Feature: Industrial Wastewater Treatment and Water Business News

New Trends in Water Purification Technology: Water Purification Systems Using MU Mixing Elements®

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1. Current state of water pollution

Rapid industrialization and accompanying developments such as population growth have in recent years made pollution of bodies of water such as lakes, marshes, and inland waterways where water circulation tends to be poor an emerging problem around the world. The problem is particularly severe in developing countries and regions undergoing economic development. Around scenic Lake Tai in China's Jiangsu and Zhejiang provinces, for example, rapid urbanization and industrialization have caused the water environment of the lake to deteriorate sharply, and the resulting pollution has become a major social problem.

In Japan, meanwhile, despite recent progress in improving river water quality in order to preserve the environment, improving the quality of large enclosed bodies of water remains hugely expensive in terms of energy inputs, and more effective methods have yet to be found. There also exists growing demand for more efficient, energy-saving aeration systems for treating industrial and domestic wastewater.

2. About the MU Mixing Element

A water purification system equipped with a MU Mixing Element[1)] is being developed to provide an effective means of cleaning lakes, marshes, reservoirs, inland waterways, and other large bodies of water. MU Mixing Elements can be used as proprietary water purification technology developed by MU Company. Structurally speaking, it is a static mixer that requires no agitating power. Because of its functionality and efficiency, however, it might more aptly be described as a groundbreaking "super" static mixer that redefines the conventional concept of a static mixer (**Figure 1**).

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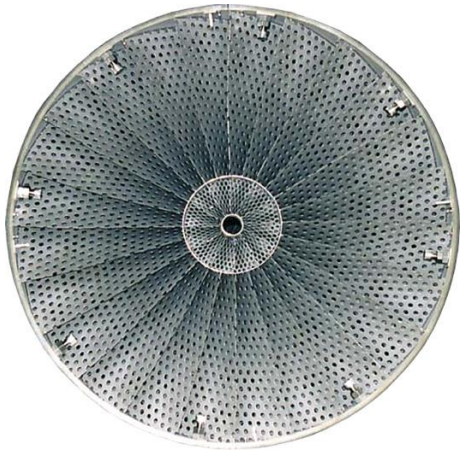


Figure 1　MU Mixing Element

The MU Mixing Element comprises a MU Mixer containing alternately arranged spiral perforated agitating blades that rotate clockwise or counterclockwise. When multiple fluids of varying compositions, concentrations, temperatures, viscosities, and so on pass continuously through the MU Mixing Element, the fluids are repeatedly divided, rotated, inverted, merged and sheared in axial and radial directions without power until completely mixed and agitated.

If used for water purification purposes, the MU Mixing Element can efficiently mix the water and gas (oxygen) circulated through it by means of a process of repeated micronization and gas-liquid contact, and its mixing and agitation efficiency is dramatically greater than that of conventional technologies.

3. Types of water purification system equipped with MU Mixing Elements

Below we review three types of water purification system that incorporate MU Mixing Elements.

Figure 2 depicts how each is typically installed. The three types are the MU Aqua Tower®, the MU Green Reactor®, and the MU Floating Tower.

The MU Aqua Tower consists of multiple MU Mixing Elements stacked together to form a tower, and efficiently purifies water by allowing water pumped up from a lake or similar source by a circulation pump to free-fall to form an artificial waterfall. The mechanism behind this and other details will be explained more fully below. Systems of this kind are typically installed on the edge of the water to be cleaned, such as on a

lakeside.

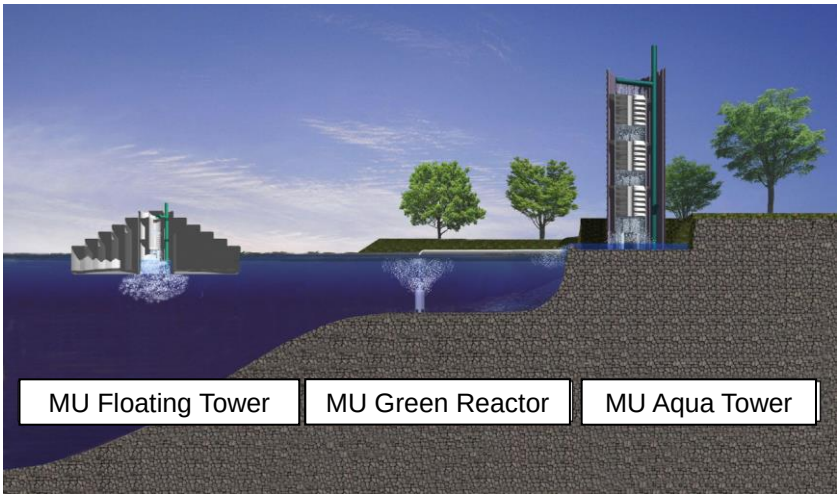


Figure 2　Types of water purification system employing MU Mixing Elements

The MU Green Reactor is a type of water purification system that is installed underwater at the bottom of a lake or similar location. Fresh pressurized air is fed to the bottom of the system underwater by a compressor or similar device to generate micro-bubbles in order to enrich the water with oxygen and activate it. Air supplied under pressure to the bottom of the system ascends under its own buoyancy. On the way it passes through several layers of MU Mixing Elements, each of which makes the air bubbles smaller and smaller to form micro-bubbles that make it easier for the oxygen to dissolve into the water.

