Approach on Global Environment Preservation by Wastewater Treatment

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OVERVIEW: The Hitachi Group is developing three key wastewater-treatment technologies, which contribute to global environmental protection, and promoting their deployment around the world. As for the first technology, a nitrogen-removal system using entrapped immobilized microorganisms, making use of its excellent nitrification performance, its application to treatment of household sewage and industrial effluent in China is targeted. In regard to the second technology, an MBR system, the MBR water-recycling business in the water-resource-poor Middle East, where household sewage is considered a precious water resource, is currently expanding. As for the third technology, a ballast-water treatment system, maritime environments are conserved through commercialization of a flocculation and magnetic-separation method (which takes environmental preservation into account by not using disinfection agents) in order to prevent disruption of eco-systems and bacterial epidemics in the oceans of the world.

INTRODUCTION

GIVEN that the 21st century is said to be the "century of water," the issue concerning water as the foundation of life around the world is becoming real. Under this circumstance, while targeting global business expansion, the Hitachi Group is developing advanced equipment and systems and providing solutions that will contribute to global environmental preservation (see Fig. 1).

Among the world's population of about 6.5 billion people, 1.1 billion people live lives in which safe drinking water is unattainable, and 2.4 billion people live lives without proper sanitary facilities (such as wastewater and night soil treatment). In the "World Water Vision" report published by the Second World Water Forum in the year 2000, it is forecast that four billion people — or more than half the world's population — will face "water stress" by 2025[1] (see

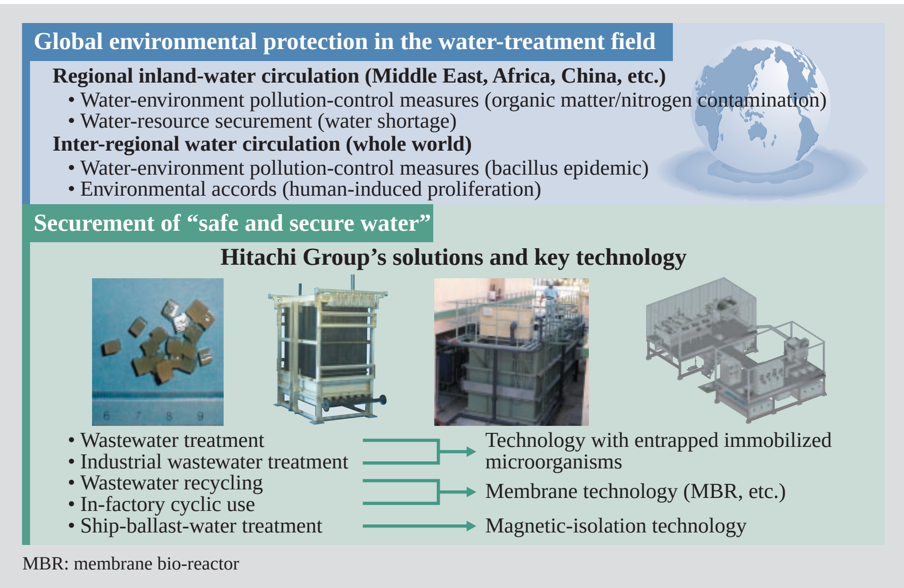

Fig. 1—Hitachi Group's Efforts Towards Global Environmental Preservation in the Wastewater Treatment Field.
Aiming to provide optimum solutions to various problems in many areas of the world, the Hitachi Group is orchestrating technologies within our group and, thereby, contributing to development of water-treatment technology for supplying safe and secure water to people throughout the world.

