Energy Self-Sufficient Wastewater Treatment Technologies by Anaerobic Ammonium Oxidation

Yasuhiro Fukuzaki,
Yasuhiro Nakamura,
Yuki Kawakubo,
Tetsufumi Watanabe

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Abstract

A Wastewater Treatment Plant (WWTP) is generally a constant "energy consumer." When the methane gas from sewage sludge is effectively utilized as renewable biomass energy, it can be turned into an "energy producer." It can realize wastewater treatment with energy self-sufficient performance. Such a next-generation type of wastewater treatment technology is now attracting attention worldwide. Our technology is built on the sewage treatment technology called "AB-process," which is a dual-stage activated sludge system practiced in Europe for well over 30 years ago. It is an application of the nitrogen processing technology recently used in the field of wastewater treatment whereby applying anaerobic ammonium oxidation (generally called "anammox") bacteria. With this technology, sewage sludge is effectively fed to the sludge digestion tank so that methane gas is maximally generated and the generated methane is used to produce electric power. The obtained electric power is used to cover all power consumption in the WWTP. In order to apply this technology to Japanese sewage-related fields based on the elementary technology of ammonium nitrogen treatment by anammox, we conducted a verification pilot test on the digestion sludge dewatering centrate treatment. As a result, we confirmed the effectiveness of this treatment.

1 Preface

The amount of electric power consumed in Wastewater Treatment Plant (WWTP) facilities occupies about 0.8% of total power consumption in Japan. Nowadays, it is a general belief that sewage treatment facilities are high energy-consuming infrastructures. The standard and commonly-used activated sludge method across Japan requires oxygen so that organic substances contained in sewage can be aerobically decomposed by microbes contained in the same sewage. This air supplied oxygen is supplied by blowers consuming a huge volume of electric power. Microbes produced as a result are turned into a large volume of sludge. In order to dispose of this sludge, additional electric power has to be consumed. In 2013, a century had passed since the first technical proposal of such activated sludge process in the world. This method is highly reliable with track records of more than 80 years of history in Japan. It is time, however, to reconsider the costly conventional method as the method which will continue for next generation.

As part of the development activities for energy saving technologies in the field of wastewater treatment, we developed a nitrogen treatment technology by the use of anaerobic ammonium oxidation (generally called "anammox," hereafter called "AMX"). In this connection, the verification test was carried out at a WWTP. Currently, the AMX-applied energy self-sufficient wastewater treatment system is getting attention in Europe and the U.S. We are conducting demonstrative research programs in Japan and Singapore to check the application fitness as to a next-generation type wastewater treatment method[1]. This was realized based on the application of a specific nitrogen metabolic pathway caused by newly discovered microorganisms. The related report was released in 1995 by Delft Institute of Technology in the Netherlands. The method is built on a wastewater treatment method called the AB-process applied since the 1980s. The AB-process is a method by which organic substances contained in wastewater are removed as raw sludge at the A-stage and nutrient removal is subsequently carried out at the B-stage. The removed raw sludge is put into methane fermentation at the anaerobic sludge digestion tank. Generated gases are then converted to energy by a digestion gas power generation. After organic substances are decomposed in the digestion tank, residual high-concentration nitrogen is processed by AMX. In addition, nitrogen treatment by AMX is performed at the latter stage of the AB-process. In this manner, nitrogen treatment can be accomplished at a higher efficiency and lower cost in a treatment plant as a whole. This treatment method having such a concept can have the most potential as biomass energy from sewage sludge.

This paper outlines the technologies of energy self-sufficient wastewater treatment system and introduces the verification test results of the digestion sludge dewatering centrate treatment as a case study of nitrogen treatment by AMX necessary for the realization of this treatment.

2 AB-Process

The wastewater treatment method called AB-process consists of an A-stage and a B-stage. At the A-stage, organic matter is removed at a high organic loading rate. At the B-stage, residual organic matters as well as nutrients such as nitrogen and phosphorus are removed. "A" denotes Adsorption and "B" denotes Bio-oxidation. Since this method can realize high-load processing, reactor volume can be compact. This is an advantageous method when the site area is limited. **Fig. 1** shows a flow chart of the treatment.

