養殖水處理及其循環利用

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摘　要

將養殖廢水經處理後再循環利用以減少單位面積用水量,一般咸認可行。本文探討養殖池廢水特性,並配合台灣省漁業局烏山頭淡水養殖示範中心現場之循環水處理設施單元,於實驗室進行實驗,研究沈澱、氣提、曝氣、吸附、過濾等方法用於處理養殖池廢水之效果。

養鰻池廢水不良的水質因子包括高濃度的氨態氮、有機物多以及黎明時分的溶氧過低等,草蝦池則可能以有害的硫化氫氣體及低的溶氧爲主。

沈澱實驗顯示養殖廢水中固形物之沈澱不易,因爲水中之固形物以有機物爲主。若加入混凝劑處理,則以硫酸鋁之效果較佳。氨態氮氣提效果相當低,在養殖廢水所含的濃度下,即使提昇廢水之 pH 值至 10.5,效果亦不佳。實驗室靜水曝氣試驗,測得養殖廢水之傳送係數 Kd 爲 0.0671,實際上應用於現場設計曝氣槽時建議可採用 0.1～0.3。活性炭吸附所需平衡時間約 25 分鐘,由等溫吸附曲線來計算,若期望得到 COD 去除 50％的效果,處理 1ton 的養殖廢水約需 0.75Kg 的活性炭。過濾與生物滴濾試驗顯示過濾池對移除懸浮固形物有效,若希望有機物之氧化及氮素硝化作用亦能進行以增進效果,則烏山頭淡水養殖示範中心循環水設施之流量應低於 7m^3/hr,水力停留時間應超過 60 分鐘。

民國 73 年 6 月及 9 月,於烏山頭淡水養殖示範中心循環水設施之水質分析結果與實驗室內試驗結果相似,沈澱池及過濾池對固形物之去除雖具成效,但不十分理想；經曝氣水路後,對溶氧之增加有效,另對氨態氮之去除則效果不佳。由現場水質分析與實驗室試驗結果顯示,就處理效果而言,養殖水之處理重點以生物處理法較有發展潛力,物理及化學處理則可作爲提供輔助之用。

關鍵詞:養殖廢水、處理、再利用。

前　言

近年來,本省養殖漁業快速發展,養殖面積一再擴大;以致用水量劇增,部分地區由於地面水源缺乏,養殖戶自行抽取地下水使用,發生了因超抽地下水而造成地層下陷的現象,據水利局報告[1],屏東沿海地區,自民國 59 年至民國 72 年間,地層下陷自 0.3meter 至 2.0meter,此與養殖戶過度抽取地下水有顯著關係。而雲林縣、彰化縣養殖魚塭密集地區同樣也有地層下陷的現象,對當地居民的生命財產已構成嚴重威脅。

將養殖廢水經處理後再循環利用以減少用水,一般認爲是可行的對策,已有多篇報告提出[2~5]。養殖池因水質變劣而必須換水,這些不良水質因子可稱之爲限制因子（Limiting factor）。若能消除限制因子,則水再利用的目的就可達到。許多文獻[6~9]指出,養殖池水的限制因子最常見的有：溶氧（Dissolved oxygen, DO）過低,有機物聚積代謝以及有毒氮化合物濃度過高

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等。

日本在養殖用水再處理利用方面的研究起步較早,近來,養鰻池用水以生物滴濾(Biofilter)法爲主的處理,其再利用效果相當良好,可將流水式養鰻生產 1kg 鰻魚所需水量由 11～83m^3 降低至 0.3m^3[10],經處理再利用後的用水量遠比國內初步調查所得的16.78～29.06m^3/Kg 爲低[11]。可見將養殖池水經適當方法處理後循環利用可大幅節省生產單位重量魚類所需的水量。

由於循環用水的重要性,漁業局在台南縣烏山頭淡水養殖示範中心設有循環水系統。如 Fig.1 所示,包括 10 個養殖池與處理設備,處理設備包含沈澱池、碎石(或牡蠣殼)濾床及曝氣水道。本文探討養殖廢水特性,並配合此現場之循環水處理設施,於實驗室進行實驗,研究沈澱、氣提、曝氣、吸附、過濾等方法用於處理養殖池廢水之效果。

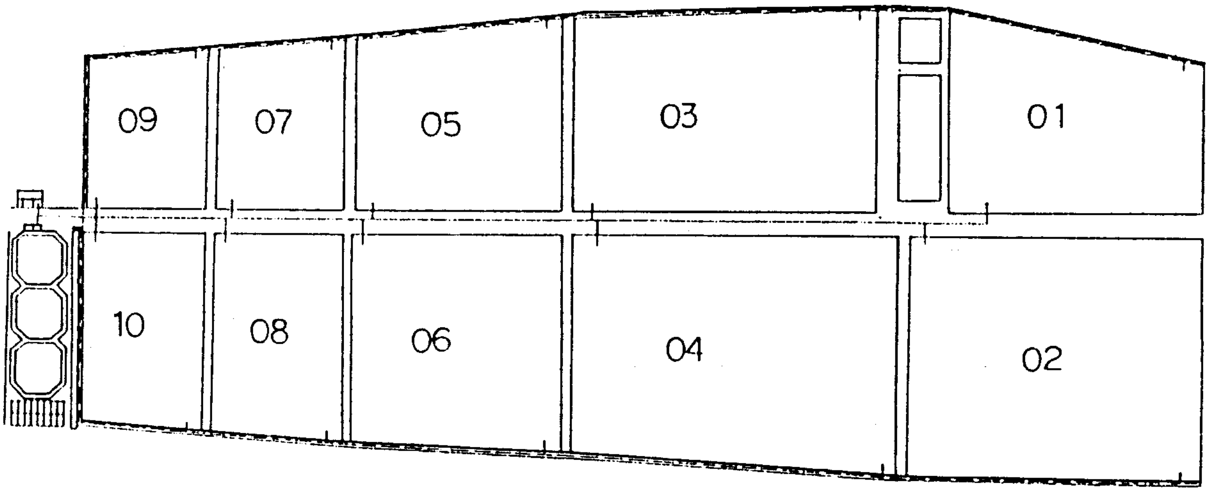

Fig.1 General layout of the ponds and associated recirculation system at Wushantou Freshwater Fish Culture Demonstration Center of the Taiwan Fisheries Bureau. – – – – – –, water supply; ...., water drainage.

