行政院國家科學委員會補助專題研究計畫成果報告

軟粒子之固液分離－子計畫三：軟粒子之結構與脫水性

計畫類別：□個別型計畫　　□整合型計畫
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計畫主持人：李篤中　　　教授
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中文摘要

本研究利用光散射法(light scattering test)及自由沉降測試(free settling test)測量不同濃度之高嶺土以及活性污泥之碎形維度。由兩種實驗方法所得之碎形維度並不相同，顯示碎形維度是一操作型定義之物理量，由不同實驗方法所得之不同碎形維度代表所量測者乃不同緻密程度之區域，可由兩層結構之模式來解釋，即微膠羽(microflocs)是由基本粒子(primary particles)所構成，其碎形維度(D_S)可由光散射法測量；而膠羽(entire floc)則由微膠羽構成，其碎形維度(D_F)可由自由沉降測試求得。應用陽離子型高分子調理高嶺土以及活性污泥，調理前後之結構變化亦可由此一雙層結構解釋。

英文摘要

In this work the structure of two kaolin sludges and a waste activated sludge are investigated using both light-scattering and free-settling methods. Fractal dimensions estimated by the light scattering and settling techniques (D_S and D_F respectively) differ significantly and support the hypothesis that naturally occurring aggregates possess a multi-level structure. A two-level floc structural model comprised of i) a primary floc (of fractal dimension D_S) consisting of primary particles and ii) a secondary floc (of fractal dimension D_F) consisting of the microflocs is proposed to interpret the experimental findings. The structural changes of sludge flocs before and after cationic flocculation were interpreted using the proposed two-level model.

簡介

有許多研究者提出污泥膠羽是由基本粒子構成之碎形結構物(Li and Ganczarczyk, 1989, Jiang and Logan, 1991)，而碎形維度(D)乃描述碎形結構物之一重要參數，一具有碎形維度 D 之碎形結構物，其質量 M 與粒徑 d_f 之關係式如下所示：

$$M \propto d_f^{\,D} \tag{1}$$

其中$1 \le D \le 3$。自由沉降測試及光散射法乃被廣泛應用於測量碎形結構物之碎形維度，若一物體具有單一之碎形結構，則應用不同之測量方法應得到相同之碎形維度。

當一聚集體是由單一機制所構成，如擴散控制聚集(diffusion-limited aggregate, DLA)，單一之碎形維度應足以描述其內部結構，然而，許多自然存在之聚集體已被證實擁有多層碎形結構(Jorand et al., 1995, Sanin and Vesilind, 1996)。因此，雙層到多層結構方足以描述一污泥膠羽。

本研究應用光散射法及自由沉降測試測量兩種不同樣品之碎形維度，證實由兩種實驗方法所得之碎形維度並不相同，並提出一雙層結構之模型，解釋應用陽離子型高分子調理樣品前後之結構變化。

光散射法

光散射技術可測量一物體之波向量(wave vector, Q)，其絕對大小可由下式表示：

$$\left|\vec{Q}\right| = Q = \frac{4\pi n\sin(\theta/2)}{\lambda} \tag{2}$$

其中 n，θ，及λ分別代表介質之折射率、散射角度以及雷射光在真空中之波長。在光散射理論中，波向量 Q 是散射強度 I 的函數，即 $I(Q) \propto F(Q)S(Q)$，其中 $F(Q)$及 $S(Q)$分別爲形狀因子(form factor)及結構因子(structure factor)。形狀因子和基本粒子之形狀有關，而結構因子則描述基本粒子在空間中之分佈

及排列。

圖 1a 爲 I 及 Q 之對數關係圖。在 $QR_p>>1$ 之情況下(R_p 爲基本粒子之半徑)：

$$I(Q)\propto Q^{-4} \tag{3}$$

即 Porod 定律。在 $QR<<1$ 之情況下，形狀因子通常爲一常數，若

$$1/R<<Q<<1/R_p \tag{4}$$

則下式成立：

$$I(Q)\propto Q^{-D} \tag{5}$$

因此，藉由光散射實驗所得之散射強度 I 及波向量 Q，以 I 及 Q 作對數圖可得直線斜率爲 $-D$，由此方法所得之碎形維度其符號爲 D_S，以別於由自由沉降測試所得之碎形維度 D_F。

自由沉降測試

考慮一膠羽在無限大之靜止流場中自由沉降，其所受之拖曳力 F_D 可以下式表示：

$$F_D=\left(\pi R^2\right)\left(\frac{1}{2}\rho V^2\right)C_D\Omega \tag{6}$$

其中 C_D 爲拖曳係數，V 爲膠羽運動速度，ρ 爲流體密度。對於一高度多孔性的球體，其拖曳力可如下式(Wu and Lee, 2000)表示：

$$F_D=\frac{A(\beta)}{8}\pi\mu V d_f \tag{7}$$

其中 μ 爲流體黏度而 $A(\beta)$ 爲修正因子。因此在浮力與重力平衡下可得下式：

$$\rho_f-\rho=\frac{3A(\beta)}{4}\frac{\mu V}{g d_f^2} \tag{8}$$

將式(1)代入可得：

$$\rho_f-\rho=C d_f^{D-3} \tag{9}$$

將式(9)代入可得：

$$V=\frac{4C}{3A(\beta)}\frac{g}{\mu}d_f^{D-1} \tag{10}$$

若修正因子 $A(\beta)$ 爲一常數，則以膠羽之終端速度 V 對粒徑 d_f 作全對數圖可得一直線斜率爲 $D-1$，圖 1b 爲自由沉降測試求取碎形維度 D_F 之示意圖。

實驗方法

本研究以高嶺土泥漿及活性污泥爲樣品，測量其內部結構。

高嶺土粒子之密度爲 2,727 kg/m^3 (Accupyc Pycometer)，平均粒徑爲 2.3 μm (Sedigraph 5100C)，高嶺土泥漿之重量百分率爲 17%及 8%，所使用之陽離子型高分子絮凝劑爲 T-3051，聚丙烯醯胺，平均分子量約爲 10^7，攪拌速度爲以 200rpm 攪拌 5 分鐘，再以 50rpm 攪拌 20 分鐘。

活性污泥樣品由 St. Mary's 污水處理廠取得(澳洲雪梨)，該廠之處理量爲每日 37,000 立方公尺。所使用之高分子絮凝劑爲 Zetag 92 (Allied Colloids, Australia)，其分子量約爲 10^6-10^7，爲聚丙烯醯胺及二甲基胺基乙基丙烯酸單體聚合而成。攪拌速度爲以 400rpm 攪拌 30 秒，再以 150rpm 攪拌 1 分鐘。

活性污泥之化學需氧量及懸浮固體濃度分別爲 41mg/L 及 90mg/L，固體濃度爲 0.55%。

小角度光散射法

小角度光散射實驗所使用的儀器爲 Malvern Mastersizer/E，於澳洲雪梨市新南威爾斯大學土木暨環境工程系實驗所得，其光源爲 5mW 的氦氖雷射(波長 632.8nm)，散射角度爲 0.03 到 6.52 度，包含 31 個散射光源接收器，實驗方法爲將測試樣品倒入測試玻璃容器內(約 20ml)，每隔 20 秒接收一次(31 組)訊號，共 400 秒。

結果與討論

圖 2a 及 2b 爲高嶺土泥漿及活性污泥之界達電位與 CST 結果。對於 8%及 17%之高嶺土泥漿，其等電位點分別在 260 ppm 與 600 pmm，並且其 CST 最低值也接近這些劑量，在本研究中稱其爲最適劑量，因此等電位點可作爲判定高分子絮凝效果之依據。

