African Journal of Biotechnology Vol. 6 (7), pp. 902-907, 2 April 2007
Available online at http://www.academicjournals.org/AJB
ISSN 1684–5315 © 2007 Academic Journals

Full Length Research Paper

The influence of aerobic sludge retention time on anaerobic co-digestion of dyeing and printing wastewater and sewage sludge

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Accepted 31 January, 2007

Two pilot-scale activated sludge systems comprising anaerobic baffled reactor (ABR) and aerobic plug flow reactor (PFR) were operated aiming to minimize excess sludge output of the activated sludge process through coupled alkaline hydrolysis and anaerobic digestion. Variations in the effluent total chemical oxygen demand (TCOD) and NH_4^+-N concentration proved that the process not only could minimize excess sludge production but also guarantee the effluent TCOD well below the discharging limit (150 mg/l) if the inverse ratio of the aerobic sludge recirculation to anaerobic reactor did not exceed 60% for system A with 10 d aerobic sludge retention time (SRT) and 40% for system B (SRT was 25 d). The sludge activity at aerobic SRT of 25 d was evidently lower than aerobic SRT of 10 d. Those differences of sludge characteristics affected the inverse sludge ratio obviously. Aerobic bacteria after internal and external decay were converted to anoxic or anaerobic biomass. The distinct differences in sludge yield of aerobic and anaerobic/anoxic processes could explain how aerobic SRT decided excess sludge activity which consequently affected anaerobic codigestion of printing and dyeing wastewater and sewage sludge.

Key words: Anaerobic co-digestion, excess sludge, printing and dyeing wastewater, sludge retention time (SRT).

INTRODUCTION

In developing countries such as China, secondary wastewater treatment plants (WWTPs) are being built rapidly throughout the country (Qian, 2000). Biological treatment, mainly represented by activated sludge processes has become the major treatment method dealing with both municipal and industrial wastewaters. The foremost problem associated with the growing applications of activeted sludge processes is the production of huge amount of sludge generated daily as a byproduct of the transformation of dissolved and suspended organic pollutants into biomass and evolved gases (CO_2, CH_4, N_2, SO_2, etc.). The methods of sludge disposal currently need processing, transport and disposal costs up to 65% of the total operating cost of a WWTP (Liu, 2003).

Owing to the fact that excess sludge production is an inevitable drawback inherent to the activated sludge processes, the ultimate removal of sludge is very difficult and costly, so it is desirable to reduce the sludge output in order to save the sludge disposal cost. Recently, many researches have introduced a series of strategies for reducing excess biomass production in activated sludge systems, such as lysis-cryptic growth (Abbassi et al., 2000; Egemen et al., 2001; Roman et al., 2006; Tiehm et al., 2001), uncoupling metabolism (Chen et al., 2003; Liu et al., 1998; Yang et al., 2003), predation on bacteria (Lapinski and Tunnacliffe, 2003), membrane bioreactors (Rosenberger et al., 2002), and so on. Some of these methods have considerable potential to cut down sludge production, but the running cost of using such techniques is still expensive.

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Table1. The main characteristics of SWWTP's wastewater.

Index	pH	COD (mg/l)	BOD (mg/l)	Color (times	SS (mg/l)	Temperature (℃)	Alkalinity (mg/l)	TP (mg/l)	NH_4^+-N (mg/l)
Max	10.21	1502	512	350	605	42.1	900	4.0	30.2
Min	9.14	1030	408	300	214	25.4	600	2.1	18.4
Average	9.52	1372	452	320	413	35.2	764	3.4	23.6

Notes: These values were obtained from the operation of real engineering project of SWWTP over the year 2005. Standard Methods (Editorial Board of Environment Protection Bureau of China, 2002) were applied for analysis of above parameters.