養殖廢水特性

本省主要之魚塭養殖魚種,係以虱目魚、吳郭魚、蝦類及鰻魚爲主,據調查,不論是單位面積用水量或單位漁獲量之用水量,均以鰻魚養殖爲最多,其餘依次爲蝦類,虱目魚及吳郭魚養殖[11]。故就節省用水之觀點,鰻魚池及草蝦池之省水問題較爲重要,若能分別針對它們換水之限制因子加以處理,則可達到循環利用進而省水之目的。

流水式集約養殖鰻魚池之廢水特性引用 Chiang and Lee[12]之報告列如 Table 1 所示。Table 1 中所測得較低的溶氧量皆在黎明時分,最低者爲 2 號池之 2.9ppm;在固體物方面,溶解固體物與總固體物比(DS/TS ratio)在 0.74～0.93 之間,顯示固體物中以有機物佔多數;NH_3-N測定值常有超過 1ppm 的結果,據研究者[13,14]考量溫度與 pH 之估算,則可推測已有 NH_4^+-N 濃度偏高,足以危害鰻魚正常生長之現象。因此,養鰻池廢水不良的水質因子包括高濃度的氨態氮、有機物多、以及黎明時分的溶氧過低等。

Table 1 Summary of water quality parameters of wastewater from eel cultrue ponds in Taiwan

Items	1		2	3	4	Range
Date	4/25−4/26	8/21−8/22	9/13−9/14	11/15−11/16	11/16−11/17	
Max. flow, CMH	29.54	32.68	19.21	21.56	47.25	19.21−47.25
W.T., ℃	19.8−21.0	26.0−28.6	25.7−30.8	24.0−28.0	24.0−27.0	19.8−30.8
pH	7.83−8.29	7.53−8.13	7.73−9.52	7.73−8.15	7.65−8.35	7.53−9.52
D.O., mg/ℓ	5.9−6.2	5.0−8.1	2.9−12.2	4.8−8.5	3.9−10.3	2.9−12.2
E.C., umhos/cm	395−415	377−395	1187−1260	785−825	680−720	377−1260
T.S., mg/ℓ	419−460	260−288	835−867	−	−	260−867
D.S., mg/ℓ	319−388	237−251	721−762	−	−	237−762
S.S., mg/ℓ	52−111	18−37	80−119	−	−	18−119
COD, mg/ℓ	15.7−23.3	16.1−34.6	57.2−76.2	13.0−17.8	13.1−20.0	15.7−76.2
NH_4−N. mg/ℓ	−	0.89−1.29	0.20−0.65	0.71−0.93	0.50−1.07	0.20−1.29
NO_2-N, mg/ℓ	−	0.19−0.22	0.004−0.014	0.02−0.07	0.18−0.35	0.004−0.35
NO_3-N, mg/ℓ	−	−	−	0.92−1.37	0.94−1.41	0.92−1.41
D.S./T.S.	0.74−0.88	0.85−0.93	0.86−0.91	−	−	0.74−0.93
Fish:water ratio	1:1100	1:786	1:542	1:935	1:397	1:397−1:1100

Table 2 Results of water quality analysis for a *Penaeus monodon* monoculture pond in I−Lan County of Taiwan*

Items	Sampling no**							Range
	1	2	3	4	5	6	7	
W.T., ℃	26.4−32.4	26.5−32.2	24.5−32.0	20.4−27.1	20.7−24.6	20.0−25.0	22.8−25.6	20.0−32.4
pH	7.54−8.50	7.60−8.65	7.95−8.70	7.66−8.32	7.70−8.35	8.0−8.8	7.5−8.2	7.5−8.8
D.O., mg/ℓ	3.6−7.4	4.2−8.5	3.2−6.6	2.36−5.06	3.0−17.8	3.0−17.8	3.1−7.7	2.36−17.8
C.O.D., mg/ℓ	3.97	3.12	3.84	4.28	3.42	3.41	3.19	3.12−4.28
NH_4−N, mg/ℓ	0.978	0.838	1.042	1.347	0.847	2.103	1.013	0.838−2.103
NO_2-N, mg/ℓ	0.039	0.022	0.038	0.080	0.024	0.034	0.021	0.021−0.080
NO_3-N, mg/ℓ	0.62	0.73	0.125	0.14	0.07	2.103	0.085	0.062−2.103
PO_4-P, mg/ℓ	0.041	0.027	0.042	0.085	0.026	0.042	0.024	0.024−0.085
H_2S, mg/ℓ	0.7	0.678	0.713	1.318	0.687	0.7	0.685	0.678−1.318
Salinity, ‰	23.0−25.3	24.1−26.7	11.9−14.5	10.1−12.2	5.5−6.4	8.2−10.1	8.8−11.2	5.5−26.7

* From Hwang, 1977[15]

