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The effect of ZnO on aerobic biodegradation of a novel polyacrylate tannage in activated sludge system

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ABSTRACT

Some analysis including differential chemical oxygen demand, total organic carbon, bacterial community composition, CO_2 production, particle size distribution, scanning electron microscopy, gel-permeation chromatography, Fourier transform infrared spectroscopy, and mass spectrum in addition to the properties of degradable products and polyacrylate/ZnO was studied in order to evaluate the effect of ZnO nanoparticles on biodegradation of polyacrylate in aerobic activated sludge system. Biodegradation mechanisms of polymer degradation with and without ZnO particles were obtained by chemical structure analysis, indicating that biodegradation was mainly considered as depolymerization and assimilation, and the depolymerization of polyacrylate was occurred more easily than polymethacrylate. Furthermore, the addition of ZnO enhanced the solubility of polyacrylate in the aqueous phase, changed the structure of polyacrylate, altered the proportion of different microbial strain, reduced the toxicity of polyacrylate on micro-organisms, and dispersed soil particles with a multiaperture surface, which are beneficial to the increased biodegradation of polyacrylate under aerobic activated sludge system.

Keywords: Activated sludge; Aerobic system; Biodegradation; Polyacrylate/ZnO; Tannage

1. Introduction

With the improvement of the environment protection and the nanotechnology development, polymeric–inorganic hybrid materials have become the research hot spot in the leather tanning agent [1–3]. Polyacrylate is a good film-forming material with superior cohesiveness, transparent, brightness, and may potentially be useful to replace chromium sulfate in applications. Among all nanomaterials, ZnO exhibits considerable properties including near-UV emission, optically transparent, photocatalysis, and antibacterial properties due to its direct wide band gap of 3.37 eV and large exaction binding energy of 60 meV at room temperature [4–6]. Due to their excellent properties, a composite of polyacrylate and ZnO could combine the properties of them and improve swelling ability, gel strength, mechanical, environmental friendly characteristics, and thermal stability of corresponding composites [7,8].

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However, the polyacrylate/ZnO tannage also exhibited the disadvantages: polyacrylate can be prepared with different functional groups such as carboxylic acid, amine, hydroxyl, amide, and sulfonic acid groups [9]. Due to strong polarity and hydrophilicity of functional groups, the polyacrylate is easily dissolved in wastewater after tanning process and also have the serious environmental impact. At the same time, although nanocomposites exhibit improved, or even novel properties when compared to micro- and macro-composites, the behavior of nanocomposite materials with length scales smaller than 1 μm in aqueous phase is still uncertain. Interfacial interactions between polyacrylates and nano-ZnO lead to some environmental issues are unknown.

In order to avoid these drawbacks, people have been focusing mainly on degradation of polyacrylate/ZnO nanocomposite. S.F. Wang et al. reported that the biodegradability of poly(3-hydroxybutyrate-co-3-hydroxyvalerate)/organophilic montmorillonite (PHBV/OMMT) nanocomposites was related to the interaction and adhesion of PHBV and OMMT, water permeability, degree of crystallinity, and anti-microbial property of OMMT [10]. Thellen et al. observed a 48% improvement in oxygen barrier and a 50% improvement in water vapor barrier for PLA/montmorillonite-layered silicates (MLS) in comparison to the PLA. Biodegradation rates in soil were slightly greater for the PLA/MLS nanocomposite than the pure PLA [11]. However, most of the literatures about this research reported on soil, or compost biodegradation of polymers-based porous materials, super absorbent, and clay. Until now, little information can be found about the biodegradation of polyacrylate/ZnO nanocomposite.

The main objective of the present work was to examine whether the activated sludge method could be optimized for the degradation of polyacrylate/ZnO composites under aerobic condition. Various reactions and influencing parameters such as total organic carbon (TOC), size, losses, and appearance of polyacrylate/ZnO composites were tested. A second objective of the current study was to explore the biodegradation mechanism, in order to better define the variables that affect biological degradability of polyacrylate/ZnO. The experimental results can be used to understand the changes of polyacrylate molecule in the biodegradation process of the polyacrylate/ZnO composites with aerobic activated sludge system, and to provide valuable information in understanding the potential effects of polyacrylate/ZnO composites on activated sludge treatment process.

2. Experiments

2.1. Materials and reagents

Polyacrylate and polyacrylate/ZnO in the current investigation were provided by the tanning laboratory for college of resources and environment and prepared as described in the literature [12]. The polyacrylate was the copolymer, seen in Fig. 1. All the other chemicals were reagent grade and used without any further purification.

2.2. Activated sludge and acclimation

The activated sludge samples were collected from a steady operating pilot-scale process in the industrial wastewater treatment system. The acclimation was performed in a 10 L tank. An aeration pump was used for the air supply and for keeping the sludge in suspended form. To initiate the acclimatization, glucose as an additional carbon source was added for the appropriate growth of the activated sludge in the biodegradation systems. After an acclimation period of about 14 d, the process exhibited complete nitrification and approximately 45% denitrification, which was an essential requirement for the biodegradation process.

2.3. Apparatus

A schematic diagram of the experimental setups is depicted in Fig. 2. An activated sludge bioreactor made of plexiglass and of working volume 2.5 L was used to determine the effect of polyacrylate/ZnO (nano-ZnO) on activated sludge. The experimental system consisted of two exits: one for biodegradation solution mixed with sludge (1 L) at the end of the reactor and other for aerating through the tube by an air pump. The same activated sludge volume of 500 mL was used in all experiments. The mixed liquor suspended solid (MLSS) concentration and the mixed liquor volatile suspended solid concentration were approximately 4.0 and 3.0 g/L, respectively. In each

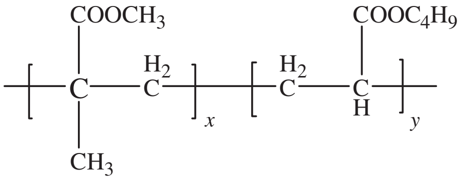

Fig. 1. Proposed chemical structure of polyacrylate, the composition of polyacrylate unit is given in mole fractions: (*x*) 4, (*y*) 6.