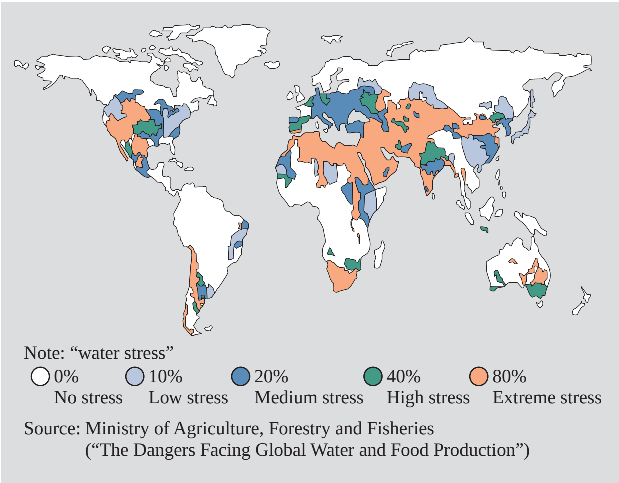

Fig. 2—Water Stress in 2025 Under the Status Quo[1].
"Status quo scenario" means that policies are maintained and a scenario in which present trends concerning water usage continue as is into the future is realized; "water stress" is an index expressing shortage of water needed by people and their environment. In 2025, it is forecast that four billion people will come face to face with high water stress.

Fig. 2).

In recent years, under the influence of global warming, the unrelenting march of water shortages has quickened, and this could lead to expansion of areas suffering water shortages. Moreover, in regions where the spread of sanitary equipment is delayed, the matter of severe environmental-water contamination is being faced, and the role of water-treatment technology in global environmental protection is becoming vital.

From the viewpoints of "measure against environmental water contamination," "water recycling," and "environmental harmony," the rest of this report describes overseas deployment of three core technologies: a nitrogen-removal system (using entrapped immobilized microorganisms) which is a core technology of Hitachi Plant Technologies, Ltd., an MBR (membrane bio-reactor) system, and a ballast-water treatment system (which has recently been attracting attention in a new water-treatment market).

NITROGEN-REMOVAL SYSTEM USING ENTRAPPED IMMOBILIZED MICROORGANISMS

The nitrogen-removal system using entrapped immobilized microorganisms — a leading technology developed by Hitachi Plant Technologies, Ltd. — is building up practical achievements — centered on water-treatment plants in Japan and private-industry wastewater treatment. Focused on China, global deployment of this system is described in the following section.

Solutions to Water Problems in China

In China, where the problem of water contamination is growing, under the Chinese Government's 11th Five-year Plan (2006–2010), sewage-treatment measures are being strictly prioritized, and achievement of a sewage-treatment ratio of 70% for major cities throughout China is targeted[2],[3].

Nitrogen-removal treatment is becoming urgent as a measure against eutrophication of lakes. In particular, a strict ("level A") treatment standard (i.e. effluent total nitrogen: 15 mg/L; ammonium-nitrogen: 5 mg/L) has been applied at all water-treatment plants of the Taihu Lake district up to Jiangsu Province since September 2007, and reconstruction plans are being implemented at about 170 locations. Furthermore, regulations concerning industrial-effluent treatment are being beefed up, and plants that do not conform to them are being reprimanded or shutdown. Under these circumstances, effective treatment technologies for various kinds of industrial effluent other than sewage water as well as for high-concentration ammonium-nitrogen contained in sanitary landfill leachate are being demanded. Accordingly, the scope for the Hitachi Group to contribute in these areas is huge.

Given the above situation, in regard to our globally successful nitrogen-removal system using entrapped immobilized microorganisms, we are aiming to offer the system to the Chinese market — which possesses great significance from the viewpoint of environmental preservation — and investigating its applicability for treating actual effluent in China.

Overview and Features of Entrapped Immobilized Microorganisms

Entrapped immobilized microorganisms combine microorganisms and a prepolymer, which are polymerized in a polymer gel, formed into a cubic shape with sides of 3 mm (see Fig. 3). By holding the nitrifying bacterium at high concentration in the microscopic matrix structure of the gel, two superior features — namely, speed of initial rise of process performance and process stability — compared to another attached immobilization method (namely, attaching microorganisms to a carrier surface) can be attained.

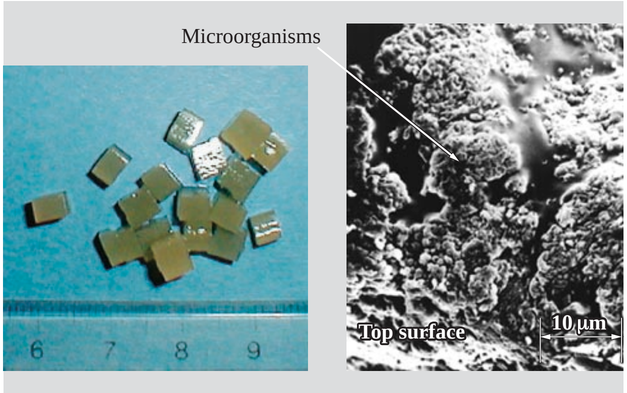

Fig. 3—Appearance of Entrapped Immobilized Microorganisms (left) and Electron Micrograph of Carrier Cross Section (Right). Microorganisms are retained at high concentration in the interior of carriers (formed as 3-mm-sided cubes).