圖 3a 及 3b 所示爲高嶺土泥漿及活性污泥之粒徑。原始高嶺土泥漿粒徑之大小約 28 μm，經過高分子調理後粒徑可上升到 200-350 μm，加入越多的高分子劑量，可形成越大的粒徑。對於活性污泥粒子，其粒徑隨著高分子加入而變化的趨勢亦如高嶺土泥漿粒

子，如圖 3b 所示。

圖 4 爲原始高嶺土泥漿及活性污泥之 I 對 Q 關係圖。在圖中可看到兩階段之直線，分界點對應於 $Q=Q_C$ 處，$Q<Q_C$ 即爲 Guinier 區域，$Q>Q_C$ 即爲 power-law 區域，根據光散射理論，Q_C 值亦對應於 $1/R$。

根據圖 1a，碎形維度可由 power-law 區域線性迴歸之斜率求得。對於 8%及 17%之高嶺土泥漿，其碎形維度分別爲 1.97-1.99。對於原始活性污泥，其碎形維度則爲 2.12。活性污泥之碎形維度大於高嶺土泥漿，此結果與 Guan(1999)符合。

圖 5 爲高分子調理高嶺土泥漿及活性污泥之 I 對 Q 關係圖。當加入高分子後，I 對 Q 關係爲線性之區域增大，Q_C 值也相對變大。

表 1 所列爲所有測試樣品之碎形維度(D_S)。當增加高分子劑量至 1000 ppm 時，碎形維度降低至 1.6-1.7，配合粒徑變化結果(圖 3)，高分子加入使得膠羽結構變疏鬆且粒徑變大，而獲得較佳之脫水性。

表 1

8% kaolin	Original	150 ppm	300 ppm$^-$	600 ppm	1000 ppm
D_S	1.98 ± 0.01	1.85 ± 0.06	1.83 ± 0.02	1.64 ± 0.01	1.68 ± 0.01
D_F	NA	2.31	1.86	2.16	1.98
17% kaolin	Original	300 ppm	600 ppm$^+$	800 ppm	1000 ppm
D_S	1.98 ± 0.02	1.76 ± 0.07	1.72 ± 0.01	1.73 ± 0.01	1.77 ± 0.01
D_F	NA	2.12	1.9	1.98	1.94
Activated sludge	Original	10 ppm$^+$	30 ppm	40 ppm	-
D_S	2.12 ± 0.02	2.06 ± 0.02	1.94 ± 0.01	1.85 ± 0.03	-
D_F	1.55	1.31	1.34	1.48	-

圖 6 所示爲自由沉降測試之結果，相對應之碎形維度(D_F)也列於表 1 中。原始活性污泥之 D_F 值爲 1.55，隨著高分子加入，D_F 值降低，當所加入之高分子超過最適劑量後，D_F 值又變大。此外，對於相同之樣品所測得之 D_S 值與 D_F 值並不相同。對於高嶺土泥漿，$D_F>D_S$ 值；對於活性污泥，$D_F<D_S$ 值。此結果顯示由不同實驗方法所得之碎形維度並不相同。

結論

本研究利用光散射法及自由沉降測試測量不同濃度之高嶺土以及活性污泥之碎形維度。由兩種實驗方法所得之碎形維度並不相同，代表所量測者乃不同緻密程度之區域，可由兩層結構之模式來解釋，即微膠羽是由基本粒子所構成，其碎形維度爲 D_S；而膠羽則由微膠羽構成，其碎形維度爲 D_F。

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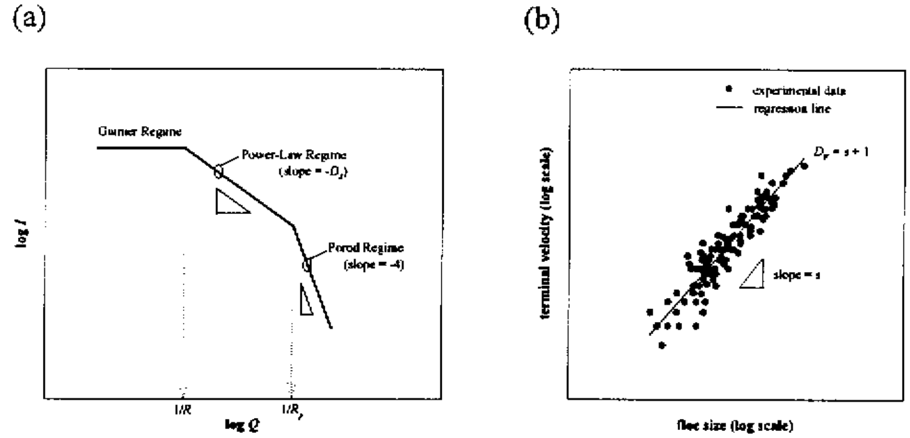

