Korean J. Chem. Eng., **20**(3), 487-491 (2003)
SHORT COMMUNICATION

Annual Variation of Fresh Water Quality in the Gachang Dam Reservoir

Joong Kon Park† and Sung Kon Kim

Department of Chemical Engineering, Kyungpook National University, 1370 Sankyuk-dong, Book-gu, Daegu 702-701, Korea
(*Received 30 August 2002 • accepted 7 November 2002*)

Abstract−This paper investigated the relationship between the annual variation of the algae population and the physicochemical properties of the water reservoired in the Gachang Dam in the hopes of serving as a guideline in the production of a clean water supply to regions of the city of Taegu. Summer thermal stratification was formed in the freshwater reservoired in the Gachang Dam and thus dissolved oxygen (DO) decreased according to the depth of the water. The pH of epilimnion was much higher than that of hypolimnion in summer because of the difference in the photosynthesis rate of algae. In July, at the beginning of the rainy season, the amount of total nitrogen (T-N) in the freshwater reached a maximum of 1.92 mg/L without an increase in the amount of total phosphorus (T-P). In August, the concentration of T-P in the freshwater increased steeply and reached 0.12 mg/L. *Aulacoseira spp*. (diatoms) were predominantly distributed in the freshwater throughout the year and *Synedra* and *Asterionella* (diatoms) predominantly populated in the spring. However, *Anabaena* and *Microcystis* (blue-green algae), which caused malodor and a bad taste, flourished predominantly in epilimnion in August when the temperature of the water at the surface region increased to the maximum and the concentration of T-P was sufficiently high.

Key words: Algae Population, Freshwater, Gachang Dam, Total Nitrogen, Total Phosphorus

INTRODUCTION

The management of high quality fresh water has become an important project not only nationally, but worldwide [Ministry of Environment, 2001]. PAI (Population Action International) classified Korea as a water-deficit nation in 1993 [PAI, 1993]. In Korea, a large amount of fresh water can be reservoired by artificial dams because most of the water sources are surface water. However, the quality of fresh water in an artificial dam gets worse with time and with increasing surface water pollutants, which are due to the rise in population density and the use of nitrogen-rich products. Nutrient salts entering a dam cause increases in the algae population. Alga is a unicellular or multicellular organism which is able to photosynthesize by using dissolved carbon dioxide and multiplies requiring nutrient salts such as nitrogen and phosphate sources for cellular growth. Alga also shows a specific color according to its inherent chromoprotein. A large population of algae causes algal bloom [Pearl, 1996], red tide, malodorousness, bad taste and some kinds of algae species can produce toxic materials in reservoired freshwater. A large amount of chloride compounds should be added to the freshwater for the removal of algae. This process causes the production of tri-halo-methanes, a carcinogenic substance. Difficulties in the treatment of freshwater contaminated with algae lead to a high production cost for drinking water [Lee, 1995]. Prior to developing an efficient technique for preventing the rapid growth of algae in a dam, we had to investigate the relationship between the physical properties of the freshwater, such as temperature, pH, dissolved oxygen, and nutrient salts, and the distribution of the algae population in the freshwater reservoired in an actual dam. In this study, annual variations of physicochemical properties, including algae population, temperature, dissolved oxygen, total nitrogen and total phosphate in the fresh-water contained in the Gachang Dam located in Taegu, were investigated in the hope that the data would be used as a guideline in controlling the quality of the freshwater.

MEASUREMENT OF WATER QUALITY

Gachang Dam was built in Taegu to supply drinking water to the people residing in the Sooseong and Dalseong districts in the city of Taegu. It reservoirs freshwater which originates in Biseul moutain, 14 km upstream from the dam. Nine million tons of water can be stored in the dam which is 260 m in length and 45 m in height. The maximum surface area of the water contained in the dam is 0.699 km^2, and the dam supplies 28,000 tons of freshwater per day. Water samples were taken periodically at some locations according to the water depth more than two times per month from January 1, 2001 to December 26, 2001. The sampling point was the intake tower, 50 m away from the edge of the dam [Kim, 2002].

