Special Report

Evolving water treatment technologies in Japan and the scaling-up of the MU Green Reactor which uses the MU-SSPW and its water treatment technology

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1. Foreword

Contemplation of the waterfall at Nachi and the powerful surf in the Japan Sea raised a question: why do waterfalls and powerful surf appear white? This question was the starting point for the creation of the MU-SSPW (MU Static Spiral Perforated Wings®).

In Western philosophy, there is a dialectic approach in which a thesis is proposed, followed by an anti-thesis, and the conflict between the two is sublated through synthesis. The basic mixing principle employed in the static mixers marketed in the 1970s by the U. S. company Kenics is the continuous mixing of fluids by dual partitioning, reversion and inversion of the fluid.

The structure is formed by two spiral elements twisting 180° clockwise and counter-clockwise, placed so the edges of the elements are perpendicular to one another, and mounted inside a pipe to form a static mixer. Fluids of different types are first divided into two layers by the clockwise spiral element, creating a clockwise swirling current. Similarly, the fluid is next divided into four layers by the counterclockwise spiral element, creating a counterclockwise swirling current that merges with the other flow.

These continuously repeated clockwise spiral, counterclockwise spiral and merging actions cause the fluid to be divided into 2^n (n: number of elements) layers and mixed by the swirling currents. By contrast, the basic mixing principle of the MU-SSPW is highly efficient continuous mixing of the fluid through improvements to the multiple fluid

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division, spiral rotation, merging and inversion actions and shear stress action in the axial and rotation directions. The core of the spiral element of the MU-SSPW has a void in the axial direction, and the element is formed by perforated plates (US Pat. 7, 510, 172B2).

The "MU Reactor"* advertisement for the MU-SSPW appeared five times in the magazine *Nature* (in the November 5 and December 3, 1998 and January 7, February 11 and March 11, 1999 issues) and attracted a worldwide response.

In the 22 years since that time, technical innovation of the water treatment technologies using the MU-SSPW have quietly and steadily evolved "From Horizontal to Vertical."

We are confident that MU Company's water treatment technology that employs natural energy (MU Green Technology®) can contribute to the crucial challenge of the modern age: the need to consider environmental, social and corporate governance (ESG) issues. With this philosophy and technical innovation as a backdrop, we published short essays on water treatment technologies using the MU-SSPW in the August 2018 and August 2019 issues of Plant and Process.

This paper will discuss the achievements in scaling up the MU Green Reactor (which uses the MU-SSPW) and its water treatment technology.

2. Design concept of MU Green Reactor®

2-1. Development

The MU Green Reactor is an impact diffuser that constitutes a more advanced version of the static aerator. This diffuser is a static fluid mixer that does not require power to operate and was developed to provide improved wastewater treatment performance, higher oxygen absorption efficiency than a non-porous (large bubble type) diffuser, no clogging, ease of maintenance and so on.

Important considerations when selecting a diffuser include choosing one that will not clog and in which foreign substances in the sewage will not tend to get stuck, and one that will offer stable performance and will not tend to break down even after operation for long periods of time. Clogging or failure of the diffuser that results in reduced aeration effectiveness and reduced treatment capacity may require replacement of the apparatus, so in general an effort is made to select the ideal diffuser based on the characteristics of the wastewater at the facility in question.

After a facility is put into service, diffuser inspection and replacement are needed at the time of maintenance inspections as the units age. However, facility managers also want to reduce running costs, so ideally they would like to have a diffuser that can be used on a permanent basis.

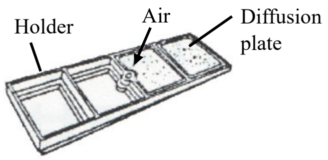
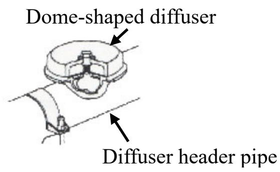
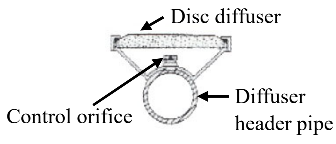
For these reasons, in 1998 we began work on the development of the MU Green Reactor, with the aim of improving the performance of the impact diffuser. Pilot plant experiments began in 1999, and operation at actual facilities began in the early years of the new century, with the units in operation at several dozen facilities with plant and household wastewater processing capacity ranging between 10 and 5,000 m^3 per day. Because the units do not experience clogging, no maintenance was required for over 15 years, and the units demonstrated stable performance.

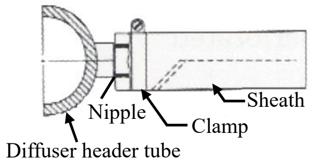
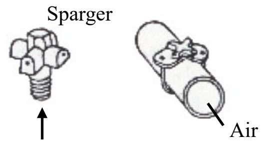
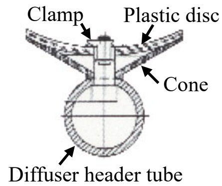
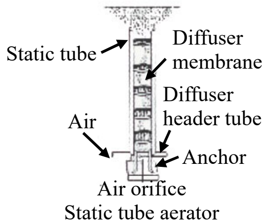
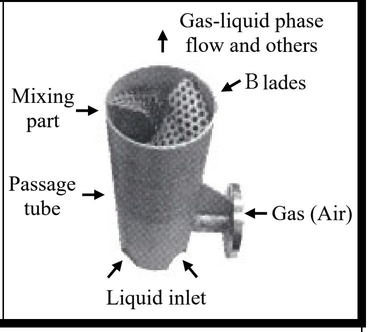
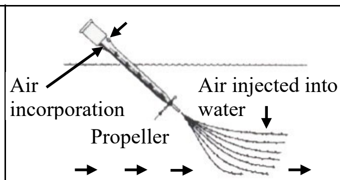
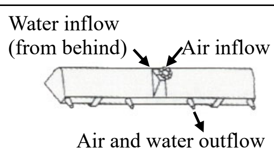
2-2. Principle and individual device flow

(1) Principle

Aerators used in bioreactors include mechanical agitators, diffusers and units made up of both types of apparatus. Diffuser methods of operation include porous (microbubble type) diffusers and non-porous (large air bubble type) diffusers, as well as impact diffusers, injection diffusers and so on. **Table 1** shows the types and features of aerators for each diffuser operation method[1].

Table 1 Types of aerators and features

Diffuser, etc. type		Oxygen transfer efficiency	Features	Reference drawing
Porous				
	Plate	High	A plate made from porcelain or synthetic resin is attached to a fixed support frame and placed at the bottom of a tank.	Porous diffuser tube (made of porcelain or synthetic resin) 
	Dome	High	A dome-shaped plate made from porcelain or synthetic resin is attached to an air line and placed at the bottom of a tank.	
	Disc	High	A porcelain or soft porous membrane is attached to an air line and placed at the bottom of a tank.	

	Pipe	Average to high	Sheath made of porcelain, soft plastic or synthetic rubber, attached to an air line.	
Non-porous				
	Sparger	Low	Made of molded plastic and attached to an air line.	
	Valve orifice	Low	Equipped with a valve to prevent back flow in the event that the air supply is cut off, and attached to an air line.	
	Impact type static aerator	Low to medium	Vertical tube fastened to the bottom of a tank; operates in a fashion similar to an air-lift pump.	
	MU Green Reactor	Average to high	Air bubbles are miniaturized as they pass through the cylinder. Attached to an air line.	
Other aerators				
	Suction diffuser	Low	An inclined propeller pump is installed at the surface of a tank. The pump sucks in air and discharges a gas-liquid mixture beneath the surface of the water.	
	Injection type aeration	Average to high	Mixes the liquid from the pump with air and sprays the mixture through the nozzle toward a location near the bottom of the tank.	

Note: Prepared based on references

The distinguishing characteristic of the impact diffuser ("static aerator") is that, when the air discharged from the diffuser tube passes through the cylinder, the air bubbles are miniaturized. **Fig. 1** shows an example of the internal structure and the flow pattern[2].

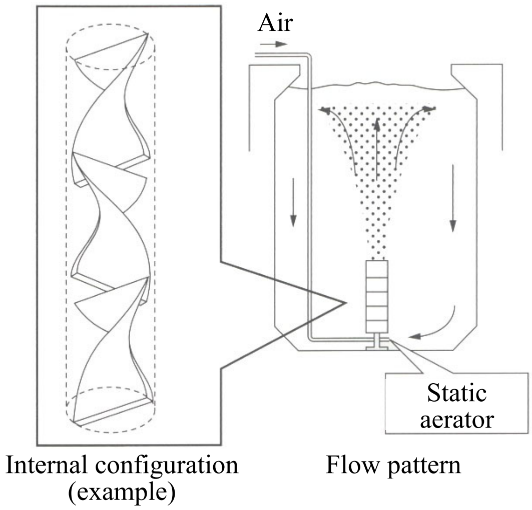


Fig. 1 Features of static aerator

The airflow rate through the static aerator can be set to several tens of multiples greater than that of a porous (microbubble type) diffuser. The outer cylinder functions as an air-lift pump and generates powerful swirling flows as the sewage in the tank is aerated and agitated. Moreover, a suction effect that draws the sewage into the static aerator is produced at the bottom of the tank, so the flow velocity at the bottom of the tank is secured and biological treatment is conducted effectively with no deposition of activated sludge.