圖 1 由實驗得碎形維度

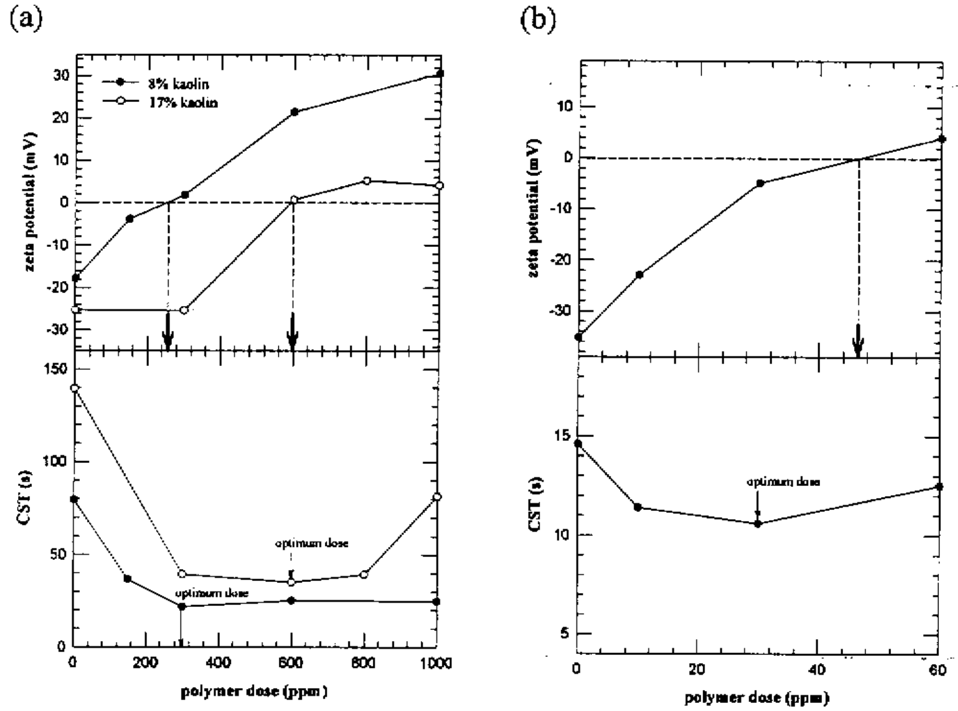

圖 2 高分子劑量與界達電位及 CST 關係

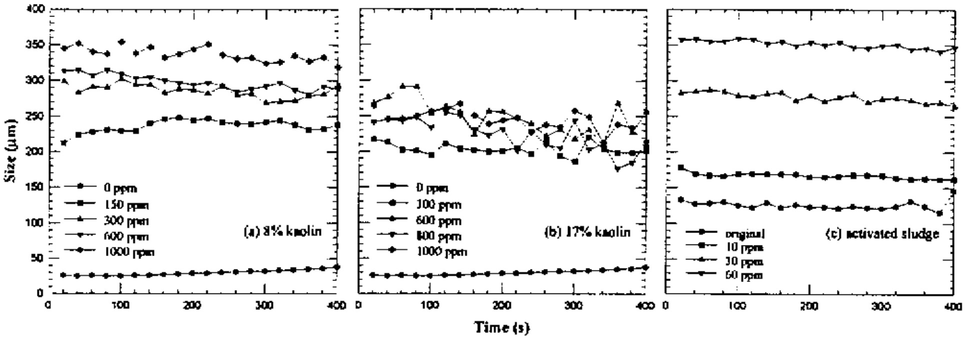

圖 3 樣品之粒徑

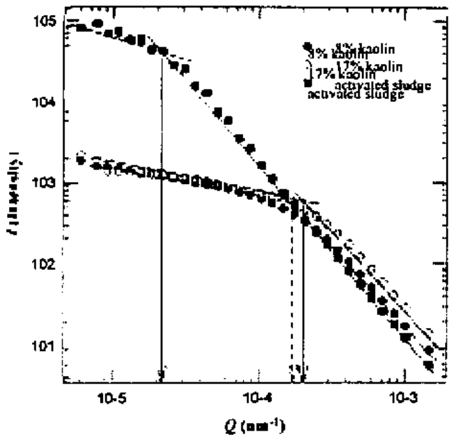

圖 4 原始樣品之 *I*-*Q* 關係圖

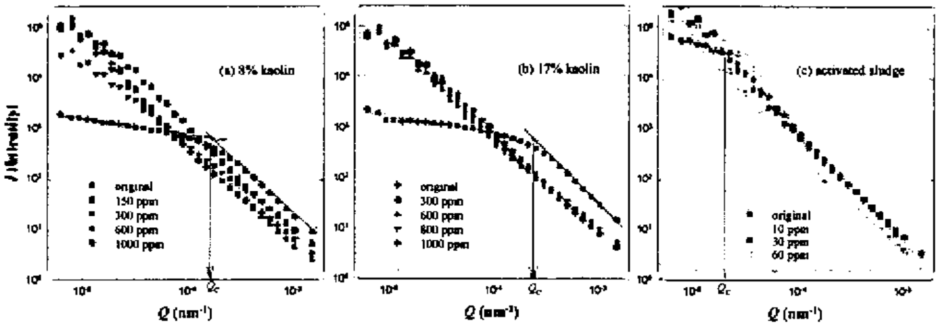

圖 5 所有樣品之 *I*-*Q* 關係圖

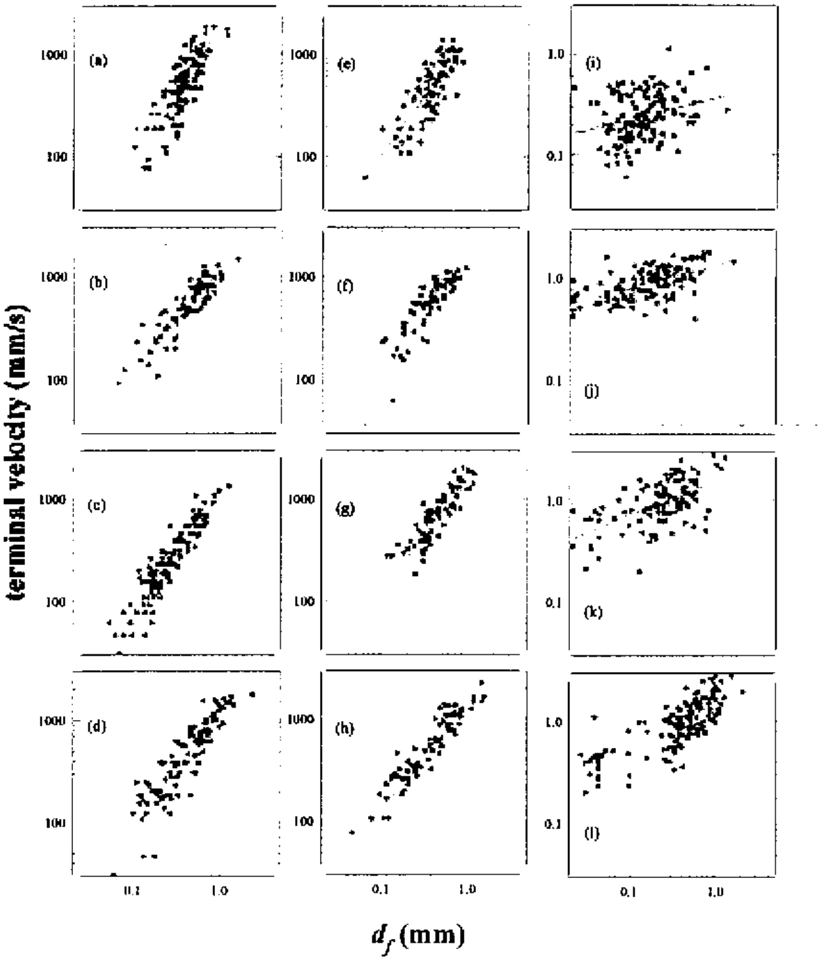

圖 6 自由沉降測試結果

軟粒子之固液分離—子計畫三：軟粒子之結構與脫水性

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其中$1 \le D \le 3$。自由沉降測試及光散射法乃被廣泛應用於測量碎形結構物之碎形維度，若一物體具有單一之碎形結構，則應用不同之測量方法應得到相同之碎形維度。

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則下式成立：

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因此，藉由光散射實驗所得之散射強度 I 及波向量 Q，以 I 及 Q 作對數圖可得直線斜率爲$-D$，由此方法所得之碎形維度其符號爲 D_S，以別於由自由沉降測試所得之碎形維度 D_F。

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考慮一膠羽在無限大之靜止流場中自由沉降，其所受之拖曳力 F_D 可以下式表示：

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其中 C_D 爲拖曳係數，V 爲膠羽運動速度，ρ 爲流體密度。對於一高度多孔性的球體，其拖曳力可如下式(Wu and Lee, 2000)表示：

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其中μ爲流體黏度而 $A(\beta)$爲修正因子。因此在浮力與重力平衡下可得下式：

$$\rho_f-\rho=\frac{3A(\beta)}{4}\frac{\mu V}{g d_f^2} \tag{8}$$

將式(1)代入可得：

$$\rho_f-\rho=Cd_f^{D-3} \tag{9}$$

將式(9)代入可得：

$$V=\frac{4C}{3A(\beta)}\frac{g}{\mu}d_f^{D-1} \tag{10}$$

若修正因子 $A(\beta)$爲一常數，則以膠羽之終端速度 V 對粒徑 d_f 作全對數圖可得一直線斜率爲 D-1，圖 1b 爲自由沉降測試求取碎形維度 D_F之示意圖。

實驗方法

本研究以高嶺土泥漿及活性污泥爲樣品，測量其內部結構。

高嶺土粒子之密度爲 2,727 kg/m^3 (Accupyc Pycometer)，平均粒徑爲 2.3 μm (Sedigraph 5100C)，高嶺土泥漿之重量百分率爲 17%及 8%，所使用之陽離子型高分子架凝劑爲 T-3051，聚丙烯醯胺，平均分子量約爲 10^7，攪拌速度爲以 200rpm 攪拌 5 分鐘，再以 50rpm 攪拌 20 分鐘。

活性污泥樣品由 St. Mary's 污水處理廠取得(澳洲雪梨)，該廠之處理量爲每日 37,000 立方公尺。所使用之高分子架凝劑爲 Zetag 92 (Allied Colloids, Australia)，其分子量約爲 10^6-10^7，爲聚丙烯醯胺及二甲基胺基乙基丙烯酸單體聚合而成。攪拌速度爲以 400rpm 攪拌 30 秒，再以 150rpm 攪拌 1 分鐘。