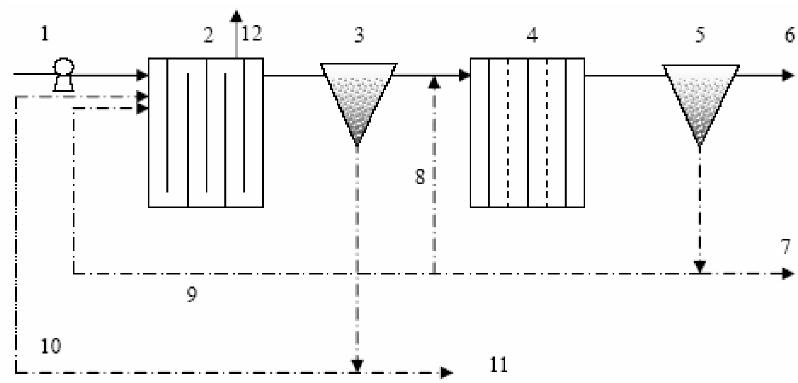

Figure 1. The schematic diagram of pilot-scale experiment: (1) influent; (2) anaerobic baffled reactor(ABR, composed of Compartment I-VI); (3) settling tank;(4) Plug Flow Reactor (PFR, composed of Compartment I-VI); (5) settling tank; (6) effluent; (7) discharged aerobic excess sludge; (8) recycling aerobic sludge to PFR; (9) recycling aerobic sludge to ABR; (10) recycling anaerobic sludge to ABR; (11) discharged anaerobic excess sludge; (12) biogas.

Being an economical biotechnology, anaerobic treatment was introduced to increased digestion of waste activated sludge, diverse kinds of industrial wastewater even municipal wastewater in recent years. However, anaerobic digestion was used as a method only to deal with wastewater or sludge separately, and few anaerobic codigestions (Zhu et al., 2005) have been tried to treat sewage sludge and wastewater were treated simultaneously, especially for the municipal wastewater of WWTPs mainly composed of industrial wastewater from printing and dyeing industries. Shaoxing Wastewater Treatment Plant (SWWTP) in Shaoxing County Zhejiang Province, P. R. China is an example of such kind comprising municipal and industrial wastewater.

The purpose of this study was to introduce a new approach to minimize excess sludge output in the activated sludge process through anaerobic codigestion of highly alkaline dyeing and printing wastewater and sewage sludge of SWWTP. Waste activated sludge is less subjected to decomposition, especially if the operational sludge age is longer (De Souza Araújo et al., 1998). In order to clarify the main factors affecting codigestion, two pilot-scale activated sludge systems consisting of aerobic and anaerobic reactors were employed to investigate the influence of aerobic sludge retention time (SRT) on excess sludge characteristics and minimization efficiency.

MATERIALS AND METHODS

Characteristics of the influent wastewater

The main characteristics of the influent of SWWTP are shown in Table 1. These data were collected from the working of real engineering project on SWWTP for the year 2005. SWWTP's wastewater composed of 8% municipal sewage, 90% dyeing and printing wastewater and 2% other industrial wastewater. Being main component of SWWTP's wastewater originated from the alkali-decomposition processes of dyeing, printing, terylene artificial silk printing and dyeing wastewater (TPD wastewater), it was characterized by high pH, COD (chemical oxygen demand), color, SS (suspended solids) and low BOD (biochemical oxygen demand)/COD ratio (different from traditional printing and dyeing wastewater and municipal sewage). TPD wastewater, which originated in 1980's and developed in the 1990's, is now the popular industrial wastewater in China. By actual test, terephthalic acid (TA) accounts 40% - 60% TCOD of TPD wastewater. TA is readily biodegradable under aerobic conditions (Guan et al., 2003) while relatively hard to be decomposed under anaerobic conditions (Kleerebezem et al., 2005).

Experimental apparatus and plan

Two pilot-scale activated sludge systems named System A and System B consisting of anaerobic and aerobic reactors were employed for present study. Their schematic diagrams of reactors are shown in Figure 1. The experimental apparatus are imitations of

No.1 Stage Project of SWWTP.