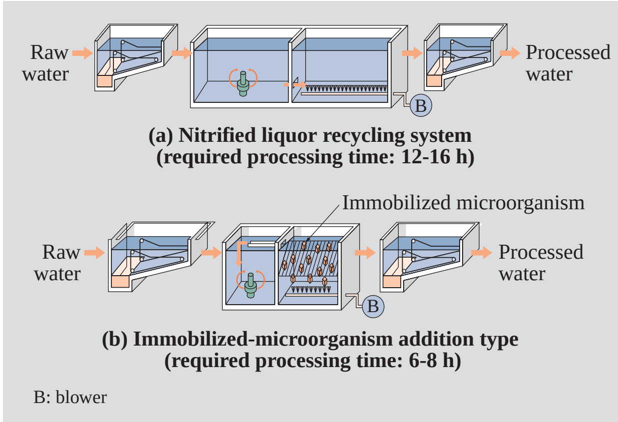

Fig. 4—Overview of Nitrogen-treatment System for Wastewater. By using entrapped immobilized microorganisms, it is possible to convert for nitrogen-removal processing without having to add reaction vessels of a conventional activated sludge process.

Overview of Nitrogen-removal System for Wastewater Treatment

The nitrogen-removal system using entrapped immobilized microorganisms improves nitrogen-removal efficiency by retaining the microorganisms injected into a nitration tank by means of a screen and facilitating a nitration reaction. In the case that a reaction vessel for the standard activated-sludge system used in most sewage-treatment plants (necessary reaction time: 6–8 h) is converted for nitrogen-removal treatment, it is necessary to double the size of the reaction vessel when the conventional nitrified liquor recycling system (necessary reaction time: 12–16 h) is used. With our new nitrogen-removal system, however, modification work can be done without expanding treatment facilities, and it is well suited to conversion of an existing treatment plant with site-expansion constrains (see Fig. 4).

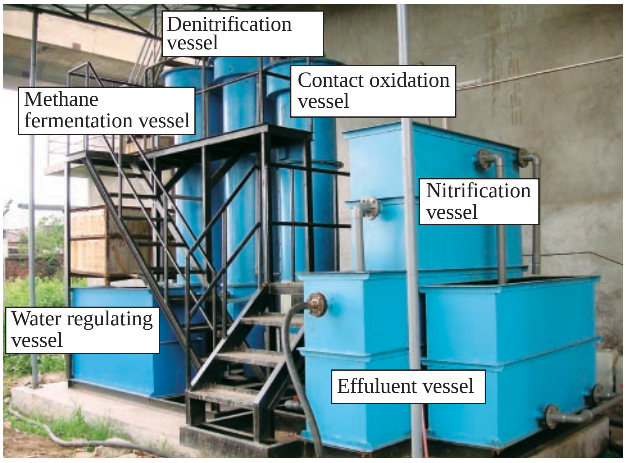

Fig. 5—Pilot Plant for High-concentration-ammonium Effluent Treatment.
Appearance of a facility for processing at 600 L/d (process flow: methane fermentation → denitrification → contact oxidation → nitrification) is shown.

Example of Performance Verification of Entrapped Immobilized Microorganisms in China

In regard to high-concentration ammonia-containing effluent, as a joint collaboration with Shanghai Jiaotong University, a pilot plant was set at a brewery company in Guangdong Province, and treatment experiments on the brewery's effluent were carried out (see Fig. 5)(4). Ammonium-nitrogen flowing into the nitration tank at a concentration of 200 mg/L could be reduced to 15 mg/L by the nitrogen-removal treatment, thereby satisfying the target value (first-class standard in China: ammonium-nitrogen concentration of 15 mg/L or less).

