No.52 ISSN 0916-8249
JANUARY 2019

For Earth, For Life
Kubota

KUBOTA TECHNICAL REPORT (EXCERPT)

Feature Theme

Working on SDGs

KUBOTA TECHNICAL REPORT (EXCERPT)

No.52　JANUARY 2019

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Special Feature

Working on SDGs

~Kubota's Contribution in the Areas of Food, Water and Environment~

Kubota Group works on the SDGs, which are the common development goals for the international community, and is challenging to solve global issues through its business activities.

What are the SDGs?

They are the 17 goals set jointly by the nations around the world regarding issues to be tackled in cooperation.
It was adopted at the United Nations Summit in 2015 with 2030 as the target year by which to address the goals.
"Sustainable Development Goals" is abbreviated as SDGs.

Association between the published articles and SDGs

Closely related:★ Related:●

Primarily related field			
Food	Water	Environment	Published article
■			Development of a Wheel Combine Harvester for China
■			Development of an Agrochemical Applicator for Direct Seeding with Iron-coated Rice Seeds
	■	■	Research of the Performance in the Field of the Energy Saving Air Diffuser K-membrane Installed in Sewage Treatment Plants
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		■	Development of the Minimal Swing Radius Type Mini Backhoe RX -506 for the Japanese Market
		■	Utilization of Waste Polyvinyl Chloride in the Volume Reduction of Radioactive Waste Using Melting Technology
	■		Development of the Compact Johkasou KRZ Type for Large Scale Facilities

SUSTAINABLE DEVELOPMENT GOALS

17 GOALS TO TRANSFORM OUR WORLD

For more information on SDGs (Sustainable Development Goals), please visit the website of United Nations Information Center.
http://www.unic.or.jp/activities/economic_social_development/sustainable_development/2030agenda

	SDG goals																
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
	●	★						★	★			●				●	●
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"For Earth, For Life" Kubota's Engagement in SDGs and Continuing Contributions

President and
Representative Director
Masatoshi Kimata

In the world that we live in, even in this day and age, there are a great number of people who are suffering due to not being able to access safe drinking water. From now and into the future, the global population will continue to increase, and as the population grows, so will the number of issues for our society, including concerns over insufficient supplies of food and energy. Under such conditions, the MDGs (Millennium Development Goals) that were formulated by the United Nations in 2001 established eight development goals to be achieved by 2015.

During this period, Kubota contributed to the economic development of China and Southeast Asia through the promotion of mechanization in the agricultural industry in those nations, and we also made contributions to prevent the spread of contagious and infectious diseases through efforts to popularize the use of septic tanks.

Though various organizations and companies made similar efforts, there are still issues, such as regional disparities, that remain worldwide.

As a successor to MDGs, SDGs (Sustainable Development Goals) were adopted at the 2015 United Nations summit. The SDGs encompass 17 development goals shared by the international community, including "Zero Hunger," "Clean Water and Sanitation," "Sustainable Cities and Communities," and "Partnerships for the Goals."

We recognize that the direction of the SDGs is the same direction that Kubota as a company is taking through our brand statement of "For Earth, For Life" and our mission of "contributing to the world in the areas of food, water, and the environment."

[Food]

We have been contributing to the abundant and stable production of food through the development and expansion of various agricultural machinery since the post-WWII era when food was still scarce in Japan.

[Water]

Since our founding in 1890, we developed Japan's first water pipes and valves in order to ensure public health, and later came to make the common use of water and sewer services a reality through the development of items such as pumps and synthetic pipes. Also, we have recently developed earthquake-resistant pipes, contributing to the safe and secure supply of water.

[Environment]

In addition to sludge treatment equipment, incinerators, and melting furnaces, we have developed engines and various construction equipment that work to continuously reduce environmental burden in line with strict emission regulations from various countries, contributing to sustainable and resilient urban infrastructure development.

As a promoter of globalization, Kubota has established development and production bases in the North American, European, and Asian markets, and works in cooperation with locals to provide products and services that contribute to their lives.

We have also quickly responded to unexpected threats such as natural disasters and other calamities. For the Great East Japan Earthquake and Thailand's Great Flood that occurred six months later, our drainage pumps contributed to the recovery of infrastructure. Our compact construction machines, which are made for work in urban areas, were also active in disaster recovery efforts for last year's flood in West Japan.

Also, we completed work on industrial waste treatment in Teshima, Kagawa Prefecture, greatly contributing to environmental restoration. Currently, we are using the melting technology and know-how that we have cultivated at our company to engage in efforts to reduce the volume of contaminated waste in the town of Futaba, Fukushima Prefecture.

In recent years, we have also put our efforts into the realization of "smart agriculture" and "smart infrastructure." To achieve this, we have invested in and are promoting advanced ICT/IoT technology and robot technology, but at the foundation of this is "continuing to support the future of earth and mankind."

Therefore, we have decided to make this 52nd issue of the Kubota Technical Report specially themed around the topic of "Working on SDGs." Kubota is making efforts in many themes that contribute to SDGs through our products, technology, and services. This includes items that are deeply connected to SDGs, so we hope that you read this report and deepen your understanding of SDGs and Kubota's efforts.

Development of a Wheel Combine Harvester for China

Combine Harvester Engineering Dept.

Kubota developed a wheel combine harvester for China in order to enter dry-field markets. There are two main demands in the target area: a compact machine with high mobility and a profitable machine with high efficiency. To satisfy customer demands, we developed a unique layout that makes the machine compact and improve operability. Moreover we sped up grain unloading, developed a thresher for wheat, and improved maintainability. The new machine ensured high mobility suited to field conditions and road conditions in the target area, and achieved high profitability exceeding that of the local competitor. The development technology in this product development is tied to "productivity improvement of an agricultural machine and an increase of the income", and can contribute to the eradication of poverty and hunger. Here we show the technical development for high mobility, high efficiency and high operation availability.

【Keywords】
Dry-field Farming Markets, Wheel Combine Harvester, High Mobility, High Efficiency, High Operation Availability, Poverty and Hunger

Related SDGs

1. Introduction

Cultivated lands around the world correspond to more than 1.4 billion hectares, and 90% of it is used for dry-field farming. In dry-field farming, crops which can be harvested using a combine harvester, including wheat, corn, and soybean, account for 40% of the world's cultivated lands[1]. In the past, Kubota introduced high-capacity and high-performance combine harvesters into the rice farming markets mainly in Asia, and contributed greatly to the elimination of poverty and hunger in these markets. However, in order to make further contributions to global agriculture in the future, it is essential that we develop products for the dry-field markets, which comprise the mainstream of agriculture around the world and that we enter the dry-field markets. Wheel combine harvesters are popularly used in dry-field farms in the world. Unlike the conventional crawler types, wheel combine harvesters can travel at a higher speed, which makes its work efficiency higher and more advantageous in-dry fields where there is little soft ground (Table 1).

The Chinese wheat market is an attractive market for developing the dry-field business. There are approximately 24 million hectares of planted area and production volume approximately 130 million tons. Both values are the largest in the world. Wheel combine harvesters in China also form a gigantic market, with the demands corresponding to 55% of those of the global market. Within China, the Central Plains Area (Fig. 1), which is located in the middle to lower basin of the Yellow River, is a vast granary accounting for 80% of China's total planted area.

However, combine harvesters with high capacity and high performance are demanded in the dry-field farming markets of China in recent years, due to the decrease in the farming population and in the area of farmlands in concurrence with urbanization and industrialization, as well as the rise in labor expenses resulting from their economic growth. Therefore, to contribute to "Increasing agricultural productivity and income" in the Chinese dry-field farming market, we developed the first wheel combine harvester for wheat from Kubota while targeting the Central Plains Area.

Table 1 Type of Combine Harvester

	Crawler type	Wheel type
Scene from harvesting		
Condition	Wet field	Dry field
Suitability	Rice cultivation	Upland farming

Fig. 1 Central Plains Area

2. Development concept and goals

2-1 Development concept

In Central Plains Area, the ratio of harvester mechanization is quite high at more than 90%, and the market share of the machines from the local competitors is overwhelmingly high. For Kubota to be able to gain a share after entering the Chinese dry-field market as a newcomer under these circumstances, we needed to “develop differentiated products.”

As characteristics of Central Plains Area, we noted that the field areas were small at 10 to 20 ares, and that the width of the farm roads was as narrow as 3 to 4 m.

Therefore, “a compact machine capable of small turns” was demanded. In addition, the main users of wheel combine harvesters were harvesting specialists called harvesting contractors, and they demand “a highly profitable machine” since they have to earn most of their annual income during the time of harvesting. Therefore, we set the development concept to high mobility for “a compact machine capable of small turns,” and high efficiency and high operation availability for “a highly profitable machines.”

2-2 Target value

In order to achieve the level of performance in the developed machine which surpasses those of the machines of the same class from the local competitors, we set rational numerical targets based on preliminary surveys and user surveys.

Target value

[1] High mobility

Total length: 6 m or smaller, turning radius: 7 m or smaller

Number of operation levers: 1

[2] High efficiency

Grain unloading period: 0.20 times or shorter compared to the machines of the local competitors

Vehicle speed during reaping: 1.2 times compared to the conventional models

Output required for chopper: 0.8 times or smaller compared to the conventional models

Work efficiency (harvested area per unit time) : 1.33 times compared to the machines of the local competitors

[3] High operation availability

Cleaning frequency for dust prevention screen: 0/day

3. Technical issues to be solved

3-1 Technical issues related to high mobility

3.1.1 Development of a compact body and low center of gravity

The general layout for the machines from the local competitors had the grain tank, engine and fuel tank arranged next to one another in the longitudinal direction of the body above the thresher, because the thresher was placed in the sideways direction (Fig. 2). Therefore, they had large overall lengths and high centers of gravity, which made it difficult to travel in narrow fields or farm roads and mobility low. In order to improve the mobility, we needed to adopt Kubota's proprietary layout and address a compact size and a low center of gravity.

3.1.2 Improved operability

The machines of the local competitors had the shift lever, the reaping section lifting lever, and the reel lifting lever independent from each other (Fig. 3), and the operator needed to move the hand to different levers to operate. Furthermore, it was necessary to step on the clutch to operate the shift lever in order to change the forward/reverse travel direction.

When the operator made an α turn (operation to switch the harvesting direction at the corner of the field) in particular, he/she needed to operate multiple levers simultaneously, which complicated the operation. In order to improve the operability, it was necessary to concentrate the levers at one place so that the operator can operate any of them without releasing the hand.

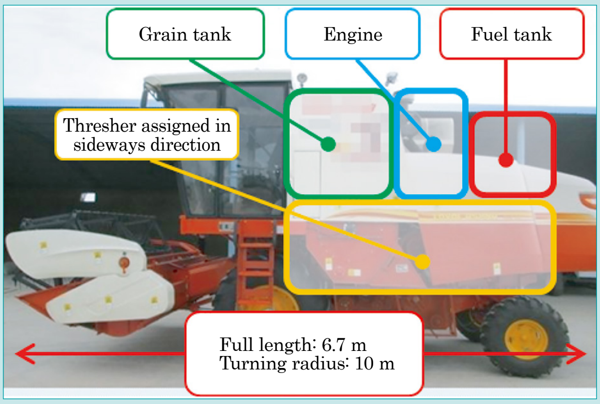

Fig. 2 Competitor's Machine Layout

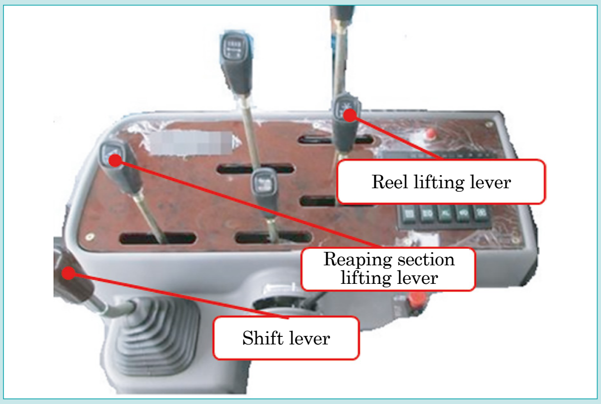

Fig. 3 Competitor's Control Panel

3-2 Technical issues related to high efficiency

3.2.1 High-speed unloading of grains

In Central Plains Area, low-floor trucks (Fig. 4) were popularly used to transport grains, and the height of the gate was 1,200 to 1,500 mm. While the most general method of unloading from the machines of local competitors was screw unloading, we needed to differentiate the developed machine from the machines of the local competitors by adopting a grain unloading method suitable for low-floor trucks.

3.2.2 Reduction in threshing load

We started the development with a conventional thresher whose specification was suited to rice. However, the amount processed per unit period was larger when wheat was harvested with a wheel combine harvester, and the reaping speed decreased as the threshing load increased and the engine speed decreased. Therefore, it was decided that the conventional threshers for rice specifications were unsuitable for wheel combine harvesters for wheat. We needed to develop a thresher specialized for high-volume wheat harvesting.

3.2.3 Reduction in chopper load

To suppress the energy for cutting at a low level, we needed to find the optimal cutting angle (angle when rotating blade and fixed blade overlap: Fig. 5), which varies by the type of crop. It was necessary to reduce the required output while maintaining the cutting performance of the chopper in the developed machine.

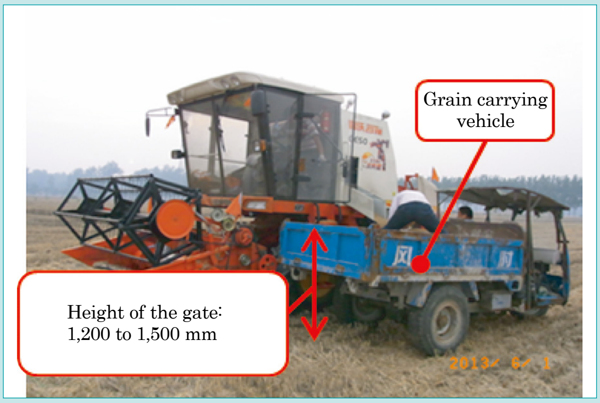

Fig. 4 Popular Grain Transporting Vehicle In the Target Area

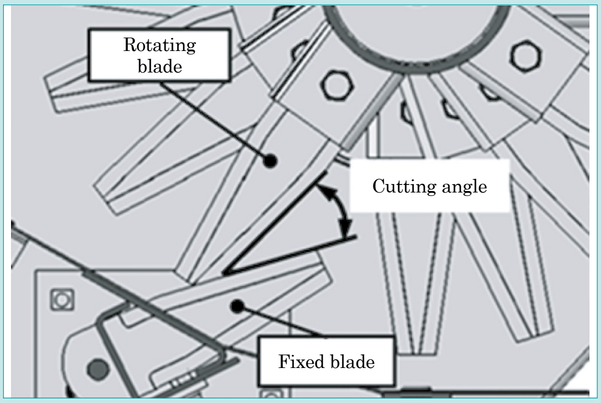

Fig. 5 Definition of Cutting Angle

3-3 Technical issues related to high efficiency

3.3.1 Improvement in maintainability of radiator

Since a high level of dust was generated during work on wheat, there was a high tendency for the dust prevention screen to become clogged and result in overheating. It was therefore necessary to stop the machine regularly 2 or 3 times a day and remove dust in order to avoid overheating. To increase the efficiency, we thus needed to reduce the dust removal period (stopping period).

4. Developed technology

4-1 High mobility

4.1.1 Vehicle body layout

We addressed a compact size in the developed machine by adopting Kubota's proprietary vertical thresher technology, which enabled the assignment of engine and fuel tank in the lower part of the machine (Fig. 6). We also ensured high mobility which overwhelmed the local competitors by addressing a low center of gravity thanks to the assignment of engine and fuel tank in the lower part of the machine body, and reduction in turning radius.

