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Effect of extended aeration on the fate of particulate components in sludge stabilization

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HIGHLIGHTS

- Excess sludge of extended aeration cannot be considered stable or mineralized.
- Magnitude of inert components in the biomass determines the level of stabilization.
- Biodegradation of particulate metabolic products is faster for extended aeration.
- Rate of stabilization is initially controlled by microbial endogenous decay.

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ABSTRACT

The study investigated the effect of extended aeration on the fate of particulate components of biological sludge in aerobic stabilization. Biological sludge was generated in a fill and draw reactor fed with domestic sewage and sustained at steady state, at a sludge age of 20 days. Particulate fractions of sludge were determined by model evaluation of the corresponding oxygen uptake rate profile. Extended aeration could not produce a *mineralized* biomass. External aerobic stabilization of the thickened sludge achieved a volatile suspended solids reduction of 68% after 60 days. High reduction could be attributed to the relatively higher rate for the hydrolysis of accumulated particulate metabolic products, compared to conventional activated sludge. Model evaluation based on death-regeneration mechanism indicated a gradually decreasing decay rate for solids; the first phase could be associated with the inactivation/death of the viable biomass and the second controlled by the slower breakdown of particulate metabolic products.

1. Introduction

Extended aeration is a modification of the conventional activated sludge system. Its distinguishing feature is the long hydraulic retention period provided in the aeration tank in order to bring about aerobic digestion of the biomass and thus, to reduce the volume of sludge for disposal. This internal stabilization process is generally attributed to the extended endogenous decay of solids in the reactor, generally evaluated as an overall biochemical reaction in terms of mixed liquor suspended solids (MLSS). There is now conclusive evidence that active biomass which undergoes endogenous decay is only a fraction of the biomass sustained in the reactor (Henze et al., 1987; Orhon and Artan, 1994); activated sludge is a complex mixture of particulate matter, also including inorganic constituents of different nature and origin, inert particulate organics coming from sewage X_I, residual particulate microbial products generated in the course of metabolic reactions, X_P and a small fraction of remaining particulate biodegradable substrate entrapped in biomass, X_S (Dold et al., 1980; Germirli et al., 1991; Orhon and Okutman, 2003). In the context, extended aeration should be characterized more in terms of X_I and X_P accumulation,

Abbreviations: X_H, heterotrophic active biomass, mg COD/L; X_S, particulate slowly biodegradable COD, mg/L; X_P, particulate metabolic products, mg COD/L; X_I, Particulate inert COD, mg/L; X_T, total particulate COD, mg/L; S_S, readily biodegradable COD, mg/L; S_H, readily hydrolysable COD, mg/L; S_I, soluble inert COD, mg/L; $\hat{\mu}_H$, maximum growth rate, d^{-1}; b_{DR}, microbial decay rate, d^{-1}; k_{hX}, *maximum* hydrolysis rate for X_S, d^{-1}; k_{hP}, maximum hydrolysis rate for X_P, d^{-1}; K_S, half saturation coefficient, mg COD/L; K_{XX}, hydrolysis coefficient for X_S, mg COD/mg COD; K_{XP}, hydrolysis coefficient for X_P, mg COD/mg COD; f_{EX}, particulate residue of X_H.

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rather than mineralization trough endogenous decay of the active microbial community, X_H. Therefore, the internal stabilization potential traditionally associated with extended aeration should be seriously questioned, as it closely depends on the fate of accumulated particulate fractions, X_I and X_P during the process.

Extended aeration was first implemented in 1947, to modify and improve an underloaded conventional activated sludge plant in the US; the plant was operated with 100% return sludge without sludge wasting and excellent effluent quality was obtained (McCarty and Brodersen, 1962). Its popularity rapidly increased, especially for small sewage flows, because it simplified technology, reduced operation requirements increased stability against shock loads (Middlebrooks and Gardland, 1968). Observations also indicated however that the quality of the effluent was susceptible to significant fluctuations because of sludge accumulation and rising problems in the settling tanks. Benedek (1965) argued that simultaneous sewage treatment and sludge oxidation taking place in the same unit often resulted in over-dimensioning of the plant, which could be avoided by separate sludge stabilization; this way "*oxidative sludge treatment*" would be more economical.