The MU Floating Tower is a more compact system that floats on the surface of the water. It comes in two types: one incorporating a miniaturized MU Aqua Tower, and one with a MU Green Reactor enclosed in a submerged casing. As both types float on the surface like a boat, they can be easily moved to purify water over a wider area.

Figure 3 shows a comparison of the performances of each type of water purification system. All three types make maximum use of natural forces, such as the free-fall of water and buoyant rise of bubbles, in order to minimize unnecessary energy load. This futuristic approach to water purification is perfectly suited to a world where energy shortages will become an increasingly serious global issue. Their compact designs also take up less space, save energy, require no maintenance, and do not affect the surrounding ecosystems.

	MU Green Reactor	MU Aqua Tower	MU Floating Tower
Name			
Structure	High-performance aeration tower containing an oscillation device and multiple spiral blades	Aeration tower comprising a cleaning column with a MU Mixing Element at the top that supplies circulating liquid whose energy of descent is used to suck air from the atmosphere and effect gas-liquid mixing and contact	Aeration tower equipped with a MU Aqua Tower or MU Green Reactor and contained in a body that floats on the surface of the water Generates its own power by a PV system
Method	Underwater installation that aerates by sucking up water by means of an air lift and forcibly mixing and agitating it with pressurized air in a mixing element to create a misty air-liquid multiphase flow	New aeration method that uses the potential energy of a liquid Designed for installation aboveground, and works along the same lines as a dam discharge or waterfall	Designed to float on the surface Available in multiple types (with Aqua Tower, Casing, Air Lift, or Green Reactor)
Model	MGR-300 - MGR-1800	MAQ-500 - MAQ-1800	
Bubble size	Super-micro	Micro	Super-micro/micro
Oxygen transfer efficiency (EA%)	8 - 16	2 - 5	
Aeration efficiency ($kg \cdot O_2/kWh$)	1.0 - 1.8		
Advantages	• Resistant to blockages • Powerful agitating and shearing action • Easy to install • Generates micro-bubbles • Requires no booster pump for liquid	• Resistant to blockages • Large volume of circulating liquid • Easy to install above ground • Requires no pressurized air blower • Can generate negative ions	• Resistant to blockages • Large volume of circulating liquid • Can be moved around on water • Allows purification of deep bodies of water
Drawbacks	None in particular	None in particular	None in particular
Additional information	• Air feed: 2-100 m^3/h • Gas mass velocity: 3.2×10 kg/m^2h • Materials: SS, SUS, Ti, Hastelloy, PP, PVC, etc. • Suitable also for gas absorption, desorption, etc.	• Liquid mass velocity: 2.5-4.5 kg/m^2h • Volume of circulating liquid: 50-1,000 m^3/h • Materials: SS, SUS, PP, PVC, FRP, etc. • Ideal for marrying water purification technology with artistic design	* See MU Green Reactor and MU Aqua Tower sections

Figure 3 Comparison of water purification systems

4. How the MU Aqua Tower works

4-1. Why do waterfalls appear white?

Figure 4 shows the Nachi Waterfall in Kumano district, Wakayama Prefecture, southern Honshu. Although water is naturally clear, it seems to turn white when it roars down a waterfall, and understanding why this happens helps us understand the mechanism behind the MU Aqua Tower.

The water in a waterfall appears to turn white because the water droplets in the fall absorb large amounts of air (referred to as “oxygen” below) on their way down. Along the way, they bump into rock surfaces that smash them into smaller and smaller droplets. As they get smaller, their surface areas increase and so too do the gas-liquid interface areas with the air, thereby making it easier for more oxygen to be absorbed into the water.

These two effects—“falling” and “smashing”—together constitute what we might call the “waterfall effect,” and the MU Mixing Element is essentially a water purification system that makes maximum use of this waterfall effect. The MU Aqua Tower comprises a stack of these MU Mixing Elements to form an artificial waterfall.

