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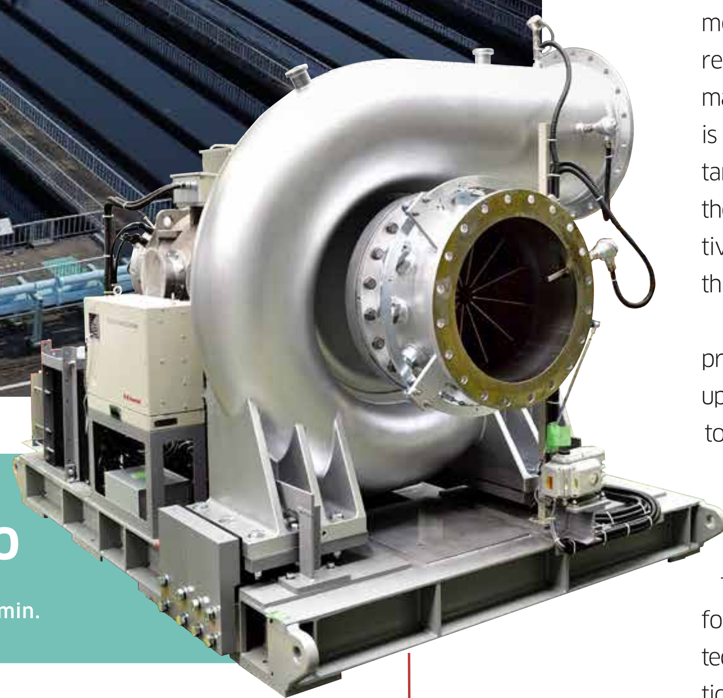
A Mega MAG Turbo M55 going through a final pre-shipping test at Kobe Works in Hyogo Prefecture, Japan. For details, see *Special Feature* (this page).

Mikasagawa Sewage Treatment Plant, operated by the Fukuoka Prefectural Water and Sewage Control Center, where the Mega MAG Turbo is undergoing an actual load test

Leading Innovation for Wastewater Treatment Around the World: Kawasaki's Aeration Blower, "Mega MAG Turbo"

Preserving a clean environment and passing it on to future generations is what every global citizen hopes for, and wastewater treatment is considered one of the key contributors to fulfilling this hope. At sewage treatment facilities, the aeration blower is regarded as the real hero behind a wastewater purification process using microorganisms. Kawasaki is the leading manufacturer in Japan of a highly efficient aeration blower using magnetic bearings called the "MAG Turbo" (named by Kawasaki by combining "Magnetic bearing" and "Turbo Blower").

Kawasaki has always been the industry's innovator. With the development of MAG Turbo's "Mega MAG Turbo," which accommodates the needs of larger facilities, the Company has reached new heights in technological advancement.



Mega MAG TURBO

- Output: 1,300 kW
- Air flow rate: 900 m^3/min.
- Pressure: 100 kPa (G)

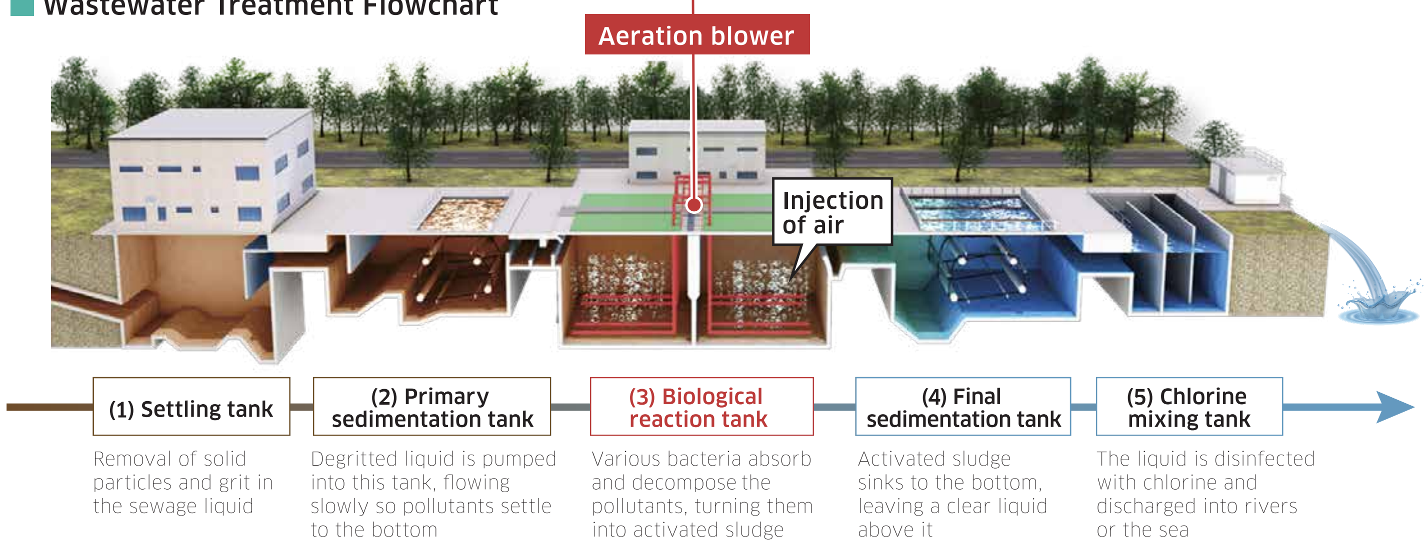
Blowers that Support the "Activated Sludge Process" — A History-Making Innovation

