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Effect of bio-surfactant on municipal solid waste composting process

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Abstract: Bio-surfactant is a new type of surfactant that is produced in microbial metabolism. Adding bio-surfactant during composting process, especially to those contain some toxic substances, has been proved to be a promising way. In this study, Strains Ⅲ(2), a bacterial with high activity to produce bio-surfactant, were isolated firstly. Following comparison experiments with and without adding Strains Ⅲ(2), namely Run 1 and Run R, were conducted, respectively. The experimental results showed that, by adding Strains Ⅲ(2), the surface tension could reduce from 46.5 mN/m to 39.8 mN/m and the corresponding time to maintain the surface tension under 50 mN/m could prolong from 60 h to 90 h. The oxygen uptake rate and total accumulated oxygen consumption with Stains Ⅲ(2) were both higher than those without Strains Ⅲ(2), while the accumulation of H_2S in outlet gas was reduced to around 50% of Run R. Moreover, two additional experiments were also carried out to examine the effects of strains coming from different systems. One is adding Strains Ⅲ(2) with a dose of 0.4% (Run 2), and the other is seedling commercial Strains at the same conditions, the composting experiments showed that: Run 2 was more effective than Run 3, because the commercial Strains can be suppressed significantly in a complex composting system with different pH, high temperature and some of metals. The bio-surfactant was also added into the solid waste, which contained some toxic substances, the corresponding results showed that the remove rate of Hg and sodium pentachlorophenolate(PCP-Na) could be improved highly. Thus, the microenvironment, reactionrate and composting quality could be enhanced effectively by adding bio-surfactant to the composting process.

Keywords: municipal solid waste; composting; bio-surfactant; composting quality

Introduction

Composting has come into widespread use as a treatment process for municipal solid waste (MSW). However, there are still some problems associated with the traditional composting process that need to be overcome, such as, long composting time, odorous gas and unstable quality. Thus, a great of researches have been made to enhance the composting efficiency and production quality (Wei, 2000). Inoculation composting technology has been reported in some special composting applications (Gaur, 1982; Matthur, 1986). Shin *et al*. (Shin, 1999) studied the enhancement of composting efficiency by seeding solid and liquid inoculation. Tiquia (Tiquia, 1996) implemented an experiment to determine the physical and chemical changes occurring during inoculation composting process. However, there are still few literatures to report the effects of adding bio-surfactant on composting rate and quality.

In composting process, the decomposition process takes place in a flat of liquid membrane on the surface of solid waste grain. Organic concentration in liquid membrane is related to composting rate. Thus, the physical and chemical conditions in the gap among solid waste grains have great effects on composting processes. Therefore, it is an available attempt to add some substances with special structures (e.g. bio-surfactant) in composting to improve this micro-environment and make it more amendable to be bio-decomposed.

Bio-surfactant is an active substance, which can reduce surface tension between liquid and solid (Chen, 1996). Because of non-toxicity, easy biodegradability and environmental compatibility, once bio-surfactant is imported into the solid waste grain gap, hydrophobic group of bio-surfactant can be affinity with organic solid waste, fix molecule on the surface of solid waste grain, and hydrophilic group will dissolve in the water (Nakano, 1992). Therefore, adding bio-surfactant could accelerate the composting process and enhance the product quality (Ishigami, 1993). However, there are few studies on composting process with bio-surfactant before.

This research was to study the technology of culturing and purifying the strains which can produce bio-surfactant. The principle and method of efficient composting technology with bio-surfactant was also investigated and discussed.

1 Methodology

1.1 Isolation of bio-surfactant

Strains can produce bio-surfactant were isolated from nature, including composting production and soil. They were isolated and maintained on trytone soy agar (TSA). Isolates were obtained by streaking out all the colonies of a spread plate within a sector containing 40 colonies. All isolates were tested for a number of properties on identical media. The culture medium containing glucose 0.1%, $NaNO_3$, KH_2PO_4, $Na_2HPO_4 \cdot 2H_2O$, $MgSO_4 \cdot 7H_2O$, $FeSO_4 \cdot 7H_2O$ and with pH 6.0—8.0. The culture conditions of the strains for producing bio-surfactant are listed in Table 1.