Despite extensive practical experience with the process, the nature of excess sludge generated was not properly studied to satisfy the basic question: Is the sludge stabilized to a degree that it may be considered "*mineralized*", or is it likely to undergo further stabilization which would significantly reduce its organic constituents? This question can best be addressed by modeling the results of stabilization experiments, which would evaluate the evolution of not only total suspended solids (TSS) or volatile suspended solids (VSS), but all relevant particulate fractions in the sludge. A death-regeneration mechanism, as described in the Activated Sludge Model No.1 (ASM1) is quite suited for this purpose, because it provides a quantitative definition a cyclic release and recovery of endogenous residues (Ozdemir, 2013). This approach has been successfully used in similar modeling efforts on aerobic stabilization, emphasizing the decisive role of particulate metabolic products (Jones et al., 2007; Ramdani et al., 2012). Recent studies showed that the solids reduction during stabilization was adjusted to the slow biodegradation rate of particulate metabolic products for sludge generated in a conventional activated sludge system (Ozdemir et al., 2013, 2014). So far, a similar evaluation has not been carried out for extended aeration.

In this context, the objective of the study was to explore the effect of extended aeration on the efficiency of aerobic sludge stabilization. The mainly study relied on evaluating and interpreting experimental data derived from aerobic stabilization. It was based on the fate and biodegradation characteristics of particulate COD fractions in sludge, as opposed to the traditional assessment approach limited with a single collective VSS parameter. Model evaluation, using the death-regeneration approach as the appropriate mechanism for sludge stabilization in the absence of external substrate, was able to determine the profiles of different sludge components during the course of the stabilization period. This way, it emphasized the effect of the hydrolysis of particulate metabolic products on the magnitude of solids reduction achieved during the stabilization.

2. Methods

2.1. Experimental design

The approach adopted in the study was designed to include three experimental stages closely related to each other in a way to provide a unified and meaningful basis for evaluation. (i) The first stage consisted of generating acclimated biomass reflecting the characteristics of an extended aeration system operated at steady-state with raw domestic sewage. (ii) The second stage involved aerobic stabilization of the acclimated sludge provided by the extended aeration unit during the previous phase; (iii) the last part of the evaluation was devoted to model calibration and evaluation of the experimental data obtained during the aerobic stabilization experiment.

In this context, the first phase of the experiments focused on generating a biomass acclimated to the sludge age of 20 days under extended aeration conditions. For this purpose, a laboratory-scale *fill and draw* reactor was operated at steady state with daily feedings of domestic sewage. During the reactor operation, the COD level in sewage was determined as 910 ± 26 mg/L. At steady state, the reactor sustained a biomass concentration of 2375 ± 85 mg/L measured in terms of VSS. The corresponding TSS concentration was 3240 ± 84 mg/L. Before the following phase, a respirometric analysis was conducted to produce the oxygen uptake rate profile (OUR) related to the biodegradation of sewage, using the acclimated biomass seeding from the reactor. The OUR profile was then used for the calibration of the selected model, which defined the composition and fractionation of the biomass, together with COD fractionation and process kinetics for substrate utilization. The characteristics of the sewage feed determined in terms of major COD components are outlined in Table 1.

In the following phase, the biomass content of the reactor was first thickened to around 5500 mg VSS/L to approximate the conditions in full-scale treatment plants and it was subjected to aerobic stabilization for a period of 60 days, without exogenous substrate feeding. VSS, TSS and COD concentrations were monitored during the stabilization period. The fate of major particulate components of sludge during stabilization was evaluated by modeling.

2.2. Reactor setup and operation

The 6 L *fill and draw* reactor, operated at sludge age of 20 days was used for the acclimation of biomass. The sludge seed used to start the acclimation reactor was taken from the aeration tank of the wastewater treatment plant that also supplied the COD feed for its operation. The reactor was operated with a feeding rate of 3 L/d, corresponding to a hydraulic retention time of 2 days. After acclimation, a stabilization reactor with a sludge volume of 3 L was operated under aerobic conditions. Dissolved oxygen concentration was always kept above 2 mg/L to avoid any possible oxygen limitation on the process. The temperature of the systems was kept constant at 20 ± 0.5 °C. The pH of the reactors was maintained at 7 ± 0.5.

2.3. Respirometric measurements

OUR measurements were conducted with a Ra-Combo (Applitek Co., Nazareth, Belgium) continuous respirometer. The acclimated biomass was transferred from the fill and draw reactor to the respirometric reactor with a total volume of 2 L. Domestic sewage

Table 1
COD fractionation of sewage fed to the fill and draw reactor.

Parameters	mg COD/L	%
Total COD, C_T	910	
Total biodegradable COD, C_S	774	85
Total inert COD, C_I	136	15
Total soluble COD, S_T	225	24
Readily biodegradable COD, S_S	48	5
Readily hydrolysable COD, S_H	141	16
Slowly hydrolysable COD, X_S	585	64
Soluble inert COD, S_I	36	4
Particulate inert COD, X_I	100	11