New Technologies Harmonized with Global Environment

Part 2 - Activities of Water and Wastewater Engineering Division -

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This Part 2 paper presents the history of pioneering businesses initiated by NKK's Water and Wastewater Engineering Division, and unique plants and technologies developed by the Division for improving the water environment.

1. Introduction

NKK's water engineering operations have a history of a considerable length when the sale and installation of water supply pipes are included. However, its modern involvement in this field began with a proposal at NKK's top management conference in 1972 to move into the business field of constructing water treatment plants. Initial product strategy was centered on advanced water treatment, and technical agreements were concluded with overseas plant makers such as Zurn and Techfina, and sales, engineering, and research sectors were integrated to obtain required technologies and to commence new business operations. The Environmental Plant & Water Supply Dept. was established in April 1976. Later, it was reorganized into the Water Supply & Sewerage Dept. in April 1977, and the Water Engineering Section was formed in the Environmental Plant Sales Dept. at the same time. Further in June 1984, the Water Supply & Sewerage Sales Dept. was established.

Since water engineering businesses in Japan are carried out centering around public works, it is a field difficult to enter for a new comer in comparison to private-sector business. Initially, NKK focused its sales efforts on nearby local authorities such as Yokohama and Kawasaki. Sales promotion activities emphasizing NKK's technical capabilities finally opened the door to the public-sector businesses, and orders gradually increased due to the trust of local authorities cultivated by high-quality construction work by NKK. As the company became increasingly recognized in this field, the business scale increased, acquiring an increasingly large number of orders for large-scale projects. **Photo 1** shows Japan's largest egg-shaped sludge digestion tanks at the North Yokohama Sludge Treatment Center, a project on which NKK was responsible for construction of machinery and equipment.

Photo 1 Egg-shaped sludge digestion tanks at North Yokohama Sludge Treatment Center

Through such a history, NKK's Water and Wastewater Engineering Division has now reached consolidated annual sales of approximately 50 billion yen, focusing mainly on construction of public facilities such as water supply and sewerage treatment systems. However, the recession in Japan which began in the 1990's, and the consequent budget reductions in public works, have made the business environment for water engineering operations increasingly subject to sudden changes. One example is PFI (Private Finance Initiative). The introduction of PFI in public works is an international trend and in Japan, the so-called PFI Promotion Law was enacted in 1999. PFI involves the widespread introduction of private funding, management, and technical capabilities in the design, construction, maintenance, and management of public facilities as a means of effectively using government funds, and effectively and efficiently providing public services. The basis of PFI is a division of roles between public and private sectors based on abilities in different areas, the mutual acceptance of responsibility, and the provision of social capital at a lower cost, the end result being a reduction in the tax burden on citizens. The fundamental requirement for the success of PFI operations is the balance between public benefit and financial profitability, and the clear delineation of responsibility between the public and private sectors. In the conventional mechanism for public works projects, procurement of finance for construction and operation of facilities, and operation itself, is undertaken by the public sector, however in PFI, such tasks are generally required to be undertaken by the private sector.

The majority of Japanese water engineering companies, including NKK, are focused on plant construction as the core of their business operations. However, in addition to the introduction of PFI, the shift from specification orders to performance orders, and from split orders to lump-sum orders to reduce costs in public works is unavoidable, and the financial scale of the market for plant construction will necessarily be reduced. Furthermore, there is a strong possibility that massive overseas privatized water companies such as Vivendi and Thames Water will enter the Japanese market on a large scale.

In order to maintain and develop water engineering operations within this changing business environment, it is necessary to develop new business areas such as consulting work (e.g., surveys and planning), diagnosis, repair, and upgrading of facilities, and operation and maintenance services. The essential requirement for success in these new operations is the development of products of a high technical level, to the extent that NKK is recognized by all as having products of a uniquely superior level of technical sophistication. NKK's water engineering sector is continuously developing new and promising technologies, not only in the area of process technology, but also in such areas as diagnostic technology to determine obsolescence of plant and equipment, methodologies for upgrading plant and equipment, technology to accommodate such upgrades, and simulation technology. This paper introduces two of these technologies: the bio-tube system and bio-reaction simulation technology.