Table 1 The studied culture conditions of bacteria under investigation (g/L)

Culture medium	Glucose	$NaNO_3$	KH_2PO_4	$Na_2HPO_4 \cdot 2H_2O$	$MgSO_4 \cdot 7H_2O$	$FeSO_4 \cdot 7H_2O$
A	20	1.0	2.0	1.0	1.0	0.01
B	20	2.0	1.0	1.5	0.5	0.01
C	20	1.5	1.5	1.0	1.0	0.01
D	20	2.0	1.0	0.5	1.5	0.01
E	20	1.0	1.0	1.0	1.09	0.10
F	20	2.0	1.0	1.0	1.0	0.01
G	20	2.0	1.5	0.59	1.0	0.01

1.2 Experimental set-up

Fig. 1 shows a specially designed composting reactor with a total volume of about 34 L and a 10 cm layer of polyurethane on all sides for heat insulation being used in this study. Air was routed through air pump, flow meter, perforated PVC tube and reactor. Airflow rate was adjusted to

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4.0—6.0 L/min by turning on and off the pump intermittently. Precise temperature sensors were used for temperature measurements. A data logger was used to record the temperature data. The exhaust gas from the reactor was put into two analyzers, an O_2-H_2S monitoring instrument (Model MD-520E), and a CO_2 analyzer (Model LX-710). The composting materials were manually turned-over and sampled once daily (Xi, 2002).

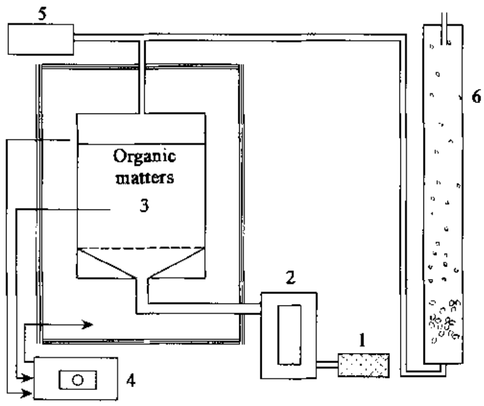

Fig.1 Schematic diagram of experimental reactor
1. Air pump; 2. gas flow meter; 3. composting tank; 4. temperature maintainence box; 5. gas analyzer; 6. filter

1.3 Analytical methods

Surface tension was determined as follows: At first, culture medium was drawn from culture dish and put into a 50 ml centrifuge tube with 25 ml distilled water. The tube was then placed first on a shaker for 5 min to mix the medium, bio-surfactant and distilled water completely, then left in a centrifuge for 2 min. Automatic Surface Tensiometer was used to determine the bio-surfactant concentrations of the upper solution by using duplicate 5 ml filtrate samples according to the critical micelle dilution method (Zhang, 2003; Desai, 1997). Surface tension remains constant at a certain value, when surfactant concentrations are above the critical micelle concentration. The surface tension increases only when the surfactant concentration drops below the critical micelle concentration. The initial surface tension was measured at the beginning of the composting process. Then surface tension of each sample was measured in terms of increasing dilution rates.

1.4 Composting procedure

MSW were collected from a typical community in Beijing, China, sorted and mixed directly with sawdust without drying. The original MSW mater content, moisture content and carbon to nitrogen (C/N) ratio were around 60%, 55% and 24:1, respectively.

Three batches of adding bio-surfactant experiments were conducted to understand bio-surfactant composting processes and determine the optimum inoculation conditions. The experiments included: (1) Added bio-surfactant to MSW system by 0.008% for Run 1; (2) added Strains Ⅲ(2) selected from composting system and producing bio-surfactant to MSW system by 0.4% for Run 2; (3) added commercial Strains by 0.4% for Run 3. Another three batches (Run 4, 5, 6) were also investigated by adding bio-surfactant or stains to those containing toxic substances (Table 2). The composting efficiency was examined in terms of several composting parameters, such as surface tension, accumulate oxygen uptake, accumulate oxygen consumption, concentration of outlet gas, and so on.