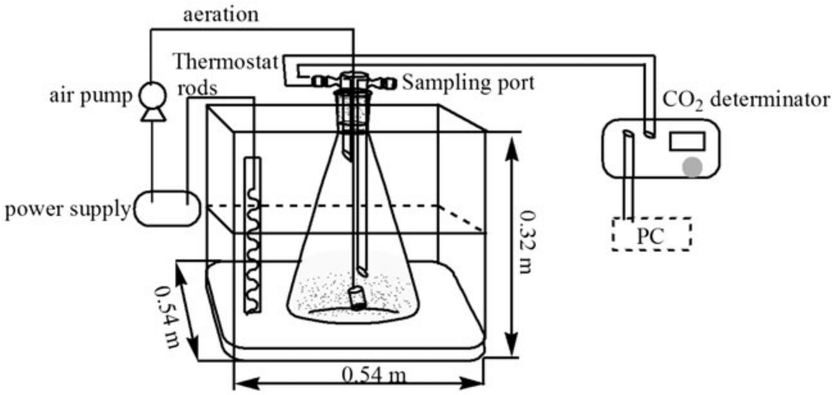

Fig. 2. Schematic diagram of the activated sludge bioreactors used in aerobic condition.

batch of the experiment, all but one reactor was added with different amounts of test chemicals (polyacrylate and polyacrylate/nano-ZnO). One reactor was used as a control without adding any chemical. The biodegradation solution (initial COD = 100 mg/L) containing the polyacrylate or polyacrylate/ZnO was added to the aerobic reactor through the top of the reactor by a feed pump. Before adding chemicals, open reactor bottles were placed in a water bath at a controlled temperature of 25℃ and mixed for 20 min to equalize the temperature and dissolved oxygen (DO). In all the experiments, the temperature and pH were kept at $T = 25 \pm 2$℃ and pH 7 ± 0.4. DO concentration was kept about 3 mg/L in the reactors.

The biodegradation system used throughout the studies was composed of polyacrylate or polyacrylate/ZnO as carbon source, ammonium chloride as nitrogen source (17 mg/L), KH_2PO_4 as phosphorus source (85 mg/L), $MgSO_4{\cdot}7H_2O$ (11 mg/L), $CaCl_2$ (27.6 mg/L), and $FeCl_3$ (0.25 mg/L) and desired initial chemical oxygen demand (COD) concentration of biodegradation solution is 100 mg/L. The biological activity in the bioreactor was monitored by measuring COD, TOC, CO_2, and molecular weight. Mixed liquor samples from the bioreactor were taken from the bioreactor to different analysis instruments at regular intervals.

2.4. Methods of analysis

Samples were centrifuged at 4,000 rpm for 25 min to remove the solids from the liquid medium. The clear supernatant was analyzed for COD and TOC. The standard method based on digestion and reflux was used for COD and TOC analyses. FT-IR spectra were registered in KBr using a BEQ UZNDX-550. COD determination was conducted with the digestion system and COD determinator (Lianhua COD determinator Ltd. Co., China). TOC values of degradation were detected by a JEOL JEM-3010, TOC analyzer to determine the extent of mineralization. DO and pH measurements were carried out by using the DO and pH meter probes. All the experiments and measurements were done in duplicate and arithmetic averages were taken throughout the analysis. The scanning electron microscopy (SEM, Hitachi-S4800) was utilized to characterize the morphologies of the activated sludge. DNA was extracted from soils, fed with polyacrylate and polyacrylate/ZnO, and isolates using the FastDNA SPIN Kit for soil (Beijing Bio-ulab. Co., Ltd, China) following the supplier's instructions. Afterwards, Partial V3 region of bacterial 16S rRNA gene were PCR-amplified from the genomic DNA using the primers 338f-GC (50-CCT ACG GGA GGC AGC AG-30 with a GC clamp attached to the 50 end of the primer) and 518r (50-ATT ACC GCG GCT GCT GG-30) [13,14]. The 16S rRNA gene sequences obtained for this study have been submitted to the GenBank database under accession numbers KC812054–KC812061, KC812063–KC812070, KC812072–KC812080, KC812083–KC812085, and KC812087–KC812099.

3. Results and discussion

3.1. Effect of polyacrylate and polyacrylate/ZnO tannage on the aerobic activated sludge system

COD is an important measure of organic pollution in water. The determination of COD can be completed conventionally by titrating the excess of dichromate that was normally used as a strong oxidant to digest organics. In order to know the biodegradation degree of different tannages, the reductions in COD was achieved at pH 7 during the process. The experiment was performed for one month so that stable and reliable data were gotten. Fig. 3 presents that COD removal shows an increasing trend with time up. However, the increase of COD removal efficiency about two tannages tended to slow and the COD removal efficiency increased fastest in first three days. After 31 d of the treatments, the COD removal effect was 94.55 and 95.39% for polyacrylate and polyacrylate/ZnO, respectively. The results indicated that the COD removal efficiency was gradually increased with increase in reaction time from 1 to 31 d. It was apparently found that most tannages were mineralized partly in the process. Lu et al. found that pre-oxidation process significantly improved aerobic biodegradability of wastewater containing tannages [15]. The introducing of ZnO nanoparticles to activated sludge process has not significantly improved the COD removal of tannage as compared with the degradation of polyacrylate.