The volume of water contained in the dam was estimated by converting the water level to the pondage by using a previously prepared calibration chart. Daily precipitation and atmospheric temperatures were obtained from reports from the Taegu meteorological center. Temperature of the sample water was measured by digital thermometer immediately at the sampling point. Two liters of the sample water in a polyethylene bottle was put in an ice cooler and delivered to the laboratory. Thereafter, other physicochemical properties of the freshwater were measured. Dissolved oxygen, pH, COD, total nitrogen, total phosphorus, suspended solid and turbidity were measured by the standard method [Ministry of Environment, 1998; APHA, 1995] using a UV spectrophotometer (UVICON, model 931, Korea) and turbidimeter (HACH, Korea). The number of individual algae species was counted by microscope (Olympus, Korea) after settling 1 mL of sample water in a Sedgwick-rafter chamber

†To whom correspondence should be addressed.
E-mail: parkjk@knu.ac.kr

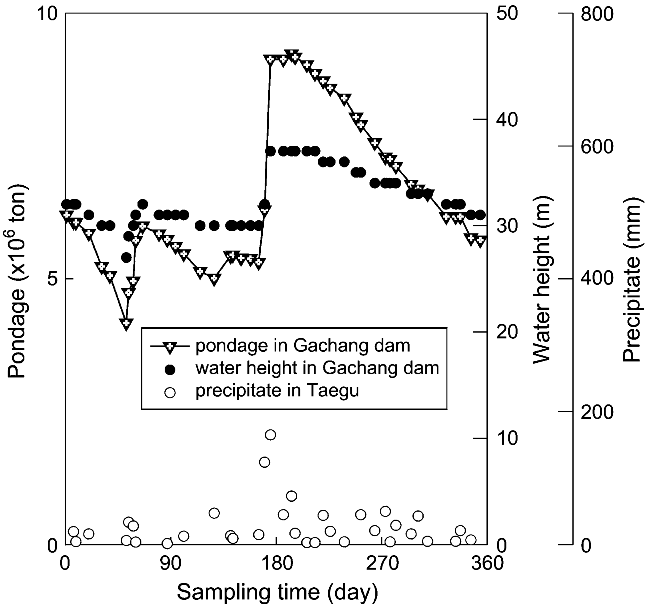

Fig. 1. Annual profiles of the pondage, the head of freshwater reservoired in the Gachang Dam and precipitation in Taegu. "Days" in the lateral axis corresponds to 360 days from January 1st, 2001 to December 26th, 2001.

for 15 or 20 minutes.

RESULTS AND DISCUSSION

1. Freshwater Temperature

Annual variations in the amount of water reservoired in the dam and water levels are presented in Fig. 1. 'Days' in a lateral axis corresponds to 360 days, from January 1, 2001 to December 26, 2001. The pondage increased vertically from 5.5 million tons to 9 million tons around the 190th day with the inflow of heavy precipitates, 124 mm on the 170th day and 165 mm on the 185th day. Taegu water supply cooperation produced 35 or 40 thousand tons of clean water per month using the freshwater reservoired in the Gachang Dam and the pondage decreased linearly from August to December. The temperature of the water reservoired in the dam is dependent on the atmospheric heat fluctuations. Water is heated at the surface from spring to summer although it remains cool at the bottom. Thermal stratification was well developed during the summer in the freshwater in Gachang Dam, as shown in Fig. 2(A). From the 220th day, the water cooled and the temperature dropped linearly. Increases in the density of the water at the surface region caused the water circulation from epilimnion to hypolimnion from the 280th day. A weak winter thermal stratification was formed after the circulation.