Issues and Future Developments Concerning Application of Entrapped Immobilized Microorganisms in Wastewater

As for present circumstances in China, four processes are being adopted for nitrogen removal from wastewater: OD (oxidation ditch), sequencing batch activated sludge process, AO (anaerobic-oxic) process, and A_2O (anaerobic-anoxic-aerobic) process(5). To apply entrapped immobilized microorganisms to the OD process and sequencing batch activated sludge process, modification of, for example, reaction vessels and carrier-separation systems, is necessary.

Moreover, it is common that industrial effluent is mixed in with wastewater at sewage-treatment plants in China, so nitrogen concentration in sewage is higher than that in Japan. This means that, and under the assumption that water quality varies greatly, the necessary treatment time for nitrogen removal is longer than that for a water-treatment plant in Japan. Since application of entrapped immobilized microorganisms shortens the nitrification reaction time and secures enough processing time for nitrogen removal, it improves nitrogen-removal ratio and is applicable to plant conversion targeting first-class sewage treatment.

To continue to apply new technologies in China, experimental verification using actual effluent in China and plant operation data are needed, and prompt demonstration at sewage-treatment plants is being targeted. Although China has many huge treatment plants that are much bigger than those in Japan, the above-described treatment technology can also be applied in China and, thereby, significantly contribute to improving the water environment in China.

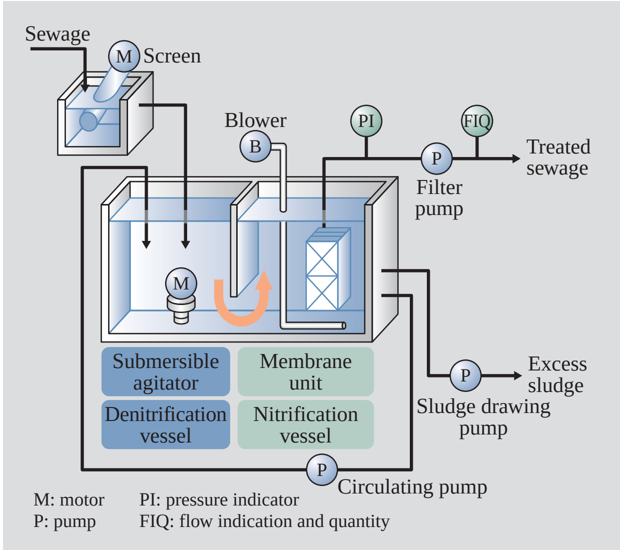

Fig. 6—Standard Flow of MBR System.
The MBR system plays a role as an advanced treatment process, in which a biological reactor is composed of a nitrogen-removal vessel and a nitrification vessel, within which a membrane unit is installed.

MBR SYSTEM

As previously mentioned, in places lacking in water resources, how to effectively utilize limited water resources is paramount. The rest of this section describes development of an MBR system — a core technology for accomplishing a sound water cycle and reusability in regions where water deficiency is becoming a grave concern — and expansion of Hitachi's water-recycling business in the Middle East.

Overview of MBR System

The MBR system performs water treatment by combining biological treatment and membrane separation. In contrast to the conventional activated sludge process, a membrane unit is submerged in a biological reaction vessel and solid-liquid separation is performed. The feature of this system is that while activated-sludge (i.e. microorganisms) concentration can be kept high and equipment can be made compact, high-caliber treated water suitable for recycling can be obtained (see Fig. 6).

PVDF Submerged-flat-sheet Membrane Unit

With flat-sheet elements (membrane area: 1 m^2), namely, a PVDF (polyvinylidene difluoride)-made micro-filtration membrane (with pore size of 0.1 μm) attached to both sides of a supporting plate, as a basic unit, the submerged-flat-sheet membrane unit introduced by Hitachi is composed of a membrane unit fitted with multiple flat cassettes into which multiple elements are bundled, a water-catchment unit that collects filtered water sucked from each element, and an air diffuser for supplying air for membrane cleaning (see Figs. 7 and 8).

Fig. 7—PVDF (polyvinylidene fluoride) Flat-membrane Cassette.
The cassette is composed of 10 flat-membrane elements (with membrane areas of 1 m^2) bundled together.

Fig. 8—Submerged-flat-sheet Membrane Unit.
An aeration device is installed in the lower part of the membrane unit, and blockage of membrane is prevented by diffused air.