The air (large air bubbles) and sewage emitted from the diffuser are subjected to repeated agitation and shear action when they pass the deflector plate, etc. inside the cylinder, and miniaturized air bubbles are discharged into the aeration tank from the top of the outer cylinder. The deflector plate is designed so microbubbles are generated and contact with sewage is promoted, increasing the oxygen absorption efficiency (E_A). The oxygen absorption efficiency of the static aerator is slightly lower as compared to a porous (microbubble type) diffuser, but it is easy to install and equipment costs are low; in addition, no clogging is produced, pure air is not required, pressure loss is low, and the unit does not break down and therefore maintenance is easy, etc. These benefits make up for the demerit of the expense as compared to the porous (microbubble type) diffuser.

In general, the important parameters for a diffuser are that it ensures high oxygen transfer efficiency (OTE) in the aeration tank, that it secures the flow of water in the tank, that it conducts aeration agitation, that the sedimentation of activated sludge in the settling tank is not impaired, and that its functioning will not be adversely affected by clogging or the like.

With the calls for reducing energy consumption and CO_2 emissions in recent years, increasingly large-scale treatment facilities are introducing ultra-fine bubble diffusers (membrane diffusers and high-density installed diffusers). Although these units offer high oxygen transfer efficiency (OTE), measures to deal with clogging after installation and fouling due to the deposition of slime and inorganic matter on the outer surfaces may be required, resulting in decreased OTE, and for this reason diligence and advanced technical expertise in the area of maintenance are needed for operation, blower pressure control and so on.

The important parameters for the oxygen transfer efficiency of the static aerator are comparison of the air emitted from the diffuser tube and the sewage taken in, as well as the gas-liquid dispersion at the deflector plate and so on. **Fig. 2** shows the air emitted from the diffuser tube[3].

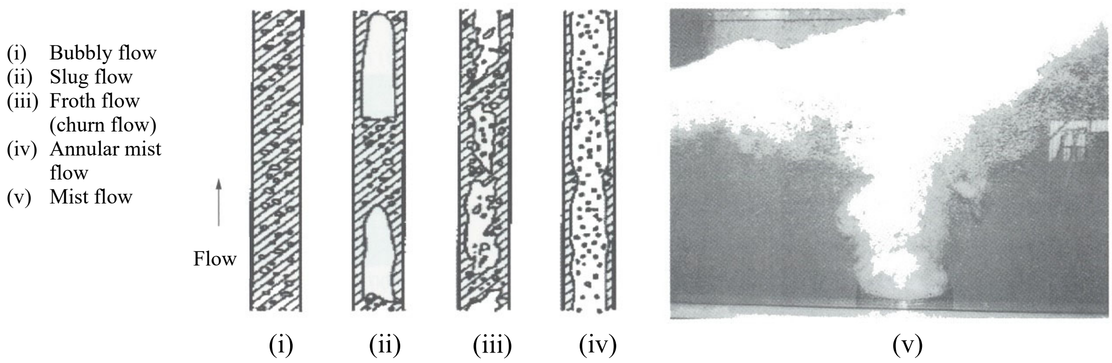


Fig. 2 Two-phase flow of air (air phase) and sewage (liquid phase) in vertical direction

With regard to the flow status of the vertical dual-phase flow, when the gas phase flow rate is low and the liquid phase flow rate is high, the result is (i) bubbly flow. When both the gas phase flow rate is low or medium and the liquid phase flow rate is low, the result is (ii) slug flow. Moreover, when the void fraction (volume ratio of gas) becomes great, a complex interface configuration is produced in which it is impossible to determine whether the continuous phase is gas or liquid, and this transitions to (iii) froth flow (churn flow). When both the gas phase flow rate and the liquid phase flow rate are high, (iv) annular mist flow and (v) mist flow are produced (the photograph shows the status in an actual MU Green Reactor), and a dispersed state is created with the flow very close to a homogeneous flow to a greater extent than in other domains.

(2) Example of MU Green Reactor introduction

As noted earlier, when the functioning of the deflector plate, etc. in the cylinder is insufficient with the air flow shown in (i) to (iv), oxygen transfer efficiency is low and the large quantity of air in the aeration tank simply rises upward. To correct this problem, we developed the MU Green Reactor in which a mist flow is produced in every domain and microbubbles are generated.

In this unit, when air passes the spiral blades mounted in the cylinder, powerful mixing, agitation, shearing and fragmentation occur, and microbubbles are discharged into the sewage, efficiently transferring oxygen to the water. **Fig. 3** shows the microbubbles produced during aeration agitation by the MU Green Reactor (MGR-125). **Fig. 4** shows the oxygen transfer efficiency. As the photos show, the air bubbles emitted from the MU Green Reactor are fine and uniform, and microbubbles are emitted as well. In addition, the standard oxygen transfer efficiency (SOTE) in the case of the MGR-125 is 20% at a water depth of 4.5m.

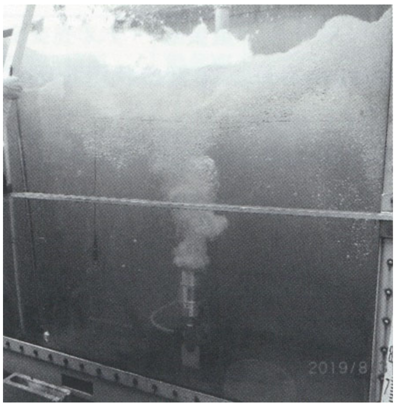


Fig. 3 Micro-bubbles produced during aeration agitation

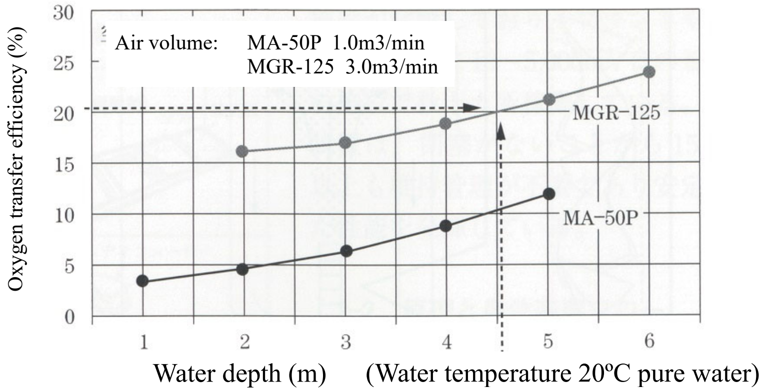
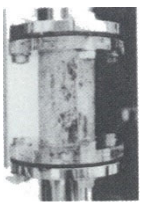
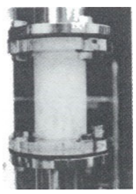
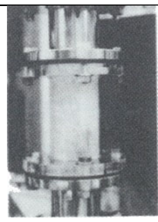
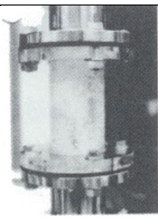
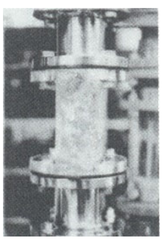
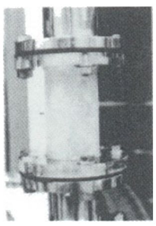
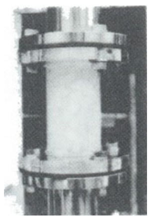
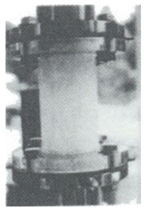


Fig. 4 Oxygen transfer efficiency of MA and MGR series

Moreover, the pressure of the MU Green Reactor is already released on the riser (air pipe) discharge side, so there is no need for the pressure loss of the diffuser, etc. to be accounted for in the blower equipment. Conversely, in the case of a microbubble (membrane type) diffuser, the pressure loss design values in the design process can be accounted for as 11 kPa for the initial pressure loss and fluctuation portion and approximately 0.15 kPa for the air filter (blower suction side air filter). However, this unit has 0 kPa pressure loss, so the pressure load of the blower equipment is reduced, and power consumption is reduced, and it is therefore effective in reducing power consumption.

Fig. 5 shows the change in vertical dual-phase flow during passage through the MU Green Reactor[5]. The photographs show the changes in gas phase and liquid phase flow rate from small to large changes, but the air and sewage are agitated and mixed evenly due to the passage of the gas and liquid through the spiral blades in the reactor forcefully, so there are no slug flows or annular flows or other irregular flows, and as a result the flow is able to be transformed into microbubbles.

