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Effect of *Aeolosoma hemprichi* on excess activated sludge reduction

Biyu Song, Xiaofei Chen *

Department of Environment Science, Wuhan University, Wuhan 430072, Hubei Province, China

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ABSTRACT

In order to stabilize the growth of *A. hemprichi* and minimize the sludge production through biological predation, *A. hemprichi* was inoculated in batch and continuous experiments to investigate the growth characteristics and the effect on sludge reduction in this study. Various available volatile suspended solid (AVSS) concentrations were obtained after the ultrasonic irradiation on pre-sterilized sludge. It was found the density of *A. hemprichi* was proportionate to AVSS concentration. *A. hemprichi* reached the maximum density when AVSS concentration was more than 3000 mg/L. No obvious difference was found between the initial specific growth ratio (μ) of *A. hemprichi* at various AVSS concentrations. When $N > 0.5N_L$, μ decreased with the increase of *A. hemprichi* and Logistic model was adopted to fit the growth of *A. hemprichi*. Sludge reduction rate was correlated with both the growth rate and the density of *A. hemprichi*. The results indicated the sludge reduction rate was maximum at the density of 315 ind./mL. Sludge retention time (SRT) could effectively control the growth density of *A. hemprichi* in continuous tests.

1. Introduction

The activated sludge process is the most widely used biological wastewater treatment for both domestic and industrial plants. One of the drawbacks is high sludge production which is difficult to treat and dispose. With the strictly enforced environmental and legislative requirements on the discharge of excess sludge, the cost of excess sludge treatment and disposal has accounted up to about 60% of the total operating cost in municipal wastewater treatment plants [1]. There is considerable impetus to explore strategies and technologies for reducing excess sludge production in biological wastewater treatment processes which represents a rising challenge for wastewater treatment plants [2–7]. One way to reduce excess biomass production would be to encourage the growth of organisms higher in the food chain which feed on sludge [8,9]. During transfer from a low level to a high trophic level, energy is lost due to inefficient biomass conversion [10]. More and more attention has been paid to this method because it is energy saving and brings no secondary pollution [11,12].

The performance of worms in biological wastewater treatment has been researched because of their bigger sizes and greater potential for sludge reduction [1,13,14]. Three dominant types of worm are usually found in the conventional activated sludge process (CAS): *Pristina aequiseta*, *Nais elinguis* and *Aeolosoma hemprichi*. Some researches found that worm growth in CAS reactors contributed to neither sludge reduction nor improvement of sludge settling characteristics because the CAS reactor was designed to treat wastewater, and the operation parameters are not suited for the bloom of worms. No significant sludge reduction was found when worms were present in low density. So reactors were developed to produce worm growth that will correlate with sludge reduction [15]. However, their growth is unstable and uncontrollable even in regulated conditions [16,17], and it is impracticable to reduce sludge production with worms unless their growth is stable in continuous operation.

In this study, *A. hemprichi* was chosen to be the sludge predator, because *A. hemprichi* was one of the three species frequently occurring during the biological wastewater plant operation. They were more dominant than the other two species of worms: *Pristina aequiseta* and *Nais elinguis* [13]. It indicated *A. hemprichi* was not strongly influenced by the changing of surroundings which made them possible to be applied in practice. The purpose of this study is to research the growth characteristics of *A. hemprichi* fed on activated sludge and the factors influencing the density of *A. hemprichi*. A Logistic model was extended to describe the density of *A. hemprichi* on specific growth ratio. Factors influencing the sludge reduction were analysed. In addition, correlations were established between SRT and the density of *A. hemprichi* in the continuous tests.

2. Materials and methods

2.1. *A. hemprichi* cultivation

Aeolosoma hemprichi is a minute meiofaunal Annelida. Its body is about 50 μm in width and 800 μm in length. The epidermal is

* Corresponding author. Tel.: +86 15926469698.
E-mail address: xfchen10@yahoo.com (X. Chen).

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covered with orange red glands and red oil globules. *A. hemprichi* reproduces asexually by the formation of pygidial buds. *A. hemprichi* used in the study was isolated from activated sludge which was aerated for a long term. *A. hemprichi* was washed repeatedly with sterilized water until no fungi or protozoa were observed under a steroscopic microscope. Then the isolated *A. hemprichi* was cultured in sterilized activated sludge.

