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Particle Removal Evaluation with Bubble Column on Eel Breeding Circulation System

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ABSTRACT

This paper applies for the parameters in the bubble column experiment along with two other indices, particle concentration and particle size distribution to find out the removal efficiency of different particle size so as to confer which is the best parameter. We use the super intensive circulation system with a bubble column behind the removal facility in medium size on the pond. We can conclude that the water and air infusion has great impact on removal efficiency. When controlled the two parameters, water infusion: 4.23 L /min and air infusion; 15 L/min., the removal efficiency is about 35% and water detention time is 328 seconds. If particle scope is between 131 and 600 μm, we had better make water infusion remain under 13 L/min while that is smaller than 131 μm, water infusion under 5 L/min. In both of air infusion remain above 7 L/min. Besides, we suggest that it would be better apply for the mass transfer coefficiency, K_{T2}, between 0.015 and 0.08. If putting removal system in series connection, then the remaining particles will be eliminated once again; as a result, the overall removal efficiency enhances.

Key words: *Particle Removal Efficiency, Size Distribution, Bubble Separation Method, Bubble Column, Breeding Circulation System.*

INTRODUCTION

The most important function of a breeding circulation system includes the particles as well as ammonia and nitrogen removal, the increase of oxygen in water and pH adjustment as well. Particle removal is the main step affecting the circulation cultural system management efficiency. The particle size in the pond varies from under 1 μm to above 100 μm, and only the latter will be in sediments. We use the bubble separation method, a bubble column behind the removal facility in medium size removing small particles. The benefit is that we have no problems in changing or backwashing filter instruments. Besides, by this natural management, there will be no chemicals added in so that nothing will change the water. Finally, there will be greater oxygen in water resulting in infusing amounts of air into the water. Hence, all we've mentioned above will be beneficial to the follow-ups in the biological filter slot. Furthermore, the instruments for this bubble column are easy to gain as well as cheap to design. This paper is mainly discussing the bubble separation method in order to design a bubble column with removal system in medium size built in breeding ponds. We focus on the removal efficiency to figure out the relationship among size distribution and concentration, the water and air infusion detention time as well as sizes among bubbles so as to confer the best parameter. In the future, we can apply this system to different water systems within various biological species including the eel breeding circulation

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system.

THEORETICAL MODEL

A. Bubble Separation Method

Bubble Separation Method is available for small particle removal and circulation system setup. Clark and Wilson (1983) stated that in infusing the air into the bubble column by the air compressor, there will be an interface between air and water. Through this interface, particles will turn into bubbles and be eliminated. Chen (1991) pointed out that there are three types of particle forms, air, liquid and solid on the process of this bubble separation method. Particles can be divided into two- pole and non-pole particles. Pole particles will be absorbed by the bubble charge, then this particle with charge turns into hydrophobic pattern and remain in the interface of the bubble and water. In conclusion, there is an interface between the bubble and water because of bubbles, there will be a combination of bubbles, pole particles and hydrophobic particles forming process in the pond.

B. Removal Efficiency of Bubble Separation Method

Marukawa Einan (1992) discovered that by applying for the intermittent method at the beginning stage, 38% of large particles (>17 μ m) were efficiently removed while 38% of medium ones in the form of particles (5 μ m~17 μ m) were slowly removed. Finally, 24% of micro particles (< 5 μm) remain as they were.

Chen (1992) discovered that by applying for this intermittent bubble separation method, the particle concentration declined from 4.1×10^6 (count/l) to 2.1×10^6 (count/l), in which the bubble concentration is 55.2 $\times 10^6$ (count/l). As to apply for the series method to the pond, no specific data presently exits.