2.1 A-Stage

The A-stage is installed just behind the grit chamber. It consists of an aeration tank and its successive intermediate sedimentation tank. Without separating the settling sludge in the primary sedimentation tank, aeration is supplied at the beginning of the sewage treatment. This feature is greatly different from the conventional activated sludge process. Organic substances in wastewater are decomposed mainly by bacteria and those entering the aeration tank are adsorbed quickly by Extracellular Polysaccharides (EPS). Low molecular substances are then taken up and stored in bacteria cells without decomposing and high molecular substances are slowly decomposed by extracellular enzymes and taken up and stored in bacteria cells. The adsorption and storing of organic substances on the surface of bacteria cells is called "biosorption." Subsequently, organic substances are oxidized by hydrolytic enzymes utilizing oxygen and energy is generated from catabolic reaction. Consequently, carbon dioxide and water are generated. The generated energy is used for cell division and new bacteria are produced; sludge is increased.

Fig. 2 schematically shows a series of processes in regard to adsorption and the storage of organic substances by bacteria and subsequent hydrolysis and cell division. At the A-stage, the reaction process from adsorption to storage is stopped at the biosorption stage. Primary sludge is extracted subsequently, while suppressing excessive decomposition of organic substances so that these organic substances can be withdrawn as much as possible. As shown in **Fig. 2**, not only solid substances, but colloidal and dissolved organic

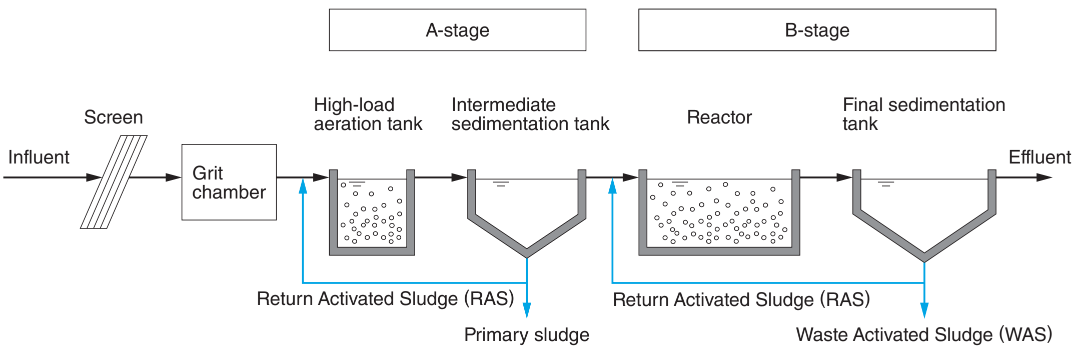

Fig. 1 Flow Chart of Treatment

An outlined flow chart of the AB-process is shown. This process consists of two steps of the former-stage (the A-stage) and the latter -stage (the B-stage).

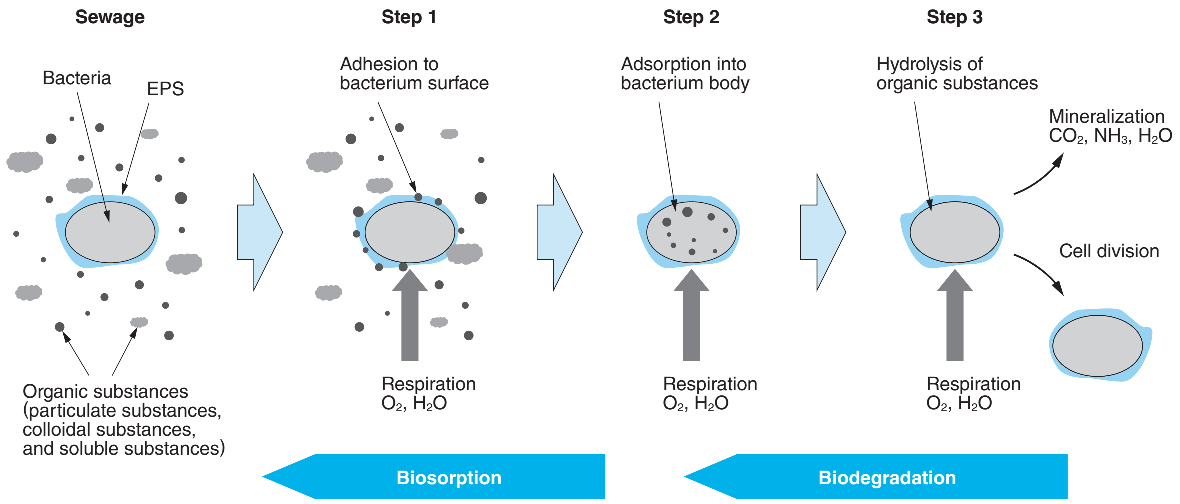

Fig. 2 Metabolism of Organic Substances by Bacteria

A schematic diagram is shown in regard to adsorption and metabolism of organic substances (particulate substances, colloidal substances, and soluble substances) caused by bacteria. The EPS plays an important role.

