中文摘要

爲瞭解質傳阻抗於膨脹顆粒污泥床(expanded granular sludge bed, EGSB)反應器去除有機物所扮演的角色，本研究以四組 EGSB 反應器(表面流速 us = 0.5、3.0、6.0 及 9.0 m/h)處理抑制性酚基質以獲得實驗數據，另亦建立 EGSB 反應器之動力模式(含 intrinsic 動力及質傳參數)及經驗模式(含 apparent 動力)，進行模式之模擬及實驗驗證。

在體積負荷率(volumetric loading rate, VLR) 4.0~12.2 kg COD/m3-d 下，EGSB 反應器中污泥顆粒平均粒徑(dp)隨著 VLR、us 之增加而增大(dp 變化範圍 0.88~2.35 mm)。在 VLR 4.0~10.6 kg COD/m3-d 下，四組 EGSB 反應器 COD 去除率皆達 97.2%以上。VLR 增加到 12.2 kg COD/m3-d 時，us 爲 0.5、3.0 m/h 之兩組反應器仍能正常操作(污泥量 = 116.8、120.3 g；COD 去除率 = 99.0、99.0%)，惟 us 爲 6.0、9.0 m/h 之兩組反應器之污泥量(110.8、104.7 g)則明顯少於前者(即 us 爲 0.5、3.0 m/h 者)，後者流失之污泥顆粒粒徑分別爲 1.39~4.28 mm (dp = 2.90 mm)及 1.93~4.72 mm (dp = 3.12 mm)，致 COD 去除率分別下降爲 65.3、63.3%。

由酚厭氣降解批次實驗得知，intrinsic k 值略大於 apparent 者，且隨著 dp (1.05、1.30、1.85、2.18 mm)之增加，apparent k 值有下降之趨勢；intrinsic Ks 值則小於 apparent 者，且當 dp 大於 1.30 mm 時，apparent Ks 值明顯隨著 dp 之增加而增大，亦即較大污泥顆粒之微生物與基質間之親和性較低。此外，intrinsic Ki 值小於 apparent 者，顯示較大的污泥顆粒(intact granule)因有較大的質傳阻抗故較不會受酚濃度之抑制，惟 apparent Ki 值隨 dp 變化之影響不明顯。

由質傳參數值(?2 = 4.7~37.8、Bi = 2.2~17.7、? = 0.64~1.12)、顆粒基質濃度剖面及參數敏感度分析可知，EGSB 反應器污泥顆粒外部質傳阻抗對基質去除速率之影響不大，但污泥顆粒內部之質傳阻抗對基質去除速率之影響則相當大，且內部質傳阻抗隨著 VLR、us 之增加而增大，亦即污泥顆粒大小才是質傳限制的主因。由 dp 對?、酚去除率影響之模擬結果亦得知，dp 大於 2.0 mm 時，酚去除率有較顯著的下降。此外，以動力模式及經驗模式模擬所得 EGSB 反應器酚去除率與實驗值之誤差大都在±5.7%範圍內，且上述兩種模式模擬之酚去除率之差異百分比亦僅 0.05~4.7%。據此，兩種模式皆頗適用於 EGSB 反應器之功能設計。

英文摘要

To comprehend the role of mass transfer resistance playing in overall substrate removal rate in expanded granular sludge bed (EGSB) reactors, four effluent-recycled EGSB reactors (superficial velocity us = 0.5, 3.0, 6.0, and 9.0 m/h) were used to treat an inhibitory substrate phenol to generate experimental data. Meanwhile, a kinetic model (incorporating intrinsic kinetics and mass-transfer parameters) and an empirical model (incorporating apparent kinetics) were developed and validaed by experiments.

When the volumetric loading rates (VLR) of the EGSB reactors were maintained at 4.0–12.2 kg COD/m3-d, the average granule size (dp; a variation range of 0.88 to 2.35 mm) increased with increasing VLR and us At the VLRs of 4.0–10.6 kg COD/m3-d, the four EGSB reactors were found very efficient for the removal of COD (greater than 97.2%). With a further increase of VLR to 12.2 kg COD/m3-d, the two EGSB reactors with us of 0.5 and 3.0 can still be operated properly (biomass = 116.8 and 120.3 g; COD removal = 99.0 and 99.0%). However, the biomass of the two EGSB reactors with us of 6.0 and 9.0 m/h (biomass = 110.8 and 104.7 g) obviously decreased, compared with the two EGSB reactors with us of 0.5 and 3.0 m/h. The granule size measured from the wash-out biomass for the two EGSB reactors with us of 6.0 and 9.0 m/h were 1.39–4.28 mm (dp = 2.90 mm) and 1.93–4.72 mm (dp = 3.12 mm), respectively. Thus, the COD removal efficiencies of the two EGSB reactors with us of 6.0 and 9.0 m/h dropped markedly to 65.3 and 63.3%, respectively.

The intrinsic kinetic constant k was slightly larger than the apparent kinetic constant k; the apparent kinetic constant k tended to decrease with increasing dp (1.05, 1.30, 1.85, 2.18 mm). The intrinsic kinetic constant Ks was lower than the apparent kinetic constant Ks; when the dp was larger than 1.30 mm, the apparent kinetic constant Ks significantly increased with increasing dp, implying that a larger granule gave lower affinity of substrate to biomass granule. In addition, the intrinsic kinetic constant Ki was lower than the apparent kinetic constant Ki, revealing that a larger granule (intact granule) with greater mass transfer resistance should encounter a smaller inhibiting effect of phenol in the bulk liquid.

According to mass-transfer parameter values (?2 = 4.7–37.8, Bi = 2.2–17.7, ? = 0.64–1.12), concentration profiles of the granule and parameter sensitivity analysis, the external mass transfer resistance of the granule in the EGSB reactor only imposed a slight effect on overall substrate removal rate. In contrast, the internal mass transfer

resistance of the granule enforced a strong effect on overall substrate removal rate; the internal mass transfer resistance increased with VLR and us. That is, the granule size is considered the main cause of mass transfer resistance in the EGSB reactor. According to the simulation results (dp vs. ?; dp vs. phenol removal), the phenol removal efficiency declines markedly if dp is larger than 2.0 mm. By using the proposed kinetic and empirical models, the phenol removal efficiencies of the EGSB reactors were mostly ±5.7% deviated from the experimental results. Moreover, the relative percentage deviation of phenol removal efficiency from kinetic-model and empirical-model simulation fell in a relatively small range of 0.05–4.7%. Accordingly, both the two models can be properly used for function design of EGSB reactors.