Desalination and Water Treatment
www.deswater.com

doi: 10.1080/19443994.2015.1137788

57 (2016) 23603–23609
October

Taylor & Francis
Taylor & Francis Group

Alkaline and acid thermal hydrolysis of biological excess sludge in sequencing batch reactor

Maryam Pazoki*, Peyman Dalaei

Graduate Faculty of Environment, University of Tehran, P.O. Box 14155-6135, Tehran, Iran, emails: mpazoki@ut.ac.ir (M. Pazoki), peymandalaei@yahoo.com (P. Dalaei)

Received 23 July 2015; Accepted 22 December 2015

ABSTRACT

The efficiency of biological wastewater treatment processes is based on pH sensitivity which leads to the reduction in the amount of sludge production. In order to achieve the best result, thermal hydrolysis is recognized and used, although acid thermal hydrolysis has serious drawbacks (corrosion, required post-neutralization, etc.). Alkaline thermal hydrolysis has been less remarkable, as the subject of the detailed pilot-scale research of two sequencing batch reactors (SBR) reported in this study. Long-term (about 8 months) continuous experiments were conducted to identify the effect of pH increasing from 4 to 11 in controlled temperature of 60˚C to achieve the optimum pH for the reduction of excess biological sludge. After providing a steady state in the reactors, sampling and testing parameters including chemical oxygen demand (COD), mixed liquor suspended solids (MLSS), dissolved oxygen (DO), specific oxygen uptake rate (SOUR), sludge volume index (SVI), and yield (*Y*) coefficient were evaluated. Results showed that in pH of 9, the kinetic yield coefficient decreased from 0.63 to 0.33. Therefore, excess sludge declined to 44%. Moreover, the soluble COD increased slightly in the effluent, whereas the removal percentage decreased to 79 in the reactor while the amount of SVI and SOUR in this pH dropped to 65 mg/l and 12 mgO_2/l.g VSS, respectively. However, no sludge was seen in the higher pH or lower pH, whereas effluent soluble chemical oxygen demand (SCOD) and turbidity was increased. Additionally, the wastewater disposal standards were not achieved and had a bad odor.

Keywords: SBR; Sludge reduction; Yield coefficient; Thermal hydrolysis; pH

1. Introduction

One of the main disadvantages of aerobic wastewater treatment processes such as SBR is high production of biological sludge. Among the outputs of municipal wastewater treatment plants, sludge is the most voluminous and difficult part for treatment and disposal. Thus, in the activated sludge process, about 40–60% of capital costs and more than 50% of operating costs and the maintenance of refineries are related to the sludge treatment from wastewater [1–4].

Anaerobic digestion of thermophilic biomass is exothermic. High temperature (thermophilic) lyses the cells that are less tolerant to heat and causes an increase in the microbial degradation of species that are incompatible with the environment. Also, high temperatures convert the biomass to pasteurized

*Corresponding author.

pathogenic organisms. Mason found out that they can find the optimal conditions for digestion of cell lysis products by a mixture of thermophilic bacteria [5].

By applying biological reactors, Canales showed that the sludge with less age improves the growth potential of biomass. However, when the biomass passes the thermal treatment loop (residence time: 3hr, temperature: 90˚C), almost 100% of cells are killed and bacterial lysis occurs. The amount of biomass that passes through thermal treatment loop returns again to the reactor, where hidden growth occurs and the metabolism increases the cause of 60% decline in the total biomass production [6].

The raw sludge contains different kinds of pathogenic microorganisms such as bacteria, virus, protozoa, and parasites whose amounts are much more than those of wastewater's sludge [7].

It should be noted that sludge production is one of the major features of biological treatment in wastewater plants. Moreover, in activated sludge treatment, plants about 40 to 60% of the investment expenses and more than 50% of the operation and maintenance expenses are spent on the sludge treatment [6,8]. Hence, sludge treatment is considered as an economically, environmentally, and practically challenging section in the wastewater and municipal landfill leachate treatment plants [9–11].

Most of the researches have addressed the effects of temperature on wastewater aerobics biological treatment which are described and analyzed as the effects of different temperatures on microbial activity and treatment performances under the steady state conditions [8].

To sum up, microbial growth yields decrease with the rise in temperature under the steady state [12,13], especially at thermophilic temperatures of 55 and 65˚C [14]. Furthermore, high substrate utilization rates occur at higher temperatures, unchanged and even low substrate utilization rates which are also reported with increasing temperature probably due to different microbial growth and different examined substrates [13,15,16].