In 1914, the year WWI began, the world's first sewage treatment plant employing an "activated sludge process" was completed in the United Kingdom. Used for treating domestic sewage and rainwater, this process was so innovative and significant that it is considered an epoch-making invention.

In this process, activated sludge, which contains microorganisms, is mixed with sewage. The microbes digest the organic material, and as they increase in numbers, clean water is the result. At a sewage treatment plant, the microbes are in a biological reaction tank, and what takes place there makes up the "heart" of sewage treatment. It is the air provided to the biological reaction tank by the aeration blower which activates these microbes. Seen from another perspective, the blower is the real hero that makes this process work.

Over the years, as the activated sludge process underwent a series of technological upgrades, the blowers' features were tailored to sewage treatment. These advancements included technologies for adjusting the amount of air being injected based on the volume of sewage, and for operating the equipment stably, without interruption, for many years. Even with the maturing of technologies, however, high power consumption remained the hardest challenge. Power used by sewage treatment plants accounts

■ Wastewater Treatment Flowchart



for approximately 1% (10 billion kWh/year) of total power consumption in Japan, 60% of which is utilized by the blowers.

To solve this problem, Kawasaki developed its innovative high-efficiency aeration blower with magnetic bearings — the "MAG Turbo" — and made its first delivery in 2004. With the MAG Turbo, an impeller is attached to the end of the rotor shaft of a high-speed, inverter-controlled motor*. The rotor is levitated by the magnetic force exerted by the magnetic bearings, rotating the impeller at high speed, which compresses air entering through the inlet and discharges it from the outlet. Due to the absence of mechanical contact, the levitated rotor requires no bearings to protect it while running at high speed, nor a lubrication system or other auxiliary equipment.

By minimizing mechanical losses, power consumption in the treatment process, overall, was reduced by 15 to 30% compared to previous models. Since delivery of the first unit, Kawasaki has received orders for more than 200 units, and in FY2019 achieved a 70% share in the domestic aeration blower market. Based on the number of deliveries, it is estimated that 50,000 tons per year of CO_2 emissions are being reduced by the MAG Turbo.

Moreover, Kawasaki took on the challenge of developing a model for large sewage treatment plants — the "Mega MAG Turbo" — which boasts of being the magnetic-bearing aeration blower with the highest output in the world. In Japan, 14 billion m³ of sewage is treated annually, but because of limited land area, most of the treatment plants are small or medium-sized and are dispersed across the country. Outside Japan, however, treatment of sewage from multiple urban areas is often done collectively at a single, much larger facility. For example, there are more than 100 plants in the United States capable of treating 300,000 m³ of sewage per day, while only 43 in Japan have the same capacity, and regardless of size, all plants are aging rapidly.

The aging of facilities is also seen outside Japan, which makes a reduction in renewal costs and operational expenses by utilizing highly-efficient equipment a common imperative for sewage treatment plants around the world. The Mega MAG Turbo was developed as one solution to that challenge.

Mega-Output Motor Runs the Rotor to Generate Massive Airflow

In the summer of 2020, a final pre-shipping test for the Mega MAG Turbo M55 was conducted at Kawasaki's Kobe Works. This powerful blower achieves an unprecedentedly high output considering its surprisingly compact size.