2. pH and DO Levels of the Freshwater

The pH measured at the surface region of the reservoired water increased from the 90th day and reached its highest value on the 230th day. As shown in Fig. 2(B), the annual pH profile of the water at the surface is very similar to the temperature profile of Fig. 2(A). However, the pH profiles of the water located at the water levels of less than 24 m from the bottom decreased and reached their minimum value on the 220th day and increased thereafter. This is much different from the temperature profile. It may be partially explained

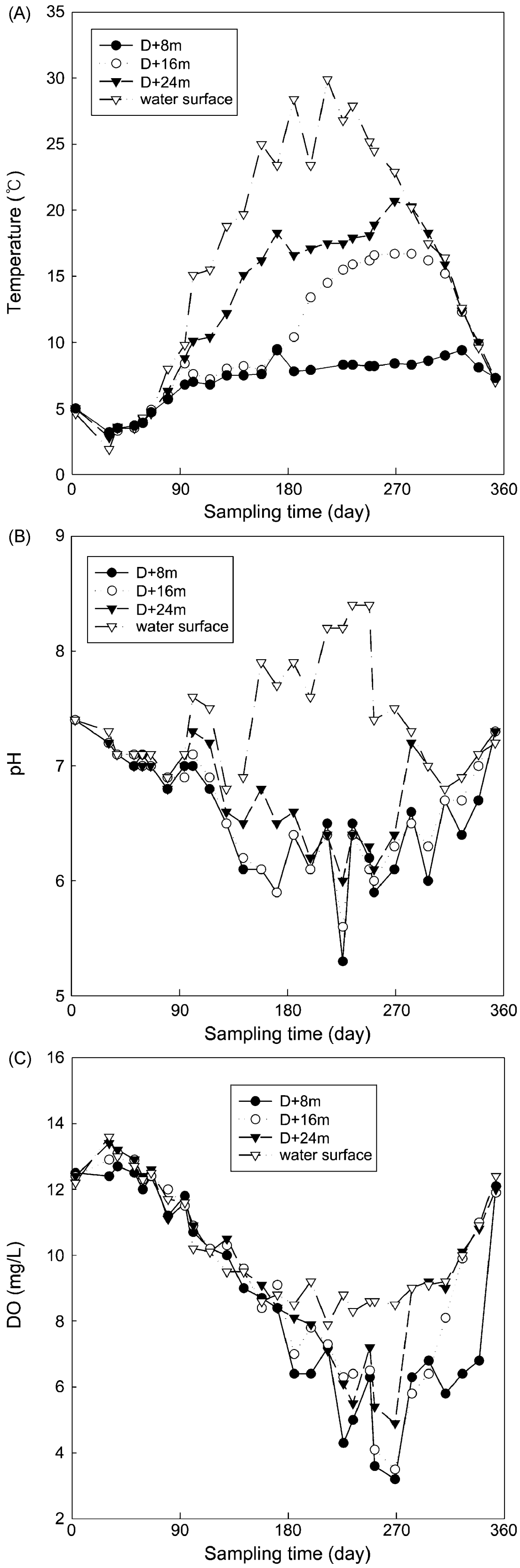

Fig. 2. Annual variation of the physicochemical properties of the freshwater reservoired in the Gachang Dam according to the water level. (A) temperature, (B) pH, (C) DO. Open triangle, water surface; Closed triangle, 24 m in height from the bottom; Open circle, 16 m; Closed circle, 8 m.

by variations in the algae population at the surface region of the reservoir. Nitrogen and phosphorus sources accumulated from summer precipitation caused rapid algae growth in high water temperatures [Yun and Park, 1997]. Algae are active for photosynthesis during this period of rapid growth. This results in a decrease in the concentration of carbonic acid [Sung et al., 1998] and thus increases the pH of the water.

