Featured Articles

Control Technology, Advanced Treatment Processes, and Next-generation Systems for Sewage and Wastewater

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OVERVIEW: A backlog of work on the enhancement and development of urban infrastructure, which has failed to keep pace with rapid population increases and urbanization in various parts of the world, has resulted in severe problems for society due to such environmental issues as aquatic degradation, unreliable water and electric power supplies, atmospheric pollution, noise problems, the generation and dumping of large quantities of waste, and traffic congestion. Through the integration of various elements, including operational control of sewage and wastewater, simplification of existing treatment techniques and improvements in their energy efficiency, advanced treatment systems, and next-generation technologies, Hitachi is contributing to the sustainable development of social infrastructure by supplying solutions for the water industry that improve the operation of its infrastructure at the city and regional level.

INTRODUCTION

THE sewage and wastewater produced by people's daily activities is normally purified by treatment systems that operate at the municipality, water basin, or work site.

Hitachi is developing technologies for sewage treatment systems in accordance with its Environmental Vision 2025. Hitachi sees these latest sewage and wastewater treatment technologies as effective ways of minimizing the emission of greenhouse gases and the generation of solid waste, and of contributing not only to maintaining and improving the environmental state of waterways in order to provide a richer way of life, but also to supporting emergency response and recovery activities at disaster sites.

This article describes Hitachi's activities in this field with a particular focus on control techniques for sewage and wastewater treatment, advanced treatment processes, and technologies for next-generation systems.

DEMONSTRATIONS INVOLVING USE OF ICT TO IMPLEMENT EFFICIENT OPERATIONAL CONTROL OF NITRIFICATION

Overview of Demonstrations

The infrastructure that treats the sewage produced by domestic and business activities faces a wide variety of challenges. These include aging equipment, financial difficulties, energy efficiency, water quality management, staff shortages, declining populations, and the need to cover wider geographical areas. With the aim of dealing with energy efficiency and water quality management in particular, Ibaraki Prefecture and Hitachi commenced "demonstration of efficient nitrification control with information and communications technology (ICT)" for improving the control of nitrification. This research was contracted by the National Institute for Land and Infrastructure Management as part of the Breakthrough by Dynamic Approach in Sewage High Technology Project (B-DASH project) of the Ministry of Land, Infrastructure, Transport and Tourism. The work involves the collection and verification of operational data from a number of water treatment lines at the Kasumigaura Sewage Treatment Plant in Ibaraki Prefecture (with a treatment capacity of approximately 6,500 m^3/day).

Overview of New Control System

Fig. 1 shows an overview of the newly developed control system. The system controls the treatment process to improve the efficiency of nitrification (part of the nitrogen treatment process) and achieve both energy efficiency and water quality management. To save power by reducing blower output (airflow rate), a downstream dissolved oxygen (DO) sensor was installed along with upstream and mid-point ammonia sensors. In addition to predictive and feedback (FB) control (FB control works by making corrections based on the deviation between the actual and desired output), the system also features the use of a treatment characteristics model for feedforward (FF) control. This combination of FB and FF control is intended to help maintain stable operation by responding quickly and appropriately to changes in the incoming sewage flow rate and concentration. Furthermore, FF control uses a treatment characteristics model that provides information on the blower output required for nitrification treatment. Because this treatment characteristics graph can be updated automatically based on the measurements from the ammonia sensors, the accuracy of the predictive model can be maintained automatically. The treatment characteristics graph also functions as a way of indicating the treatment characteristics of the activated sludge (microbes). This improves the efficiency of maintenance by making possible the early identification of changes in the behavior of the microbes or trends in treatment problems.

Progress of Demonstrations

Trial operation commenced in January 2015. Fig. 1 shows how the aeration airflow varies over time under the new control system and constant-DO control respectively. The new control system has a lower airflow than constant-DO control at all times of the day. The aeration airflow during the trial was 85.9%, with the FY2014 results showing a 14.1% reduction in airflow compared to constant-DO control while still keeping the concentration of ammonia in the treated water to 0.3 mg-N/L. The trial is continuing in FY2015 to verify the reliability of the system over long-term use.