2. The bio-tube system

2.1 Progress of the development

The Ministry of Construction implemented a comprehensive technical development project called "Bio-focus WT" from 1985 to 1999 to develop new methods of sewerage treatment. The project was aimed at solving problems associated with conventional sewerage treatment technology, and focused on the development of new technologies for improving the quality of treated water, reducing the energy required for such treatment, and making the land area required for constructing such facilities smaller. As part of this project, NKK developed a new microbial carrier named the bio-tube as shown in **Photo 2**, along with an advanced sewerage treatment system that uses this carrier.

Photo 2 Bio-tubes

2.2 Features of the bio-tube system

Two methods are available to immobilize the microorganisms in the carrier: entrapping and binding. Entrapping involves mixing a water-soluble high polymer (e.g., polyethylene glycol, polyvinyl alcohol) with the microorganisms and polymerization initiator to polymerize the high polymer to form a gel, and immobilize the microorganisms within the lattice of the gel.

Binding involves the natural adherence of the microorganisms and polymerization initiator to the surface of particles (e.g., sand, activated carbon, plastic beads) using a bio-polymer created by the microorganisms themselves to form a bio-film.

During a period around 1986, a number of companies involved in water treatment, including NKK, began development work on the entrapping method. In an early stage however, NKK discovered a number of problems in the entrapping method such as (1) the entrapped microorganisms tend to be extinguished, and (2) the reaction tends to be completed near the surface of the bio-film as oxygen diffusion works as a rate-determining factor. Hence, NKK transferred its focus to the binding method.

The bio-tube developed by NKK (**Photo 2**) employs polypropylene as the base material. Each bio-tube is a hollow cylinder with an outside diameter of 4 mm, inside diameter of 3 mm, and length of 5 mm. It has a roughed surface to promote adhesion of the microorganisms. The bio-tube has the following characteristics.

(1) The relative surface area is large, providing for adhesion of large volumes of microorganisms.
(2) A specific gravity similar to that of water ensures that they are evenly distributed in the aeration tank.
(3) The polypropylene base material is not biodegradable and has a high physical strength, thus providing good resistance to wear, and eliminating the need for replenishment of the carrier.
(4) It can hold effective microorganisms having low growth rates (e.g., nitrifying bacteria) in the aeration tank.
(5) It needs not be held under moist conditions, thus simplifying storage.

2.3 Representative xases of bio-tube systems installed

A variety of uses are possible for a fluidized bed bio-reactor system using bio-tubes. The most representative cases are shown in **Figs.1** to **5**, and are described below.

(Case 1)

In the system shown in **Fig.1**, the influent is introduced into the aeration tank (fluidized bed bio-reactor) containing the carriers, and subjected to a treatment using the microorganisms adhering to the carriers. Next, the SS in the treated water is removed in the solid-liquid separation equipment to produce clean water[1),2)].

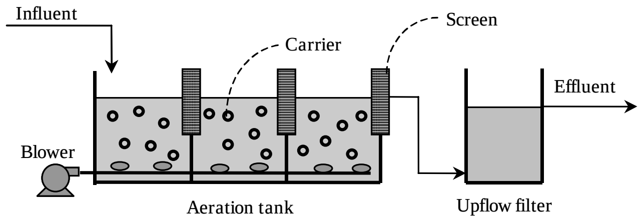

Fig.1 Flow diagram for BOD removal system (Case 1)

In this system, the microorganisms are maintained at a high concentration in the aeration tank, thus reducing the size of the tank. The system differs from conventional activated sludge systems in that it does not require the precipitation separation of activated sludge in the clarifier, and therefore returning of the precipitated sludge, eliminating the problem of bulking. It has been verified that the microorganism phase that matches the properties of the wastewater and loads in each stage of the aeration tank is formed, making this treatment system a highly rational one.

The system was selected for the new sewerage treatment plant in Miyakonojo City in Miyazaki Prefecture, and has been in service since May 1996. Under the initial operating conditions of a true carrier packing density (volume basis) of 10%, and influent rate of approximately 16% of the planned value, average values for BOD and SS in the treated water were at quite satisfactory levels of 2.8 mg/L and 1.1 mg/L respectively. The fluidity of the carriers during operation was also satisfactory with the carriers almost uniformly distributed in the aeration tank[3)].

