Introduction

As President of MU Company Limited, I would like to share my thoughts about past research and development efforts and the future prospects for the Static Mixer.

1. The birth of the static mixer

In 1966, C. D. Armeniades et al. acquired a patent (USP 3,286,992) for a "mixing device." The company Kenics received a license for, and successfully developed a product based on, this patent. It was the Japanese company N that introduced the technology for this Static Mixer.

The basic configuration of the Static Mixer is to have curved blades twisting 180° clockwise and counterclockwise, placed alternately in a passage tube, with the blades bonded end-to-end and at right angles to each other.

The basic mixing principle of the Static Mixer consists of three fluid actions: splitting, rotation and reversal. Multiple fluids are mixed by means of fluid energy alone.
In splitting, the stream of fluid is split repeatedly into 2^n branches, where n is the number of curved blades. Suppose there are 12 curved blades. In that case, the total number of branches is $2^{12} = 4096$, and fluids made up of two or more components are mixed through the repeated continuous action of splitting (shear), rotation (vortex flow) and reversal (transposition).

2. Invention of the MU Mixing Element

The invention of the 90° helical blade and the invention of a manufacturing method using dies (USP No. 4,466,741, August 1984) made it possible to use the mold injection method and precision casting method to manufacture the MU Mixing Element with integrated blades and passage tube.
Even now, this is in use as a major component of the MU Mixer, MU Scrubber, MU Aerator, MU Reactor and other products. The completion of the 90° twist MU Mixing Element enabled the following:

1. Successful manufacture of an element with the world's smallest inner diameter (2.85 mm). The inner volume is 0.4 ml.
2. Successful product development of a 2-liquid mixing and dispensing unit for a base compound and a hardener.
3. Prevention of the occurrence of ribbons of unmixed material passing through the tube due to complete mixing not being achieved in laminar flow regions, which was one of the shortcomings of a static mixer.
4. Successful mixing of powder and granular material (due to having a spiral angle greater than the angle of repose, no bridging occurs).

3. Applications for mixing of powder and granular material

1) Mixing of Portland cement and blast furnace slag (fly ash)
2) Mixing of Portland cement, foaming agent and quick setting agent for use as a backfilling agent in tunnel construction
3) Manufacture of aerated concrete by mixing cement slurry and foaming agent
4) Manufacture of aerated concrete for use as a thermal insulation agent and wall material (used as a non-combustible material for safes, etc.)
5) Mixing for homogenization of steel dust with different particle diameters
6) Mixing of pharmaceuticals (active pharmaceutical ingredient + bulking agent)
7) Manufacture of autoclaved lightweight concrete panels (ALC) by mixing silica stone, cement, quicklime and foaming agent (aluminum powder)

4. Invention of Spiral Perforated Wings

In the beginning, we invested both funding and labor in the effort to fabricate a spiral-shaped blade body. However, even if we bent the fan-shaped blade body, warping and cracking of the fan shape caused by the expansion and contraction of the outer arc and inner arc prevented the product from being completed. One day, we received an order for the manufacture of an element using a PVC perforated plate. After a trial-and-error process, we were able to successfully fabricate a single precision spiral-shaped wing using a mold. When we observed the holes in the perforated plate to investigate why the effort had been successful, we found that the "holes" absorbed the stress caused by expansion and contraction by deforming flexibly. Observations of metal yielded the same result as the PVC discovery. One day, we fabricated a mixing element using a number of these perforated plates and observed the flow of water. When we did so, we saw white foam like that in a waterfall. I remember being profoundly affected by the fact that my question for many years — why does a waterfall appear white? — was the same as what I was seeing in front of my eyes. It was like the Japanese proverb: "Pray, and any flower of yours will come out."

These experiences led to the development of the MU Scrubber, and the invention of the MU Static Spiral Perforated Wings® — the world's first spiral-shaped internal.

The features of the MU Static Spiral Perforated Wings® are as follows:

1) High performance.
2) Maintenance-free operation.
3) Gas-liquid contact can use both parallel flow and countercurrent flow.

Functionally, it can be used for gas cooling, cleaning, absorption, desorption, and dust removal.
I think that the major reason that it has these features and functions is humankind's discovery of the spiral. This began with observations of natural phenomena, after which many people worked together to create the Static Mixer as an industrial product.