The new monitoring and control system incorporates advanced control functions and is particularly effective when used with blowers that have a high level of controllability. Accordingly, it is anticipated that using this technology when upgrading monitoring and control systems, blowers, and other equipment will deliver improvements in energy efficiency and water quality management.

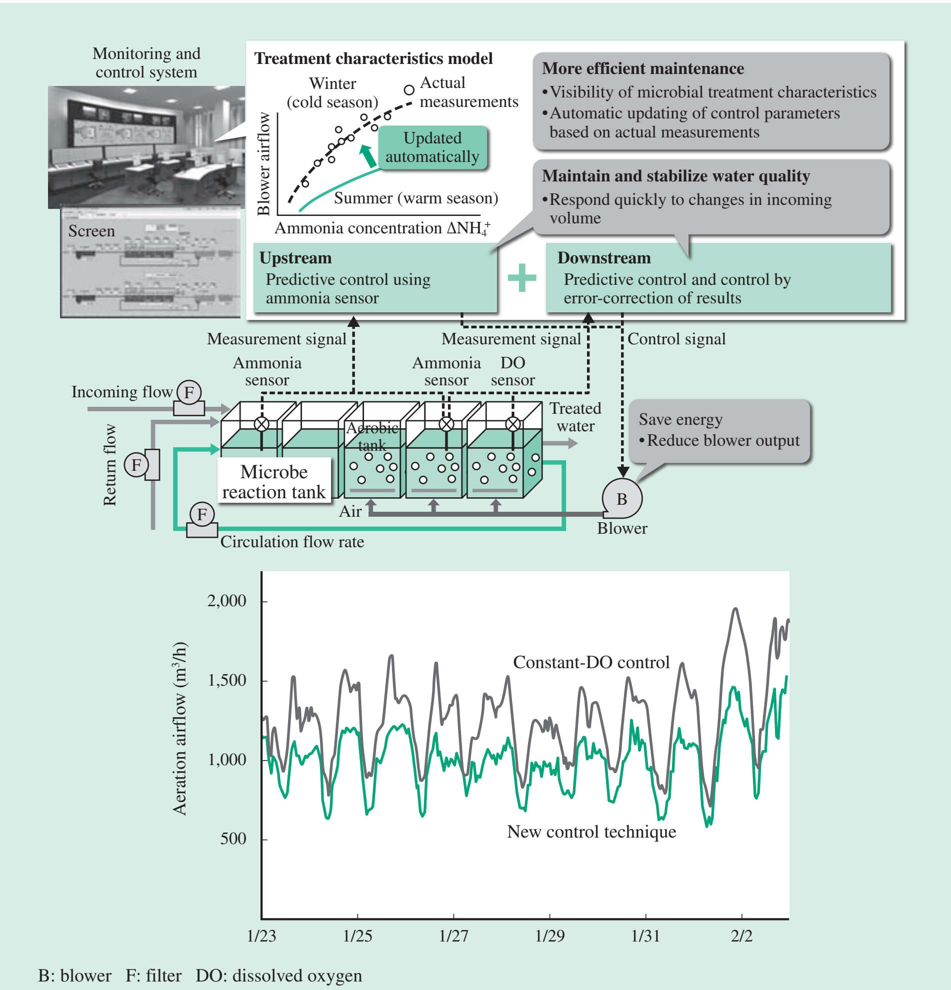

Fig. 1—Overview of New Control System (Top) and Graph of Variation in Aeration Airflow over Time (Bottom).
The results for FY2014 indicated a 14.1% reduction in aeration airflow without compromising the quality of treated water. The trial is continuing in FY2015 to verify the reliability of the system over long-term use.

