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Technology for Advanced Treatment of Rural Sewerage in Japan

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Abstract
It is important to develop techniques for advanced wastewater treatment in rural communities, based on an extension of biological treatment methods. The target for treated water quality is less than 10 mg/l for BOD, COD, SS, T-N and less than 1 mg/l for T-P. In this paper, the application of (1) contact aeration process with treated water returning system, (2) batch-activated sludge process, (3) oxidation ditch process, was introduced, after reviewing the principles of biological denitrification, biological dephosphorization and phosphorus removal using a submerged iron contactor. Operation control for the above processes and new developments in technology such as immobilization methods and membrane separation method were also described. The studies conducted so far have enabled to develop denitrification methods, while phosphorus removal methods require further investigations.

Discipline: Agricultural environment/Irrigation, drainage and reclamation
Additional key words: aeration, batch-activated sludge process, design and operation, nitrogen removal, phosphorus removal

Introduction

In Japan, wastewater treatment has been mainly undertaken in populated cities. The percentage of facilities for wastewater treatment is 48% for the whole population, while 8% only for rural areas. In such areas, the quality of river, swamp and irrigation water has deteriorated.

The Rural Sewerage Project (RSP) was initiated in 1973 by the Ministry of Agriculture, Forestry and Fisheries (MAFF). The present project was developed in 1983 for full-scale implementation. The project is commonly implemented by the municipal government.

As the number of households in rural communities in Japan ranges from a few dozen to a hundred, with most of them being located at a disance from each other, the RSP has adopted the small-scale scattered plant-system which can cover from one to a few communities. The small-scale scattered plant-system has the following advantages:

(1) It saves construction cost, especially of pipelines.

(2) It accelerates the construction of sewerage facilities in the wide rural areas of Japan.

(3) It facilitates the application of sludge from treatment plants to farmland use.

(4) It facilitates the participation of users in the operation and maintenance.

The treatment must be stable and economical with easy maintenance in response to variations in flow and load.

The standard of treated water quality applied to a general area is such that the BOD value is less than 20 mg/*l* and SS value, less than 50 mg/*l*. In some areas, however, advanced treatment must be carried out in addition to the usual secondary treatment to control eutrophication in closed water areas. Therefore, in some areas standards are set up not only for BOD and SS, but also for nitrogen, phosphorus and COD.

Though the definition of the term "advanced treatment" is ambiguous, it can refer either to the treatment, the level of which is higher than formerly or treatment in which pollutants not controlled previously are dealt with. In this paper, water treatment methods will be discussed, with emphasis placed on nitrogen and phosphorus removal by setting a target of treated water quality of less than 10 mg/*l* for BOD, COD, SS and T-N and less than 1 mg/*l* for T-P.

Two approaches for the implementation of advanced treatment can be adopted: in one facilities are improved using a biological treatment method, namely, the traditional secondary treatment method, while in the other new facilities are constructed depending on the pollutants to be removed. The former approach employs such techniques as biological denitrification and biological dephosphorization while the latter employs the rapid sand filtration method for BOD and SS removal, the coagulating sedimentation method or crystallized dephosphorization method for phosphorus removal and the activated carbon adsorption process for COD removal. Techniques for the latter methods have almost all been developed. Here, focus is placed on advanced treatment techniques which are an extension of biological treatment methods.

Principle of nitrogen and phosphorus removal

1) Biological denitrification

As shown in Fig. 1, biological denitrification consists of a nitrification process where, among the various types of nitrogen contained in wastewater, organic nitrogen is decomposed into ammonia by heterotrophic bacteria, and the ammonia oxidized into nitrite/nitrate by nitrifying bacteria under aerobic conditions, and a denitrification process where nitrite/nitrate are reduced to nitrogen gas by denitrifying bacteria under anaerobic conditions.

Nitrifying bacteria, aerobic autotrophic bacteria, reduce/assimilate carbon sources such as carbon dioxide or inorganic carbon compounds to synthesize cells, using the energy obtained through the process of nitrification of ammonia or nitrite. On the other hand, main denitrifying bacteria, heterotrophic bacteria (facultative anaerobes), breathe using DO under aerobic conditions and the oxygen contained in nitrite or nitrate molecules under anaerobic conditions. Organic matter included in wastewater is required as hydrogen donor for denitrification.