	Air phase flow rate (low) →			(high)
Liquid phase flow rate (low) ↓				
	18,000	18,000	20,000	Aeration rate m3/m-h 20,000
	200	1,200	700	Aeration rate m3/m-h 1,200
				
	33,000	35,000	32,000	Aeration rate m3/m-h 32,000

(high)	250	500	1,400	Aeration rate m3/m-h	1,400

Fig. 5 Dual-phase flow gas and liquid mixing during passage through MU Green Reactor

(3) Treatment characteristics

At a food processing effluent treatment facility in Y City, T Prefecture, up to now effluent treatment has been conducted in a pre-aeration tank (flow regulating tank) using a loop diffuser. However, sewage concentration was not uniform and flow regulation was inadequate, so in the middle of May 2019 the facility replaced the existing loop diffuser (VP φ40 staggered holes) with twelve MA-25P MU Aerators (the compact version of the MU Green Reactor; hereafter MU Aerator) (blow volume 0.350 m^3/minute per unit). **Fig. 6** shows a plan view of the bottom of the pre-aeration tank. **Table 2** shows the planned sewage volume for the facility, the planned inflow water quality and planned discharge water quality, and an overview of the equipment. The facility inflow water volume and pollutant load are roughly 100% and are close to the design planning values.

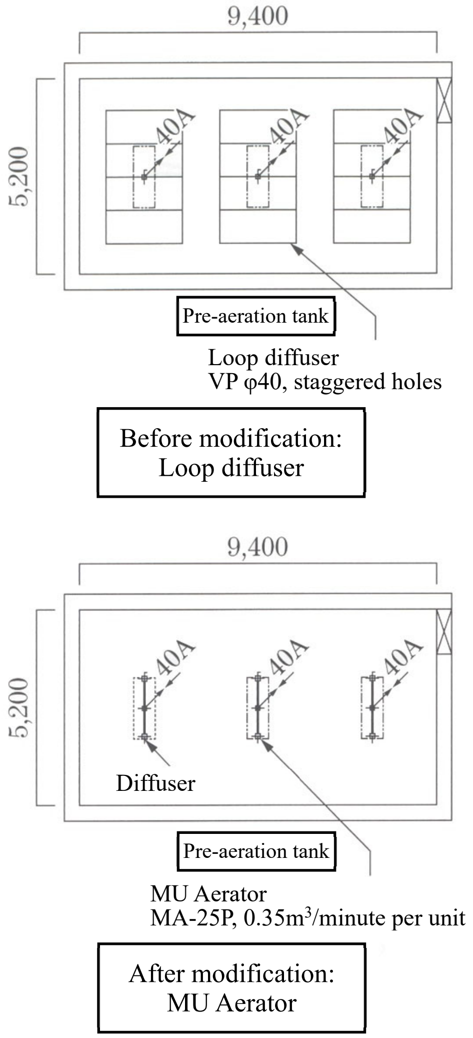


Fig. 6 Plan view of bottom of pre-aeration tank

Note: There are two pre-aeration tanks, but only one is shown in the figure.

Table 2 Facility design specifications

(1) Planned sewage volume

Name / Item	Water volume	Notes
Average daily sewage volume	1,000m^3 / day	Water volume rate 100%. Water volume decreases on non-work days.
Maximum hourly sewage volume	105m^3 / hour	Peak coefficient 2.5. Discharge time per day is 12 hours.

(2) Planned inflow water quality and planned outflow water quality

Item	Unit	Inflow water quality	Outflow water quality	Notes	
BOD	mg/L	500	40		

SS	mg/L	500	40		
T-N	mg/L	100	20		
T-P	mg/L	—	2		
N-hx	mg/L	200	→		
pH		5.8 - 8.6	5.8 - 8.6		

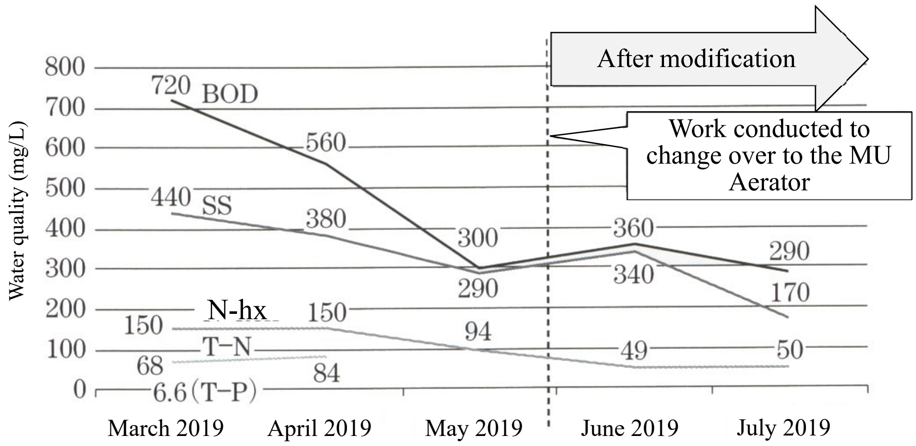
3) Overview of equipment

Tank and equipment	Dimensions and equipment specifications	Notes
Pre-aeration tank	5.2 × 9.4 × 6.15m (effective water depth 5.15m) × 2 tanks	Reinforced concrete construction
Actual holding time	12.0 hours	Not including supernatant liquor
Aeration time	24 hours continuous, aeration rate $1.0m^3/m^3$.hour	
Water feed apparatus	φ80 × $0.695m^3$/min × 8.0m × 2.2kW × 2 units	Of which one is a spare
Diffuser (before modification)	Loop diffuser VPφ40, 6 units	Staggered holes
Diffuser (after modification)	MU Aerator, 12 units	MA-25P
Blower equipment*	φ65 × $4.20m^3$/min × 70.1kPa × 7.5kW × 1 unit	Onshore roots blower

* The existing blower equipment was used, as it had the required aeration capacity.

1) Removal performance

Fig. 7 shows the results of water quality testing for BOD, SS, N-hx, T-N and T-P in the water flowing out from the pre-aeration tank. The BOD (biochemical oxygen demand) in the outflow from the pre-aeration tank was 560 to 720mg/L, but after the changeover to the MU Aerator this value was roughly halved to 290 mg/L. In general, pre-aeration tanks differ from aeration tanks (bioreactors) in that BOD removal cannot be expected, but as a result of the installation of this unit, BOD removal has been promoted, reducing the load in the bioreactor in the next stage. Moreover, prior to modification, a white soap-like foam was produced in the pre-aeration tank and bioreactor, making inspection and maintenance difficult, but this has almost completely disappeared after installation of the MU Aerator.



Notes

1) Water quality inspections are conducted once each month.
2) Water is sampled using the sewage examination method by means of grab sampling (spot testing).
3) The T-P test is conducted in March to check nutrient salts. Other water items are checked by means of simple water quality tests.
4) The work to change over to the MU Aerator MA-25P was conducted in the latter half of May.
5) The water quality in the pre-aeration tank decreased in May. However, on the day before water sampling, the sewage volume inflow was low due to the extended vacation period, so the load was decreased (interview with facility manager).
6) The operational settings were not changed during the water sampling period, and there were no changes in the pattern of inflow water volume and the pollution load.
7) Return of sludge to the pre-aeration tank is not being conducted.

Fig. 7 Results of BOD, SS, N-hx, T-N and T-P water quality tests for water discharged from pre-aeration tank

At the same time, the suspended substances (SS) were reduced from 380–440 mg/L to 170–340 mg/L. Furthermore, the extracted n-hexane (N-hx) content (animal and vegetable oil and fat content) was reduced to approximately one-third, from 150 mg/L to 50 mg/L.

2) Fresh sewage

In terms of biological treatment, from the standpoint of reducing BOD, SS and N-hx, introduction of the MU Aerator has resulted in the removal of organic matter, primarily due to aerobic bacteria, and the organic matter is physically adsorbed to the surface of the bacteria and ingested into the bacterial cells (**Fig. 8**)[4].

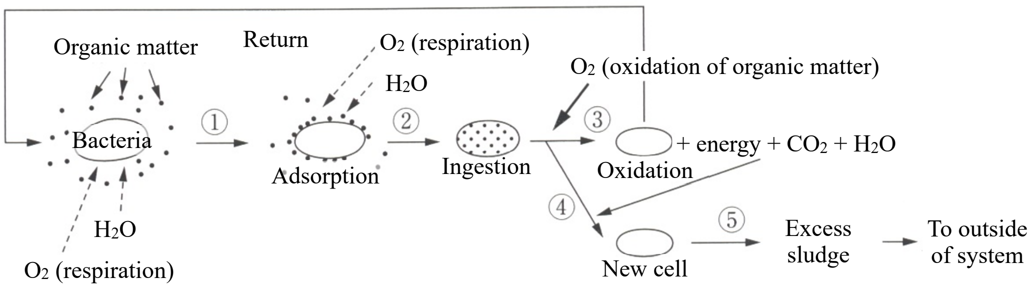


Fig. 8 Diagram showing process of organic matter (SS) removal by bacteria

The floc in activated sludge has particle sizes of 500 to 600μm (05–0.6mm) and has excellent agglomerating properties, and the bacteria attaches to or suspends itself from the floc. The size of the protozoa body depends on the species, but the typical type *Vorticella* measures approximately 30 to 150μm (0.03–0.15mm) (**Fig. 9**). Meanwhile, of the suspended substances that flow in, the foreign matter and sludge are removed by screening equipment (with screen holes measuring 1 to 2mm in the case of a fine screen), and the suspended substances (organic matter) measuring approximately 1μm to 2mm that are able to pass through the screen are subjected to biological treatment.