DEVELOPMENT OF TECHNIQUES FOR IMPROVING ENERGY EFFICIENCY OF MEMBRANE BIOREACTORS

Development of Techniques for Improving Energy Efficiency of Membrane Bioreactors

Membrane bioreactors (MBRs) consist of a waste water treatment process with activated sludge in tanks for biological treatment, and a micro filter for separating suspended solids and other pollutants, to gain clear treated water. Furthermore, one of the major benefits of MBRs is that they are far smaller in size than conventional methods. Hitachi markets smaller-scale MBRs in the Middle East area. As a part of national projects coordinated by the New Energy and Industrial Technology Development Organization (NEDO) and the Japan Science and Technology Agency (JST), research and development work aimed at providing energy saving solutions has been conducted since FY2009, especially on the reduction of aeration, which accounts for 60% of system energy consumption for aeration during the membrane surface cleaning and biological treatment process as stated above. The newly developed techniques reduced membrane cleaning and thus achieved a reduction of system power energy consumption per cubic meter of treated water of 0.4 kWh.

The aeration unit employed for membrane surface cleaning is installed at the bottom of the membrane unit, which consists of a series of membrane sheets. The shear stress, which is generated by the air-liquid two-phase flow in the channels between the membrane element panels, works effectively for membrane surface cleaning, thereby realizing a continuously filtering cleaning process. In these projects, a new type of aeration tube, which is orthogonally oriented to the element panels, was developed (see Fig. 2). This aerator uniformly distributes bubbles into the channels between membrane element panels to increase the efficiency of membrane surface cleaning. Consequently, the aeration flow rate for membrane surface cleaning is reduced by 30%. In addition, intermittent aeration (see Fig. 3) was found to increase the velocity differential between bubbles and liquid phase (see Fig. 4), and promote turbulence around bubbles (in the boundary layer of bubbles), especially in the wake, with computational fluid dynamics (CFD). The larger velocity differential increases shear stress in the wake of bubbles compared to conventional continuously aerating operation, and thus cleans the membrane surface more efficiently. And the validation experiment shows that this aeration process substantially decreases the rate of trans membrane pressure (TMP) (see Fig. 5). As shown in the result of this experiment, the intermittent aeration method achieves further reduction of the aeration rate. The combination of the newly developed aerator and intermittent aeration process was confirmed to eventually reduce membrane cleaning aeration and the system energy consumption per cubic meter of treated water to achieve 0.4 kWh.

In the future, Hitachi plans to assess possible energy saving methods on other equipment (including aeration blowers for biological treatment and circulation pumps) as well, to realize further energy

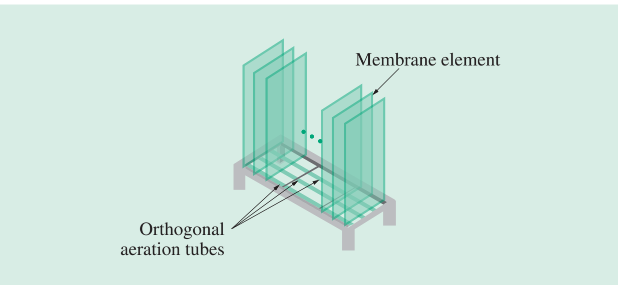

Fig. 2—Membrane Elements and Orthogonal Aeration Tubes.
The orthogonally aligned aeration tubes uniformly distribute bubbles into the channels between membrane element panels.

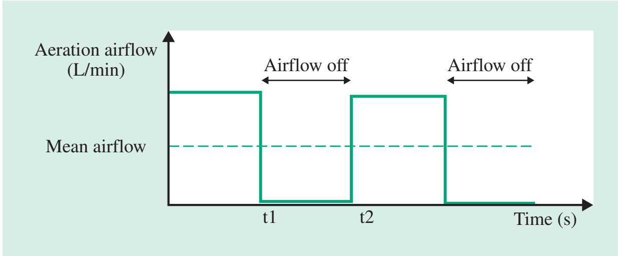

Fig. 3—Intermittent Aeration Process.
Aerating and halting intermittently reduces the amount of aeration while the airflow is off.