(Case 2)

The system shown in **Fig.2** incorporates carrier separation screens in the conventional activated sludge aeration tank to separate the carriers charged in the tank. The system was selected for the plant in Takanezawa Town in Tochigi Prefecture as a means of upgrading the existing combination of the long-hour aeration method with the contact oxidization method using submerged fixed filtration beds. The maximum treatment capacity was increased from 600 m^3/day to 2100 m^3/day by this upgrading work. The operation of this system commenced in March 1993. At a carrier packing density of 5% and retention time in the aeration tank of 4.6 hrs, the T-BOD value of 4 mg/L and the SS value of 2 mg/L were achieved, satisfying the target values of 5 mg/L and 20 mg/L respectively[4)].

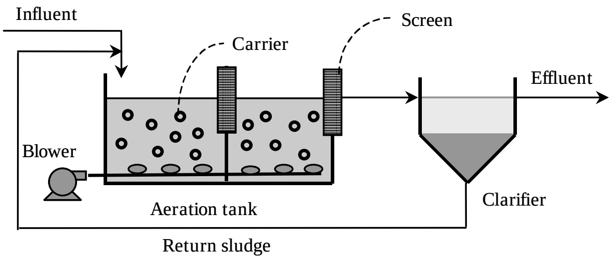

Fig.2 Flow diagram for BOD removal system (Case 2)

(Cases 3 and 4)

The systems shown in **Figs.3** and **4** involve introduction of carriers into the aerobic zone in the anoxic-oxic method and anaerobic-anoxic-oxic method respectively. These carriers are used to maintain a high concentration of nitrifying bacteria in the aerobic zones, reducing the size of the tank and stabilizing the nitrification process.

These systems were employed in a joint trial with Kawasaki City using a pilot plant capable of treating 15 m^3 of water per day. The system shown in **Fig.4** employs conditions of a retention time of nine hours, water recirculating rate of 2.0, return sludge rate of 0.3, MLSS of 1750 mg/L, and carrier packing density of 5%. The T-N value of 7.8 mg/L for the water treated by this system was below the target value of 10 mg/L[5)]. The system shown in **Fig.4** was adopted for the Iriezaki Sewerage Treatment Plant in Kawasaki City, and is currently undergoing commissioning and adjustment operation in preparation for full operation.

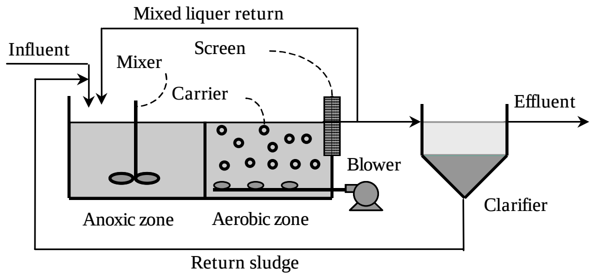

Fig.3 Flow diagram for BOD and nitrogen removal system (Case 3)

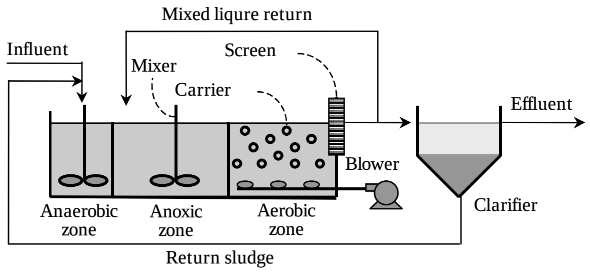

Fig.4 Flow diagram for BOD, nitrogen, and phosphorus removal system (Case 4)

(Case 5)

The system shown in **Fig.5** is basically similar to that in **Fig.3** in that carriers are introduced into the aerobic zone of the anoxic-oxic method. The system differs from the one in **Fig.3** in that the carriers are introduced into two downstream aerobic zones only and are not introduced into the initial upstream aerobic zone. This system was employed in a joint trial with Otsu City in which one line in the activated sludge plant already in use at the Otsu City Water Purification Center was modified for trials [6]. As shown in **Fig.6**, the aeration tank at this Center is of a deep structure with diffusers positioned approximately at the mid-depth of the tank. The trial was conducted with an influent rate of 11800 m^3/day, water recirculating volume of 10200 m^3/day, return sludge of 7200 m^3/day, air blowing volume of 43000m^3/day, and retention time of 5.2 hours. The carrier packing density was 2.5% until December 8, 1996, after which it was increased to 3%. Average values for T-BOD and T-N of the treated water during the trial were 2.3 mg/L and 5.7mg/L respectively, satisfying the target values of 10 mg/L or less for both throughout the trial. The system is called as “Nitrogen removal system from sewerage by the anoxic-oxic method applying new carriers” and received the technology prize of Japan Society of Water Environment” in 2001.