2.2. Sludge preparation

For the present study the domestic wastewater sludge was collected from an aeration tank at the Wuhan Water Treatment Plant. It was placed in a plastic container to maintain the temperature at 4 °C. Fresh activated sludge was withdrawn from the container and aerated for 24 h before experiments.

Many species of activated sludge microorganisms live together with *A. hemprichi* in sludge without sterilization. Endogenous respiration of floc and the excreta of *A. hemprichi* reused by activated sludge was necessary to be considered. Sludge predated by protozoa would also cause sludge reduction. It is difficult to distinguish the part of sludge reduced by *A. hemprichi* from that by other species. In addition, the growth of *A. hemprichi* was greatly influenced by interspecies competition and soluble microbial products in fresh sludge. Therefore, the sludge was sterilized for the convenience of studying the growth characteristics of *A. hemprichi*. The sterilization was set at 120 °C for 20 min. The supernatant containing the soluble fraction of organic materials was removed after the sludge was centrifuged at 4000 rpm for 10 min. Then the sludge was used for batch and continuous tests.

A reactor was set up in order to find the self-solubility effect of sterilization sludge during the long-term mixing in the reactor. It was found the MLSS in the reactor was almost unchanged without inoculating *A. hemprichi*. So sludge reduction caused by solubility effect was ignored and not discussed in the paper.

2.3. Batch tests

Batch tests were used to investigate the growth characteristics of *A. hemprichi*. Five Erlenmeyer flasks with working volume of 500 mL were used as reactors. Sludge after the pretreatment was transferred to the flasks and diluted with sterilized water. The initial VSS was 6000 mg/L in each flask. Most of the sludge flocs in the sludge were larger than *A. hemprichi*'s body size which is 50 μm in width. It is more difficult for *A. hemprichi* to predate the large size floc, and their growth is slowed down with low efficiency of predation. Only flocs of a size smaller than 50 μm were considered as available volatile suspended solids (AVSS) in the tests. It was found only 9% of the total VSS was in this size range. Due to the lack of enough food for *A. hemprichi*'s growth, results could not reflect the growth characteristics of *A. hemprichi* at high density. So ultrasonic treatment was used to disintegrate the flocs and increase the amount of AVSS concentration [18]. In batch tests, five sludge samples at the same VSS of 6000 mg/L were sonicated for different irradiation time in a water bath-type ultrasonic processor (KQ-100VD, China). The ultrasonic frequency was set at 28 kHz and the power level was 0.2 W/mL which would not severely destroy the activated sludge sample and change the properties of the floc. Total volume of particles smaller than 50 μm increased with the increase of ultrasonic irradiation time as shown in Table 1. After the sonication, *A. hemprichi* was inoculated into five flasks. The initial density of *A. hemprichi* was set to 3 ind./mL. Then the flasks were placed in a shaking incubator at 25 °C and 150 rpm to provide mixing and aeration.

The main purpose of ultrasound treatment was to destroy the structure of floc, but the property of sludge was changed at the same time. Some of the bacterial cells were destroyed and EPS was released to the supernatant fluid. It would be unlikely to totally disrupt the floc by sonication without causing cell lysis. It was desired to keep the sludge property as close to its original conditions as possible. Therefore for this study, the ultrasonic power was set at a low level which would not severely destroy the activated sludge samples and change the properties of flocs. The change of components and their concentrations were not discussed in this study. The soluble chemical oxygen demand (SCOD) in supernatant was slightly increased when sludge was treated at a short period of sonication, but 60 min ultrasonic treatment could markedly increase SCOD from 25 mg/L to 280 mg/L. The property of sludge could be taken on as unchanged in the tests.

Table 1
The effect of ultrasonic treatment on AVSS concentration

Reactor	Ultrasonic irradiation time (min)	Volume of particle size <50 μm (%)	AVSS (mg/L)
R1	0	9.5	570
R2	4	12	720
R3	8	22.9	1374
R4	40	51.4	3084
R5	80	70.2	4212

2.4. Continuous tests

In order to reduce sludge efficiently and stimulate the growth. *A. hemprichi*'s density was controlled by exhausting some amount of sludge containing *A. hemprichi* from the reactor at a given time. In continuous tests, sludge treated by sterilization and ultrasonic was continuously pumped into the bottom of a cylindrical reactor with the working volume of 2 L (Φ = 120 mm, H = 250 mm), and the excess sludge after the predation was wasted continuously. VSS concentration of sludge was 6000 mg/L. Four parallel reactors were set up at SRT of 6, 8, 10 and 15 days, respectively. The initial density of *A. hemprichi* was set to 3 ind./mL. The pH was held at 6.86 by addition of 1 M solutions of nitric acid and sodium hydroxide. The oxygen concentration in the reactor was kept above 2 mg/L due to the mixing and aeration provided by fine bubble air diffusers at 0.6 L/min.