Heat treatment is known as a simple treatment method compared to other treatments such as ozonation and chlorination. However, it can be applied separately or combined with other methods, such as alkaline, acid treatment, or membrane methods [6,17]. Unfortunately, the biological response of sludge matrix induced by heat treatment was poorly understood [18].

Biological wastewater treatment processes are sensitive to temperature, so the reduction of sludge production is highly increased by the temperature variation. Low-temperature operation leads to the increase in sludge production, i.e., the sludge production at 8˚C in the activated sludge process compared with 20˚C increased by a rate of 12–20% [19].

A side-stream membrane bioreactor treating synthetic wastewater by Pseudomonas fluorescent, coupled with a continuous sludge thermal treatment system, was used to reduce the excess sludge production. Nearly, 60% of sludge reduction was achieved when the returned sludge passed through a thermal treatment loop (90˚C for 3 h) [6].

The reduction of excess sludge by heat treatment is induced by sludge lysis and further cryptic growth (lysis-cryptic growth) [17].

High temperature is able to be combined with acid or alkaline treatment to reduce the excess sludge. Moreover, different cell lysis techniques (thermal, combination of thermal and alkaline or acid) were compared with break Alcaligenes eutrophus and wasted activated sludge [20,21]. However, their results showed that alkaline treatment by adding NaOH combined with thermal treatment (pH 10, 60˚C for 20 min) was the most efficient process to induce cell lysis and produce biodegradable lysates. Additionally, the coupling of this lysis system to a biological wastewater treatment bioreactor achieves 37% reduction in the excess sludge production compared with the CAS process.

This research aims to study reducing the biological excess sludge by controlling the sludge temperature which is heated in 60˚C in different pH.

2. Materials and methods

2.1. Reactor

The reactor consisted of two cylindrical sequencing batches that were used as the reactors with an inner diameter of 25 × 60 cm height. Moreover, they are made of poly glass, 20 l of efficient volume, and have the capacity of 10 l in each cycle. In addition, the programmable logic controller (PLC) is used to operate the system. The run time of two reactors selected in the same manner based on the type and characteristics of influent wastewater is shown in Table 1.

Table 1
Sequence of operation time in SBR

Stages	Time
Fulfilling	3 min
Aeration	4 h
Settlement	100 min
Drainage	15 min
Idle	30 min

2.2. Stage control and synthetic wastewater characteristics

Since the time control of different operation stages is of huge importance in sequencing batch reactors (SBR) system, a computerized system along with its auxiliary parts was used to adjust and control the different stages, measure and record the data related to the concentrations of the dissolved oxygen (DO), temperature degree, and pH. It should be mentioned that the amount of DO was kept between 1.5 and 2 mg/l. Fig. 1 demonstrates the layout of SBR. The summary of operational conditions is presented in Table 2.

2.3. Pilot start-up

Seeds are chosen from the returned activated sludge of Ekbatan wastewater treatment plant located in the west of Tehran. Also, to operate the SBR, about 4 L of the aforementioned sludge was used for a SBR with 20 L of capacity. Next, the synthetic wastewater was added to the reactor.

In the reactor, pH varies from 4 to 11 and after reaching a steady state and stable situation in pilot running, the parameters of COD, BOD_5, mixed liquor suspended solids (MLSS), mixed liquor volatile suspended solids (MLVSS), SVI, SOUR, and yielding kinetics were tested during 8 months. The tests were performed based on the standard methods for the examination of water and wastewater [22].

2.4. Determination of the synthetic efficiency of yield (the biomass production efficiency)

To determine the biosynthetic coefficients, especially biomass production coefficient (Y), the changes of biomass production per unit of time are used based on COD consumption changes per unit of time.

Therefore, the biomass production coefficient in operation time (yield operation) can be calculated by the equation below:

$$dX/dt = Y\, dS/dt \tag{1}$$

in which dX/dt = the amount of increase in biomass concentration or MLSS (mg/l) and ds/dt = the amount of substrate removal or COD (mg/l).

A simpler equation that represents the relationship between these three parameters is as follows:

$$Y\, q = \mu \tag{2}$$

where μ = the amount of specific growth (per unit of time) and q = the amount of substrate removal (mg/l d).

$$Y = \frac{X_0 - X}{S_0 - S} \tag{3}$$

In which S_0 and S = the initial and final substrate concentration, respectively, and X_0 and X = the initial and final biomass concentration (mg/l), respectively.