By using a PVDF membrane in this manner, physical and chemical deterioration is less likely, and operation at low pressure is possible by suppressing formation of sludge layers on the membrane surface(6). The membrane separation is structured so that an external casing for maintaining a clearance between the elements is unnecessary. Moreover, as a result of the elements being stacked up in multiple layers heightwise, in comparison to the conventional method, the amount of air needed for cleaning the membrane surface can be reduced, thereby reducing energy consumption.

Deployment of Water-recycling System in the Middle East

At present, in the Middle East, particularly in rapidly developing urban areas like Dubai (part of the United Arab Emirates), the water-recycling business is expanding rapidly.

In Dubai, as the construction boom in urban areas continues, a great many foreign workers are entering the country for work in such areas, and the construction companies that employ these workers are housing them in special accommodation for foreign workers. Conventionally, human sewage discharged from such camps is stored in wastewater tanks within the compound and picked up by tanker lorries for a fee. In recent years, however, the cost burden has piled up owing to steep rises in wastewater-treatment costs. In the meantime, as for water used for construction sites, mains water has been used.

Water supply and demand under the business environment besetting this construction market is drawing attention; accordingly, by considering wastewater as not simply household sewage but as a water resource and implementing an MBR system, we are proposing recycling of treated sewage as water for construction use. With the expansion of this business, a small-scale MBR unit with a capacity of 250–750 m^3/d was standardized, and a system for promptly providing facilities that meet customer needs was prepared. An MBR system with a capacity of 250 m^3/d has already started operation at a construction-worker camp in Dubai City in 2007, and orders for more than 10 MBR units followed (see Fig. 9).

From the viewpoint of recycling household wastewater, various applications of MBR other than construction-use water are expected. In the case that high-level water quality is required (such as cooling water for building ventilation systems), it is possible to add a reverse-osmosis-membrane unit as a subsequent stage of the MBR facility and use it to remove ionic constituents from MBR-treated water. By provision of treatment facilities that meet water supply and demand in conjunction with appropriate operational management, it is possible to effectively recycle household wastewater and secure it as a valuable water source.

Fig. 9—MBR Facility for Construction-worker Camps.
The appearance of an MBR facility installed at a construction-worker camp in Dubai City in 2007. The facility has a treatment capacity of 250 m^3/d in processing human wastewater for about 1,500 people.

In general, securing tap water in the Middle East is entrusted to desalination of saltwater. As a result of the subsequent returning of extra-concentrated saltwater to coastal waters, however, the increased salt concentration of seawater is becoming a serious environmental problem. Decreasing the volume of consumed tap water recycled from household wastewater is also linked to suppressing the increase in salinity of seawater, and from the viewpoint of global environmental protection, MBR is thus an extremely productive processing technology.

BALLAST-WATER TREATMENT SYSTEM

Trends Surrounding Ballast Water

Ballast water is carried in a ship to maintain ballast, and in the form of seawater, brackish water, or fresh water, more than 10 billion tons of ballast water is washed out from ships around the world every year. Plankton and types of bacterium found in seawater, brackish water, and fresh water in harbors of a particular country are incorporated in the ballast water in a ship's ballast tank. When such ballast water is

TABLE 1. Effluent Standards for Ballast Water
Ballast effluent standards adopted by the International Maritime Organization (IMO) are tabulated.

Target	Control criterion
Aquatic organism with minimum size of 50 µm or more	Under 10/m³
Aquatic organism with minimum size of 10–50 µm or more	Under 10/mL
Epidemic cholera (01, 0139)	Under 1 cfu/100 mL
Escherichia coli	Under 250 cfu/100 mL
Enterococcus	Under 100 cfu/100 mL

cfu: colony forming unit (group unit)

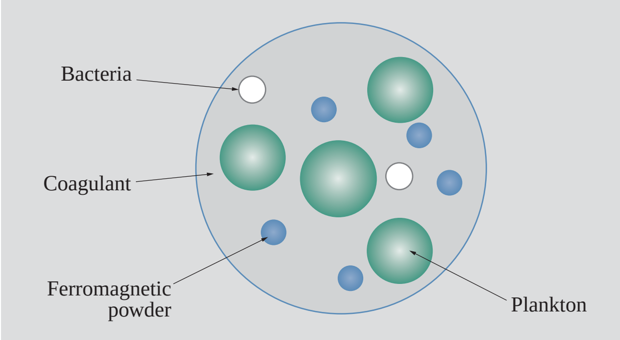

Fig. 10—Concept of Flock.
By means of an agglomeration operation, bacteria, plankton, etc., in flock can be trapped.

then discharged in harbors of other countries, these bacteria and plankton are also discharged. Once discharged in such coastal waters, they are said to cause disruption of the eco-system and bacterial epidemics.