活性污泥之化學需氧量及懸浮固體濃度分別爲 41mg/L 及 90mg/L，固體濃度爲 0.55%。

小角度光散射法

小角度光散射實驗所使用的儀器爲 Malvern Mastersizer/E，於澳洲雪梨市新南威爾斯大學土木暨環境工程系實驗所得，其光源爲 5mW 的氦氖雷射(波長 632.8nm)，散射角度爲 0.03 到 6.52 度，包含 31 個散射光源接收器，實驗方法爲將測試樣品倒入測試玻璃容器內(約 20ml)，每隔 20 秒接收一次(31 組)訊號，共 400 秒。

結果與討論

圖 2a 及 2b 爲高嶺土泥漿及活性污泥之界達電位與 CST 結果。對於 8%及 17%之高嶺土泥漿，其等電位點分別在 260 ppm 與 600 pmm，並且其 CST 最低值也接近這些劑量，在本研究中稱其爲最適劑量，因此等電位點可作爲判定高分子架凝效果之依據。

圖 3a 及 3b 所示爲高嶺土泥漿及活性污泥之粒徑。原始高嶺土泥漿粒徑之大小約 28 μm，經過高分子調理後粒徑可上升到 200-350 μm，加入越多的高分子劑量，可形成越大的粒徑。對於活性污泥粒子，其粒徑隨著高分子加入而變化的趨勢亦如高嶺土泥漿粒

子，如圖 3b 所示。

圖 4 爲原始高嶺土泥漿及活性污泥之 I 對 Q 關係圖。在圖中可看到兩階段之直線，分界點對應於 $Q=Q_C$ 處，$Q<Q_C$ 即爲 Guinier 區域，$Q>Q_C$ 即爲 power-law 區域，根據光散射理論，Q_C 值亦對應於 $1/R$。

根據圖 1a，碎形維度可由 power-law 區域線性迴歸之斜率求得。對於 8%及 17%之高嶺土泥漿，其碎形維度分別爲 1.97-1.99。對於原始活性污泥，其碎形維度則爲 2.12。活性污泥之碎形維度大於高嶺土泥漿，此結果與 Guan(1999)符合。

圖 5 爲高分子調理高嶺土泥漿及活性污泥之 I 對 Q 關係圖。當加入高分子後，I 對 Q 關係爲線性之區域增大，Q_C 值也相對變大。

表 1 所列爲所有測試樣品之碎形維度(D_S)。當增加高分子劑量至 1000 ppm 時，碎形維度降低至 1.6-1.7，配合粒徑變化結果(圖 3)，高分子加入使得膠羽結構變疏鬆且粒徑變大，而獲得較佳之脫水性。

表 1

8% kaolin	Original	150 ppm	300 ppm$^+$	600 ppm	1000 ppm
D_S	1.98 ± 0.01	1.85 ± 0.06	1.83 ± 0.02	1.64 ± 0.01	1.68 ± 0.01
D_F	NA	2.31	1.86	2.16	1.98
17% kaolin	Original	300 ppm	600 ppm$^+$	800 ppm	1000 ppm
D_S	1.98 ± 0.02	1.76 ± 0.07	1.72 ± 0.01	1.73 ± 0.01	1.77 ± 0.01
D_F	NA	2.12	1.9	1.98	1.94
Activated sludge	Original	10 ppm$^+$	30 ppm	40 ppm	-
D_S	2.12 ± 0.02	2.06 ± 0.02	1.94 ± 0.01	1.85 ± 0.03	-
D_F	1.55	1.31	1.34	1.48	-

圖 6 所示爲自由沉降測試之結果，相對應之碎形維度(D_F)也列於表 1 中。原始活性污泥之 D_F 值爲 1.55，隨著高分子加入，D_F 值降低，當所加入之高分子超過最適劑量後，D_F 值又變大。此外，對於相同之樣品所測得之 D_S 值與 D_F 值並不相同。對於高嶺土泥漿，$D_F>D_S$ 值；對於活性污泥，$D_F<D_S$ 值。此結果顯示由不同實驗方法所得之碎形維度並不相同。

結論

本研究利用光散射法及自由沉降測試測量不同濃度之高嶺土以及活性污泥之碎形維度。由兩種實驗方法所得之碎形維度並不相同，代表所量測者乃不同緻密程度之區域，可由兩層結構之模式來解釋，即微膠羽是由基本粒子所構成，其碎形維度爲 D_S；而膠羽則由微膠羽構成，其碎形維度爲 D_F。

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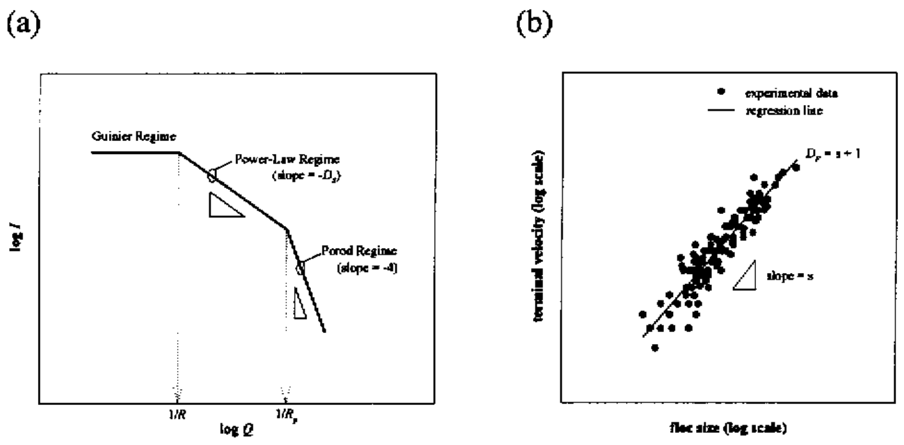