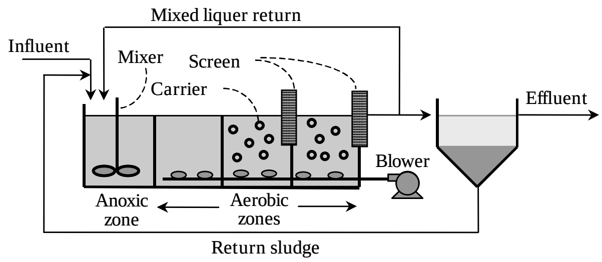

Fig.5 Flow diagram for BOD and nitrogen removal system (Case 5)

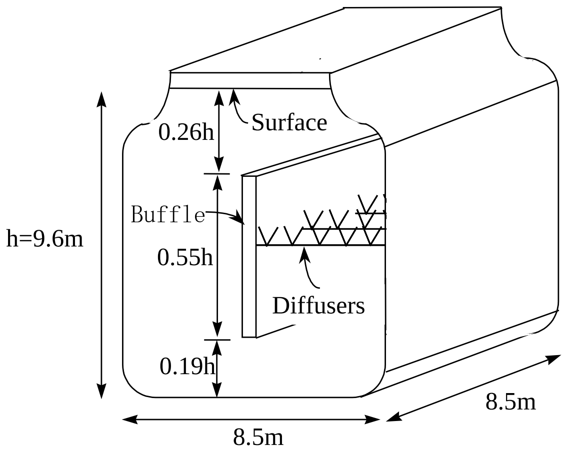

Fig.6 Configuration of deep aeration tank system

It has been reported[7] that, for introducing entrapping-type carriers into a deep aeration tank, a fundamental modification to the equipment is required due to the low fluidity of the carriers. However in this experiment, excellent carrier fluidity was realized without such modification, with carriers distributed almost uniformly throughout the aeration tank.

In this trial, the bio-tubes were used continuously for a period of two years and four months after which they were checked visually. They were found to be free of deformation and changes in dimensions, confirming that they are stable over long periods of time even when used in deep aeration tanks in full-scale plants.

This paper has described selection of carriers and the progress of the development, and representative cases of wastewater treatment systems using bio-tubes. The common characteristic of all these systems is the reduction in size of the treatment plant because microorganisms are immobilized at high concentrations in the carriers. The bio-tube system is also effective and economical when employed for modifying existing treatment plants to accommodate higher loads and advanced treatment.

3. Bio-reaction simulation technology

3.1 Background of the development

Simulation technology has been employed in the field of academic study on sewerage treatment for a considerable time, however methodology has varied significantly between researchers. Indeed, methods used differ between adjacent research laboratories, and even within individual research laboratories. Each method is employed by a small group of researchers without being verified using on-site data from large numbers of treatment facilities, and none of the methods have been used in the design and operational control of actual facilities.

The International Water Association (IWA, previously IWAPRC) formed a task group in 1983 to promote research on the activated sludge model. This research resulted in release of the Activated Sludge Model No.1 in 1986 and the Activated Sludge Model No. 2 in 1995, and expectations have rapidly increased for the practical use of mathematical models for bio-reaction simulation. In particular, the increasing sophistication of sewerage treatment plants has resulted in increasingly complex and advanced processes, necessitating more rational approaches to the design and operational control of such plants. The Activated Sludge Model can simulate the mechanism of microbial and physicochemical reactions based on a widely applicable concept, and as such is a core model that allows the addition of new microbial and physicochemical reactions with the same methodology as necessary. This model has had considerable impact on the thinking of researchers in both fields of wastewater treatment and numerical modeling.