Table 2 Characteristics of seed agents to composting systems

Process	Agents	Composting materials	Dose, % w/w
Reference Run A	No-inoculation	Biodegradable MSW	- -
Run 1	Bio-surfactant	Biodegradable MSW	0.008
Run 2	Strains Ⅲ(2)	Biodegradable MSW	0.4
Run 3	Commercial strains	Biodegradable MSW	0.4
Run 4	Bio-surfactant	MSW contain some Toxic	0.008
Run 5	Strains Ⅲ(2)	MSW contain some Toxic	0.4
Run 6	Commercial strains	MSW contain some Toxic	0.4
Reference Run B	No-inoculation	MSW contain some Toxic	- -

1.5 Chemical and biological analyses

1.5.1 Oxygen uptake rate

The oxygen uptake rate can be calculated by Equation (1) as follows:

$$R = \frac{q \cdot (z_i - z_e)}{V_M M_d}. \quad (1)$$

Where, R is the oxygen uptake rate (mol/(h·kg)); q is the airflow (m^3/h); z_e is O_2 concentration of outlet gas (mol/kg); z_i is O_2 concentration of inlet gas (mol/kg); V_M is the volume of per mol gas (m^3/mol); M_d is the weight of dry matter (kg).

1.5.2 Degradation rate of organic matter

The degradation rate of organic matter is as follows:

$$v = \frac{M_d R A_0}{aS}. \quad (2)$$

Where, v is the organic matter degradation rate (g/(kg·h)); a is the oxygen quantity of per unit organic matter degradation (1.27 kg/kg); A_0 is the molecular weight of oxygen (0.032 kg/mol); R is the oxygen uptake rate (mol/(h·kg)); S is the substrate concentration (kg/h).

1.5.3 CO_2 conversion rate

$$\Delta_{CO_2} = \int_0^t z_c q \mathrm{d}t, \quad (3)$$

Where, z_C is CO_2 concentration of outlet gas; t is the composting time.

$$r_{CO_2} = \Delta_{CO_2}/W = \frac{\Delta_{CO_2}}{\left[W_0 - Y_{VM/CO_2}\int q z_c \mathrm{d}t - \sum_{i=1}^{i} W_{Si}\right]}, \quad (4)$$

$$W = W_0 - Y_{VM/CO_2}\int_0^t q z_c \mathrm{d}t - \sum_{i=1}^{i} W_{Si}. \quad (5)$$

Where, r_{CO_2} is the conversion rate (mol/(h·kg)); W is the dry matter weight in the reactor (kg); W_0 is the initial dry matter weight in the reactor (kg); Y_{VM/CO_2} is the yield coefficient; W_{Si} is the sample weight of different time (kg).

2 Results

2.1 Structure of bio-surfactant

Extracting and purifying the bio-surfactant from the culture medium, raw rhamnolipid, single rhamnolipid and double rhamnolipid were observed and their mass spectrogram are shown in Fig.2 (raw rhamnolipid) and Fig.3 (single rhamnolipid).

2.2 Effects of bio-surfactant on MSW composting process

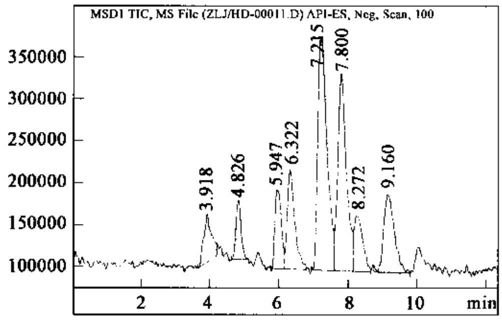

Fig.2 Mass spectrogram of raw rhamnolipid

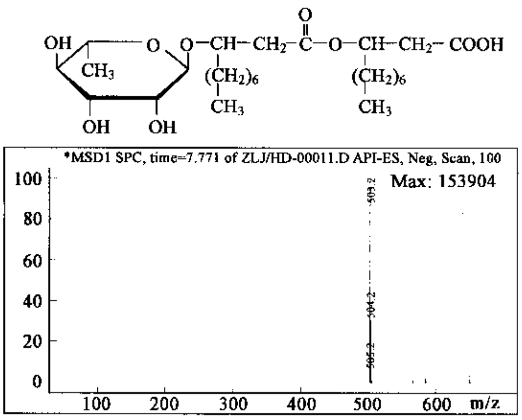

Fig.3 Mass spectrogram of single rhamnolipid

2.2.1 Surface tension profile of composting process

Track study about the change of surface tension was performed during the composting process. The surface tension profile during the first week of composting is shown in Fig.4. The initial surface tension of filtrated solution of solid waste was around 70 mN/m. At the first day, it decreased rapidly, surface tension of filtrated samples decline to 50 mN/m, 42 mN/m, 36 mN/m, 38 mN/m, in Run R, Run 1, Run 2 and Run 3, respectively. The experimental results are shown in Table 3.