The TOC concentration is very important, because it is one of the best observations to conclude the exact point in time when the polyacrylate has been entirely degraded and the complete mineralization has been achieved. Fig. 4 was about the TOC removal rate of polyacrylate and polyacrylate/ZnO using activated sludge method. It could be easily found that efficiency of TOC removal was increased with reaction time gradually no matter whether the ZnO nanoparticle was added in. Decrease of TOC can be attributed to the mineralization of polyacrylate by micro-organisms from activated sludge during aerobic treatment. The addition of ZnO to the polyacrylate increased the TOC percentage of polyacrylate to 68.23%. This means that an increase in efficiency of TOC removal by 8.63%. It could be concluded that the nano-ZnO could stimulate micro-organisms in activated sludge to utilize polyacrylate as carbon and energy source.

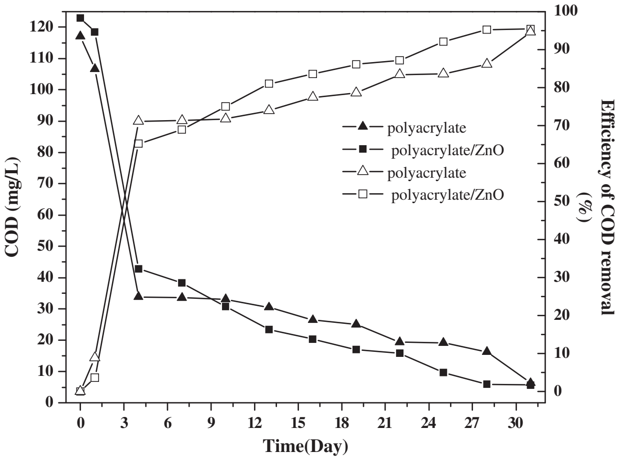

Fig. 3. The effect of reaction time on COD removal in batch aerobic degradability of different tannages ($T = 25^\circ\text{C}$, pH 7.0, and MLSS = 4 g/L).

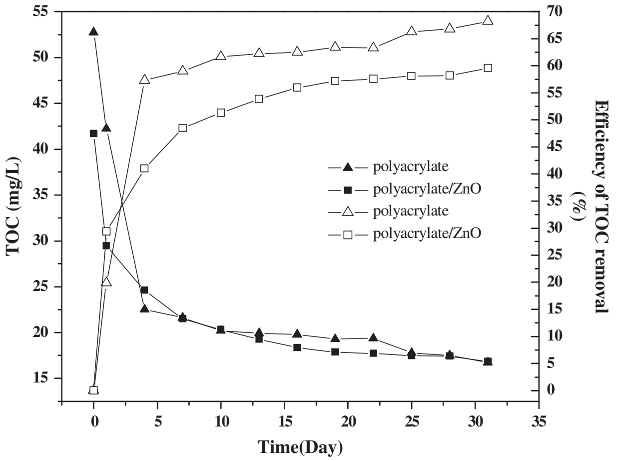

Fig. 4. Effect of reaction time on the total TOC removal of different tannages.

The characteristics of tannages, before and after biodegradation are summarized in Table 1. Both TOC and COD were decreasing with the increasing of the contact time. While COD elimination of different tannages was almost similar, the elimination of TOC was regularly different after 31 d. The improvement of TOC and COD elimination was obvious in the presence of ZnO and the reaction time of 31 d; while 95.4% of COD and less than 68.23% of TOC were eliminated in ZnO presence, and about 94.6% of COD and 59.6% of TOC were eliminated in polyacrylate. These comparisons could be seen clearly in Figs. 3 and 4. Under aerobic conditions, the degradation of organic pollutants depends on the ratio of COD and TOC. The smaller ratio of tannage was, the easier it became to oxidize. Table 1 clearly indicated the addition of nano-ZnO leads to an increase in oxidation feasibility of the soluble polyacrylate.

In this work, the concentrations of sludge were stable during two degradation processes. Based on the references [16–18], the changes of anaerobic micro-organism in the activated sludge during different extent were used to the effect of ZnO on the sludge. Fig. 5 showed the bacterial community composition for each activated sludge sample according to DGGE analysis during the degradation process. The highest similarity of bacterial community structure was found among four samples and there are four major types: *Alphaproteobacteria* (Alpha), *Betaproteobacteria* (Beta), *Gammaproteobacteria* (Gamma), and *Deltaproteobacteria* (Delta) in all samples. From Fig. 5, introducing ZnO nanoparticle to polyacrylate latex bring no influence on the bacterial community structure in sludge. However,

Table 1
Analysis of biodegradation by variety of biochemical indicators

Sample	COD after 31 d (mg/L)	COD removal efficiency after 31 d (%)	TOC after 31 d (mg/L)	TOC removal efficiency (%)	COD/TOC after 31 d
Polyacrylate	6.377	94.6	16.848	59.60	0.379
Polyacrylate/ZnO	5.667	95.4	16.752	68.23	0.338