In order to achieve efficient denitrification, it is necessary to control the environmental conditions such as DO concentration, as well as to provide a system where these microorganisms can properly function. Aerobic and anaerobic conditions can be created either in separate treatment tanks or in the same treatment tank but at different times.

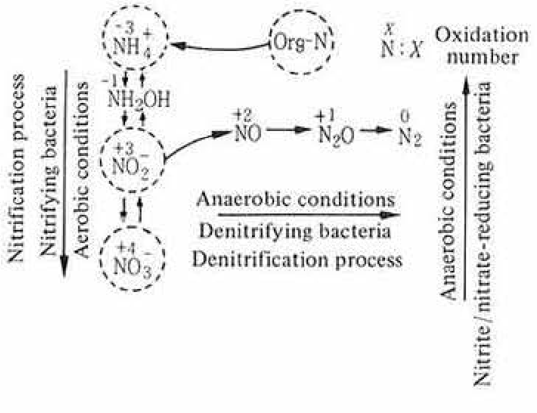

Fig. 1. Principle of denitrification

The rural wastewater treatment processes utilizing the above mechanism, include the contact aeration process applied in the treated water returning system, the batch-activated sludge process where such controls as intermittent aeration are carried out during treatment operation, and the oxidation ditch process, etc.

2) Biological dephosphorization

Phosphorus differs from nitrogen in that its structure simply changes in water and it does not drift into the air.

In the conventional activated sludge process, the phosphorus concentration (kgP/kgSS) in sludge reaches values of about 0.02–0.025. On the other hand, when the biological dephosphorization method is applied, the values increase by 2–4 times compared with sludge processing using the conventional biological reaction method. Thus, it is possible to obtain supernatant water with a low phosphorus concentration by carrying out solid-liquid separation under conditions where the activated sludge has absorbed excess phosphorus.

The following two reactions are required before activated sludge can absorb excess phosphorus:

(1) In a completely anaerobic environment with neither DO nor NO_X–N, phosphorus is released from activated sludge.

(2) In an aerobic environment, activated sludge absorbs large amounts of phosphorus.

When these reactions proceed adequately, the phosphorus concentration in treated water can be temporarily lowered to less than 0.5 mg/*l*.

When activated sludge containing excess phosphorus settles in a sedimentation tank or sludge storing tank for a long time, the phosphorus is again eluted. Fig. 2 shows the changes in the phosphorus concentration measured over time. In this experiment, activated sludge was removed and placed in a 3 m high water tank. The samples were taken at a depth of 10 cm under the water surface. To decrease the amount of phosphorus eluted, it is necessary to shorten the precipitation time of activated sludge and the transportation time of the supernatant water.

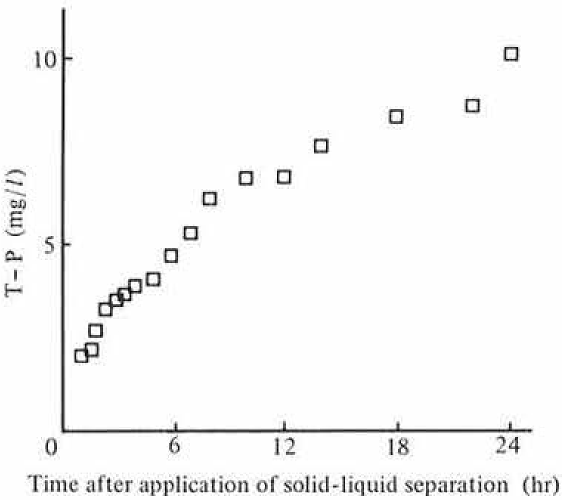

Fig. 2. Re-elution of phosphorus

However, since the amount of sludge produced is limited, it is unlikely that this high efficiency phosphorus-removing method, which makes use of the phosphorus-absorbing characteristics of activated sludge, can be applied readily, unless the present sludge collection method (sludge being simply taken out of the system) is modified. In designing a phosphorus removal process which utilizes activated sludge characteristics, the inter-relation between sludge circulation and wastewater treatment must be taken into consideration. In another dephosphorization method where treated water containing the smallest amount of phosphorus is obtained, phosphorus is eluted from activated sludge containing excess phosphorus, and the drifting liquid (supernatant water) with a high phosphorus concentration is removed efficiently in the subsequent treatment process.