NKK is handling a wide variety of sewerage treatment facilities, including six types of bio-tube systems mentioned above. In the past, when designing a new sewerage treatment plant, the most appropriate type was selected based on the experience of the technical personnel involved taking into consideration such factors as influent conditions and required levels of treated water quality. To select a treatment system with an optimum type and scale, and operate it under optimum conditions, is extremely important in terms of improving the quality of treated water, and reducing the treatment costs.

NKK therefore commenced development of an advanced sewerage treatment simulation technology as a means of optimizing the design and operational control methods of sewerage treatment plants.

3.2 Features of NKK's simulation technology

(1) Model of bio-film adhering to bio-tubes

Aiming at building a simulation technology for the bio-tube system based on the Activated Sludge Model, NKK developed a model of the bio-film adhering to the bio-tubes using its own data. Possible reaction processes occurring in the bio-film, and components contributing to these processes, were described in the same manner as in the Activated Sludge Model, incorporating changes in the volume of the bio-film due to mass transfer and microbial reproduction within the film. It was assumed that the bio-film adhering to the carriers is gradually peeled off into activated sludge so that its thickness does not increase indefinitely.

The newly developed model was employed in an attempt to reproduce the pilot trial results for the bio-tube system shown in **Fig.4**. A simulation was performed for a period of approximately four months from October 16 to February 13. Actual values obtained by measuring the water quality for the pilot plant are compared with those obtained by the simulation in **Fig.7**.

Simulated values are in good agreement with measured values obtained from the pilot plant not only in phosphorus as shown in **Fig.7** but also in organic substances and nitrogen, confirming the validity of this simulation model. It was also verified that it is possible to reproduce the results of a pilot trial conducted over a period of four months using the basically same reaction parameters in a simulation.

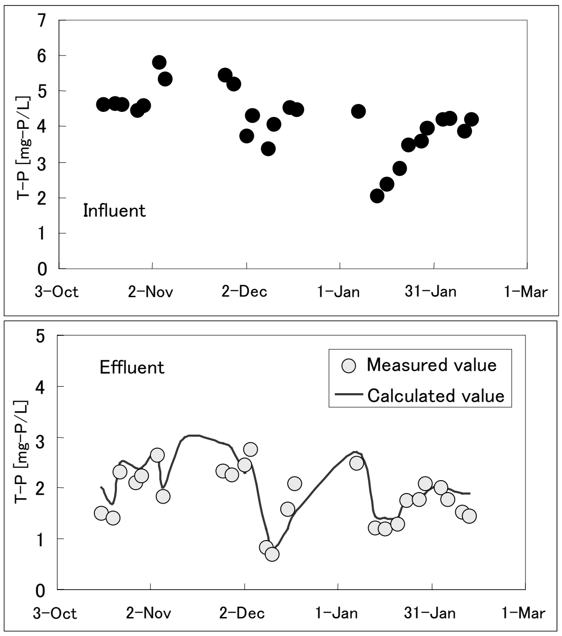

Fig.7 Comparison of simulated and measured values

(2) Development of an oxidation ditch model

The oxidation ditch is a suitable system for small- to medium-scale sewerage treatment facility. It employs an endless circulating water channel as a reaction tank, and its use as a treatment system is rapidly increasing due to the ease with which its operation may be controlled.

The volume and quality of water entering the oxidation ditch varies considerably with local conditions, and a range of variation, or a considerable margin, needs to be incorporated for establishing a uniform set of standard design values. Methods of design and operational control for oxidation ditch facilities designed for advanced treatment have been considerably improved by introducing new design factors such as A-SRT. However, their design method is still heavily dependent on experience. It is effective in this regard to use simulation software developed based on the activated sludge model and perform quantitative analysis. The simulation software is helpful for establishing appropriate design values and standards for HRT (Hydraulic Retention Time), tank shape, SRT (Solids Retention Time), required oxygen amount, etc. Thus, it permits comparative investigations and rational and efficient evaluation, as well as allowing design of facilities optimized to local conditions.

In the past, operational control was mostly dependent on experience. However, it has been shown that the control method employing this simulation model allows appropriate operation of oxidization ditch facilities, and is particularly effective for removing nitrogen.

Simulation using this model helps establish optimum operation methods such as intermittent aeration in response to influent conditions, providing an increase in treatment performance, while at the same time reducing treatment costs.

Based on the results obtained as above, NKK is currently developing the simulation methodology of using this model in cooperation with the Japan Sewerage Works Agency.

