Expanded Granular Sludge Bed （EGSB）Reactor Treating Actual Domestic Wastewater: Temperature Influence

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Abstract – To demonstrate the feasibility of using expanded granular sludge bed (EGSB) reactor as the single reactor for the treatment of domestic treatment when the temperature fluctuates between 15℃ (winter) and 26℃ (summer), the effects of operation temperature (15℃, 26℃) on the performance, methanogenic activity and granular size distribution were investigated in this paper. The results indicated that the EGSB reactor could keep very high COD removal efficiencies (80.2%-82.3%) at 0.5h-0.8h HRT when treating actual domestic wastewater at ambient temperature (15℃ to 26℃). The COD average removal efficiencies would decrease to only 78.3% and/or 72.3% for 0.4h HRT and/or 1.0-3.0h HRT. Although enhancing V_{up} could increase COD removal efficiency, the increasing quantity was comparatively limited. When using EGSB reactor to treat actual domestic wastewater at ambient temperature (15℃-26℃), the 15-24L.h^{-1} influent flow and 3.0m.h^{-1} V_{up} was suitable. At 26℃, the SMA was not decreased. But at 15℃, the SMA was distinctly decreased, however which could resume at 35℃. Low temperature would compel the microorganisms to get together as soon as possible. Compared with 26℃, the average size of the granules was increased from 0.9mm to 1.0mm at 15℃.

Keywords -- EGSB reactor; domestic wastewater; temperature; SMA; granules; size distribution

I INTRODUCTION

Traditionally, anaerobic digestion has been applied to medium and high strength wastewater. In recent years, growing efforts have been applied in order to establish the feasibility of high rate anaerobic digestion to the treatment of diluted effluent. But many low strength wastewaters are discharged at low ambient temperatures, including domestic wastewater and a large variety of industrial wastewater.

Microorganisms are classified into ‘temperature classes’ on the basis of the optimum temperature and the temperature span in which the species are able to grow and metabolize. But the overlapping growth temperature ranges indicate that there isn’t a clear boundary between these classic groups of psychrophilic, mesophilic and thermophilic microorganisms. However, under psychrophilic conditions, chemical and biological reactions proceed much slower than under mesophilic conditions. Moreover, a strong temperature effect on the maximum substrate utilization rates of microorganisms has been observed by many researchers.

One of the major successes in the development of anaerobic wastewater technology was the introduction of high-rate reactors in which biomass retention and liquid retention are uncoupled. This feature comprises a crucial issue for the treatment of low(er) strength wastewater. Obviously, the low COD influent will result in low substrate levels inside the reactor and also in a low biogas production rate. And for the well-known Upflow Anaerobic Sludge Bed (UASB) reactor, this implies low mixing intensities in the reactor and consequently in a poor substrate–biomass contact. Thus, Practically all full-scale applications of anaerobic wastewater treatment so far are restricted to wastewater with temperatures exceeding 18℃[1].

Because temperature strongly affects the rates of the anaerobic conversion processes, some essential improvements have to be made in the conventional design of high-rate reactors to enable their application under sub-optimal temperatures and for very low strength wastewater. The results of experiments into optimizing the contact of sludge and wastewater in UASB reactors, led to the development of an advanced reactor design, namely the expanded granular sludge bed (EGSB) reactor [2-3]. The EGSB system uses exclusively granular sludge, and meanwhile through applying effluent recycle and/or using tall reactors, the upflow velocities (V_{up}) applied in the EGSB system can range from 4 to 10m.h^{-1}. But so far, for domestic wastewater treatment when the temperature fluctuates between 15℃ (winter) and 25℃ (summer), a staged reactor is recommended. At higher temperatures (>20℃), a single reactor could suffice for raw sewage[4-5].

The objectives of this research are to demonstrate the feasibility of using EGSB as the single reactor for the treatment of domestic treatment when the temperature fluctuates between 15℃ (winter) and 26℃ (summer). The performance of EGSB reactor at ambient temperature and the effect of temperature were reviewed. Meanwhile, to confirm the feasibility of using EGSB to stably treat domestic wastewater at ambient temperature and to suggest the prevalence of psychrotolerant organisms, the granular characteristics, such as methanogenic activity, granular size distribution, were also analyzed.