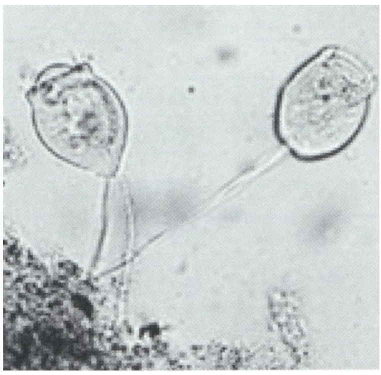


Fig. 9 *Vorticella convallaria*

The sewage that passes through sewer systems with long extended pipe and drain systems, pumping stations and the like contains solids that have been thoroughly fragmented. However, septic tanks and treatment facilities within the same area have short piping equipment lengths and it takes only a very short time for the effluent to reach the effluent treatment facility. This type of sewage has solid matter that is in its original state and does not tend to become fragmented, and the effluent can be called fresh sewage.

If we presume that the particle size of the organic matter is spheres measuring 2.0mm, this is 2,300 to 300,000 times larger than a Vorticella body, and it can be easily inferred that no matter how a protozoan community attaches to organic matter measuring 2.0mm, it will be difficult for such small individual organism to efficiently ingest something of this size within its cell.

The organic matter within suspended substances is indicated indirectly by BOD, COD, N-hx and so on. When it passes through the MU Aerator, it is powerfully mixed, agitated, sheared and fragmented, promoting the breakup of the organic matter. This causes the surface area of the particles to be increased, and it is easier for the protozoan community to efficiently adsorb and remove the organic matter. This improves treatment effectiveness as compared to the aeration agitation of conventional loop diffusers.

In addition, in contrast to the 5 kPa (500mmAq) pressure loss of the existing loop diffuser, the MU Aerator offers lower pressure loss of approximately 1 kPa (100mmAq), so the current value is reduced by approximately 10% and power consumption is also lower. Moreover, effluent treatment capacity is also improved due to the fragmentation of the SS, and the sludge conversion rate is reduced, so excess sludge can also be expected to be reduced.

In the pre-aeration tank renovation work at this food processing effluent treatment facility, installation of the MU Aerator improved biological treatment capacity and ensured stable water quality. This was also done in an effort to facilitate maintenance and inspection work and reduce maintenance costs. Since no installation of additional aeration tanks or new individual units was needed, facility functions were enhanced at a low cost.

(4) Scope of application

1) Ease of operation

The MU Green Reactor is a static fluid mixer. Unlike the aeration agitation systems that use a motor or the like, the diffuser has no moving or sliding parts, so it does not require replacement of worn-out parts or other components. For this reason, maintenance, inspection and operational control are easier as compared to other diffusers. Even for sludge treatment, which requires the most effort of the daily work operations, it offers improved biological treatment in the aeration tank, etc., making it possible to both reduce the sludge conversion rate and ease the work burden.

Moreover, the MU Green Reactor can be used for many purposes, including preventing the raw water pump tank and building drainage pit from becoming anaerobic, aerating grease traps and flow rate control tanks, aeration agitation of bioreactors and agitation of sludge storage tanks. When operating the MU Green Reactor to eliminate nitrogen as an advanced treatment process, the unit must be operated intermittently and the air quantity must be regulated to clearly define the aerobic and anaerobic periods. However, no clogging or the like will occur as a result of intermittent operation, so no complex operational processes are required once the system has been set to operate in this manner.

It has been more than 15 years since the first MU Green Reactor unit was installed, and there has been no unit failure and no decrease in equipment performance.

2) Scope of application

Planning and construction of the MU Green Reactor (static aerator) are underway in India, Thailand and Indonesia for the construction of new and renovation of existing effluent treatment facilities (conversion from surface aeration agitation system to static aerator). Increasingly the system is being adopted in Japan as well, for treatment of dairy effluent and seafood processing effluent in the agriculture, forestry and fishing industry and various other types of industrial effluent, and as a diffuser for the treatment of intermediate water in building equipment and effluent treatment and the like in small and medium-size facilities.

3. Air Stripping and steam stripping

Let us take a look at an example of the use of the MU-SSPW element for effluent stripping.

3-1. Air Stripping

Stripping is a process that is widely conducted to bubble the air and nitrogen from the bottom of a packed tower to remove the foul-smelling components in the effluent.

Formerly, air was bubbled in an effluent pond to aerate low-concentration NH_3 and other foul-smelling components. To improve the work environment and reduce the equipment area and the quantity of air used, the system was converted to air stripping using a tower loaded with the MU-SSPW element. The results are shown in **Fig. 10** and **Fig. 11**.

Previous → After modification

[Reference] Conversion to packed tower

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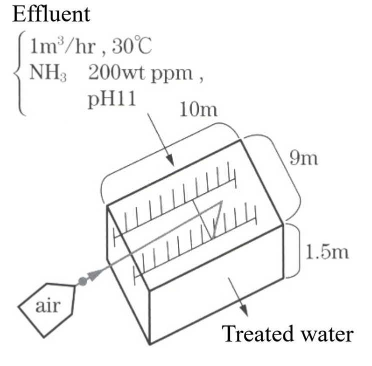
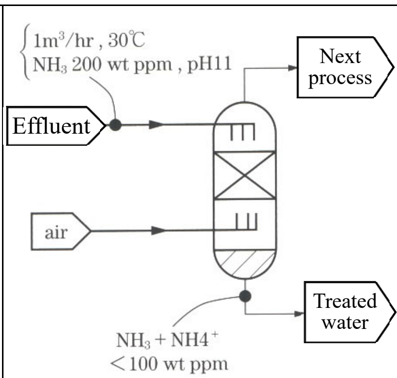
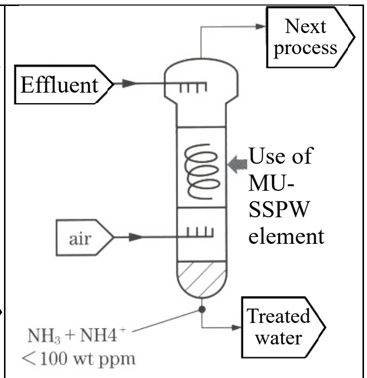
<tr><td colspan="2">
</td><td colspan="2">
</td><td>
</td></tr>
<tr><td colspan="2">Aeration</td><td colspan="2">Fill material used</td><td>MU-SSPW element used</td></tr>
<tr><td>Air use volume</td><td>1,100Nm³/hr</td><td colspan="2">900Nm³/hr</td><td>540Nm³/hr</td></tr>
<tr><td colspan="2" rowspan="4">Issues
(1) Sludge deposition is present; decomposition produces toxic gas.
(2) Air use volume is great.</td><td>Tower diameter x tower height</td><td>750mmφ×7mH</td><td>250mmφ×5mH</td></tr>
<tr><td>Flow velocity inside gas tower</td><td>0.5m/sec</td><td>3m/sec</td></tr>
<tr><td>Total differential pressure</td><td>5kPa</td><td>1kPa</td></tr>
<tr><td>Fouling / clogging</td><td>Yes</td><td>No (maintenance-free)</td></tr>
<tr><td>Advantages</td><td colspan="4">1. Energy-saving (air, power)
2. Improved work environment
3. Reduced equipment area
4. Maintenance-free</td></tr>
</table>

Fig. 10 Use of MU-SSPW element (compared with conversion to packed tower)

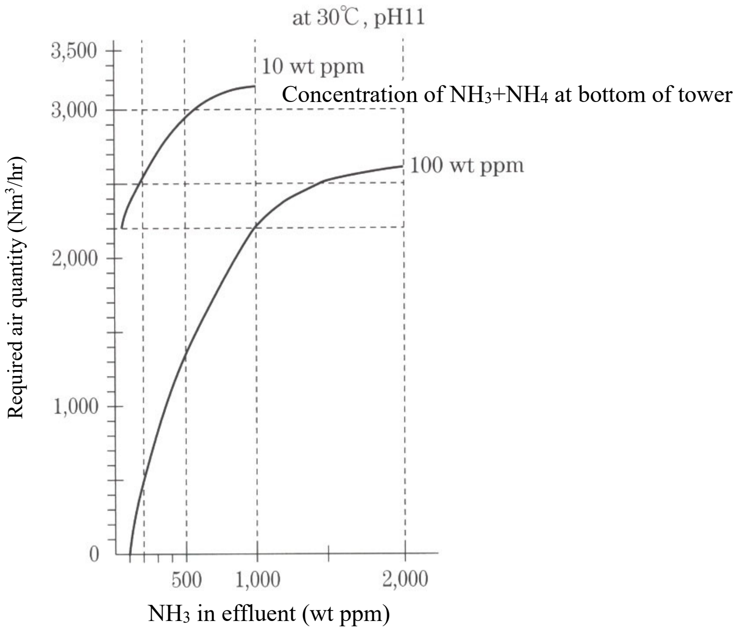


Fig. 11 Required air quantity (Nm^3/hr)

The use of the MU-SSPW element in the NH_3 stripping tower made it possible to increase the gas flow rate in the tower to 3m/sec (as compared to 0.5m/sec in the case of the packed tower) and enable dynamic gas-liquid mixing with no dead space, which enabled the diameter and height of the tower to be significantly reduced.