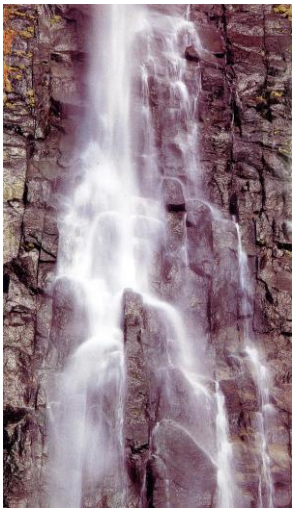


Figure 4 Nachi Waterfall

4-2. The principle behind the MU Aqua Tower

Below, we explain how the MU Aqua Tower works in a little more detail by juxtaposing the mechanism behind it against the principle of the waterfall. The

waterfall effect in the MU Aqua Tower refers specifically to the two oxygen dissolving effects described next.

(1) Oxygen dissolving effect created by free-fall of water

First is the oxygen dissolving effect of free-fall. When water falls from one elevation to another, as in a waterfall or weir, it appears to turn white as it falls. At this time, there occurs a phenomenon like that shown in **Figure (5)-1** at the micro-space level. When water falls, Newtonian physics come into play and the velocity of descent of the water accelerates in accordance with the distance fallen. When the water droplets have fallen distance ΔH after Δt seconds as shown in the figure, a velocity differential arises due to acceleration, creating areas of vacuum between the droplets. When this happens, air flows in from around the falling water toward the vacuums, where the air and water droplets become mixed through gas-liquid contact and oxygen is absorbed into the droplets. The fact that water in the area of descent looks white means that the water droplets have absorbed oxygen and are in a supersaturated state. In this way the MU Aqua Tower makes maximum use of the oxygen dissolving effect that occurs when water free-falls.

(2) Droplet smashing effect of spiral agitation blades

Second is the droplet smashing effect of rock surfaces. The water cascading down a waterfall hits rock surfaces to form white spray. This is because the water droplets are smashed into smaller droplets as they collide with rock surfaces on their way down, increasing the gas-liquid contact interface area between the droplets and oxygen and increasing the efficiency of oxygen absorption.

The MU Aqua Tower's perforated spiral agitation blades, shown in **Figure 5-(2)**, act like the rock surfaces in a waterfall, smashing the water droplets into smaller droplets as they collide with them. This accelerates gas-liquid mixing between the water droplets and oxygen.

