Water Quality Control in the Semiclosed Culture System Growing a Flounder, *Paralichthys Olivaceus*

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A comparative evaluation of water quality in the existing semiclosed fish culture system was made to improve the system management. From the comparison of water quality between the flow-through mode and the recycle mode of the semiclosed system, the malfunctioning of the settling channel deteriorated water quality and reduce the nitrification rate in the recycle mode. The peak concentrations of COD, PO_4-P and SS in the fish tanks appeared just after feeding, and then decreased to normal levels within two hours. However, the NH_4-N concentration increased slightly after two hours of feeding in the recycle mode. The water exchange rate was directly related to the water quality in the semiclosed fish culture system.

Introduction

The water quality in an aquaculture system is directly related to productivity of the fish. Particularly, residues after feeding and fecal organic matters become major sources that deteriorate water quality in the system, Now a semiclosed system is commonly used especially for flounder culture in Korea, because it has the merits of the controlled application of feed and programed water quality monitoring, temperature control, disease prevention and therapeutic treatment compared to a natural culture system like a cage culture system.

The semiclosed cultrue system can be classified into two types according to its operation mode. The first one is the flow-through mode in which sea water is pumped into tanks, used for rearing and discharged into the sea. The other is the water recycling mode. In which, the certain portion of the effluent from fish tanks is treated in the water treatment units and then returned to the fish tanks for reuse. Therefore, the water quality control in the semiclosed system can be achieved by water treatment and water exchange.

The comparative evaluation of water quality in the both systems has not been made in Korea particularly for the flounder culture. It is interesting to know whether there are differences in both systems in term of efficiency of water quality control. The scientific data on the design of these system is not available. Thus, fish farmers have designed and operated the system based on their experiences without scientific background in terms of the cost-effective and water quality control.

The objectives of the present study are to evaluate the water quality in an existing semiclosed system and to suggest countermeasures for the improvement of the system.

Materials and Methods

For the present study, one aquaculture system was chosen to compare the water quality between in both flow-through and recycle modes. The overall layout of the system is shown in Fig. 1.

In the flow-through mode, the fish tank volume was 44.8 m^3 and influent flow was 76.3 m^3/day. Thus hydraulic retention time (HRT) became 14.1 hours that is equivalent to 1.7 cycles/day of the water exchange rate.

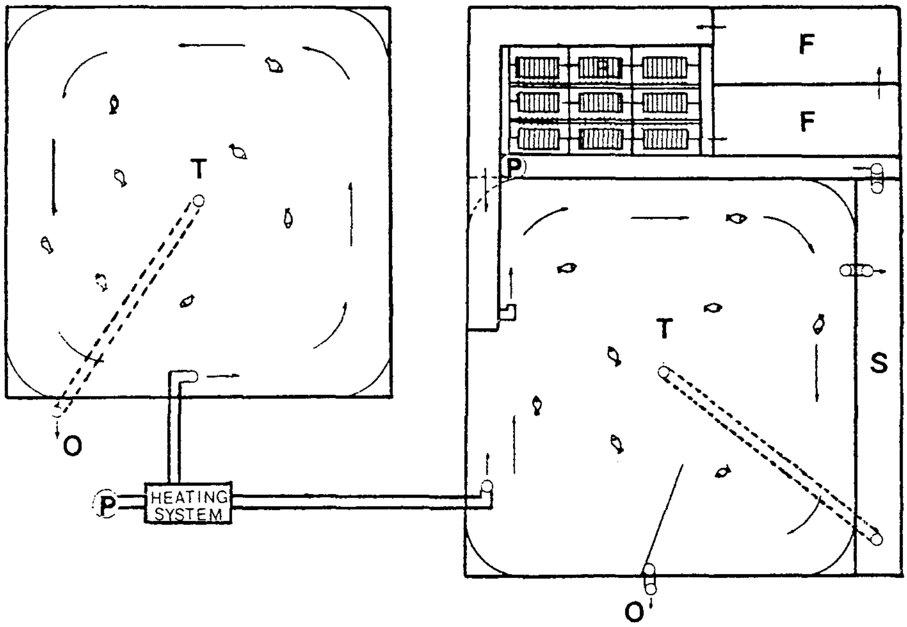

Fig. 1. The overall layout of aquacultural system(T: Fish tank; P: Pump; S: Settling channel; F: Submerged filter unit; R: RBC unit; O: Outlet.)