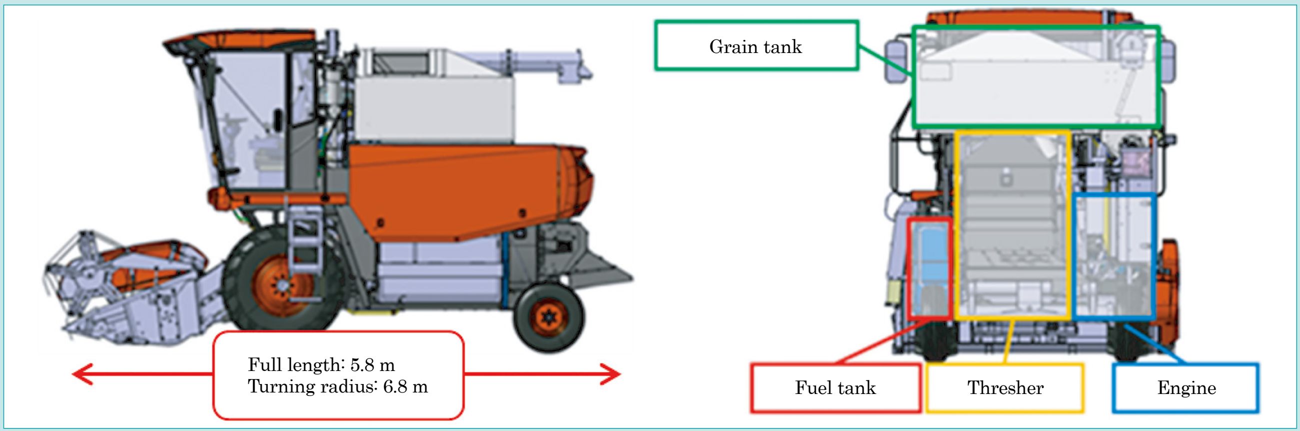

Fig. 6 Machine Layout

4.1.2 Multifunction lever

We adopted a multifunction lever (Fig. 7) in the developed machine to improve operability. The multifunction lever is a lever which integrates the main gear change lever, the reaping section lifting lever, and the reel lifting lever into one, and it can be operated without moving the hand to a different lever. The forward/backward travel switching can be executed by operation of only the multifunction lever. Therefore, the operability is remarkably higher than the machines of the local competitors.

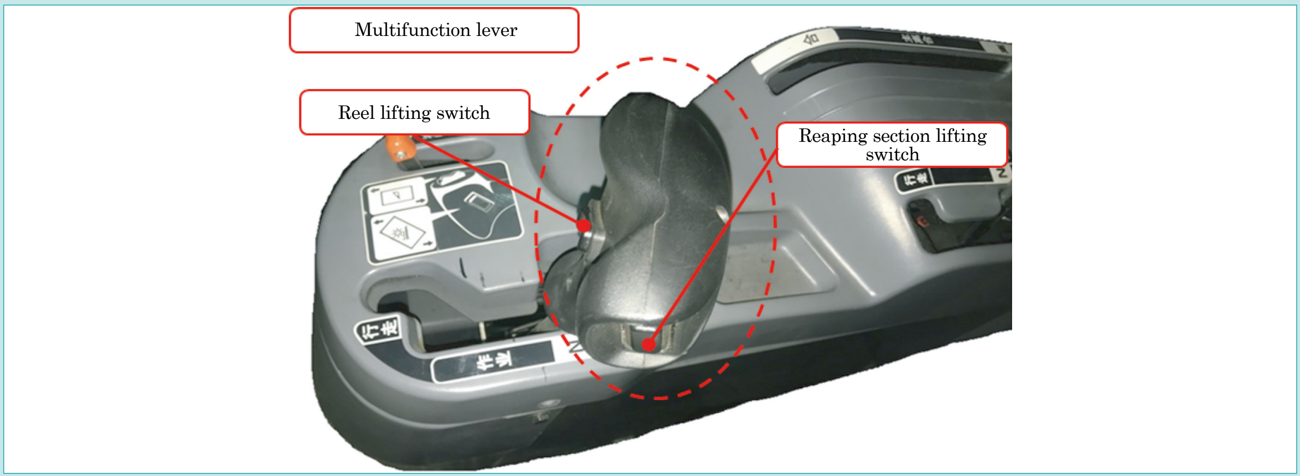

Fig. 7 Control Panel of the Developed Machine

Feature Text 1 Development of a Wheel Combine Harvester for China

4-2 High efficiency

4.2.1 High-speed grain unloading

We adopted the dumping style which is suited to low-floor vehicles in the developed machine to improve efficiency. Using the side plate of the grain tank on the unloading side as the discharge port entirely, the grains are unloaded by tilting the grain tank with the lift of a hydraulic cylinder (Fig. 8). Unlike the screw unloading in the machines of local competitors, this machine can unload the grains at once under their own weight, and the time for grain unloading can be reduced dramatically. We also adopted a grain unloading method which combined unloader discharge in the developed machine so that it can also be used for vehicles with raised floors. As a consequence, we established an highly advantageous grain unloading period which is 0.16 times those of the machines of the competitors (Fig. 9).

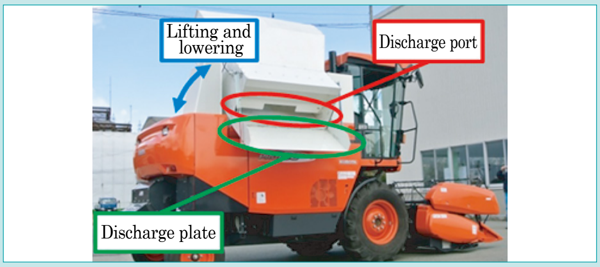

Fig. 8 Dumping Type Grain Tank of the Developed Machine

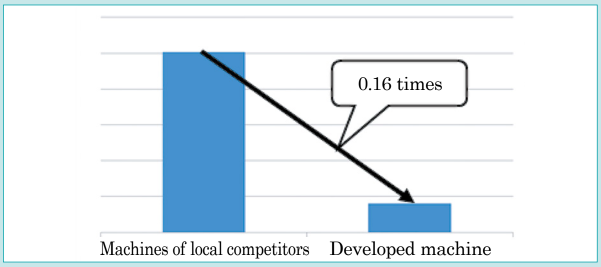

Fig. 9 Comparison of the Unloading Time

4.2.2 Reduction in threshing load

In general, the conventional threshers had rectangular top plates to handle crops such as rice which are difficult to thresh. In addition, they had specifications suited to the crawler combine harvesters whose processing quantities per unit period were smaller than those of wheel combine harvesters, which included the space in the threshing cylinder through which the crops pass being small, resulting in a high tendency for crops to stagnate and increase the threshing load (Fig. 10). We therefore adopted in the developed machine around top plate which is suited to more easily threshed wheat, and suppressed crop stagnation by expanding the space in the threshing cylinder for the crops to pass so that the increased processing quantity could be handled. As a consequence, we were able to reduce the threshing load and achieve our goal for the reaping speed (Fig. 11).

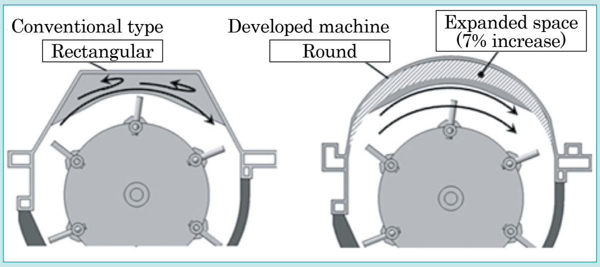

Fig. 10 Comparison of the Current Model and Developed Model

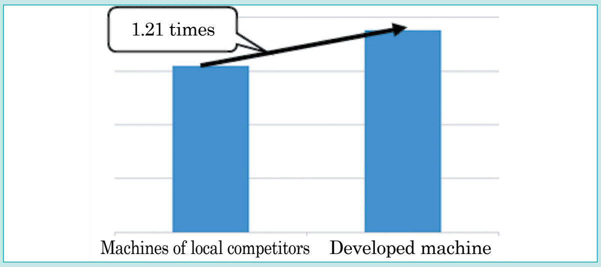

Fig. 11 Comparison of the Reaping Speed

4.2.3 Reduction in chopper load

In the developed machine, we measured the required output for the chopper during the reaping operation while varying the cutting angle in the field. According to the results, the required output was lowest when the cutting angle was 30 degrees, and we were able to reduce it by 25% compared to the conventional type (21°) (Fig. 12).

4.2.4 Work efficiency

Fig. 13 shows the work efficiency of the developed machine and the machines of the local competitors. We were able to achieve the work efficiency goal, with the efficiency being 1.4 times higher than those of the machines from local competitors, and develop a highly profitable machine which satisfies the market needs.

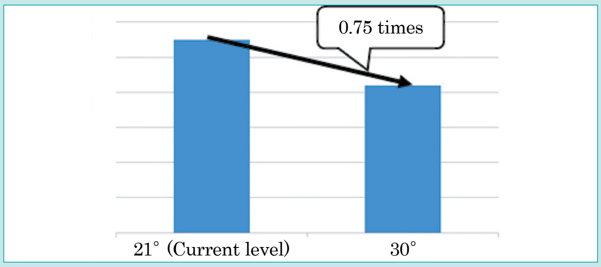

Fig. 12 Comparison of Output

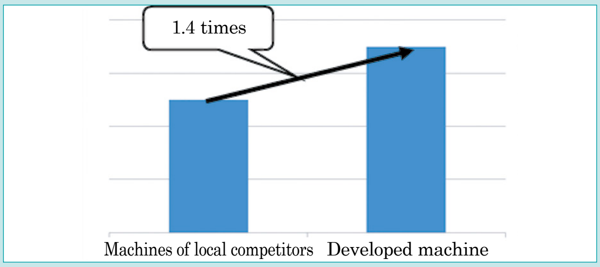

Fig. 13 Comparison of the Operating Efficiency

4-3 High operation availability

4.3.1 Improvement in maintainability of radiator

We adopted the automatic reversing fan, which is a proprietary technology of Kubota, in the developed machine (Fig. 14). It can blow away the dust accumulating on the dust prevention screen by automatically reversing the radiator fan at a specific cycle. This eliminated the work to remove dust, and we achieved our goal of zero cleaning frequency per day.

We also simplified the maintenance in the developed machine by assigning the dust prevention screen and radiator at positions where they are easily reached in the rear of the machine body (Fig. 15). Separate assignment of the engine and the radiator also made it easier to access the engine, contributing to improved maintainability of the engine including easier inspection on engine oil.

Since dust removal is much more difficult in the machines of local competitors which have the dust prevention screen located at the top of the machine body, it puts our machine at a considerable advantage.

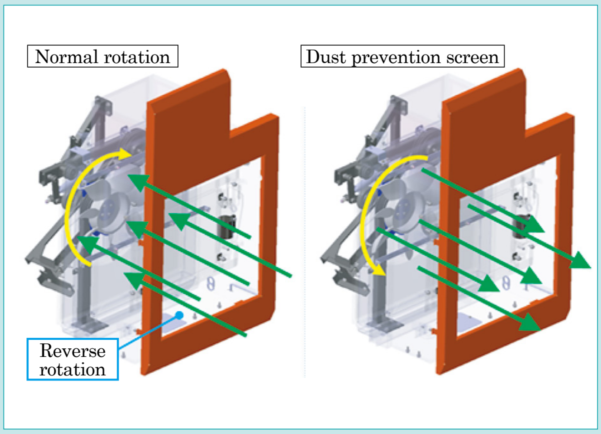

Fig. 14 Automatic Reverse Fan

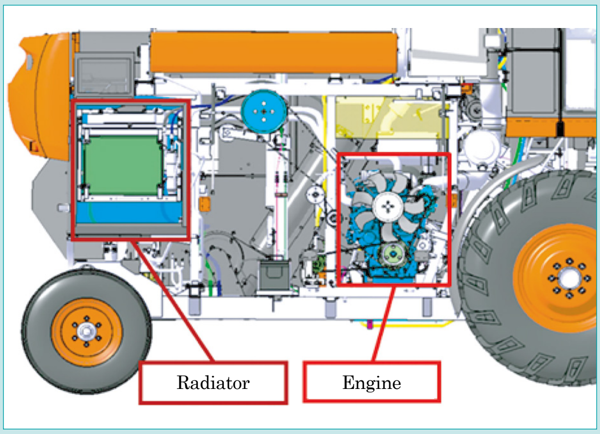

Fig. 15 Layout of the Radiator

Feature Text 1 Development of a Wheel Combine Harvester for China

5. Conclusion

We ensured high mobility suited to the field and farm road conditions in Central Plains Area with development of a compact size and improvement in operability. With high-speed grain unloading, development of a thresher for wheat and improvement in maintainability, our product became a highly profitable combine harvester with high work efficiency. Development of this high-capacity, high-performance wheel combine harvester has allowed us to contribute to "Increasing agricultural productivity and income" in the Chinese dry-field farming market. In the future, we will try to make further contributions to the Chinese dry-field farming market with increased output, improved functions, and smart agriculture. Regarding the expansion in crop types, we will make developments to expand to dry-field markets for soybean and corn in addition to wheat. Regarding the expansion in geographical area, we plan to expand to emerging countries outside China and large-scale dry-field farming markets. We will continue to contribute to the agriculture of the world through the development of these new businesses (Fig. 16), while also aiming to make Kubota "the global major brand".

Fig. 16 Future Prospects

Contribution to SDG targets

2.3	Increasing agricultural productivity and income	Contribution to the increase in income of farmers in China through improvement in work efficiency
8.2	Improvement in productivity through innovation	Contribution to agricultural productivity through development of low-cost, high-durability, and high-efficiency combine harvesters
9.2	Strengthening inclusive and sustainable industrial infrastructure	Contribution to the strengthening of agricultural infrastructure in China

Literature

1) Data by Food and Agriculture Organization (FAO) of the United Nations

Development of an Agrochemical Applicator for Direct Seeding with Iron-coated Rice Seeds

Transplanter Engineering Dept.

The KUBOTA group has encouraged the spread of the method of direct seeding of iron-coated rice seeds, which meets the increasing demand for low-cost and labor-saving in domestic rice cultivation. As a consequence of the activity, the method has become prevalent among large-scale farmers and the cultivated area has also been expanding. However, the method had the problem that it needed to apply insecticides and fungicides after seeding because of the non- existence of a simultaneous application technique of those agrochemicals for direct rice seeding. In order to improve the labor- saving effect of direct rice seeding, we newly developed a simultaneous agrochemical applicator for direct rice seeding ahead of our competitors, involving the agrochemical industry. This paper describes our efforts in development.

[Keywords]
Direct Seeding with Iron-coated Rice Seeds, Labor Saving, Agrochemical Applicator

Related SDGs

2 ZERO HUNGER · 8 DECENT WORK AND ECONOMIC GROWTH · 15 LIFE ON LAND · 1 NO POVERTY · 12 RESPONSIBLE CONSUMPTION AND PRODUCTION · 16 PEACE, JUSTICE AND STRONG INSTITUTIONS · 17 PARTNERSHIPS FOR THE GOALS

1. Introduction

In Japan, the number of farmers is decreasing, with aging of the population and shortage of successors in the background[1]. Meanwhile, the ratio of farmland area for rice farmers with a relatively large areas of 10 hectares or larger has increased from 13% in 2005 to 31% in 2015[1], indicating that the integration of farmlands in rice cultivation by large-scale farmers is accelerating (Fig. 1). Furthermore, the government-led "Aggressive agriculture, forestry and fisheries" sets out a goal to reduce the production cost of rice for large-scale farmers[2], and there is an increasing need for labor saving and cost reduction in rice cultivation. Kubota Group has worked on popularizing direct seeding cultivation with iron-coated rice seeds as a technology which can meet this demand. Our efforts bore fruit and the cultivation area has grown mainly in large-scale farmers.

The current rice transplanters are considered to incorporate "5 roles in 1 unit," and are capable of applying fertilizer, spraying herbicides, leveling the headland, and spraying insecticide-fungicides at the same time as they plant seedlings. On the other hand, the direct rice seeder (Fig. 2) used for direct seeding with iron-coated rice seeds, could execute seeding, fertilization, herbicide application, and grooving at the same time, but not the work equivalent to insecticide-fungicide application, requiring separate application work after seeding. Care was necessary to prevent the chemicals from scattering in the area in this work, and it was difficult to spray evenly in an appropriate quantity with manual spraying. Therefore, we worked on the development of a more environmentally friendly Agrochemical Applicator to be used simultaneously as direct seeding, which would further improve the labor-saving and cost reduction advantages of direct seeding.