While expressing gratitude for having been able to encounter these types of products, I would like to discuss the MU Mixer, MU Mixing Element and MU-SSPW.

5. Interactions with people I have encountered up to now

1) Initial encounter

My first encounter was with Mr. M, who stopped by on the way back from a business trip, carrying an article about the MU Scrubber that he had clipped from a newspaper. I still feel a sense of pride in getting this comment from him, someone with a physics background who had established an admirable track record in theoretical analysis:

"The MU Scrubber is the only unit that can treat gas containing dense particles by means of highly concentrated slurry cycling without the scrubber unit becoming blocked."

The contact person at Company T has retired, but we still get orders from time to time.

2) When I heard that Mr. I, factory manager at the time, had mentioned during the morning assembly that there was a new technology called the MU Scrubber, I remember being very grateful. It seems like only yesterday that he was always the first person to come to the exhibition hall and give words of encouragement.

3) At around the same time, I was introduced to Mr. M, who had deep connections with top foreign government officials. I remember him telling me stories of mistakes he had made in connection with plant exporting in his youth, talking about the difficulties of international business and sharing his wisdom, and mentioning things to watch out for in company operations and so on. Up until a few months before he died, we met and shared a meal several times a year. I have a clear memory of him always wearing a necktie and never relaxing his posture as he drained his sake cup. I would like someday to be able to repay the debt that I owe to him.

4) Mr. S was president of the distribution company that covered the cost of the test unit. Mr. T took time out of his busy schedule to accompany me on sales activities to regional factories. Mr. T told me about his struggles doing research and development that resulted in the invention of rare earth magnets. Each time I encountered difficulties, I remembered him telling me that it takes 20 years to develop a new product, and I would continue fighting my one-man battle. Think of a spiritual communion between sentient beings and the buddhas. I wonder whether modern companies are capable of providing support and waiting for a period of several years.

5) Another memorable encounter was with Shuzo Oe, former professor at Tokyo University of Science, a world-famous expert on distillation. Professor Oe was interested in the MU Scrubber (MU Mixing Element), and he used a test unit for a student's master's thesis. Even today, the basic data presented in the master's thesis is very useful for design. The relationship of blade total surface area to element volume for

element design (m^2/m^3) is expressed as apparent fill density, and is helpful in the design of element area, gas and liquid contact time, calculations of the number of stages and so on. Even today Professor Oe continues to provide valuable views and guidance.

6. Absorption and detoxification through hydrolysis reaction with $SiCl_4$ gas

Company A was the first to use the test unit to conduct a test with an actual gas and an actual liquid (absorbing liquid). Previously, the company had used a spray tower, fill tower, venturi, etc., but these units experienced problems such as equipment blockage. What solved these problems was the MU Scrubber.

Although this is not possible at the moment, what solved these problems was the frank exchange of views with the engineers on site.

1) $SiCl_4$ reacts very quickly with water.
2) Fine SiO_2 powder is generated instantly.
3) Highly concentrated HCl gas is generated.

The solutions to these problems were as follows:

1) N_2 or a dry air seal was used for the exhaust gas inlet to prevent the exhaust gas from coming in contact with moisture.
2) A large space was provided for initial contact of the exhaust gas, water and N_2 (the exclusive area needed for the reaction). This was because the volume of the fine powder and granular material that was produced became a problem, and it was the cause of blockages.
3) A large liquid-gas ratio (L/G) was used to cool the reaction heat.

7. Functions and principle of MU Scrubber comprising a spiral-shaped internal MU-SSPW (my personal view, the "waterfall theory")

1. Dust removal function

1) Effects of micro-bubble generation
   (1) Negative ions are generated.
   (2) OH^- ion concentration increases.
   (3) Occurrence of ultrasound; generation of cavitation through ultrasonic irradiation
   (4) Specific surface area increases in proportion to the decrease in air bubble diameter; gas and liquid contacting surface also increases.
   (5) Although only momentarily, the air bubble internal pressure and internal temperature become extremely high.

2) Influence of Lenard effect

When the water is suddenly atomized, the large water particles are positively charged and fall, and the small water particles are negatively charged and they negatively charge the surrounding air. Philipp Lenard confirmed that the fine mist created by the spray from a waterfall is primarily negatively charged, while the area near the water's surface is positively charged. He theorized that the molecular structure was $[2H_2O+e][3H_2O+H^+][3H_2O+OH^-]$. When atmospheric ions are produced, it is known that the fiercer the force of the water, the more ions are generated.