SWWTP is responsible to treat municipal and industrial wastewater with a total treatment capacity of 700,000 m^3/d. The conventional anaerobic-aerobic treatment process is employed in No.1 Stage Project comprising ABR (anaerobic baffled reactor having Compartment I-VI) and aerobic Plug Flow Reactor (PFR). No.2 Stage Project applies Orbal anaerobic ditch and Orbal oxidation ditch processes. According to the real engineering project parameters, pilot plant ABR and PFR both were designed for 8.55 m^3 reaction volumes with hydraulic retention time (HRT) of 20 h followed by a settling tank whose HRT was 5 h. The aerobic SRT of System A and System B were 10 and 25 d, respectively. During the entire investigation, the temperature of the reactors was kept fixed at average value of 35.2℃ suitable for activated sludge systems.

Chemical analysis

The pH value was measured using digital pH meter (PHS-3C, China). Standard Methods (APHA,1999) were used for analysis of the following parameters: (1)mixed liquor suspended solids (MLSS) or suspended solids (SS); MLVSS (g/L): mixed liquor volatile suspended solids in the effluent and sludge samples; (2) TCOD; (3) NH_4^+-N and TP. The DO (dissolved oxygen) was determined by a digital DO meter.

DAPI and CTC counting

The 4,6-diamidino-2-phenyl indole (DAPI) cell counting technique was used to measure the number of total bacteria as this technique can stain the DNA in all kinds of bacterial membranes regardless of they are viable or dead (Saby et al., 1997). The 5-cyano-2, 3-ditolyl tetrazolium chloride (CTC) counting technique was adopted only to count respiring or active facultative bacteria because CTC staining can produce red-fluorescent CTC-formazan granules in respiring cells (Saby et al., 1997). Both DAPI and CTC-stained cells can be counted under an epifluorescence microscope (Olympus BX51), using UV light of a specific wavelength (Saby et al., 1997).

Heterotrophic plate counting

In order to find the difference in the bacteria population present in aerobic sludge of different SRT plate count method (Saiki et al., 1999) was employed. After dilution with physiological salt solution (0.9% NaCl), samples were routinely transferred into the sterilized culture medium under the conditions of aerobic bio-cultivating box SPX-250B-III and anaerobic incubator YQX-II (Shanghai Yuejin Medical Instruments Factory, China), respectively. The culture medium was adjusted to neutral pH and was composed of (g/l):glucose 10; beef extract 2.5; peptone 8; NaCl 3; ammonium acetate 2; KH_2PO_4 0.5; $MgSO_4{\cdot}7H_20$ 0.3; $FeSO_4{\cdot}7H_20$ 0.01; agar 20. The results were reported as the colony number on one plate in terms of CFU unit (APHA, 1999) after cultivation at 37℃ for 7 days.