3. Results and discussion

3.1. The effect on COD removal

The pH has been fixed in control reactor, while in test reactor, pH varied between 5 and 9.

Fig. 2 shows the effect of pH on the percentage of COD removal. With the increase in pH to 9 or its decrease to 5, the COD removal percentage decreases and drops to 65 and 59%, respectively.

Variation in pH amount from acidity to alkalinity and vice versa is shown in Fig. 2. Since most involved microorganisms in biological treatment can only handle fluctuations in pH at the range of 6 to 9, in situations where the wastewater pH is below 6 or higher than 9, the nutrient phosphorus are deposited and are not available for bacteria, causing an increase in the amount of COD. pH has effect on bacterial enzyme

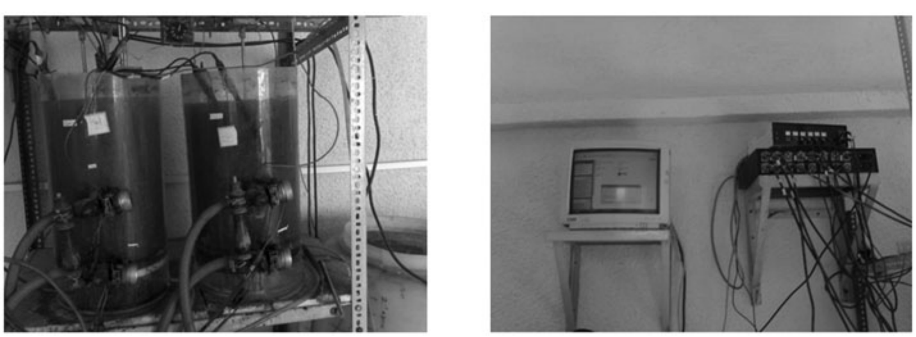

Fig. 1. General view of SBR layout.

Table 2
Detailed operational conditions

	Reactor 1 (control)	Reactor 2 (test)
Working volume (L)	10	10
SRT(day)	10	10
Sludge temperature (°C)	23 (wastewater temperature)	60
pH	7	4–11
Effluent COD (mg/l)	500	500
Effluent BOD_5 (mg/l)	350	350

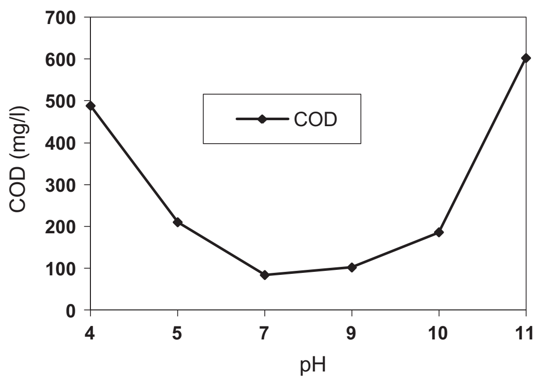

Fig. 2. The trend of COD changes at 60°C for half an hour at different pH sludge.

activity and also changes the amount of chemical ionization and the transfer of nutrients and toxic substances toward bacteria, and due to the loss of microorganisms degrading organic matter, COD removal efficiency decreases.

3.2. The effect on MLSS and TSS (total suspended solid)

Most bacteria in wastewater treatment plant are neutrophil and most microorganisms involved in biological treatment can handle fluctuations in pH in the range of 6–9 and have the most activity in pH range between 6.5 and 8.5. In situations where the wastewater pH is below 6, protogens and methanogens and many bacteria cannot survive. But such an environment is suitable for growing mushrooms. In high pH, the nutrient phosphorus which were stored are not available for bacteria. The change in sludge pH at the end of the final stage of wastewater treatment sludge causes the reduction of COD removal. Changes in pH between acidity and alkalinity cause the reduction in enzymatic activity and stop the clots production, neutrophils bacteria disappeared, but acidophilic bacteria (with a change in pH to acidity) or alkaliphile bacteria (with a change in pH to alkalinity), and also some types of mushrooms (which prefer pH less than 5) survived in the environment and continue to break down organic materials. As shown in Figs. 3 and 4, with the increase in pH to acidity and alkalinity, the amount of TSS in output wastewater has increased and the amount of MLSS in this pH has decreased.