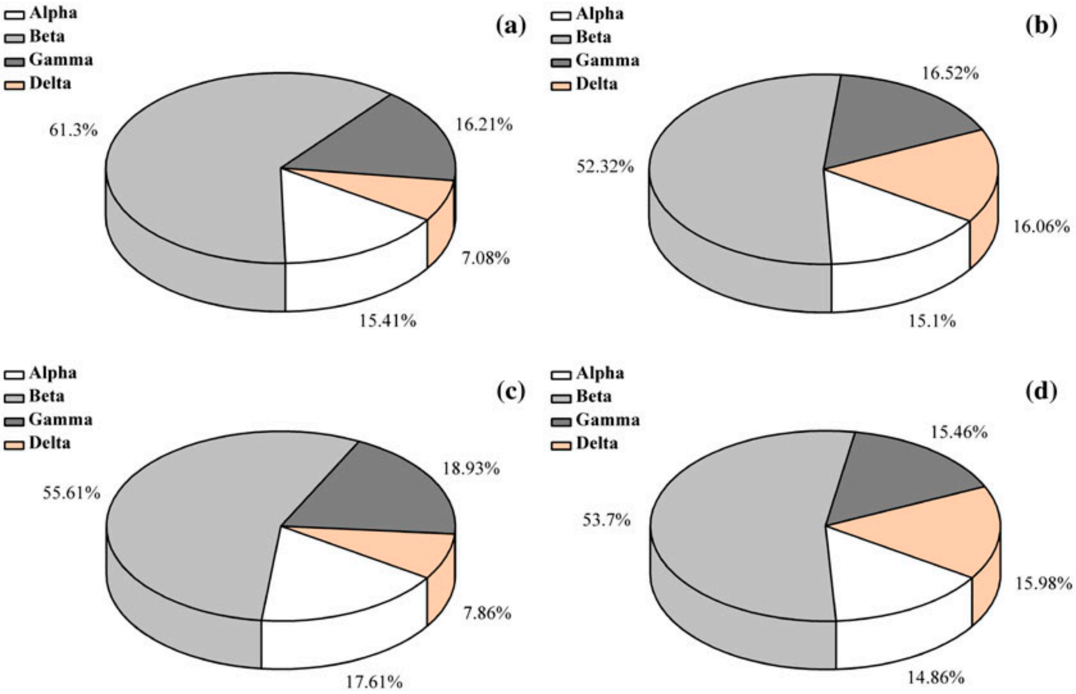

Fig. 5. The changes of bacterial community composition during the degradation ((a) polyacrylate 5 d, (b) polyacrylate 30 d, (c) polyacrylate/ZnO 5 d, and (d) polyacrylate/ZnO 30 d).

it changes the proportion of different microbial strain. *Betaproteobacteria* is absolutely dominant population in all samples in this study, from 61.3% in "polyacrylate 5 d" to 55.61% in "polyacrylate/ZnO 5 d", whereas its population scale shrank in different extent during the degradation process. Obvious shift on dominant population indicated that the addition of ZnO may decreases the adsorption of polyacrylate on the activated sludge. The population scale of *Deltaproteobacteria*, comparing with that of different 5th-day-sludge (7.08% in polyacrylate and 7.86% in polyacrylate/ZnO), gained great growth in all treatments, with the highest value being found in 30th-day-sludge (16.06% in polyacrylate and 15.98% in polyacrylate/ZnO). The results showed that the bacteria associated with the electron transport has always increased during the degradation process and the addition of ZnO did not changes the trend. The populations of *Alphaproteobacteria* and *Gammaproteobacteria* have been stable in the degradation of polyacrylate, but they all have been reducing during the degradation of polyacrylate/ZnO. To sum up, the addition of ZnO has not affect the relationship between polyacrylate and the activated sludge and it may increase the solubility of polyacrylate in the degradation system. The main degradation of two samples occurred in aqueous phase.

3.2. *Effect of polyacrylate and polyacrylate/ZnO tannage on CO_2 production under aerobic process*

The CO_2 produced is proportional to the percentage of substrate biodegraded. Mineralization studies involving measurements of total CO_2 production can provide excellent information on the biodegradability potential of hydrocarbons [19]. CO_2 evolution measures ultimate degradation (mineralization) in which a substance is broken-down to the final products. To determine how adding nano-ZnO can improve the biodegradability of polyacrylate, CO_2 production graph can be produced as shown in Fig. 6. The amount of CO_2 generated from the samples was listed in Table 2. The CO_2 production of blank, polyacrylate, and polyacrylate/ZnO were 11,441.84, 7,834.93, and 8,082.73 ppm in 30 d. Different amounts of CO_2 produced from the sample can be explained by the use of different carbon source for microbial growth. Addition of ZnO to polyacrylate sample resulted in an increased total amounts of CO_2 produced from this system, which were less than that of blank. This results indicated that polyacrylate cannot be biodegraded, and the curve of CO_2 production was similar to the trend of blank, which was originated from the endogenous respiration of micro-organism in the activated sludge. It revealed that the inhibition of growth of micro-organism by the polyacrylate alone may take place in the activated sludge reactor, which limited the biodegradation of polyacrylate. According to the experimental results, the polyacrylate is toxic to micro-organisms due to their devastating effects on cell membranes. Furthermore, polyacrylate/ZnO composite also have not change nonbiodegradation of polyacrylate and the addition of ZnO could decrease the toxic of polyacrylate to micro-organism. Because the nano-ZnO added to the polyacrylate brings about the changes of structure of polyacrylate.

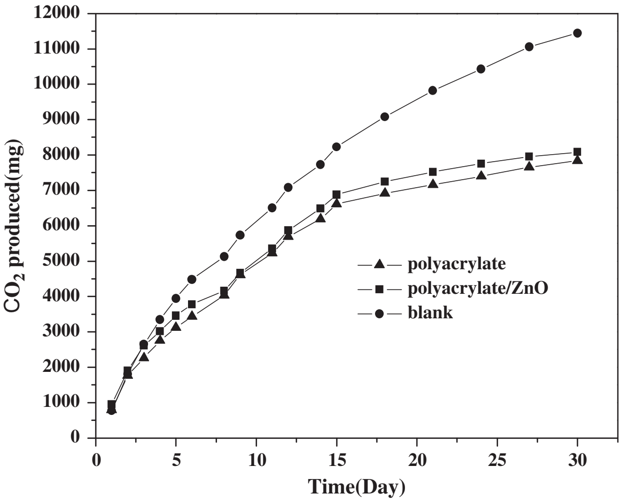

Fig. 6. The CO_2 production of different samples in activated sludge reactor.