The system of the recycle mode consists of a fish tank, a settling channel, a rotating biological contactor (RBC) and a submerged filter unit. The squared fish tank had an effective volume of 44.8 m^3. The RBC consists of the corrugated circular plates having total surface area of 1,215 m^2. The rectangular corrugated plates having nearly equal amount of surface were placed in the submerged filter unit. Total effective volume of the system except the fish tank was 11.2 m^3. The influent flow rate was 93 m^3/day. The HRT of the system was 14.5 hours which is 1.66 cycles/day of the overall water exchange rate. The recycling flow rate from the fish tank to the water treatment unit was 2,232 m^3/day. Therefore, the hydraulic surface loading on the RBC and the submerged filter unit was 1.83 $m^3/m^2 \cdot$ day in both cases. About 2,500 flounders having mean weight of 450 *g* were growing in the both systems, and fishes were fed with the moist pellets made of the mixture of raw fish (70%) and dry feed (30%) twice a day at 7: 00 and 16: 00. Sea water heated to 15℃ was pumped into the fish tank during the present study.

Samples for water quality evaluation at the flow-through mode were taken at the inlet and outlet. At the recycle mode, samples were taken at the influent and the effluent of the fish tank and the water treatment units. Samples were taken with one hour interval for 7 hours from 11: 00 to 18: 00, and analyzed according to the standard method (APHA, AWWA and WPCF, 1989). The water quality parameters examined were COD, SS, PO_4-P, NH_4-N, NO_2-N and NO_3-N.

Results and Discussions

Water quality in the flow-through mode

The variation of the major water quality parameters are shown in Fig. 2. In the influent the mean csconcentrations of COD, suspended solids (SS), PO_4-P and total inorganic nitrogen (TIN) were 1.06, 0.96, 0.03 and 0.05 *mg/l*, respectively, most of which are slightly higher than the ranges(1.0, 10.0, 0.007 and 0.05 *mg/l*) of the sea water quality standard for marine life cultivation in Korea(Ministry of Environment, 1992).