3.3. The effect on SVI

As shown in Fig. 5, with changes in sludge pH between 5 and 9, SVI is reduced, respectively, about 52 and 65 mg/l. The effect of settling and low compressibility of sludge with changes in pH increase turbidity of wastewater and decrease the efficiency of system. The amount of SVI less than 50 mg/l represents the low efficiency due to the dispersed growth of fluke. Therefore, the best rates for SVI are between 50 and 150 mg/l. At pH below 5 and above 9, SVI is less than 50 mg/l. As a result, the best removal efficiency is at pH 9, since at this pH, the growth of fluke and filamentous bacteria is in balance, and SVI is 65 mg/l.

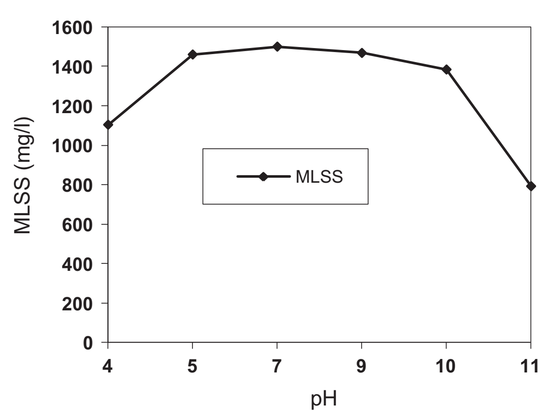

Fig. 3. The trend of MLSS changes at 60°C for half an hour at different pH of sludge.

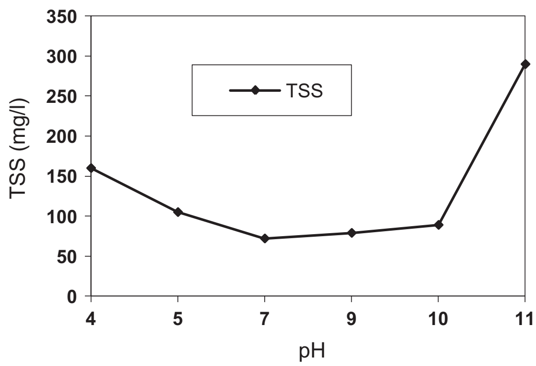

Fig. 4. The trend of TSS changes at 60˚C for half an hour at different pH of sludge.

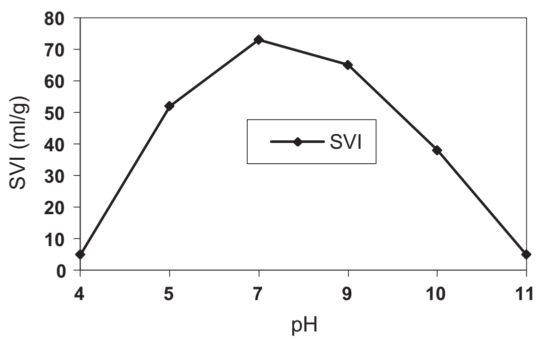

Fig. 5. Effect of pH changes with simultaneous sludge heating on SVI.

(1) By changing the pH between acidity and alkalinity, the amount of sludge dry weight decreased. Reducing the amount of dry sludge by changes in pH can be described by hydrolyzing the intracellular and extracellular material and destruction of the colloidal properties of macromolecules.

3.4. The effect on specific oxygen uptake rate (SOUR)

As shown in Fig. 6, with changes in pH between acidity and alkalinity, most of the microbes are disabled due to the effect of pH on microorganism (except for a limited number of acidophilic microorganisms or thermo-acidophilic which do not play any role in the wastewater treatment plant and fungi in acidic conditions, and alkaliphilic bacteria in alkalinity conditions), resulting in reduced microbial activity SOUR (respiration rate) which is a good indicator that shows the amount of biological activity resulting in

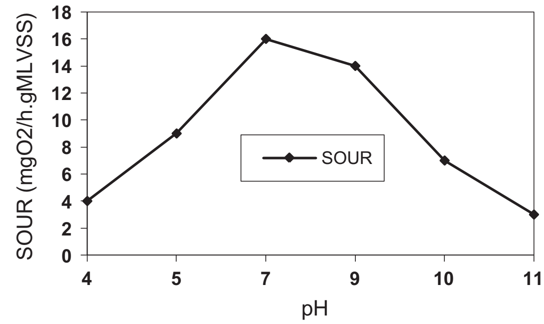

Fig. 6. The effect of changes in pH with simultaneous heating sludge per SOUR.

the effect of death. SOUR reduction demonstrates the reduction in microbial activity caused by pH changes.