2.5. Analysis items and methods

VSS concentrations were measured according to the Chinese SEPA standard methods [19]. Auto Sizer instrument (Mastersizer 2000E) was used to size the particles of sludge flocs. *A. hemprichi* was counted using a stereo microscope (CX31, OLYMPUS, Japan) at 100× magnifications. The value of *A. hemprichi*'s density was the average of three samples.

3. Results and discussion

3.1. Influence of AVSS concentration on the growth of A. hemprichi

Batch tests were used to investigate the growth of *A. hemprichi* with various available volatile suspended solids concentrations. Time changes of *A. hemprichi*'s density at different AVSS was shown in Fig. 1. It was found *A. hemprichi* grow at the maximum specific growth ratio at the initial stage in five reactors. The growth rate of *A. hemprichi* decreased and their density came into dynamic balance after several days cultivation. The influence of AVSS on the density of *A. hemprichi* when their population was stable in the reactor was shown in Fig. 2. It was found the balance density (N_L) of *A. hemprichi* increased with elevated AVSS concentration. The results could be well fitted to the linear regression line when AVSS concentration was below 3000 mg/L. The reciprocal of the slope coefficient

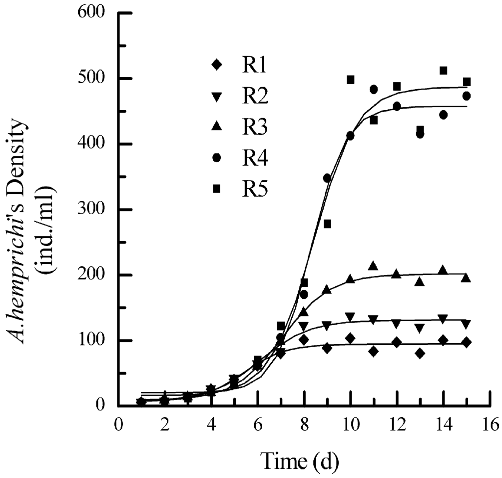

Fig. 1. Time changes of *A. hemprichi*'s density.

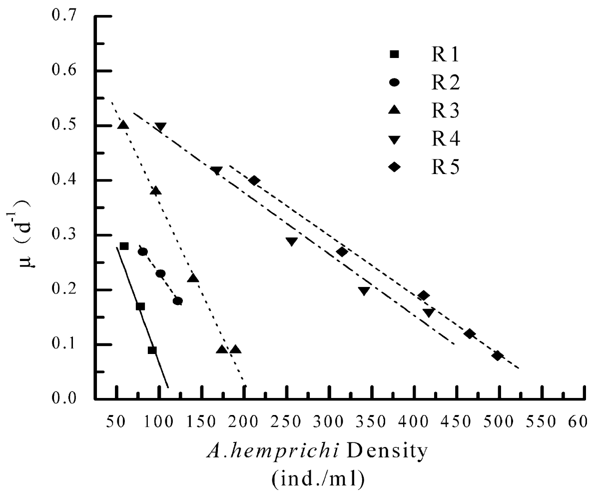

Fig. 3. Dependence of μ on *A. hemprichi*'s density.

represents the balance ratio of AVSS to the density of *A. hemprichi* (F/M) which is 7×10^{-3} mg/ind. The density of *A. hemprichi* was lower than the balance density at the beginning of the batch test, which means observed F/M was over 7×10^{-3} mg/ind., so the density of *A. hemprichi* tended to increase. With increasing the density of *A. hemprichi*, observed F/M gradually decreased until it reached 7×10^{-3} mg/ind. As observed F/M was lower than 7×10^{-3} mg/ind. which means the sludge was not enough to support the growth of *A. hemprichi*, *A. hemprichi*'s density tended to decreased. F/M could be used as an effective tool to estimate the growth trends of *A. hemprichi*. and 7×10^{-3} mg/ind. was considered as the minimum substrate to *A. hemprichi* ratio requirements for the growth of *A. hemprichi*. The fluctuation around the balance F/M dedicated to the unstable growth of *A. hemprichi* in the reactor. In some cases, *A. hemprichi* disappeared in the reactors for a short period in our tests (results were not shown in this paper).