However, the dissolved oxygen concentration (DO) in epilimnion is very low in summer, 8 ppm, because of the high temperature of the water at the surface region. The diffusive oxygen transfer rate is very slow at the water medium where the thermal stratification is well developed. The light intensity received at hypolimnion is very weak [Kim and Lee, 2001]. Thus, the rate of oxygen production is slower than that of oxygen consumption by the dark respiration of the microorganisms [Guieysse et al., 2002; Lee and Lee, 2001]. Thereby, the DO level in hypolimnion is very low, less than 5 ppm, and the water temperature is low, less than 10 °C as shown in Fig. 2(C). Especially, in summer, the light intensity received in shallow water at about 8 m in depth from the surface was very weak because of the high turbidity caused by the suspended solids that accumulated with the heavy precipitation. The weak light intensity received at water levels of less than 24 m in height from the bottom caused a slow photosynthesis by the algae [Yun and Park, 1997] and thus the pH was much lower than that in epilimnion in summer, as shown in Fig. 2(B).

3. Algae Population

The size of the algae population, according to water levels starting from the bottom of the dam, is described in Fig. 3. The total number of algae on the 130th day, in spring, is larger than that at the middle of summer. Most of the algae population is located at the surface region in summer, although an algae-dense layer was formed at a water level of 24 m from the bottom of the dam on the 130th day in spring. The algae population was composed of various species, so the monthly mean number of a dominant species was evaluated according to the water level and presented in Table 1. The dominant algae species in the Gachang Dam were *Asterionella*, *Synedra*, *Aulacoseira* as diatom, *Anabaena*, *Microcystis* as cyanobacteria, and *Sphaerocystis*, *Eudorina spp*. as green algae.

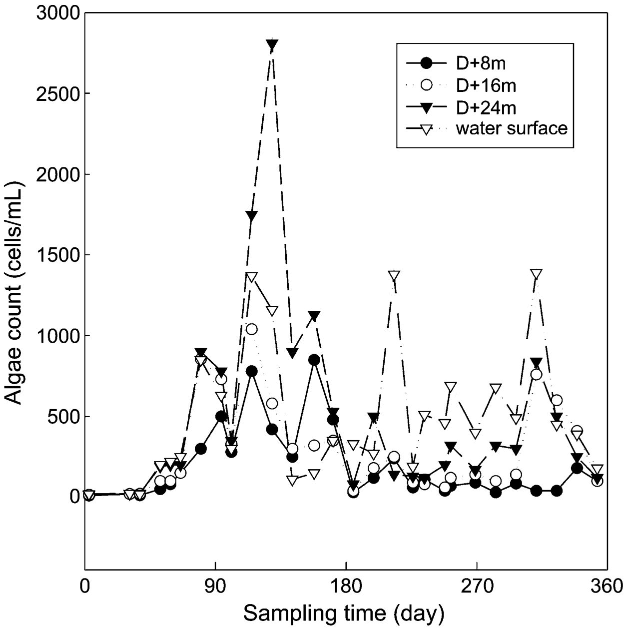

Fig. 3. Annual profiles of total algae species according to the water level at the Gachang Dam. Open triangle, water surface; Closed triangle, 24 m in height from the bottom; Open circle, 16 m; Closed circle, 8 m.

Asterionella and *Synedra* flourished in spring in all regions, re-

Table 1. Monthly variation of the population density of algae species according to the water level in the Gachang Dam Reservoir

		Algae population (cells mL^{-1})											
		Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
Sphaerocystis	Surf[a]									180			
Eudorina	Surf								130				
	D+24								21				
Anabaena	Surf								100				
	D+24								10				
Microcystis	Surf								300	47			
Asterionella	Surf				217								
	D+24				297								
	D+16				260								
	D+8				167								
Synedra	Surf	5	77	250	30	10				11	11		
	D+24		33	245	197	30				13	18		
	D+16		17	140	30	10	5	5					
	D+8		13	100	13	10							
Aulacoseira	Surf	8	5		210	685	150	180			235	570	220
	D+24	17	33		300	1205	520	220	27	113	165	600	145
	D+16	14	23	35	173	265	175	95	123	70	97	545	190
	D+8	13	13		147	180	515	55	103	57	43	13	115