Table 2
Analysis of biodegradation by the CO_2 production

Sample	CO_2(30 d)/ppm
Polyacrylate	7,834.93
Polyacrylate/ZnO	8,082.73
Blank	11,441.84

3.3. Particle size distribution of polyacrylate/ZnO tannage during the biodegradation processes

Fig. 7 shows, the evolution of particle size distribution with reaction time for polyacrylate/ZnO tannage. Notice that the particle size distribution depends on function biodegradation of the reaction time. Polyacrylate/ZnO latex produced with a larger particle size can be observed in the early biodegradation stage (1 d) and a narrow particle size distribution will be achieved. Polyacrylate/ZnO tannage shows a monomodal particle size distribution with a median value (Intersity 47.6%) of 458.7 nm and low intensity distribution extended from 342 to 615 nm in the first day of biodegradation. As polyacrylate/ZnO was biodegraded for 30 d, then this distribution was transformed to a wide monomodal particle size distribution with a median value (intersity 23%) of 342 nm. At the same time, particles size distribution of polyacrylate/ZnO for 30 d clearly shows that it suppressed the formation of the low intensity of the relative distribution reduced, the smaller particles size distribution at around 190–712 nm. This indicates that the polymer chain in the molecular of polyacrylate/ZnO broke down and resulted in the smaller particle size

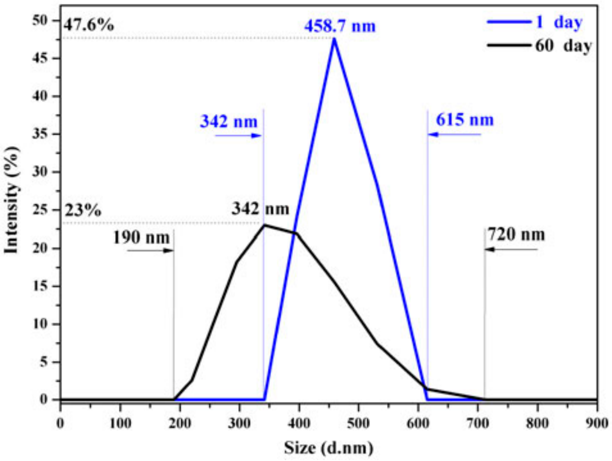

Fig. 7. Particles size distribution of polyacrylate/ZnO latex particles at different biodegradation times.

distribution, and the wider the particle size distribution with increased in degradation time.

3.4. Surface morphology

In addition to CO_2 production, scanning electron microscopy (SEM) was used to investigate the activated sludge surface in the different period. Using SEM, polyacrylate/ZnO sample, which had biodegraded for 30 d, were compared to polyacrylate/ZnO, which had biodegraded for only 1 d. When the polyacrylate/ZnO was not added to the reactor, the activated sludge can be observed with water included in it and the soil particle appears mostly as dense. In the initial stage of the reaction, soil spheres with polyacrylate/ZnO lose their integrity, since they tend to agglomerate when intend to dry. Because, when polyacrylate/ZnO was added, the system shows two phases: one being water and the other one being the mixture of polymers. After 30 d biodegradation, the microbes appear to be divided to each other, as well as mixed with the sample and micro-organism. Because, the majority of the aggregates observed by electron microscopy (Fig. 8(C)) was of smaller size, nano-ZnO was predominantly cleared by adsorption to the sludge (bacteria). Because the bacteria are much larger and relatively heavy, such adsorbed particles stay in the unit and are removed from the wastewater. This behavior is a direct result of the fact that the sludge is living agglomerate of bacteria and subject to sludge agglomerate breakup, adhesion of sludge to gas bubbles, and occasional transfer of sludge into the outlet of the setup. The change in surface of the composite is highly dependent on the amount of the micro-organism and the CO_2 production. An increase in the amount of more micro-organism and the CO_2 production disperses soil particles with a multiaperture surface.

3.5 Mechanisms of degradation

The four stages of biodegradation are: (i) biodeterioration (fragmentation of biodegradable materials by the combined action of microbial communities, other decomposers and/or abiotic factors); (ii) depolymerization (cleavage of polymeric molecules reducing progressively their molecular weight); (iii) assimilation (molecules are integrated into microbial metabolism); and (iv) mineralization(completely oxidized molecules are released) [20,21].

Biodeterioration of polyacrylate/ZnO was observed with molecular weight in value (Fig. 9). Further, attachment of micro-organisms to the surface was inferred from IR spectrum from degraded samples, which showed bands associated with microbial markers that are distinguished from polyacrylate/ZnO characteristic bands. Biodeterioration was coupled with depolymerization (bond cleavage through which oligomers and monomers were formed, and subsequently assimilated) [22].

Biodeterioration occurs at the interface between activated sludge and sample and is limited by biodeterioration and depolymerization [23]. As polyacrylate/ZnO was constant and only a small decrease in molecular weight was detected, ZnO was considered to be relatively unaffected, also shown by changes in estimated mechanical properties from mass spectrum (MS) data.