When AVSS concentration was more than 3000 mg/L, the density of *A. hemprichi* approached the limit of environmental capacity, which is the maximum density of *A. hemprichi* allowed to exist in the reactor. Therefore the growth of *A. hemprichi* was restrained and the density fluctuated at about 500 ind./mL even though more AVSS was provided in the reactor.

3.2. Influence of AVSS concentration on specific growth ratio and growth rate of A. hemprichi

Observed specific growth ratio (μ_{obs}) was usually used to evaluated the growth ability of *A. hemprichi* individual. At the initial stage

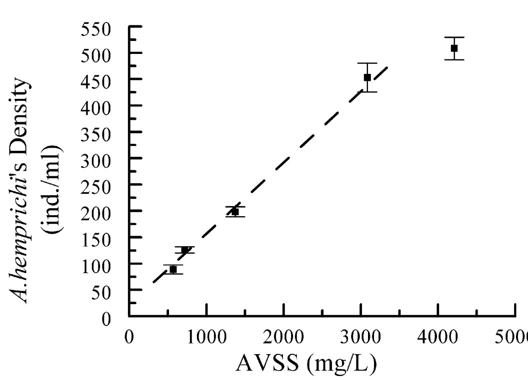

Fig. 2. Influence of AVSS on the *A. hemprichi*'s density. Concentrations of *A. hemprichi*'s density are given as mean ± S.D.

of batch tests, no obvious difference was found between μ_{obs} of *A. hemprichi* in different reactors. Without the limit of food and space. *A. hemprichi* proliferated at the maximum specific growth ratio. μ was equal to μ maximum which could be calculated by Eq. (1):

$$\mu = \frac{2.303(\log N - \log N_0)}{t - t_0} \quad (1)$$

where N is the density of *A. hemprichi*, t the time, t_0 is the time at the beginning of the cultivation, N_0 is the density of *A. hemprichi* at the beginning of the cultivation. When $N > 0.5N_L$, observed specific growth ratio (μ_{obs}) decreased with the increase of *A. hemprichi*. The specific growth ratio calculated from Fig. 1 was shown in Fig. 3. It was found the Logistic model could be well fitted to simulate the decrease of μ_{obs}. The Logistic model was shown in Eq. (2):

$$\mu_{obs} = \mu_M\left(\frac{N_L - N}{N_L}\right) \quad (2)$$

where μ_M is maximum specific growth ratio. It gives values of $0.5\,d^{-1}$ for μ_M which is comparable with that presented elsewhere [20]. It indicated the growth potential was dominated by the density of *A. hemprichi*.

Growth rate was an important factor to evaluate the growth ability of *A. hemprichi* in the whole reactor which was related to both the specific growth ratio and the density of *A. hemprichi*. It could be calculated by Eq. (3):

$$\frac{dN}{dt} = N_t \mu_{obs} \quad (3)$$

where dN/dt is the growth rate of *A. hemprichi*. Subsituting Eq. (2) to Eq. (3), growth rate could be calculated by Eq. (4):

$$\frac{dN}{dt} = \mu_M N_t\left(\frac{N_L - N_t}{N_L}\right) \quad (4)$$

It was found the growth rate of *A. hemprichi* was dependent on the density of *A. hemprichi*. It was maximum when the density of *A. hemprichi* was equal to $0.5N_L$. Then the growth rate of *A. hemprichi* decreased with increasing the density of *A. hemprichi*.

3.3. Effect of A. hemprichi on sludge reduction in batch tests

Three causes were contributed to sludge reduction in the presence of predator [21]. First, the sludge predated by the predator to produce energy for growth and maintenance; Second, the excreta of the predator was reused by microorganisms in the sludge [22]; And

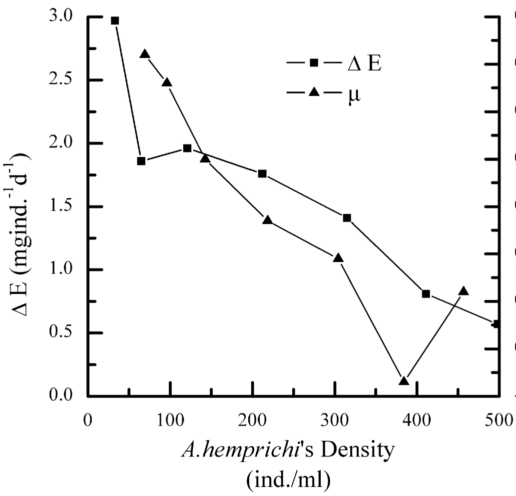

Fig. 4. Influence of *A. hemprichi*'s density on ΔE and μ.