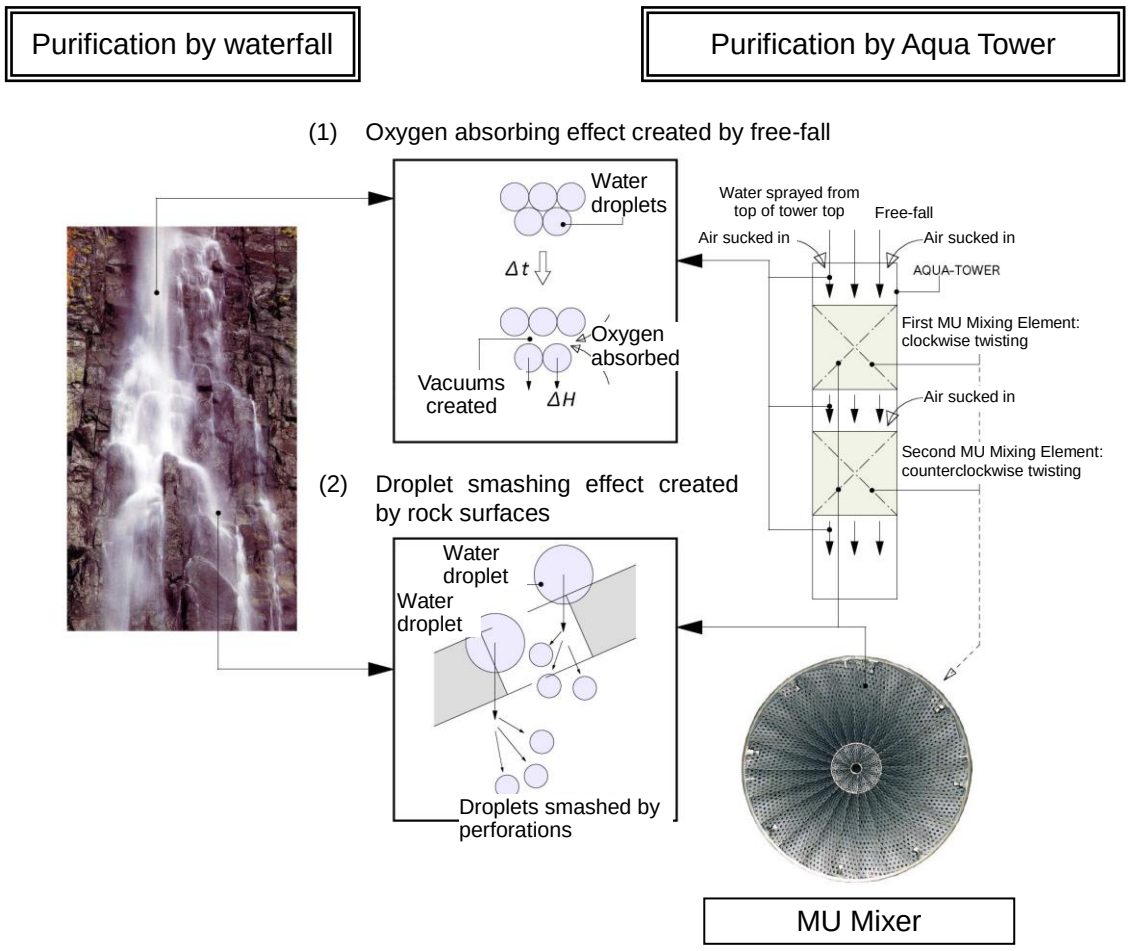


Figure 5 How the MU Aqua Tower works

4-3. Design concept for the MU Aqua Tower

Oxygen-rich water also has an activating effect on ecosystems that contributes to water depuration. As this system does not depend on any chemical processes and creates no demand for motive power, moreover, it has virtually no ecological impact.

Figure 6 shows a suggested design for a MU Aqua Tower. The MU Aqua Tower recreates an artificial waterfall, which dissolves oxygen into the water to increase its dissolved oxygen (DO) content. It can also prevent hydrogen sulfide from being generated and reduces the ammonia content of water. In addition, it exerts an ameliorative effect on suspended solids (SS) by causing water throughout the lake to move. To the periphery of the MU Actuator are attached photovoltaic sheets in order to generate electricity independently from natural resources, and

the electricity thus generated provides the power to drive the water pump. As the MU Mixing Element that functions as the purification unit does not itself require any maintenance, hardly any running costs will be incurred in the future. Thus the exterior can be designed to ensure that the tower does not detract from the landscape, allowing water purification technology to be assimilated into the environment. Other possibilities include artistic designs that incorporate elements of sculpture and music alongside technology.

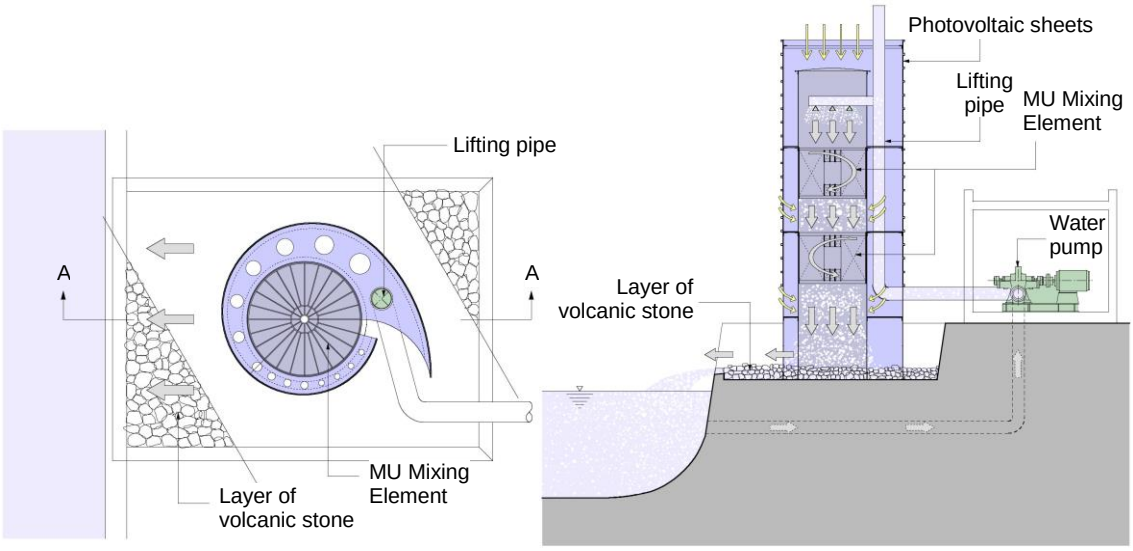


Figure 6 Suggested design of MU Aqua Tower

5. How the MU Green Reactor works

Like the MU Aqua Tower, the MU Green Reactor contains a stack of MU Mixing Elements. However, whereas the MU Aqua Tower is designed to be installed in the open air and to mix oxygen with water by means of free-falling water, the MU Green Reactor is installed underwater, where the buoyancy of air is used to generate micro-bubbles and dissolve oxygen into the water. While thus using the same MU Mixing Elements, the MU Green Reactor is like a MU Aqua Tower that has been inverted around the surface of the water.