3) There is a proportional relationship between the gas velocity inside the MU Scrubber and dust removal efficiency. The higher the gas velocity is, the greater the dust removal efficiency for fine particles becomes. It has been confirmed that the tinier the water particles are, the higher the dust removal efficiency becomes. This phenomenon has been confirmed for SiO_2 at the submicron level.

2. Chemical reactive absorption function

1) The hydrolysis reaction that occurs in parallel flows of silane gas ($SiCl_4$, $SiHCl_3$, SiH_2Cl_2, SiH_3Cl, etc.) and absorbing liquid (water) results in HCl gas absorption and dust particle treatment of SiO_2 at the submicron level. The reaction formula is $SiCl_4+2H_2O \rightarrow SiO_2+4HCl$.

Previously, primarily spray, Venturi tube and filler methods had been used. An alkali aqueous solution was used as the cleaning solution. In contrast, the MU proposal was to use the MU Mixing Element (MU-SSPW) to perform 1) gas cooling, 2) gas absorption and 3) dust particle treatment simultaneously in the same tower. Coke oven gas (COG) and carbon capture and storage (CCS) and other large capacity process flows comprise gas cooling → gas cleaning (SOx, NOx and dust removal) → gas separation and absorption → gas desorption → gas sequestration.

The main point of this process, and its major feature, is the achievement of high-performance, maintenance-free continuous operation.

CCS using the high-performance, maintenance-free spiral internal MU-SSPW (MU Static Spiral Perforated Wings) has been proposed to a power company in Canada.

The need for high-performance, maintenance-free operation is the same for a chemical company that handles silane gas, even if the process flow is different, and the technology has been deployed there, too.

2) The use of water (pure water, industrial water, neutralized water, etc.) as a cleaning fluid has the following benefits:

(1) Effluent treatment becomes easy (no precipitation of silicate compounds).

(2) It is possible to separate and recover only HCl for cyclic use (reducing costs).

(3) Effluent can be reduced to zero. Reaction products can be filtered using a filter.

(4) Highly concentrated HCl can be cooled directly with water. A heat exchanger is not needed. This eliminates the problem of pipes becoming blocked by SiO_2.

8. The road to increased equipment size

1) In terms of functions, the unit is easy to scale up.

A small test unit is used to obtain test data for actual gas and actual liquid. Data are obtained for the gas flow rate in parallel flow and countercurrent flow directions, the liquid-gas ratio (L/G), the gas-liquid contact time, the pressure loss (kPa) and so on.

Based on the results, the tower diameter of the scaled-up unit, the number of element stages, and the quantity of circulating liquid are finalized, and next the detailed element design is conducted. Factors comprising the hole diameter for the blade body, the hole shape, the element filling density (m^2/m^3), the aperture ratio (%), the spiral angle, and the selection of the spray nozzles (model, quantity, spray angle, etc.) are finalized. In addition, a reduced scale model is fabricated and simulations of liquid flow are conducted.

2) Applications for waste gas treatment equipment through new mixing element development

    (1) Direct gas cooling
    (2) Gas deodorization
    (3) Hydrolysis reaction treatment equipment for silane-based compounds
    (4) Silane compound and gaseous H_2 reaction treatment and refining treatment equipment
    (5) Removal of fine dust particles (in particular, removal of submicronic radioactive material)
    (6) Dust removal equipment for vent gases at nuclear power plants
    (7) Exhaust gas treatment equipment for large ships

As waste gas treatment equipment with gas cooling, deodorizing, reactive absorption and dust removal functions, the equipment performs gas and liquid contact treatment for waste gas and cleaning solution in both parallel flow and countercurrent flow directions.

Especially in parallel flow operation, MU-SSPW element can fully demonstrate its excellent features.

Its features are as follows:

(1) No flooding occurs.

(2) No channeling (drift) occurs.

(3) Clogging by dust and reaction products does not occur by the self-cleaning function of MU-SSPW.

(4) Absorption towers are placed in series on multiple levels, enabling the unit to treat submicronic dust at a concentration of 0.1 mg/Nm^3 or less. Dust can be reduced to near zero. We recommend applying the MU-SSPW to the treatment of waste gases from incinerators used for radioactive waste.