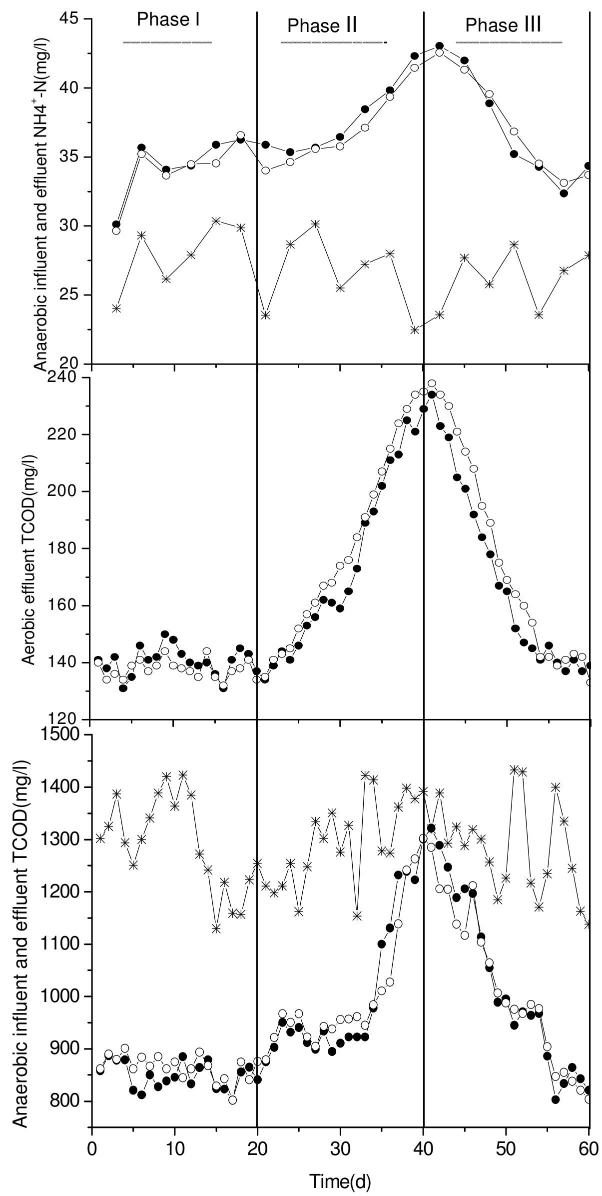

Figure 2. Experimental performances of system A and B. Aerobic excess sludge recirculation ratio for system A: Phase I (1 - 20 d): 60%; Phase II (21 - 40 d): 70%; Phase III (41 - 60 d): 60%. Ratio of system B: Phase I: 40%; Phase II: 50%; Phase III: 40%.
Note: "—*— Influent, —●— System A (SRT: 10 d), —○— System B (SRT: 25 d)"

RESULTS AND DISCUSSION

The performance of minimizing excess sludge production

After activated sludge system A and B were run steadily for over a month without excess sludge recirculation from aeration tank to anaerobic tank to ensure the effluents were below the discharge limit, the experimental data was collected. Owing to the difference in aerobic SRT of the two systems and the results of previous lab-scale experiment, the recirculation ratio of System A from aeration tank to anaerobic tank was set at 60% of the total aerobic excess sludge production while System B was set at 40%. In spite of daily fluctuations in the influent characteristics, the obvious conclusion can be obtained by the critical comparison of working of two reactor systems.

Figure 2 summarizes the variations in TCOD and NH_4^+-

Table 2. Main characteristics of aerobic sludge of system A and B.

Parameter		Sludge of System A	Sludge of System B
SRT(d)		10	25
MLSS(g/l)		2.79±0.11	3.42±0.14
MLVSS(g/l)		2.26±0.08	2.46±0.12
MLVSS/ MLSS (%)		80.2±0.1	72.4±0.1
DAPI counting(cfu/ml×10^9)		5.11±0.52	7.25±0.49
CTC counting(cfu/ml×10^9)		1.25±0.45	0.96±0.10
SOUR (mgO_2/gvss·h)		52	41
Plate counting	Aerobic bacteria (cfu/ml×10^8)	7.35±0.55	8.14±0.43
	Anaerobic/anoxic bacteria (cfu/ml×10^8)	2.48±0.38	5.29±0.71

Values represent means of three determinations ± SD (Standard deviation).
– = absence.
DAPI counting: total number of bacteria.
CTC counting: number of respiring bacteria.

N concentration of the influent and effluent of the two systems. It can be seen from Figure 2 that, in Phase I (1-20 d), the TCOD of anaerobic effluent significantly decreased and NH_4^+-N increased obviously compared with the influent. This can be attributed to the anaerobic co-digestion product of azo dye of TDP wastewater (Razo-Flores et al., 1997; Yemashova and Kalyuzhnyi, 2006) and protein which is the largest constituent of excess biomass (Yuan et al., 2006). At the same time, the aerobic effluent TCOD was well below the discharging limit of 150 mg/l all the times. During the Phase II (21 - 40 d), all given indices of the effluent increased gradually showing that the increased excess sludge had overrun the digestion ability of the anaerobic system when the inverse ratio was set at 70% for A and 50% for B. Then in Phase III (41-60 d), all indices were gradually shifted close to Phase I. The aerobic effluent TCOD decreased gradually below the discharging standard when the inverse sludge ratio of system A was set below 60% and that of system B was below 40%.

This demonstrates that the process not only could minimize excess sludge production but also could guarantee the effluent quality under the recirculation sludge ratio below 60% for A and 40% for B. It can be concluded that the longer was the SRT of aerobic sludge; the lower was the inverse sludge ratio of system.