substances can also be adsorbed by bacteria. These substances can be extracted in a form of primary sludge. A report[2] indicates that the composition of organic substances in wastewater is particulate : colloidal : soluble = 45% : 31% : 24%. The rate of composition other than solid is not very low and this can be taken out as an output of primary sludge. This is the greatest feature of the A-stage.

In the anaerobic digestion tank, primary sludge is more easily decomposed rather than Waste Activated Sludge (WAS) and the volume of generated digestion gases is larger[3]. In order to take out more energy by raising the yield of gases, it is therefore preferable to feed as much primary sludge as possible to the digestion tank and reduce the WAS as much as possible.

The method of biosorption control comes in the following two approaches:

(1) Contact and adsorption reaction of organic substances to bacteria occur within about 30 minutes. The Hydraulic Retention Time (HRT) in the aeration tank of A-stage is set at around 30 minutes.

(2) If the Sludge Retention Time (SRT) is long, decomposition of organisms tends to be stimulated. In order to control this reaction, the SRT is set at about 0.5 days.

The HRT in the intermediate sedimentation tank is generally 1 to 2 hours. This duration is shorter than that of the primary sedimentation tank for the conventional activated sludge process (e.g. 2 hours when the HRT in the intermediate sedimentation tank is 1.5 hours, even though the HRT in the aeration tank is added). In this operation mode, the organic substance removal rate at the A-stage is approximately 60%. To attain a high organic substance removal rate, aeration, Return Activated Sludge (RAS), and WAS are controlled. These controls are performed with an index of Dissolved Oxygen (DO) for aeration and that of the SRT for the WAS. In order to suppress excessive oxidation of organic substance, the aeration rate is controlled to a lower level. Practically, DO is set at about 1.0mg/L and the operation is maintained at a low DO level.

2.2 B-Stage

The B-stage is intended for the activated sludge treatment. It is installed to remove low-load residual organic substances as well as nitrogen and phosphorus at the latter stage of the A-stage. It is composed of an aeration tank and a final sedimentation tank. The HRT in the aeration tank is 2 to 5 hours. The HRT in the final sedimentation tank is 3 to 4 hours. In some cases, anaerobic and aerobic zones are provided in the aeration tank and the aeration area is increased or decreased depending on variations in the load. Since much organic substances are removed at the A-stage ahead, organic substances for denitrification become insufficient and the nitrogen removal rate is restricted at the B-stage. Accordingly, organic substances necessary for denitrification are required to remain so that the nitrogen removal rate can rise. Phosphorus is caught in the sludge and biologically removed, or coagulated with the use of chemicals and removed physically and chemically in a form of sludge. At the B-stage, aeration, RAS, and WAS are controlled. DO is set at 2.0mg/L or below and SRT is set around 10 to 20 days. Since the retention time is long in the aeration tank, the generated WAS increases high-order organisms like metazoans. As a result, cell walls of organisms composing sludge become thicker and they are difficult to decompose in the digestion tank. As such, the maximum suppression of WAS generation contributes to efficient operation of the digestion tank. Furthermore, there is a sludge hydrolysis technology that is effective in decomposing the WAS into an easily digestive form. A large volume of energy, however, is needed for this treatment. In order to minimize energy consumption in a sewage treatment plant, it is essential to decrease the volume of WAS which has difficulty decomposing.