In addition to effluent stripping, the stripping tower containing the MU-SSPW element has been widely adopted for many other uses, including (i) extraction of the radon accumulated in pure water at the Super-Kamiokande neutrino observatory (ii) extraction and collection of iodine in brine water (iii) degassing of O_2 and CO_2 in seawater and (iv) use in activated sludge processing. In particular, it allows the equipment footprint to be significantly reduced, so its use as a stripping tower is being actively promoted with the slogan "From Horizontal to Vertical."

In addition, depending on conditions, co-current flow operation is more effective than the aforementioned countercurrent flow operation in some cases. In co-current flow operation, there is none of the flooding that occurs during countercurrent flow operation, and this makes it possible to increase the gas flow rate in the tower to 6 m/sec or greater. This operation is only possible with the MU-SSPW element and is used primarily for reactions, dust removal and direct cooling of gases. Either co-current or countercurrent flow operation is selected for stripping based on a consideration of conditions such as feed concentration (in particular whether or not there is dust content), processing water specifications and so on.

We are conducting workplace demonstration tests with a test unit at customer request in order to allow customers to get a sense of the system's effectiveness for themselves.

3-2. Steam Stripping

When stripped gas cannot be discharged into the atmosphere, combustion cracking using a boiler, RTO, plasma treatment system or the like is performed. However, when the effluent contains VOC content or the like at high concentrations, stream stripping is sometimes conducted.

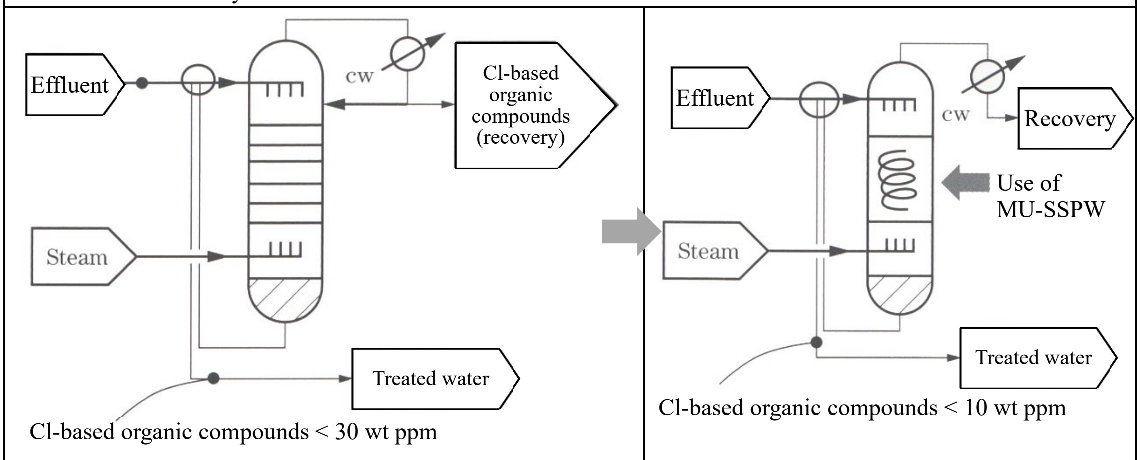
This method uses not heat input from a reboiler but steam blown directly into the base of the tower. In many cases, the components removed and collected at the top of the tower are reused. However, effluent contains impurities, and in many cases these cause problems. These may be the expected dust and sludge, or sludge and polymers broken down by heat and produced in the tower. These cause fouling and clogging inside the tower and make it impossible for operation to continue, and this constitutes a headache that necessitates shutdown of the production line and enormous maintenance expenses.

This is because even eliminating the reboiler that is easily fouled does not eliminate the clogging of the fill material in the tower itself.

The spiral flow of liquid that descends dynamically through the MU-SSPW element as described in the previous section improves gas-liquid mixing and contact efficiency. In addition, the self-cleaning action of the liquid itself also plays a major role in preventing clogging. This enables the MU-SSPW element to offer many years of maintenance-free service and has enabled it to gain many repeat customers. Steam stripping towers equipped with the MU-SSPW element are being used to process effluent containing highly concentrated NH_3 and chlorine-based organic compounds, helping to reduce energy consumption (reducing steam, power and cooling water use quantities), achieve maintenance-free operation and reduce initial investment costs.

Fig. 12 shows steam stripping of chlorine-based organic compounds. **Fig. 13-1** shows NH_3 steam stripping. **Fig. 13-2** shows an example of NH_3 concentration in effluent and steam use quantity.

Previously → After modification



Tower specifications	Sieved tray tower	Use of MU-SSPW element
Tower diameter × height	2.8 mφ × 8 levels	1.5 mφ × 8 mH
Total differential pressure	7 kPa	1.5 kPa
Reflux ratio (R/D)	2.5	0
Steam use quantity	12 t/hr	4 t/hr
c/up frequency	3 times / year	None
Issues	1. Ca-based substances are precipitated, causing clogging. 2. Steam use quantity is great. 3. Operation is unstable. → Treated water specifications	–

	cannot be maintained.	
Advantages	1. Maintenance-free 2. Energy-saving (steam, power) Benefit of JPY 200 million / year	