** Sampling date: 1: 7/8/78−7/9/78; 2: 8/5/78−8/6/78; 3: 9/28/78−9/29/78; 4: 10/3/78−10/8/78; 5: 11/11/78−11/12/78; 6: 3/11/79−3/12/79; 7: 4/27/79−4/28/79

草蝦流水式養殖之水質情況,引用黃[15]之分析數據列於 Table 2,作者並認爲草蝦養殖池之水質恐以硫化氫(H_2S)最有問題,DO 亦値得注意。

養殖廢水處理

養殖廢水之處理,類似一般污水處理,方法相當多,然考量養殖廢水特性,並配合烏山頭循環水設施之處理設備,本文僅討論沈澱、氣提、曝氣、吸附、過濾等方法用於處理養殖池廢水之效果。

取養鰻池排放水進行沈澱實驗,繪出沈降特性曲線如 Fig.2 所示,懸浮固體去除率與停留時間之關係則如 Fig.3 所示。由圖可知,雖然一般沈降法被認爲是廣泛用於水及廢水處理中固液相分離最經濟的方法之一,若用於處理養殖廢水這種以有機物爲主要固形物之廢水時,並不能達到良好的效率。以氫氧化鈣[$Ca(OH)_2$]、氯化鐵($FeCl_3$)、氫氧化鋁[$Al(OH)_3 \cdot 18H_2O$]、硫酸鋁[$Al_2(SO_4)_3 \cdot 14H_2O$]等 4 種混凝劑加入供試養鰻廢水中,在用量達 40ppm 時,只有硫酸鋁處理的水有明顯絮狀物呈現,可知其效果爲 4 種中最佳者。以硫酸鋁進行類似杯瓶試驗結果,(Fig.4),在 pH 値 8.3 時,其用量在 30ppm 爲佳。然而,硫酸鋁對鰻魚的毒性如何?尙無充分資料,混凝沈澱之可行性有待評估。

氨態氮主要來自魚類之排泄物,如同鳥類排泄尿酸,哺乳類排泄尿素。由於非解離氨毒性高,一般有兩種方法減低其毒性:一種是生物處理法,即進行硝化作用(Nitrification)將其轉化成毒性低的硝酸態氮;一種是物理處理法,即氣提(Air stripping)。在所設定的實驗條件下(Table 3),氨態氮不因 4 小時之內之曝氣氣提而有明顯之變化,即使提昇養殖廢水之 pH 値至 10.5,效果亦不佳。

取養殖廢水進行曝氣試驗之結果列如 Table 4 所示,據該項的結果,以時間(t)對缺氧量對數値(lnD)作圖,得 Fig.5,如此可計算出本試驗所採用的養殖廢水,其氧之傳送係數(Transfer coefficient)Kd 爲 0.0671。然而,Kd 値除與廢水性質有關外,尙與打氣方法、溫度、風速等有關,其値並不易正確掌握。Welch[16]指出,在美國 Georgia 之魚池,其 Kd 値在 0.1～0.5。故實際上應用於現場設計曝氣槽時,建議可採用 0.1～0.3。

活性炭之吸附有機物早爲人們所熟知,廢水經活性炭處理後,其 COD 會降低,且降低量與活性炭濃度及溫度有關,在一定溫度下可求得等溫吸附曲線來顯示其吸附特性。以養殖廢水進行活性炭吸附所需平衡時間之試驗結果如 Fig.6 所示,可知吸附平衡時間於 25 分鐘左右已足夠。等溫吸附曲線實驗結果見 Fig.7,有了吸附曲線,就可計算在某一去除率時,所需活性炭的量,若以 COD 去除 50% 的效果來計算,處理 1ton 的養殖廢水約需 0.75Kg 的活性炭。

依照台灣省漁業局烏山頭淡水養殖中心現有之循環水設施過濾池部分,製作直線比爲 10:1 之模型,於實驗室內進行過濾池之操作研究。在不同流速及停留時間下,觀察水質改善之情形,代表性結果如 Fig.8 至 Fig.13 所示,顯示在模型研究之流量範圍(63.3ml/min 至 189.9ml/min),過濾池對去除養殖水中之懸浮固形物有效,但若希望有機物之氧化及氮素硝化作用亦能進行以增進效果,則模型流量應低於 126.6ml/min,即烏山頭現有設施流量應低於 7㎥/hr,水力停留時間應超過 60 分鐘。

烏山頭養殖水循環利用設施效果評估

於民國 73 年 6 月及 9 月,於烏山頭淡水養殖示範中心循環水施設進行兩次之水質採樣分析,採樣點示如 Fig.14,分析結果則列於 Table 5 及 Table 6。與實驗室內試驗結果相似,在沈澱池及

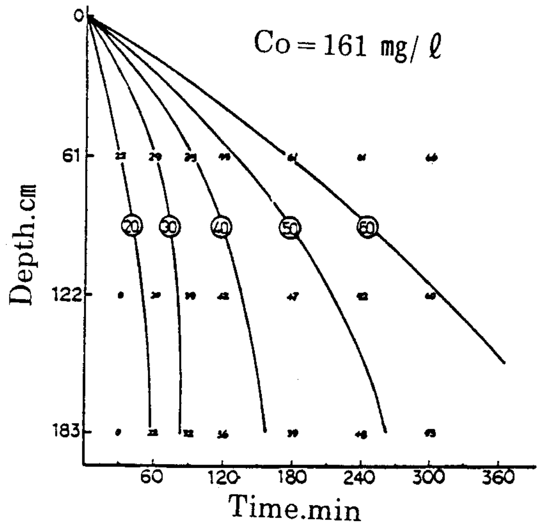

Fig.2 Settling paths of the eel pond water as measured by cylinder test.