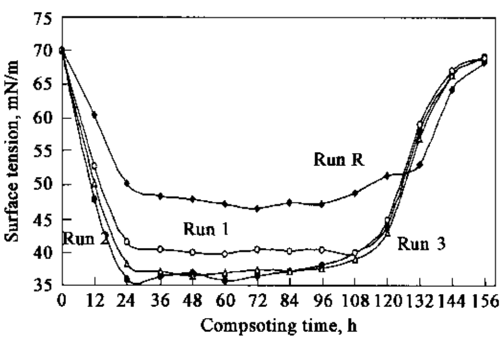

Fig.4 Surface tension profile of composting process
◆: Run R; ○: Run 1; ●: Run 2; △: Run 3

Table 3 The value of lowest surface tension and maintaining time under 50 mN/m

Run	Lowest surface tension, mN/m	Time of the lowest surface tension, h	Maintain time under 50 mN/m, h
Run R	46.5	72	60
Run 1	39.8	60	96
Run 2	36.0	24	108
Run 3	36.5	48	96

Table 3 shows the surface tension of Run 1, Run 2 and Run 3 were lower than that of Run R during composting processes, and could maintain under 50 mN/m in a much longer time. Adding bio-surfactant to composting system of Run 1 is better than Run R. The results indicated that the bio-surfactants had high bioactivities to amend the composting microenvironment and make organic matters become biodegradable. Thus, adding bio-surfactants is a useful method to enhance composting system.

Comparing Run 2 to Run 3, Run 3 was less effective than Run 2. The possible reason is that the commercial strains could be suppressed significantly in a complex composting system with different pH, high temperature and some metals, and so on. On the contrary, adding Strains III (2) selected from composting system, which could adapt to high temperature and different pH, could produce bio-surfactants incessantly during composting processes, and thus in turn to enhance the rate of organic degradation.

2.2.2 Oxygen uptake rate and accumulation oxygen consumption

Oxygen uptake rate, accumulated oxygen consumption had been used to measure decomposition rates for composting processes performed under different Runs (Klind, 2000). When aeration flow was 5.0 L/(min·kg), moisture content was around 50%—60%. The oxygen uptake rate and accumulated oxygen consumption are shown in Fig. 5 and Fig. 6.

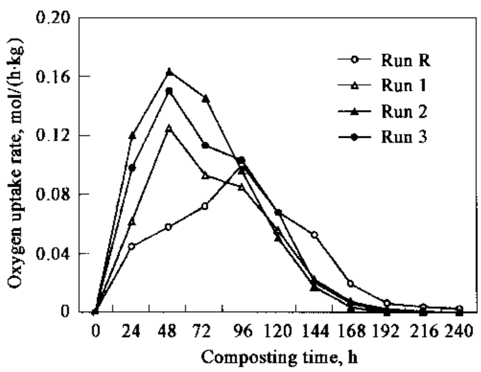

Fig.5 Oxygen uptake rate profile of composting process

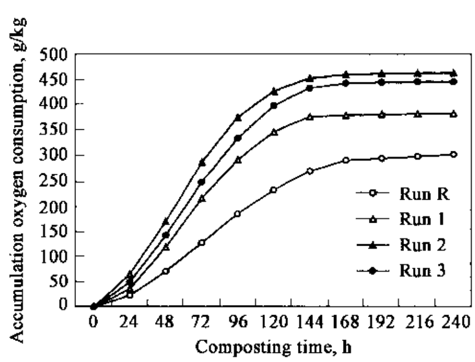

Fig.6 Accumulated oxygen consumption profile of composting process

As shown in Fig.5 and Fig.6, for Run R, Run 1, Run 2 and Run 3, the accumulated oxygen consumption were 300.5 g/kg, 380.17 g/kg, 460.1 g/kg, 442.8 g/kg, respectively with 240 h operation, and the maximum oxygen uptake rate were 0.100 mol/(h·kg), 0.125 mol/(h·kg), 0.163 mol/(h·kg), 0.150 mol/(h·kg), respectively. The results indicated that the oxygen uptake rate and total accumulated oxygen consumption were all higher in Run 1, Run 2 and Run 3 than those of Run R. Since oxygen uptake rate can be considered as an indicator of the respiratory activity of the composting microflora, the conclusions can be drawn that the biological activities were higher in Run 1, Run 2 and Run 3, and was the lowest in reference Run A and Run C. The oxygen uptake rate of Run 1 was 1.5 times of control.

