscosity of the media

1. INTRODUCTION

The effective separation of biomass from the treated effluent leads to the success of any biological treatment process. 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.

Research showed that it is possible to grow granular sludge in a batch-wise operated system resulting in high biomass concentrations and high organic loading rates (7.5 kg COD/(m^3.d)) [1,2]. 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 Sequencing Batch Reactors (SBRs). The homogeneous circular flow generated in column type upflow SBR can force microbial aggregates to be shaped as regular granules. A higher height to diameter (H/D) ratio can ensure a circular flow trajectory and more effective hydraulic attrition of aggregates.

Aerobic granules are considered as dense microbial consortia packed with different bacterial species and typically contain millions of organisms per gram of biomass [3]. When compared with conventional activated sludge flocs, the advantages of granular activated sludge are compactness and strength of the structure. It also has good settleability, high capacity for biomass retention and is able to withstand high organic loading rates [4]. This paper makes an attempt to prove experimentally the suitability of aerobic granulation technology to treat a high strength wastewater with low settling time.

2.MATERIALS AND METHODS

2.1 Feed 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. [4]. It gives a total chemical oxygen demand (COD) of 2000 mg/l. The composition of the influent is given in Table I.

The seed sludge was collected from the activated sludge processing unit of the Petrochemical Division of Fertilizers And Chemicals Travancore (FACT) Limited, Cochin, Kerala. The sludge had a gray colour with sludge volume index (SVI) of 245 ml/g and mixed liquor suspended solids (MLSS) of 5050 mg/l.

2.2 Reactor Configuration and Operating Conditions

A column type SBR with internal diameter 6.5 cm and height 60.3 cm was used for the study. The effective volume of the reactor was 2 l. Influent was fed from the bottom of the reactor and effluent was withdrawn from a port provided at the middle height of the column so that the volume exchange ratio (VER) was 50 %. The feeding and discharge were done by two peristaltic pumps. Air was applied at the bottom of the reactor using an air compressor at a rate of 4 l/min.

The reactor was operated in a cyclic mode with the help of a micro-controller (AT81C51). One complete cycle takes 4 hours and consists of 5 min for filling, 227 min for aeration, 3 min for settling, and 5 min for discharging. With the present cycle time and influent concentration, the organic loading rate (OLR) was worked out as 6 kg COD/(m^3.d). Fig 1 shows the experimental set-up in the laboratory.

TABLE I: COMPOSITION OF THE FEED

Constituent	Concentration
Sodium acetate	2.93 g/l
NH_4Cl	350 mg/l
K_2HPO_4	30 mg/l
KH_2PO_4	25 mg/l
$CaCl_2.2H_2O$	30 mg/l
$MgSO_4$ $7H_2O$	25 mg/l
$FeSO_4$ $7H_2O$	20 mg/l
Micro nutrients solution	1 ml/l

FIGURE 1. EXPERIMENTAL SET-UP

2.3 Analytical Methods

Determination of COD, MLSS, mixed liquor volatile suspended solids (MLVSS) and SVI as per standard methods [5]. 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.

3. RESULTS AND DISCUSSION

The reactor was started with 750 ml of seed sludge and feeding the influent at an OLR of 6 kg COD/(m^3.d) in a sequencing mode. As the settling time was very short (3 min), drastic reduction and high fluctuations were observed in the MLSS and MLVSS values of the reactor content for the initial two weeks. Suspended solids concentration of the effluent showed the wash-out of the loose flocculant sludge particles from the reactor.

Tiny granules were appeared on day 19, and they were found to be matured by the end of 4th week. The MLSS concentrations were shown a marked increase since the appearance of the granules. The MLSS concentrations achieved a steady value of around 10000 mg/l after 5th week, with a fairly good ratio of MLVSS/MLSS of 0.9. The reactor was operated for 40 days. The variation of MLSS and MLVSS with time was shown in Fig.2.