The prefix "Mega" reflects the much greater output of the motor compared to the original MAG Turbo. While the motor output of the largest MAG Turbo is only 400 kW, that of the M55 is 1,300 kW (i.e., 1.3 megawatts — hence the appellation, "Mega MAG"). In terms of discharge air volume and discharge pressure, the M55 is rated at 900 m³/min. and 100 kPa (G), respectively, compared to the 300 m³/min. and 80 kPa (G) of the largest MAG Turbo.

Its weight, however, is significantly greater — the rotor alone weighs 700 kg, or more than five times that of the MAG Turbo. This rotor is levitated by 10 electromagnets installed in three bearings, with a shaft vibration displacement of a mere 20 ㎛.

Soichiro Takemura, Assistant Manager at the Aero-Dynamic Machinery Department of the Energy System & Plant Engineering Company, comments, "To stably levitate such a heavy shaft, which rotates 11,500 times per minute with only 20 ㎛ of vibration displacement, we were compelled to improve not only the electromagnets' magnetic attraction performance but also to develop new technologies for the controller and control systems for the magnetic bearings."

The controller uses position sensors installed at several places in the magnetic bearings to accurately determine the rotor's position relative to the X, Y, and Z axes at all times. The rotor is maintained in its reference position by controlling the amount of electric current provided to the magnetic bearings. This technology, called "High Frequency Feedback Control," enables high speed control by receiving positional information 10,000 times per second. Kawasaki developed this innovative technology and applied it in controlling the high-speed, high-output motor.

High-Output Model Made Possible by the Fusion of Machine and Electrical Engineering Technologies

Along with developing needed technologies, Kawasaki also reviewed the design of the impeller — a vital component in compressing the air. Since the first model was developed by Kawasaki half a century ago, the design of the impeller's shape and airflow path has undergone a series of upgrades using cutting-edge technologies. The resulting impeller is also a core part of the supercharged Ninja H2, Kawasaki's flagship series of motorcycles, which boasts outstanding power.

Akio Hashimoto, Senior Staff Officer at the Aero-Dynamic Machinery Department of the Energy System & Plant Engineering Company, says, "For the development of the M55, we've used an analytic method called 'Genetic Algorithms' to identify the optimal shape for the impeller, achieving both high pressure and high efficiency at a relatively low rpm." In addition, a special aluminum alloy was used to ensure the impeller's strength when it experiences high temperatures due to compression heat as the discharge pressure approaches 100 kPa (G).

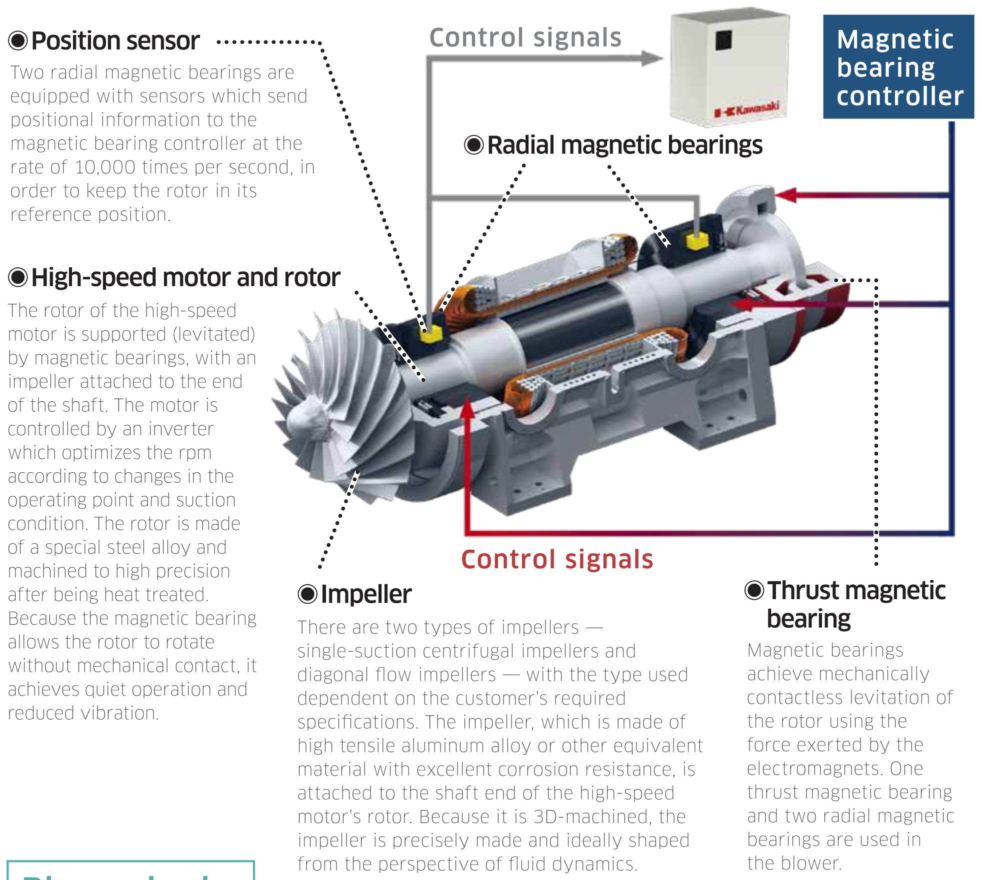
Moreover, the inlet guide vanes placed at the suction port open and close to cause the air to swirl, and coupled with the motor, which is controlled by the inverter to optimize rotor speed, they make highly-efficient control of a wide range of airflow volume possible. Thanks to this feature, the blower demonstrates excellent partial-load efficiency when it is not operating at full capacity.