The COD concentration in the fish tank ranged

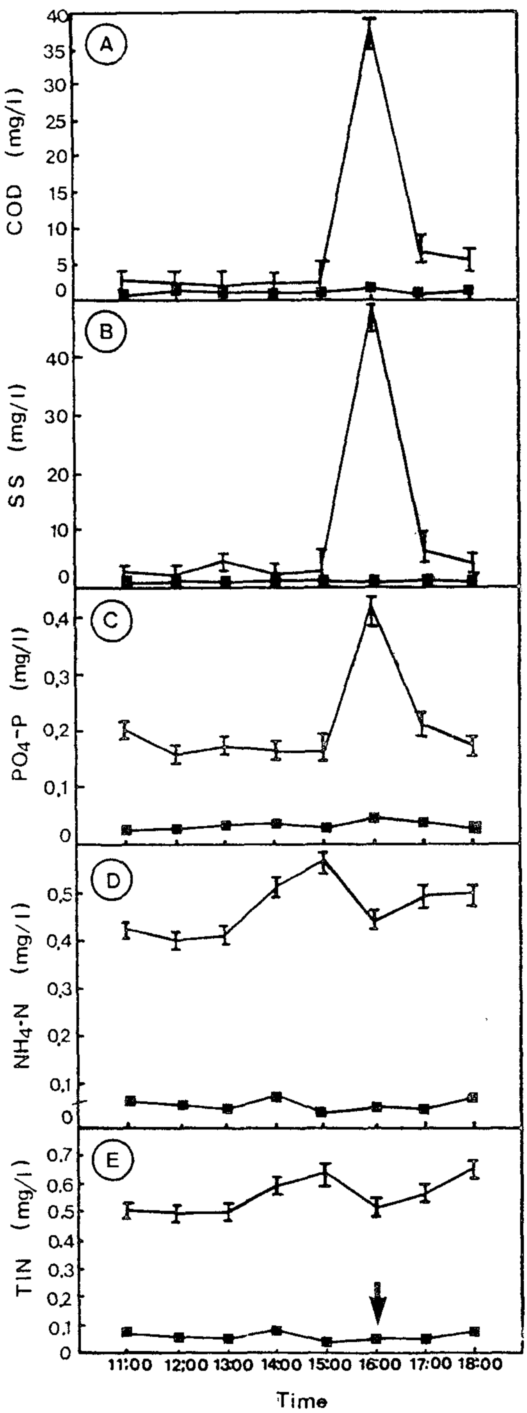

Fig. 2. Variation of major water quality parameters with time in the flow-through mode.(■: the influent; I: the effluent; → feeding time).

from 1.9 to 2.6 *mg/l* before feeding as shown in Fig. 2(A). Although 38 *mg/l* of COD was detected during the feeding period, it decreased to 7 *mg/l* about one hour later and seemed to gradually decrease to normal COD level of 1.9~2.6 *mg/l* within several hours. The suspended solids concentration in the tank ranged from 2 to 5 *mg/l* during non-feeding period, while it rose rapidly up to 49 *mg/l* during the feeding period and then decreased gradually. Thus, this decrease of COD was due to settlement of suspended solids to the bottom.

The PO_4-P concentration in the effluent ranged from 0.16 to 0.2 *mg/l*, and it also rose up to 0.42 *mg/l* just after feeding. The NH_4-N concentration did not change much even during feeding period. The NH_4-N concentration in the tank ranged from 0.40 to 0.56 *mg/l*, being the average of 0.47 *mg/l*. A similar trend was observed in TIN concentration. The TIN concentration ranged from 0.5 to 0.66 *mg/l* and the average concentration was 0.56 *mg/l*. The effluent concentration of the TIN was nearly 11 times higher than that in the influent as shown in the Fig. 2(E).

The differences in concentrations of the water quality parameters between the influent and the effluent were probably due to the mineralization of fecal matters and debris of feeds remaining in the fish tank.

Water quality in the recycle mode

The variations of water quality parameters are shown in Fig. 3. Although the variation trend is quite similar to that in the flow-through mode, the concentrations of all the water quality parameters except NH_4-N are relatively higher in the recycle mode.

The COD concentrations in the effluent from fish tank was over 3 *mg/l* before feeding and increased up to 46 *mg/l* after feeding, which is more or less 2 to 8 *mg/l* higher than those observed in the flow-through mode. This was mainly due to the fact the COD concentration of the water returning from the treatment unit to the fish tank was higher than that of the influent. This results postulate that the COD accumulation might take place in the system. The