3.5.1. GPC analysis

If the polyacrylate undergo degradation, molecular weight will be decreased [24–26]. When measured by gel-permeation chromatography (GPC), the polyacrylate/ZnO shows decrease in molecular weight as listed in Fig. 9. The residual polymer and its oligomers are often analyzed by applying GPC to measure a possible shift in M_w distribution. Molecular weight (M_w)

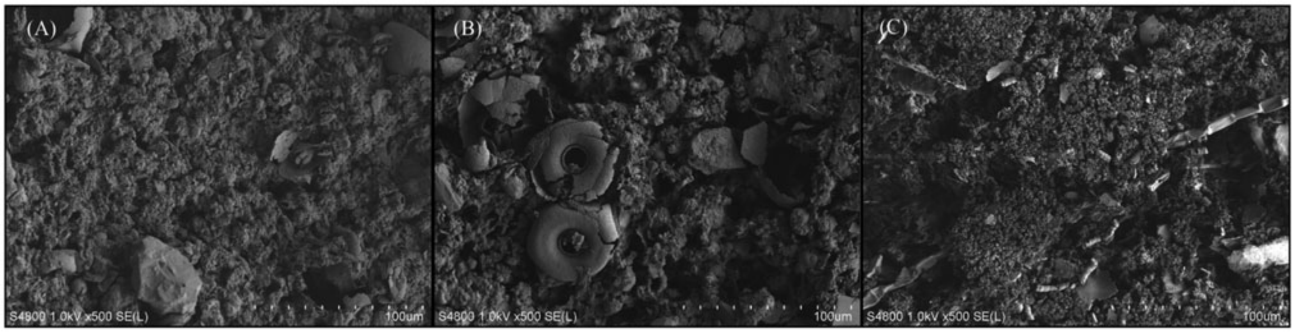

Fig. 8. SEM images of a typical activated sludge found in an aerobic reactor during different biodegradation period: (A) 0 d (pure activated sludge), (B) 1 d, and (C) 30 d.

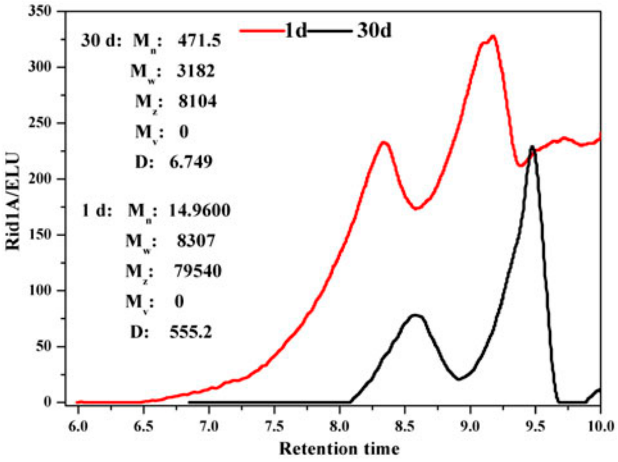

Fig. 9. Influence of reaction time on the molecular weight distribution of the polyacrylate/ZnO.

of polyacrylate/ZnO during different biodegradation period was 8,370 for 1 d and 3,182 for 30 d, respectively. The polydispersity index was 555.2 for 1 d and 6.749 for 30 d, which were obtained with aqueous GPC. The results showed that polyacrylate in polyacrylate/ZnO was depolymerized by aerobic activated sludge [27,28]; however, the degree of fragmentation is small, which indicates that polyacrylate is difficult to degrade.

3.5.2. FTIR spectra

The chemical structures of the raw ZnO, activated sludge, polyacrylate/activated sludge, and polyacrylate/ZnO/activated sludge were detected by Fourier transform infrared spectroscopy (FTIR) and the results are presented in Fig. 10. All sample except ZnO exhibited the characteristic stretching peaks of C–H (CH_2) at 2,921and 2,852 cm^{-1}, while the bands in the region between 3,500 and 3,300 cm^{-1} being due to the –OH in the sludge. The spectrum of ZnO showed a weak band at 1,627 cm^{-1}, which could be assigned to the –OH in $Zn(OH)_2$. Two partial overlapping bands from 1,629 to 1,728 cm^{-1} were observed in the cases except the ZnO. They were attributed to the richness of humic structures in etherified and peptidic compounds of activated sludge. Peaks at 1,033, 1,028, and 1,091 cm^{-1} could be due to the $H_2PO_4^-$ in KH_2PO_4, which is the phosphorus source in the system [29–31].

When ZnO was encapsulated by polyacrylate, compared with the spectrum of polyacrylate, some new peaks of Zn–O dissymmettry flexible vibration was detected at about 792 cm^{-1} in the spectrum of the polyacrylate/ZnO/activated sludge [32]. In addition, the ZnO impregnated onto the interface of polyacrylate/activated sludge caused a slight red shift in the peak at 443 and 493 cm^{-1}, which are attributed to the stretching vibration and wagging vibration of Zn–O bonds [22,33].

3.5.3 MS analysis

To explore $(\text{methacrylate})_x$ – $(\text{butyl acrylate})_y$ construction of biodegradation products onto the ZnO, the biodegradation products of polyacrylate/ZnO were collected and analyzed by MALDI-TOF MS for identification of fragments. Fig. 11 shows the analytic

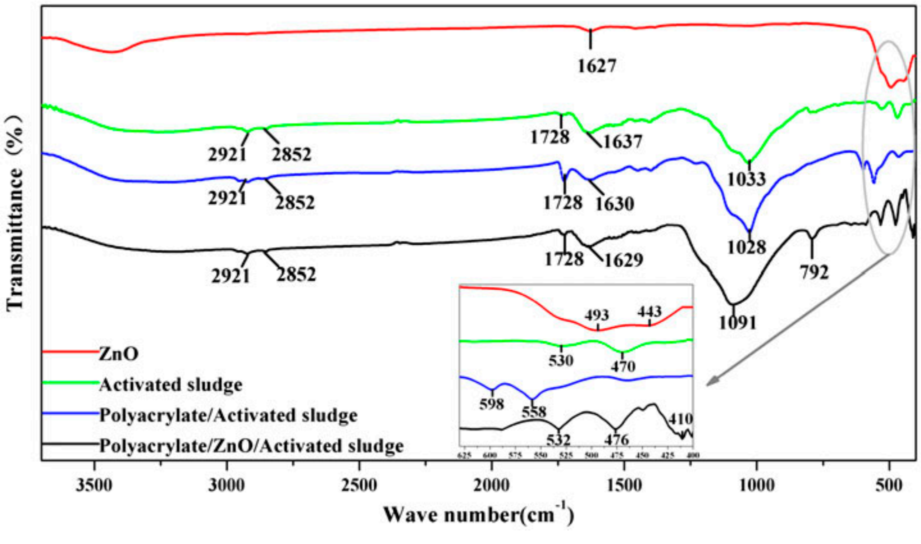

Fig. 10. FTIR spectra of different tannages in an aerobic activated sludge system.