[a]D+8, D+16, D+24 denote the water level of 8 m, 16 m, 24 m from the bottom of the dam, respectively.

gardless of water level. *Anabaena*, *Microcystis*, *Eudorina*, and *Sphaerocystis* were dominant at the surface region in August and September. *Aulacoseira* was found all year except in March, regardless of water level. Nonetheless, there were no *Aulacoseira* cells on the surface region when green algae and cyanobacteria were the dominant species in this region in summer.

The essential nutrients required for the rapid growth of algae are known as nitrogen and phosphate. Algae populations increase rapidly when large quantities of the nitrogen and phosphorus enter into a freshwater lake [Lee, 2000]. It was reported that the optimum temperature for the growth of diatom was 18-30 °C [Cairns, 1956]. However, it was an interesting observation that *Aulacoseira*, one species of diatom, was found nearly throughout the year at the Gachang Dam. Moreover, *Synedra* and *Asterionella*, other species of diatom flourished regardless of the water level in Gachang Dam Reservoir in March and April, although the water temperature was as low as 6-9 °C and T-N and T-P levels were relatively low, as shown in Fig. 4. The most algae-dense layer was located not on the surface layer but at a water level of 24 m from the bottom of the dam. This can be explained by the following report [Ruth, 1948]. Light intensity is stronger than the saturation point on the surface of the water and decreases exponentially with the vertical distance from the surface. The photosynthesis is depressed at the water surface because of the strong light intensity, and the rate of photosynthesis decreases with the water depth because of the decrease in light density. Thus, there exists an adequate water depth for the maximum photosynthesis and multiplication of plankton.