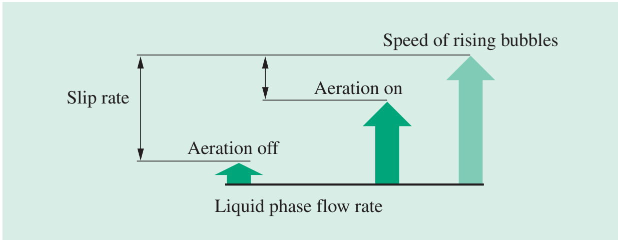

Fig. 4—Velocity Differential between Bubbles and Liquid Phase.
Change of liquid phase velocity generates larger velocity differential, and larger shear stress around the bubbles to further efficiently clean membrane surface.

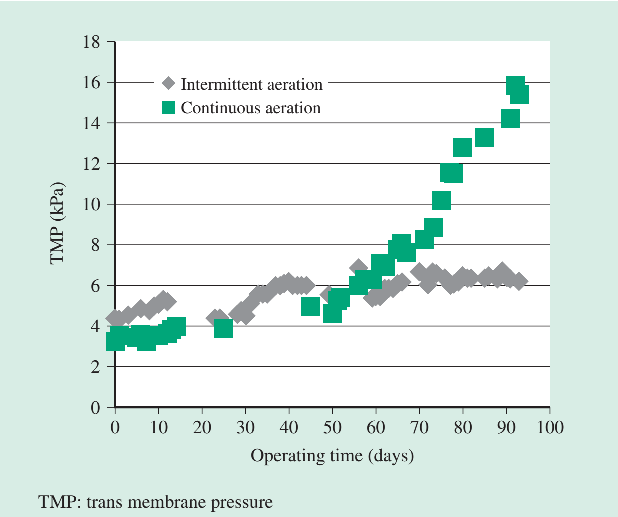

Fig. 5—TMP Trends in Conditions of Continuous and Intermittent Aeration.
The intermittent aeration process greatly improves the efficiency of membrane surface cleaning to substantially decrease the TMP rate.

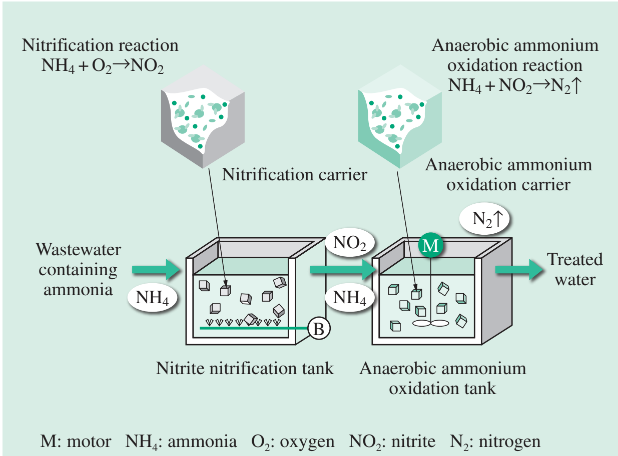

Fig. 6—Overview of Anaerobic Ammonium Oxidation Treatment System Using Inclusive Immobilization.
Nitrifying bacteria contained in inclusive immobilization carriers are added to the nitrite nitrification tank to oxidize half of the ammonia to nitrite. Similarly, anammox bacteria contained in inclusive immobilization carriers are added to the anammox tank to perform denitrification of ammonia and nitrite.

efficiency improvement aiming at 0.3 kWh or lower for the system energy consumption per cubic meter of treated water.

NITROGEN TREATMENT SYSTEM USING ANAEROBIC AMMONIUM OXIDATION

A variety of industries produce nitrogen-rich effluent, including inorganic chemical and semiconductor manufacturing and livestock. To prevent eutrophication and other forms of pollution of enclosed waterways such as harbors or lakes and marshes, the regulation of nitrogen effluent has been getting progressively stricter, including the introduction of the seventh total emission control standard in 2014. The nitrogen treatment technique currently in widespread use employs activated sludge for biological nitrification and denitrification. This consists of a nitrification process that uses nitrifying bacteria to oxidize all of the ammonia (NH_4) in wastewater to nitrate (NO_3), followed by a denitrification process in which nitrifying bacteria convert this nitrate and organic matter to nitrogen gas (N_2).

