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In situ disruption approach on aerobic sludge biomass for excess sludge reduction in tannery effluent treatment plant

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HIGHLIGHTS

- Effect of mechanical disruption on aerobic sludge biomass in effluent treatment.
- In situ excess sludge reduction of 47% was achieved.
- Optimal treatment frequency was 0.5 d^{-1}.
- Mathematical expressions deduced for various parameters.

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ABSTRACT

Excess sludge biomass generation is one of the major problems in effluent treatment plants and it is an unavoidable byproduct generated due to the growth of microorganisms. Moreover, the treatment and disposal of excess sludge costs about 60% of the plant total operating cost. In this work it has been attempted to limit the excess biomass generation during effluent treatment itself, by applying mechanical stress on aerobic sludge biomass. The concept of maintenance metabolism has been implemented in this study to enhance the microbial maintenance requirements along with cell lysis for excess sludge reduction. The experiments have been carried out using identically sequenced continuous reactors with two different hydraulic retention times (HRT), two sludge treatment volumes and three treatment frequencies (TF). Mathematical expressions were deduced to estimate various parameters. Maximum excess sludge reduction of 47% was achieved with treatment frequency of 0.5 and sludge treatment volume of 40%. Further increase in TF resulted in the release of more suspended solids leading to deterioration of the treated effluent. Better COD removal efficiency was achieved with the HRT of 36 h.

1. Introduction

Rapid industrialization in developing countries has resulted in generation of large amount of effluent. Activated sludge process is the most commonly used biological method to treat the industrial effluent. The main problem associated with this process is the generation of large amount of excess sludge. When the effluent is pretreated and then brought into contact with sludge microorganisms, these organisms will degrade the organics by generating carbon dioxide, water and fresh biomass [1]. This freshly generated biomass would turn into excess sludge. The buildup of fresh biomass constituents for the growth is directly linked to the effluent organic matter being incorporated (60–70%) and the remaining one being oxidized by the micro organisms (30–40%) [2]. At present, tanneries generate about 40 L of effluent while processing 1 kg of leather. Thus the tanning operation releases about 15 million liters of effluent while processing 1 ton of raw skins and hides thereby resulting in 50–60 kg of primary sludge and 15–20 kg of secondary sludge generation [3]. Moreover, previous studies have stated that treatment and disposal of excess sludge costs about 60% of the total operating cost of treatment plant [4].

Non sustainable practices of utilizing excess sludge as fertilizer or soil conditioner in agricultural land have been considerably reduced due to presence of pathogens, heavy metals and organic pollutants [5]. Although incineration method is still being practiced, there are potential environmental problems due to gaseous emissions and residual ashes which are generally classified as hazardous wastes [6].

In recent years anaerobic digestion of excess sludge (with additives) is being carried out for biogas production and subsequent

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reduction of sludge volume. It has been stated that volume reduction considerably improves the dewatering properties [7]. In order to enhance the hydrolysis of anaerobic digestion, earlier researchers have suggested that pre-treatment of feed sludge (prior to anaerobic digestion) would subsequently increase the biogas production [8]. Different pretreatment methods viz., thermal, chemical, mechanical, biological and also combination of two different methods have been adopted to minimize the sludge to be disposed off to the environment [9]. On the other hand it has been reported that aerobic digestion can lead to excess sludge reduction through self consumption [10]. Excess sludge handling methods convert sludge into value added products such as activated carbon, recovery of heavy metals, nutrients, and bio oil [11]. In activated sludge process researchers have worked with two different strategies which include wastewater and sludge line approaches to minimize the excess sludge biomass production [12]. Wastewater line approaches follows cryptic growth for enhanced cell lysis [14], increasing oxygen concentration, uncoupling mechanism, microbial predation and maintenance energy metabolism [13]. Sludge line approach has been established as anaerobic digestion of generated excess sludge with pretreatment strategies [14].

At this juncture, it can be stated that excess sludge is an unavoidable byproduct during effluent treatment process preponderantly generated in the aerobic treatment process. Therefore the ideal way to curtail the excess sludge biomass is by integrating minimum sludge production methods in the effluent treatment part itself rather than post treating the generated sludge without altering the efficacy of the treatment process.