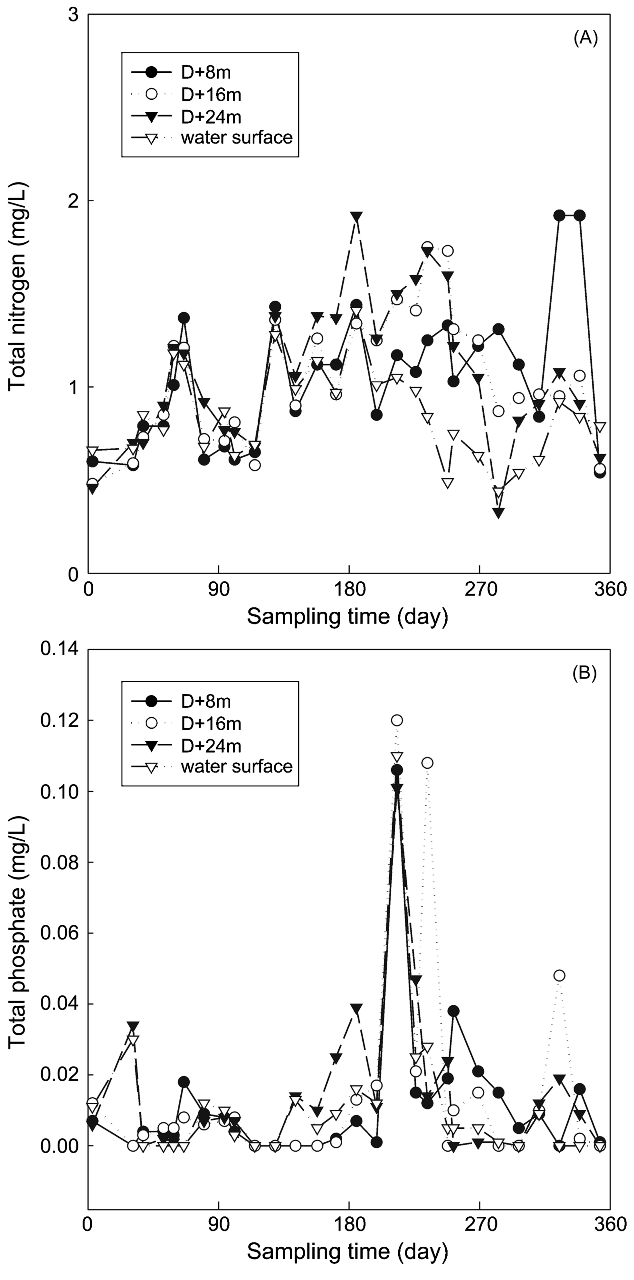

Fig. 4. Annual profiles of total nitrogen (A) and phosphorus (B) distribution according to the water level in the Gachang Dam Reservoir. Open triangle, water surface; Closed triangle, 24 m in height from the bottom; Open circle, 16 m; Closed circle, 8 m.

The water temperature is one of the most important environmental factors for the algae multiplication. Cyanobacteria (blue green algae) and green algae require high temperatures of 30-35 °C and 35-40 °C, respectively [Cairns, 1956]. *Anabaena*, *Microcystis* (cyanobacteria), *Eudorina*, *Sphaerocystis* (green algae) flourished at the surface region when the water temperature was 26-30 °C and the T-P level reached as high as 0.1 ppm. The rapid multiplication of algae required higher amounts of nitrogen than phosphorous [Yun and Park, 1997]. These reports can be confirmed by the observed results that the nitrogen concentration in the epilimnion is lower than that in the hypolimnion at the end of summer, although the phosphorus concentration was nearly constant throughout the water level from the bottom to the top of the reservoired water, as shown in Fig. 4.

Anabaena and *Microcystis* produce geosmin ($C_{12}H_{22}O$), 2-MIB (2-methyl isoborneol, $C_{11}H_{20}O$) which bring about malodor and bad taste. A filtration process using activated carbon particles is required for the removal of these compounds when the algae population density is larger than 3,000 cells/mL and another filtration system using the oxidation with ozone is required at the algae density of greater than 30,000 cells/mL. Moreover, *Anabaena* produces anatoxin-A which causes a nervous disorder and microcystin which is composed of seven amino acid molecules and causes another nervous disease. Only 1 mg of microcystin-LR is sufficient to kill fifty mice, and therefore, these experimental results mean that 3 mg is required to kill a man on the basis of average body weight [Okino, 1973]. A complete removal of microcystin requires an adsorption process using activated carbons or oxidation with ozone because the conventional coagulation, sedimentation, and filtration could not effectively trap this small molecule whose molecular weight was about 1,000 [Falconer, 1989].

CONCLUSION

The annual investigation of the quality of the water reservoired at the Gachang Dam from January to December, 2001 gave the following conclusions. The well developed thermal stratification reduced the oxygen transfer rate through the water medium and thus the dissolved oxygen concentration in the hypolimnion was very low, at less than 5 ppm. Diatom flourished from spring to winter and cyanobacteria was found at the surface region in August and

September. This phenomenon suggests that the water in hypolimnion can be used to produce drinking water in summer. Cyanobacteria, which causes malodor, bad taste and a nervous disease, can be inactivated by using the photocatalysis of TiO_2 [Lee et al., 2001]. However, it is more advisable to develop a process or install equipment that can prevent the inflow of nitrogen and phosphorus sources in order to depress the multiplication of cyanobacteria because the amount of water reservoired in a dam is too large. Destroying the thermal stratification by using airlift equipment may cause decreases in the temperature of the water in the upper region and thus depress the multiplication of the cyanobacteria. The cultivation of floating leaved plants such as water hyacinth in a dam is recommended because cyanobacteria appears only on the surface region in the late summer. Floating leaved plants efficiently absorb nutrient salts and the large leaves decrease the light intensity received in the water. Thereby, it would effectively depress photosynthesis and the growth of cyanobacteria in late summer.

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