C. Parameters and Factors of Bubble Separation Method

Lawson (1978) pointed out that the following factors have great impact on the efficiency of bubble separation method: flow, size of bubble column and exposure. The following year, Spoutte (1979) pointed out two other factors, the time that bubbles touch water and bubble size. Chen (1991) pointed out that the bubble size is the main factor which decides the ratio between air square and volume as well as the flow way of bubbles. Kumar (1970), Kuloor (1970) and Axbel (1981) pointed out that when in a typical bubble generation system, the following factors have certain impact on bubble size, that is, air velocity, bubble hole size and liquid surface strength. Combine with the above research, Chen (1992) concluded the following statements:

a. Bubble size enlarges when air velocity speeds up.
b. Bubble size shrinks when the concentration of white stuff increases.
c. When bubble hole size is larger, the bubble size is bigger. However, when air velocity speeds up, there is little impact.
d. When the diameters of most bubbles (90%) in the bubble swarm are between 0.5 and 3.0 mm, we can regard the bubbles as in regular size.

EXPERIMENT INFERENCES

A. Assumption:

a. Time has nothing to do with particles concentration and size distribution on the process of experiment.
b. Particle diameter is Stokes diameter, which means the diameter of a ball with same volume.
c. Particle density is fixed.
d. No interactive action among particles.
e. Particles and bubbles motion with a terminal velocity.
f. Laminar flow inside the bubble column is considered.
g. The adsorption coefficient of bubbles for particle is constant.

B. Parameters in experiment:

a. Original water concentration (C_o, ppm): The particle concentration to be tested.

b. Water infusion velocity (U_u, m/s): The infusion velocity to be tested = Q_w/A. Q_w is water volume (liter/min) and A is the bubble column cross-section area (m^2).
c. Air infusion velocity (U_g, m/s): The infusion velocity to be tested = Q_g/A. Q_g is air volume (liter/min).
d. Bubble terminal velocity (U_∞, m/s).
e. Bubble diameter (r_b, μm): The average diameter when bubbles comes into column via separation plates.
f. Particle diameter (r_p, μm): The middle (50% distribution) size of particles.
g. Ratio of increased water level by gas holdup: ϵ_g, dimensionless, $\epsilon_g=(Z - Z_o)/Z$. Z is the water height when infusing air in the column (m). Z_o is the water height without infusing (m).
h. Particle removal constant in overall liquid-phase mass transfer coefficient (K_{T2}, μm/s)

C. Specific Parameters on the process of management :

Two focus on the physical properties of particles, as follows:

a. The total particle concentration change (ppm) before and after treatment.
b. The size water distribution change (count/l) before and after treatment.

D. The formula of particle removal efficiency:

Base on the general change on particles:

$$V^* dCi/dt= Q^*C-Q^*Ci \text{ --------------(1)}$$

V is bubble column volume (cm^3), Q is water flow (m^3/s),
C is original particle concentration, Ci is the particle concentration after testing for t time (mg/l).

$$dCi/dt=(Q/V)^*(C-Ci) = Q/V^* \Delta C =(1/\tau)^* \Delta C \text{ ------------------(2)}$$

τ is water detention time (min).

$$\Delta Ci/ \Delta t=(1/\tau)^* \Delta C \text{ ----------------(3)}$$

Take $\Delta t = \tau$ and $Ci = \Phi C$, and Φ is the removal rate coefficient for particle.

$$\Delta C=C- \Phi ^*C \text{ ------------------------(4)}$$
$$\Delta C/C=1- \Phi$$

Chen (1991) presented efficiency parameters as follows:

$$\Phi =K_{T2}{}^*Ug * r_p/(r_b{}^{2*}(1- \epsilon g)^*U\infty) \text{ --(5)}$$

By above formula, we can calculate the removal efficiency.

$$\Delta C/C = 1-KT_2{}^*Ug^*r_p/ (r_b{}^{2*}(1- \epsilon g)^*U\infty) \text{ ---------(6)}$$

E. Sensitivity and Error Analysis:

This paper discusses two parameters that have impact on removal efficiency: water infusion and air infusion. According to the sensitivity analysis pointed out by Beck (1983), we have made some experiments.

$$S = (\Delta E/E)/ (\Delta I/I);$$

S is sensitivity coefficient, E is removal efficiency, I is changing parameter, including water infusion and air infusion.