As it dispenses with the need for an underwater aerating agitation device to mechanically agitate the water and air and requires only motive power for a Roots blower or compressor to feed air to the bottom of the reactor, it is capable of purifying water extremely efficiently.

Figure 7 shows a photo of a MU Green Reactor taken immediately after its removal from an aeration tank following testing. The MU Green Reactor is already in widespread use as a water purification system, and is gaining recognition for its outstanding cost performance. As can be seen in **Figure 8**, it can instantaneously produce large amounts of tiny micro-bubbles without any unnecessary mechanical or electrical load being generated by a forced aeration device. It measures 1,800 mm in diameter and is capable of air throughput of 6,000 m^3/h. Purifying the waters of Lake Tai using a large-scale version of this aeration system is the dream of these authors.

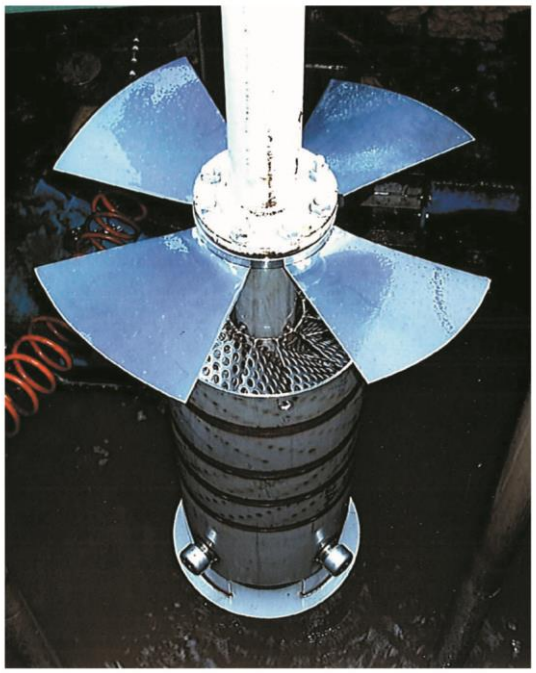


Figure 7　MGR-300 MU Green Reactor

(1)

(2)

(3)

(4)

(5)

(6)

(7)

(8)

(9)

Figure 8 Micro-bubbles being generated

6. One application of a MU Green Reactor

Working in collaboration with Taiyo Kankyo Co, Ltd., MU Company conducted batch aeration tests at an agricultural wastewater facility to determine the feasibility of using the MU Green Reactor in a batch aeration tank system.

1) Test conditions
   - Raw water: 350 m^3/day
   - Aeration tank capacity: 165 m^3×2 tanks
   - Aeration tank dimensions: 5.8×5.8 m
   - Water depth: 5.03 m
   - MLSS: 3,300 mg/l

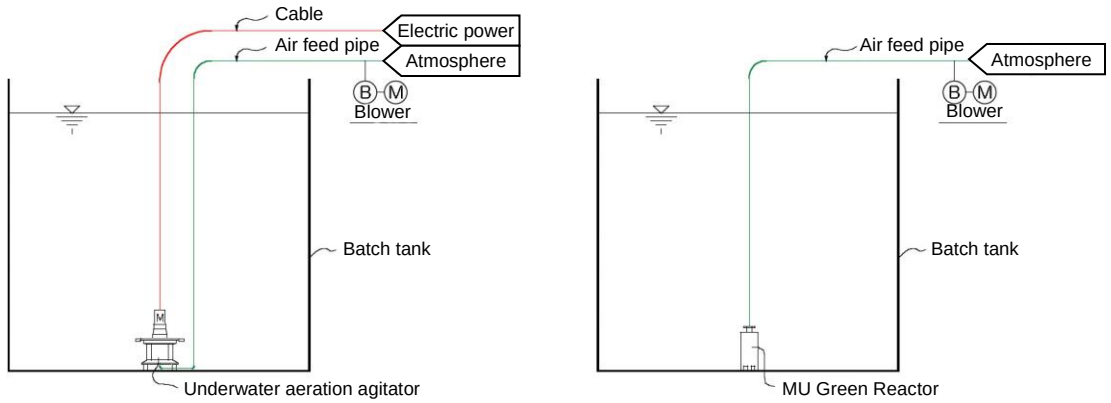
2) Performance comparison

   Comparisons of performance and flows are shown in **Table 1** and **Figure 9**. From the test results, the MU Green Reactor was found to have the following advantages:

   (1) A 48% power saving
   (2) Lower maintenance costs due to having no powered (rotating) parts
   (3) Absence of hardware susceptible to equipment failures due to electrical leakage, abrasion, etc.