Both the oxygen uptake rate and total accumulated oxygen consumption of Run 3 were lower than those Run 2. Because commercial strains need a period to adapt the complex composting system with different materials. However, Strains Ⅲ (2) selected from composting system, could adapt the compost matrix environmental quickly and produce bio-surfactants incessantly during composting process.

2.2.3 CO_2 and H_2S evolution of outlet gas

CO_2 and H_2S evolution were used to measure decomposition rates for composting processes performed under different Runs. The CO_2 conversion and H_2S concentration of outlet gas are shown in Table 4.

Table 4 Emission of gas in outlet

Time, h	Emission of carbon dioxide(CO_2), %				Emission of H_2S, ml/m^3			
	Run R	Run 2	Run 3	Run 1	Run R	Run 2	Run 3	Run 1
24	2.27	7.11	5.58	4.19	3.5	0.54	1.9	1.9
48	4.62	11.89	9.13	8.48	5.6	1.14	5.4	6.3
72	6.89	10.72	7.57	6.85	16	3.5	4.8	8.8
96	7.61	7.43	5.09	5.92	13	2.1	3.6	8.4
120	5.63	3.02	3.70	3.21	10	1.8	3.1	3.9
144	3.63	2.00	0.99	1.14	5.8	0.8	1.3	0.5
168	2.87	0.43	0.405	0.31	2.0	0.09	1.01	0.2
192	1.25	0.1	0.12	0.19	0.9	0.06	0.08	0
216	0.54	0	0.08	0.14	0.2	0.0	0	0
240	0.20	0	0	0	0.1	0	0	0

Table 4 indicates that CO_2 concentration in outlet gas of Run R was only about 4.62% at 48 h. However, in Run 1, Run 2 and Run 3, it reached up to 8.48%, 11.89% and 9.13% at 48 h. H_2S concentration in Run R was highest during composting processes, whose maximal emission could even reach 16 ml/m^3, while the concentrations in Run 1, Run 2 and Run 3 were 8.8 ml/m^3, 3.5 ml/m^3, 5.4 ml/m^3, respectively. In terms of these results, feeding bio-surfactant or Strains were both useful to control H_2S-emission.

2.2.4 Composting production quality

2.2.4.1 Humus of composting production

Generally, composting quality relates to physical, chemical and biological characters, such as organic matter(i.e. humus), nutritions(N, P and K), humic degree, noxious substance, and seed of weeds, etc. Among them, humus and nutritions are very important factors.

The product qualities including total humus, TN, TP, TK, date rate of ova and colibacillus are investigated and listed in Table 5.

Table 5 shows that the quantity of humus in Run 1, Run 2 and Run 3 is more than that in Run R. The total of nutritions(N, P and K), were 2.37%, 2.75%, 3.75% and 1.8% in Run 1, Run 2, Run 3 and Run R, respectively. The humus value of Run 3 is about two times of the value of Run R. Therefore, adding strains or bio-surfactant to composting systems not only can enhance composting rate, but also can improve the composting quality greatly.

Table 5 Composting quality of different systems

Items	Humus (Organic C), %	TN, %	TP, %	TK, %	T(N+P+K), %	Date rate of ova, %	The value of colibacillus
Run R	10.6	0.70	0.50	0.6	1.8	95	10^{-1}—10^{-2}
Run 1	14.2	0.93	0.54	0.9	2.37	95	10^{-1}—10^{-2}
Run 2	15.8	1.4	0.55	0.8	2.75	95	10^{-1}
Run 3	18.2	2.1	0.75	0.9	3.75	100	10^{-1}

2.2.4.2 Toxic concentration of composting products

Aside from adding Hg and PCP-Na to composting process, the other materials adopted were the same as Run R. Hg and PCP-Na were measured by Atomic Absorption method and HPLC method. The results of reference Run B, Run 4, Run 5 and Run 6 are shown in Table 6.

Table 6 The concentration of Hg and PCP-Na in composting products unit: mg/kg

Items	Run B	Run 4	Run 5	Run 6
Hg/PCP-Na	6.8/16	2.2/5	5.5/10	4.7/9.0

Table 6 shows that Hg and PCP-Na concentrations of Run 4, Run 5 and Run 6 were lower than that of Run B. In reference Run B, the removal rate of Hg and PCP-Na were only about 32% and 20%. The Hg and PCP-Na removal efficiencies(78% and 75%, respectively) in Run 4, were higher than those in Run B. Simultaneity, the results indicated that the values of Run 5 and Run 6 were also superior to reference Run B. Thus, adding bio-surfactants was an efficient method to remove toxic matters and improve the composting quality.