Fig. 12 Steam stripping of chlorine-based organic compounds

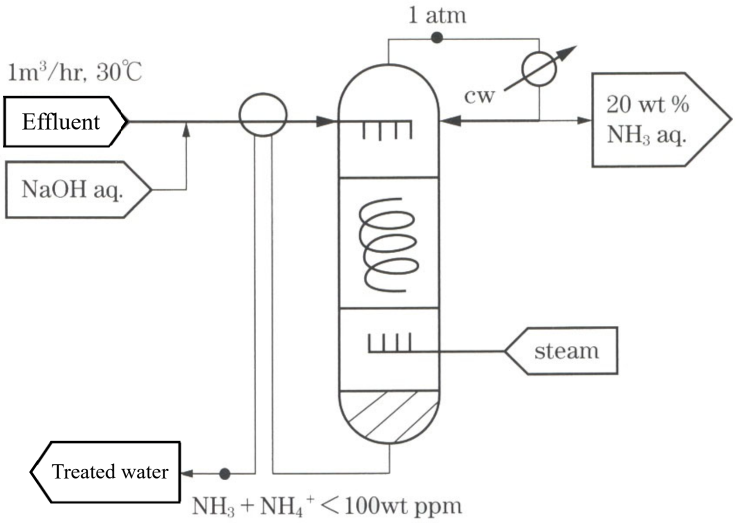


Fig. 13-1 NH_3 steam stripping

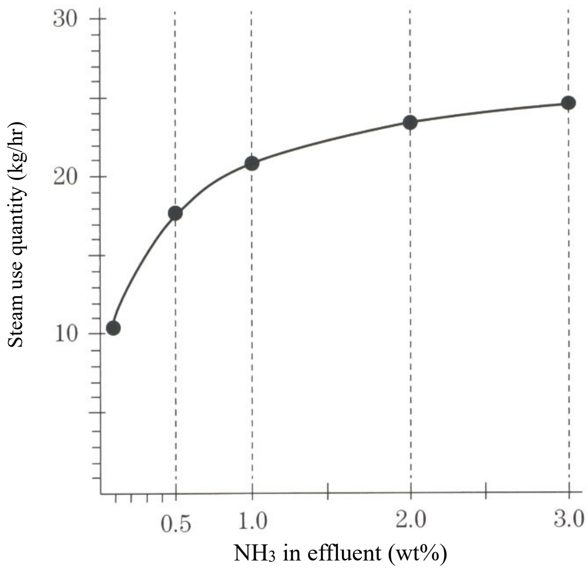


Fig. 13-2 Use of MU-SSPW

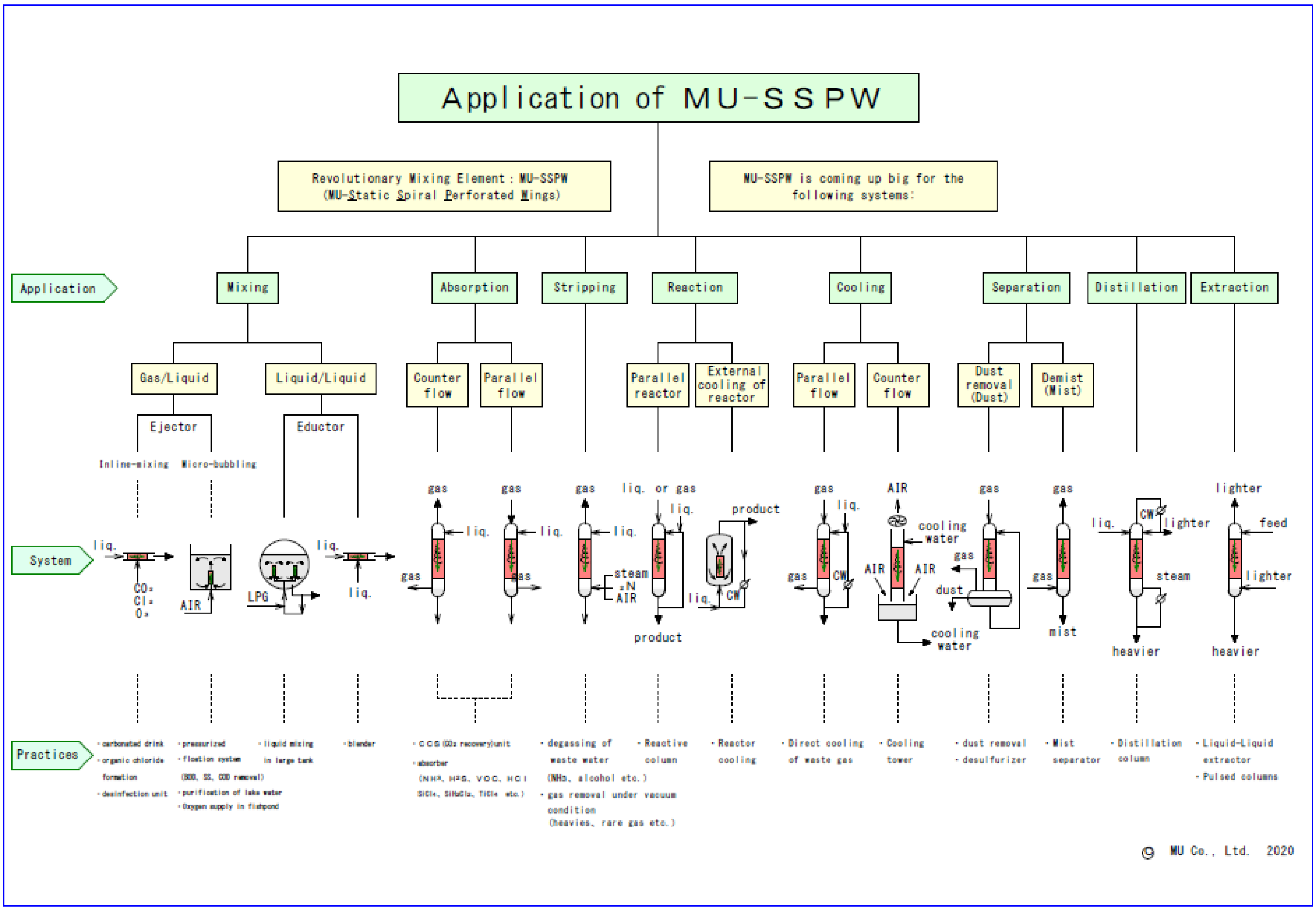
We receive many inquiries regarding how the equipment handles varied combinations of various constituents. Ultimately, the process is to have demonstration tests conducted with a test unit (with a tower diameter of 125A or 200A) and then, after the results have been confirmed, to deliver a scaled-up full-fledged unit.

The MU-SSPW unit can be made of PVC, HT-PVC, PP, teflon, various types of stainless steel, titanium, hastelloy and so on.

4. Scaling up from a test unit to a full-fledged unit

Based on the aforementioned test results, we design a system comprising a tower equipped with the MU-SSPW element (the main unit) and ancillary equipment. As shown in **Fig. 14**, the MU-SSPW has a wealth of applications. This section will focus on the basic approach to scaling up the stripping system.

Fig. 14 MU-SSPW applications © MU Co., Ltd. (Jan. 2014)



4-1. Preparations for demonstration test using test unit

MU Company configures the basic concept of the process based on simulations and previous experience, and then proposes the results to the customer. Subsequently, if there are any other points that need to be cleared up at the stage at which the conditions are refined, we add a further step in which tests of the actual fluid are conducted using a demonstration test unit. In such cases, we prepare a demonstration test unit through consideration of the gas and chemical conditions, the need for pumps and fans, the material from which the demonstration test unit is made, the instrumentation, the sampling and analysis methods and so on.

4-2. Data to be measured during test

(i) Confirmation of temperature, pressure (pressure loss), and operational status particularly at lowest and highest flow rates (confirmation of operational stability by sensory evaluation, using a sight glass or the like).

(ii) Measurement under various conditions (gas flow velocity, L/G [liquid-gas ratio: L/m^3], gas and liquid contacting time, allowable pressure loss, pH) of concentration of gas at aperture, and analysis of physical and chemical state of liquid at aperture.

(iii) Dust measurement. As this will take some time, simultaneously check the interface of the liquid section at the bottom of the tower and check for deposits or other foreign matter; also inspect the pump piping strainer and check the operation of the spray nozzle through the sight glass.

(iv) Appropriateness of material.

(v) After setting the ideal conditions, begin long-term continuous operation. (A long period of time may be needed to determine the effect of dust and sludge.)

4-3. Full-fledged unit design (scaling up)

(i) Design of MU-SSPW element diameter and height

Determine the flow velocity of the gas in the tower, the L/G, the gas and liquid contacting time, the allowable pressure loss and so on under the finalized ideal conditions. If simulation is possible, determine HETP from the tower height and the number of theoretical stages and confirm the appropriateness of the design.

(ii) Optimize the position and type of spray nozzle and the spray pattern, etc. based on the status of dust and sludge generation and fouling.

(iii) Design of MU-SSPW element configuration

(1) Finalize the number of blades based on the blade fill density (total blade surface area / element volume: m^2/m^3).

(2) Determine the angle of rotation for blade clockwise and counter-clockwise operation.

(3) Determine the blade hole diameter and hole area ratio formed by the porous body.

(4) Finalize the configuration of the core MU-SSPW element by studying past values and test results to determine a configuration that will ensure high performance and maintenance-free operation and making an overall judgment that takes into account the factors in chemical reaction processes, etc.

(iv) Determination of total pressure loss in tower

Based on the pressure loss data obtained from the test unit, the total pressure loss inside the tower during operation of the full-fledged unit is estimated from the flow velocity of the gas in the tower, L/G, blade fill density, element height and so on. This value is checked to make sure that it is below the allowable pressure loss and then finalized. The most important factor that makes it easy to scale up using the MU-SSPW is that it can be manufactured in a configuration that does not create fluid dead space (stagnation area) inside the reactor. This enables the temperature, concentration and pressure distribution to be made uniform and homogeneous, and the fluid can react completely and continuously at the same speed with no unevenness in both streamlined flow regions and turbulent flow regions.

A scrubber containing the MU-SSPW designed and provided based on this concept has been operating continuously for 30 years without requiring maintenance. For an engineer, it is a source of great joy that, even though during that time there has been a change of multiple generations at the customer's workplace, the unit's maintenance-free operation has been highly regarded and it has been introduced at new plants as well. **Fig. 14** shows the applications for the MU-SSPW. Currently we are pursuing the development of a 10m diameter MU-SSPW with a design based on a spider's web. When the 10m diameter Aqua Tower is used for water treatment, the treatment capacity is 28,000 to 55,000 m^3/hr. When it is used as a gas absorption tower, the treatment capacity is 570,000 to 1,000,000 m^3/hr for counter-current flow and 2,000,000 to 2,500,000 m^3/hr for co-current flow.

Fig. 15 shows a plan view of a 10m diameter MU-SSPW unit. **Fig. 16** shows a three-dimensional view of a 10m diameter MU-SSPW unit. The pursuit of these designs allows us to draw one step closer from determination of manufacturability to the achievement of an actual full-fledged unit.