3 Anaerobic Ammonium Oxidation

3.1 Outline of Anaerobic Ammonium Oxidation

The AMX reaction was reported in 1995 by a research group of Delft Institute of Technology in the Netherlands. It is a new metabolic pathway of nitrogen by newly discovered microorganisms. The AMX reaction is a denitrification reaction by autotrophic microorganisms where NH_4^+ is an electron donor and NO_2^- is an electron acceptor, and the following stoichiometric equation is proposed[(4)]:

$$1NH_4^+ + 1.32NO_2^- + 0.066HCO_3^- + 0.13H^+ \rightarrow 1.02N_2 + 0.26NO_3^- + 0.066CH_2O_{0.5}N_{0.15} + 2.03H_2O \quad \cdots (1)$$

Equation (1) suggests that 1.32mol of nitrite ions make a reaction with 1mol of ammonium ions and 1.02mol of nitrogen gas is produced. This is the most significant feature of this reaction.

Fig. 3 shows the metabolic pathways of conventional nitrification/denitrification and AMX. In (a), the metabolism of Ammonium Oxidation Bacteria (AOB) and Nitrite Oxidation Bacteria (NOB) has to be used to nitrify all the amount of influent ammonium to a level of nitrate. In (b) for AMX, however, the metabolism of AOB may only be used for the nitritation (Partial Nitritation: PN). According to Equation (1), 56.9% mol rate of influent ammonium should nitrify to a level of nitrite. The produced nitrite can then be removed together with remaining ammonium by virtue of the metabolism of AMX bacteria. Utilizing a difference in the inhibitory concentration to free

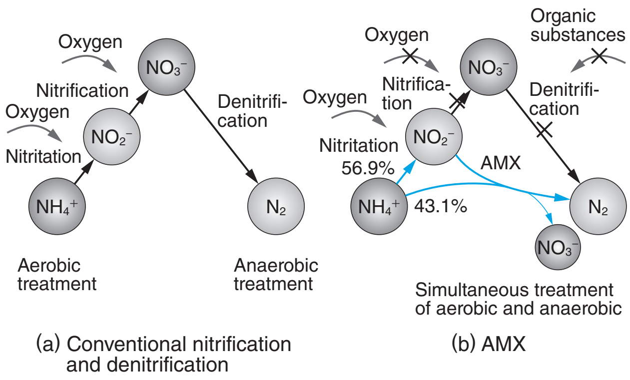

Fig. 3 Metabolic Pathway

Reactions of (a) conventional nitrification and denitrification and (b) AMX are shown. For the AMX, nitrification to a level of nitrate is not required.

ammonia between AOB and NOB, reactor conditions are adjusted so that they are an inhibition to NOB, but maintaining its activation to AOB. The concentration of free ammonia is affected by the concentration of ammonium ions, pH, and water temperature[(5)].

As suggested by Equation (1), another noteworthy feature of AMX reaction is that about 11.2% of total nitrogen in the reaction remains in a form of nitrate. In the case of nitrogen removal by this reaction, it is therefore obvious that about 88.8% nitrogen removal rate is the maximum value. Consequently, post-treatment is needed to remove the nitrate whenever more complete nitrogen removal treatment is required. Though the AMX reaction leaves a specific challenge such that nitrate remains in the process, there are many advantages as described below:

(1) Compared with conventional denitrification that utilizes heterotrophic bacteria, the Nitrogen Removal Rate (NRR) is high and the reactor for this reaction can allow for a high Nitrogen Loading Rate (NLR). The reactor can therefore, be made compact.

(2) Not by nitrate forming nitrification/denitrification treatment but by PN treatment, nitrogen removal is performed by ammonium and nitrite. The oxygen demand can therefore be reduced almost to half. As a result, the cost of power consumption attributable to aeration can be reduced.

(3) In case the low C/N ratio where a hydrogen donor-like BOD is low for conventional denitrification, it is necessary to dose an organic substance such as methanol. In the case of the AMX reaction, however, adding organic substances is unnecessary thanks to the use of autotrophic metabolism. In

addition, the nitrogen treatment is possible without the use of chemicals and running cost can be reduced.

(4) It is generally reported that the doubling time for AMX bacteria is approximately 11 days[6]. Since the biomass yield is low and the amount of WAS generation during processing is small, sludge treatment cost can be reduced.