For example, compared to a conventional high-output blower, the power required by the M55 to raise the pressure to 60 kPa (G) of a volumetric airflow unit of 1 m³ is 20% lower. In addition, while producing the same amount of compressed air, the M55 achieves a 50% reduction in installation footprint, proving that it is a high-output model with energy- and space-saving advantages.

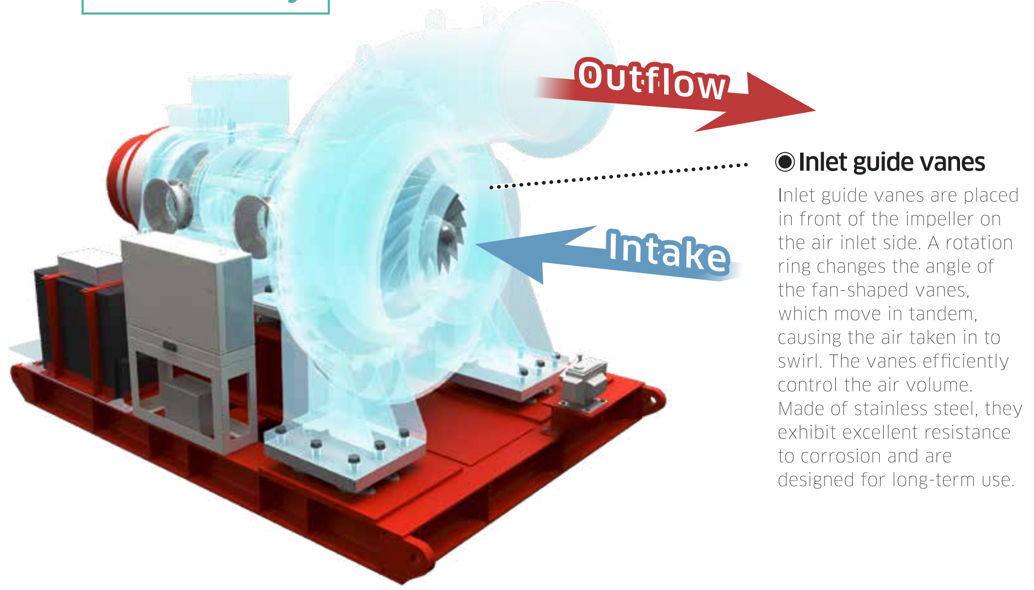
Hashimoto adds, "The same principle of levitating the rotor utilizing magnetic bearings is applied to all MAG Turbo models,

* An inverter alters the frequency and voltage of supplied power to control the rotation speed of a motor.

Structure of Aeration Blower



Blower body



Soichiro Takemura
Assistant Manager, Blower Engineering Section, Aero-Dynamic Machinery Department, Energy System Division, Energy System & Plant Engineering Company

(Above) The M55 sits to the rear of the photo. The equipment in the foreground is the M25. In 2007, Kawasaki introduced the MAG Turbo, the components and parts of which are all Kawasaki-made. Since that model is considered the "second-generation" blower, the Mega MAG Turbo is technically the third generation. (Left) The Mega MAG Turbo being assembled. The fan-shaped objects inside the intake opening are inlet guide vanes.