(5) Gas velocities of up to max. 20 m/s are possible. However, it is necessary to be careful about wear.

(6) Even if cleaning fluids that contain highly concentrated reaction products are used, these will not stick to or grow on the element. This has been demonstrated. The cleaning fluid keeps the front and back of the blades formed of perforated material and the interior of the unit clean.

(7) The unit can be used to absorb highly concentrated HCl gas and perform hydrolysis reactions for $SiCl_4$ gas. Treatment can be conducted with a high liquid to gas ratio (L/G). Direct cooling is also possible.

    L = absorbing liquid quantity (l/min)

G = Gas quantity (m^3/min)

(8) The single tower has gas cooling, gas cleaning, gas absorption and dust removal functions.

9. The first step toward increased equipment size

With the increase in treatment gas volume, an increase in the size of the MU Mixing Element (MU-SSPW) has become necessary. Absorption towers with element diameters of 3m, 5m and 10m are needed.
Noticing that the 180° twist of the Static Mixer blades is 180° = 90° + 90°, we made it possible to freely select a blade body rotational angle of 180°, 90°, 60°, 45°, 30°, 20°, 10° and so on.
As a perforated plate is used for the spiral wing, the aperture area and the element filling density can be selected freely to match the objective. In terms of manufacturing, the use of molds makes the process easy and enables a precision spiral wing to be manufactured at a low cost.

1) Applications

The unit can be used to treat large quantities of waste gas at coal-fired thermal power plants, coal-fired coking plants, nuclear power stations and so on.
(1) CO_2 cooling, dust removal, absorption, desorption and recovery, and storage processes
(2) Cooling, dust removal, absorption, refining and recovery processes for the COG from coking plants
(3) Dust removal process for vent gas from nuclear power stations in the event of an accident
(4) There are also applications for the treatment process, etc. for waste gas from large ships.

2) Ease of manufacturing scale-up

The MU Mixing Element (MU-SSPW) is made up of a passage tube and multiple spiral-shaped perforated wings (blade body). In the case of a large size unit, the perforated wings are placed on multiple levels in plan view through a reinforcing ring and the adjacent blade bodies are joined to one another. In plan view, the MU-SSPW has multiple layers like a German baumkuchen cake, so there are no restrictions in terms of manufacturing an absorption tower with a diameter of 5m or 10m. The spiral angles that can be designed are 10°, 20°, 30° and 45°, and free use can be made of existing manholes to fabricate and assemble the MU Mixing Element inside the absorption tower.
The problem of structural safety with respect to the weight of the element can be resolved with an in-plane configuration of intersecting beams. With such a configuration, fluid flow will be unimpeded and the fluid will flow smoothly.

3) Other

(1) Separation and recovery of microplastics in seawater by means of flotation
(2) Neutron absorption or capture through contact between tritium and gadolinium

Fine bubbling of tritiated water and radiation of beta rays from gadolinium to absorb or capture neutrons, resulting in nuclear transmutation from tritiated water to water.

(3) Separation, absorption, refining or capture of powder dust, SOx, NOx, CO_2, organic matter, H_2, CO, etc. in the coke oven gas (COG) from coal coking plants, and use for gas cooling treatment. Valuable gases such as H_2 and CO make up approximately 55% of COG. The results of COG tests using actual gas and actual liquid were absorption efficiency of 98% or higher with no clogging. Currently an absorption tower containing MU-SSPW units with a diameter of 5m assuming use as an actual unit has been proposed for Company N.

(4) Applications for CCS by means of the treatment of waste gas from a coal-fired thermal power plant. The system flow comprises gas cooling, powder dust removal, pretreatment of NOx, SOx etc., CO_2 absorption, and CO_2 desorption, recovery and storage treatment. At present, a problem has arisen in the CO_2 absorption process that impedes long-term operation. We are currently proposing the use of the high-performance, maintenance-free spiral-shaped internal MU-SSPW for the pretreatment, absorption and desorption processes to a Canadian power company. For details, see References 9, 11, 12, 13 and 16.

(5) This unit can be used for various agitation and mixing processes. We think it is particularly ideal for use in radioactive material extraction processes.