INSTRUMENTS AND METHODS

A. Instruments

a. Bubble Column: See Fig. 1. Composed of air compressor, bubble collector, motor, and water control valve, see Fig. 2.
b. GS-25, Φ 47 mm filter paper made in Toyo Ltd., Japan: filter and measure water samples.
c. Photographer and camera: Record the size of bubbles and particles as well as the interaction.
d. Laser Sizer Meter (Model Mastersizer, Marlvern Ltd., England): Measure the size distribution before and after treatment samples. Size scope is set 0.50 μm.
e. Motor: Offer bubble in the bubble

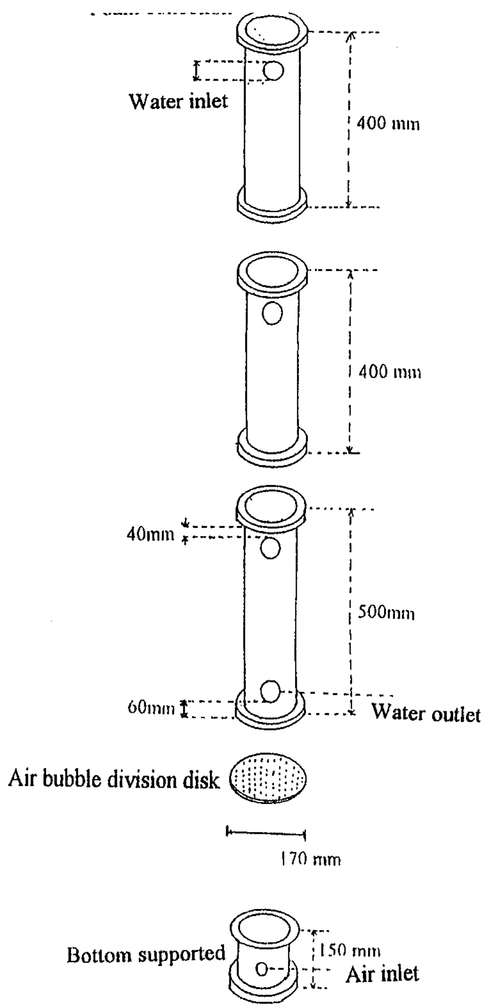


Fig. 1. Schematic presentation of the Bubble column design.

column and circulating power in water.

f. Water Flow Meter: Measure the water infusion. Omega Ltd. Model FP 7020, measurable scope from 1 l/min to 100 l /min.
g. Air Flow Meter: Measure air infusion. Australia Ltd. Model Lw-25., measurable scope from 1 l/min to 150 l/min.
h. Air Bubble Division Disk: 16 cm diameter thick 1 mm, polyethylene plate, the minimum hold up is set 1.8%.

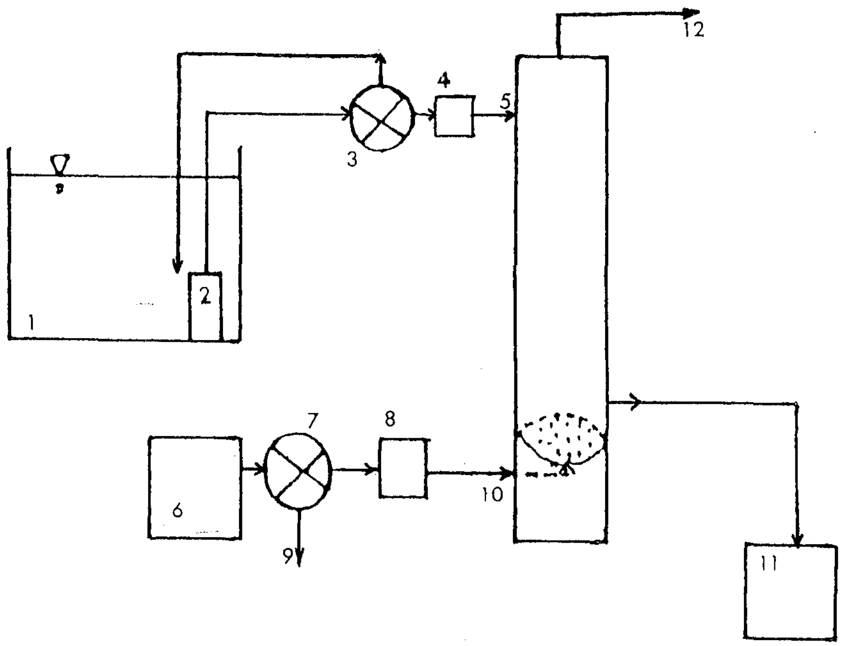
B. Methods:

a. Set up a intensive eel cultural circulation system behind a mechanic roller filter to pump filtered water for the original sample, and take into the bubble column. The system is set in Chungli and shown in Table 1 and Fig. 2, water circulation rate is 27 times per day.