Table 1 Batch sewage treatment (sewage temperature: 15.5°C, MLSS 3,300 mg/l)

	For aeration		For agitation		Motive power (kW)		Total (kW)	Oxygen dissolving efficiency (%)
Existing underwater aeration agitator	Air feed (m^3/min)	Blower (kW)	Underwater aerator (kW)	Underwater pump	Aerobic	Anaerobic		
	1.0	2.64 (rated 3.7)	2.2	Unnecessary	4.84	2.2	7.04	12.1
MU Green Reactor MGR-300	1.0	2.64	Unnecessary	0.75	2.64	0.75	3.39	9.7



(1) Underwater aeration agitation system (2) MU system

Figure 9 Flow diagrams of an underwater aeration agitation system and the MU system in a batch tank

7. How the MU Floating Tower works

The MU Floating Tower is a water purification system that consists of a boat-like floating structure that incorporates in one part a miniaturized MU Aqua Tower or MU Green Reactor. Where it incorporates a MU Green Reactor, a double pipe is inserted into the water to circulate water and generate micro-bubbles by means of an air-lift effect.

Figure 10 shows one possible installation of a MU Floating Tower. Being floatable, it can be easily installed in locations such as particularly deep reservoirs and lakes and in large enclosed coastal seas, making it suitable for a wide range of applications. The main unit incorporates a photovoltaic power system so that it can generate its own electricity, and water pumping and compressed air feed are also being considered. If this can be achieved, it should then be possible to build a semi-permanent water purification system.

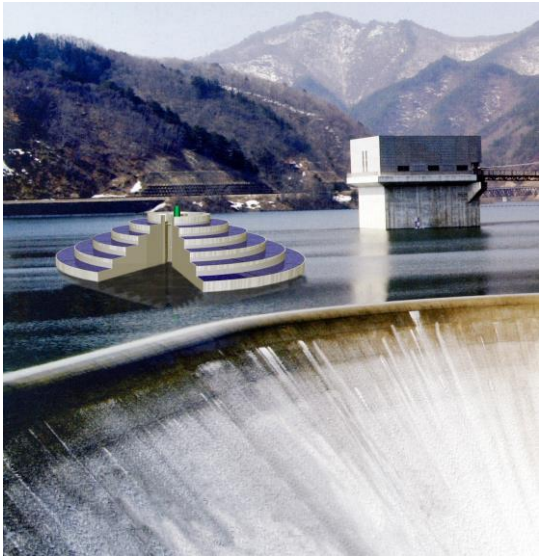


Figure 10 MU Floating Tower

8. Industrial wastewater treatment system

A MU Mixing Element is used in the MU Reactor for treating industrial wastewater containing organochlorides. **Figure 11** shows the system in full. Before treatment, the wastewater contains 300-500 ppm of chlorine compounds, and 3-5 wt% of calcium-based compounds. After treatment, the concentration of chlorine compounds does not exceed 20 ppm.

This continuous wastewater treatment system has a diameter of 1,500 mm and a tower height of 18,000 mm. It is used as a decompressed steam diffuser, with 400-600 m^3/h of wastewater being supplied from the top of the tower and 3-5 t/h of water vapor from the bottom. The wastewater is supplied by the overflow method and does not require use of a distributor. The mixing element has a diameter of 1,500 mm and a filling height of 12,000 mm. It is unaffected by the accretion of calcium-based compounds, and has been in continuous operation for over 10 years with pressure loss not exceeding 2 kPa.

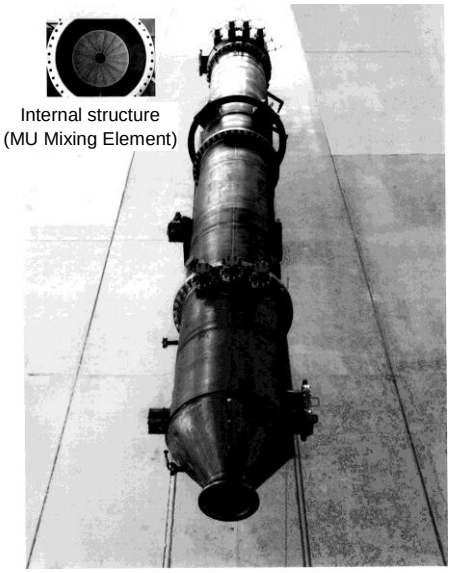


Figure 11　MU Reactor

Figure 12　MU Aerator
MA-125-PP

9. Development of the MU Aerator aeration tube for aerating wastewater

MU Company has developed a compact, maintenance-free, high-performance, durable, low-cost aerator that requires little piping work. Called the MU Aerator®, it consists of a MU Mixing Element and MU Oscillator®.