10. Applications for water treatment

1) MU Reactor for degassing of industrial wastewater and as a stripping treatment unit
2) Steam desorption and recovery treatment of effluent containing VOC and calcium compounds
3) Vacuum deaeration treatment of CO_2 and O_2 in brine
4) Deaeration of NH_3 in wastewater and COD and BOD aeration treatment using the activated sludge method
5) Ozone treatment of ballast water
6) Treatment of waste liquids from mines and recovery of valuable resources

11. For miscellaneous water and sewage treatment (MU Aerator, MU Magrator)

1) Aeration and desorption of COD, BOD, n-hexane, etc. using the activated sludge method
2) Sterilization treatment using ozone (O_3) for bacteria, microbes, etc.
3) Ozone treatment of household wastewater through the use of the non-sealed MU Aerator (MU oscillation element) for sterilization and NH_3 aeration treatment

12. Water treatment in animal husbandry, fisheries, agriculture, etc. (MU Aerator, MU Magrator, MU Scrubber)

1) Air aeration treatment to preserve water quality in enclosed water areas
2) Aeration and recovery treatment of gaseous H_2 from NH_3 in water

3) Oxygen enrichment for the activated sludge method by means of air and oxygen aeration
4) Promotion of crop growth, etc. through the manufacture of oxygen-enriched water, carbonated water, magnetized water, etc.
5) Oxygen enrichment and agitation unit to prevent "red tides"
6) Humic acid addition and mixing unit to prevent sea desertification

13. New Products: MU Aerator and MU Magrator

1) The MU Aerator comprises a MU oscillation element and a static mixer made up of a MU Mixing Element. The MU oscillation element has a passage tube for air, inside of which is a tangential spiral-shaped blade body. Gas is sprayed into the liquid at a gas flow rate within the range of 0.5–200 m/sec and is emitted at high speed from the spray nozzle as a powerful gas-liquid multiphase flow. Gas-liquid mixing is conducted with the liquid introduced from the surrounding area, and the mixture is passed through the MU Mixing Element that is placed above. This results in the formation of micro-bubbles and fine bubbles, which are sprayed upward as a gas-liquid multiphase flow.

2) The MU Magrator has the same basic configuration as the MU Aerator, but it also contains a magnetic body that forms a magnetic field in the gas-liquid multiphase flow of the atomized micro-bubbles that are sprayed out at high speed, efficiently irradiating the flow with powerful lines of magnetic force and further atomizing the bubbles. The theoretical analysis as to why irradiation with lines of magnetic force causes atomization is unclear, but it can be confirmed visually that the bubbles become smaller and are turned into micro-bubbles. It is a phenomenon that still awaits a theoretical analysis.

There are references concerning micro-bubbles.

- "When bubbles contract, not much of the heat inside the bubble escapes to the liquid side, and the action of the surrounding liquid to shrink the bubble is transferred to the heat, causing the temperature and pressure inside the bubble to momentarily become extremely high — several thousand degrees and several hundred atmospheres or more." This is from Kyuichi Yasui et al., "Sonoluminescence and bubble dynamics" IEICE Transaction on Fundamentals of Electronics, Communications and Computer Sciences (Japan Edition) Vol. 89-A, No. 9, pp. 686-694. The article also states that "OH radicals, etc. are generated," and "This is thought to be evidence that the gas is dissociated inside the bubble — in other words, that plasma is present." In addition, it mentions "Bubble Nuclear Fusion" according to the "Shock Wave Theory" and the "Quasi-Adiabatic Compression Theory."

14. Advertisement for MU Reactor in Nature magazine

An advertisement for the MU Reactor water treatment unit inspired by the water flowing in a waterfall appeared five times in the journal Nature beginning in November 1998 in cooperation with one of our agencies, garnering a worldwide response. The dates were November 5 and December 3, 1998, and January 2, February 11 and March 11, 1999.

15. Newspaper advertisement for MU Eductor

A MU Eductor was delivered to a major chemical company in Taiwan as a mixing and agitation unit for a large reaction vessel (diameter 20m, inner volume 4000 m^3). This helped to shorten reaction time and ensure product homogeneity (An article concerning this matter appeared in the March 25, 2013 edition of the Nikkan Kogyo Shimbun.) In addition, an article entitled "Continuous Effluent Treatment Technology using the MU Mixing Element" appeared in the August 2000 issue of *Plant and Process* (Kagaku Sochi).