The International Maritime Organization (IMO), which represents 167 countries around the world, adopted a ballast-control convention in February 2004, which made the fitting of ballast-treatment equipment compulsory for ships. In addition, this convention has been ratified by more than 30 IMO-affiliated countries, and it will come into effect in those countries in 12 months time — at which time it will cover 35% of the sum total of all countries' commercial shipping. Although accomplishment of this treaty faced a huge hurdle, in consideration of current global trends regarding environmental preservation, it was presumed that it would come into effect in the near future(7).

Under these circumstances, aiming at commercialization of the concept of creating a system in consideration of the environment, Hitachi is developing new ballast-water treatment systems that combine "flocculation" and "magnetic separation."

Development Concept and Treatment Method

The effluent standards set by the ballast-water-treatment convention are very strict, namely, less than 10 individuals per 1 m^3 of aquatic life of more than 50 µm (plankton) in size and less than 250 cfu (colony forming unit) of bacterium per 100 mL of water, and is equal to the water-quality level set for swimming beaches (see Table 1). As for typical fungi-removal methods used at water-treatment and sewage treatment plants, a common one uses fungicides like sodium hypochlorite. However, under this convention, plankton (which is considered to possess more resistance to fungicides than fungi) is also a removal target; therefore, there is a concern that fungicide concentration increases, and it is difficult to say that use of fungicides is effective.

Moreover, as for selecting the treatment method, it is important not only to observe the standards covering ballast discharge but also to select a treatment method that does no harm to creatures living in the ocean when the ballast is discharged.

Hitachi is proposing a treatment system that places a premium on environmental considerations and that does not use fungicides and the like. The system combines two techniques — flocculation and magnetic separation — in order to separate targeted organisms at high speed. In stark contrast to methods using pesticides, this method presents no problems concerning remnant medical effects and causes no harmful effects in regard to sea pollution.

Removal Principle

By adding ferromagnetic powder and coagulant to seawater, plankton, bacteria, sand, and so on contained in the seawater form tiny clusters called flock (about 1 mm). Then, by means of magnetic separation, the flock can be removed and the ballast-water effluent standard can be satisfied. The flock is generally separated by a floatation process using air bubbles or gravitational settling. However, in the case of ballast-water decontamination, space for installing equipment is limited; therefore, high-speed separation of the flock is required and, to meet the ballast-water effluent standard, the flock must be almost completely removed. To satisfy those requirements, however, application of settling separation (which takes a long time, i.e. 30 min to 1 h) and flotation by air bubbles is difficult.

Hitachi has devised a method — called magnetic

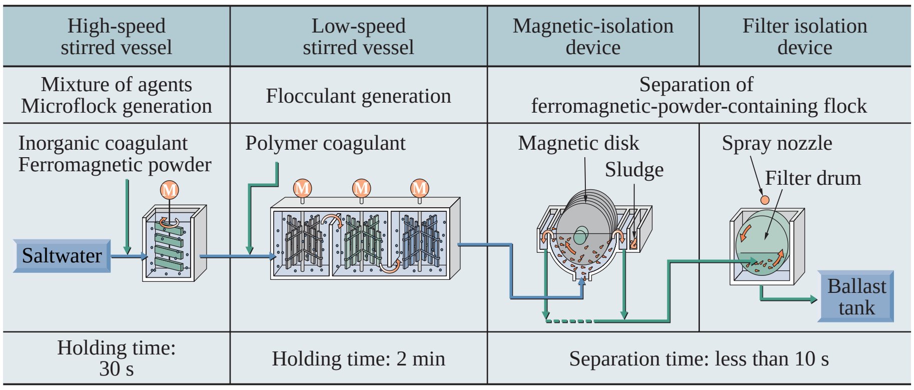

Fig. 11—Concept of Process Flow in Ballast-water-treatment System.
The conceptual flow of the treatment system is shown. A magnetic-isolation device in which magnetic disks embedding permanent magnets are stacked was developed.

separation — that incorporates magnetic powder with the flocculant and, subsequently, removes the flock by means of magnetic force. This magnetic-separation method can remove the flock in several seconds, and its removal precision is extremely good, so it is particularly suited to ballast-water treatment (see Fig. 10).