The COD of the effluent was monitored daily and found no considerable reduction during the initial two weeks. By the end of 4th week, the effluent COD was reduced to a value around 50 mg/l and it continued till the end of the operation. The COD removal efficiency during the steady state was 97.6 %. Fig. 3 shows the % COD removal efficiency during the run.

SVI is an important property to test the settleability of the sludge. The SVI of the seed sludge was 245 ml/g and showed the presence of fluffy flocs. The mean size of the seed sludge used for this study was 0.1 mm. The evolution and growth of granules were monitored by micrography or image analysis. Tiny granules appeared on 19th day in the reactor were grown to an average size of 2.1 mm towards the steady state of operation. A very low SVI of 23 ml/g showed the healthy condition of the sludge and the reactor as a whole. Fig 4 shows the variation of SVI with operating days.

The specific gravity of the matured granules was measured as 0.011 with excellent settling velocity of about 72 m/hr. Images of seed sludge and matured aerobic granules obtained are shown in Fig 5 (a) and (b) respectively. It showed the rapid growth of sludge particles in size and density. Compact matured granules performed the function of pollutant removal in an effective manner.

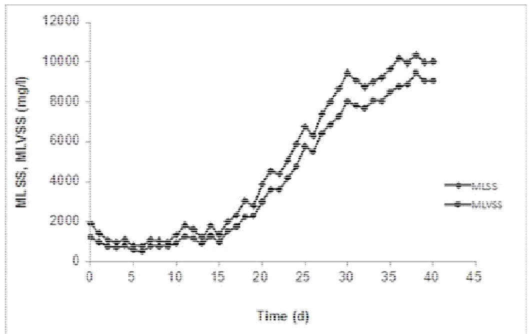

FIGURE 2. VARIATION OF MLSS AND MLVSS WITH TIME

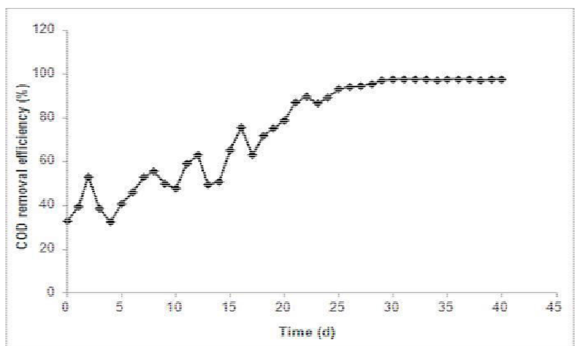

FIGURE 3. VARIATION OF COD REMOVAL EFFICIENCY WITH TIME

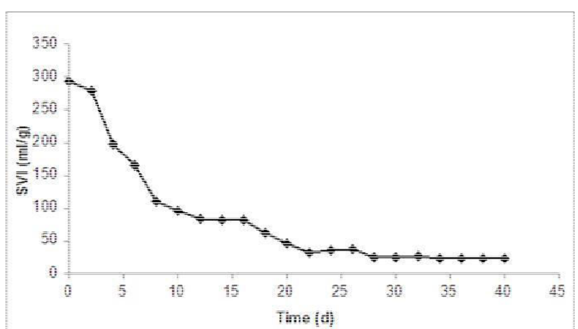

FIGURE 4. VARIATION OF SVI WITH TIME

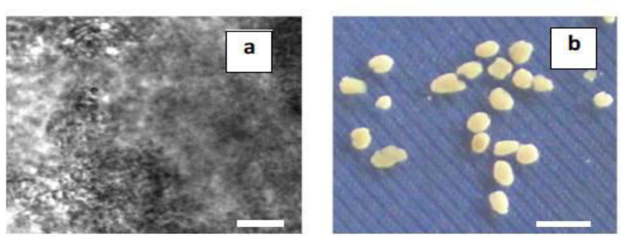

FIGURE 5. IMAGES OF (a) SEED SLUDGE (b) MATURED GRANULES (BAR = 4 mm)