3.5. The effect on sludge yield coefficient

Overall, with changes in pH in stable conditions, biomass yield coefficient (*Y*) is reduced, particularly outside the pH range of 6–9 (neutrophils bacteria tolerance).

As shown in Fig. 7, at wastewater temperature and COD = 500 mg/l, the amount of biomass yield coefficient (*Y*) is equal to 63 (mg biomass per mg COD). With increasing temperature to 60˚C and increasing pH to acidity and alkalinity, due to the loss of bacterial enzymes and proteins coagulation in the cytoplasm of bacteria, vegetative bacteria (mesophilic bacteria) were gone, but spores bacteria and some species of thermophilic bacteria, acidophilic, thermoacidophilic, and alkalophilic survived in the environment and continued the decomposition of organic materials. Spore formation in bacteria is the cause of resistance from unfavorable environmental conditions such as temperature, pH, and toxic substances. While by increasing the temperature and pH changes, heterotrophic

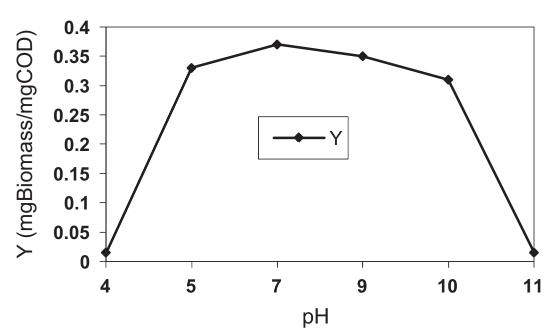

Fig. 7. *Y* coefficient determination at different pH with simultaneously heating the sludge.

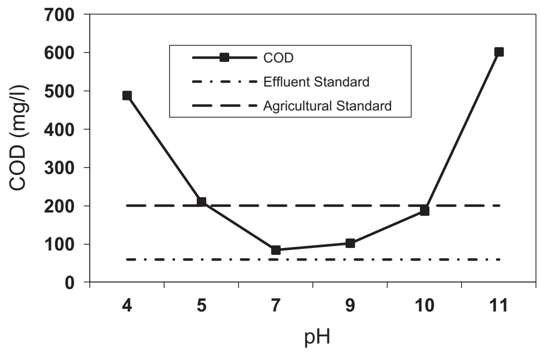

Fig. 8. Comparison of effluent COD at different temperatures and pH with disposal standard and reuse.

bacteria (mesophilic without spores) and neutrophils die. In other word, heat lysis alkaline and acid will occur. In this case, due to some bacteria which were deactivated, decomposition rate and microorganisms' activity will be decreased and it causes a reduction in the production of new cells.

According to Fig. 7, with temperature increases to 60˚C and pH changes by as much as 5, 9, and 10, the amount of biomass yield coefficient (Y) is reduced to a 33/0, 35/0, and 31/0, respectively. There was almost no sludge produced at pH 4 and 11, but system was hampered, water above the sludge became turbid, and effluent disposal was not standardized.

3.6. Comparison of effluent COD with wastewater disposal and reuse standard

As shown in Fig. 8, maximum COD removal efficiency is achieved. And at the standard pH, the reuse in agriculture is provided. That makes it able to estimate standard provisions for the reuse in agriculture at pH between 5 and 9. But the pH outside this range does not meet this standard.

4. Conclusion

Consequently, alkaline thermal treatment is considered as a simple method compared with other treatments such as ozonation and chlorination. At the temperature of 60˚C, at different pH during heating the sludge, at pH 9 coefficient of synthetic (Y) is reduced from 63 to 35 (excess sludge is reduced approximately 44%), but soluble COD in the refined effluent compared to the control reactor was increased and COD removal efficiency reached to 80% at pH 5 at 60˚C, the coefficient of synthetic (Y) is reduced from 63 to 33 (excess sludge is reduced approximately 48%), but COD removal efficiency came down to less than 60%, thereby soluble COD is increased in the effluent.

Results showed that the largest sludge reduction volume or the highest efficiency was at pH 9 and effluent had the standard for the reuse in agriculture. However, pH value outside this range does not meet the standard. In addition, heat treatment combined with pH changes in the SBR process would be a useful and simple technology for reducing excess sludge production. Hence, this method can be significantly considered and compared with the other methods based on technical and economic issues.