3) Phosphorus removal using a submerged iron contactor[6,8)]

When an iron contactor is submerged in a treatment tank in the activated sludge process or biological film process, the phosphoric acid ion in wastewater is chemically bonded with iron ion eluted as a result of iron corrosion. This product, differs from the phosphorus absorbed in activated sludge in that it is not eluted again, even when stored for a long period of time in an anaerobic tank. Phosphorus can be eliminated by removing this product as excess sludge. Corrosion refers to the phenomenon whereby a metal is eroded chemically or electrochemically by the surrounding environment.

When aeration/stir are applied after submerging the iron contactor in an aeration tank, oxygen concentration cells with a mixture of wastewater containing DO and microorganisms as an electrolytic solution and iron contact materials as electrodes, are formed. As a result, a local electric current is generated, causing electrochemical corrosion. Through the chemical reaction, eluted iron ions are transformed into ferrous hydroxide {$Fe(OH)_2$}, ferrous oxide {$FeO \cdot nH_2O$}, ferrous phosphate {$FePO_4 \cdot nH_2O$}, ferric oxide {$Fe_2O \cdot nH_2O$}, triiron tetraoxide {Fe_3O_4}, etc.

The film which is formed after these iron compounds settle on and adhere to the surface of the iron contactor, restricts oxygen diffusion. When the DO concentration increases above a certain value, the film becomes stabilized, resulting in a decrease in corrosion speed. In order to ensure conditions under which phosphorus removal can continue, it is necessary both to adjust the DO concentration to prevent the formation of an anti-corrosion oxidized film on the iron contactor surfaces and to remove reaction products physically by stirring the solution appropriately.

Elution of iron ions can also be caused by sulfate-reducing bacteria. In other words, when an iron contactor is submerged in an anaerobic tank or the first room of a contact aeration tank and the solution inside the tank is stirred, the number of sulfate-reducing bacteria increases and iron ions are eluted as a result of iron corrosion. This phenomenon is ascribed to the fact that sulfate-reducing bacteria use the hydrogen adhering to the surface of the iron contactor when SO_4^{2-} is reduced. The iron ion eluted reacts with the environment to become ferrous hydroxide {$Fe(OH)_2$}, or ferrous sulfide {FeS}.

Since iron is depleted by corrosion, the corrosion speed and the service life of the iron must be taken into consideration when designing facilities.

Advanced treatment processes and operation control

Since most of the treatment facilities in rural communities are designed to cover less than about 1,000 people, influent load over time within a day inevitably experiences considerable changes. An inspection is performed for facility operation control once a week or once a month. As some rural facilities receive water of unknown origin different from wastewater drained from houses, which flows in when it rains, it is difficult to carry out advanced wastewater treatment in these areas. Advanced treatment requires the appropriate selection of a treatment process which ensures superior performance, a proper design and proper execution, and appropriate operation control by the persons in charge of maintenance and control.

Among the treatment processes applied to wastewater treatment in rural communities, those from which advanced treatment of nitrogen and phosphorus can be expected are described in this chapter. References are also made to operation control for advanced treatment.

1) Contact aeration process with treated water returning system

When the contact aeration process with the treated water returning system is applied, tanks are arranged so that the anaerobic filter bed tank is followed by the contact aeration tank