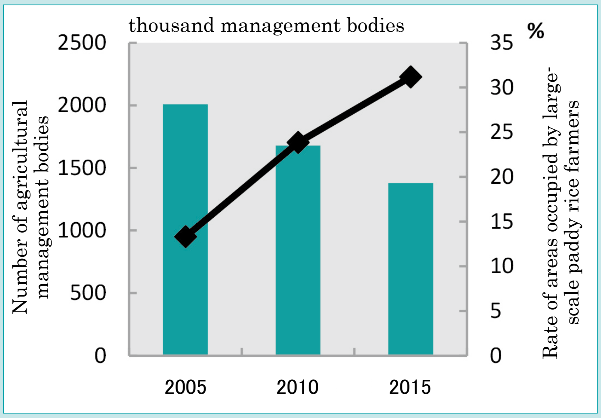

Fig. 1 Change in Agricultural Management Entities and Large-scale Rice Farmers Area Ratio

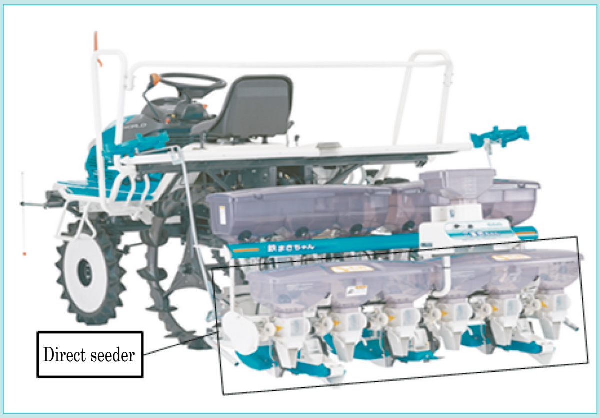

Fig. 2 Direct Seeder for Iron-coated Rice Seeds

2. Development concept and goals

2-1 Development concept

Our development concept was to develop a machine which is capable of applying insecticide-fungicides at the same time as direct seeding, so that it can further improve the labor-saving property of direct seeding with iron-coated rice seeds and promote its popularization.

2-2 Establishment of agrochemical application method

Since the development of an agrochemical applicator required the development and establishment of an agrochemical application method, we conducted a joint research with a chemical manufacturer.

It was recommended that the insecticide-fungicide be applied in the soil because of the photolytic property of the insecticide-fungicides and a mechanism in which their effectiveness was enhanced by absorption from the roots of rice plants. We studied the optimal positional relationship between rice seeds and the chemicals in order to ensure the effect during the sprouting period after direct seeding, and found that the position directly under rice seeds would be the most effective.

Based on the above, we determined the method to apply the chemicals as burying in soil directly under rice seeds, and we worked on the development of a machine to realize the method.

2-3 Development goal

(1) Realization of a new agrochemical application method

We set as our goal a structure which can address "in-soil application directly under rice seeds," which we concluded as a result of the joint study.

(2) Structure which can be attached to existing direct rice seeders

Since the direct seeder for iron-coated rice seeds is a relatively new product and the renewal demand is still low, we decided to make it an attachment which can be attached to the machine later.

(3) High precision delivery

In order to ensure the effectiveness of the chemicals, the machine was required to be capable of delivering the chemicals at 1 kg/10 ares. Since the physical properties and granular shape of each chemical vary, we set a goal to a capacity to continuously deliver various chemicals in a stable quantity.

3. Technical issues to be solved

3-1 Issues in realizing the new agrochemical application method

As a method to bury granular materials in soil, we already have the side row fertilization technology in rice transplanters. The parts attached to a float which comes in contact with the ground to level the unevenness of the field are used to bury fertilizer in the ditch cut in the paddy field, cover the ditch with soil and fill the ditch (Fig. 3). Since rice seeds can be sown in dots at a fixed interval in the direct rice seeder, it would be possible to execute in-soil application of the chemicals directly below rice seeds, by forming a path for chemical dropping and assigning this structure in front of the seed dropping position and on the same line in the direction of advance as the seeding position (Fig. 4).

There was a risk in which the rice seeds might fall into the ditch if we formed a ditch on the exact same line as the seeding position. Since the germination rate decreases when iron-coated unhulled rice is buried in mud, we needed to address the issue of high soil-covering performance to fill the ditch that was formed.

In addition, since new parts were to be added to the bottom surface of the float, which played the role of ground leveling, there was an issue of deterioration in leveling performance at the bottom surface of the conventional float caused by disturbance in mud flow. Another issue was that the chemicals have the tendency to scatter or adhere to the drop port and become accumulated when they are delivered and dropped due to their smaller size and specific gravity compared to fertilizers.

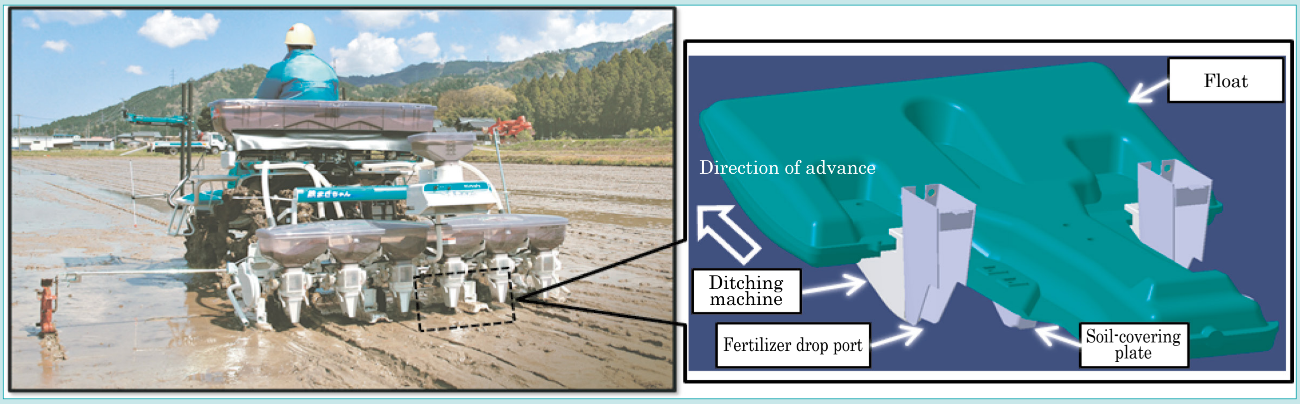

Fig. 3 Part of Burying Fertilizer in Soil

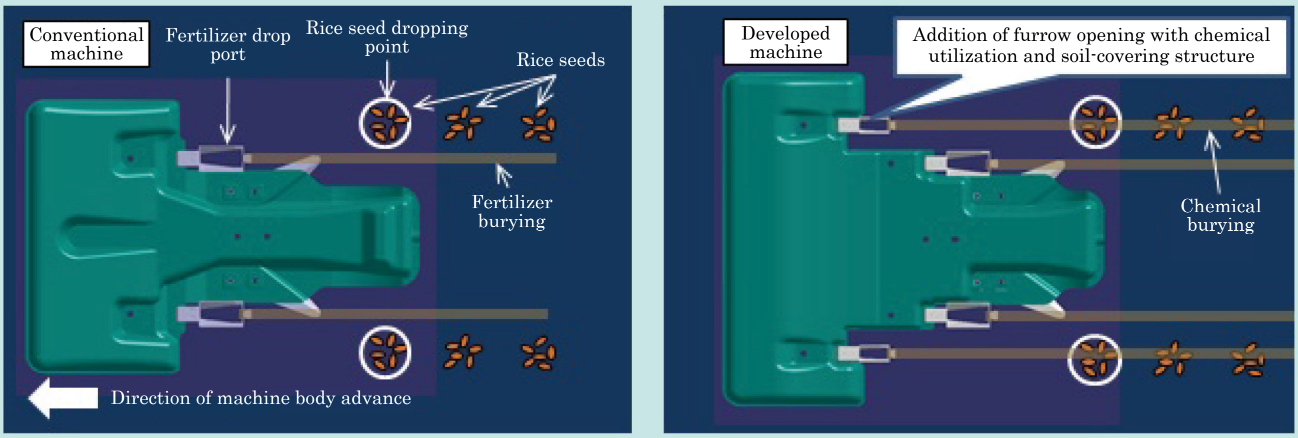

Fig. 4 Way to Apply Agrochemical Under Rice Seeds

3-2 Issues in developing a structure which can be attached to existing direct rice seeders

Although the grain size and specific gravity of the chemical vary depending on the brand, the application rate for each is 1 kg/10 ares. Therefore, we needed a mechanism on the machine side to control the amount that was delivered. We needed the applicator to be mechanically driven in order to set a reasonable price, even though it was easier to adjust the number of revolutions in the feed roll with electric motor drive in a structure which adjusts the amount of the granular materials with various different physical properties. A mechanical drive tends to have more parts than an electric motor drive, and it was necessary that we establish a compact size to fit within the limited space of the direct rice seeder which was not originally designed for later attachment.

In addition, a machine which can be attached later tends to deteriorate the balance between the front and rear of the entire machine body as it increases the overall length of the body, and it became our additional issue to design a layout which would not increase the overall length.

3-3 Issues in realizing high precision delivery

Fig. 5 shows the feed roll structure for fertilizer, which is a conventional technology. Granules enter the grooves on the rotating roll surface, and the brush with bristles levels off the granules spilling out of the grooves, thereby making the number of grains per groove uniform to feed the specified quantity of the granules. The bristles of the brush are made of nylon to prevent the granules from breaking when they are leveled off.

When we prototyped this structure and conducted a chemical delivery test, the delivery quantity did not stabilize. This was because the chemical was much smaller in size than fertilizers and the granules entered the gaps between the bristles of the brush. The bristles were easily deformed, and increase in the gap between the bristles and the roll due to deformation also became a problem. In addition, since the grooves on the roll surface were parallel to the rotation axis, the granules fell intermittently. While the rice seeds were sown at a regular interval to form a rice plant hill (spot seeding), this formed spots directly below the rice seeds where no chemicals were present (Fig. 6). This led to another issue, which was to eliminate the phase difference between rice seeds and chemical so that the sown rice seeds could immediately absorb the effective components through the root.

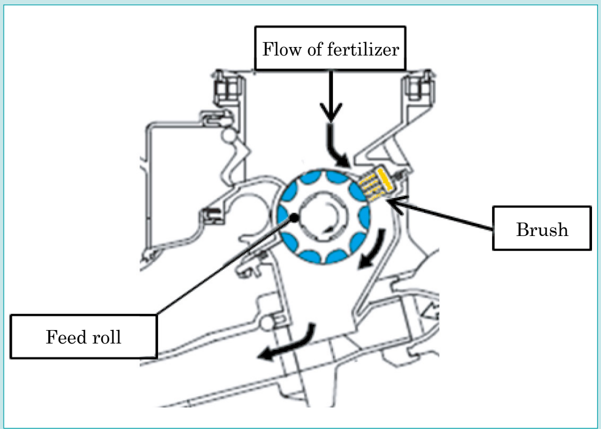

Fig. 5 Structure of the Feeding Fertilizer Part

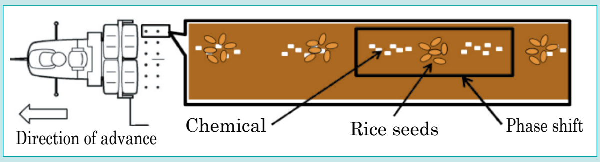

Fig. 6 Unevenness of Applying Agrochemicals for Rice Seeds

4. Developed technology

4-1 Technological development for realizing the new agrochemical application method

4.1.1 Mechanism of Agrochemical Applicator

Fig. 7 shows the mechanism of agrochemical application in the developed machine. We adopted a structure in which it forms a ditch in the paddy field surface with the ditching machine, drops the chemical into the ditch, and covers with soil to be followed by rice seeding onto the soil. In order to set a reasonable price, we adopted a natural dropping method instead of air conveyance using a blower.

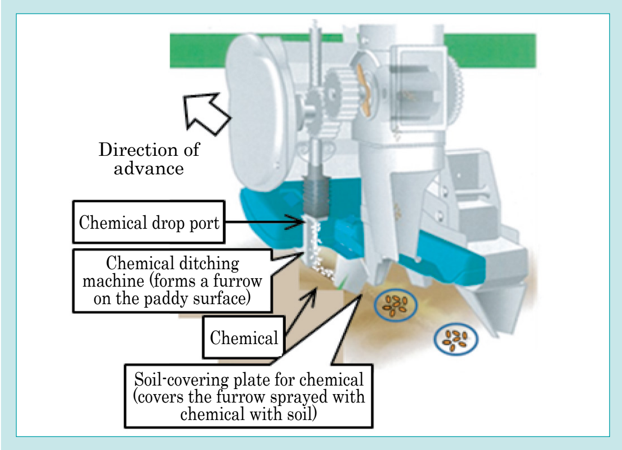

Fig. 7 Mechanism for the New Agrochemical Application

4.1.2 Layout of each part in burying part

Fig. 8 shows the newly developed burying part. We incorporated the optimal position and shape for each part after checking in an actual field.

(1) Float

In order to stabilize the groove depth and soil-covering performance of the ground leveling float section, we reduced the vertical fluctuations of the float by shifting the float rotation fulcrum forward compared to the conventional position.

(2) Ditching machine

We assigned the chemical ditching machine on the front side of the machine body and kept it from overlapping with the fertilizer ditching machine when seen from the side, so that mud would not be caught between the ditching machines and the ground leveling performance would be maintained.

(3) Soil-covering plate

We determined the shape and mounting position of the soil-covering plate for chemical by repeating field tests so that it would be adaptable to a wide range of field conditions, and improved the adaptability by adopting a structure in which the right and left opening angles and the height of the soil-covering plate could be adjusted (Fig. 9).

(4) Chemical drop port

We established a straight part in the pipe section immediately before the drop port in the agrochemical application part so that the chemical can fall into the groove without scattering, and adopted a slant cut shape for the drop port to prevent clogging of the chemicals due to adhesion of muddy water (Fig. 9).

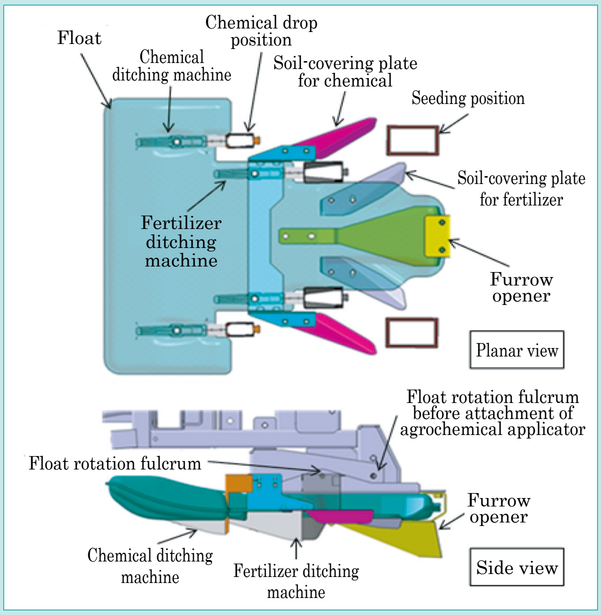

Fig. 8 Part Layout in the Burying Part

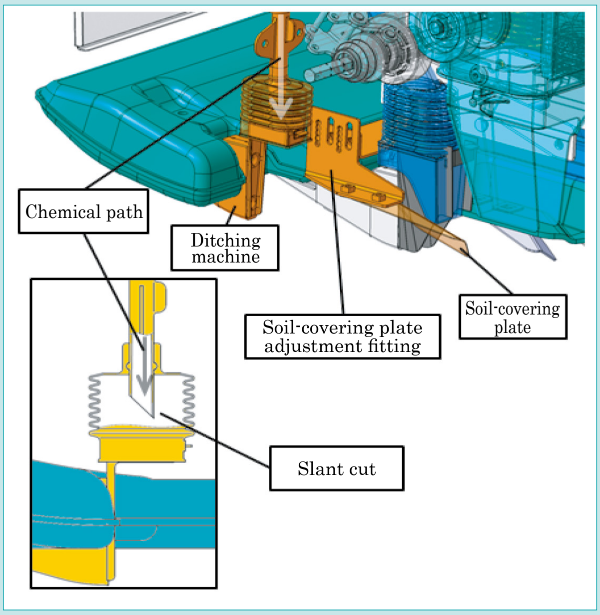

Fig. 9 Structure of Changing the Amount of Covering Soil and Falling Agrochemicals

4-2 Compact layout which can be attached to existing machines

Fig. 10 shows the overall layout of the newly developed machine when it is attached to a direct rice seeder. The orange part is the newly developed Agrochemical Applicator, which is added to an existing machine. To make the later attachment to the conventional direct rice seeder easier, we designed the layout with the agrochemical hopper located between the fertilizer hopper and the rice seeds hopper, and the delivery part located in the narrow space directly above the chemical drop point to allow the chemical to fall naturally. This also addressed our goal not to change the full length of the machine body while adopting a mechanical drive.