Akio Hashimoto
Senior Staff Officer, Engineering and Development Section, Aero-Dynamic Machinery Department, Energy System Group, Energy Solution Business Division, Energy System & Plant Engineering Company

A Mega MAG Turbo M55 going through a final pre-shipping test at Kawasaki's Kobe Works. This unit is for a sewage treatment plant in Russia.

but in order to accommodate a motor with an output that far exceeds what we have been producing, our machinery and electrical engineering departments had to put their heads together to develop a new model from scratch. We also couldn't let the price go too high or it won't sell, so we tried to achieve both high output and reduced cost by reviewing the design and production method of the magnetic bearings and other core parts."

Evolution from Stand-alone Blower "MAG Turbo" to MAG ENERGY MANAGEMENT SYSTEM — the "MAG E^2"

Since November 2019, a Mega MAG Turbo has been undergoing an actual load test at Mikasagawa Sewage Treatment Plant in Fukuoka Prefecture. This facility is one of the largest sewage treatment plants in the Kyushu region, processing up to about 300,000 m^3 of wastewater per day. Replacing two medium-sized blowers, the M55 is currently operating under actual load conditions and has shown a reduction in power consumption. Its construction cost was also lower than that of the previous equipment, because of its smaller installation footprint.

Jun Ichikawa, Manager of the Blower Sales Section at the Energy System & Plant Engineering Company, comments, "Thanks to its high efficiency energy-saving feature and small footprint, the Mega MAG Turbo boasts an overwhelming competitive edge. Our sales department can proudly recommend the product to customers for their renewal projects."

He adds, "The Mega MAG Turbo has transformed the landscape of Kawasaki's blower business." What he means is that the Company can now offer not only an extensive lineup of blowers — from compact to large — but also an "Energy Management System."

The system allows for the control of more than one blower and for collaborating with the manufacturers of air diffusers (equipment that diffuses the air injected by the blower into the biological reaction tank) in designing an aeration system that offers reduced power consumption as a whole. In addition, Kawasaki is planning to propose new ways to operate the system based on analyses of the data collected through remote monitoring of the blowers.

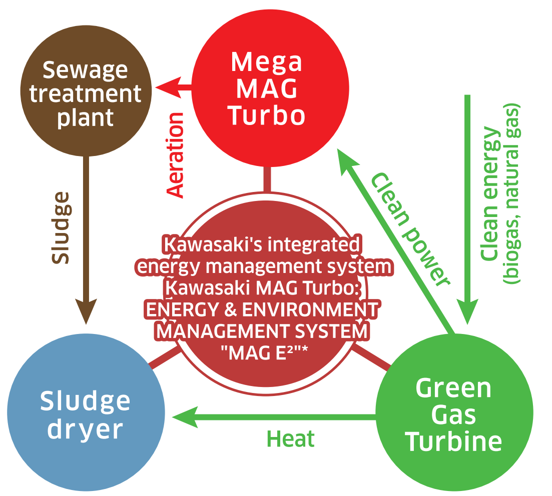
A unit of the Mega MAG Turbo M55 which went through a pre-shipping test at Kobe Works in August 2020 will soon be delivered to a large underground sewage treatment plant in Russia. This plant is one of the largest in Europe, capable of treating 3 million m^3 of wastewater per day. (In Tokyo, the largest plant is Morigasaki Water Reclamation Center which treats 1.14 million m^3 per day.) The first unit is scheduled to start operations in January 2021, followed by seven more units in the future. Ichikawa says, "This is a huge project to modernize sewage treatment facilities in Russia. I believe that the larger the facility, the greater the efficiency offered by the Mega MAG Turbo."

The evolution of the Mega MAG Turbo is ongoing. Together with the New Energy and Industrial Technology Development Organization (NEDO) of Japan, Kawasaki has launched a feasibility study for an international demonstration project on cogeneration systems, the "MAG E^2," involving the Mega MAG Turbo, the Green Gas Turbine, and a sludge dryer. This system utilizes a gas turbine power generator powered by "clean" natural gas and biogas harvested from sewage treatment facilities. The electricity generated by the gas turbine will be used to power the blower, while the heat generated will be used to dry the sludge. In summary, Kawasaki is building an "eco system" that generates electricity, heat, and air.