Flow of Ballast-water Treatment System

The ballast-water treatment system is composed of four main parts: a high-speed stirred vessel, a low-speed stirred vessel, a magnetic separator, and a filter separator. As for the high-speed stirred vessel and the low-speed stirred vessel, which utilize coagulant and ferromagnetic powder for flocculating plankton, bacteria, sand, etc. contained in seawater, the required holding time is significantly shortened by optimizing the paddle impeller and vessel shape. The flock removal is performed by magnetic separation followed by filter separation (pore diameter: several tens of micrometers). Along with stabilizing water quality, this system improves separation efficiency and enables compactization of equipment. The coagulant used by the system is on a par with the agents used around the world for water treatment (and for drinking water in Japan), so its margin of safety is high (see Fig. 11).

Features of Ballast-water Treatment System

Since the ballast-water treatment system does not use any disinfectants, it brings the following advantages.

(1) Organic toxicity tests laid down by the Organisation for Economic Co-operation and Development (OECD) confirmed that the system is safe, even in the case that treated water is discharged into the environment without dilution, and that environmental contamination is not a concern at the time of treated-ballast discharge.

(2) Since there are no remnant disinfectants (such as oxidizing agents) in the treated ballast water, there are no adverse effects on the ballast-tank paint and, in turn, the life of the ship can be extended.

(3) Since suspended solids in the target treatment water can also be efficiently removed, the degree of clearness of the treated ballast water can be increased, and the amount of deposited mud inside the ballast tank (i.e. sludge, dead organisms, etc.) can be significantly decreased.

(4) As a consequence of suppressing mud deposition inside the ballast tank, the risk of microorganisms proliferating in the tanks of ships is eliminated. On top of that, because of phosphorous (which is an essential nutrient for eggs of organisms and their subsequent growth) elimination, proliferation of microorganisms can be dramatically reduced.

Future Deployment

At present, development of ballast-water-treatment equipment is continuing all over the world. Hitachi must also seek type approval at the earliest date possible, so we are engaged in such development at a frenzied pace. The ballast-water treatment system has already been equipped as test equipment (treatment capacity: 50 m^3/h) in a new LPG (liquefied petroleum gas) tanker built for the Yuyo Steamship Co., Ltd. by the Nagasaki Shipyard & Machinery Works of Mitsubishi Heavy Industries, Ltd., and on-board trials of the system will continue for about one year (the trials started in April 2008). During these trials, not only ballast-treatment performance but also environmental resistance and maintenance management of the system's equipment are being evaluated.

Ships targeted by the IMO convention, which presently covers only new ships, number about 1,500 built per year; however, from 2017 onwards, it will also be applied to existing ships (which will number more than 100 thousand by then).

Hitachi will continue to implement our "ballast-water treatment system" in such a manner as to contribute to preservation of the world's maritime environment.

CONCLUSIONS

This report described Hitachi's systems developed as water-treatment technologies that contribute to global environment protection while addressing issues concerning environmental water contamination, water shortage, and environmental destruction, namely, a nitrogen-removal system using entrapped immobilized microorganisms, an MBR system, and a ballast-water treatment system.

The position of the water-treatment field — which is related to water as a basis for life — within the global environmental strategy being pursued by Hitachi is extremely important. Seawater makes up 97.5% of the total amount of water on the earth's surface, but the water actually available for human usage (namely, groundwater, river water, lake water, etc.) makes up a mere 0.77% of that total. Protecting that precious water source from the viewpoint of both quality and quantity is thus Hitachi's mission. In accordance with that mission, concentrating the technologies of the Hitachi Group and aiming to provide the most suitable "total solutions," we intend to continue contributing to development of water-treatment technologies.

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