We established a chemical quantity adjustment part (first quantity adjustment part) for changes between hill space and another chemical quantity adjustment part (second quantity adjustment part) for changes in the type of chemical in each drive section in the middle of the power transmission path for driving the roll so that each can be operated without a tool.

We ensured visibility of the remaining amount from the rear by assigning the agrochemical hopper above the rice seeds hopper, and also secured sufficient capacity for the hopper to continue operation of more than 1 hectare with one supply.

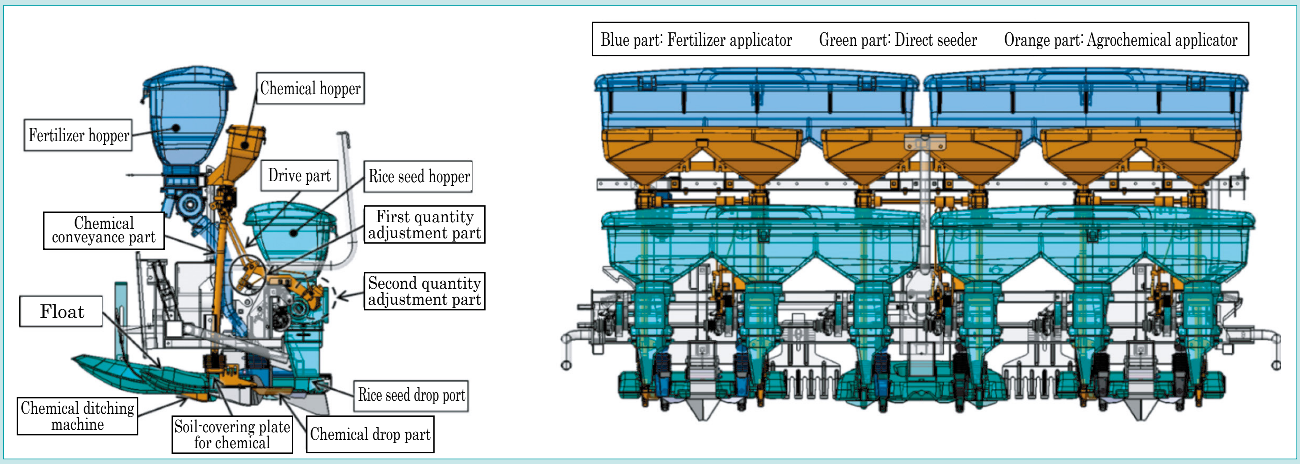

Fig. 10 Overall Layout of the Developed Applicator Mounted on the Direct Rice Seeder

4-3 Technological development for high precision delivery

Since the granules of the chemical are smaller than those of the fertilizer and are difficult to break, we adopted a scraper shape made of elastomer for the brush (Fig. 11) while placing the priority on the leveling-off performance. While this change reduced the fluctuations in delivery to 1/6, it also increased the wear in the roll, which caused a problem in terms of durability. Therefore, we combined a highly rigid resin and an elastomer excelling in elasticity as the roll material, and were able to address both delivery accuracy and durability.

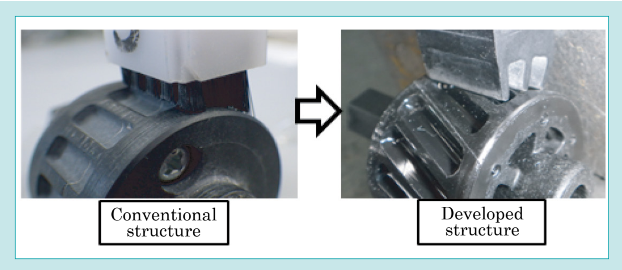

Fig. 11 Brush on the Feed Roll

Since the vehicle speed and the distance between hills (spacing between seedling/rice seeds in the traveling direction of the machine) vary depending on the user, it was considered necessary to have a structure in which the chemical was continuously dropped so that the chemical was present under the rice seeds in any conditions. Therefore, we ensured that the chemical would fall constantly even at a low number of revolutions by tilting the grooves on the feed roll with respect to its rotation axis (Fig. 12).

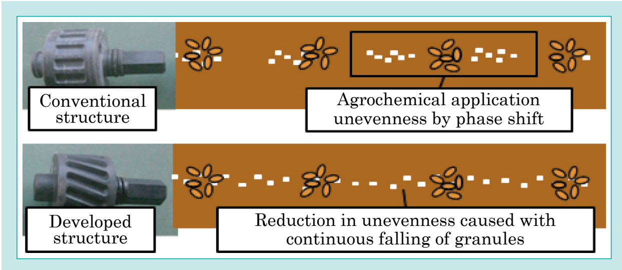

Fig. 12 Continuous Falling of Agrochemicals

4-4 Evaluation of effectiveness

We conducted chemical effectiveness tests using the developed machine at agricultural experiment stations in various locations throughout Japan, and confirmed that effective performance of the chemical was ensured under various field and working conditions. In addition to the effectiveness, we also confirmed that various chemicals with different granular shapes and specific gravity values could be delivered with the targeted accuracy thanks to the quantity adjustment structure we mounted.

Furthermore, we conducted a nationwide monitoring test in the direct seeding season in 2015, and confirmed that soil covering performance was delivered under various field and working conditions.

5. Conclusion

In order to eliminate the pest control work immediately after seeding, which had been an issue in the direct seeding cultivation of paddy rice, a rice production technology which can address labor saving and cost reduction, we worked on the development of Agrochemical Applicator which can apply insecticide-fungicides simultaneously as the direct seeding. By working on the development in cooperation with a chemical manufacturer, we were able to realize direct seeding and simultaneous chemical application for the first time in the industry.

Since the chemical is applied locally into the soil in this application method, there is no dispersion of the chemical outside of the field. Furthermore, there is no need for the operator to touch the chemicals except when supplying the chemicals into the hopper, and the mechanical delivery of the chemicals prevents excessive application and ensures uniform application. These functions will also contribute to reduction in residual agricultural chemicals and water pollution.

Development of the conventional agrochemical applicator simply tried to mechanize the work that had been done manually. This development is quite different from the conventional developments in that it started from the development of the chemical application method, as the work itself had not existed. As a consequence, we were able to establish the method as Kubota's proprietary technology. To contribute to labor-saving, low-cost and sustainable agriculture, we will continue to promote the development of new technologies ahead of the industry.

Fig. 13 Direct Seeding with the Developed Machine

Contribution to SDG targets

2.4	Realization of sustainable and robust agriculture	Realization of zero chemical dispersion outside the fields
8.2	Improvement in productivity through innovation	Contribution to improvement in agricultural productivity through realization of direct seeding and simultaneous agrochemical application
15.1	Conservation, restoration and sustainable use of terrestrial and inland freshwater ecosystems	Suppression of impacts on ecosystems outside the fields through elimination of excessive agrochemical application

Literature

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Research of the Performance in the Field of the Energy Saving Air Diffuser K-membrane Installed in Sewage Treatment Plants

Environmental Engineering Dept.

Kubota developed a low pressure loss membrane diffuser (referred to as K-membrane) in order to reduce energy consumption in sewage treatment plants. K-membrane was adopted in 39 plans in Japan and overseas. We investigated the performance of K-membrane installed in sewage treatment plants and confirmed K-membrane had long-term high performance. We report the results in this paper. In addition, K-membrane is exported to Southeast Asia and it contributes to conservation of the water environment. We also introduce some cases in the area.

[Keywords]
Low Pressure Loss Membrane Diffuser, Energy Saving, Oxygen Transfer Efficiency, Swing Reactor

Related SDGs

6 CLEAN WATER AND SANITATION
7 AFFORDABLE AND CLEAN ENERGY
9 INDUSTRY, INNOVATION AND INFRASTRUCTURE
11 SUSTAINABLE CITIES AND COMMUNITIES
12 RESPONSIBLE CONSUMPTION AND PRODUCTION
16 PEACE, JUSTICE AND STRONG INSTITUTIONS
17 PARTNERSHIPS FOR THE GOALS

1. Introduction

The electric power consumption of sewage treatment facilities corresponds to approximately 0.7% of the total domestic consumption, which is quite high, and "energy saving" is considered an essential issue. In addition, efficiency improvement in energy usage in water treatment is an essential matter to be worked on in order to address a sustainable society in terms of both economic and environmental aspects, as well as from the perspective of improving the energy efficiency in the global scale, which is set forth in the SDGs.

In sewage treatment processes, organic matters and nitrogen in sewage are decomposed and removed by microorganisms (activated sludge) in the reaction tank. In order to efficiently supply air to the activated sludge, a diffuser is installed in the reaction tank, and the air sent from the blower spurts out from the diffuser in fine bubbles. The power consumption of the blowers accounts for approximately 30 to 60% of the consumption at sewage treatment facilities, and the capacity (power) of each is determined by the supplied air flow × air feed pressure. Therefore, a high performance air diffuser which reduces the power consumption of an air blower would greatly contribute to energy saving in a sewage treatment.

In the domestic sewage treatment market, "membrane panel diffusers" were introduced from overseas around 2000 to respond to the growing needs for energy saving. Since a membrane-type air diffuser can generate fine air bubbles, the oxygen transfer efficiency (ratio of the amount of oxygen dissolved in water to the amount of oxygen blown) is high, and the supplied air flow can be reduced. On the other hand, since the slit (pore) through which the air comes out is small, it had some disadvantages such as a large pressure loss in equipment, a high air feed pressure of the blower, and getting easily clogged.

In order to solve these problems, Kubota developed and released in 2010 ahead of our competitors "low pressure loss membrane diffuser K-membrane," which is resistant to clogging and has low pressure loss while maintaining high oxygen transfer efficiency.[1] Fig. 1 shows an overview of K-membrane. K-membrane is comprised of bag-shaped membrane sheets with diffuser parts, support pipes, and so forth, and it has been delivered to 34 customers in Japan, mainly for sewage treatment.

In this article, we investigated the effect of introducing K-membrane in actual facilities and its long term operation performance, and report on our results as we were able to confirm that it has been operating with high energy saving performance. We will also introduce in this report some case examples of oversea introduction, as K-membrane has been introduced in 5 oversea facilities.

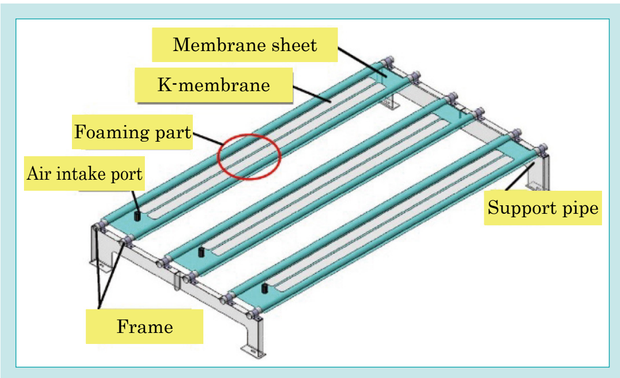

Fig. 1 Structure of the K-membrane

2. Concept and features of the developed product

2-1 Concept

K-membrane is a product which was developed based on the concept to "achieve energy saving with a balance between low pressure loss and ultra-fine bubbles."

Regarding pressure loss, the pressure loss of K-membrane was reduced from 11 kPa of the conventional membrane to 6 kPa or smaller by increasing the slit through which air bubbles are blown to approximately 3 times larger than that of the conventional membrane type diffusers (hereinafter referred to as the conventional membranes) and reducing the ventilation resistance. In addition, the material of the foaming part which would allow the bubbles to separate before it grows on the surface of the membrane was selected so that ultrafine bubbles could be generated even if the slit was increased. As a consequence, the oxygen transfer efficiency became the same design value (28 to 31%) as the conventional membranes. According to a trial calculation assuming a sewage treatment plant with water treatment volume of 10,000 m3/day, K-membrane addresses an energy saving effect (power reduction effect) of approximately 13% compared to the conventional membranes thanks to these measures.

3. Technical issues addressed and survey items

As air diffusers play a central role in sewage treatment, an operation failure in an air diffuser causes a considerable impact on the entire water treatment. Therefore, customers strongly demand reliability and results in air diffusers. It is important that we build up the reliability of K-membrane and utilize it in sales promotion as we show our customers favorable operation results (performance and durability) over a long term.

In this report, we investigated four items, which were (1) oxygen transfer efficiency, (2) changes in pressure loss, (3) supplied air flow reduction effect, and (4) application in swing reactors, at four sewage treatment plants where K-membrane is in operation.

4. Performance survey on the developed technology

4-1 Oxygen transfer efficiency in actual equipment[2)]

4.1.1 Overview of the survey

We checked that the high performance equivalent to the initial level was maintained by measuring the oxygen transfer efficiency of K-membranes which have been in operation for several years in actual facilities. The survey was conducted at Sewage Treatment Plant A, which has been in continuous operation for 4 years and 3 months at longest. Sewage Treatment Plant A had three series of reaction tanks with K-membranes which had been in operation for varying periods of 2 to 4 years, and we measured the oxygen transfer efficiency in all of these series. Table 1 lists the measurement conditions at the time of the survey.

Table 1 Measurement Condition of Oxygen Transfer Efficiency

Item		Measurement condition
Aeration method		Overall aeration method (with nitrification)
Date of measurement		June 2017
Number of years in operation (at the time of measurement)		1-1 Series (3 years and 7 months) 1-2 Series (4 years and 3 months) 2-1 Series (2 years and 3 months)
Inflow water quantity		Approx. 3,400 m3/day/pond (68% of the planned value)
Inflow water into reaction tank	Water temperature	23 ℃
	S-BOD	Approx. 30 mg/L
MLSS		Approx. 1,300 mg/L
Supplied air flow		Approx. 800 Nm^3/h・pond (89% of the planned value)

We adopted the off-gas method for measuring oxygen transfer efficiency during operation[3)]. The off-gas method is a method to calculate the oxygen transfer efficiency by using the difference between the amount of oxygen blown into the reaction tank in a certain period and the amount of oxygen found in the gas exhausted from the reaction tank (off-gas), and it can be used to measure the oxygen transfer efficiency in reaction tanks (sewage) during operation. In this survey, in order to compare the oxygen transfer efficiency value with the designed value, we converted the oxygen transfer efficiency in sewage into the oxygen transfer efficiency in fresh water using correction coefficients (values α and β). Fig. 2 outlines the measuring method.

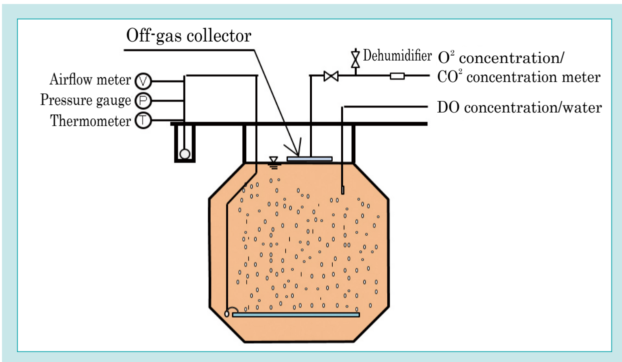

Fig. 2 Off-gas Measurement Method

4.1.2 Results of survey

Table 2 and Fig. 3 show the measurement results on oxygen transfer efficiency in Sewage Treatment Plant A.