Table 1. The management condition in intensive eel culture system

system water volume	210 ton
input water volume per day	21 ton
total culture fish	4×10^5 accounts about 10 accounts/k
feeding times per day	4 times
recycle equipment	mechanic filter → bio filter tank → UV → intensive DO aerator

b. Compared with the particle concentration and size counting of the sample before and after treatment to calculate the efficiency and changes. The measurement and data analysis process is shown in Fig. 3.
c. Adjust the strength of air compressor, and change the air velocity to figure out the relative curve between bubble suspending time and removal efficiency. Infusion is from 1 l/min to 15 l/ min., including 4, 5, 7, 10 l/min. six designs in total.
d. Adjust the strength of motor, and change the water velocity to find out the relative curve between bubble detention time and removal efficiency. Infusion is from 3.84 l/min to 38.4 l/ min., including 4.23, 7.7, 13.1, 19.2 l/ min six designs in total.
e. Base on the water and air infusion quantity and two experiments, including intermittent experiment and series experiment, there are 11 combinations of conditions, shown in Table 2.
f. Keep adjusting water and air infusion, as well as search the best parameter based on the removal and economy efficiency.
g. Take the results of c. and d. to gain the relationship between removal effi-



1. treatness water tank
2. pump
3. controller valve
4. water flow meter
5. water inlet
6. compressor
7. controller valve
8. air flow meter
9. air regulation pipe
10. air inlet
11. treatment water tank
12. foam collection pipe

Fig. 2. Process of flow design.

Table. 2. The designed water and air flow rate in continuous process.

Condition No.	Water flow (L/min)	Air flow (L/min)
1	15	38.4
2	1	38.4
3	15	4.3
4	7	4.3
5	4	7.7
6	4	13.1
7	4	19.2
8	7	19.2
9	10	4.3
10	5	4.3
11	4	4.3

ciency and Φ parameter, so as to figure out the mass transfer coefficient, K_{T2}.

h. Process the sensitivity and error analysis.

RESULTS

A. Outcome

a. The analysis of water quality divided into two: particle weight in total and particle size counting. The weight in total is between 6.1~9.4 ppm after filtering by cartridge filter following 11 experiments.

b. After cartridge filtering, the average concentration of particles is about 7ppm, and size counting is about 200 μ m. There is no abrupt change. In conclusion, there is only slight difference on concentration, so the original concentration is regarded as a constant.

c. According to the figure of size counting, particles are gathered at the figure of 200 μm. It means that the cartridge filter with 80 μm is not capable of eliminating particles larger 80 μm.