II MATERIALS AND METHODS

A. Reactor Set-up

The research was carried out in a lab-scale EGSB reactor. The 2.3m height EGSB reactor was an acrylic column with a conical-shaped bottom, a working volume of 12L, an internal diameter of 10cm. The wastewater used as influent to the reactor was collected from the residential area of Tai-Yuan University with 88-952 mg.L^{-1} COD, 146-391 mg.L^{-1} alkalinity, 25-72 mg.L^{-1} NH_3-N and 80-320 mg.L^{-1} SS, respectively. Some trace metals for Fe, Co, Ni were added. A schematic diagram of the EGSB reactor used is presented in Fig.1.

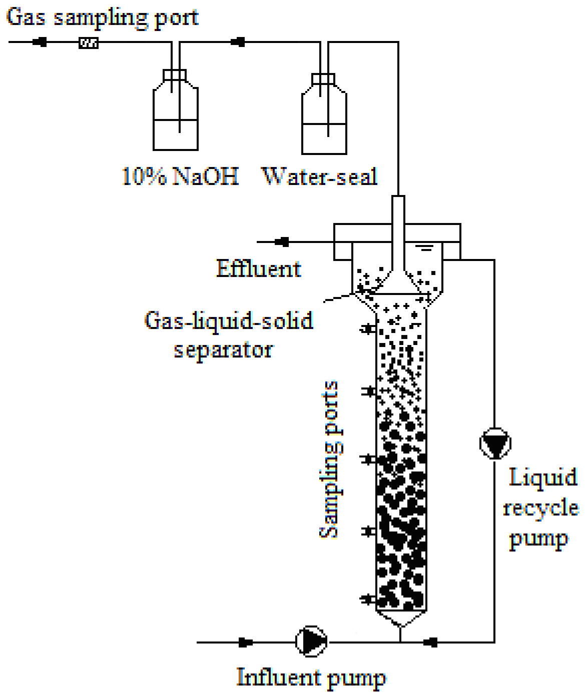

Fig.1 Schematic diagram of the experimental EGSB reactor

B. Seed Sludge

The inoculum used in this experiment was municipal digestion sludge and little granules. The anaerobic digestion sludge was obtained from the dehydrated sludge from an anaerobic digester at YangJiaBu Wastewater Treatment Plant, TaiYuan (its activity was resumed before seeding into the EGSB reactor). And the granular sludge was obtained from a pilot-plant anaerobic EGSB reactor treating actual brewage wastewater for two years. Moreover, the granular sludge was deposited without any nutrients addition for two years under ambient temperature. Thus, the granules were loose. The steady-state operation EGSB reactor had 25.4g.L^{-1}gSS·L^{-1} biomass concentration and 0.77 VSS/SS, respectively.

C. Analytical Methods

Effluent was collected and centrifuged at 4000rpm for 3min with a centrifuge (80-2B, ANTING). And then the supernatant was used for further analysis. The measurement of COD, MLSS and MLVSS were according to the Chinese Standard Methods for Water and Wastewater Monitoring and analytical methods [6]. Specific methanogenic activity test was accomplished as described by Zhao et al [7]. Each analysis was carried out in triplicate and the results presented are the mean values.

D. Operating strategy

The operation process of the EGSB reactor was separated into two stages. First, at stage Ⅰ, to investigate performance of the EGSB reactor treating actual domestic wastewater, the COD removal efficiency was investigated with varied influent flow and varied OLR, in which the term “performance of the EGSB reactor” was defined as the COD removal efficiency(%) $= \frac{COD_{in} - COD_{eff}}{COD_{in}} \times 100$. The influent flow was varied between 4L.h^{-1} and 30L.h^{-1}, and meanwhile with the influent COD concentration of 84-952mg.L^{-1}, the OLR was fluctuated between 1.99kgCOD.m^{-3}.d^{-1} and 57.12kgCOD.m^{-3}.d^{-1}. And then at stage Ⅱ, to investigate the temperature influence on the EGSB performance, the EGSB reactor was operated at 26℃ and 15℃, respectively, and the investigated influent flow was 9L.h^{-1}、15L.h^{-1}、24L.h^{-1} with 3.0m.h^{-1} V_{up}. Moreover, for 15℃ low temperature and 9L.h^{-1} low influent flow, the V_{up} was increased from 3.0m.h^{-1} to 4.2m.h^{-1} to investigate the performance of the EGSB reactor. The Specific methanogenic activity and size distribution of the granules in the EGSB at 26℃ and 15℃ was also assayed, respectively. The granules samples taken from the 26℃ EGSB reactor was used to assay the Specific methanogenic activity (SMA) at both 26℃ and 35℃(expressed as 26℃ from 26℃ and 35℃ from 26℃, respectively). And the SMA assays of the granules sample at 15℃ EGSB reactor were preformed at both 15℃ and 35℃ (expressed as15℃ from15℃ and 35℃ from15℃, respectively).