Hashimoto explains, "The project is an initiative to build a system with the Mega MAG Turbo as its key element to optimize energy use and thereby achieve a sustainable sewage treatment model." Goal 6 of the Sustainable Development Goals (SDGs) endorsed by the United Nations is to "ensure availability and sustainable management of water and sanitation for all." Kawasaki's blower business has become one of the drivers that moves forward the fulfillment of the SDGs.

Jun Ichikawa
Manager, Blower Sales Section, Land Machinery Sales Department, Marketing & Sales Division, Energy System & Plant Engineering Company

Kawasaki MAG Turbo Energy Management System in Sewage Treatment Plant



* Using innovation from a sanitation facility [sewage plant] to enable economical coexistence with a local wastewater enegy center by realizing an "integrated control system for sewage energy" through combining the Kawasaki Mega MAG Turbo and its Gas Turbine.

A Supporter's Voice

Yasuhiro Kasai
Director, International Affairs Office and Office for Promotion of International Project, Infrastructure System and Water Industry Manufacturing Industries Bureau, Ministry of Economy, Trade and Industry

High-Quality Water Infrastructure for the World: Strategy for Selling the First MAG Turbo in North America in FY2021

In 2013, the Japanese government formulated an "Export Strategy for Infrastructure Systems," with the goal of winning approximately 30 trillion-yen worth of overseas infrastructure projects in 2020. The Strategy's four pillars for meeting this goal ware to: 1. Strengthen competitiveness through collaborative efforts between public and private sectors; 2. Implement strategic initiatives for winning orders; 3. Promote high-quality infrastructure; and 4. Expand the range of infrastructure to be developed. Due to these measures, the Strategy has yielded certain results, such as orders totaling 25 trillion yen in 2018.

To further increase exports by improving recognition among Japan's trading partners of its sophisticated technologies, the Ministry of Economy, Trade and Industry (METI) has been actively implementing various policy tools, including top-to-top sales meetings, intergovernmental negotiations, feasibility studies, and human resource development.

As one such endeavor, METI has been conducting a series of studies called "Project on Feasibility Study Toward Overseas Expansion of High Quality Energy Infrastructures," and in FY2019 and FY2020, it made Kawasaki's high-output MAG Turbo subject to this study, focused on entry into the US market. To be more specific, the study provides marketing analyses, a select list of local after-sales service partners, and plans for actual operation of the blowers in North America under the presumption that more than 100 wastewater treatment plants are potential Kawasaki customers. In short, the study provides an infrastructure export strategy for Kawasaki to close deals in FY2021 and onwards.

Although Japanese companies' share in the water business market in North America (valued at 18 trillion yen in 2016) – the second largest after Europe – is 0.1%* and still limited, we think market entry opportunities are expanding, as the number of renewal projects for aging sewage treatment plants is rising, and the need for reclaimed water for drinking due to water resource shortages is increasing.

To promote market entry, METI will continue its efforts to increase the presence of Japanese companies using the results of the feasibility studies, and by broadly communicating their technological prowess at international events and other opportunities in cooperation with the private sector.

Today, with the global spread of COVID-19, new strategies are called for in meeting infrastructure needs that previously did not exist. In this age of digitization, in which social paradigm shifts are accelerating, strategies for water infrastructure must focus on a fundamental improvement in public sanitation and include the development of new technologies that allow for remote monitoring and contactless maintenance. METI plans to pro-actively support Japanese companies in expanding their business opportunities, and to improve competitiveness in these new segments as well.

Given all this, we hope to win our first order for the MAG Turbo in the North American market in FY2021, and become one of the icons of infrastructure exports in the new era.

*Source: "Overseas Development Strategy of Water Industry" released by METI in July 2018

Looking Forward to Tomorrow

Kawasaki's Advanced Technology: Supporting the Transfer of Wastewater Treatment Expertise from Osaka City to St. Petersburg

Osaka City has a long history of operating sewage treatment plants and possesses time-tested know-how in the field. Using this expertise, the City has been expanding its international activities and signed a Memorandum of Understanding (MOU) in 2015 with its sister city, St. Petersburg, for a technical exchange of expertise in the field of water and sewage systems. Every year since then, Osaka has been supporting the improvement and modernization projects of St. Petersburg's water supply and sewage through technical exchanges. Kawasaki is part of this program in the area of sewage treatment, and is gaining a high rating. Observing Kawasaki's efforts, an Osaka City official is quoted as saying, "The Company's sophisticated technology and passion for market development are strongly supporting our technical exchanges. I was quite impressed that the person in charge of plant operations in St. Petersburg was still asking questions of Kawasaki after an allotted time had ended."