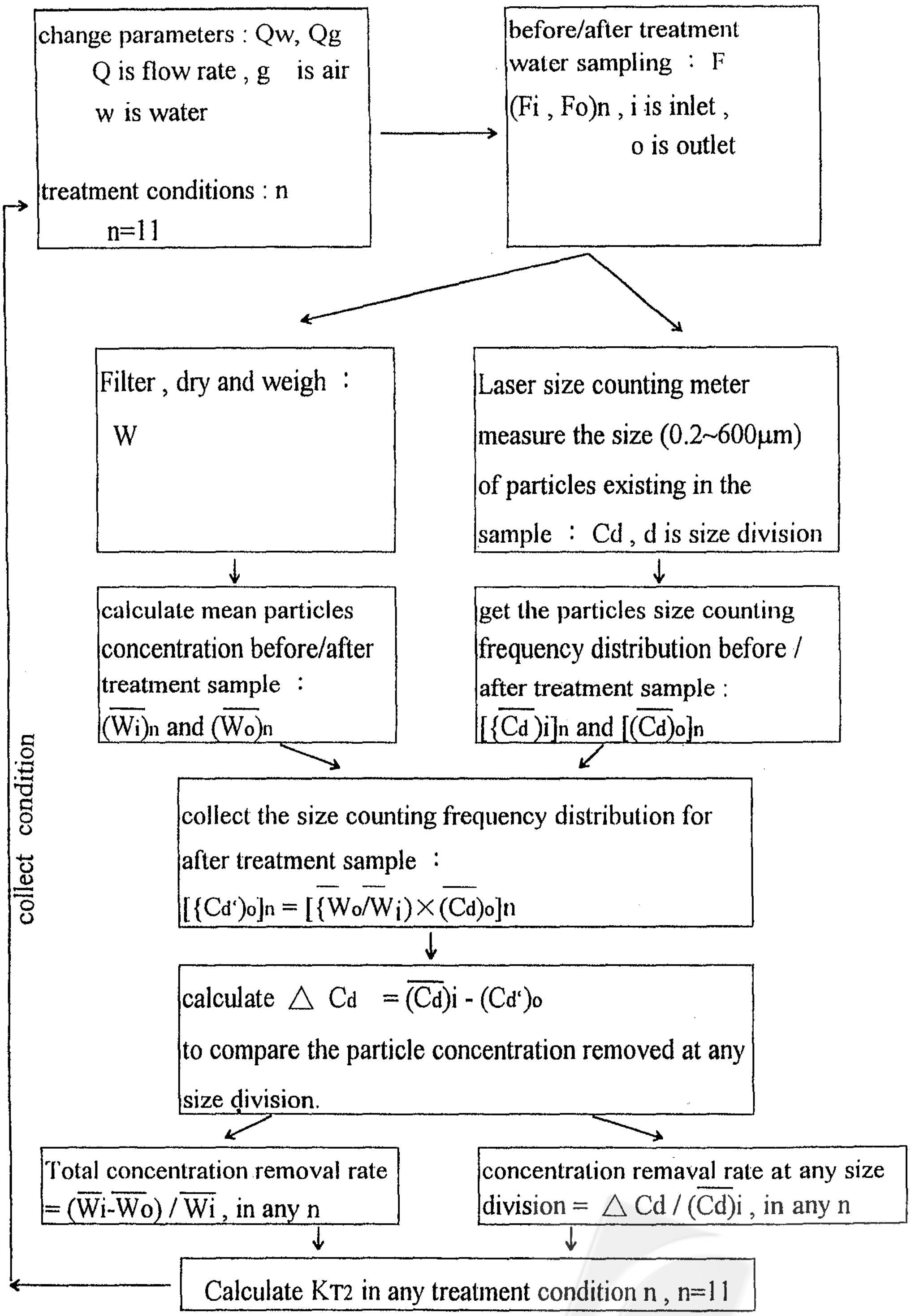


Fig. 3. Data analysis process for particle size distribution remove.

B. Series Experiment

a. Now that particles are generated continuously, it's necessary to be cleared outright away for saving the space, Intermittent Experiment is not available in this system.

b. When water infusion is the most, removal efficiency is low as a result of lacking of sufficient suspending time. Hence, the water detention time is the main factor for the removal efficiency. Likewise, as air infusion is the least, removal efficiency is low as a result of too little interface.

c. Fig. 4 to Fig. 6 show an example that as air infusion is the most and the water detention time is longest, the size eliminated particles is over 223 μm. The main transmitted mechanics is promoted by the bubble upward strength. When water infusion lowers, the eliminated particles' size are between 30~123 μm. The main transmitted mechanics is promoted by the bubble sucking force.

d. See Table. 2, compared Experiment 3 (air infusion = 15 L/min., water infusion = 4.2 L/min. water detention time = 328 sec.) with Experiment 6 (air infusion = 4 L/min., water infusion = 13.1 L/min water detention time = 105 sec.), though both of them with same removal efficiency, 34.8%, with a combination of various parameters, Experiment 3 eliminated small-medium particles (size smaller than 100 μm) while Experiment 6 eliminated large-medium particles (size larger than 180 μm). Therefore, with same efficiency, particles can be eliminated through a combination of various parameters. From Fig. 6, we can figure out the specific removal efficiency and size counting should be under a certain condition.