An alternative to this, devised in the 1990s, is the anaerobic ammonium oxidation (anammox) reaction that enables more energy-efficient water treatment. This reaction relies on autotrophic anammox bacteria to convert a quantity of ammonia and approximately 1.3 times that quantity in nitrite (NO_2) to nitrogen gas. Its advantages include not requiring organic material and the fact that roughly half the ammonia in the wastewater is converted directly to nitrogen gas without being oxidized, thereby reducing the energy used for the nitrogen treatment. Nitrogen treatment systems that use this reaction (anammox treatment systems) have two tanks, with the addition of a nitrite nitrification tank in which roughly half the ammonia is oxidized to nitrite located upstream of the anammox tank. A feature of Hitachi's anammox treatment system is its use of an inclusive immobilization technique. This involves immobilizing the anammox bacteria and other active microbes in a polymer gel that acts as a carrier (see Fig. 6). Because the active microbes are present in this carrier in high concentration, they can be expected to provide reliable treatment performance and a fast treatment rate. The effectiveness of the system has already been demonstrated in experimental trials using actual wastewater, where benefits included a reduction of approximately 50% in energy use compared to previous methods and reliable long-term performance(1).

Hitachi also supplied equipment for the treatment of wastewater at a chemical plant that manufactured ammonia in 2013 (see Fig. 7). At about 100 m^3, the reaction capacity of the anammox was among the largest in Japan. The anammox treatment systems that use inclusive immobilization are at the leading edge, with few examples in operation anywhere in the world. The following section describes one example(2).

The wastewater at this site has an ammonia concentration of approximately 700 mg-N/L, with

Fig. 7—Supplied Treatment System.
Hitachi supplied a nitrogen treatment system that uses the anammox reaction to treat wastewater from a plant that manufactures ammonia.

approximately 100 to 400 mg/L of methanol included to provide the organic matter. It has been reported that methanol is very detrimental to both the nitrification and anammox bacteria used in anammox treatment systems. Accordingly, an upstream denitrification tank and biochemical oxygen demand (BOD) oxidation tank for removing methanol were fitted in the upstream part of the anammox treatment system (see Fig. 8). All of the tanks other than the downstream denitrification tank are supplied with carriers that use inclusive immobilization to contain the bacteria required for their respective functions.

The upstream denitrification tank and BOD oxidation tank eliminate all of the methanol from the wastewater. After this treatment, the wastewater continues to the nitrite nitrification tank where approximately half of the ammonia is converted to nitrite. The ammonia and nitrite contained in the wastewater discharged from this tank is then converted to nitrogen gas in the anammox tank. The mean total nitrogen concentrations of the inflow and outflow of the anammox tank are 676 mg/L and 110 mg/L respectively, indicating removal of more than 80% of the nitrogen. To date, the plant has already maintained reliable nitrogen treatment performance for more than a year. Hitachi believes this ongoing reliable performance demonstrates the validity of the development work to date.

SEWAGE TREATMENT USING MFCs

Sewage is treated by a biological process using activated sludge, and organic matter in the sewage is decomposed by microbes. An issue with this method is the disposal of the excess sludge that accumulates due to the multiplying number of microbes. While it can be disposed of as industrial waste, this accounts for approximately 20% of operating costs. This has created demand for a new treatment technique that reduces the quantity of sludge produced by sewage treatment.

Hitachi is developing a new sewage treatment system that incorporates a microbial fuel cell (MFC) into the sewage treatment system. This not only reduces sludge production by more than 30%* compared to previous treatment methods, it also generates "eco-power" to supply some of the on-site loads such as lighting.

* Estimate by Hitachi based on comparison with previous oxidation ditch method.