The November 2015 MOU signing ceremony at State Unitary Enterprise (SUE) Vodokanal of St. Petersburg for a technical exchange between Osaka City and the City of St. Petersburg.

The fully-recovered MGWTTP, with sedimentation tanks, a biological reaction tank, the blower/pump station building, and a discharge gate on the ocean side, and the sludge treatment facility and administration building on the land side.

SUPPORTING LIFE WITH TECHNOLOGY

MAG Turbo Is Driving Forward Recovery Efforts in Sendai

Minami-Gamo Wastewater Treatment Plant (MGWTTP) is a large sewage treatment facility that provides municipal wastewater services to 70% of Sendai City's population. It was severely damaged by the Great East Japan Earthquake. Shortly after the disaster, MGWTTP staff undertook recovery activities under the conviction that Sendai had to be protected from sewage overflow and that wastewater should be cleaned before reaching the sea. Kawasaki's MAG Turbo played an integral part in supporting these efforts.

In the new blower/pump station building, six units of the MAG Turbo M25 are in operation.

Sendai is a city rich in greenery, nicknamed *"Mori No Miyako"* (City of Trees). It is also a city known for its advanced sewage system, having achieved the third earliest installation of a modernized sewage system in Japan (1899), after Tokyo and Osaka. Beginning operations in 1964, MGWTTP is located in the city's Miyagino Ward and is the largest such facility in the Tohoku region (Northern Honshu), treating 400,000 m³ of wastewater a day.

Located near Sendai Port on the Pacific Ocean, it was hit on March 11, 2011, by a 10-meter-tall tsunami caused by the giant earthquake, with the water covering the land area at a depth of more than four meters. The situation was so devastating that the only good news was the survival of all of the staff and workers, who fled to the roof of the administration building which is further from the coast.

The day after the earthquake, they were rescued by helicopters dispatched by the Japanese Self-Defense Force. However, they had no time to relax, as they had an urgent mission to fulfill — ensuring that the water-releasing functions were working, removing debris, restoring electricity, treating wastewater, etc. Recalling the recovery effort, Shinya Igarashi, in charge of maintenance, says, "Our plant is a mission-critical facility, providing services to about 70% of Sendai's 1.08 million residents. Because most of the sewage flows down naturally from the city center, which is 30 meters higher in altitude than the plant's location, we knew we had to continue the sewage treatment to avoid an overflow."

In preparing for temporary recovery measures, finding blowers was one of the highest priorities, as all 11 existing blowers had failed. Since Kawasaki had been providing blowers to the plant, the Company fixed two of the 11 units that were comparatively less damaged, and quickly supplied the plant with a prototype of the MAG Turbo M35. Thanks to these temporary measures, the plant began to recover.

Concurrent actions were taken to achieve complete recovery, and by April 2016, the plant had resumed full-fledged operations, with six units of the MAG Turbo M25 supporting its sophisticated wastewater treatment program. Igarashi comments that because the plant's primary mission is to return cleaned water to the Pacific Ocean, the MAG Turbo continues to play a significant role. In addition to being energy efficient, space saving, and quiet, owing to its magnetic bearings, Igarashi cites stable operations backed by great durability and 24/7 monitoring as among the blower's valuable benefits.

Asked what he expects of the future, Igarashi replied, "Our declining population will compel us to achieve sewage treatment with even higher efficiency and reduced costs. On top of that, to meet environmental standards, reducing energy use will be a must. For blowers, it will be especially important to achieve reductions in operating time, quantity, and output, so I hope to see AI-based optimization and other innovations from future blowers."

Shinya Igarashi
Section Head
Minami-Gamo Wastewater Treatment Plant Servicing Section
Sewage Operation Department
Construction Bureau, Sendai City

2011.3.11

(Left) On March 11, 2011, the MGWTTP was severely damaged by a giant earthquake and a tsunami which swept away much of its equipment and facilities. After the tsunami subsided, the blower bodies and pipes were found submerged in seawater inside the blower/pump station building, while floating debris had damaged various pieces of equipment.
(Right) A temporary blower/pump station building was constructed in October 2012, housing two of 11 submerged blowers which had been disassembled, repaired, and reassembled, as well as a prototype of the MAG Turbo M35.