The average value of oxygen transfer efficiency in the series we subjected for this survey was 34.3 to 35.2%, which was higher than the design value of 28% (fresh water, 5 m conversion value). We did not observe deterioration in oxygen transfer efficiency in concurrence with the number of years in operation, since the operating conditions of K-membrane in each year showed that the oxygen transfer efficiency of 1-2 Series, which has the longest operation period, was nearly equivalent to those of the other series. Furthermore, while the solubility of oxygen in sewage varies depending on the water quality, MLSS (concentration of suspended matters) in reaction tank and so forth in general, we did not observe in this survey any differences in α value, which is used as an indicator for the solubility. It is therefore assumed that there was no large difference in operating conditions of the reaction tanks of these series as well as the using conditions for the diffusers.

In this survey, we confirmed that K-membrane operated continuously while maintaining high oxygen transfer efficiency. Similar performance tests using the off-gas method have been conducted at other sewage treatment plants, and we have confirmed that all sewage treatment plants are operating at or above the design value.

Table 2 Measurement Results

Subject of measurement	Oxygen transfer efficiency (sewage)	Oxygen transfer efficiency (fresh water, 5 m conversion value)	Correction value
1–1 Series	21.0%	34.3%	α :0.66 β :0.99
1–2 Series	19.7%	34.5%	α :0.71 β :0.86
2–1 Series	20.9%	35.2%	α :0.74 β :0.87

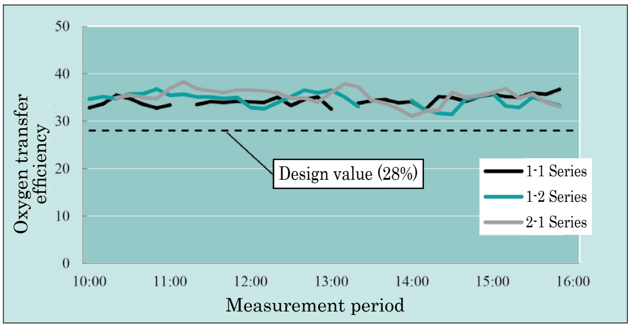

Fig. 3 Temporal Variation of Oxygen Transfer Efficiency

4-2 Changes in pressure loss in actual facilities

4.2.1 Overview of the survey

We checked if K-membrane was operating stably without clogging by continuously measuring the pressure loss of K-membrane that has been in operation for several years at Sewage Treatment Plant B. This equipment was installed at the same water depth for air diffusion (4.2 m) as the existing air diffuser, and operated using the air source branched from the existing air pipe (Figs. 4 and 5).

We measured the pressure losses during operation (including pressure loss during pressure operation of piping inside the pond and air flow control valve, and loss in the piping inside the pond and air flow control valve) using a manometer. In addition, we checked if there was deterioration in strength of the foaming part by taking back a part of K-membrane in use at the time of overhaul on reaction tank, which implemented once a year.

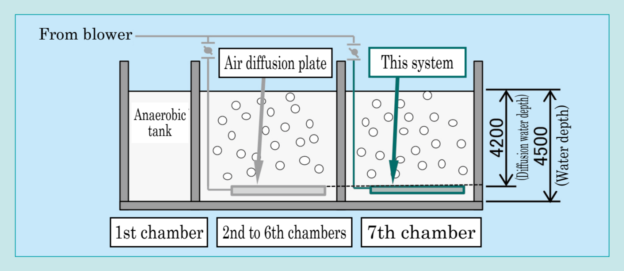

Fig. 4 Diagram of the K-membrane Arrangement

Fig. 5 View of Aeration in the Field (August 2018)

4.2.2 Results of survey

Fig. 6 shows the diurnal changes in pressure loss from December 2009 to August 2018. They conducted continuous operation for approximately 7 years and a half from January 2011 to August 2018 (including shutdowns for inspection of the reaction tank) without performing pressure loss increase prevention operation (operation to remove biofilm attached to the membrane surface). The pressure loss in this diffuser shifted at approx. 2.5 to 4 kPa, and it has operated stably without clogging at design value of 6 kPa or lower.

Fig. 7 shows the results of the strength test on the foaming part. There was no large difference in tensile strength between the new product and the product which was used for 6 years in operation, and we confirmed that there was no deterioration in strength.

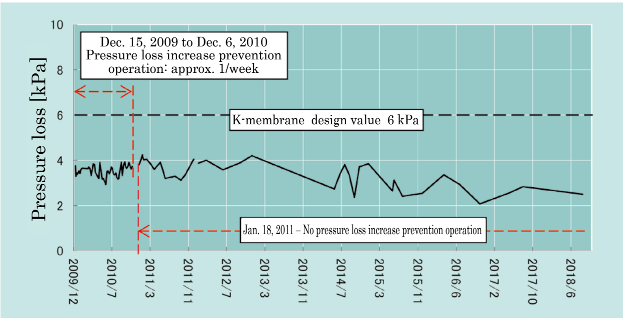

Fig. 6 Variation of the Dynamic Wet Pressure of the K-membrane

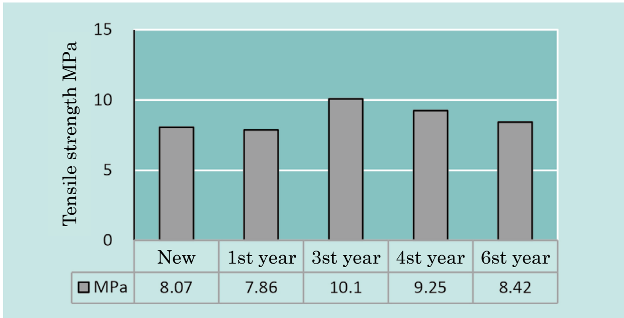

Fig. 7 Tensile Strength of the Membrane

4-3 Supplied air flow reduction effect by introduction of K-membrane in actual equipment[4)]

4.3.1 Overview of the survey

We studied the effect of introduction of K-membrane on reduction of supplied air flow in reaction tank at Sewage Treatment Plant C.

This facility started using K-membrane since April 2014, although it had been using ceramic air diffusion plates (swirl flow method) until October 2013. We compared the supplied air flow with ceramic air diffusion plate for FY 2012 to 2013 and that of K-membrane in FY 2014. Table 3 shows the measurement conditions in this survey.

Table 3 Measurement Condition of the Reduction Effect of the Air Blow Volume

Item	Measurement condition	Remarks
Aeration method	Overall aeration method	Operation started in March 2014
Volume of treated water	19,500 m^3/day/pond	Maximum daily volume of sewage
Supplied air flow control	Control with constant DO (end of the reaction tank) Control on opening of air discharge valve and air flow control valve based on DO No air flow control at the blower main unit	
Supplied air flow in reaction tank	Orifice flowmeter	Within air pipe
Volume of discharged water	Submerged electromagnetic flowmeter	End of the final sedimentation tank

4.3.2 Results of survey

Fig. 8 shows the measurement results on supplied air flow from April 2012 to March 2014. While the supplied air flow was 6.5 million m^3/month on average for ceramic air diffusion plate in FY 2012 to 2013, it decreased by approximately 35% to 4.2 million m^3/month on average in FY 2014 after the introduction of K-membrane. The total blower operation period (total for 2 units) was reduced by 42% after the introduction of this diffuser, whereas they had been operating 2 units of blowers constantly when air diffusion plates were in operation. In addition, there were little difference in dissolved oxygen concentration (DO) or water quality (COD, total nitrogen, and total phosphorus) in reaction tank, and we were able to confirm that the equivalent level of water treatment was executed with a smaller amount of air.

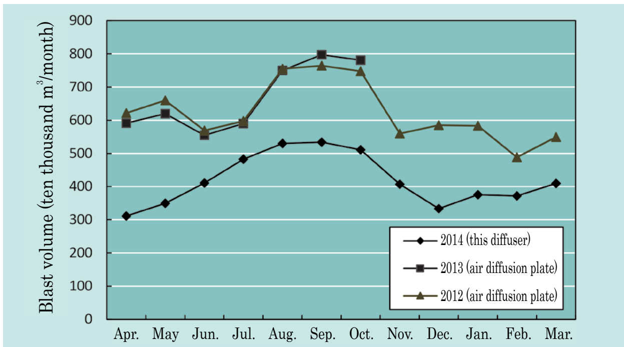

Fig. 8 Variation of the Air Blow Volume

4-4 Application of K-membrane in swing reactors

4.4.1 Background of survey

In sewage treatment processes, a reaction tank may be operated as a swing reactor in which the conditions are switched to suit the season or the time, in addition to the aerobic operation in which oxygen is supplied to the activated sludge and the anaerobic operation in which the activated sludge is only stirred without oxygen supply. To support the diverse operation modes at treatment plants, Kubota developed "Kubota Swing Reactor System," which combines K-membrane and "K-Wing," a low power agitator product by Kubota, as an energy-saving system for swing reactors which is capable of switching between anaerobic and aerobic operations. In this system, it was basically assumed that K-membrane would be assigned in locations that were not directly under K-wing in order to avoid the influence of the downward flow generated by K-wing. Therefore, the aeration method for K-membrane had to be "double swirl flow method" (Fig. 9), where the oxygen transfer efficiency is inferior to that of the "overall aeration method" in which diffusers are laid on the entire bottom surface of the reaction tank (Table 4).

Therefore, to address further energy saving in Kubota Swing Reactor System, we conducted a survey to see if it was possible to arrange K-membrane directly under K-wing.

Table 4 Selection of the Oxygen Transfer Efficiency

Air diffusion method	Water depth for air diffusion (m)	Oxygen transfer efficiency (%)	
		With nitrification	Without nitrification
Overall aeration	5.0	28	31
Single swirl flow Double swirl flow	5.0	26	30

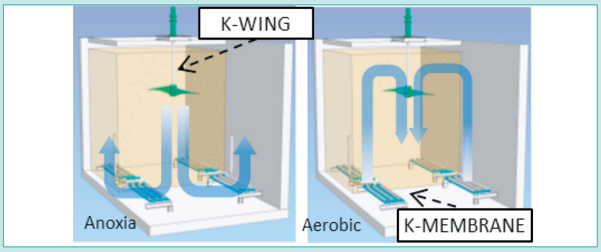

Fig. 9 Kubota Swing Reactor System

4.4.2 Outline of the survey

In Sewage Treatment Plant D, K-membranes are arranged on the entire bottom surface of the reaction tank directly below K-wing (Fig. 10). They have only operated K-wing most of the times since this equipment was put into operation (anaerobic operation) at this station, and the K-membrane has not been operated.

In this survey, we conducted an inspection on the reaction tank 4 years and 10 months after the start of its service, and confirmed visually if there were damages and so forth in K-membrane. We also took 1 piece of K-membrane back to the company as a sample, and confirmed the aeration conditions in a test tank.

Fig. 10 Swing Reactor in the D Sewage Treatment Plant

4.4.3 Results of survey

As a result of the field survey, we found no damage on K-membrane. Aeration of the sample we brought back in a test tank revealed no damages including air leak, and we confirmed that it was in good condition (Fig. 11). We also measured the pressure loss by supplying the design value amount of air to this sample, and confirmed that there was no clogging, with the value being approximately 2.6 kPa, which was lower than the design value of 6 kPa.

There is a concern that the agitation performance of K-wing would be affected if K-membrane is arranged on the entire bottom surface of the reaction tank. We therefore conducted fluid analysis using a model case with the maximum dimensions which can be agitated with one unit of K-wing. As a consequence, we confirmed that the flow velocity of 0.1 m/s or higher, which is necessary for sludge agitation in tank, was ensured for nearly the entire surface of the tank bottom as shown in Fig. 12, even when K-membrane was assigned over the entire bottom surface. Based on the above, we confirmed that it was acceptable to adopt overall aeration with Kubota Swing Reactor System.

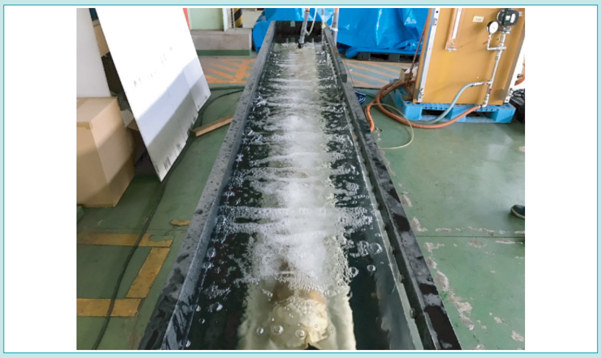

Fig. 11 Condition of Aeration of the K-membrane Used in the Field

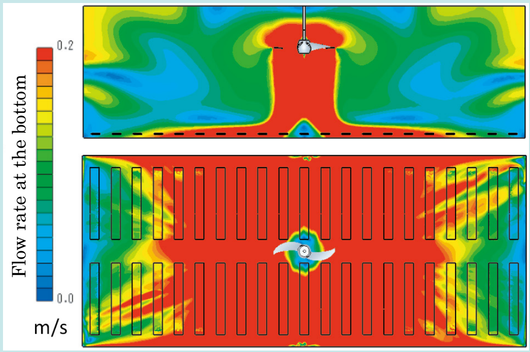

Fig. 12 Fluid Analysis Result of the Swing Reactor at Anoxic Mixing

5. Case examples of overseas introduction

K-membrane has been exported to Southeast Asia and contributed to the conservation of the local water environments.

In Thilawa, Myanmar, a new industrial park was developed under cooperation between Japan and Myanmar, and Kubota undertook the construction of the local water treatment system. With the concept to "adopt energy-saving equipment to reduce running costs while satisfying the environmental regulations," K-membrane was selected as the sewage treatment system for this area, and it currently treats sewage at the rate of 4,800 m^3/day (Fig. 13). K-membrane was also adopted for wastewater treatment at the factory of a major food manufacturer which is located within the same area.

Furthermore, in Phong Khe, paper manufacturing village in Vietnam, wastewater from the factories was discharged untreated and caused a major environmental problem. A project on environmental measures in Phong Khe paper manufacturing village was approved by the government and Kubota received an order for wastewater treatment facilities in 2013. In this treatment facility, K-membrane was introduced in order to meet the need to treat wastewater in an energy-saving manner (Fig. 14). The amount of water treated is approximately 5,000 m^3/day, and it is being operated stably at present, even though the processing condition includes a higher load of organic matter concentration and so forth than usual.

Fig. 13 K-membrane Installed in the Thilawa SEZ Zone

Fig. 14 K-membrane Installed in Vietnam

6. Conclusion

In this survey, we conducted field performance investigation on low pressure loss membrane diffuser “K-membrane” after the installation at multiple sewage treatment plants, and confirmed that all of the products exhibited stable energy saving performance. We also checked the applicability of overall aeration method in swing reactors, and our results indicated that more energy-saving operation was possible than the conventional swing reactor systems.

In the future, the needs for energy conservation are expected to grow further both in Japan and overseas. Since diffusers play a central role in reaction tank, it is especially demanded that they exhibit high performance over a long period of time in order to achieve energy saving in sewage treatment. In this survey, we obtained data which will greatly contribute to improving the reliability of K-membrane. As members of global major brand Kubota, we hope to continue to contribute to energy saving in sewage treatment and conservation of water environments by further popularizing K-membrane in domestic and oversea areas while using these results in sales promotion.

Contribution to SDG targets

6.2	Strengthening access to sewage and sanitation facilities	Contribution to stable sewage treatment with 31 cases in Japan and 5 cases overseas
7.3	Improvement in energy efficiency	Contribution to energy saving in sewage treatment
9.4	Infrastructure improvements through introduction of environment-friendly technologies	Contribution to improvements in sustainability with increase in efficiency of resource utilization

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Feature Text

Development of the MBR Control System for the North American Market

Membrane Systems Dept.

Membrane Bioreactor (MBR) is a treatment method suitable for the reuse of treated water. For SDGs to be achieved, it is necessary to reduce the cost of the MBR system in order to increase the availability of this technology. Therefore, we aimed at cost saving by establishing the MBR control method. In this development, control specifications were decided based on findings on MBR possessed by KUBOTA and by conducting experiments. Then, the sustainability of membrane filtration was demonstrated through testing in municipal MBR systems with this control. In conclusion, we showed that more efficient MBR processing is possible, and accordingly, we succeeded in making a lower cost MBR system that can be designed with 10% increase in flux and up to 30% reduction in the air scour rate compared with the MBR system without this MBR control system.