16. Separation and recovery of VOC in industrial wastewater

An MU Reactor was delivered (in 1998) to a major chemical company, where it is currently in operation as a separation and recovery unit using vacuum distillation of industrial wastewater that includes organic matter and calcium chloride.
The MU Reactor is 1500A x 12 mH, and the quantity of treated water is approximately 600 m^3/hr. The unit is operating properly with no problems caused by calcium chloride adhesion or growth. A similar unit has also been delivered to China.

17. Purification of tritiated water into water

The water reforming unit is made up of a MU oscillation element, MU-SSPW, magnetic body and neutron-absorbing material. The MU oscillation element sprays gas at high velocity into the liquid and can induce cavitation. The MU-SSPW mixes the gas and liquid to generate fine bubbles. The magnetic body irradiates the fine bubbles with magnetic lines of force. And the neutron-absorbing material absorbs or captures neutrons from the nucleus. These functions combine to create a method for purifying tritiated water (in my personal view). It is thought that gadolinium, boron, aluminum and other elemental substances, or alloys, or ceramic or the like, can be used as neutron-absorbing material. Neutrons have been referred to as tiny magnetic bodies. To my knowledge, no papers have been presented on the subject of bringing tritiated water in contact with gadolinium as a neutron-absorbing material to derive ordinary water (H_2O).

Another separation method is as follows. An acidic gadolinium solution is brought into contact with the water to be treated (tritiated water) to absorb or capture the neutrons in the nuclei making up the tritium, for the purposes of purification. A gadolinium solution in which gadolinium is dissolved in organic acid is manufactured, and the acidic gadolinium and tritiated water are mixed and agitated. A magnetic eductor is used as the mixing and agitation unit and the mixture is aged thoroughly — in other words, the neutrons are absorbed or captured by the gadolinium. Subsequently, the mixture is neutralized in a neutralization tank and then supplied to a settling tank. The settled gadolinium is separated and recovered and then recycled. (This description is my personal view of what is happening.) This system would require a large reaction vessel, neutralization tank and settling tank. Previously, an MU Eductor was placed in a reaction vessel with an inner volume of 4,000 m^3. This achieved homogeneity of industrial products and helped to shorten reaction time. (An article about this matter appeared on Page 12 of the March 25, 2013 edition of the Nikkan Kogyo Shimbun)

Tests in which gadolinium sulfate was introduced into the Super-Kamiokande (SK) facility at the Institute for Cosmic Ray Research at The University of Tokyo were announced as the SK-Gd Project (Motoyasu Ikeda et al., The Astronomical Herald (*Tenmon Geppo*) Vol. 113, No. 10d, pp. 599–609, October 2020).
It is hoped that the valuable experience obtained at the Super-Kamiokande (SK) facility will result in successful neutrino observations at the Hyper-Kamiokande facility (HK). I am interested in the contact mixing of radon and gadolinium in an enormous tank with an effective volume of 190,000 tons.

18. Removal of tritium and radioactive material in treated water

There is a question whether, when tritium (^3H) and neutron-absorbing material or capture material (for example, gadolinium) are brought into contact with one another, two neutrons forming the nucleus of the tritium will be absorbed or captured to achieve a nuclear transformation of the tritium to ^3He. Gadolinium continuously experiences beta decay, emitting 18.6 keV radioactive rays (beta rays) to the ambient environment, and it is said to exhibit ferromagnetic properties at temperatures of 20°C or below. Gadolinium is currently used as a neutron-absorbing material for the control rods in nuclear reactors.
Currently, gadolinium sulfate is being used at the Super-Kamiokande (SK) facility at the Institute for Cosmic Ray Research at The University of Tokyo, in the SK-Gd Project to study the use of ^{222}Rn and Kr to lower background values. Based on the results of the Rn, Kr deaeration equipment at the Kamioka Liquid Scintillator Anti-Neutrino Detector (KamLAND), an Rn desorption unit (MU Reactor) containing a MU Mixer (MU Mixing Element) is being used to measure the concentration of ^{222}Rn in the SK tank. (An article on this matter appeared in the February 24, 2011 edition of the Nikkan Kogyo Shimbun.) The volume of water kept in the SK tank is 50,000 tons.
The concentration of the extremely low concentration ^{222}Rn is 0.8–10 mBq/m^3. The presence of ^{222}Rn affects measurement sensitivity as noise.