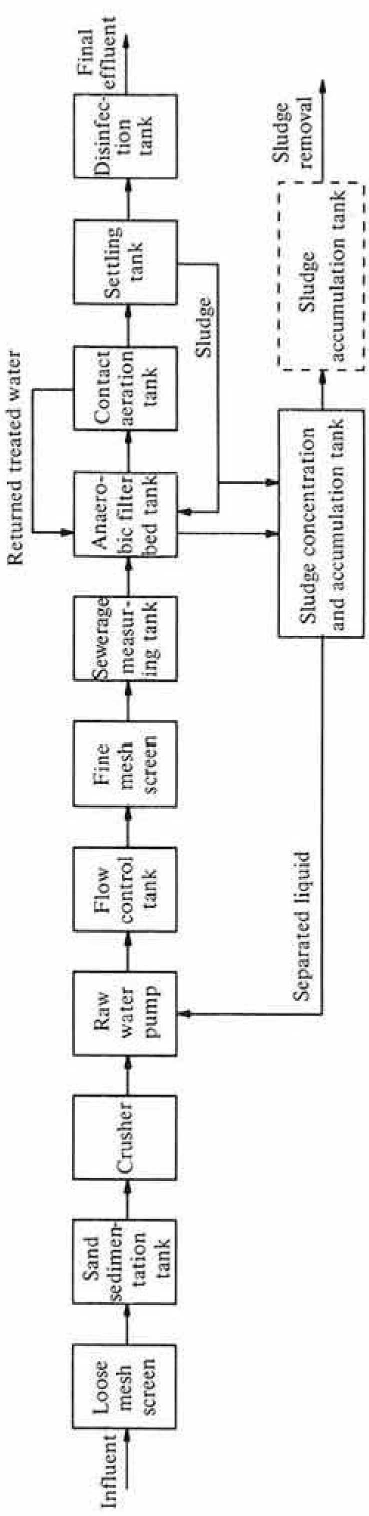

Fig. 3. Flow of contact aeration process with treated water returning system

which act as a denitrification tank and a nitrification tank, respectively (Fig. 3). Therefore, in this method, aerobic and anaerobic conditions for denitrification are provided in different places. When treated water in which nitrification has proceeded in a contact aeration tank is returned to the anaerobic filter bed tank, a denitrification reaction takes place.

Even if it is assumed that the nitrification and denitrification reactions are completed in each water tank, nitrogen removal efficiency achieved in this process is less than 50% when the return ratio (ratio of the amount of water returned to the amount of wastewater flowing in) is 1.0, less than 67% when the ratio is 2.0 and less than 75% when the ratio is 3.0, in case nitrogen removal by pulling out sludge is not taken into account. Nakasone et al.[5] obtained a 72% removal efficiency on an average by setting the return ratio at 3.0 in an experimental plant. However, when the return ratio is too high, the amount of DO brought into the anaerobic filter bed tank increases, resulting in the inhibition of the development of anaerobic conditions. Based on the results obtained so far, a treatment target of less than T-N 20 mg/*l* may be achieved, while a target of less than T-N 10 mg/*l* is unrealistic.

Regarding phosphorus, Haruta et al.[1-3] confirmed, on an experimental basis, the effect of the iron contactor on phosphorus removal when it is submerged into a contact aeration tank or an anaerobic filter bed tank.

Operation control for this method is relatively easy. However, there is some room for improvement in the methods of filter material selection, filter packing, DO concentration control, return ratio control and cleaning of filter clogged with sludge.

2) Batch-activated sludge process[20,21]

In the batch-activated sludge process which is introduced here, organic matter and nitrogen can be removed very efficiently by intermittent aeration. In this case, aerobic and