Figure 12 shows a full view of the MU Aerator, and **Figure 13** shows a structural view. Structurally, the MU Aerator consists of a cylindrical tube (13-①), MU Mixing Element (13-②), MU Oscillator® to generate oscillation (13-③), air tube to supply compressed air (13-④), and opening through which wastewater enters (13-⑤). A comparison of a conventional membrane system and the MU Aerator is shown in **Table 2**, and their functions are compared in **Figure 14**.

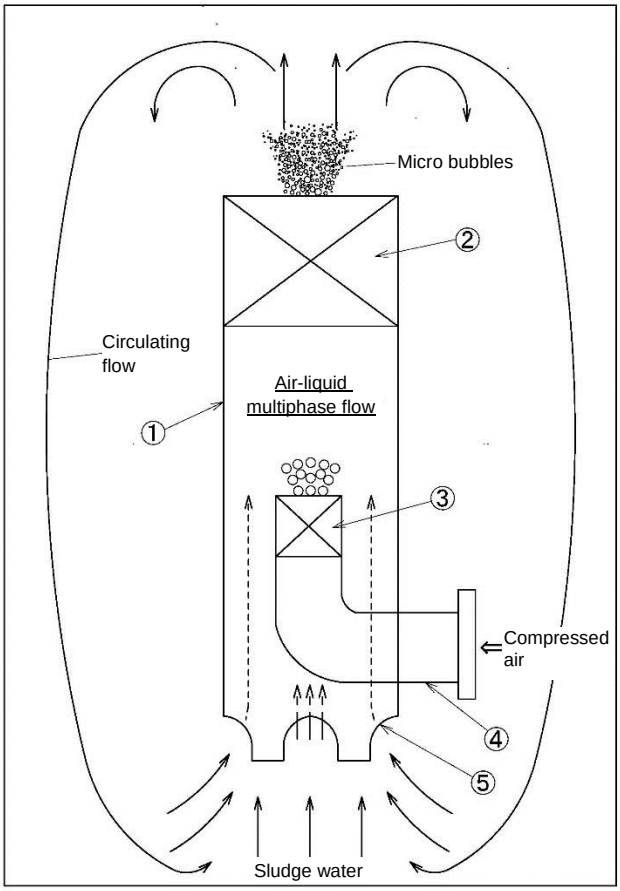
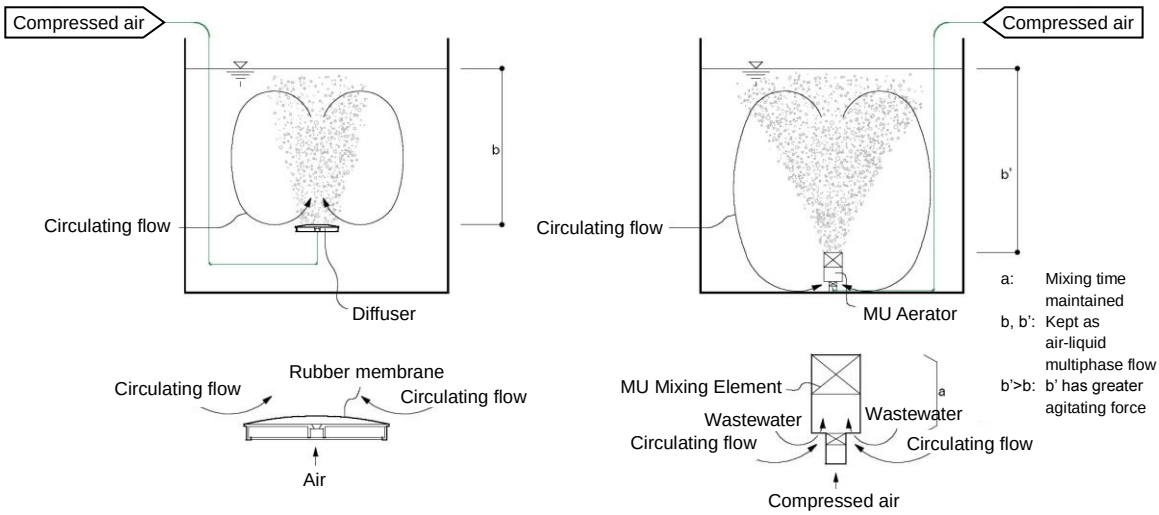


Figure 13　Structural view of MA-125 MU Aerator



(1) Membrane diffuser　　(2) MA-125 MU Aerator

Figure 14　Comparison of membrane method and MU method

Table 2　Comparison of membrane method and MU method

	Membrane method	MU method
◎ Bubble size	Determined by membrane pore size and pressure	Determined by gas velocity
◎ Oxygen transfer efficiency (%)	8-16	10-12
◎ Pressure loss (kPa) Installation Replacement (cleaning)	 5-8[1)] 10-13	 4-5[2)] 4-5 (almost constant)
◎ Sludge deposition	Yes	No
◎ Durability	6 months-3 years	At least 5 years
◎ Material	EPDM, etc.	PP