In SBR, particles those cannot reach the discharge point within the allowable settling time are washed out from the reactor, and particles with good settleability are retained in the reactor. If the distance for the sludge particle to reach the discharge port is L, the time taken for traveling by the particle is:

$$\text{Traveling Time} = \frac{L}{Vs} \qquad (1)$$

Where Vs is the settling velocity, and it can be estimated by Stoke's law as

$$Vs = \frac{g(\rho_p - \rho)\,d^2}{18\mu} \qquad (2)$$

d = diameter of the particle
ρ_p and ρ = density of the particle and media respectively
μ = viscosity of the media

As the equation (2) shows, settling velocity is a function of size and density of the particles. Bioparticles with low settling velocity and hence longer settling time than the designed value will be washed out of the reactor. Thus a minimum settling velocity $(Vs)_{min}$ is needed for the particles to be retained in the reactor. This velocity can be determined as:

$$(Vs)_{min} = \frac{L}{SettlingTime} \qquad (3)$$

In the present study with settling time as 3 min, the minimum settling velocity was determined as 6.03 m/hr. Qin et al. [6] operated four SBRs with settling times 20, 15, 10 and 5 minutes and investigated the effects of settling time on granulation. Fastest development of granules and best performance in terms of sludge settleability (measured as SVI), cell surface hydrophobicity and microbial activity were observed in reactor with lowest settling time of 5 minutes. This study support the fact that at a longer settling time, poorly settleable flocs can not be effectively removed and they may outcompete granule forming bioparticles, leading to the failure of granulation. Thus settling time is proved to be a strong selection pressure in aerobic granulation.

Shorter settling times seem to stimulate the respirometric activity of the bacteria. It shows that microorganisms may regulate their energy metabolism in response to the changes in hydraulic selection pressure exerted on them [7]. Adav et al. [8] found by experiment that a short settling time of the order of 5 min helped to develop a microbial community much simpler than seed sludge due to the wash out of non-flocculating strains. The settling velocity of aerobic granules is associated with granule size and structure and is as high as 30 to 70 m/h. This is comparable with that of the UASB granules, but is at least three times higher than that of activated sludge flocs (typical settling velocity of around 8 to 10 m/h for activated sludge flocs) [3]. The high settling velocities of aerobic granules allow the use of relatively high hydraulic loads to the reactors without having to worry about washout of biomass.

de Bruin et al. [9] studied the economic advantage of granular sludge sequencing batch reactors (GSBR) by treating a wastewater by different options. It was found from the study that the footprints of GSBR alternatives were only around 25% of the footprints of the reference alternatives. The footprint of the total treatment plant was calculated by sum of the net surfaces of all process units and buildings. On the basis of the total specific annual costs, again the GSBR alternatives (with primary treatment and post treatment) proved to be the most attractive. The total annual costs of the GSBR alternatives with primary and post treatment respectively were on average 17% and 7% lower compared to the reference alternative. The capital costs of the GSBR alternatives were relatively high because of the high share of the mechanical/electrical works in the investments (40–45%). The part of the mechanical /electrical works for conventional activated sludge systems amounts to 25–30%. But in general, it was concluded that GSBR technology is very compact, which is an important advantage in relation to activated sludge technology, especially in densely populated areas.

4. CONCLUSIONS

Aerobic granular sludge is a very promising technology from an engineering as well as economic point of view, and should therefore be further developed. 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 at a very short settling time of 3 min with an OLR of 6 kg COD/(m^3.d) Compact and dense granules of average size 2.1 mm were developed. The SVI of the granular sludge was 23 ml/g and the settling velocity was 72 m/hr. A COD removal efficiency of 97.6 % was achieved in the experiment. The MLSS concentration reached a value of 10000 mg/l.

A short settling time can apply a selection pressure on granular sludge and reduce the overall cost of the treatment.

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