Third, sludge was reduced during the endogenous processes of bacteria for maintenance [23]. Because the sludge was pre-sterilized, endogenous respiration of floc was ignored. Predation was the only reason for sludge reduction in the tests.

The sludge reduction rate of *A. hemprichi* individual and whole reactor were two important factors to evaluate the reduction ability. Their relationships could be represented by Eq. (5):

$$\Delta\text{AVSS} = N\Delta E \tag{5}$$

where ΔE is sludge reduction rate of *A. hemprichi* individual, ΔAVSS is sludge reduction rate of the whole reactor. It was found ΔE and μ was negatively correlatively with the density of *A. hemprichi* as shown in Fig. 4. It indicated most of the energy produced by predation was used for growth of *A. hemprichi*. ΔE decreased when the growth of *A. hemprichi* was restrained as the density increased.

The effect of *A. hemprichi* on sludge reduction rate of the reactor and *A. hemprichi*'s growth rate at various *A. hemprichi*'s density was shown in Fig. 5. It was found ΔAVSS increased to 445 mg/L d when the density of *A. hemprichi* was 315 ind./mL in the reactor. Then ΔAVSS tended to decline as the density of *A. hemprichi* increased which means that high density of *A. hemprichi* did not improve the sludge reduction rate. Intraspecific competition slows down the growth rate of *A. hemprichi* and decreases the sludge reduction rate. Results clearly showed that reduction ability of the reactor could be effectively improved by controlling *A. hemprichi* at the optimal density.

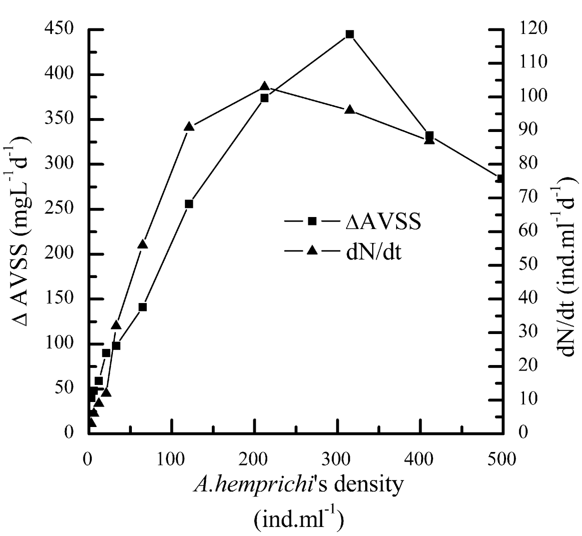

Fig. 5. Influence of *A. hemprichi*'s density on ΔAVSS and dN/dt.

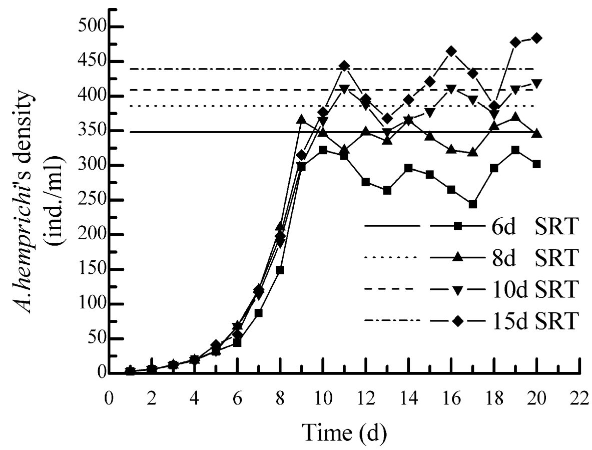

Fig. 6. Effect of SRT on *A. hemprichi*'s density (lines were the value calculated by Eq. (9), points were the density measured in the continuous test).

As it was discussed, sludge reduction rate was correlated with the growth rate of *A. hemprichi*, but there was a delay between the maximum sludge reduction rate and the maximum growth rate as shown in Fig. 5. The sludge reduction rate kept on increasing as the growth rate decreased. It could be reasonably explained by the increasing energy for the maintenance of *A. hemprichi*. As *A. hemprichi* approach their dynamic balance density, the growth rate of *A. hemprichi* was low enough to be ignored. Most of the sludge predated was used for satisfying maintenance energy requirements.