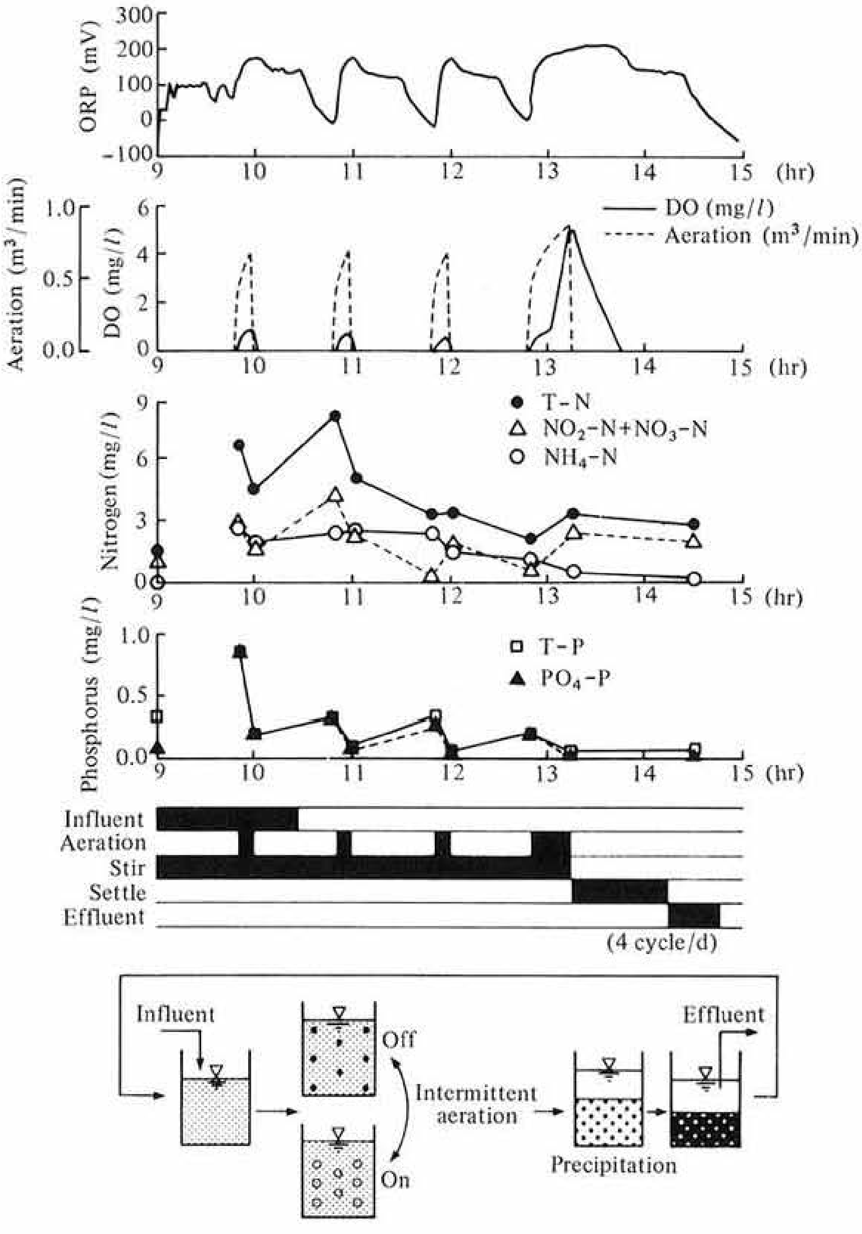

Fig. 4. Changes in water quality with time for one cycle

anaerobic conditions for denitrification are created at different times.

According to the results obtained so far, when the hydraulic retention time is approximately 24 hr for wastewater in a batch tank (an aeration tank used in the batch-activated sludge process), the concentrations of BOD, COD, SS, T-N in the treated water reach a value of less than 10 mg/*l*, by using the DO concentration as the main index. Fig. 4 shows an example of changes in water quality over time in one cycle. At this time, biological

Table 1. Results of treatment in the FUNAKO-facility

Date	Item	Load ($m^3/m^3 \cdot d^{-1}$)	MLSS (mg/l)	Temp. (°C)	pH	BOD (mg/l)	COD (mg/l)	SS (mg/l)	T-N (mg/l)	T-P (mg/l)
1989 7.2-7.3	Influent	0.76	3,030	21.8	7.5	128	89	155	20.7	2.80
	Effluent				6.7	3	6.9	3.9	3.8	1.48
1989 10.2-10.3	Influent	0.56	3,370	24.6	7.5	160	80	152	25.2	2.92
	Effluent				6.9	4	8.6	6.5	4.9	1.81
1990 2.6-2.7	Influent	0.76	3,030	13.7	7.5	133	72	105	27.9	2.98
	Effluent				6.9	7	9.3	8.9	6.6	1.37
1990 5.8-5.9	Influent	0.76	2,200	19.3	7.5	117	73	129	21.8	2.58
	Effluent				6.7	Tr	7.0	2.1	3.7	1.40

dephosphorization proceeds simultaneously with other reactions. Table 1 shows the results of treatment in the FUNAKO-facility in Ibaraki Prefecture.

Nishiguchi et al.[7] and Yamaguchi et al.[15] confirmed that highly efficient phosphorus removal can be carried out by submerging the iron contactor in a batch tank. This method is not designed for the absorption of excess phosphorus by activated sludge. It is difficult to carry out biological dephosphorization and dephosphorization using an iron contactor at the same time, due to the differences in the two principles involved.