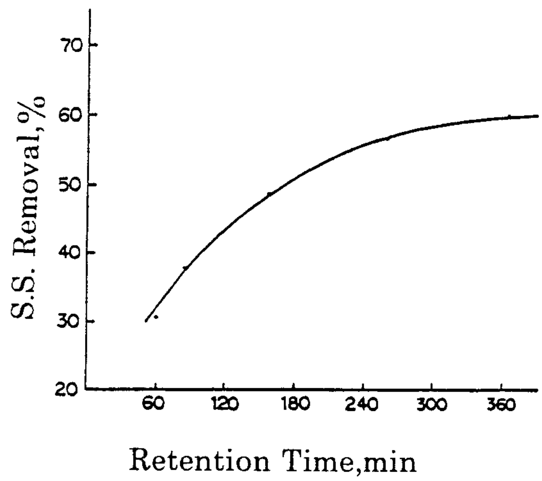

Fig.3 Relationship between suspended solid removal and retention time.

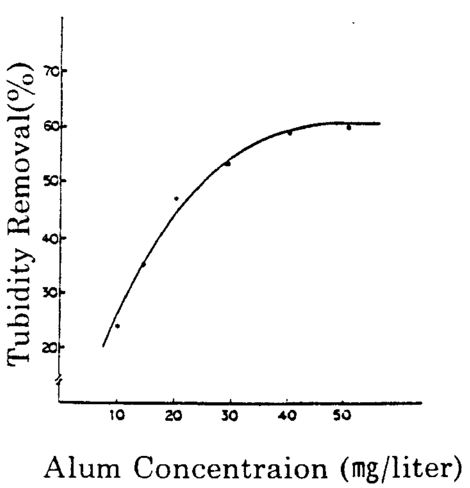

Fig.4 Effect of concentration of Aluminum Sulfate to the turbidity removal rate.

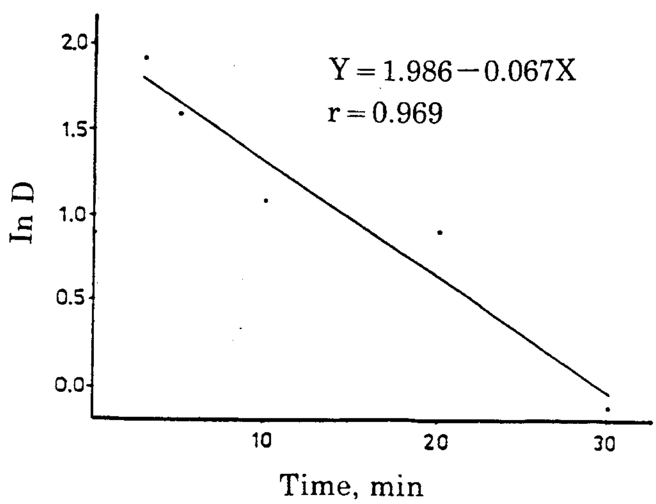

Fig.5 Relationship between aeration time and Oxygen deficit.

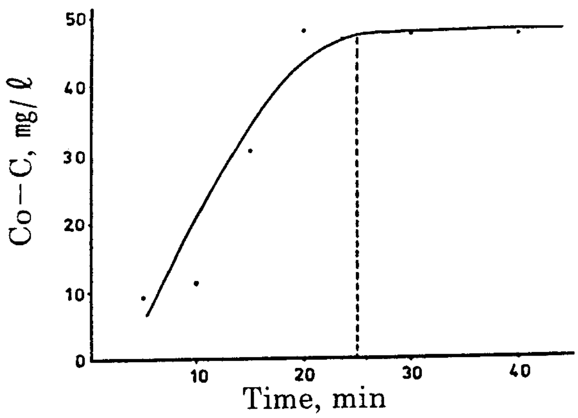

Fig.6 Equilibrium time of adsorption of active carbon.

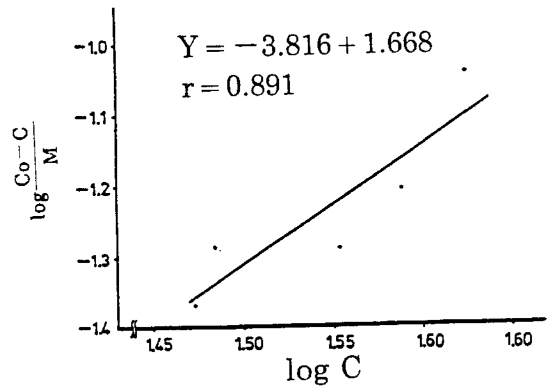

Fig.7 Freundich isothermal adsorption curve of active carbon.