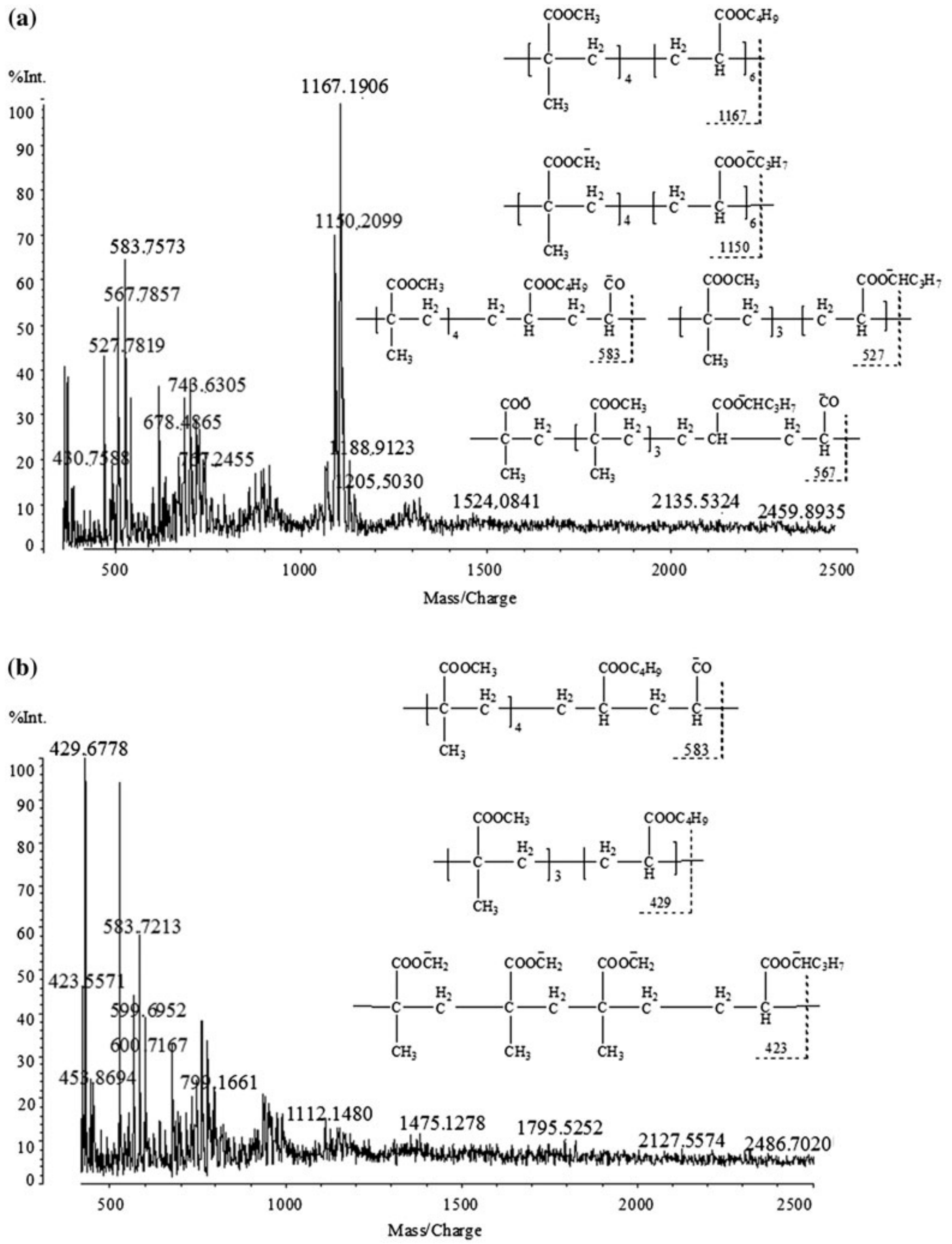

Fig. 11. Mass spectrogram of polyacrylate/ZnO during aerobic activated sludge treatment: (a) 1 d, (b) 30 d.

results of degradation solution from 1 to 30 d. Many positively identified fragments were observed from the MS spectra. However, consequences of the compared experiment showed that the polyacrylate molecules were not completely mineralization, because a number of peaks from the loaded organic products peaks appeared in the low- and high-*m*/*z* ranges, respectively.