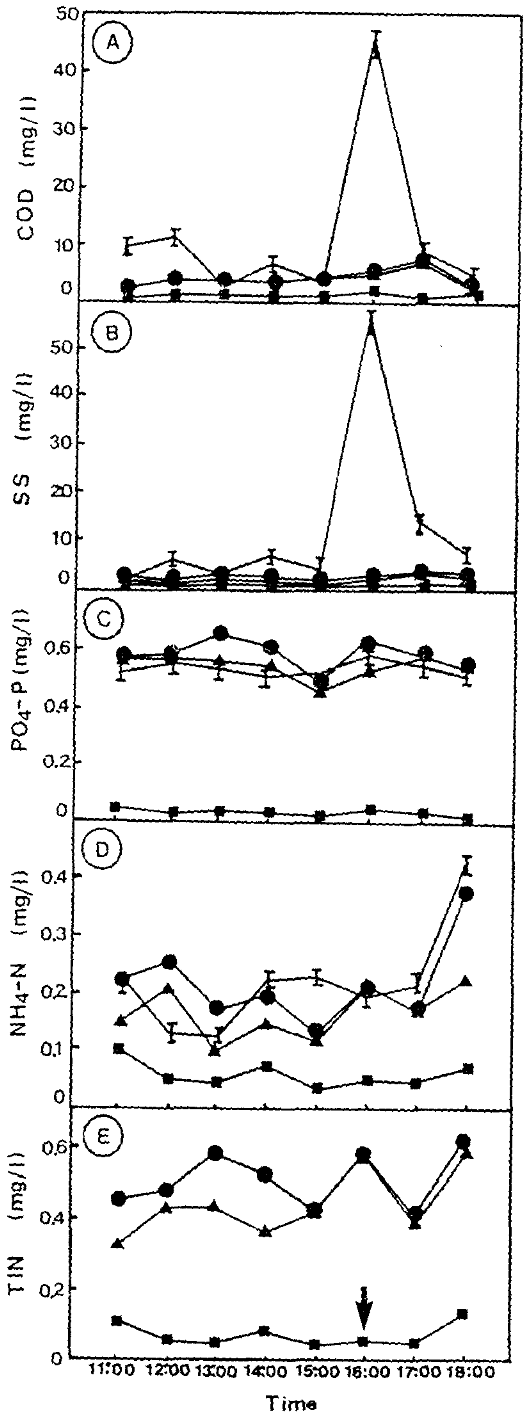

Fig. 3. Variation of major water quality parameters with time in the recycle mode.(■ : the influent; ●: before treatment; ▲: after treatment; I : the effluent; → feeding time).

SS concentrations in the effluent is quite similar to those in the flow-through mode. However, the PO_4-P concentration of 0.55 *mg/l* in the tank was about 3 times higher than that (0.16 *mg/l*) in the flow-through mode.

The effluent NH_4-N concentration before feeding was almost below 0.22 *mg/l* and rose to 0.43 *mg/l* about two hours after feeding. However, the NH_4-N concentration in the treated water did not change significantly with time. The average NH_4-N concentration of the influent and effluent of the treatment unit was 0.22 and 0.17 *mg/l*, respectively, thus being only 23% of removal efficiency.

Gas bubbles rising to water surface from the submerged filter was observed. This indicate that denitrification seemed to occur at the inner layer of the biofilm and dead zone in the filter where oxygen diffusion was limited. The differences in the TIN concentration of the water before and after passing the units are shown in Fig. 3(E). The TIN removal efficiency in the units was 13.8%, The nitrate concentration in the fish tank ranged from 0.62 to 0.84 *mg/l*, being the average concentration of 0.73 *mg/l*

Fig. 4 shows the monthly variation of the major water quality parameters in the recycle system. The water exchange rate during the period from December to April was maintained to be 1.5~2.5 cycles/day, while the rate from May to November was about 4 cycles/day. The concentration of the water quality parameters were clearly varied consequentially by the change of the water exchange rate, which might be due to the dilution effects. The monthly variation of the water quality was probably attributed to the variation of the rearing density and feeding rate in the fish tank.