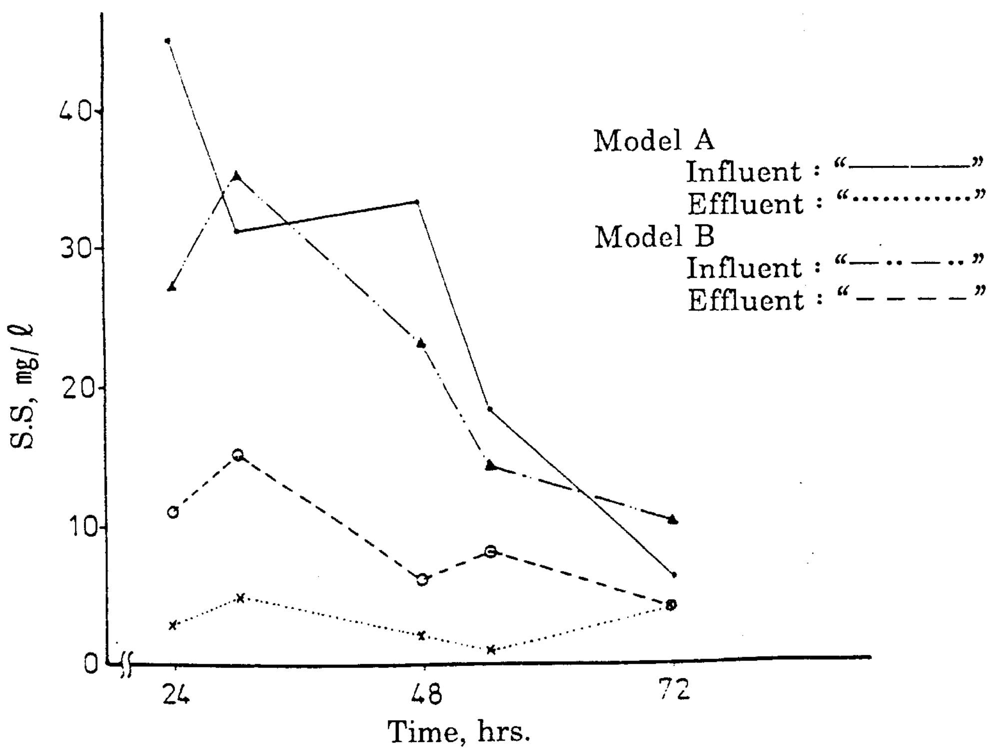

Fig.8 Change of the conceration of S.S. of influent and effluent with filtration and biofiltration.
(flow rate:63.3 mℓ/min, Original S.S.:63mg/ℓ)

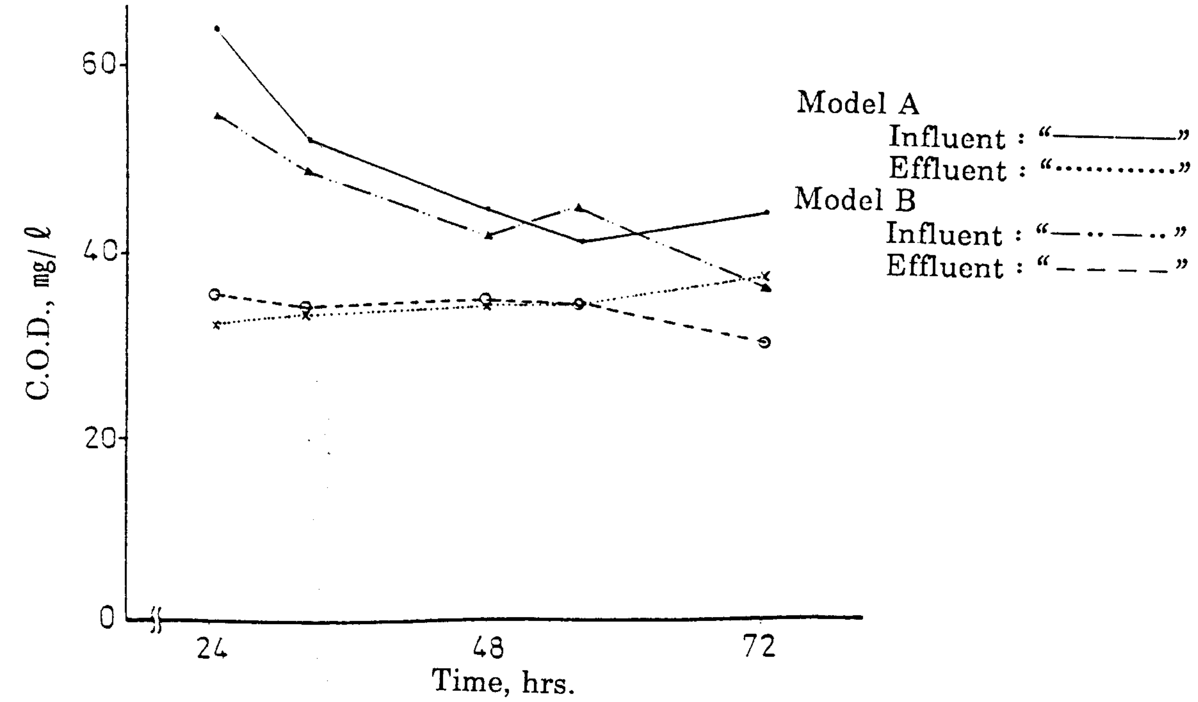

Fig.9 Change of the C.O.D. of influent and effluent with filtration and biofiltration.
(flow rate:63.3 mℓ/min, Original S.S.:50.72mg/ℓ)