e. Fig. 6 shows that particles with various size can be eliminated through a combination of several parameters under same removal efficiency in general.

f. Fig. 8 shows that when air infusion increases, the surface square of bubbles increases resulting in increasing removal efficiency. In conclusion, the removal efficiency and air infusion are in direct proportion. The slope is most obvious when air infusion is below 7 L/min. We had better control the air infusion over 7 L/min.

g. Fig. 7 shows that when water infusion increases as well as water suspending time declines, bubbles get sufficient time to suck in particles resulting in declining bubble concentration even the overall removal efficiency. Hence to well control a certain water detention time is to maintain the certain

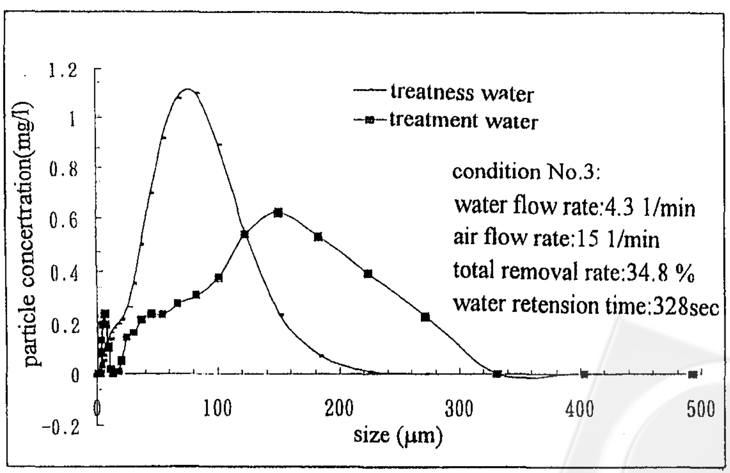


Fig. 4. The curve of particle size concentration distribution.

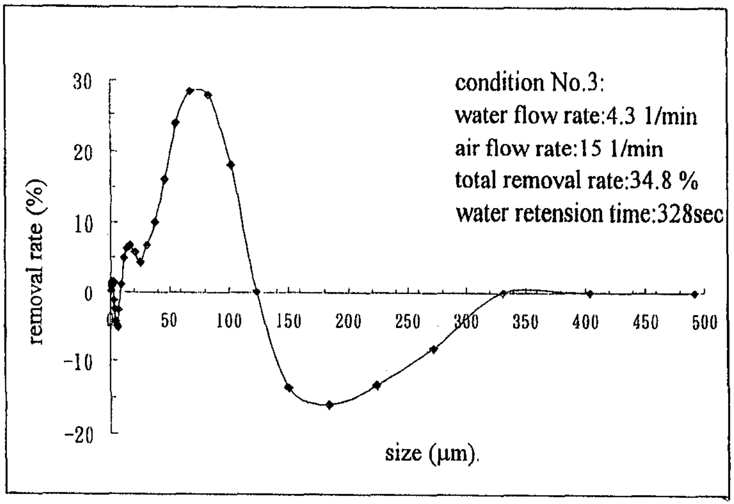


Fig. 5. The removal rate at any particle size division.