The mechanism analysis

In order to explore the influence mechanism of SRT upon the inverse sludge ratio, the main characteristics of aerobic sludge of system A and system B were determined and were presented in Table 2. It shows that, with the increase of SRT from 10d to 25 d, in spite of the increased MLSS and MLVSS (average values of 2.79 and 2.26 g/l to 3.42 and 2.46 g/l respectively), the value of MLVSS/MLSS decreased obviously on the average from 80.2 to 72.4%. At the same time, the ratio of the number of CTC counting (respiring bacteria) vs. DAPI counting (the total number of bacteria) decreased from 24.46 to 13.24%; and the SOUR reduced 11 mgO_2/gVSS·h.

Above results indicate that the sludge activity decreased with the increase in SRT and this decrease cut down the inverse sludge ratio which also demonstrates that the diminishing efficiency of the waste activated sludge depended strongly on the proportion of the active fraction of the sludge. De Souza Araújo et al. (1998) reported the similar results concerning an anaerobic digester operating at 25℃, in which 53% of the active fraction and 15% of the inactive fraction were digested.

Plate counting method was adopted to investigate the impacts of SRT on the microbial community structure in the sludge. The results of plate counting are also presented in Table 2. These demonstrate that the population of anaerobic/anoxic bacteria and the proportion of anaerobic/anoxic bacteria to aerobic bacteria were both increased evidently with the increase in SRT. It can be concluded that with the increasing of aerobic SRT, the anaerobic/anoxic species found in aerobic activated sludge would increase.

Such results can explain why the recirculation sludge ratio of system decreased with the increasing SRT. When the aerobic activated sludge was recirculated to anaerobic reactor, the aerobic bacteria could not adapt to the anaerobic environment and had to go into a state of dormancy or die for internal or external decay (Van Loosdrecht and Henze, 1998). Kaprelyants and Kell (1996) indicated that the most bacteria probably do not die, instead they become dormant. However self-digestion (decay) generally occurs when the growth environmental factors such as temperature, pH, aerobic condition etc are changed (Saiki et al., 1999). When the activated sludge inversed to anaerobic reactor, especially the system with high influent pH, aerobic bacteria could undergo decay more easily due to alkaline solubilization and anaerobic digestion compared with anaerobic/anoxic bacteria. Moreover protozoa are not active under anaerobic/anoxic conditions (Griffith, 1997) and also can undergo decay. The decay may lead to a reduction in the number, weight and the activity of microorganisms. At the same time, the decay products of aerobic bacteria and other organic materials are converted into soluble substrates. The substrates are then convened to anoxic or anaerobic biomass again by growth process. An anoxic yield of 0.402 mg particulate COD/mg consumed COD was calculated to be 62% of the corresponding aerobic yield of 0.645 mg particulate COD/mg consumed COD (Copp and Dold, 1998). A sludge yield of 0.040 mgVSS/mgCOD was calculated for anaerobic biomass (Herbert et al., 1995). The obvious difference in sludge yield for aerobic and anaerobic/anoxic is the essential reason for the minimization of excess sludge production by anaerobic codigestion.

Conclusion

The present study produced following conclusions:

1. Through the variations of TCOD and NH_4^+-N concentration in the settlers of two contrast systems, it proved that the process not only could minimize the excess sludge production but also could guarantee the effluent quality well below the discharging limit of 150 mg/L when the inverse sludge ratio did not exceed 60% for system A (aerobic SRT of 10 d), and 40% for system B (SRT of 25 d).
2. With the increasing SRT for aerobic activated sludge from 15 d to 25 d, the bacterial activity decreased and the increase of the proportion of anaerobic/anoxic to aerobic bacteria of sludge cut down the inverse sludge ratio from 60% to 40%.
3. Aerobic bacteria after internal and external decay are converted to anoxic or anaerobic biomass. The obvious difference in sludge yield for aerobic and anaerobic/anoxic seems a possible mechanism for the minimization of excess sludge production.

ACKNOWLEDGEMENTS

The authors thank Professor Wen-hua WANG of Shanghai Jiao Tong University for her assistance with analytical approaches and useful comments and would like to express their gratitude to the Major Scientific Key Problem Program of Scientific Commission of Zhejiang Province of China (2004C13027).

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