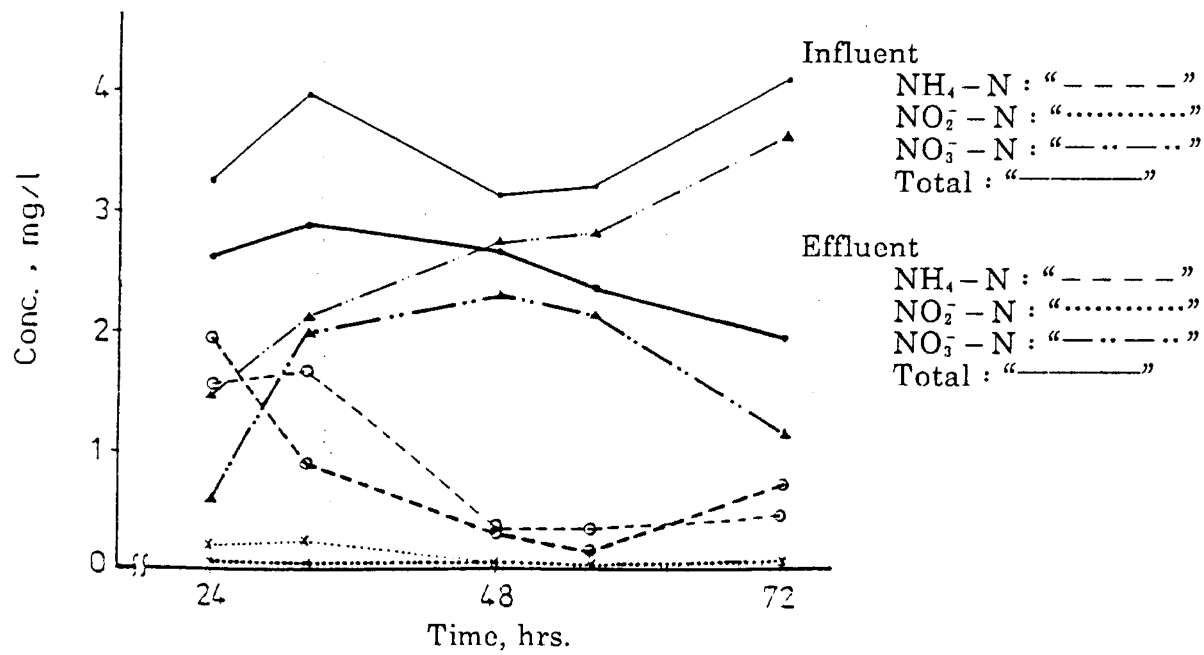

Fig.10 Change of the inorganic nitrogen of influent and effluent with filtration and biofiltration.
(flow rate:63.3 mℓ/min, Original NH_4-N:2.81mg/ℓ, NO_2-N:0.08mg/ℓ, NO_3-N:0.4mg/ℓ)

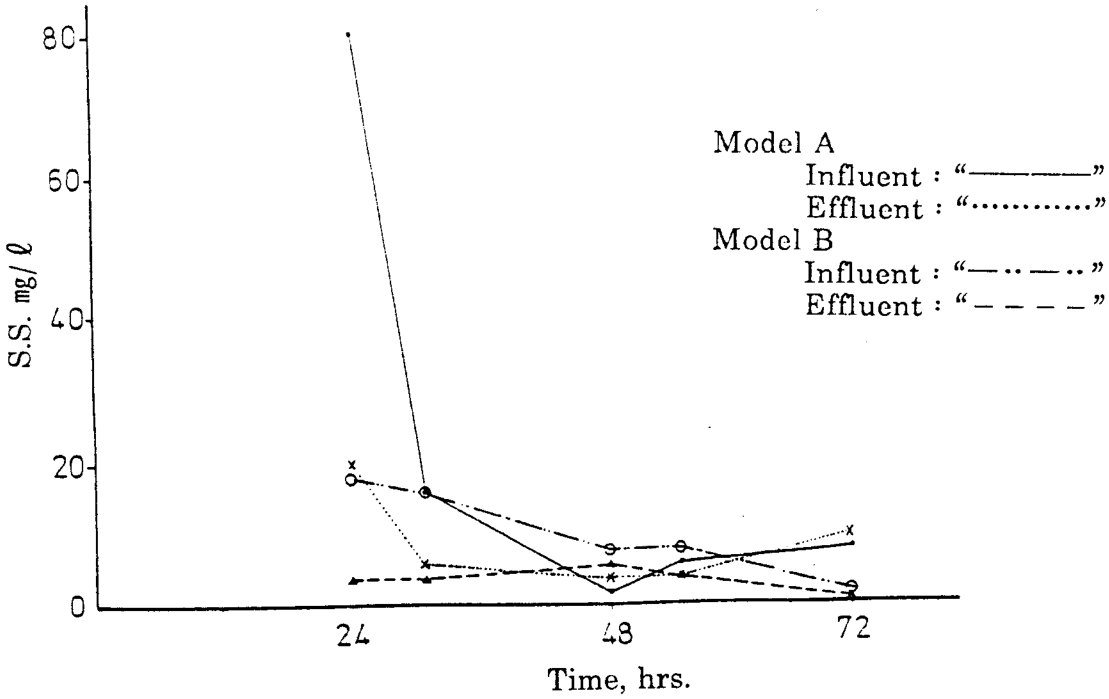

Fig.11 Change of the conceration of S.S. of influent and effluent with filtration and biofiltration.
(flow rate:189.9mℓ/min, Original S.S.:82mg/ℓ)