圖 1 由實驗得碎形維度

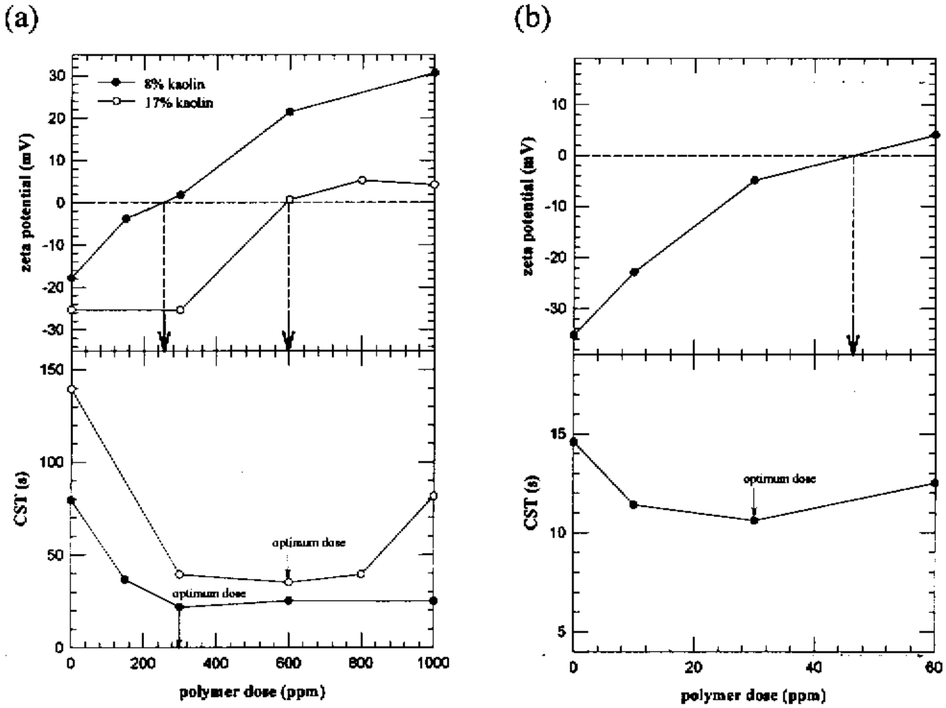

圖 2 高分子劑量與界達電位及 CST 關係

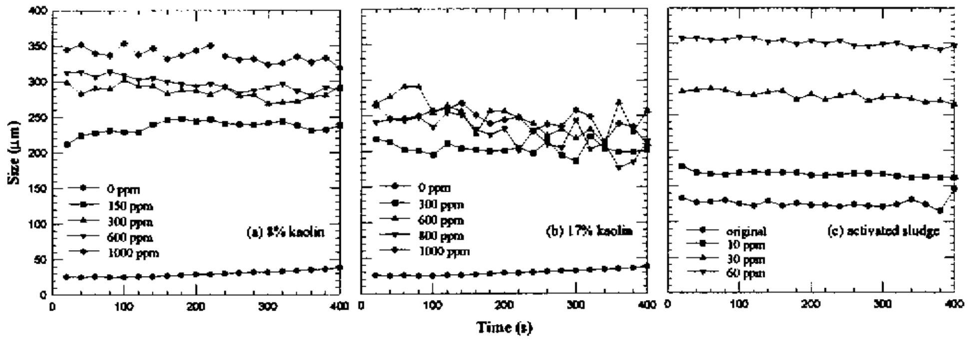

圖 3 樣品之粒徑

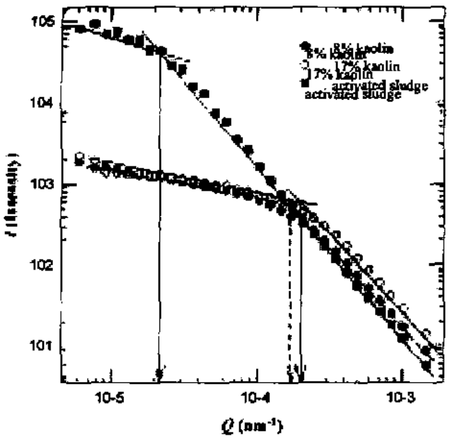

圖 4 原始樣品之 *I-Q* 關係圖

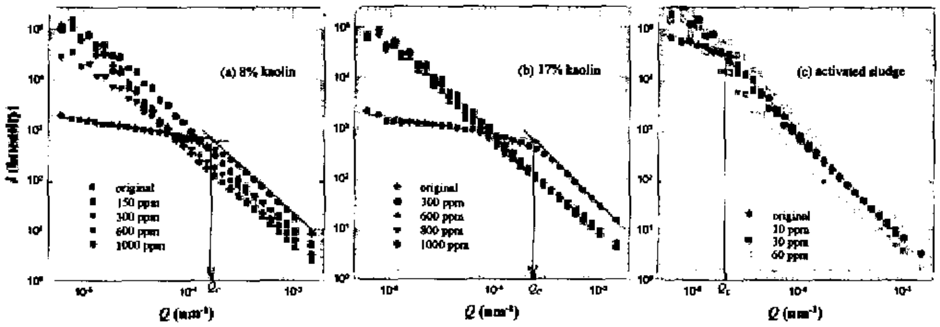

圖 5 所有樣品之 *I-Q* 關係圖

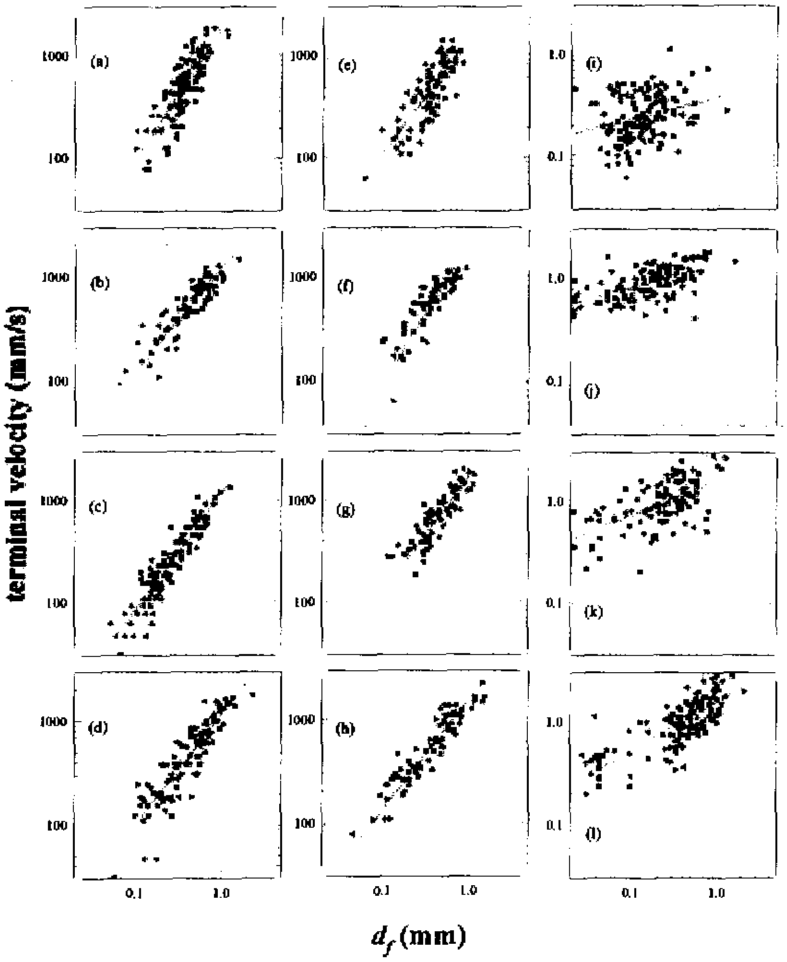

圖 6 自由沉降測試結果

出國報告書

李篤中

國立台灣大學化工系

本人於2000年10月12日至16日間在國科會專題研究補助下赴希臘雅典參加國際水質協會(IWA)國際污泥處置研討會，獲得豐碩成果。因本人將於2001年3月25日-28日主辦下一屆之國際研討會，因此參與本次會議負有協調國際組織行政支持及宣傳的雙重任務。以下即將此次行程概述。

10月12日：　自中正機場搭乘新加坡航空經新加坡轉機至雅典，於半夜11時半抵達機場。至會場時已近凌晨。於雅典機場最好是搭乘排班計程車，外場計程車會亂計價收費。本人搭乘之計程車後經詢價高出公定價近六倍之多。

10月13日：　本日一早即舉行開幕典禮，隨即開始各場次之發表。本次大會有逾100篇口頭論文發表，因此行程十分緊湊。

10月14日：　本日繼續進行各場次之口頭發表，本人負責其中一場次之會場主持工作(chair)，並在其中發表論文「Effects of pH Adjustment and Ultrasonic Treatment on Microbial Density Level in Waste Activated Sludge」，其中對污泥有效殺菌之概念，引起熱烈討論。本日會後於會場大廳與協會負責人員

商討台灣研討會事宜。

10月15日：　本日繼續各場發表，於下午3時起因本人為IWA污泥處置之執行委員，因此與各國代表共七人舉行 Board meeting，會中通過未來一年之工作計劃，及踴躍出席台灣研討會之結論。

10月16日：　搭乘新加坡航空返國。

與會心得：

雅典會議雖然與會者眾多，發表熱烈，為一成功之研討會，但在籌備上有許多疏失，其中尤其以無人不抽煙為一大敗筆。但已獲得與會者全力支持下屆污泥研討會之共識，可謂成果豐碩。

攜回資料：

「IWA Sludge Management Conference, Greece」論文集一冊。

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Reduction of microbial density level in sewage sludge through pH adjustment and ultrasonic treatment

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Abstract This work investigated the effects of using ultrasound and pH-value adjustment on the microbial density levels in sewage sludge, with total coliform and heterotrophic-plate-count (HPC) bacteria as the microbial indices. Application of ultrasound at a high intensity level could sufficiently disinfect both the total coliform and HPC bacteria. Adjustment of pH value could also disinfect the micro-organisms in the sewage sludge, but at a less efficient rate. For the present sewage sludge, the application of ultrasound of 0.33 W/mL level for 1–2 hours could make it a Class B sludge.