The model was simplified by dividing an endless circulating water channel characteristic of the oxidation ditch system into a number of tanks and assuming that the bio-reaction described above for the Activated Sludge Model takes place in each of these tanks. The adaptability of this simplified simulation model was verified with NKK's propeller-type oxidation ditch system that uses blowers and diffusers to supply oxygen, and a submerged propeller to generate water flow within the tank.

A simulation was performed taking into account changes over time. As shown in **Fig.8**, the results provide a good reproduction of actual data. It is planned to develop simulation software that incorporates characteristics of systems of other types such as a vertical aeration system that uses surface aeration for both oxygen supply and generation of water flow within the tank, and investigate appropriate design criteria and operating conditions.

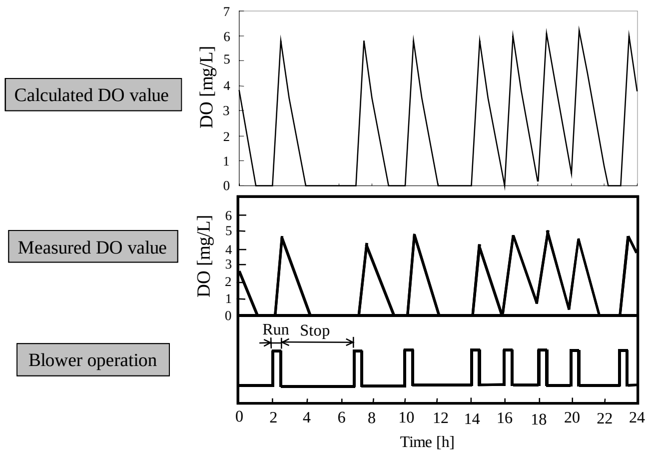

Fig.8 Calculated and measured DO (Dissolved Oxygen) concentration in oxidation ditch system

3.3 Implementation of simulation technology

Development of simulation technologies for the bio-tube and oxidation ditch systems has been introduced above. It is further planned to develop practical simulation technologies applicable to a variety of other systems. Major purposes are two-fold: (1) support for design, and (2) support for operation.

Much benefit will be derived from using these tools that simplify the simulation. They will be used by designers as a means of performing quantitative investigations of the systems being designed, as well as by operation managers as a guideline when changing operating conditions. A work flow diagram for using such a support tool is shown in **Fig.9**.

The simulation software developed based on the activated sludge model will be effectively used for designing sewage treatment systems optimized for changes in the assumed external conditions, for proposing optimized operational control methodologies of these systems, and for performing quantitative evaluation of the performance. As such, the new simulation software will prove extremely effective in investigating lifecycle cost and performing lifecycle assessment, factors considered to become essential in planning, designing, and controlling sewerage treatment facilities in future.

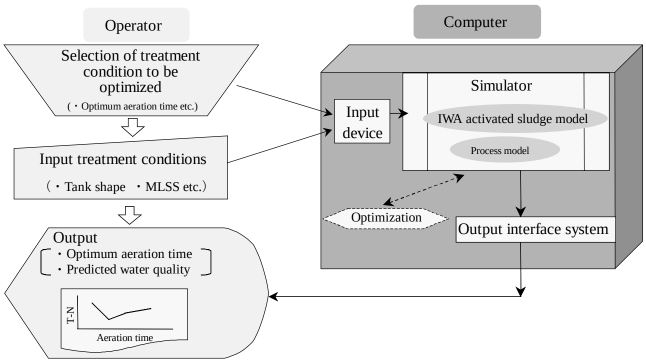

Fig.9 Work flow diagram for using support tool

5. Conclusion

In 1998, regulations governing general discharge of nitrogen and phosphorus were implemented to deal with eutrophication of sea areas. In 2002, total emissions of nitrogen and phosphorus became subjected to regulations. It is anticipated that these regulations will be further tightened according to local conditions in many areas in future.

To implement countermeasures and responses in view not only of the water environment, but also of the entire global environment, will be increasingly required. Under these circumstances, it is hoped that the bio-tube system and bio-reaction simulation technology described above, and NKK's expertise in environmental technologies and systems, will make contributions to the improvement and preservation of both the water environment and the global environment. It is NKK's intention to engage positively in the development of superior new technology in this field in future.

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