The NH_4-N concentration of the influent in the treatment unit from December to April ranged from 0.18 to 0.25 *mg/l*, being the average of 0.22 *mg/l*. The nitrification efficiency varied only from 11 to 34.4% with the average efficiency of 22%. The PO_4-P concentration during the period of from December to May was about 7 times higher than that during the other months. The large amount of PO_4-P seemed to be released from the mineralization of organic debris in the system. The average

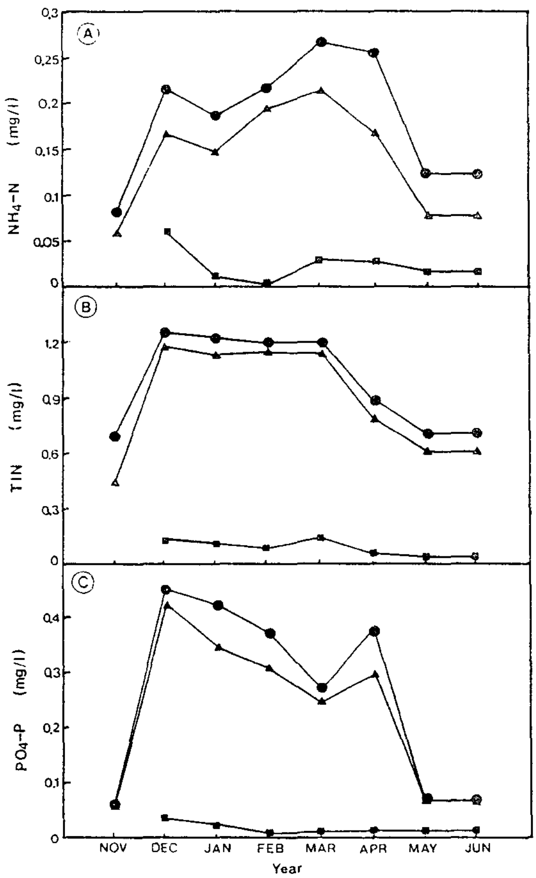

Fig. 4. The variation of monthly water quality in the recycle mode(■: the influent; ●: before treatment; ▲: after treatment).

TIN concentrations in the influent and in the effluent of the treatment unit were 0.97 and 0.91 *mg/l*, respectively, thus resulting 6.6% of TIN removal efficiency.

Comparison of water quality

Table 1 shows the differences in water quality parameters between the two aquaculture systems. Although the system HRT in the flow-through and the recycle modes are quite similar, the differences in water quality were great.

It was expected that the water quality in the recycle mode would be much better than in the flow-through mode because of the operation of the water treatment unit. However, the concentrations of all the water quality parameters except ammonia

Table 1. The major water quality parameters in the fish tanks of the flow-through and the recycle modes

Parameters	The flow-through mode	The recycle mode
COD	7.81	11.52
SS	9.30	12.26
PO_4-P	0.21	0.54
NH_4-N	0.47	0.22
NO_2-N	0.01	0.06
NO_3-N	0.08	0.73
TIN	0.56	1.01

unit: *mg/l*

in the recycle mode were rather higher than those in the flow-through mode.

The increase in PO_4-P, COD and TIN concentration could not be explained without considering internal organic loading in the recycle mode. The main cause is likely due to mineralization of the organic debris accumulated in the water treatment unit. The hydraulic surface loading in the settling in the water treatment unit. The hydraulic surface loading in the settling channel was 398 $m^3/m^2 \cdot$ day, which is quite higher compared to the normally applied hydraulic loading of 33~41 $m^3/m^2 \cdot$ day for obtaining 50~60% of SS removal (WPCF, 1977).

It was not surprising to expect the lower removal efficiency of the SS in the settling channel at the hydraulic surface loading. Most of the SS accumulation in the treatment unit probably occur in about one hour after feeding even though the SS concentration of the influent to the treatment unit at usual feeding time 16:00, was merely 2.8 *mg/l* as shown in Fig. 3(B). The grab samples were taken at each sampling point simultaneously within 5 minutes after the first feeding. Therefore, it was thought the SS concentration increasement due to feeding was not detected in the influent to RBC unit.

The ammonia accumulation might be regarded as the critical factor of the first priority in the water recycle system. Consequently, the nitrification process is the key for the design of a water treatment installation. Although the NH_4-N concentration in the recycle mode was quite low compared to that in the flow-through mode, the nitrification rate in the recycle mode was remarkably low. The nitrification efficiency in the recycle mode was only 23 %.