III RESULTS AND DISCUSSION

A. Performance of reactor at ambient temperature

The EGSB reactor treating actual domestic wastewater was performance at ambient temperature (between 13℃ and 26℃) along with the change of the climate temperature for about six months. Fig.2 showed the variation in COD in the reactor influent and effluent as well as the removal efficiency. Accordingly, the changes of the influent flow and OLR were depicted in Fig.3 and Fig.4.

With 84-952mg.L^{-1} influent COD concentration, the EGSB reactor could attain average COD removal efficiency of 79.5% (fluctuating between 61% and 93%). Except for initial stages of about days 15 (with higher effluent COD concentration, and high to 180mg.L^{-1}), the effluent COD concentrations could keep below 100mg.L^{-1} for subsequent about 5 months stable operation stages. Even for the distinct influent COD fluctuation of 179mg.L^{-1}→952mg.L^{-1}→300mg.L^{-1}(at days 85 → days 87

→ days 89), the effluent COD concentrations were very stable and the corresponding COD values were 38mg.L^{-1}→68mg.L^{-1} →40mg.L^{-1}, which indicated that the performance of the EGSB reactor treating actual domestic wastewater at ambient temperature was very well and stable.

For about six months, the EGSB reactor undergo a topmost OLR value of 57.1kgCOD.m^{-3}.d^{-1} and an undermost OLR value of 2.0kgCOD.m^{-3}.d^{-1}, and the effluent COD concentrations were only 68.0mg.L^{-1}(only 0.4h HRT) and 62mg.L^{-1}(with 3.0h HRT), respectively, and which indicated that the EGSB reactor had very strong supporting OLR shock ability when treating actual domestic wastewater at ambient temperature.