3 Analysis and discussion

In order to understand the key mechanisms of the composting process with bio-surfactant, the bio-surfactant composting mechanism was studied from the viewpoint of dynamic kinetics.

3.1 Mechanisms of bio-surfactant transport process

There are two types system between microorganisms and substrates, namely, homogeneous phase and polyphase. As shown in Fig. 7, MSW composting belongs to polyphase system form which extract substrate to be used by microorganisms(Xi, 2004). The character of this system is that the substrate mainly is bio-decomposed in aquatic phase and on solid-aquatic membrane (Drouin, 1992). In this system, to ensure enough substrates to be used by microorganisms, firstly, it is necessary to dissolve the substance of solid waste. Bio-surfactant play an important role between bacterias and inherent substance(Desai, 1993), because bio-surfactant can enhance the mobility of microorganisms. The main reasons are as follows: (1) Adding bio-surfactant give rise to the change of electric density and make the adsorption decline; (2) bio-surfactant can restrain flocculation and enhance the ability of transfer; (3) seedling bio-surfactant can reduce the surface tension between liquid and solid and make the substance easily to be extracted from inherent of solid waste(Banat, 1995). Thus, in the process of composting, bio-surfactant can improve the microenvironment of solid waste, make substance more degradable and improve the active of microorganisms. Once bio-surfactant was imported into the solid waste grain gap, hydrophobic groups of bio-surfactant can be affiliated with organic solid waste, and thus the molecules can be fixed easily on the surface of solid waste grain, while hydrophilic group will dissolve in the water.

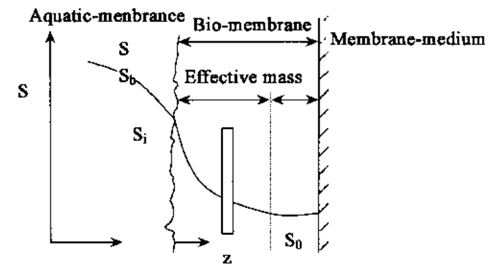

Fig.7 Mass transfer of composting system

3.2 Mechanisms of bio-surfactant extracted toxic substance

The relationship between bio-surfactant and composting materials with toxic substance is shown in Fig.8. Due to the limitation of refuse classification in China, it is inevitable that composting materials contain some toxic substances. Conventional composting methods may have some difficulties in removing toxic substances because of the huge adsorption forces between toxic substances and solid waste itself. This phenomenon causes a challenge to human being. Thus, it is very important to improve micro-environment and remove toxic substances from solid waste. By adding some active substances, for example, bio-surfactant, the surface tension between liquid and solid can be reduced and thus the toxic molecules can be easily removed from the surface of solid waste grain.

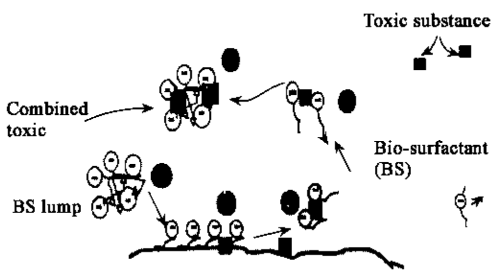

Fig.8 Bio-surfactant and composting materials with toxic substance

In addition, adding bio-surfactant could change the vapor-liquid equilibrium of toxic substance obviously and give rise to Henrys Constant of organic contaminant such as benzene, methylbenzene and xylene decline significantly (Michael, 1999). Therefore, the transition of toxic substances from solid waste to aquatic phase or atmosphere could be sped up easily. Meanwhile, the product quality could be improved. The experimental results also verified that adding Bio-surfactant can reduced Hg and PCP-Na contents efficiently.

4 Conclusions

Adding bio-surfactant to MSW composting can not only accelerate the composting reaction rate but also improve the quality of composting products. This is a promising way in composting process.

The Strains Ⅲ (2), which were isolated from composting system and could produce bio-surfactant, were more efficient than that of the Commercial Strains. Adding Strains Ⅲ(2) selected from composting system, could adapt to high temperature and different pH easily.

Adding Strains Ⅲ (2) or bio-surfactant to composting systems can adjust the surface adsorption effect of solid waste and thus can improve the removal efficiency of toxic substances effectively.

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