[Keywords]
MBR, KUBOTA Submerged Membrane Unit®, Control System, Cost Saving

Related SDGs

1. Introduction

Membrane Bioreactor (hereinafter referred to as "MBR") is a wastewater treatment technology which combines the purification capacity of microorganisms with the solid-liquid separation capacity of membranes. Compared to the conventional treatment technologies, this technology is characterized by its space-saving properties and delivery of high-quality treated water. It therefore is suited to wastewater treatment in areas and factories where there is no surplus land or which need to reuse the treated water. MBR is thus a technology which can contribute to a SDG called "Ensure availability and sustainable management of water and sanitation for all."

KUBOTA Submerged Membrane Unit™ is a membrane filtration device which is used in MBR (see Fig. 1). As a pioneer in MBR technology, Kubota implements a membrane equipment sales business worldwide, and an MBR systems sales business (design, procurement, and supervisor of installation of MBR facilities such as KUBOTA Submerged Membrane Unit™, blowers, pumps, and control panels) in North America. It currently boasts a track record of more than 6,000 installations, and leads the MBR market.

In order to realize the SDG "Safe water for all," it is necessary that we pursue cost reduction of MBR systems. To do so, not only the improvement development in KUBOTA Submerged Membrane Unit™ (Fig. 2)[1] but also the optimization of the operating conditions of system components including KUBOTA Submerged Membrane Unit™ are essential. We have therefore developed a control method to optimize the operating conditions of KUBOTA Submerged Membrane Unit™ and its peripheral devices. This report introduces the current status of our development efforts.

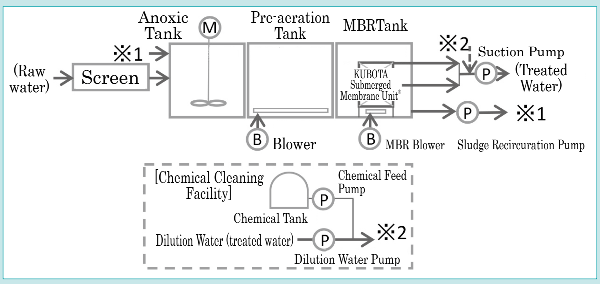

Fig. 1 Basic MBR Process Flow

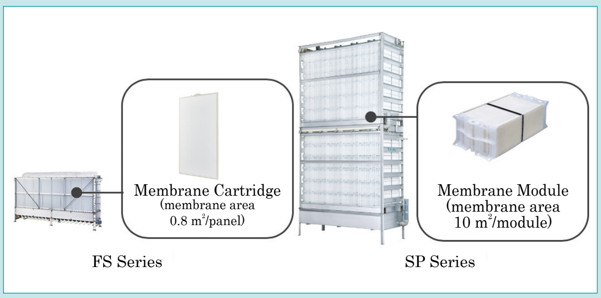

Fig. 2 Recent Development of KUBOTA Submerged Membrane Unit™
(Left; For Lower Water Depth MBR Facility, Right; For Large Scale MBR Facility)

2. Development concept and goals

2-1 Development concept

At the time when KUBOTA Submerged Membrane Unit™ was introduced to the market, Kubota constructed an MBR system based on the concept of being "Simple" in order to speed up the permeation of MBR into the wastewater treatment market. The equipment was thus operated at constant values with simple ON/OFF control. In addition, we intended to establish an MBR system with minimum chemical cleaning frequency of only once in several months in order to suppress the labor cost, with basic presumption that chemical cleaning, which is required on a regular basis, would be done manually for KUBOTA Submerged Membrane Unit™. We therefore designed the MBR system with a high safety factor in mind as it was necessary to minimize the load on the membrane. This was one of the reasons why our MBR system required high costs.

On the other hand, as MBR became popularized in the market and the scale of treatment grew larger, a tendency to promote automatic operation and save labor began to arise. Because chemical cleaning is also automated, there would be few restrictions on the frequency of chemical cleaning in this market, if the overall cost of the system can be reduced.

In this development, we therefore aimed to establish a new MBR system with the concept of "Efficiency" through utilization of our control technology.

- To address a design in which the load on the membrane (filtration volume) is increased through establishment of a control system which actively cleans the membrane, and
- Improvement in operation efficiency of the equipment through establishment of a control system which finely adjusts the operating conditions according to the inflow of wastewater.

We set our main targets in North America, where Kubota implements a membrane system sales business, and its large-scale sewage market, which tends to actively introduce controls for cost reduction.

2-2 Target value

2.2.1 Development target value

We specified our development target values with a view to adopt the design specifications for higher filtration efficiency compared to the conventional systems and expansion of the scope of use.

Typical design specifications of an MBR system include flux, membrane scouring air rate, and MLSS in MBR Tank.

Flux indicates the filtration rate per area of membrane. The number of KUBOTA Submerged Membrane Unit™ decreases and the initial and running costs decrease when flux is higher.

Membrane scouring air is supplied from a blower and plays a role of membrane cleaning necessary for filtration by generating sludge upward flow with air lift effect. The power consumption of the blower is reduced and concurrently the running cost when membrane scouring air rate is lower.

MLSS is the concentration of activated sludge (indicates the microbial groups hereinafter referred to as "sludge"), and the biological treatment capacity per tank volume increases when this value is larger. Furthermore, flexible operation to suit the season or the changes in inflow load conditions becomes possible, thereby reducing the running cost when the application range of MLSS is expanded.

Table 1 shows the development target values for these design specifications.

Table 1 Development Target for MBR System Design Parameters

Design data	Target value
Flux	Improvement by 10% or larger compared to the application of the conventional MBR systems
Membrane Scouring Air Rate	Reduction by 5 to 30% compared to the application of the conventional MBR systems
MLSS	5,000 to 14,000 mg/L (expansion in range of use compared to conventional 5,000 to 13,000 mg/L)

2.2.2 Estimation of cost effect

Changes in the life cycle cost (LCC) of an MBR system addressed in this development for 20 years are shown below. Since the cost of an MBR system varies depending on the design conditions for the wastewater (inflow conditions, etc.), this report simply shows an example.

We estimated the LCC based on the general design conditions for sewage in North America as shown in Table 2, while setting the area around the membrane separation tank including the chemical cleaning facility as the scope.

Table 2 Calculation Condition of the Life Cycle Cost of the MBR System

Item	Condition	
Raw water inflow	Maximum monthly	2.5 MGD (9,463 m^3/d)
	Maximum hourly	5.0 MGD (18,925 m^3/d)
Raw water quality	SS	250 mg/L
	BOD_5	250 mg/L
	T−N	50 mg/L
	Water temperature	12 ℃
Quality of treated water	SS	<2 mg/L
	BOD_5	<2 mg/L

Based on Fig. 3, it can be confirmed that in this case, the initial cost is reduced by 8.6%, the running cost by 21.6%, and the LCC by 15% thanks to the reduction effects in device expense and electricity expense.

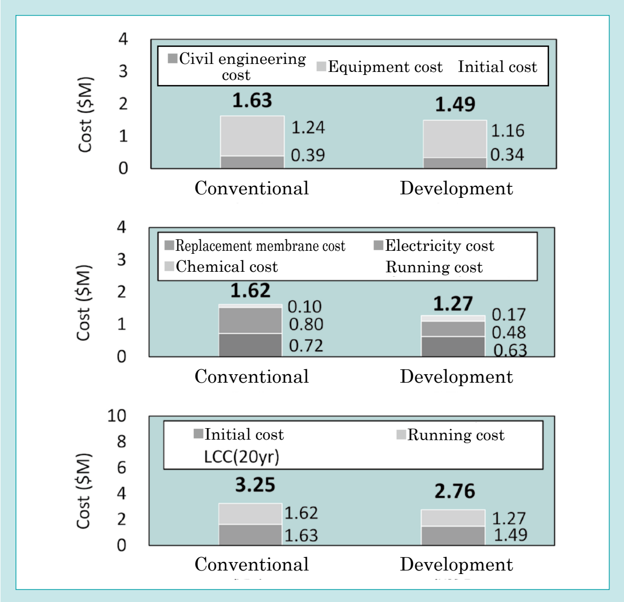

Fig. 3 Example of Development Effect: Comparison of LCC (Top: Capital Costs, Center: Operation Costs, Bottom: LCC)

3. Technical issues to be solved

In this development, we placed the priority on speed and decided to establish the control methods based on the knowledge we obtained through actual results.

- The amount of sewage inflow into a treatment plant varies in concurrence with the living activities of the people, and thus it is quite small at night.
- When the raw water volume is small, the volume of filtration can also be reduced. In addition, since the inflow load (quality x quantity) is small, the sludge circulation amount and the sludge drawing amount can also be reduced.
- Membrane cleaning can be utilized without difficulty if filtration is actively stopped when the raw water volume is small.
- If membrane cleaning can be actively utilized, there will be no need to underestimate the design flux.
- Membrane scouring air rate varies depending on the operating flux and the viscosity of the sludge.

Based on these findings, we aimed to establish an MBR control system comprised of the following four control packages. These are “Membrane Cleaning Control”, “Filtration Control”, “Air Scour Control”, and “Sludge Control” (Fig. 4).

(1) The purpose of “Membrane Cleaning Control” is to keep the membrane in clean conditions at all times and to maintain high permeability of the membrane by removing the colloids from sludge which adhered to the membrane. It is a control to determine the type of membrane cleaning and operate the necessary equipment such as Chemical Feed Pump depending on the type of membrane cleaning while filtration is paused, by monitoring the filtration rate and filtration pressure and grasping the degree of membrane fouling.

(2) The purpose of “Filtration Control” is to execute efficient filtration, and it is a control to determine the filtration rate according to the inflow of raw water per unit period, which is calculated based on the rate of sludge volume increase/decrease obtained in monitoring of sludge level in Anoxic Tank, Pre-aeration Tank, and MBR Tank, and operate the pump. In addition to the capability to adjust filtration rate according to the inflow, since filtration pause period can be actively created when the inflow of raw water is small, it is possible to execute membrane cleaning as necessary instead of executing inefficient filtration.

(3) “Scouring Air Control” is a control in which the MBR blower is operated while calculating the required membrane scouring air rate based on the measurement values, which are obtained from monitoring on the filtration rate and MLSS. We adopt MLSS, for which there is a general-purpose measuring instrument, as a substitute value for sludge viscosity. While membrane scouring air was conventionally supplied at a fixed rate, this control can reduce membrane scouring air rate when flux are small due to low inflow of raw water, and can result in energy-saving operation. Under the conditions in which a large amount of suspended solids (hereinafter referred to as “SS”) in sludge tends to adhere to the membrane due to high flux and high MLSS, and in which the membrane is

susceptible to clogging as adhesion of SS advances, it is possible to reduce the risk of sludge clogging by increasing membrane scouring air rate.

(4) “Sludge Control” is a control to operate Sludge Recirculation Pump and so forth by calculating the inflow of raw water and determining the sludge circulation rate and sludge withdrawal volume based on it.

In order to establish Kubota original MBR Control System, it was necessary to quantitatively express our knowledge which had been limited to qualitative expressions in the past, and to determine control formulae.

In addition, the required quality for MBR systems was “Sustainability of filtration operation”. The inflow of wastewater cannot be stopped without planning when there is a failure in the treatment facility. In the MBR system to be developed, the membrane load would be increased. It was expected that the risks of failure to continue filtration due to damages to the KUBOTA Submerged Membrane Unit™ or sludge clogging on membrane would increase. It was therefore necessary to actually apply the load and demonstrate the durability of filtration.

As described above, we had 2 items of technical issues in this development:

- Preparation of control formulae
- Demonstration of the durability of filtration

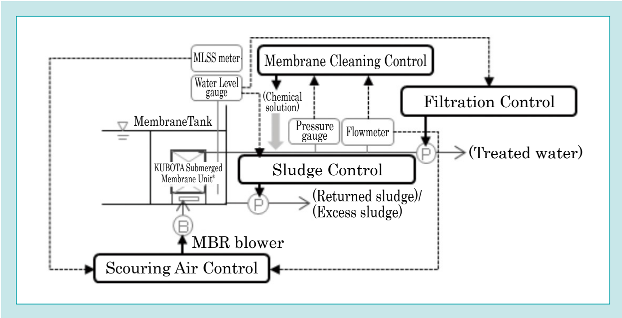

Fig. 4 MBR Control Packages

4. Developed technology

In this section, we report with a focus on the technical issues related to Membrane Cleaning Control and Scouring Air Control.

4-1 Membrane Cleaning Control technique

4.1.1 Summary

There are four types of membrane cleaning that are handled in Membrane Cleaning Control, which are Scrubbing, L-CIP, H-CIP, and Acid CIP. The purpose of all of these methods is to remove the colloids from sludge which adhered to the membrane. Table 3 shows an outline of each type of cleaning.

In the conventional systems, membrane cleaning was executed once every few months only by using sodium hypochlorite containing 0.3 to 0.6% Cl (H-CIP) or 1.0% acidic chemical solution (Acid CIP) at almost the same frequency.

Application of this membrane cleaning control would increase the contact period between the chemical solution and the membrane as well as the number of times of the chemical solution is injected. Therefore, it was assumed that the risk of KUBOTA Submerged Membrane Unit™ damage would increase with higher chemical and physical loads on the membrane.

Regarding this issue, we demonstrated that the risk of KUBOTA Submerged Membrane Unit™ damage was low over the expected life, and assured the durability of filtration.

Table 3 Outline of Cleaning Methods Using Membrane Cleaning Control

Cleaning	Summary
Scrubbing	・The purpose is to remove the matters adhering to the membrane. ・Only membrane scouring air is supplied without filtration. ・Once a day to once in several days, with duration of approximately 1 hour in each execution.
L-CIP	・The purpose is to remove the organic matters adhering to the membrane. ・Sodium hypochlorite containing 0.06% Cl is injected into the KUBOTA Submerged Membrane Unit™ from the secondary filtration side to leave it standing for the specified period. ・Once every few days to weeks, duration of approximately 1 hour in each execution.
H-CIP	・The purpose is to remove the organic matters adhering to the membrane. ・Sodium hypochlorite containing 0.2 to 0.6% Cl is injected into the KUBOTA Submerged Membrane Unit™ from the secondary filtration side to leave it standing for the specified period. ・Once every few months, with duration of approximately 2 hours in each execution.
Acid CIP	・The purpose is to remove the inorganic matters adhering to the membrane. ・An acid (citric acid, etc.) of concentration 0.2 to 0.6% is injected into the KUBOTA Submerged Membrane Unit™ from the secondary filtration side to leave it standing for the specified period. ・Once every few months, with duration of approximately 2 hours in each execution.

4.1.2 Efforts to address the technical issues "Ensuring durability of filtration with durability check"

We installed KUBOTA Submerged Membrane Unit™ in sludge, and repeated filtration and membrane cleaning to check its durability.

We executed membrane cleaning for the number of counts assumed to be implemented during the expected life of 10 years as the guideline values (L-CIP: 53 times/year, H-CIP: 4 times/year, and Scrubbing: 365 times/year). We made judgments on durability based on the fact that the solid-liquid separation performance, which is the basic performance of membrane, was maintained, and adopted turbidity in treated water as the indicator, with 0.2 NTU or lower specified as the standard value.

Fig. 5 shows the results.

The turbidity of treated water was maintained at 0.2 NTU or less without detection of any tendency to increase. As shown above, we confirmed through execution of a durability test that the KUBOTA Submerged Membrane Unit™ maintained the solid-liquid separation performance without suffering damages even when the membrane cleaning loads equivalent for the expected life of 10 years were applied.