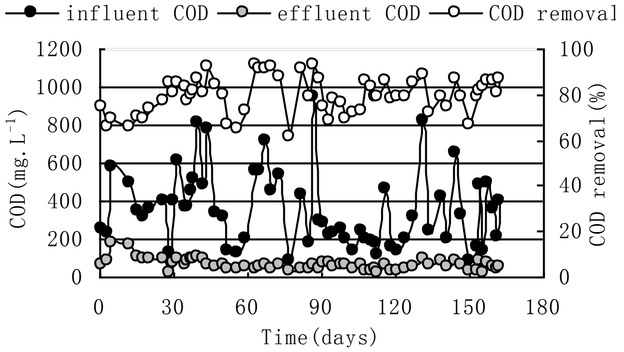

Fig.2. influent and effluent COD and COD removal changes

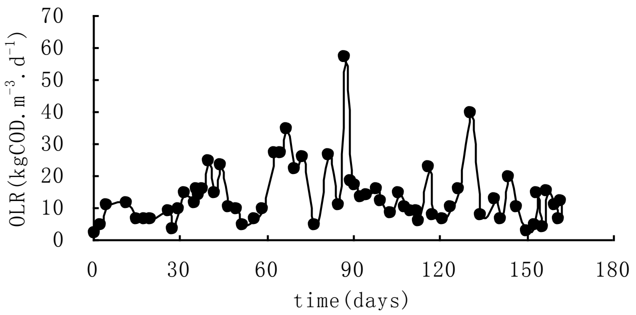

Fig.3. influent OLR changes

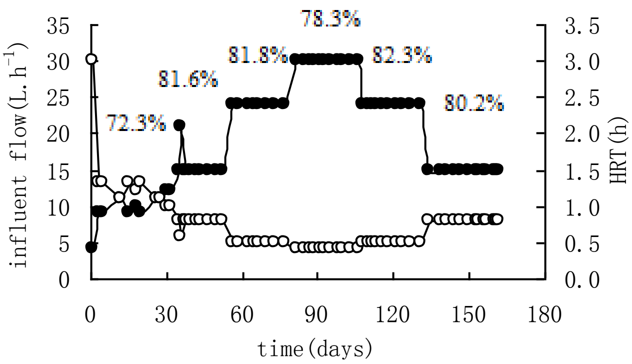

Fig.4. influent flow and HRT changes

At the initial stages of about 15 days, the performance of the EGSB was not stable. At day 1, only with 4L.h^{-1} influent flow (249mg.L^{-1} influent COD concentration), the COD removal was only 75%. And with gradually increasing influent flow to 11L.h^{-1} and COD concentration to 575mg.L^{-1}, the COD removal had a little decreasing (to 69%). But subsequently with gradually increasing influent flow (15L.h^{-1}→24L.h^{-1}→30L.h^{-1}), the COD removal efficiencies began to increase and the average COD removal efficiencies were 81.6%, 81.8% and 78.3%, respectively, and which indicated that the EGSB reactor could keep very high COD removal at quite low HRT (only 0.4h-0.8h) when treating actual domestic wastewater at ambient temperature. Moreover, as showed in Fig.4, when the HRT was between 0.8h and 0.5h, the EGSB reactor could attain 80.2%-82.3% high average COD removal efficiencies. However, only 78.3% and 72.3% average COD removal could attain for 0.4h HRT and 1.0-3.0h HRT. Thus, for the EGSB reactor treating actual domestic wastewater at ambient temperature, the high influent flow of 15-24L.h^{-1}, low HRT of 0.5-0.8h and high OLR of 4.2-57.1kgCOD.m^{-3}.d^{-1} were suitable.

B. COD removal for varied performance temperature

To investigate the temperature influence on performance, the EGSB reactor was operated at 26℃ and 15℃, respectively, and synchronously the investigated influent flow was 9L.h^{-1}、15L.h^{-1}、24L.h^{-1}. The results were presented in table 1.

Table 1 temperature influence on performance of reactor

Temperature (℃)	Influent flow (L.h^{-1})	HRT (h)	V_{up} (m.h^{-1})	COD removal (%)
26	15	0.8	3.0	83.9
15	15	0.8	3.0	81.4
26	24	0.5	3.0	84.7
15	24	0.5	3.0	81.9
26	9	1.3	3.0	86.0
15	9	1.3	3.0	75.0
15	9	1.3	4.2	79.0

At 26℃, for 9L.h^{-1}、15L.h^{-1}、24L.h^{-1} influent flow, the EGSB reactor could all have high COD removal efficiencies of 86.0%、83.9%、84.7%. At 15℃, the EGSB could still have high COD removal efficiencies of 81.4% and 81.9% for 15L.h^{-1} and 24L.h^{-1} influent flow, but only had 75.0% COD removal for 9L.h^{-1} influent flow. And subsequently, through increasing V_{up} form 3.0m.h^{-1} to 4.2m.h^{-1}, the COD removal efficiency could increase from 75.0% to 79.0%, but still not up to 80.0%. The low temperature could decrease the COD removal. But for higher influent flow (following higher OLR), the decreasing degree of COD removal efficiencies was not distinct. To the contrary, for low influent flow to 9L.h^{-1}(following lower OLR), the decreasing extent of COD removal was high to 11%.

Although enhancing V_{up} could strengthen the mass transfer effect and then increase COD removal efficiency, the increasing quantity was comparatively limited. Thus, when using EGSB reactor to treat actual domestic wastewater at ambient temperature (15℃-26℃), 15-24L.h^{-1} influent flow and 3.0m.h^{-1} V_{up} was suitable, and only 0.5-0.8h HRT was employed, above 80% COD removal could attain.

C. SMA for varied performance temperature

Afterwards, the effects of low temperature on specific methanogenic activity (SMA) were explored. The experiments need to take on two purposes, one was to review the changes of SMA along with the operation temperature changes from 26℃ to 15℃, and the other was to compare the difference of SMA between 35℃ and 26℃ or 15℃, and the SMA changes was presented in Fig.5.