Under the condition of attachable debris loading, the fixed-biofilm nitrification can be also reduced by the reduced oxygen penetration of the biofilm, caused by the oxidation of organic debris by heterotrophic bacteria(Bovendeur et al., 1990), Hence, mal-functioning of the settling channel in the water recycle system probably resulted in low nitrification. From the comparison of water quality between the flow-through and the recycle mode, it is noticed that the poorly designed water treatment unit in the recycle mode can deteriorate the water quality in fish tank.

Water exchange rate

Most of the recycle systems are operated for the specific purpose to maintain better water quality and effective use of heated water during the cold season. The increased expenses are offsetted by the more uniform and higher quantites of fish product in the system. The increased product over that of the natural or the flow-through systems also helps financially balance the increased expenses.

In a recycling system, the accumulation of ammonia may be regarded as the most critical factor as mentioned earlier. Total ammonia, generally called ammonia, in water consists of ionized(NH_4^+) and unionized species(NH_3). The equilibrium between the two species depends on temperature, pH and ionic strength. The NH_3 is favored by increasing temperature and increasing pH(EPA. 1976).

The unionized fraction of total ammonia is well-known to be toxic to fish. Mortality and morbidity of fish is the result of gill hyperplasia, causing inadequate transfer of gases and wastes between the capillaries and the aqueous environment(Roberts, 1978). For marine life, the unionized NH_3 concentration of hazard level is 0.4 *mg/l*, and the minimal risk level of deterious effects is 0.01 *mg/l* as NH_3. Application factor applying to 96hr LC_{50} is 0.1(EPA, 1977).

Chang and Yoo(1988) reported that no adverse effect was observed in the growth of the flounder at NH_4-N concentration of 0.07~0.48 *mg/l*, NO_3-N concentration of 3.89~34.06 *mg/l*, and NO_2-N concentration of 0.006~0.33 *mg/l* in a closed circulation system. This results was quite agreeable to the fact that the flow-through system was being operated well at the NH_4-N concentration range of from 0.4 to 0.56 *mg/l* with the average of 0.47 *mg/l* without any problem. The fish species might exhibit the various degree of susceptability to pollutants. Therefore, in the present study the recycle system seemed to have been operated relatively at the low NH_4-N concentrations ranging from 0.12 to 0.43 *mg/l* with the average of 0.22 *mg/l*. The monthly variation of the water quality also showed that the NH_4-N concentration of the influent to the treatment unit from December to April ranged from 0.18 to 0.25 *mg/l*, being the average of 0.223 *mg/l*. Hence, water exchange rate in the recycle system could be reduced to some extent if more efficient system management could be applied. Also it was found that the system was discharging the heated water without the effective use of it.

Fig. 5 shows distribution of the water exchange rate in the culture systems of Kyungnam and Cheju Province. The rate is determined by various parameters like water quality, temperature, stock density and, etc.. However, differences of the rates were also significant even among the systems in the same area. The rate of water exchange of the system in Kyungnam Province ranged from 0.4 to

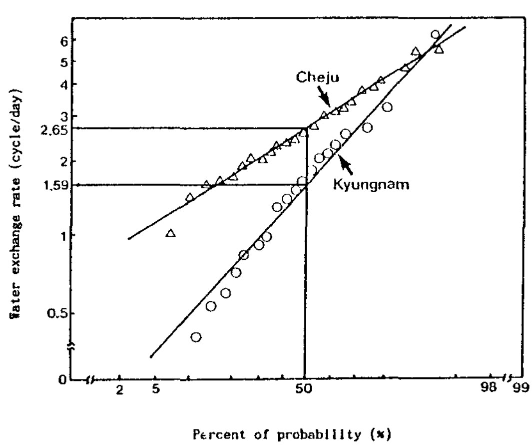

Fig. 5. Distribution of water exchange rate in Kyungnam and Cheju province.