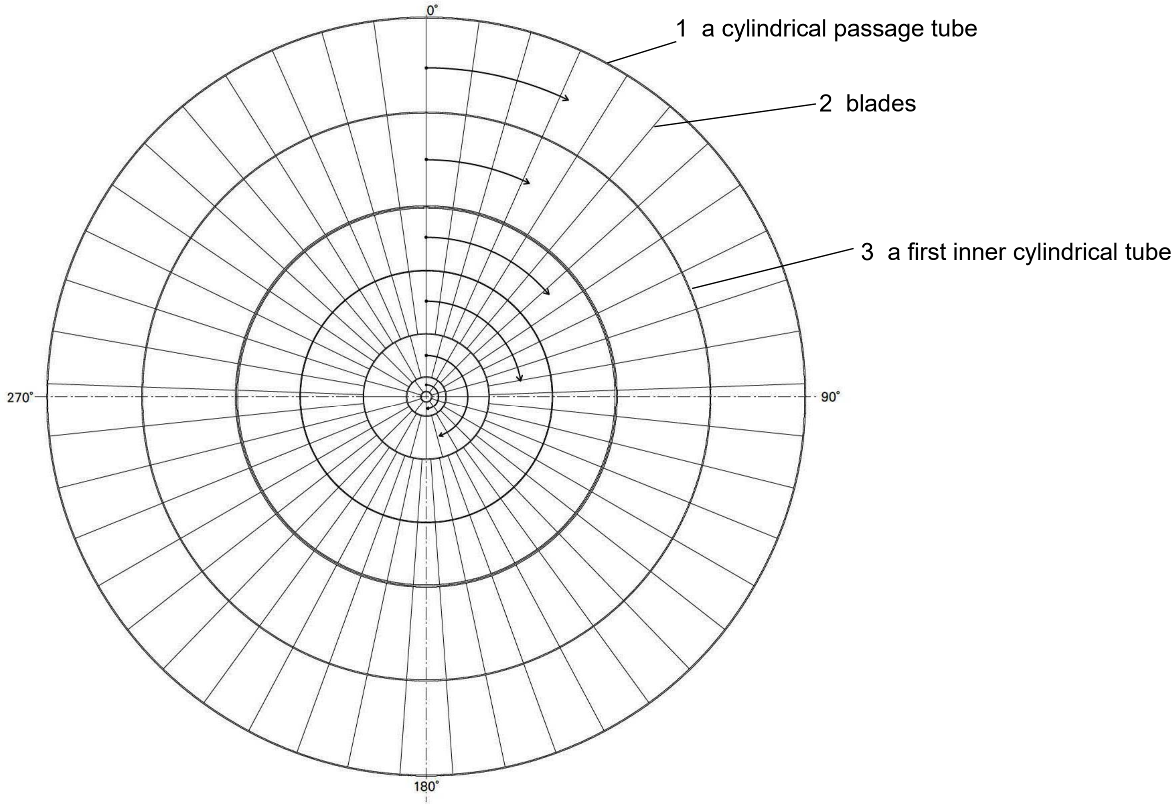
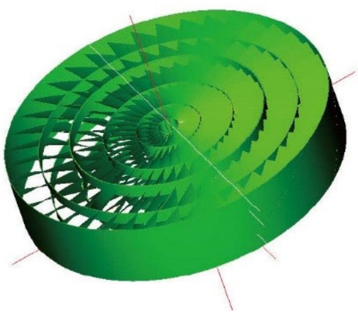


Fig. 15 Plan view of 10m diameter MU-SSPW (©2020 Anemos Co., Ltd.)



Fig, 16 Three-dimensional view of 10m diameter MU-SSPW (©2020 Anemos Co., Ltd.)

In the future, new disruptive technical innovations for achieving large-scale systems with features that include high performance, maintenance-free operation, and reduced energy consumption and space requirements can be anticipated in the various mixing and agitation sectors shown in Fig. 14. MU Company is prepared to move forward step by step to locate engineers, managers and financiers who retain “the courage to accept change and the ability to anticipate change”[7].

5. A final note

In the 36 years since its founding, MU Company has charted a non-linear course through rough seas without foundering.

Existing equipment is deteriorating, and we are nearing the point at which it must be upgraded or replaced. We hope that customers will recognize the benefits of more compact equipment, high performance, and maintenance-free operation provided by the MU-SSPW element, and we are ready to introduce many of these systems.

In recent years, we have been faced with the worldwide economic downturn in the wake of the “Lehmann Shock” as well as the need to recover from natural disasters such as the Great East Japan Earthquake and tsunami of 2011. Moreover, the state of emergency resulting from a novel coronavirus measuring only 0.1μm has brought dramatic changes to the appearance of our cities. We have also come to realize that aspects of our lifestyle patterns that we had thought were ordinary were actually very special, as a result of the introduction of teleworking and working at home, and meeting online rather than face to face.

Beginning with masks, disinfectant and periodic ventilation, we are using various methods to ensure “social distancing” and prevent infection. These include postponing or canceling meetings and discussions with clients, avoiding face-to-face meetings as much as possible, making sure employees maintain a distance of at least two meters with one another, and reducing the number of occupants when traveling by car.

We still do not know when the COVID turmoil will end. But it is unlikely that society will return to exactly the same state that it was in before.

In the post-COVID world, the approach to business continuity planning (BCP) and crisis management as well as design and maintenance will need to change. It is our hope that there will be opportunities for us to make some small contribution to society, through products such as the MU Aerator that generates microbubbles and offers maintenance-free operation and the MU Scrubber that can capture ultrafine dust measuring 0.1μm or smaller.

Next spring, we will introduce the MU Aerator® that produces free radicals and generates ultra-fine super-microbubbles, and a new product called the MU Magnetic Aerator that comprises an aerator combined with a high-performance magnetic material that conducts irradiation with powerful lines of magnetic force (electromagnetic waves).

A master who had devoted his life to "an investigation of all things through observation, with the aim of self-cultivation" said the following:
"There is no creation without competition."
"There is no creation without freedom."
"There is no creation without imagination."
"There is no evolution without destruction and creation."

While maintaining a child-like innocence,
And finding a way to create new things,
And sometimes deviating from the main path,
Always moving through time,
We repeat the cycle of death and life in a MU — no-mind — world with no beginning and no end, pursuing a far-off dream from horizontal to vertical. Like the DNA that forms a double helix, like a waterfall, like powerful surf, we travel a long, spiral path while diligently continuing to compose our poem (meditation), fulfilling our mission as a venture company (albeit a small one), we continue to travel step by step in the world of no-mind.

The flower innocently invites the butterfly;
The butterfly innocently visits the flower.
When the flower blooms, the butterfly comes;
When butterfly comes, the flower blooms.
I also don't know others,
Others also don't know me.
With not-knowing it we follow nature's course.
— Ryokan

Acknowledgements

We would like to express our gratitude to the many people who have provided us with

guidance and cooperation.

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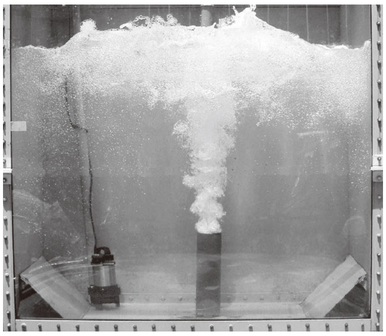
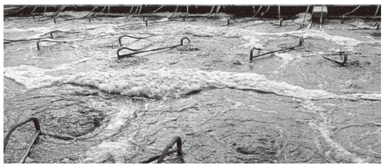
MU Company products use innovative technologies to contribute to improving the environment, energy saving and maintenance-free operation.

MU Green Technology®
MU-Static Spiral Perforated Wings <MU-SSPW>
Diffusing cylinder / stripping tower
MU AERATOR®

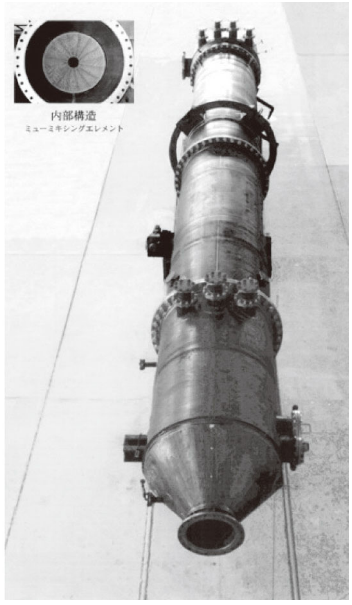
Waterfall + MU-SSPW



MA-125 (microbubbles aerating)



Aeration tank with MA-125 aerators



VOC stripping tower
φ 1500 x 18 mH
(Capacity: 600 m^3/hr)

1. Principle:
   This compact unit is made up of two elements and can efficiently generate microbubbles. The gas is agitated and sprayed out at high speed (20 - 100 m/sec) by the MU oscillation unit and then conveyed to the MU-SSPW element. There the flow is converted to a shear flow spiraling alternately to left and right, a linear flow that advances in the axial direction, and divided by perforated blades (wings) into a divided flow with multiple layers, forming a dense gas-liquid multiphase flow and generating microbubbles.
   The gaseous phase is completely mixed, dissolved into and absorbed by the liquid phase, and each of the volatile substances in the liquid phase (NH_3, H_2S, VOC, Kr, Rn, etc.) is stripped to the gaseous phase, promoting separation.