References

[1] M. Pazoki, A. Takdastan, N. Jaafarzadeh, Investigation of minimization of excess sludge production in sequencing batch reactor by heating some sludge, Asian J. Chem. 22(3) (2010) 1751–1759.
[2] A. Takdastan, M. Pazoki, Study of biological excess sludge reduction in sequencing batch reactor by heating the reactor, Asian J. Chem. 23 (2011) 12–29.
[3] A. Takdastan, N. Mehrdadi, A. Torabian, A.A. Azimi, G.N. Bidhendi, Investigation of excess biological sludge reduction in sequencing Bach reactor. Asian J. Chem. 21(3) (2009) 2419–2427.
[4] A. Takdastan, A.A. Azimi, N. Jaafarzadeh, Biological excess sludge reduction in municipal wastewater treatment by chlorine, Asian J. Chem. 22(3) (2010) 1665.
[5] C. Mason, G. Hamer, J. Bryers, The death and lysis of microorganisms in environmental processes, FEMS Microbiol. Lett. 39(4) (1986) 373–401.
[6] A. Canales, A. Pareilleux, J. Rols, G. Goma, A. Huyard, Decreased sludge production strategy for domestic wastewater treatment, Water Sci. Technol. 30 (1994) 97–106.
[7] G. Bitton, Wastewater microbiology, Willey-Liss, New York, NY, 2002.
[8] Y. Liu, J.-H. Tay, Strategy for minimization of excess sludge production from the activated sludge process, Biotechnol. Adv. 19(2) (2001) 97–107.
[9] M. Pazoki, M. A. Abdoli, A. Karbassi, N. Mehrdadi, K. Yaghmaeian, Attenuation of municipal landfill leachate through land treatment, J. Environ. Health Sci. Eng. 12(12) (2014) 1–8.
[10] M. Pazoki, M. Abdoli, A. Karbasi, N. Mehrdadi, K. Yaghmaeian, P. Salajegheh, Removal of Nitrogen and phosphorous from municipal landfill leachate through land treatment, World Appl. Sci. J. 20(4) (2012) 512–519.
[11] M.A. Abdoli, A.R. Karbassi, R. Samiee-Zafarghandi, Zh. Rashidi, S. Gitipour, M. Pazoki, Electricity generation from leachate treatment plant, Int. J. Environ. Res. 6 (2012) 493–498.
[12] R.O. Mines Jr., J.H. Sherrard, Temperature interactions in the activated sludge process, J. Environ. Sci. Health Part A 34 (1999) 329–340.
[13] C. Krishna, C.M. Van Loosdrecht, Effect of temperature on storage polymers and settleability of activated sludge, Water Res. 33 (1999) 2374–2382.

[14] L.A. Lishman, R.L. Legge, G.J. Farquhar, Temperature effects on wastewater treatment under aerobic and anoxic conditions, Water Res., 34 (2000), 2263–2276.
[15] T M. LaPara, A. Konopka, C.H. Nakatsu, J.E. Alleman, Effects of elevated temperature on bacterial community structure and function in bioreactors treating a synthetic wastewater, J. Ind. Microbiol. Biotechnol. 24 (2000) 140–145.
[16] R. Johnson, E.R. Hall, The biological Treatment of Recirculated Whitewater at High Temperatures, in CCPA Tech, Jasper Alberta, Canada, Sect. Pacific Coast & Western Branches Joint Spring Conf. (1996) 1–7.
[17] Y. Wei, R.T. Van Houten, A.R. Borger, D.H. Eikelboom, Y. Fan, Minimization of excess sludge production for biological wastewater treatment, Water Res. 37 (2003) 4453–4467.
[18] S. Yan, K. Miyanaga, X.-H. Xing, Y. Tanji, Succession of bacterial community and enzymatic activities of activated sludge by heat-treatment for reduction of excess sludge, Biochem. Eng. J. 39 (2008) 598–603.
[19] S. Tian, L. Lishman, K.L. Murphy, Investigations into excess activated sludge accumulation at low temperatures, Water Res. 28 (1994) 501–509.
[20] M. Rocher, G. Roux, G. Goma, L. Louvel, J.L. Rols, Excess sludge reduction in activated sludge processes by integrating biomass alkaline heat treatment, Water Sci. Technol. 44 (2001) 437–444.
[21] M. Rocher, G. Goma, A. Pilas Begue, L. Louvel, J.L. Rols, Towards a reduction in excess sludge production in activated sludge processes: Biomass physicochemical treatment and biodegradation, Appl. Microbiol. Biotechnol. 51 (1999) 883–890.
[22] AWWA APHA, and WPCF, Standard Method for the Examination of Water and Wastewater, in twenty second ed., NW, Washington, DC, USA, 2014.