Keywords Microbial density; ultrasound; pH values; pre-treatment

Introduction

The biodegradability of sludge can be improved by using thermal energy (Stuckey and McCarty, 1984; Li and Noike, 1992), enzymes (Knapp and Howell, 1978), ozonation (Yasui and Shibata, 1994), acidification (Gaudy *et al.*, 1971; Woodard and Wukasch, 1994), alkaline (Mukherjee and Levine, 1992; Lin *et al.*, 1989; Haug *et al.*, 1978), high pressure (Dollerer and Wilderer, 1993), mechanical disintegration (Baier and Schmidheiny, 1997; Kopp *et al.*, 1997) and ultrasound (Kunz and Wagner, 1994; Neis *et al.*, 1994; Muller and Schwedes, 1996; Tiehm *et al.*, 1997). Some investigations discussed the combined treatment of alkaline addition and ultrasound (Stuckey and McCarty, 1984, Kenzevic *et al.*, 1994; Chiu *et al.*, 1997a, b).

The hygienic properties of sludge and organic waste are of essential importance in sludge handling and disposal. The land usage of sewage sludge is severely limited by the density level of pathogenic microorganisms. Pretreatment of sludge is generally required prior to ultimate disposal for reducing the pathogenic organisms (Chu *et al.*, 1999). A few studies elucidated the effects of pretreatment on the pathogenic microorganisms. Allievi *et al.* (1994) noted that alkaline treatment could inactivate fecal bacteria in sewage sludge. Treatment of sludge with quicklime, which brought the pH greater than 12, could effectively inactivate viruses (Bossart and McCreary, 1983, Pancorbo *et al.*, 1988) and damage parasite eggs (Schuh *et al.*, 1985). Jepsen *et al.* (1997) discussed several pretreatment methods on the efficiencies of microbial reduction.

The amount of the sewage sludge in Taiwan had increased substantially in the past decade since the wide installation of sewer systems. Information regarding the hygienic properties of the sewage sludge in Taiwan, however, is still largely lacking. This work elucidated the effects of ultrasound and pH values on the microbial density level in sewage sludge. Herein, the total coliform and the heterotrophic-plate-count (HPC) bacteria density levels are used as the microbial indices. In practice the application of ultrasound and/or acid/alkaline could be placed after the sedimentation tank and prior to the digestion processes.

Experimental

Two sludge samples were taken from the reflux stream of recycled activated sludge from Min-Shen Sewage Treatment Plant, Taipei, which handles domestic wastewater of capacity

15,500 m^3/day. The chemical oxygen demands for the supernatant (SCOD) and for the whole sludge (COD) were determined using EPA Taiwan standard methods. The results for sample #1 read 212 mg/L (SCOD) and 7,400 mg/L (COD), respectively. The weight percents of sludge samples were determined by weighing and drying. The results for samples #1 and #2 were 0.96% and 1.6%, respectively. Particle size distribution (PSD) was determined via particle size analyzer (Coulter LS230). The mean floc size of the original sewage sludge is approximately of 31 μm. The SCOD and COD data for sludge #2 are 62 and 12,100 mg/L, respectively. The corresponding floc size is 57 μm. The pH values of both sludge samples were all around 6.7–7.0.

Ultrasonic tests were conducted at two intensity levels with the help of a sonicator (XL-2020, Heat System-Ultrasonics, Inc.). We herein denote the tests at an intensity of 0.11 W/mL as "low-intensity" tests, and those at 0.33 W/mL as the "high-intensity" test. Owing to the energy dissipation in the ultrasonic field, during the test the bath temperature would increase to a level of 50–60°C. The sludge chamber was thereby immersed in an ice pool to control the bath temperature. The total time for ultrasonic tests was fixed at two hours.

By adding $HClO_4$ or NaOH the pH value of the sludge was adjusted to a range of 3–11. For the sake of comparison with the ultrasonic tests sludge #2 was stabilized at the specific pH value for two hours before testing.

Sludge samples were analyzed for total coliform and HPC bacteria by the membrane filtration technique (APHA, 1992) by passing sludge through Millipore type HA 0.45-μm-pore-size membrane filters (Millipore Corp., Bedford, Mass.). Samples of 0.1 mL were each tested in triplicate for all samples to increase the likelihood of obtaining plates counts within acceptable ranges.

HPC bacteria were enumerated by using R2A medium. Plates were incubated for seven days at 35°C (APHA, 1992). Coliform was grown on M-Endo medium and incubated at 35°C for 24 hours (APHA, 1992). Confirmation tests, using brilliant green lactose bile broth and lauryl sulfate broth, were conducted on selected sheen and nonsheen colonies to achieve accurate coliform counts (APHA, 1992). All ingredients for medium were purchased from Difco Laboratories (Detroit, Mich.). The density levels of the total coliform and of the HPC bacteria of the original sludge #1 were 1.1×10^7 MPN/ml and 1.0×10^8 CFU/mL, respectively. For sludge #2, the results are 3.9×10^6 MPN/mL and 2.1×10^9 CFU/mL, respectively. The present sludge thereby could not be classified as the Class B sludge.

Results and discussion

Effects of ultra-sonication

Figure 1 depicts the floc size as a function of sonication time. At a low intensity, the floc size decreases gradually from 31 μm to 20 μm in 60 minutes, that is, a 35% reduction in size. In contrast, at the high intensity tests, the floc size reduces to its plateau value at a sonication time less than 20 minutes. The corresponding plateau size of floc (14 μm) is also less than that obtained at the low ultrasonic intensity (20 μm). Restated, ultrasonic vibration could deteriorate the structure of the sludge flocs. The higher the vibration intensity the easier the floc is to be disintegrated. Microphotographic observation revealed that the sludge flocs had been transformed into tiny aggregates after treating at a high intensity level.

Figures 2a and 2b illustrate the total coliform and HPC density levels, respectively, after sonication. At a low intensity level, the HPC level mildly changes with the sonication time. For the total coliform, in contrast, a marked reduction in the density level could occur after 40 minutes of treatment. The total coliform is thereby easier to be inactivated than is the HPC.

At a high intensity level, on the other hand, within 40 minutes of treatment both the HPC bacteria had been reduced by 82%. For the level of the total coliform, the reduction reached 93% within 10 mins of treatment. At 40 mins of ultra-sonication, the survival ratio of total coliform bacteria is less than 1%.