Compared with conventional nitrification and denitrification treatments, the nitrogen treatment by AMX reaction is a promised technology resulting in space saving and cost reduction. The wastewaters suitable for application with this technology are: a liquid separated by anaerobic digestion treatment with a small C/N ratio obtained after removing organic substance, a centrate obtained after sludge dewatering and filtration, livestock waste liquid, land-fill leachate, denitration wastewater from power stations, and wastewaters containing high ammonium nitrogen. This type of treatment is very advantageous in facilities where various kinds of wastewater must be processed. This is a case where high-concentration wastewater is treated one by one before processing as combined wastewater. As described previously, the AMX treatment comes in two kinds of processes: the aerobic PN process to turn part of ammonium into nitrite and the AMX process in the anoxic tank where produced nitrite and ammonium are simultaneously removed. There are two processing types: the two-stage type where the respective processes are performed in separated tanks and the single-stage type where both processes are realized in a single tank.

3.2 Single Stage Type Deammonification Treatment

The single-stage type of processing system is widely applied to WWTPs in western countries. It is used for the treatment of centrate from digestion sludge dewatering treatment such as side-stream containing high-concentration nitrogen. The most common system among a variety of similar ones is that both reactions of nitritation and AMX are maintained in a single-stage utilizing the suspending sludge under the completely mixed condition. It is based on the deammonification treatment developed by DEMON GmbH, generally called "DEMON[7]." **Fig. 4** shows a flow chart of this treatment.

This system is of the Sequencing Batch Reactor (SBR) type. Raw influent as a continuous flow is first stored in an equalizing tank and is then intermittently

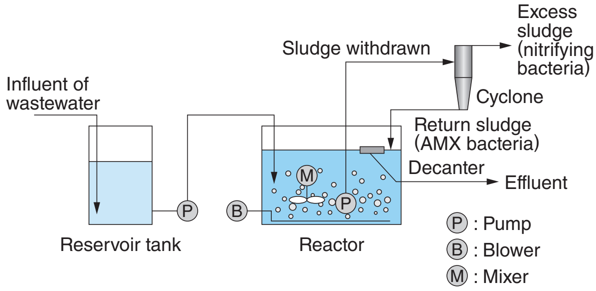

Fig. 4 Flow Diagram of Deammonification Treatment DEMON

A diagram of DEMON is shown. DEMON is operated in a single stage. Raw influent and aeration are managed by intermittent operation. The feature of DEMON is that sludge treatment is performed by a cyclone.

supplied to the reactor where aerobic and anoxic conditions are controlled by aeration with blower and agitation with mixer. In this manner, both nitrification and AMX are simultaneously performed to remove nitrogen. When water in the reactor reaches a specific water level (full level), the supply of influent is suspended and aeration and agitation are also stopped. Sludge in the completely mixed state begins to settle, and after a lapse of specified time, the sludge begins to undergo sedimentation and decants. The supernatant water regarded as the treated water is discharged from the reactor by means of a decanter. Raw influent is then intermittently supplied again and aeration and agitation are restarted. An adjustment of pH with chemicals and of substrate concentration by circulation of treated water is not required. Typical MLSS in the tank is 1.0～3.0g/L and DO is around 0.3mg/L. Value pH is variable according to the characteristic of raw influent, but 6.8～7.4 is considered to be a typical value.

The sludge consists of nitrifying bacteria in flocculated sludge and AMX bacteria in red granular sludge. By the use of a cyclone technology that is a unique feature of this system and a difference in specific gravity, granular sludge can only be separated from the extracted sludge which is a mix of two kinds of sludge. Inlet sludge entering the cyclone is turned at a high speed and heavy sludge is separated from light sludge by the effect of a strong centrifugal force. Since the nitrifying sludge is in the floc, it is lighter than AMX bacteria that form high-density granules. It is separated from the cyclone overflow together with incoming SS and turned into WAS. Since the cyclone underflow contains heavy AMX bacteria, they are returned to the reactor as return sludge. By this operation, AMX bacteria in slow growth rate can be kept in the tank at a high concentration. Features of the single-stage type deammonification treatment are summed up below.

(1) Control of the SBR system is simplified. According to changes in water quality and water quantity, automatic controlled treatment is carried out. This makes for a very robust system.

(2) It can accommodate a wide range of water temperatures within 15℃ to 38℃. When sufficient acclimation is carried out before operation at a low water temperature, it can process at a water temperature of 25℃ or below.

(3) The reaction requires alkalinity in raw influent. So far as the degree of alkalinity is sufficient, it is unnecessary to add any pH control chemicals.