1) Water depth: 4.5 m, air intake: 0.05-0.12 m^3/min

2) Water depth: 5 m, air intake: 1 m^3/min

10. Future development

10-1. Use to treat radioactive water

Considering the scale of the half-life of radioactive substances (said to be over 100,000 years) relative to the human lifespan, the mind boggles when thinking of ways of disposing of water contaminated by multi-nuclide high-level radioactive substances. Since humans have created artificial elements, experts in relevant fields have to pool all their expertise to devise innovative methods to dispose of such waste safely, securely, efficiently, and cost effectively without contaminating the global environment.

In the United States, experts are wracking their brains about how to process the radioactive waste generated by the 104 reactors now in operation. No method of disposal that is safe, stable, and secure over the long term (at least 100,000 years) has yet been published.[5)]

China, meanwhile, has learned from the Fukushima nuclear disaster and is showing a positive stance toward effective use of nuclear energy. It is designing reactors to ensure that they are safe and do not release radioactivity into the environment, and has designed a new type of third-generation nuclear reactor called the AP1000. [6)]

According to an acquaintance, the problems with multi-nuclide radioactive water treatment systems that are often reported in the press are caused by “the accretion of

refuse, rust, sludge, slime, algae, and other matter in contaminated water to materials such as adsorbents and ion exchange resins, thus blocking the interiors of adsorption tower, ion exchange resin towers and pipes." This sounds quite probable.

Going from nuclear (*genshi*) power back to primitive (*genshi*) power, we need to take time to dispose of radioactive waste and water step by step, for generations to come, by finding the optimal volume reduction factors and decontamination factors by means such as evaporation, liquid-liquid extraction, and incineration.

Possible applications for MU Mixing Elements to treat radioactive water and reduce the volume of radioactive waste include:

(1) Use to improve the performance and efficiency of evaporators

(2) Installation of MU Mixing Elements in ion exchange resin towers and adsorption towers to enhance the performance of adsorption and cleaning processes

(3) Installation of MU Scrubbers in processes to clean vent gas from contaminated water storage tanks and waste gas from incinerators

10-2. Application in treatment systems to sterilize ballast water using ozone (O_3) gas

The engineering requirements are:

(1) Must be maintenance free and not clog

(2) Must have high-performance sterilizing action

(3) Must save space

(4) System must be simple

(5) No residual O_3

The MU Mixing Element appears to be able to satisfy these requirements.

In addition to the above, other possible applications include use in treatment systems to sterilize utility water and sewerage using ozone gas, and decontamination systems to remove mercury from wastewater.

11. Inspiration for the MU Mixing Element

Since ancient times, "technology" in Japan has served as a means of gently connecting nature and people. As is well known, flood control strategies such as the Shingen Embankment were conceived to prevent flooding and other disasters by making use of the existing topography to provide a natural release for the forces of water. Rather than beating the forces of nature into submission, the uniquely Japanese approach has thus been to explore what can be achieved through *chisui*—the "waters of wisdom"—to allow humans and nature to coexist. In a similar vein, it is from natural stone that the dikes of the Netherlands that hold off the North Sea are made, providing further evidence of what can be achieved through the marriage of human science and technology with nature (history).

This approach is at the very heart of the concept behind the water purification systems that make use of the MU Mixing Element, and hidden in the rich natural environment of this country we will find more crucial ideas for technological innovations that will help us build a more sustainable society in the future.

The above concludes our brief review of water purification technologies using MU Mixing Elements.

Taking Matsuo Basho's principle of *fueki ryuko* (constancy and change) as our "root," Einstein's $E=mc^2$, Lavoisier's Law of Conservation of Mass, and Newton's Law of Inertia as our "weft," and the Spiral as our "warp," little by little we shall weave a mandala as we peer into the Mu of nothingness and explore the mysteries of the unknown.

For as long as we draw breath, our mission as engineers – indeed, as humans – is to explore every avenue to ensure that our nuclear power stations do not fall into ruin.

One drop descending the surface of a ruin,
Delving the fossil past,
Seeking the unknown way, the unmapped path
To a clear sea of beauty
In search of the indivisible Pluto, the eternal cosmos.

The pitiful sight

Of a dying butterfly—

The dream falls to earth.

Matsuo Basho, *Hisago* (The Gourd), "*Hanami no Maki*"

"In the thorough study of the flowing or the not-flowing of a single drop of water, the entirety of the ten thousand things is instantly realized."

Eihei Dogen, *Treasury of the True Dharma Eye* ("Sutra of Mountains and Rivers")

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