In the batch-activated sludge process, since a high denitrification efficiency can be obtained and the facilities used are relatively compact, this process is suitable for small, scattered wastewater treatment systems in rural areas. However, compared with the biological film process, the major treatment process used in rural areas, a relatively higher level of operation control is needed. In addition, the ratio of organic matter converted into sludge is higher.

3) Oxidation ditch process

DO concentration in the normal oxidation ditch process is highest immediately downstream of a rotor and it decreases as wastewater flows down the circulation water channel. When anaerobic conditions are induced by this process, a denitrification reaction occurs.

Hata et al.[4], Takahashi et al.[14] and Ozaki et al.[10] confirmed that by regulating the intensity of aeration operations such as intermittent aeration or rotor cycle control, the removal efficiency of nitrogen exceeded 80%. In this case, aerobic and anaerobic conditions for denitrification are created in separate places, at different times or in combination.

Ozaki et al.[11] reported that a phosphorus removal efficiency of more than 90% could be obtained by the addition of ferric chloride to wastewater as a flocculating agent so that the mol ratio of Fe/P to the phosphorus content in influent wastewater reached a value of 1.0. The addition of a flocculating agent can be also applied to the batch-activated sludge process. Ozaki et al.[10,11] applied a unique process where falling water was used for aeration.

4) Advanced treatment operation control

When the above treatment processes are improved to function as advanced treatment processes, the technicians in charge of the maintenance and control of such facilities must acquire a higher technical expertise along with the development of an automatic control system[9,12,16].

Since each treatment facility used in rural communities has its own characteristics, it is not easy to develop an operation control method that can be uniformly applied. To achieve an efficient operation, it is suggested that a standard manual be prepared and the facilities operated according to it, with corrections being made based on actual experience[18]. Therefore, even if a facility is equipped with an automatic control system, maintenance and control technicians would have to understand the manual so that they can implement regulations and/or corrections.

For example, in the case of the batch-activated sludge process, the DO value increases rapidly, following the completion of both decomposition of organic matter and nitrification. Excessive DO value leads to a waste of electricity and results in lower denitrification efficiency. DO control (control of aeration hours and aeration intensity) depending on the water temperature or wastewater load is necessary for an efficient operation. In this case, however, it is essential that the facility be equipped with a reliable sensor. If inspection frequency creates a problem, control support using a remote monitor system[19] should be considered.

New developments in technology

Newly devised treatment processes which can be applied to wastewater treatment in rural communities are outlined here.

If the concentration of microorganisms can be markedly increased in biological treatment, treatment efficiency will be improved. This method, generally called the immobilization method, includes the following processes which are variations of the activated sludge process: contact oxidation process where activated sludge adheres to a contactor, covering immobilization process where activated sludge is artificially immobilized using polymer materials, and self-granulating process where activated sludge is granulated using the coagulating capacity of microorganisms themselves, etc. A variation in the biological film process is also possible by using the biofilter process[17], where ceramic carriers are filled.

Membrane separation techniques have greatly improved. Shimizu et al.[13] developed a method for advanced treatment in which a flat membrane is submerged in an aeration tank to keep the MLSS concentration at 10,000–20,000 mg/l, and treated water then pulled out. This process has the following advantages: facilities for the treatment are compact, and problems such as bulking of activated sludge and outflow of it can be solved. For the membrane separation method further studies should be carried out on the mechanism of membrane clogging, membrane life, control of abnormal wastewater inflow increase, etc.

Conclusion

Studies conducted so far have enabled to develop denitrification methods. On the other hand, the phosphorus removal methods require further developments in technology. Advanced treatment/control techniques of a resource recycling type will increase in importance in the future. Challenges to develop variable treatment processes and to make flexible choices possible must be met, keeping in mind the need for stability, low cost, simplicity and energy-saving. It has been noted that, the more frequent use of automatic control technology and the development of hybrid treatment processes which combine biological treatment and physicochemical treatment, are essential to achieve this objective.

Rural sewerage treatment enables to preserve the water quality in rural areas. However, it is not recommended to apply hard technology to solve problems without making other efforts. Contributions to global environmental preservation that can be made individually at home, by attempting to save water and detergent, not pouring oil into drains, and burying solid leftover food in private gardens, are preferable to energy-consuming types of treatments. Such efforts will lead to a decrease in treatment loads and contribute to energy-saving. Therefore, environmental education and environmental preservation practices on an individual basis are the first steps in the development of attractive villages.