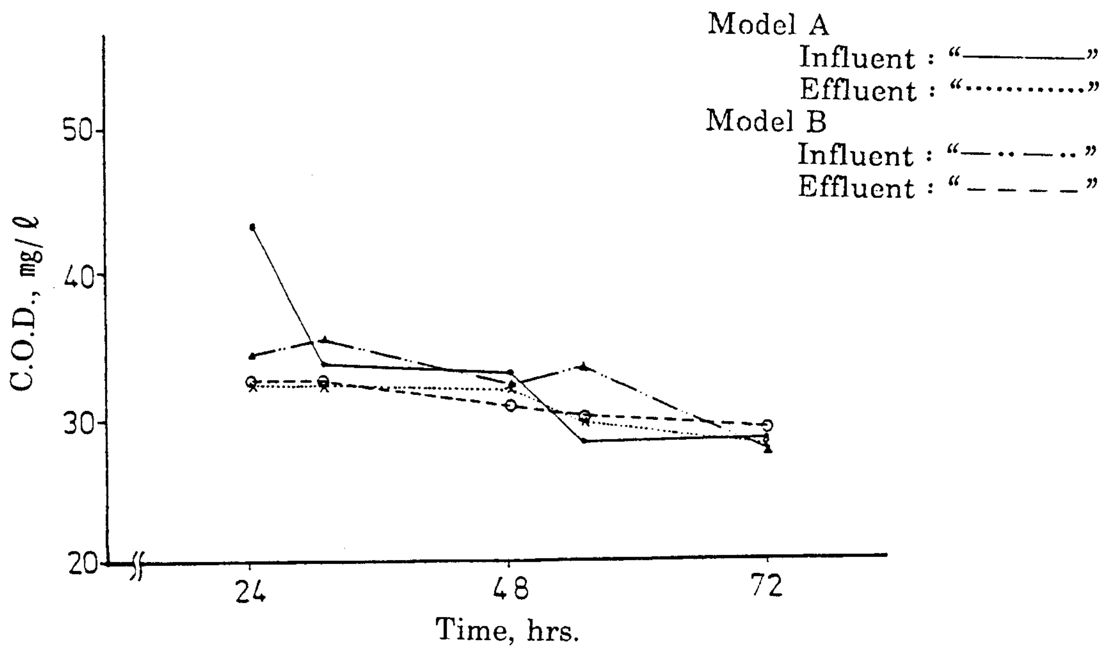

Fig.12 Change of the C.O.D. of influent and effluent with filtration and biofiltration.
(flow rate:189.9mℓ/min, Original C.O.D.:48.99mg/ℓ)

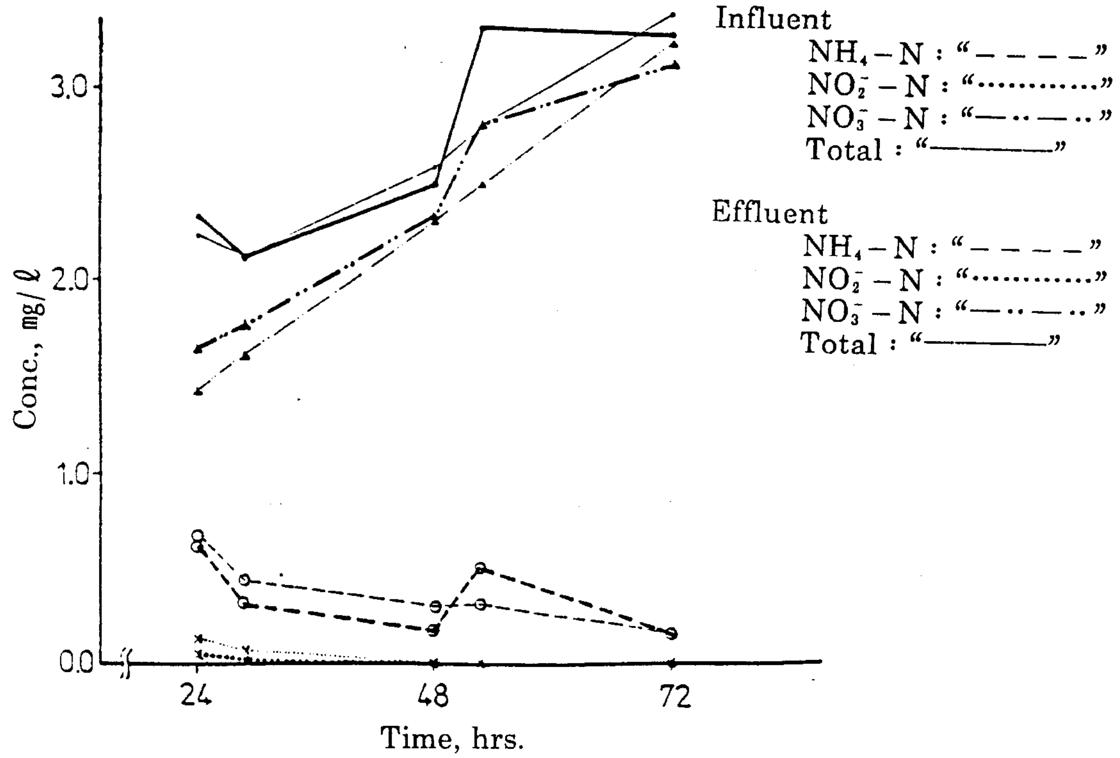

Fig.13 Change of the conceration of S.S. of influent and effluent with filtration and biofiltration.
(flow rate:189.9mℓ/min, Original NH_4-N:94mg/ℓ, NO_2-N:0.095mg/ℓ, NO_3-N:0.37 mg/ℓ)