19. Separation and recovery of radioactive material from treated water

Heavy metal radioactive materials (such as uranium, plutonium, strontium, etc.) on the submicron level that are included in the water to be treated can be separated and recovered using the MU Reactor, MU Aerator and MU Magrator with built-in MU-SSPW.
The infinitesimal radioactive materials located here and there in the wastewater can be separated and recovered using a technology called flotation, in which the materials are enveloped by the fine bubbles and float upward and are separated.
By placing separation units with aeration and desorption functions (such as the MU Reactor) in series on multiple levels, it is possible to reduce the emission density of radioactive materials to near zero. Cyclic

use of pressurized gases is possible through the use of inert gases such as N_2, Ar and H_2. Moreover, separation and recovery are possible without the use of ion-exchange resin, adsorbents, surface-activating agents, filters and so on that will become radioactive wastes.
(However, demonstration tests will be needed for these removal methods.)

20. Conclusion

For the 39 years since MU Company Ltd. was founded in 1983, I have served as president under the banner of MU Green Technology. This year I will celebrate my 77th birthday.
In this paper, I have discussed the development of the MU Mixer, MU Mixing Element and MU-SSPW which is made up of multiple spiral perforated wings, as well as questions about similar patents, the 90° helical blade body and the method of manufacturing the mixing element that integrates the blades and the passage tube, the development of new uses for these inventions, the path to an enlarged unit through the invention of the MU-SSPW that is made up of multiple spiral-shaped perforated wings, the development of applications for COG and CCS using the large MU-SSPW, a proposal for purifying tritiated water and so on.

There is no evolution without competition.
There is no creation without imagination.
Creative destruction cannot happen in a place with no freedom.

The Tokamak method has been proposed, in which spiral-shaped lines of magnetic force are generated in a nuclear fusion reactor to confine plasma. I am deeply indebted to the painter Tawaraya Sotatsu for his painting *Wind God and Thunder God*, through which I encountered the "spiral" that has a deep significance that extends to the "black holes of particle physics. Many thanks.
It is my hope that the things I have talked about may be of use to you as something to think about.

For almost 30 years, I have tried to master the correct *zazen* pose as instructed by the venerable teacher Hirano — a world in which an old priest, silently sitting in the meditation hall illuminated by the light reflected from the snow, says: "Don't be a quitter!" ”Look deeper!" And "Shikantaza" ("just sitting").
I have treasured two things given to me at the time of the company's founding by the teacher Cho Kojiro: the words of Mencius, "*Tora gu wo ou*" (Tigers fights bravely and boldly in their own territory) and the *Kakubutsu*[1)] inscribed on a hard woodblock. Now, with the words of the late Head Priest Takeda ("Treasure the mysteries of the life that exist here right now") in my heart, I will go surely, step by step, without feeling rushed, taking detours from time to time, all the while striving to hear the timbre of the Buddhist temple bell, and the sound of a far-away babbling brook, in search of the limitless — the world of "nothingness is emptiness" and "emptiness is nothingness."
Even if the way is covered with deep snow, I am committed to stepping along with kindred minds, believing in the future.

Author: Hisao Kojima
Member, American Chemical Society

Note 1) *Kakubutsu*: In Neo-Confucianism, this is "investigation of things."