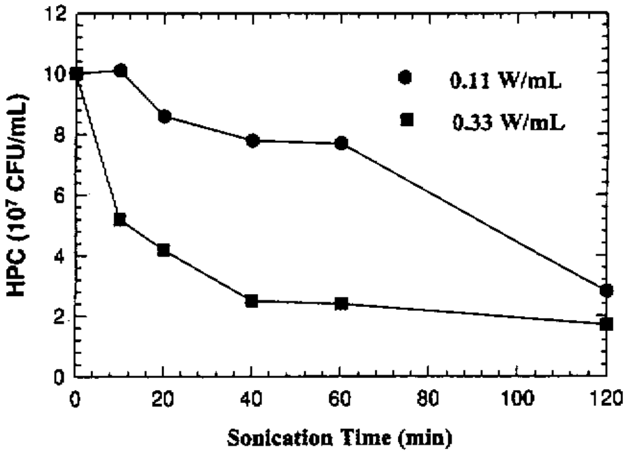

Figure 1 The mean size of flocs versus sonication time. Sludge #1

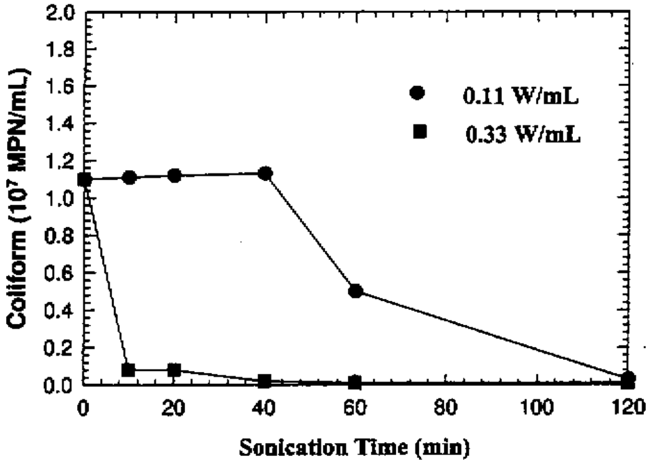

Figure 2a The total coliform and HPC bacteria density levels versus sonication time. Sludge #1

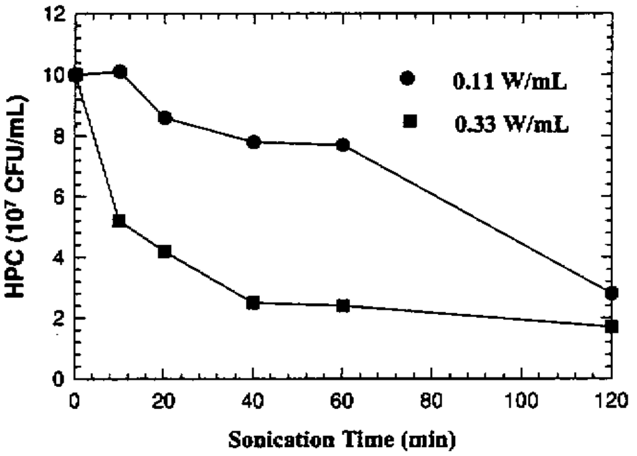

Figure 2b The total coliform and HPC bacteria density levels versus sonication time. Sludge #1

Figure 3 depicts the SCOD data. As compared with the original sludge (212 mg/L), the SCOD increases by 12 times at 60 mins of sonication at a high intensity. At the low intensity tests the SCOD remains almost unchanged after sonication. Such an observation reveals that the ultra-sonication, at a high intensity level, could largely transform the COD in the

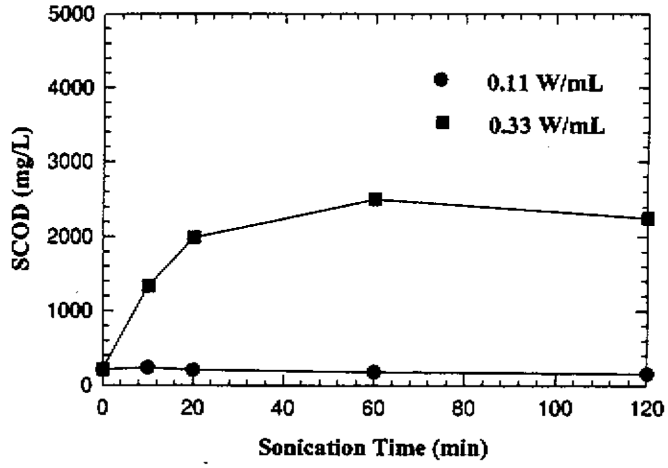

Figure 3 SCOD data versus sonication time. Sludge #1

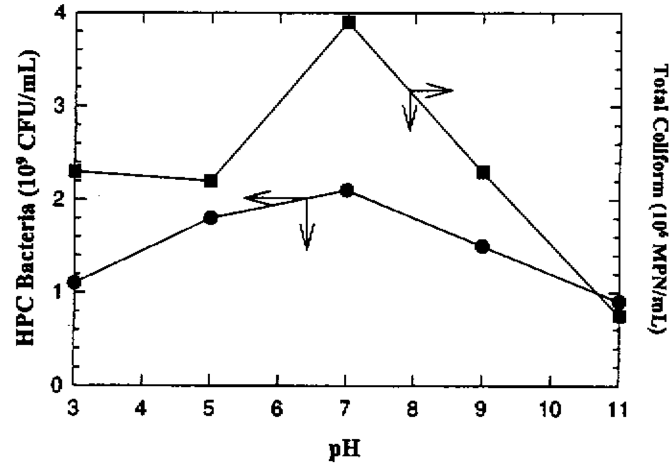

Figure 4 Total coliform and HPC bacteria density levels after two hours of pH adjustment. Sludge #2

sludge into a soluble form, which is beneficial to the subsequent digestion processes. Furthermore, there exists a critical intensity between 0.11 and 0.33 W/mL, exceeding which the dissolution of the COD could occur.

Adjustment of pH-value

Figure 4 displays the total coliform and HPC bacteria density levels at various pH values. At pH 11 the reduction ratios of total coliform and HFC bacteria are respectively 80% and 57%, when compared with those of the original sludge. Such an occurrence correlates with Allievi *et al.* (1994) but at different magnitudes. Microscopic observation reveals that the floc structure deteriorates in a basic environment. The filamentous bacteria expose outward from the flocs while apparent dissolution of the constituent components is noticeable. Floc size measurement also suggested that the large flocs had been transformed into smaller aggregates after alkaline treatment.

At pH 5, on the other hand, the corresponding reduction ratios are 46% and 14% for total coliform and HPC bacteria, respectively. At pH 3, the disinfection efficiency of total coliform could not be further enhanced. Meanwhile, the reduction ratio of HPC bacteria goes up to a level of 40%. Comparison of the results at pH 5 and at pH 9 illustrates that both the total coliform and HPC bacteria could sustain more readily to the acidic than to the basic environment. Microscopic observation noted that the global structure of the flocs almost

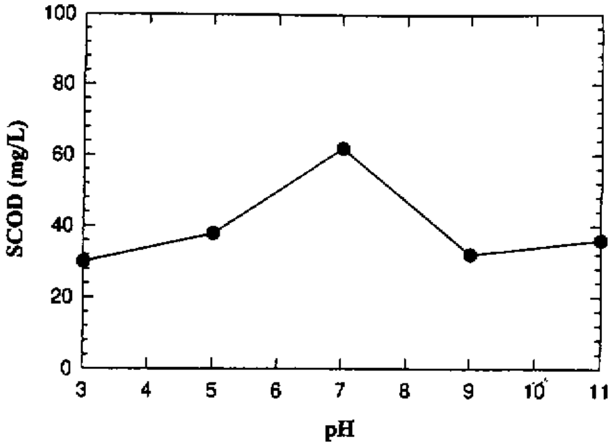

Figure 5 SCOD data versus pH value. Sludge #2

keep intact in an acidic environment, except that the floc size has become even greater than that of the original sludge.