Compared with "26℃ from 26℃", the SMA of "15℃ from 15℃" was decreased distinctly. If we defined the slope of the SMA curve (the steepest sect) as "γ", the values of γ for "15℃ from 15℃" and "26℃ from 26℃" were 12.7 and 28.8, respectively. But the values of γ for "35℃ from 15℃" and "35 ℃ from 26 ℃" were almost equal (29.8 and 30.9, respectively). Which adequately showed that low temperature was not restrained the SMA of the granules, 26℃ operation temperature could ensure high SMA, and the SMA at 15℃ had the possibility to be increased. Perhaps enhancing V_{up} was an effective method, and moreover optimizing characteristic of the granules was also another choice.

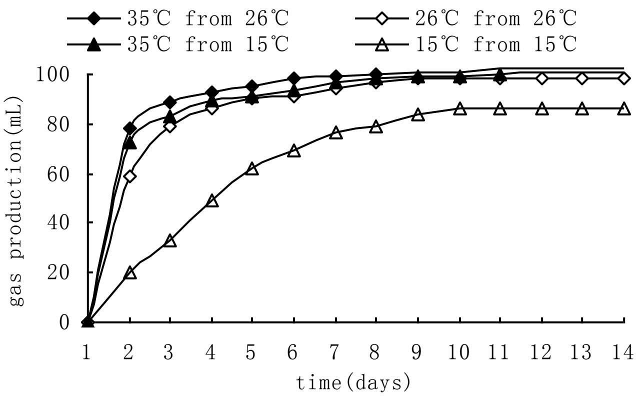

Fig.5. SMA changes of granules for 26℃ and 15℃ reactor

D. Size distribution for varied performance temperture

When operation temperature gradually decreased from 26℃ to 15℃, the granules were taken out from the EGSB reactor to investigate the changes of granules size distribution (presented in Fig.6).

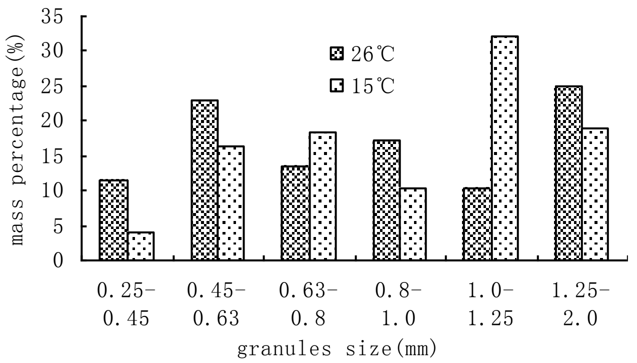

Fig.6. size distribution of granules for 26℃ and 15℃ reactor

Compared with 26℃ operation condition, the average size of the granules was increased from 0.9mm to 1.0mm at 15℃, in which the average size of the granules was calculated in this case through following formula: $d_{average} = \frac{\sum d_i p_i}{100}$. Mass percentage of 0.25-0.45mm granules was decreased from 11.4% to 4.0%, and synchronously the granules with d>1.25mm had a decreasing range of 5.9% (from 24.9% to 19.0%). The granules were still distributed in such size range as 0.25-1.25mm, but low temperature caused the mass percentage of the 0.25-1.25mm granules increase from 63.7% to 77.3%. Perhaps disadvantage of low temperature could compel the microorganisms to get together as soon as possible, which was favorable for the metabolic transfer and exchange rate interspecies.

Ⅳ CONCLUSIONS

The low temperature could decrease COD removal efficiencies. But for higher influent flow (15-24L.h^{-1}) (following higher OLR), the decreasing of COD removal efficiencies was not distinct with the operation temperature decreasing from 26℃ to 15℃. However, for low influent flow (9L.h^{-1})(following lower OLR), the decreasing extent of COD removal was high to 11% for 26℃ and 15℃. Although enhancing V_{up} could increase COD removal efficiency, the increasing quantity was comparatively limited. Thus, when using EGSB reactor to treat actual domestic wastewater at ambient temperature (15℃-26℃), 15-24L.h^{-1} influent flow and 3.0m.h^{-1} V_{up} was suitable, only 0.5-0.8h HRT was employed, and 80.2%-82.3% COD removal could attain.

At 26℃, the SMA was not decreased. At 15℃, the SMA was distinctly decreased, but which could resume at 35℃.Low temperature would compel the microorganisms to get together as soon as possible. Compared with 26℃, the average size of the granules was increased from 0.9mm to 1.0mm at 15℃.

ACKNOWLEDGEMENTS

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