6.0 cycles/day, being the mean value of 1.59 cycles/day, while that in Cheju Province varied from 1 to 5.5 cycles/day, being the mean value of 2.65 cycles/day. It can be easily noticed that optimization of the water exchange rate might reduce a great amount of expense in the running cost of the culture system.

All these inefficient management seemed to come from the lack of the intensive data on water quality, the proper measuring instruments, and the trained personels. The development of water treament facilities, the standardization of the system and the efficient operation methodology are urgently required to manage the semiclosed culture system properly.

Summary

Water quality in a semiclosed system of flounder culture in Korea was evaluated to improve the fish culture system management skill with particular emphasis on enhancement of water quality. From the comparison of water quality between the flow-through mode and the rccycle mode of the existing semiclosed system, the followings were found.

The peak concentrations of COD, PO_4-P and SS appeared just after feeding, and decreased gradually to normal levels within two hours. However, the ammonia nitrogen concentration in the recycle mode tended to increase after two hours of feeding. Concentrations of all the water quality parameters except ammonia in the rcycle mode were slightly higher than those in the flow-through mode. These were attributed to the mineralization of organic debris accumulated in the RBC and the submerged filter unit due to the poor functioning of the settling channel. Consequently, the average nitrification efficiency of the recycle mode was 22 %, that was not effective than might be expected.

The water exchange rate was directly related to water quality in the semiclosed fish culture system. The rate should be optimized based on water quality to reduce the running cost of the fish culture system.

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References

APHA, AWWA and WPCF. 1989. Standard methods for examination of water and wastewater, 17th ed. APHA, AWWA and WPCF. Washington D. C. USA. 4.111~5.17.

Bovendeur, J. et al. 1990. Fixed film reactors in aquacultural water recycle system, Efffect of organic matter elimination on nitrification kinetics. Water Res. 24(2): 207~213.

Chang, Y. J. and S. K. Yoo. 1988. Rearing density of a flounder in a closed recirculating sea water system, J. Aquacult. 1(1): 13~24.

Ministry of Environment. 1992. Environmental preservation Law.

Roberts, R. J. 1978. Fish pathology, Balliere and Tindall, London.

US EPA. 1976. Quality criteria for water, US EPA, Washington D. C. 10~11.

US EPA. 1977. Multimedia environmental goals for environmental assessment. Vol. II. EPA-600 17-77-136b. E364~E365.

WPCF. 1977. Wastewater treatment plant design. MOP8. Washington D. C. 20037. 322~323.

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반폐쇄 순환여과식 넙치양식장의 수질제어에 관한 연구

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넙치양식장의 수질관리 및 제어 방안을 검토하기 위하여 같은 조건에서 양식되고 있는 유수식 및 순환여과식 양식장을 선택하여 상호수질의 비교 평가를 행하였다. 두양식장 공히 COD, PO_4-P 및 SS의 최대농도는 급이와 동시에 나타났고 2시간 이내에 평상농도로 회복되어 일정한 농도로 거의 유지되었다. NH_4-N의 경우 유수식에는 급이후 시간 경과에 따라 농도차이가 별로 없으나 순환식의 경우는 급이후 2시간 이후에 다소 증가하는 경향을 보였다. NH_4-N을 제외한 COD, PO_4-P, SS 및 TIN의 농도는 순환여과식에서 다소 높은 경향을 보였다. 이는 처리 시스템내에 축적된 유기부유물이 무기화에 기인된 것을 평가되었으며, 이것이 질산화율을 떨어뜨리는 결과를 초래한 것으로 사려되었다. 유수식 및 순환여과식의 수질에 직접적인 영향을 주는 해수 교환율이 양식장마다 크게 다르게 나타나 이에 대한 최적화가 시급한 것으로 나타났다.