21. Academic papers, references, U. S. patents

1. Kojima, Hisao: "Mayan Ruins and the Path to Technical Innovation," prefatory note, *Plant and Process*, July 2008.
2. Kojima, Hisao: "Continuous Effluent Treatment Technology using the MU Mixing Element," *Plant and Process*, August 2000, pp. 61–63.
3. Kojima, Hisao: "Wet Exhaust Treatment Unit using the Static Mixing Scrubber Method," *Plant and Process*, March 2004.
4. Kojima, Hisao: "Desorption and Absorption Treatment Technology for Effluent Containing Highly Concentrated Ammonia," *Plant and Process*, April 2005 (supplementary volume).
5. Kojima, Hisao: "'MU Scrubber' High-Performance Wet Waste Gas Treatment Unit," *Plant and Process*, March 2006.
6. Kojima, Hisao: "Maintenance-Free Wet Exhaust Treatment Unit, " *Plant and Process*, July 2007, pp. 36–40.
7. Kojima, Hisao: "Development and Productization of High-Performance Wet Dust Removal Unit," *Plant and Process*, January 2009, pp. 154–155.
8. Kojima, Hisao: "Applications for MU Mixing Element (MU-SSPW)," *Engineering Materials*, Vol. 62, No. 11, November 2014, pp. 90–95.
9. Kojima, Hisao and Suzuki, Terutoshi: "Applications for MU Mixing Element® at Chemical Plants," *Plant and Process*, July 2015.
10. Kojima, Hisao and Ikeda, Jun: "Water Purification Technology Using the MU Mixing Element®," *Plant and Process*, August 2015.
11. Suzuki, Terutoshi and Kojima, Hisao: "Issues Facing CCS Plants and Proposed Solutions" *Plant and Process*, February 2018.
12. Kojima, Hisao, Suzuki, Terutoshi et al.: "Water Treatment Technology Using the MU Static Spiral Perforated Wings (MU-SSPW)™: The Path from Horizontal to Vertical," *Plant and Process*, August 2018, pp. 33–42.
13. Kojima, Hisao, Suzuki, Terutoshi, Kojima, Teruhiro et al.: "Prospects for an Enlarged Version of the MU Static Spiral Perforated Wings (MU-SSPW)™ Element," *Plant and Process*, April 2021.
14. Kojima, Hisao, Arisaka, Koichi and Takebayashi, Masahiro: "Development of MU Magrator which Incorporates a Magnet," *Plant and Process*, May 2021, pp. 65–69.

15. Kojima, Hisao, Arisaka, Koichi, Nakatsuka, Masafumi et al.: "Examples of Effluent Treatment Using the MU Magrator: Aiming for Generation of Fine Bubbles and Improved Effluent Treatment," *Plant and Process*, November 2021.
16. Suzuki, Terutoshi: "Prospects for an Enlarged Version of the MU-SSPW Element," *Bunri Gijutsu* ［Separation Technology］，Vol. 51, No. 4, The Society of Separation Process Engineers, Japan, 2021, pp. 254–259.
17. Nakano, Yuuki: "Measurement of Radon Concentration in Super-Kamiokande Tank," Institute for Cosmic Ray Research, The University of Tokyo, 2nd Master's and Doctorate Research Symposium, February 2013.
18. Tasaka, Shigeki et al.: "Observations of Radon Flux between Atmosphere and Ocean," National Institute of Polar Research 30th Symposium of Polar Meteorology and Glaciology, 200711.
19. Yamamoto, Nobuyuki: "Ki・Gyo・Tan・Po [Corporate Inquiry]," *Infodia*, April 1999, pp. 32–33, published by Mitsubishi Corporation.
20. Company Newsletter, Shin-Etsu Chemical Co., Ltd., No. 577, p. 5, November 2001.
    The MU Scrubber (MS-1400) is installed upstream of the electrostatic precipitator and is used for gas absorption and dust removal.
21. J. Terasaki et al.: "Introduce a Solution for Volatile Components in a Cement Preheater Kiln," *Worldcement.com*, November 2009, pp. 139–144.
22. S. Kambara et al.: "Mercury Emission Control by Wet Scrubber with Super Static Mixer," 2011 International Pittsburgh Coal Conference, September 2011.
23. Oe, Shuzo: *Joryu Gijutsu Kiso no Kiso* [Distillation Technology: Foundation Basics], 2008, pp. 155–157 (Nikkan Kogyo Shimbun, Ltd.).
24. Oe, Shuzo: *Tokoton Yasashii Joryu no Hon* [Distillation Made Simple], Nikkan Kogyo Shimbun, Ltd., September 2015, p. 77.
25. Mitani, Yoshio and Nishino, Kouji: "Recent Dry Silica Manufacturing Technology and Environmental Measures (2): Environmental Measures / Chlorine Recovery," *Plant and Process*, April 1995, pp. 91–95.
26. Zongyue, Zheng and Hong-xiang, Lin, editors: "Air Pollution Control: Theory and Design" 5th Edition, New Wun Ching Developmental Publishing Co., Ltd., February 2018, pp. 384–391.

USP:
4,466,741
4,747,697
4,878,925
5,605,400
6,431,528
7,510,172
7,975,991
10,124,396

10,195,695
11,253,812