The polyacrylate was the copolymer of methacrylate and butyl acrylate. It could be inferred that the peak of *m*/*z* 1,167 corresponds to the structure of polyacrylate molecule, and the structure was shown in Fig. 11(a). The structure corresponding to peak of m/z 429 was partially biodeterioration and it was shown in Fig. 11(b). The observation corresponded to the detection of fragments containing possible

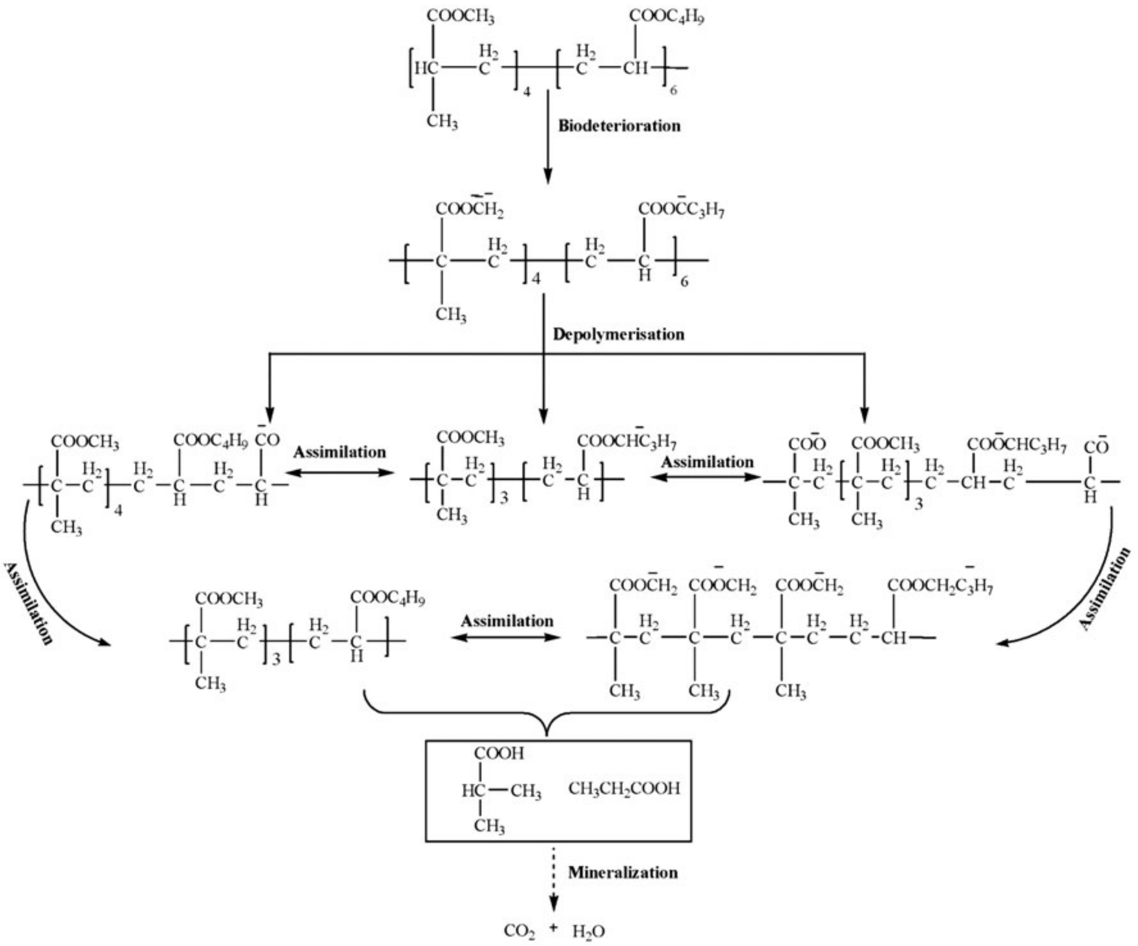

Fig. 12. Mechanism description of polyacrylate/ZnO during aerobic activated sludge treatment.

depolymerization products of polymethacrylate and polybutylacrylate, respectively. Similar identification results witnessed by MS, demonstrated that the stability of polymer molecules and their bioactivity was preserved well in the microsystem. Furthermore, compared with the MS spectrograms of degradation solution in separate reaction times, it could be inferred that the degradation process contains two stages: biodeterioration and depolymerization. From the molecular formula $(C_5H_8O_2)_x$–$(C_7H_{12}O_2)_y$ and the MS peaks, molar composition of the two monomers in 30 d was calculated as $x{:}y = 3{:}1$, smaller than that calculated in 1 d (about 4:6) of the copolymer, which indicated that the depolymerization of polyacrylate was more likely to occur than polymethacrylate [34,35].

From MS results, the mechanism description of polyacrylate in polyacrylate/ZnO is suggested in Fig. 12. Furthermore, the biodegradation of polyacrylate in polyacrylate/ZnO mainly occurred in depolymerization and assimilation, and the depolymerization of polyacrylate was occured more easily than polymethacrylate. According to the results of TOC, the polyacrylate did not completely mineralized into CO_2 and H_2O. However, based on the results from COD, TOC, bacterial community composition, CO_2 production, SEM, FTIR spectra, GPC as well as MS, the addition of ZnO enhanced the solubility of polyacrylate in the aqueous phase, changed the structure of polyacrylate, altered the proportion of different microbial strain, reduced the toxicity of polyacrylate on micro-organisms, and dispersed soil particles with a multiaperture surface, which are beneficial to the increased biodegradation of polyacrylate under aerobic activated sludge system.

4. Conclusion

From the above results, we can conclude that polyacrylate and polyacrylate/ZnO composites have not been completely degraded. Some analysis, including

COD, TOC, SEM, GPC, FT-IR, and MS in addition to the properties of degradable products, and polyacrylate/ZnO was studied in order to evaluate the effect of ZnO nanoparticles on biodegradation of polyacrylate in aerobic activated sludge system. Polyacrylate/ZnO composite also have not been completely biodegraded and ZnO could change the structure and make polyacrylate more easily biodegradation. The biodegradation of polyacrylate, $(C_5H_8O_2)_x$–$(C_7H_{12}O_2)_y$, was mainly thought as depolymerization and assimilation. With the addition of ZnO, the depolymerization of polyacrylate was more likely to occur than polymethacrylate in polyacrylate structure. The biodegradability of polyacrylate/ZnO composites was related to the interaction and adhesion of polyacrylate and ZnO.

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