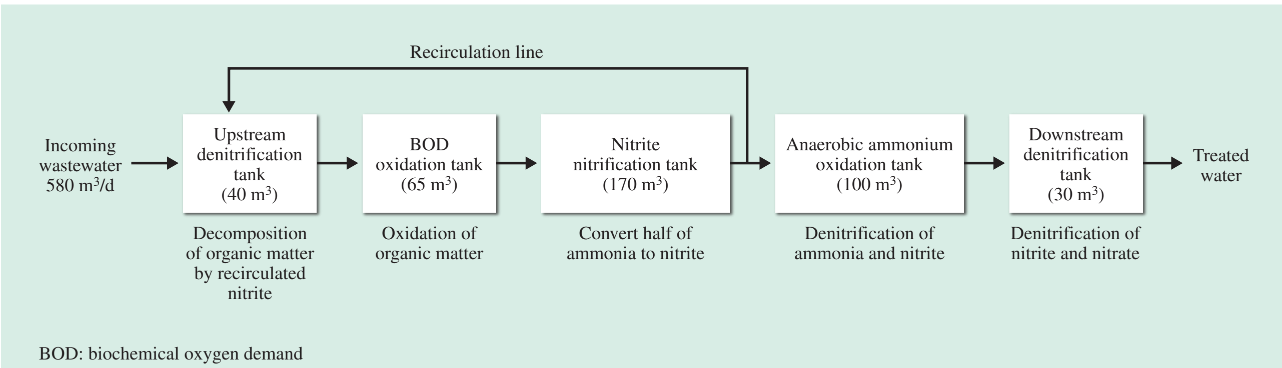

Fig. 8—Flow of Wastewater at Treatment Plant that Uses Inclusive Immobilization.
The diagram shows the flow of wastewater through a treatment system with a rated flow rate of 580 m^3/day. The methanol present in the wastewater is removed in the upstream denitrification tank and BOD oxidation tank. Nitrogen removal involves first converting half of the ammonia in the wastewater to nitrite in the nitrite nitrification tank, followed by the denitrification of ammonia and nitrite in the anammox tank. The downstream denitrification tank then eliminates some of this residual nitrite and nitrate together with the added organic matter.

This groundbreaking technology reduces the volume of sludge produced by using an MFC to recover the electrons and hydrogen produced by microbes in the process of decomposing organic matter in the form of electrical energy, thereby inhibiting microbe multiplication. The anode is submerged in the wastewater and the cathode is located on the treatment tank wall with an oxygen-permeable waterproof layer. The electrons produced by microbes as they decompose organic matter are collected by the anode. At the cathode, which has an oxygen-permeable film with a catalyst coating, water is produced by the reaction on the catalyst of hydrogen ions with the oxygen passing through the film[3]. In other words, the principle of operation of the MFC is that it generates electric power and produces water through the reverse electrolysis of water. (see Fig. 9).

Whereas microbes normally use the electrons freed by the decomposition of organic matter to drive their own multiplication, this process is impeded due to some of these electrons being captured by the anode. As a result, less sludge is produced.

The challenges associated with the development of a sewage treatment system that incorporates an MFC are to conduct system evaluation using actual wastewater, to significantly reduce the cost of the anode and cathode, and to increase electrode size from several centimeters to about 1 m.

As it works toward commercialization, Hitachi has been seeking to identify and overcome the challenges by conducting continuous long-term trials using wastewater obtained from a municipal sewage treatment plant. One of the factors in the high cost of the cathodes is the platinum (Pt) commonly used as the catalyst required by the reaction[4]. In response, Hitachi has reduced the cost of the cathode to roughly one-quarter the previous cost by adopting a carbon cathode that does not contain Pt. Continuous testing using this cathode demonstrated its ability to process the organic material contained in wastewater reliably and for long periods of time, while also generating electric power at a rate, albeit small, of 8.8 mW per square meter of electrode. Measuring effluent chemical oxygen demand (COD) concentration, an indicator of how much organic matter is being decomposed in the wastewater, the technique achieved a mean value of 9.7 mg/L, which represents water quality similar