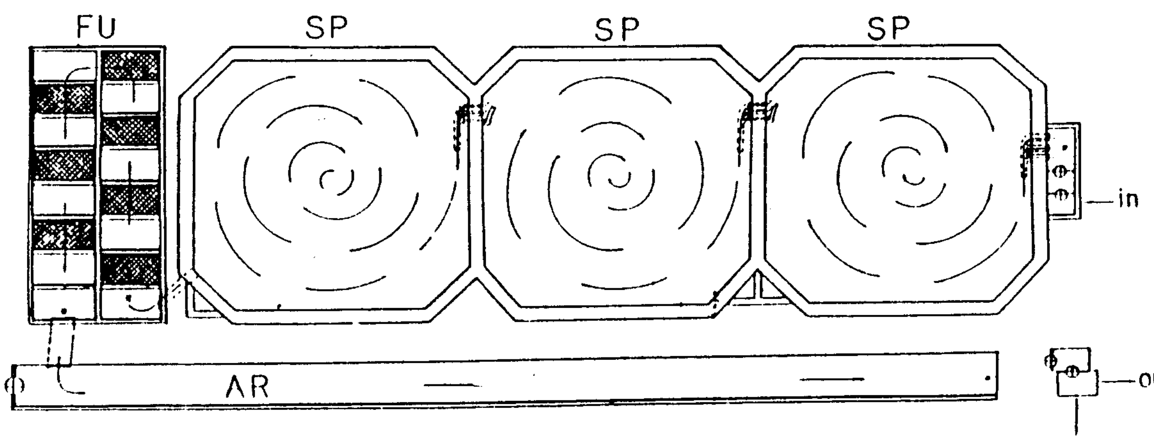

Fig.14 The wastwater treatment unit of recirculation system at Wushantou Freshwater Fish Culture Demonstration Center.

Table 3 Air stripping effect of ammonium nitrogen with different pH and aeration time

Treatment		Time，hrs					
pH	Aeration	0.0	0.5	1.0	2.0	3.0	4.0
7.6	–	2.258	2.301	2.345	2.035	2.570	2.490
7.6	+	2.258	2.709	2.037	20164	2.127	2.527
9.0	+	2.403	2.14	2.220	2.037	1.983	2.218
10.0	+	2.491	2.810	2.580	2.052	2.745	2.382
10.5	+	2.309	2.491	2.200	1.855	1.964	1.946

Table 4 Result of aeration test of aquaculture effluent

Time	DO_m	D*	ln D
min		mg / ℓ	
3	2.1	6.78	1.914
5	4.0	4.88	1.585
10	5.9	2.98	1.902
20	6.4	2.48	0.908
30	8.0	0.88	– 0.128

* $D = DO_{eq} - DO_m$，DO_{eq} : 8.88 mg / ℓ, during the experiment.

Table 5 Changes of water quality with different treatment of recirculation system at Wushantou Freshwater Fish Culture Demonstration Center (Sampling time : 10AM, 25, June, 1984)

Treatment	W.T. ℃	pH	E.C. umhos/cm	D.O.	T.S.	D.S.	S.S.	COD	NH_4^+ · N	Alk	D.S. / T.D.
				mg/ ℓ							
NO	29.0	8.60	240	7.8	264	242	22	20.6	0.12	78.0	0.92
Setting Only	30.0	8.70	240	7.9	256	238	18	32.8	0.10	75.8	0.93
Setting Filtration	30.0	8.75	240	7.8	236	214	22	19.1	0.12	76.6	0.91
Setting Filtration Aeration	30.0	8.85	240	8.3	224	194	30	18.3	0.06	76.6	0.87

Table 6 Changes of water quality with defferent treatment of recirculation system at Wushantou Freshwater Fish Culture Demonstration Center (Sampling time : 10AM, 8, Sep, 1984)

Treatment	W.T. ℃	pH	E.C. umhos/cm	D.O.	T.S.	D.S.	S.S.	COD mg / ℓ	NH_4-N	NO_2-N	Alk	D.S. / T.D.
NO	31.0	230	7.2	239	199	40	40	30.1	0.63	0.005	75.6	0.83
Settling Only	30.0	225	7.3	197	193	4	4	29.4	0.54	0.005	75.4	0.98
Settling Filtration	30.0	220	7.3	203	197	6	6	30.8	0.68	0.006	74.0	0.97
Settling Filtration Aeration	29.5	220	7.8	215	191	24	24	30.9	0.50	0.005	74.2	0.89

過濾池對固形物去除上有效,但不是很好;經曝氣水路後對溶氧之增加有效,另對氨態氮之去除則效果不佳。

結論與建議

本省鰻魚養殖戶流水式養殖之管理習慣,係採用很低的魚水比(1:397~1:1100),若魚與水之比例提高,則不冒然嘗試,寧可增加用水以利水質管理,建議推廣節省用水之觀念方能使養殖戶逐漸接受循環利用水資源之技術。

由現場水質分析與實驗室試驗結果顯示,就處理效果而言,養殖水之處理重點以生物處理法較有發展潛力,物理及化學處理則可作為輔助之用。

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THE TREATMENT AND REUSE OF AQUACULTURAL WASTEWATER

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ABSTRACT

The treatment and reuse of aquacultural wastewater have been extensively studied to reduce water requirement of aquacultural ponds. The essential characteristics of wastewater are investigated in eel and shrimp ponds. The effectiveness of some simple methods for improving the wastewater quality was carried out in the laboratory. A pilot water recirculation system in Wushantou Freshwater Fish Culture Demonstration Center (WFFCDC) of Taiwan Fisheries Bureau was also evaluated.

The main limiting factors in eel culture wastewater were low concentration of dissolved oxygen at dawn, accumulation of debris and toxic nitrogen compounds, while in the shrimp ponds were the harmful H_2S gas and low concentration of dissolved oxygen.

The settling experiment shows that organic suspended solid was not easy to settle in aquacultural wastewater. The effectiveness of ammonia stripping was not significant, even pH value of aquacultural wastewater was increased up to 10.5. The transfer coefficient of aquacultural wastewater, Kd, was measured to be 0.0671 from the aeration experiment. The equilibrium time for activate carbon adsorption is 25 minutes.

The results of the pilot experiment show that most of suspended solids in pond water could be removed in the settling pond and gravel filter unit. Dissolved oxygen concentration was significantly increased after passing through an aeration raceway. Biological carbon oxidation and nitrification should be improved and further incorporated in this system.