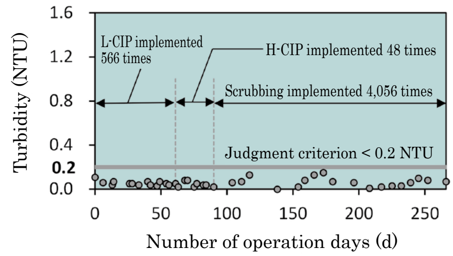

Fig. 5 Result of Durability Test: Time vs Treated Water Turbidity

4-2 Scouring Air Control

4.2.1 Summary

The minimum membrane scouring air rate to prevent SS in sludge from adhering to the membrane is designated as the required membrane scouring air rate. This value depends on both flux and MLSS. We expressed the relationship among them quantitatively and defined it as the control formula for membrane scouring air rate.

4.2.2 Efforts to address the technical issues "Determination of the control formula" "Confirmation of filtration durability"

(1) Determination of membrane aeration control formula

We installed KUBOTA Submerged Membrane Unit™ in the sludge of a domestic wastewater treatment facility, and conducted experiments to determine membrane scouring air rate required for each flux and MLSS value. The necessary level of membrane aeration increased as flux or MLSS rose.

As a consequence, we confirmed that the relationship between flux or MLSS and the required membrane scouring air rate can be approximated with a certain equation (Equation (1)), and defined this equation as the control formula. Details are omitted here as it is Kubota's undisclosed know-how. Besides control, Equation (1) is also used as the calculation formula for determining the design value for membrane scouring air rate during MBR system design.

Level of membrane aeration = F (flux, MLSS) (1)

(F indicates a multiple function of flux and MLSS)

(2) Confirmation of filtration durability

We conducted operation in the experimental facility of a sewage treatment plant for 1 month under the condition in which MLSS was set to approximately 13,000 mg/L. Table 4 lists the experiment conditions. In order to confirm that the control formula shown as Equation (1) can be applied to other facilities, we conducted an experiment at a different facility from the one we used in the previous section. We made judgments on whether the membrane was clogged with sludge by adopting the weight of the membrane module as the indicator and 23 kg/unit as the standard value. As a consequence, operation was continued without interruptions in filtration, with the membrane modules at the end of the test all remaining within the range of 20 to 21 kg/unit. We therefore determined that there was no sludge clogging on membrane. Fig. 6 shows the appearance of the membrane module at the end of the test. As shown in the appearance, we observed no clogging on the membrane module by visual inspection.

As described above, we also verified the durability of filtration in high-MLSS operation through demonstrations.

Table 4 Confirmation Test Condition for High MLSS Operation

Item	Operating condition
Membrane Unit type	SP40, (experimental Membrane Unit which is composed of 4 membrane modules)
Flux	0.70 m/d
Level of membrane aeration	0.36 Nm^3/min on average (0.32 to 0.40) *Standard value of membrane aeration level (0.4 Nm^3/min)
MLSS	12,700 mg/L on average (11,200 to 13,900)
Water temperature	13° C on average (10.2 to 16.0)

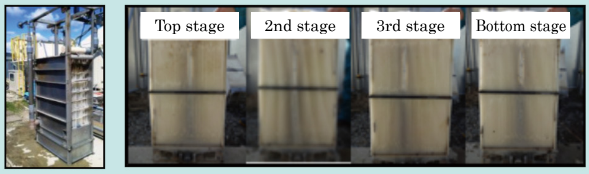

Fig. 6 Experimental Membrane Unit SP 40 and Appearance of the Membrane Module at the End of the Test.

4-3 Demonstration of MBR control system

We integrated the development outcomes described so far, and worked on a demonstration to confirm that membrane filtration can be continued under the operating conditions specified in our development targets.

We compared the filtration conditions between a conventional system (Train A) and the developed system (Train B) in the experimental facility of a sewage treatment plant.

Fig. 7 shows the system flow, and Table 5 the operating conditions. We determined the inflow of raw water while taking into consideration the flow characteristics of sewage and specifying a value for each time zone to then specify the filtration volume (flux) for each train accordingly.

Train B operated with flux 10% higher than that of Train A. We adjusted membrane scouring air rate in Train B according to flux and MLSS. As a consequence, it operated at membrane aeration level 19% lower than that of Train A.

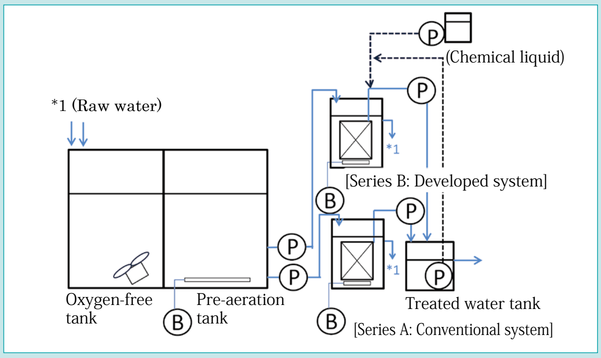

Fig. 7 Process Flow of the Pilot Plant

Table 5 Comparison Test Conditions

Item		Conventional system	Developed system
Flux	Normal operation	0.82 m/d	0.90 m/d
	Peak operation[1]	1.40 m/d	1.60 m/d
	Daily average	0.92 m/d	1.02 m/d
MLSS		Average 11,000 mg/L (10,300 to 11,200)	

1) Peak Operation with higher flux was executed for 4 hours a day.

In Train B (developed system), we specified a pause process for 1 hour during nighttime and executed the membrane cleaning according to the degree of membrane fouling.

Fig. 8 shows the changes in filtration pressure in time when filtration was executed. In the conventional system, in which a higher filtration pressure indicates that the membrane has more foulants when the flux is constant, a situation occurred where the filtration pressure rose rapidly while flux was high, resulting in a pause in filtration to execute a chemical cleaning on the following day as an urgent measure.

On the other hand, the developed system continued operation without any unplanned interruptions in filtration, as permeability recovered from the membrane cleaning which was scheduled in advance and executed at appropriate timings, even though the filtration pressure rose when the flux was high.

As described above, we demonstrated the durability of filtration under operating conditions set in development targets through comparative tests between a conventional system and the developed system.

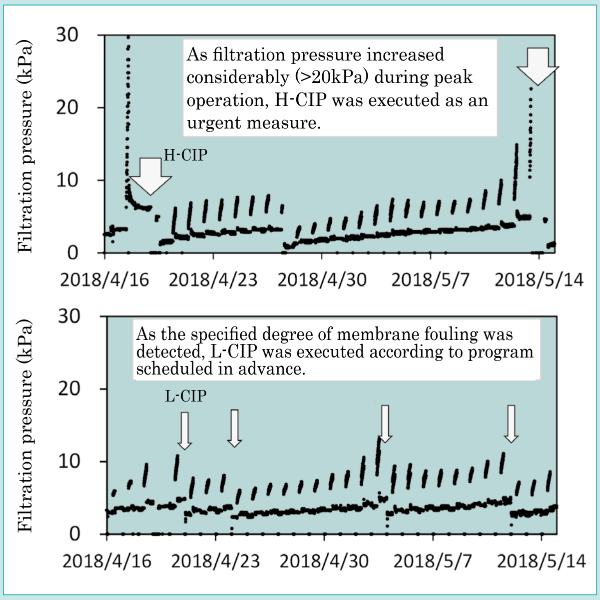

Fig. 8 Time vs Filtration Pressure
(Upper: Conventional Control System,
Lower: Developed Control System)

5. Conclusion

MBR is a useful technology to "Ensure availability and sustainable management of water and sanitation for all." To make this technology more accessible to people around the world, it is essential that we reduce the cost of MBR systems. In this theme, we made approaches to cost reduction through development of an MBR control method.

In North America, where attention on MBR is growing due to concerns about conservation of water quality and water recycling, it is expected that Kubota's MBR system sales business will increase by 34% in 2020 compared to 2018, once this development is adopted.

This indicates that Kubota will supply MBR facilities for tens of thousands of people in total, and it can be said that Kubota will contribute to the treatment and recycling of wastewater by people in this scale.

In November 2018, we began a demonstration to determine the limit design values of Kubota's MBR systems while trying to realize MBR systems with lower costs and brushing up on the control method from this development at Kubota Water and Environment R&D Center U.S.A. We will continue to work on technological developments for KUBOTA Submerged Membrane Unit™ and MBR systems utilizing KUBOTA Submerged Membrane Unit™ so that we can contribute to the delivery of safe water to more people around the world.

Contribution to SDG targets

6.3 Improvement of water quality through reduction, recycling and so forth of untreated wastewater	Contribution to water quality conservation and water recycling through involvement in wastewater treatment processes of more than 6,000 sites
7.3 Improvement in energy efficiency	Contribution to energy saving in sewage treatment
9.4 Infrastructure improvements through introduction of environment-friendly technologies	Contribution to improvements in sustainability with increase in efficiency resource utilization

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Development of the Minimal Swing Radius Type Mini Backhoe RX-506 for the Japanese Market

Construction Machinery Engineering Department for Excavator

The new minimal swing radius type mini backhoe RX-506 which has been placed on the Japanese market was developed as a new model to meet new emission regulations in Japan. This model was developed aiming at differentiation from the competitor's model by attaching added value that can maintain cost performance against an increase in the selling price due to the new emission regulations, and retains the basic performance of the current model which obtained a good reputation. The following three points represent the added value of the RX-506. 1. KUBOTA original energy saving mode system. 2. New development of front attachments. 3. Improvement of maintenance.

[Keywords]
Mini Backhoe, Emission Regulations, Energy Saving Mode, Variable Gain Control Routed the Front Hose Through the Front Inside, One Side Maintenance

Related SDGs

1. Introduction

A new model of 5-ton class minimal swing radius type mini backhoe for the domestic market was introduced in 2001. Since then, RX-505 (the current model), which was released in 2007, has steadily gained market share thanks to its vehicle class, workability, maintainability and so forth being accepted by the rental market, while getting several minor changes such as the addition of crane specifications and compliance with the Third Emission Regulations. Since our competitors did not make major model changes during this period, we were able to further increase our market share. However, as the need to comply with the 2014 Regulations of Emissions From Non-road Special Motor Vehicles arose, it was expected that the competitors would also take this opportunity and make model changes. In addition, since it was not possible to directly reflect the increase in the selling price due to compliance with emission regulations on the product price, it was necessary to give additional values that would meet the increase in the selling price due to emissions regulations compliance and suppress the impression that the price was comparatively high. We needed to develop a product with high added values while taking into consideration the measures for the environment, which also suppressed the increase in selling price in order to make it a product with cost performance.

Setting the following 2 items as the issues to be solved in order to renew the outdated design while inheriting the vehicle class (vehicle width, total height, rear radius, and working range) which has been received well with the current model and comply with the emissions regulations, we set out to develop a machine with high cost performance (Fig. 1 and Table 1).

(1) To provide functions which delivers a good balance between energy saving and work efficiency, and

(2) To renew the exterior design and reduce the running cost by changing the front hose into an interior part, which had been requested from the market.

Fig. 1 Appearance of RX-506

Table 1 Specifications of the RX-506

Main specifications		Unit	Reference value
Machine mass		kg	5400
Bucket capacity (heaped)		m^3	0.21
Overall length		mm	5170
Overall height		mm	2540
Overall width		mm	2000
Maximum digging height		mm	6420
Maximum digging depth		mm	4065
Maximum digging radius		mm	5730
Maximum digging force		kN	36.5
Travel speed	1st gear	km/h	2.6
	2nd gear	km/h	4.5

Specifications: Standard blade + rubber crawler + canopy

2. Development concept and goals

2-1 Development concept

We implemented development on this machine with the following 2 concepts:

(1) Balance between energy conservation and work efficiency

To ensure equivalent level of workability to the current model while reducing the fuel consumption with the downsized engine conforming to the emission regulations, we were to develop KUBOTA original energy saving mode system, and introduce a hydraulic regeneration circuit on the scraping-in side of the arm and boom lowering side. This would deliver a good balance between energy saving and work efficiency.

(2) Renewal of exterior design and reduction in running cost

In the current model, the front hose was arranged with a routing in which it passed on the outside of the front implement. This was a structure from 15 years ago, and an outdated design with poor appearance with the hose protruding outside. We therefore planned to make changes so that the hose was incorporated in the front implement and would not protrude outside, and improve the external design to unify the external appearance with that of the 3-ton class which had been released in advance. In addition, by arranging the alternator and the compressor on the rear side of the machine body, we would address an arrangement in which parts that require daily inspection could be accessed only by opening the rear hood. This would facilitate daily inspection and replacement of parts around the engine, thereby reducing the running cost.

2-2 Development goals

(1) We set our goal in addressing the work efficiency in light-duty work at an equivalent level as the current model by reducing the fuel consumption per standard work cycle (digging and loading + leveling + traveling + standby) measured by JCMAS measurement method during energy-saving mode (Eco Mode) by 20% or more.

*JCMAS stands for the Japan Construction Machinery and Construction Association Standards.

(2) Another goal was to improve the external design by changing the routing of the front hose and incorporating it as an interior part of the front implement instead of passing it on the outside of the front implement as in the current model.

(3) Our last goal was to address an arrangement in which parts that require daily inspection could be accessed only by opening the rear hood.

3. Technical issues to be solved

In order to achieve the development concepts, we proceeded with development while specifying the following 3 points as technical issues to be solved.

(1) KUBOTA original energy saving mode system

While many of the energy-saving methods installed in the mini backhoes of our competitors simply reduce the engine speed to reduce fuel consumption, they result in reduced work efficiency as it also reduces the hydraulic pump discharge at the same time. Therefore, users rarely use these energy-saving methods. In this development, the technical issue we needed to solve was to realize an energy-saving method (Eco Mode) which could be used with high work efficiency while reducing fuel consumption.

(2) New development of front implement

In order to realize the interior incorporation of the front hose, it was necessary to make a hole in the boom cast steel which is the main strength member, and it was easily expected that the rigidity of the boom would deteriorate. Therefore, our technical issue was to ensure the durability of the front implement with which the interior incorporation of the front hose was addressed.

(3) Improvement in engine maintainability

Many mini backhoe engines are located on the rear side of the machine body, and the front side of the engine corresponds to the operator's seat. Therefore, they need to be accessed from the side of operator's seat when the daily inspection parts are located on the front side of the machine body, making it time-consuming to maintain the parts in the narrow space. In the current model, the alternator and the compressor were arranged on the front side of the machine body in installation layout. Fig. 2 shows the engine room layout of a current model (RX-505).

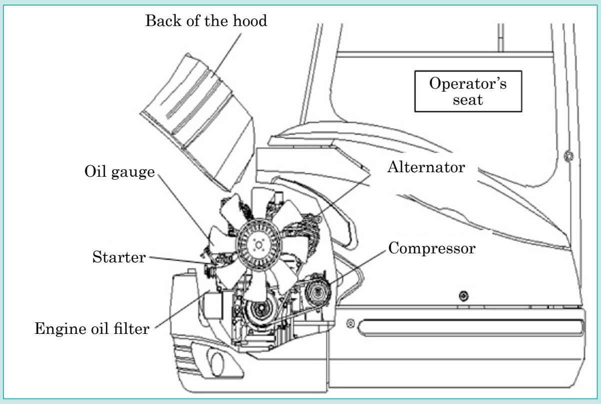

Fig. 2 Engine Room Layout (RX-505)

4. Technology for differentiation

4-1 Balance between energy conservation and work efficiency

4.1.1 Development of KUBOTA original energy saving mode system

We will explain the definition of fuel consumption in construction machinery in this section. Fuel consumption is measured by the JCMAS method, and it is evaluated as the fuel consumption value per standard work cycle which is tested in simulated operations.

$$F_1 = \frac{q}{c}$$

F_1 : Fuel consumption per standard work cycle (g/cycle)
q : Fuel consumption (g)
c : Standard Operating Cycle (cycle)

To reduce the fuel consumption per standard work cycle, it is thus necessary to address both (1) reduction in fuel consumption and (2) improvement in work efficiency.

4.1.1.2 Reduction in fuel consumption

The engine equipped in RX-506 satisfies the 2014 emission regulations for non-road special motor vehicles. In order to reduce fuel consumption, we downsized the engine displacement from 2 L to 1.8 L, and adopted turbo method so that the engine output would be equivalent to or higher than that of the current model.

We also incorporated a control to limit the maximum engine speed to 1800 rpm in Eco Mode. Table 2 shows a comparison between the current model and the engine mounted on RX-506.