3.4. Growth control of A. hemprichi in continuous test

Time changes of the *A. hemprichi*'s density at various SRT were shown in Fig. 6. It could be seen that with the prolongation of SRT, *A. hemprichi*'s density experienced a sharp increase [24]. It implied SRT could effectively control the growth density of *A. hemprichi* in continuous tests. A model was developed in order to find the relationship between SRT and the density of *A. hemprichi* [25,26]. Assuming that, at continuous tests with no excess sludge exhausted from the reactor, the growth of *A. hemprichi* was represented by Eq. (3). At continuous tests with excess sludge continuously exhausted from the reactors, the time evolution of the density of *A. hemprichi* can be written as:

$$\frac{dN}{dt} = N_t\mu_{\text{obs}} - N_tD \tag{6}$$

D is the dilution rate in the continuous test. When the growth of *A. hemprichi* was equalled to the exhaustion, it is given by

$$\frac{dN}{dt} = 0 \tag{7}$$

$$\mu_{\text{obs}} = D \tag{8}$$

Assuming SRT was θ_x which is the reciprocal of D. Substituting Eq. (2) into Eq. (8) and solving for N_t:

$$N_t = N_L\left(1 - \frac{1}{\mu_M\theta_x}\right) \tag{9}$$

It is evident that N_t is dependent on θ_x. The density of *A. hemprichi* at various SRT was calculated by Eq. (9). The result was shown in Fig. 6. The dynamic balance density of *A. hemprichi* was 333, 375, 400, 433 ind./mL at SRT of 6, 8, 10 and 15 days. *A.*

hemprichi's density in continuous tests could be roughly fitted with the density calculated by Eq. (9). It was found that the density of worms fluctuated without sludge exhausting appropriately [27]. In this test, it is indicated that the operation of predation reactor at an appropriate SRT may be feasible from the viewpoint of controlling the growth of *A. hemprichi* and stimulating the activity of *A. hemprichi*.

4. Conclusions

(1) The density of *A. hemprichi* was affected by AVSS concentration. When AVSS was more than 3000 mg/L, the balance density of *A. hemprichi* close to the environmental capacity and the growth of *A. hemprichi* was restrained.
(2) The specific growth ratio of *A. hemprichi* was constant at the beginning stage of cultivation. Exponential correlation was observed between N and μ. When $N > 0.5N_L$, μ decreased with the increase of *A. hemprichi*, and Logistic model could be well fitted to simulate the growth of *A. hemprichi*.
(3) The sludge reduction rate was found to have a correlation with the growth rate of *A. hemprichi*. The maximum sludge reduction rate by *A. hemprichi* was 445 mg/L d at the density of 315 ind./mL.
(4) The density of *A. hemprichi* could be effectively controlled with the elongation of SRT. When SRT was more than 15 days, it did not affect *A. hemprichi*'s growth in continuous tests.
(5) This study was aimed to establish a relationship between the growth of *A. hemprichi* and sludge reduction. Therefore, the sludge was sterilized for the convenience of studying the growth characteristics of *A. hemprichi*. It is more complicated to study the growth characteristics of *A. hemprichi* in fresh sludge than that in sterilized sludge. The growth characteristics of *A. hemprichi* was similar to that in sterilization reactors with the absence of protozoa and metazoan. If an abundance of protozoa and other metazoan were presented before *A. hemprichi* inoculated, the growth of *A. hemprichi* was restrained. Interspecific competition play an important role in the growth of *A. hemprichi* and their predation ability. Further research should study the stable growth of *A. hemprichi* in fresh sludge.