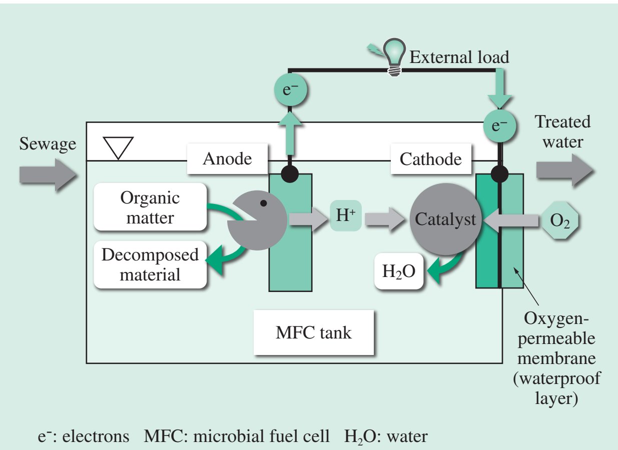

Fig. 9—Decomposition of Organic Matter and Electric Power Recovery Using MFC.
Electrons released by the decomposition of organic matter are collected by the anode, while oxygen permeates through the cathode to react with hydrogen on the catalyst to form water.

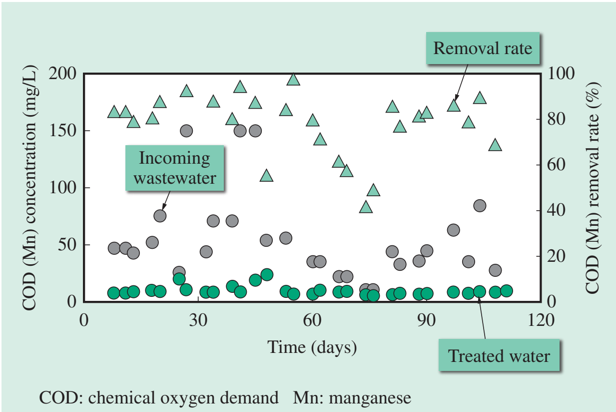

Fig. 10—Evaluation of Sewage Treatment Performance on Benchtop Pilot Plant.
The benchtop pilot plant has demonstrated reliable treatment performance over long-term operation, as measured by COD. The quality of treated water is equivalent to existing wastewater treatment plants.

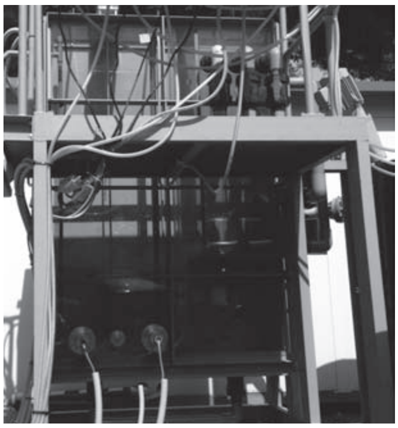

Fig. 11—Pilot Plant Using Large Anodes and Cathodes.
A pilot plant fitted with four large anodes and cathodes (1,000 × 250 mm) has been installed at a sewage treatment plant and commenced operation.

to that at existing wastewater treatment plants (see Fig. 10).

Hitachi has also been developing large anodes and cathodes suitable for a full-scale plant, and has succeeded in building prototypes with sizes in the 1-m range. A pilot plant that uses these large anodes and cathodes has been built and installed at the abovementioned municipal water treatment plant (see Fig. 11). Hitachi is currently commencing continuous operation trials using actual sewage to verify the effectiveness of the technique by evaluating how well it decomposes organic matter, reduces the production of sludge, and generates electric power.

CONCLUSIONS

Hitachi intends to continue offering new ways in which it can play a part in maintaining and improving wholesome water environments, and achieving the sustainable development of water infrastructure that reduces the load on the environment.

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