References

1) Haruta, S. et al. (1992): Experimental study on dephosphorization technique using the aerating submerged iron contactor process (II). *Trans. JSIDRE*, **158**, 57-63 [In Japanese with English summary].
2) Haruta, S. et al. (1992): Experimental study on dephosphorization technique using the aerating submerged iron contactor process (III). *Trans. JSIDRE*, **158**, 65-72 [In Japanese with English summary].
3) Haruta, S. et al. (1993): Basic studies on the characteristics of phosphorus removal by the anaerobic submerged iron contactor process. *Trans. JSIDRE*, **166**, 45-53 [In Japanese with English summary].
4) Hata, K. et al. (1993): Study on improvement of nitrogen removal efficiency by oxidation ditch form (1). *Tech. Rep. Natl. Inst. Agric. Eng.*, **188**, 25-39 [In Japanese with English summary].
5) Nakasone, H. et al. (1988): Nitrogen removal in the contact aeration process. *J. JSIDRE*, **56**, 159-164 [In Japanese].
6) Nishiguchi, T. et al. (1988): Experimental study on dephosphorization technique by the aerating submerged iron contactor filter. *Trans. JSIDRE*, **135**, 41-47 [In Japanese with English summary].
7) Nishiguchi, T. et al. (1989): Field experiment on simultaneous removal of phosphorous and nitrogen by intermittent aeration with submerged iron contactor. *Jpn. J. Water Poll. Res.*, **12**, 788-795 [In Japanese with English summary].
8) Nishiguchi, T. (1990): Techniques for removing phosphorus using iron-filter (IV). *J. Water Waste*, **32**, 239-249 [In Japanese].
9) Oba, Y. et al. (1993): Intermittent aeration activated sludge process by aeration time controller. *J. Res. Environ.*, **29**, 785-790 [In Japanese].
10) Ozaki, M. et al. (1990): Study on the denitrification in the oxidation ditch applying falling water as an aerator. *Trans. JSIDRE*, **150**, 85-92 [In Japanese with English summary].
11) Ozaki, M. et al. (1992): Study on denitrification and dephosphorization in an oxidation ditch applying falling water as the aerator. *Trans. JSIDRE.*, **159**, 45-52 [In Japanese with English summary].
12) Sekine, T. et al. (1992): The most appropriate operation of an aeration tank with fuzzy control. *J. Water Waste*, **34**, 405-411 [In Japanese].
13) Shimizu, K. et al. (1993): Advanced wastewater treatment with high concentrated activated sludge employing membrane process. *J. Res. Environ*, **29**, 763-768 [In Japanese].
14) Takahashi, T. et al (1993): Operation and maintenance for high rate removal of nitrogen by oxidation ditch process. *Trans. JSIDRE*, **163**, 111-118 [In Japanese English summary].
15) Yamaguchi, Y. et al. (1992): Dephosphorization performance by batch-activated sludge process. *In* Summ. lect. given at 1992 JSIDRE meet., 542-543 [In Japanese].
16) Yamamoto, M. et al. (1993): Advanced treatment system for domestic wastewater using intermittent aeration process control led by dissolved oxygen. *J. Res. Environ.*, **29**, 747-755 [In Japanese].
17) Yamamoto, Y. et al. (1993): Nitrogen removal using biofilter process with ceramic carrier. *J. Res. Environ.*, **29**, 756-762 [In Japanese].
18) Yuyama, Y. et al. (1992): Operation control indicator for the batch-activated sludge process. *Environ. Cons. Eng.*, **21**, 33-36 [In Japanese].
19) Yuyama, Y. et al. (1992): Remote monitor system with personal computer communication for rural sewerage facility. *J. JSIDRE*, **60**, 933-938 [In Japanese].
20) Yuyama, Y. et al. (1993): Study on advanced treatment of wastewater from rural settlements with batch-activated sludge process. *Bull. Natl. Res. Inst. Agric. Eng.*, **32**, 63-185 [In Japanese with English summary].
21) Yuyama, Y. et al. (1993): Treatment system of wastewater from rural settlements with batch-activated sludge process. *Wat. Sci. Tech.*, **28** (10), 223-232.

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