(4) Compared with the two-stage type, the number of equipment and control parameters is less. Construction cost is therefore lower, maintenance is easier, and running cost can be reduced.

(5) In the process with a biomass carrier, it is necessary to create a strong flow with the use of aeration and agitation in order to utilize the biomass carrier effectively. In this case, a large amount of aeration power is consumed. Contrary to the case of deammonification treatment, the minimum oxygen supply is maintained and agitation of activated sludge is only required. As such, required power consumption can be suppressed to a minimum. Power consumption per unit removed nitrogen is approximately 1.1kWh/kg-N.

(6) By the use of a cyclone technology, AMX bacteria only with a low growth rate can be selectively retained inside the reactor. Nitrification bacteria with a comparatively high growth rate and other microorganisms can be discharged from the overflow so that the abundance ratio of nitrification bacteria vs. AMX bacteria can be controlled.

(7) By the effect of cyclone, the incoming SS can be removed from the reactor together with sludge other than the AMX bacteria. Therefore, this system is strong against the incoming SS.

According to the above advantages, the single-stage type of deammonification treatment is regarded as the most common treatment system for the AMX applicable to wastewater treatment. Application to high nitrogen concentration wastewater treatment is taking a lead in its adaptation. This system, however, makes it theoretically possible to realize deammonification treatment at a low nitrogen concentration. Accordingly, the AMX treatment by this system can be realized as a mainstream process in a sewage treatment plant where wastewater contains low nitrogen concentration.

4 Energy Self-Sufficient Wastewater Treatment

As mentioned in Section 2, the AB-process is advantageous because a large volume of organic substances can be extracted in the state of primary sludge. There is a disadvantage, however, as it makes it difficult to remove nitrogen at the latter stage. In such a situation, the advent of AMX bacteria discovered in the 1990s, the method of nitrogen removal without any organic substances was found. Later, a useful system was invented to remove nitrogen without using any organic substances even after a large amount of organic substances has been withdrawn at the A-stage. This system enables deammonification treatment in the B-stage without any problem.

In order to introduce the deammonification treatment to the B-stage, it is necessary to inoculate the AMX bacteria in the reactor of the B-stage as a large amount of AMX sludge is needed there. If a facility of deammonification treatment for the side stream is available so that high-concentration nitrogen can be treated, excess sludge generated there can be fed in the reactor of the B-stage. In this manner, AMX bacteria can be inoculated into the main stream. This is because the efficiency of AMX bacteria separation by cyclone is not 100% and excess sludge of the overflow contains some granular AMX bacteria. In order to prevent the withdrawal of AMX bacteria which begins to increase activity in the B-stage, a cyclone is also introduced to WAS line of the B-stage so that the extracted sludge from the final sedimentation tank can be processed by cyclone and only heavy AMX sludge is returned to the reactor. At that time, other lighter sludge can be removed as the WAS. Fig. 5 shows a conceptual diagram of a combination of the AB-process and deammonification treatment.

By virtue of this method, even a low ammonium concentration of 30 to 40mg-N/L in the reactor the process can maintain enough nitrogen treatment performance without losing the AMX activity. In order to remove all the nitrogen by heterotrophic denitrification, it is realized by removing autotrophic nitrogen removal by AMX with insufficient organic substances for the conventional denitrification. With