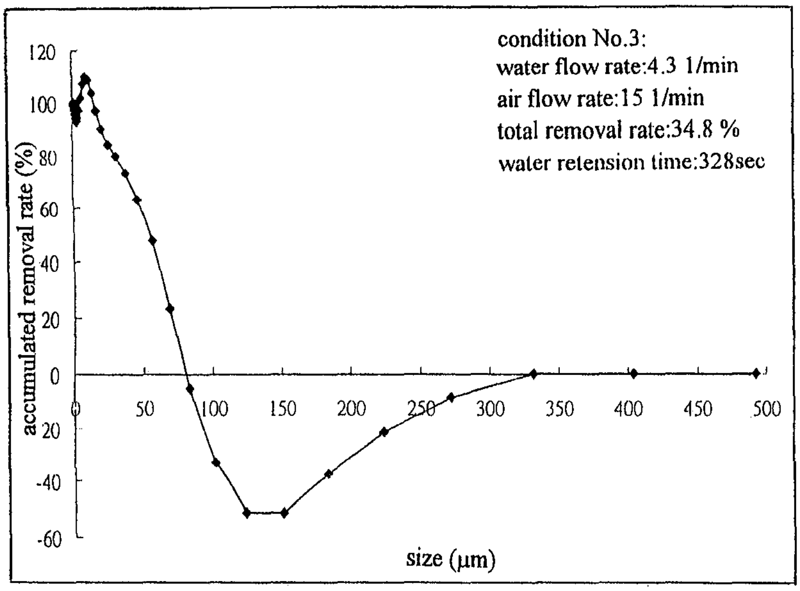


Fig. 6. The accumulated removal rates of particle size distribution.

removal efficiency. When infusion is over 15 L/min, the removal efficiency has great decline.

DISCUSSION

According to several series experiments with various parameters, K_{T2} is between $1.23 \times 10^{-3} \sim 1.14 \times 10^{-1}$, the curve with equalvent value, see Fig. 9. The bubble velocity, Ug is the main parameter that has great impact on K_{T2}. When calculating the removal efficiency, various bubble velocity should be changed with different K_{T2}. Fig. 7 and Fig. 8 show that when a certain removal efficiency is calculated, we can figure out the water infusion as well as air infusion. It is available in the real pond. If particles size are smaller then 131 μm, air infusion should be controlled over 7 L/min., and water infusion below 5 L /min. If particles are between 131 and 600

μm, air infusion should be controlled above 7 L/min and water infusion under 13 L/min. K_{T2} should be between 0.015 and 0.08. When water infusion at 4.2 L/min, water suspending time at 328 sec and air infusion at 15 L/min. that are best parameters of this bubble column system will result in removal efficiency at 35%. To enhance overall removal efficiency, connect several bubble column systems in series so as to eliminate remaining particles once again even increase the oxygen in the water.

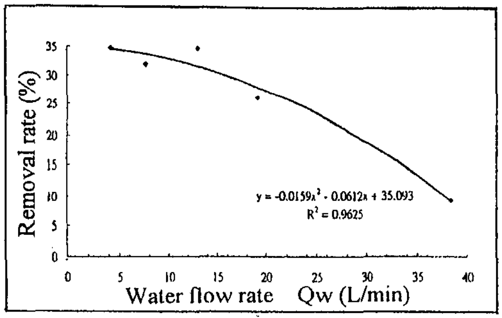


Fig. 7. Removal rate vs. water flow rates.

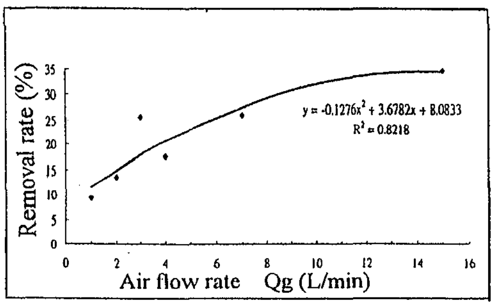


Fig. 8. Removal rate vs. air flow rates.

The result of sensitivity and error analysis, Table 3 shows that changing air infusion has greater impact on removal efficiency than water infusion. When increasing air infusion, removal efficiency increases while increasing water infusion, removal efficiency declines. The more water infusion, the greater impact on removal efficiency; the less water infusion, the less impact on removal efficiency. Although we have done some adjustment on the instruments ahead experiments,

Table. 3. The results of response analysis at parameter changes.

	air flow rate Qg		water flow rate Qw	
Δ I/I	+14.3%	-14.3%	+33.3%	-33.3%
E (%)	24	31	23	34
Δ E (%)	4	-3	-9	2
Δ E/E	0.125	-0.094	-0.321	0.071
S	0.874	0.657	-0.946	-0.213