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References

[1] 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. 18 (2003) 4453–4467.
[2] G.H. Chen, K.J. An, S. Saby, E. Brois, M. Djafer, Possible cause of excess sludge reduction in an oxic-settling-anaerobic activated sludge process (OSA process), Water Res. 16 (2003) 3855–3866.
[3] E.W. Low, H.A. Chase, M.G. Milner, T.P. Curtis, Uncoupling of metabolism to reduce biomass production in the activated sludge process, Water Res. 12 (2000) 3204–3212.
[4] T. Mahmood, A. Elliott, A review of secondary sludge reduction technologies for the pulp and paper industry, Water Res. 11 (2006) 2093–2112.
[5] S. Saby, M. Djafer, G.H. Chen, Feasibility of using a chlorination step to reduce excess sludge in activated sludge process, Water Res. 3 (2002) 656–666.
[6] G. Zhang, P. Zhang, J. Yang, Y. Chen, Ultrasonic reduction of excess sludge from the activated sludge system, J. Hazard. Mater. 3 (2007) 515–519.
[7] H. Zhu, J.h. Chen, Study of hydrolysis and acidification process to minimize excess biomass production, J. Hazard. Mater. 1–3 (2005) 221–227.
[8] J.H. Rensink, W.H. Rulkens, Using metazoa to reduce sludge production, Water Sci. Technol. 11 (1997) 171–179.
[9] W. Ghyoot, W. Verstraete, Reduced sludge production in a two-stage membrane-assisted bioreactor, Water Res. 1 (2000) 205–215.
[10] C.H. Ratsak, K.A. Maarsen, S.A.L.M. Kooijman, Effects of protozoa on carbon mineralization in activated sludge, Water Res. 1 (1996) 1–12.
[11] J. Lapinski, A. Tunnacliffe, Reduction of suspended biomass in municipal wastewater using bdelloid rotifers, Water Res. 9 (2003) 2027–2034.
[12] N.M. Lee, T. Welander, Reducing sludge production in aerobic wastewater treatment through manipulation of the ecosystem, Water Res. 8 (1996) 1781–1790.
[13] X.S. Guo, J.X. Liu, Y.S. Wei, L. Li, Sludge reduction with Tubificidae and the impact on the performance of the wastewater treatment process, J. Environ. Sci. 3 (2007) 257–263.
[14] A. Masse, M. Sperandio, C. Cabassud, Comparison of sludge characteristics and performance of a submerged membrane bioreactor and an activated sludge process at high solids retention time, Water Res. 12 (2006) 2405–2415.
[15] H.J.H. Elissen, T.L.G. Hendrickx, H. Temmink, C.J.N. Buisman, A new reactor concept for sludge reduction using aquatic worms, Water Res. 20 (2006) 3713–3718.
[16] C.H. Ratsak, Effects of *Nais elinguis* on the performance of an activated sludge plant, Hydrobiologia 1 (2001) 217–222.
[17] H. Salvado, A. Palomo, M. Mas, J. Puigagut, M.d.P. Gracia, Dynamics of nematodes in a high organic loading rotating biological contactors, Water Res. 10 (2004) 2571–2578.
[18] C.P. Chu, B.-V. Chang, G.S. Liao, D.S. Jean, D.J. Lee, Observations on changes in ultrasonically treated waste-activated sludge, Water Res. 4 (2001) 1038–1046.
[19] S.E.P.A. Chinese, Water and Wastewater Monitoring Methods, fourth ed., Chinese Environmental Science Publishing House, Beijing, China, 2006.
[20] P. Liang, X. Huang, Y. Qian, Influence of food sludge on growth of *A. hemprichi*, China Environ. Sci. 2 (2004) 159–162.
[21] C. Ratsak, J. Verkuijlen, Sludge reduction by predatory activity of aquatic oligochaetes in wastewater treatment plants: science or fiction? A Review, Hydrobiologia 1 (2006) 197–211.
[22] M.C.M. Van Loosdrecht, M. Henze, Maintenance, endogeneous respiration, lysis, decay and predation, Water Sci. Technol. 1 (1999) 107–117.
[23] M.D. Coello Oviedo, J.A. Lopez-Ramirez, D. Sales Marquez, J.M. Quiroga Alonso, Evolution of an activated sludge system under starvation conditions, Chem. Eng. 2 (2003) 139–146.
[24] P. Liang, X. Huang, Y. Qian, Use of *Aeolosoma hemprichi* for reducing excess sludge yield, China Water Wastewater 20 (2004) 13–16.
[25] E.W. Low, H.A. Chase, The effect of maintenance energy requirements on biomass production during wastewater treatment, Water Res. 3 (1999) 847–853.
[26] M.S. Moussa, C.M. Hooijmans, H.J. Lubberding, H.J. Gijzen, M.C.M. van Loosdrecht, Modelling nitrification, heterotrophic growth and predation in activated sludge, Water Res. 20 (2005) 5080–5098.
[27] K.X. Zhou, M.Q. Xu, H. Cao, J. Xu, Using microfauna to reduce excess sludge production, Tech. Equipment Environ. Pollut. Control 1 (2003) 1–5.