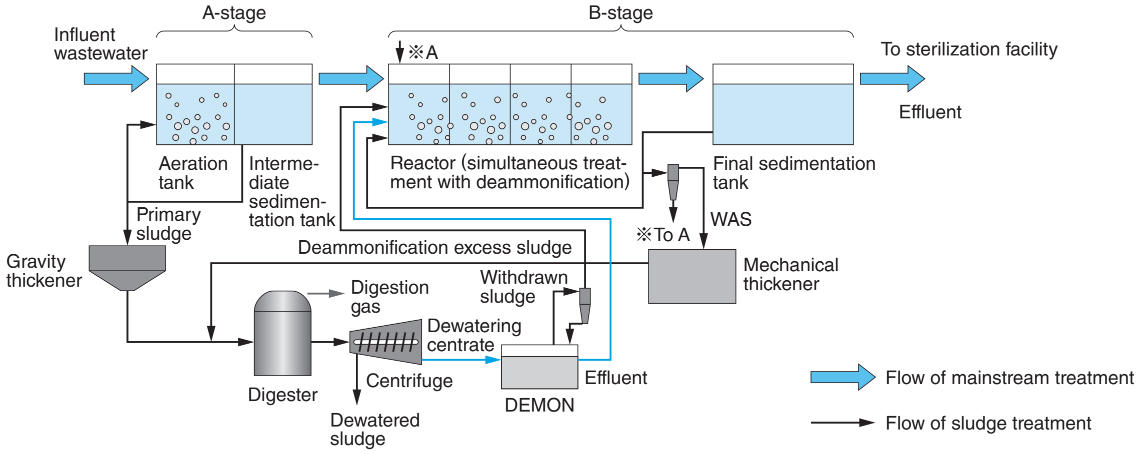

Fig. 5 Conceptual Diagram of a Combination of AB-Process and Deammonification Treatment

An example is shown in regard to a combination of AB-process at the mainstream and deammonification treatment for side stream. AMX bacteria are cultivated with high-concentration ammonium and excess bacteria are inoculated in the aeration tank of the mainstream.

influent residual organic substances from the A-stage, heterotrophic denitrification can occur at the same time. Nitrate generated as a result of AMX reaction is partly removed and the nitrogen removal rate is further raised. Compared with conventional nitrification and denitrification, the following advantages can be expected:

(1) Complete nitrification from ammonium to nitrate is not necessary even at the mainstream treatment. Since about half the amount of influent ammonium is nitrified to a level of nitrite, the air volume for aeration can be reduced.

(2) Since the nitrogen removal treatment is not required for the circulation of nitrification liquid, pumping power necessary for the circulation of nitrification liquid can be omitted.

(3) Since the biomass yield of AMX bacteria is low, the amount of WAS can be decreased.

(4) The dewaterability for the WAS is increased by 3～5% and dewatered sludge concentration amounts to more than 30%.

(5) When 60% organic substance load is removed at the A-stage, only 40% load remains in the B-stage. Compared with the aeration tank for the conventional activated sludge process, the load is therefore lightened and this leads to the reduction of blower capacity and tank volume.

As mentioned above, regarding a problem of nitrogen which is a major problem of the AB-process, it can solve by the introduction of the AMX method. While increasing the amount of withdrawal of easily digestive primary sludge at the A-stage, hard-to-digest WAS is decreased at the B-stage. As a result, the volume of digestion gas generation is increased. Since there is minimal concern for organic substance to remove residual nitrogen at the B-stage, these organic substances can be recovered liberally at the A-stage in the form of primary sludge. Here, there is a method for a further enhancement to raise the organic substance removal rate by adding a coagulant into the reactor of the A-stage. In such a case, the organic substance removal rate attains 75% or higher and the volume of primary sludge to be fed to the digestion tank is further expanded.

The energy self-sufficient WWTP developed by the DEMON is called “EssDe (Energy Self-Sufficient by DEMON).” The energy self-sufficient WWTP is a systematic facility where the above processing system is utilized to maximally remove organic substances from the A-stage in the form of primary sludge. The withdrawn primary sludge is transferred to the digestion tank to increase the volume of digestion gas generation (exceeding twice the yield by standard method in terms of weight ratio of produced methane). The electric power is generated by the increased digestion gas as fuel and all the generated electric power is used to cover the total power consumption in a treatment plant. No particular modification is required for ordinary digestion tanks. Since the volume of gas generation is inflated however, it is necessary to expand a digestion gas power generating facility capacity. Because the volume of generated gas is increased, the amount of electric power generation is increased and energy self-sufficiency rate is raised at the treatment plant. If there is excess power generation, electric power can be sold to the power company and the WWTP can be a power station for its regional area.

5 DEMON Demonstration Test in Japan

In order to demonstrate whether the single stage type deammonification treatment DEMON as the elementary technology of the EssDe is applicable in Japan, we conducted a demonstration pilot test for the treatment of ammonium nitrogen contained in the anaerobic digestion sludge dewatering centrate. This demonstration test was carried out at the Hokubu Sludge Treatment Plant in cooperation with City of Yokohama.