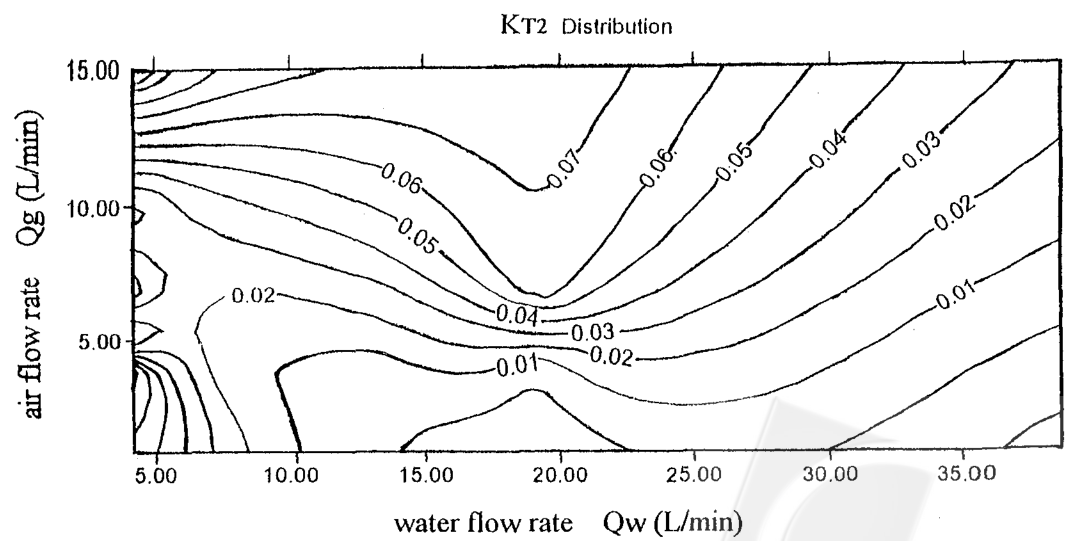


Fig. 9. K_{T2} equable curve relationship vs. water and air flow rate.

there is still ± 3% tolerance of accuracy allowed from flow meter.

In combination of weight change and size counting as well as parameters, we can calculate the removal efficiency in different size scope. Focus on the particles with various sizes and the removal rates, we can find out that different air infusion, water detention time as well as plate hole size are available in various breeding ponds.

This pond we choose which are 27 times of water circulation per day resulting in large particles turning into small ones. If we decrease the circulation times, not only the save the cost but also decrease the number of small particles, which the burden of latter process will be lowered. We have several experiments based on count size, height, and plate hole size on this research. In the future, we can focus on various size, height and plate hole size along with sensitivity analysis to figure out the best parameter suitable for the breeding pond.

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應用氣泡柱於循環水養鰻系統中去除顆粒之效率評估

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本文應用氣泡柱操作參數因子，結合顆粒重量與顆粒粒徑分佈等兩種實測資料，求出不同粒徑範圍的去除效率，針對不同粒徑大小的懸浮性顆粒與要求的去除效率，推導出最佳操作因子，以利於養殖現場操作。實驗場地選擇一超集約式循環水養鰻系統，將氣泡柱架設於中大型顆粒去除設備之後，由實驗可得知：當入水流量增加或入氣流量降低時，顆粒去除效率隨之降低。且由靈敏度分析得知入氣量變化對處理效率影響較大。目前此組氣泡柱設備在控制操作參數下，最佳的操作參數為入水流量4.23升／分，入氣流量15升／分時，其最佳的顆粒處理效率約為35%，水力停留時間為328秒。當處理目標顆粒範圍為131至600 μm之間時，水流量應控制在13升／分以下，當處理目標顆粒範圍為131 μm以下時，水流量控制在5升／分以下較容易去除。此兩種狀況的氣流量均應控制在7升／分以上較容易去除。建議設計用物質傳遞係數K_{T2}為0.015至0.08間。若考慮串聯幾組氣泡柱處理設備，則可將未去除的殘餘顆粒做多次處理，以提高整體去除效率。

關鍵詞：顆粒去除效率，粒度分布，泡沫分離法，氣泡柱，循環水養殖系統。

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