Figure 5 illustrates the SCOD data at various pH values for sludge #2. When compared with the original sludge (62 mg/L) the SCOD decreases to approximately 30–40 mg/L when pH deviates from neutral. Restated, although the bacteria had been largely disinfected, no excess organic compounds had been released to the bulk solution after pH adjustment. Such a trend is different from that observed in ultrasonic treatment.

Effects of ultra-sonication and pH-adjustment

The total bacteria count usually detects a majority of the heterotrophic bacteria. These bacteria, like *Pseudomonas*, *Alcaligenes*, *Paracoccus*, *Flavobacterium*, and *Coryneform* cannot form endospore or capsule. The total coliform bacteria, such as *Escherichia* and *Klebsiella* can form capsule (Holt, 1984). The formation of capsule has been noted to correlate with the survival ratio of micro-organisms subject to freeze/thaw treatment (Chu *et al.*, 1999). The present results, however, revealed that the total coliform is easier to be disinfected than is the HPC bacteria. The presence of capsule hence does not enhance the capability of micro-organisms to resist ultrasound and/or pH adjustment as does the freeze/thaw treatment.

With the same treatment time, ultra-sonication is superior to pH-adjustment on the disinfection ratio of micro-organisms. The lowest density levels for total coliform after ultra-soniocation and pH adjustment are 5×10^4 and 7.5×10^5 MPN/mL, respectively. Therefore, the application of ultrasound for 1–2 hours to the present sewage sludge could make it classified as the Class B sludge. Change in pH value may require more time to achieve the same criterion.

Conclusions

This work experimentally elucidated the effects of ultrasonication and pH-value adjustment on the microbial density levels in Min-Shen Sewage Treatment Plant by using total coliform and HPC bacteria as microbial indices. At a low ultrasonic intensity, the floc size and the HPC bacteria level only mildly decrease, but the total coliform level markedly reduces after 40 minutes of sonication. At a high intensity level, on the other hand, both the total coliform and heterotrophic-plate-count (HPC) density levels as well as the floc size are sufficiently reduced. The structure of the sludge flocs had largely deteriorated. The SOCD increases by 12 times at the high-intensity level, but keeps almost unchanged at the low-intensity level.

Adjustment of pH value for two hours could also disinfect the micro-organisms in the sewage sludge, although not as efficiently as the ultra-sonication treatment. At pH 11, the reduction ratios of total coliform and HFC bacteria could reach respectively 60% and 57%

compared with the original sludge. At pH 3, the corresponding reduction ratios are 41% and 39%, respectively. Microscopic observation revealed that in acid conditions the sludge floc retained its shape and structure, but exhibited a large size. In basic conditions, in contrast, most sludge flocs dissolved while the whole structure deteriorated accordingly.

For the same treatment time, ultra-sonication is superior to the pH adjustment for the disinfection ratio of micro-organisms. The application at 0.33 W/mL level for 1–2 hours to the present sewage sludge could make it be classified as Class B sludge.

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研習報告

姓名：台大化工系　吳容銘
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日期：2000 年 1 月至 3 月
地點：澳洲雪梨新南威爾斯大學土木及環境工程學系

一、研習動機：

新南威爾斯大學土木及環境工程學系 David Waite 教授於小角度光散射技術經驗豐富，並與化工系 Rose Amal 教授、昆士蘭大學粉粒體技術實驗室有密切合作關係，有鑑於此，於 2000 年 1 月至 3 月赴該實驗室研習小角度光散射技術。

二、研習內容：

許多研究者提出污泥膠羽是由基本粒子構成之碎形結構物，而碎形維度(D)乃描述碎形結構物之一重要參數，一具有碎形維度 D 之碎形結構物，其質量 M 與粒徑 d_f 之關係式如下所示：

$$M \propto d_f^{\,D} \tag{1}$$

其中 $1 \le D \le 3$。自由沉降測試及光散射法乃被廣泛應用於測量碎形結構物之碎形維度，若一物體具有單一之碎形結構，則應用不同之測量方法應得到相同之碎形維度。

本次研習應用光散射法及自由沉降測試測量兩種不同樣品之碎形維度，證實由兩種實驗方法所得之碎形維度並不相同，並提出一雙層結構之模型，解釋應用陽離子型高分子調理樣品前後之結構變化。

<u>光散射法</u>

光散射技術可測量一物體之波向量(wave vector, Q)，其絕對大小可由下式表示：

$$\left|\vec{Q}\right| = Q = \frac{4\pi n \sin(\theta/2)}{\lambda} \tag{2}$$

其中 n，θ，及λ分別代表介質之折射率、散射角度以及雷射光在真空中之波長。在光散射理論中，波向量 Q 是散射強度 I 的函數，即 $I(Q)\propto F(Q)S(Q)$，其中 $F(Q)$ 及 $S(Q)$分別爲形狀因子(form factor)及結構因子(structure factor)。形狀因子和基本粒子之形狀有關，而結構因子則描述基本粒子在空間中之分佈及排列。

在 $QR_p>>1$ 之情況下(R_p 爲基本粒子之半徑)：

$$I(Q)\propto Q^{-4} \tag{3}$$

即 Porod 定律。在 $QR<<1$ 之情況下，形狀因子通常爲一常數，若

$$1/R<<Q<<1/R_p \tag{4}$$

則下式成立：

$$I(Q)\propto Q^{-D} \tag{5}$$

因此，藉由光散射實驗所得之散射強度 I 及波向量 Q，以 I 及 Q 作對數圖可得直線斜率爲-D，由此方法所得之碎形維度其符號爲 D_S，以別於由自由沉降測試所得之碎形維度 D_F。

自由沉降測試

考慮一膠羽在無限大之靜止流場中自由沉降，其所受之拖曳力 F_D 可以下式表示：

$$F_D=\left(\pi R^2\right)\left(\frac{1}{2}\rho V^2\right)C_D\Omega \tag{6}$$

其中 C_D 爲拖曳係數，V 爲膠羽運動速度，ρ爲流體密度。對於一高度多孔性的球體，其拖曳力可如下式表示：

$$F_D=\frac{A(\beta)}{8}\pi\mu Vd_f \tag{7}$$

其中μ爲流體黏度而 $A(\beta)$爲修正因子。因此在浮力與重力平衡下可得下式：

$$\rho_f-\rho=\frac{3A(\beta)}{4}\frac{\mu V}{gd_f^2} \tag{8}$$

將式(1)代入可得：

$$\rho_f-\rho=Cd_f^{D-3} \tag{9}$$

將式(9)代入可得：

$$V=\frac{4C}{3A(\beta)}\frac{g}{\mu}d_f^{D-1} \tag{10}$$

若修正因子 $A(\beta)$爲一常數，則以膠羽之終端速度 V 對粒徑 d_f作全對數圖可得一直線斜率爲 D-1。

本次研習利用小角度光散射法(small angle light scattering test)及自由沉降測試(free settling test)測量不同濃度之高嶺土以及活性污泥之碎形維度。由兩種實驗方法所得之碎形維度並不相同，顯示碎形維度是一操作型定義之物理量，由不同實驗方法所得之不同碎形維度代表所量測者乃不同緻密程度之區域，可由兩層結構之模式來解釋，即微膠羽(microflocs)是由基本粒子(primary particles)所構成，其碎形維度(D_S)可由光散射法測量；而膠羽(entire floc)則由微膠羽構成，其碎形維度(D_F)可由自由沉降測試求得。應用陽離子型高分子調理高嶺土以及活性污泥，調理前後之結構變化亦可由此一雙層結構解釋。