For the DEMON reactor, a water tank with an effective volume of 6.6m^3 was used. A concentration of ammonium nitrogen contained in the dewatering centrate was about 1000mg-N/L, which is considered a high concentration. The processing time per batch treatment was 8 hours. The batch treatment was made three times a day. The goal value for the nitrogen treatment was set at the same performance level of a full scale plant in Europe or the U.S. Nitrogen Loading Rate (NLR), which was 0.7kg-N/m^3/d. The treatment capacity was 4.6m^3/d and nitrogen load was 4.6kg-N/d. The DEMON sludge consisting mainly of AMX bacteria as the seed sludge was injected in the reactor to start up the operation from a low load. **Fig. 6** shows a flow chart of treatment for the DEMON pilot plant.

Fig. 7 shows time courses in nitrogen load, volume of processing water, and NLR during the demonstration test. Since this testing was performed without any means of heating, water temperature in the reactor at the beginning of testing was low, less than 25℃ due to the lowering of ambient temperature. As such, the rise of microbe activity was moderate and hence nitrogen treatment capability was kept low. Around the 80th day after the start of the operation, water temperature in the reactor had begun to rise as high as 30℃ along with the rise of ambient temperature. As a result, activities of microorganisms were intensified to increase the volume of processing water to raise the nitrogen load. With the rise of the nitrogen load, sludge concentration was raised to 1500mg/L on the 90th day and 2500mg/L on the 104th day. Thereafter, the NLR realized the goal value of 0.7kg-N/m^3/d. After reaching the goal load, the mean nitrogen removal rate of 80.6% had been attained and maintained for about 3 weeks. We confirmed the stable nitrogen treatment performance.

We demonstrate the capability of providing the same performance in the Japanese WWTPs by the processes common in Europe and the U.S.

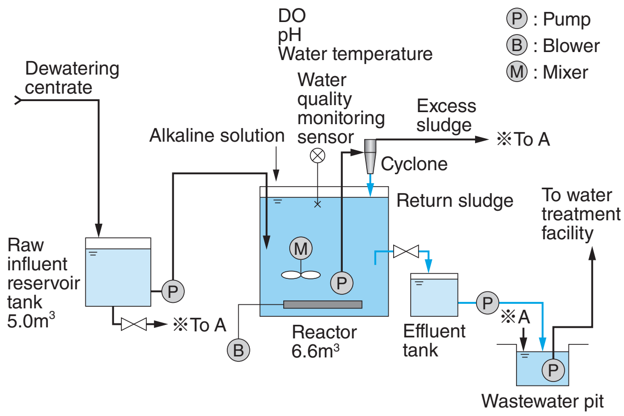

Fig. 6 Flow Chart of Treatment for the DEMON Pilot Plant

A processing flow diagram of the DEMON pilot plant is shown.

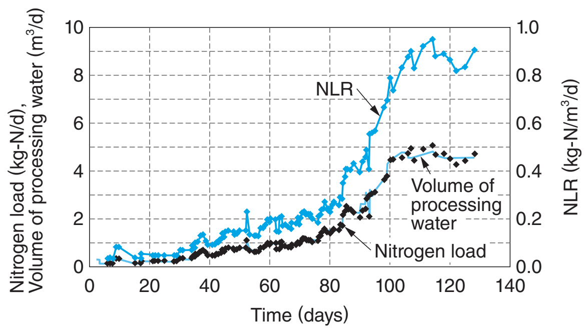

Fig. 7 Time-Courses in Nitrogen Load, Volume of Processing Water, and NLR Observed during the Pilot Test.

The result of nitrogen removal treatment during the pilot test is shown and the treatment reached the target load on day 104th.

6 Postscript

In Europe, there is a belief that sewage water is not waste material, but a reusable energy resource. Based on this concept, energy self-sufficiency is currently pursued at several WWTPs and we found some successful cases in the WWTPs.

We demonstrated the feasibility of DEMON in the field of Japanese sewage treatment as this expertise is indispensable for energy self-sufficient wastewater treatment. Building on this success, we intend to further demonstrate that energy self-sufficient sewage treatment can be realized in Japan, although there is a difference in wastewater quality between Japan and those of Europe and the U.S.

In closing this paper, we would like to propose that the next-generation wastewater treatment should be changed from high energy consuming type sewage treatment to self-sufficient wastewater treatment by the energy of sewage.

Lastly, we would like to express our sincere gratitude to the Environmental Planning Bureau of City of Yokohama for their cooperation extended during the demonstration test on ammonium nitrogen treatment of the wastewater digestion sludge dewatering centrate.

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