1.1. Past studies

The earlier studies have ascertained that minimization of excess sludge generation could be achieved by different methodologies viz., uncoupling mechanism, cryptic-growth cell lysis, maintenance metabolism and predation of microorganisms. The uncoupling metabolism was induced under abnormal circumstances at higher substrate to biomass concentration in which the catabolism is allowed to continue unhindered, whereas the anabolism is restricted to reduce the biomass yield. Yang et al. [15] have studied the batch process with different metabolic uncouplers for the reduction of excess sludge and have achieved 85% reduction. Mehrdadi et al. [16] have studied the cryptic cell lysis method with the return sludge by applying different treatment techniques such as thermal, ultrasound and ozone to achieve lower yield coefficient. Thus a maximum sludge reduction of 78% with sonication and 30% with ozone and thermal methods was achieved. Similarly, Zuriaga-Agusti et al. [17] have studied the addition of chlorine-di-oxide (in sequenced batch reactor) which oxidizes the bacterial cells leading to disintegration and subsequent reduction of sludge up to 43.4%. The advanced oxidation techniques use hydrogen peroxide and Fe for the minimization of excess sludge by inducing Photo-Fenton reactions. The addition of Fe and H_2O_2 dosage enhances sludge disintegration and thus excess sludge reduction was achieved. Ultrasonic treatment studies by Zhang et al. [18] shows that the activated sludge was partially ruptured and then recycled into the bioreactor for degradation and thus achieved a reduction of 91.1%, along with a deteriorated COD removal efficiency. Mohammadi et al. [19] have studied with the generated excess sludge with ultrasound and found that it required more energy to achieve more sludge reduction. The combined treatment methods were studied with the return sludge by Lin et al. [20] for lysis-cryptic growth system (with ClO_2 and ultrasonication) and Lan et al. [21] for lysis cryptic growth (high pressure homogenizer) thereby reducing the excess sludge up to 55% and 42.4%, respectively. Luo et al. [22] studied the addition of species such as *Tubificidae* and *Pristina* in activated sludge process for the excess sludge reduction through predation and thus 75% was achieved.

1.2. Present work

From the past studies it is understood that most of the work on excess sludge biomass reduction were carried out by post treatment of generated sludge or return sludge and subsequent degradation in activated sludge process. In this study an attempt has been made to introduce diligent disruption method in the aerobic biological degradation system i.e., by stressing the microorganisms. This was intended to increase the microbial maintenance energy requirements along with cell lysis. This was suspected to be concomitant, resulting in higher oxidation of organic substances in the effluent. This expected scenario retards the microbial growth rate and also diverts the energy for the microbial cell integrity i.e., self repair rather than multiplication. Though Low and Chase [23] stated that increasing the microbial maintenance energy results in lowering the conversion yield, the same has been induced in this work by mechanical disintegration and proved experimentally with sequenced identical continuous reactors.

2. Materials and methods

2.1. Sludge biomass and wastewater

Aerobic sludge biomass and the real tannery effluent (pre treated) were collected from the nearby Tannery Common Effluent Treatment Plant (CETP), Chennai. The collected samples were analyzed for MLSS, MLVSS, pH, COD. Sludge and wastewater samples were refrigerated at 4 °C to avoid putrefaction. The characteristics of tannery effluent and the secondary sludge are given in Table 1.

2.2. Bench scale effluent treatment plant

The reactors (R1, R2 and R3) used in this study are of cylindrical shape made up of Perspex material with a working volume of 1.9 L. Each reactor was bifurcated into two halves with the nylon material through the groove provided in the inner wall of the reactors so as to make one part as aerobic and the other as anaerobic. The secondary biomass used in this study is facultative microorganism. In the aerobic part, aquarium pump was used to supply air and the multi head peristaltic pump was used to feed effluent both at constant flow rates. Synthetic sponge filters were installed at the exit point of the treated effluent (i.e. at anaerobic part) in order to prevent biomass leaving the reactor. In addition lab scale clarifiers were installed to collect the biomass if any leaving the system. After routine treatment and sample analysis the sludge biomass was charged back into the respective reactors. The schematic view of the experimental setup is shown in Fig. 1.

Table 1
Characteristics of the secondary sludge and tannery effluent.

Parameters	Units	Secondary sludge	Effluent
pH	–	6.8–7.4	6.7–7.5
COD	mg/L	810–840	1500–2500
MLSS	mg/L	10.25	–
MLVSS	mg/L	6.38	–
Phenol	mg/L	–	32–40
Sulfates	mg/L	–	970–1000
Oil and grease	mg/L	–	12.5–14.0
Dissolved solids	mg/L	–	5620–5700