2. Features:
   (1) A large quantity of microbubbles is generated by the roots blower itself.
   (2) The unit has no mechanical moving parts, so it will not experience chemical contamination or mechanical failure due to wear or the like, so no maintenance costs are incurred.
   (3) The unit offers excellent acid and alkali resistance, mechanical strength and durability.
   (4) The unit is compact and offers high performance. Oxygen transfer efficiency is 8 - 25%.
   (5) The MU-SSPW element provides unique agitation, mixing, dissolving, dispersion and emulsification functions. At the same time, the unit's self-cleaning function prevents fouling and clogging, and provides maintenance-free operation.
   (6) The unit can be made from PVC, polypropylene, SUS316, titanium, special metals, etc.

3. Applications
   (1) Aerator / diffuser
   (2) Activated sludge treatment unit
   (3) Gas-liquid reactor
   (4) Floatation separator
   (5) Bioreactor
   (6) Treatment unit using ozone
   (7) Ballast water treatment unit
   (8) Microplastic collection and treatment unit
   (9) Treatment water radioactive contamination extraction device

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Technical cooperation: MU USA CORPORATION
Patented in Japan, USA, EU, China, Czechoslovakia, India and Singapore

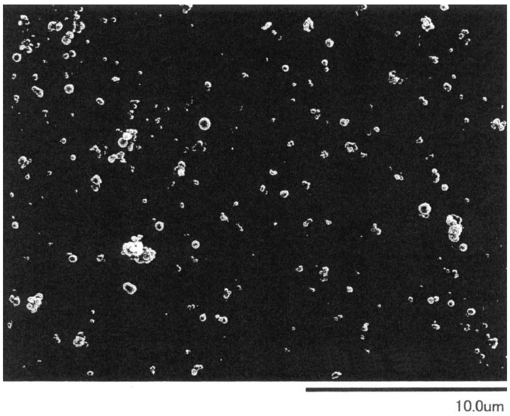
MU Green Technology®

helps provide environmental and energy solutions

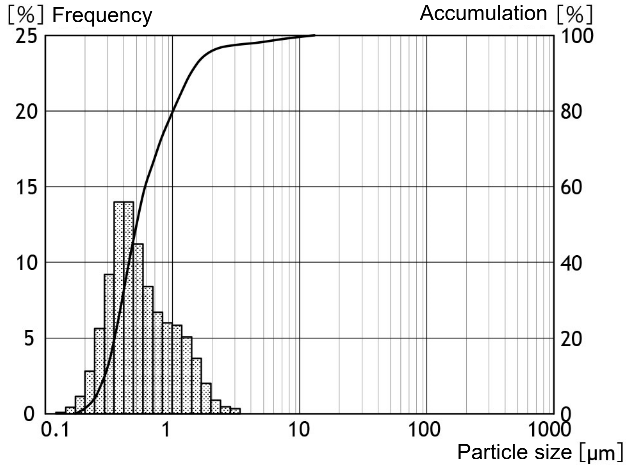
World's first wet type exhaust gas treatment unit using parallel current flows, equipped with the MU-Static Spiral Perforated Wings (MU-SSPW) that eliminate PM2.5+α atmospheric pollutants

MU SCRUBBER®

Compact High-performance Maintenance-free Energy-saving



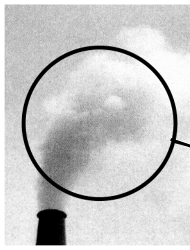
SEM photograph of Oxide A in washing liquid



Particle size distribution of Oxide B removed from washing liquid

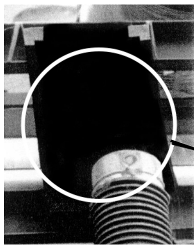
Features

1. Used by many customers for hydrolysis/reactive absorption of highly concentrated HCl, SiCl4, SiH2Cl2, Si(CH3)Cl3 and TiCl4 gases.
2. MU SCRUBBER has a MU-SSPW element in the reactive absorption section and a unique patented structure in the exhaust gas lead-in section. It can provide stable operation for 8,000 hours per year without blockages in order to meet customer needs.
3. There is no need for a spare scrubber tower, greatly reducing initial investment costs.



Before use of MU SCRUBBER (SiO_2: 400 mg/Nm^3)

White smoke visible



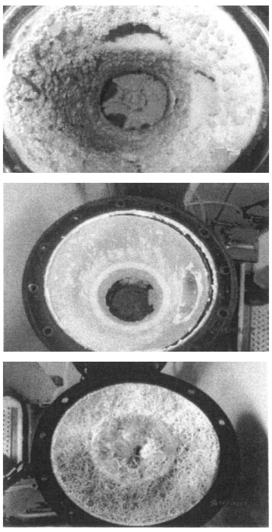
Using MU SCRUBBER (SiO_2: 20mg/Nm^3 max.)

No white smoke visible!

MU SCRUBBER performance

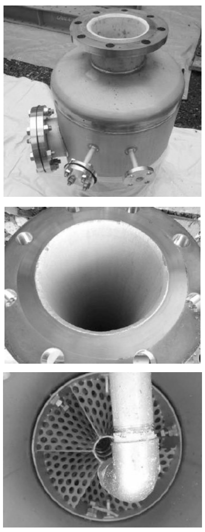
Comparison between MU SCRUBBER and others

Company A scrubber



- Maintenance interval: between 10 days and 2 weeks.
- Photograph provided by customer at time of estimate.

MU SCRUBBER



- Maintenance-free for 1 year or more
- Photograph taken at time of disassembly and inspection (with customer's permission).

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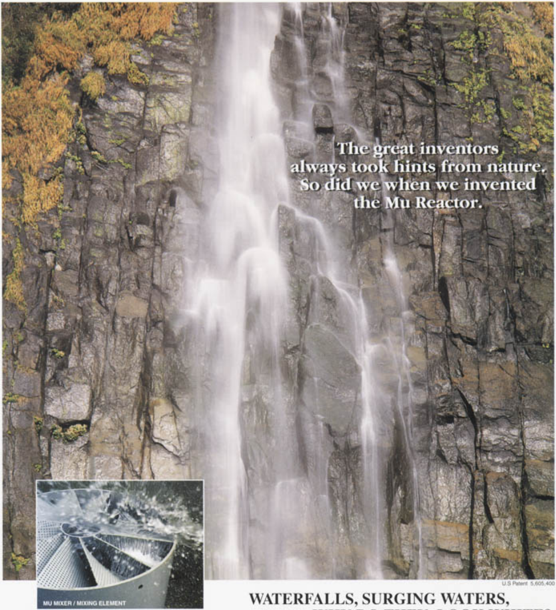

U.S Patent 5,605,400

WATERFALLS, SURGING WATERS, WHY DO THEY LOOK WHITE?

A simple question led to the invention of the Mu Reactor. This question further inspired a number of relevant ideas. Like, what if we placed our Mu Mixer, a new generation, high-performance motionless fluid mixer, in the waterfall? What can we learn from Bernoulli's theorem? And, why does entropy, a measure of kinetic randomness, increase with pressurization?

From there, we went on to ponder ways to reduce the cost of environmentally friendly technologies, and further ways to harness natural energy sources (gravity, wind, wave and geothermal power) for industry. Observations inspired questions, questions required experiments, experiments led to refinements, and thus waterfalls and surging waters inspired the Mu Reactor. ©

New Static Mixing Technology
Revolutionary Aeration System

MU REACTOR

• Energy saving • Space saving • Cost saving

Our epoch-making gas-liquid contact reaction system uses clean natural energy and requires no power supply to agitate or aerate.

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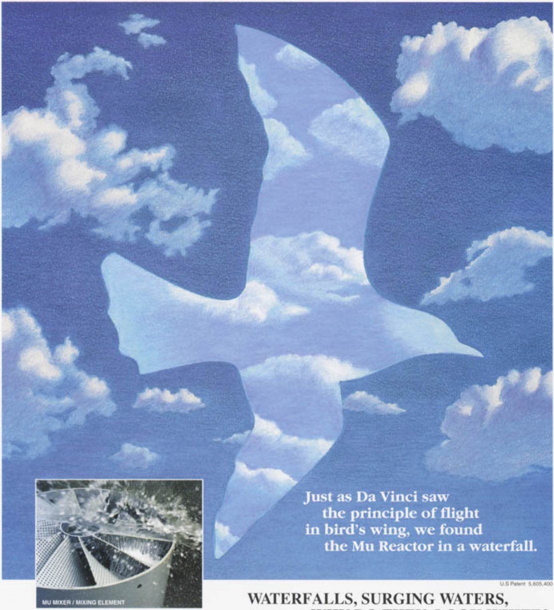
Just as Da Vinci saw
the principle of flight
in bird's wing, we found
the Mu Reactor in a waterfall.
MU MIXER / MIXING ELEMENT