Table 2 Comparison of the Equipped Engine

		RX-505	RX-506
Engine	Displacement (L)	2.197	1.826
	Output (kW)	28.8	30.1
	Combustion system	4-cylinder vortex system	3-cylinder direct-injection turbo
	Number of revolutions (rpm)	2250 (Standard Mode)	1800 (Eco Mode)

4.1.1.3 Improvement in work efficiency

The work of a mini backhoe consists of heavy-duty work such as traveling, digging, and lifting and light-duty work such as gathering-in the soil and leveling work to finish the soil surface (Fig. 3). While the load on the engine is large in heavy-duty work, light-duty work requires speed even though the load is smaller. We tried to address a good balance between energy-saving and work efficiency with a focus on this point.

The hydraulic system mounted on RX-506 is a load-sensing hydraulic system which executes control to reduce the discharge amount of the hydraulic pump in response to a decrease in the engine speed (gain control).

Therefore, the fuel consumption is reduced when the engine speed is reduced. However, work efficiency also decreases since the discharge amount of the hydraulic pump is reduced. We thus improved the work efficiency when the engine speed was low by restoring the reduced amount of oil Q_1 due to decrease in engine speed to Q_2, which is the amount of oil before reduction (variable gain control). The mechanism of the variable gain control is described below. Fig. 4 shows the relationship between engine speed and amount of oil.

In the current model, control is executed so that the pressure difference between hydraulic pump discharge pressure signals P_{PS} and P_{LS} (LS differential pressure), and the sum of spring force F_{SPL} in LS regulator and gain differential pressure ΔG which is the differential pressure caused by the changes in engine speed (LS set pressure), becomes a constant value depending on the engine speed (gain control). Fig. 5 shows the conventional hydraulic circuit.

P_{PS} - P_{LS} = F_{SPL} + ΔG = constant
(LS differential pressure) (LS set pressure)

Fig. 6 shows the hydraulic circuit mounted on RX-506. In Standard Mode, the P_{ig} pressure is controlled in the direction in which the LS set pressure is lowered, before it is introduced into the LS regulator. This pressure is set in the same manner as when the engine speed is 2200 rpm in the current model.

On the other hand, in Eco Mode, the engine speed is limited to 1800 rpm by the ECU of this machine when Eco Mode switch is turned on, and the LS set pressure is increased as the P_{ig} pressure is returned to the tank via the variable gain solenoid valve. This P_{ig} pressure corresponds to the gain differential pressure which decreased in accordance with the limitation in engine speed. Variable gain solenoid valve switches between 2 stages; one to introduce the P_{ig} pressure into the LS regulator and the other to return it to the tank. As described above, variable gain control is a control capable of switching the gain differential pressure in 2 stages. This control suppresses the decrease in the discharge amount from the hydraulic pump even in Eco Mode in which the engine speed is reduced, and thus suppresses the decrease in the single-unit speed of the implement.

P_{PS} - P_{LS} = F_{SPL} + ΔG_{2200} ………………… Current model
= F_{SPL}' + ΔG_{2200} - P_{ig} ………… Standard mode
= F_{SPL}' + ΔG_{1800} ………………… Eco Mode

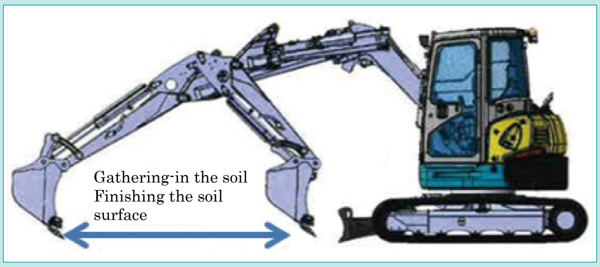

Fig. 3 Leveling Work

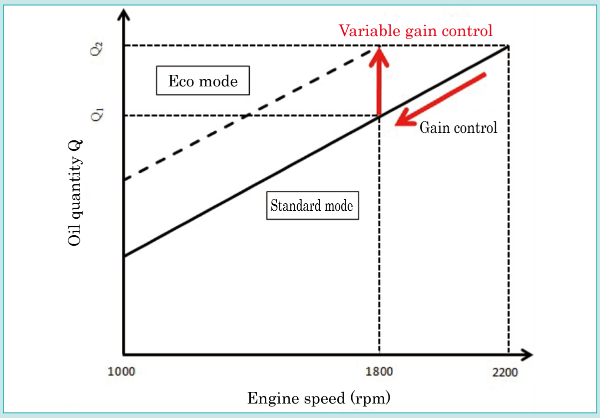

Fig. 4 Relation Engine Speed and Oil Flow

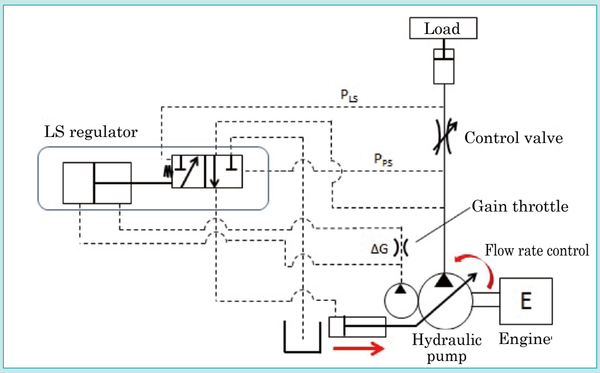

Fig. 5 Hydraulic Circuit of the Current Model

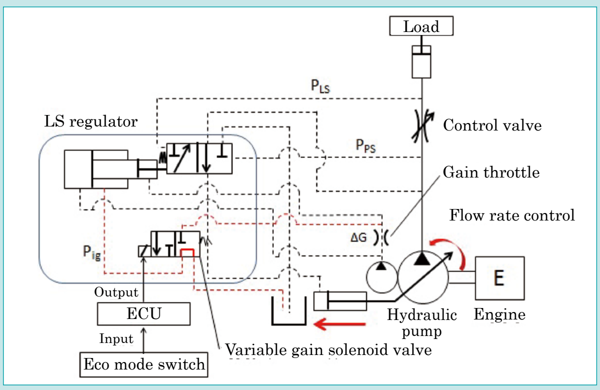

Fig. 6 Hydraulic Circuit of RX-506

In this development, we adopted a hydraulic regeneration circuit for scraping-in at the arm and boom lowering. A hydraulic regeneration circuit makes a part of the returned oil from the cylinder merge with the feeding side. It is therefore effective in leveling work, as it can speed up the machine with a small amount of oil when the load is small. We introduced KUBOTA original energy saving mode system and hydraulic regeneration circuit, and evaluated the work efficiency. We conducted work efficiency evaluation with the required period per work cycle of simulated digging work and leveling work. Table 3 shows the results of digging using the current model as the reference.

According to the results, Eco Mode delivers a higher work efficiency than Standard Mode with engine speed of 1800 rpm, and we were able to ensure the work efficiency during light-duty work which is equivalent to or higher than that of the current model.

Mounting the downsized engine, KUBOTA original energy saving mode system, and hydraulic regeneration circuit, we measured the fuel consumption per standard work cycle. Fig. 7 shows the results of comparing the fuel consumption per standard work cycle in RX-506, which was equipped with the energy-saving functions and an engine complying with the emission regulations, with those of the machines by our competitors, while using the current model as reference.

Based on the results, the fuel consumption reduction effect per standard work cycle in Eco Mode corresponded to 25% reduction compared to that of the current model, and 25% lower than those of the competitors. We were able to address our target of 20% reduction or more in fuel consumption per standard work cycle compared to the current model.

Table 3 Results of the Work Time

	RX-506		RX-505
	Standard mode	Eco Mode	Standard mode
Engine speed (rpm)	1800	1800	2250
Excavation	109%	106%	100%
Leveling work	100%	97%	100%

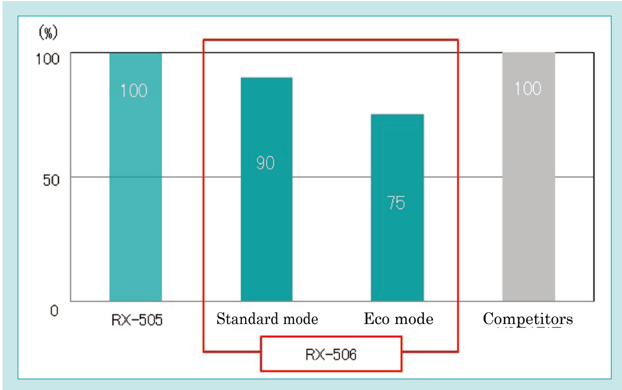

Fig. 7 Effect of Fuel Consumption Per Standard Work Cycle

4-2 Renewal of exterior design and reduction in running cost

4.2.1 New development of front implement

In the current model, the front hose had a routing in which it passed on the outside. There were also demands from the market for reducing the risk of damage due to the hose protruding outside and for incorporation into the interior in the same manner as the 3-ton class, which was released in advance, in terms of exterior design. Fig. 8 shows the front hose routing on the current model.

For RX-506, we established a path to route the front hose in the interior with some structural changes without reducing the strength of Booms 1, 2, and 3. As a consequence, we unified the appearance with the 3-ton class minimal swing radius machine which was released in advance with interior incorporation of the hose, and developed them into a series in addition to the renewal in external design. Fig. 9 shows the structure of the front implement, and Fig. 10 a comparison of the front hose routing between the current model and RX-506.

Since we were to establish a path for the hose in the cast steel part of Boom 1, which was a major strength member, in order to address interior incorporation, there was a concern that the strength would deteriorate with the cross-sectional coefficient decreasing by 10%. However, we ensured the quality by implementing strength estimation using analysis during the design stage as well as the following

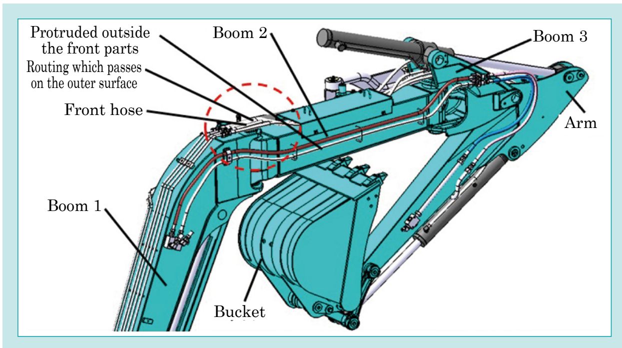

Fig. 8 Front Hose Route(RX-505)

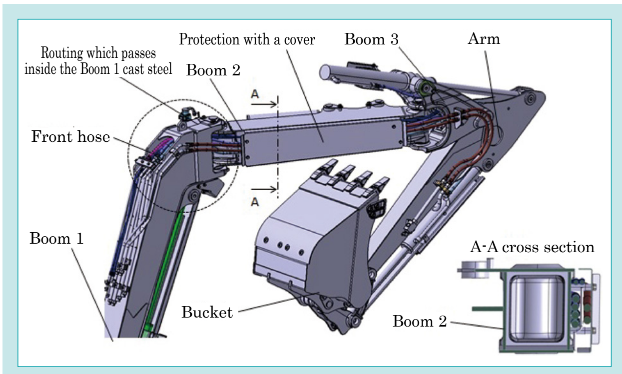

Fig. 9 Front Hose Route(RX-506)

tests. Fig. 11 shows the structures of Boom 1 in the current model and RX-506.

(1) Implementation of stress tests in each digging mode
(2) Turning lateral impact test in which a high stress is applied on the front parts
(3) Check on wear in hose and parts by changes in the front hose routing (practical endurance test and breaker test)

To clear the above three verification tests, we carefully built the products and parts, and addressed the interior incorporation of the front hose, which had not been possible with the current model.

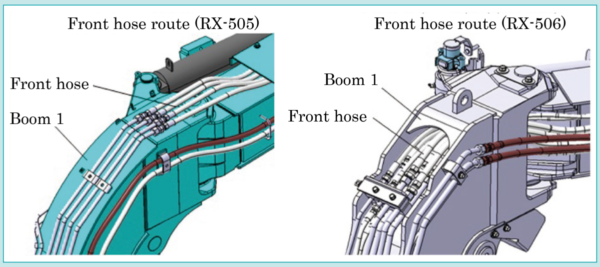

Fig. 10 Comparison of Hose Route RX-505 and RX-506

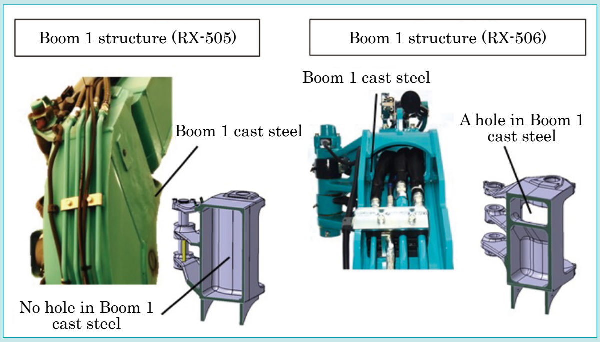

Fig. 11 Comparison of the Structure of Boom1 RX-505 and RX-506

4.2.2 Improvement in engine parts maintainability

In maintenance of the engine parts in the current model, it has been difficult to check and replace some parts, because the alternator and the compressor are arranged so that they cannot be directly reached when the operator accesses the parts from the rear hood.

In this development, we devised the layout in the narrow engine room so that the alternator and compressor were arranged on the rear side of the machine body, thereby addressing a one side maintenance structure (a structure which enables access and inspection of the parts that require daily inspection by only opening the rear hood) and improving maintainability. As a consequence, we were able to reduce the maintenance period by 12 minutes, and thus the running cost. Fig. 12 shows the layout of the engine compartment.

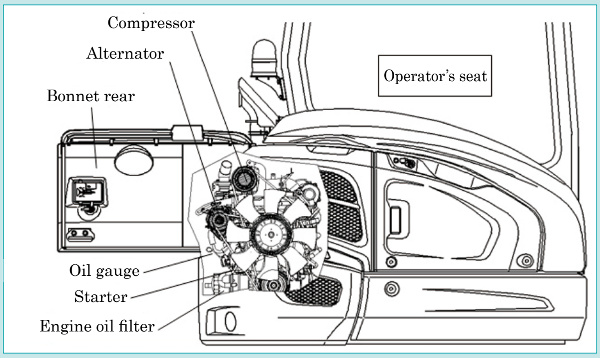

Fig. 12 Engine Room Layout (RX-506)

5. Conclusion

We were able to address the initial product concept for RX-506. Eco Mode, which addresses a good balance between reduction in fuel consumption and securing work efficiency, is a technology which is more useful in field work than the eco modes of our competitors. In addition, we renewed the exterior design with interior incorporation of the front hose, and unified the design with that of the 3-ton class minimal swing radius work machine, in which the front hose is already incorporated in the interior. This enabled us to develop a series for Kubota's ultra-small turning work machines. We were also able to improve the maintainability by developing the one side maintenance structure, and thus reduce the running cost.

In recent years, environmental problems have become more and more serious in the global scale, and emission regulations keep becoming more stringent. In general, fuel efficiency deteriorates when we comply with emission regulations. However, KUBOTA original energy saving mode system which was achieved in this development reduces fuel consumption and ensures work efficiency while complying with emission regulations. It can therefore contribute to the solution of environmental problems and infrastructure development, as it emits clean exhaust gas during machine operation, and is capable of completing work quickly while minimizing fuel consumption.

In the future, we hope to continue our contribution to global environmental problems and infrastructure establishment through developments of low-fuel consumption and high-performance machines by addressing further efficiency improvements in KUBOTA original energy saving mode system.

Contribution to SDG targets

7.3 Improvement in energy efficiency	Reduction in fuel consumption per standard work cycle by 25% in Eco Mode compared to the current model
11.a Support for connections between urban and rural areas	Contribution to domestic infrastructure development
12.2 Sustainable management and efficient use of natural resources	Reduction in fuel consumption per standard work cycle by 25% in Eco Mode compared to the current model

Literature

1) ISO7135 Earth-moving machine-Hydraulic excavators-Terminology and commercial specifications (2009)
2) Takatoshi Sugimoto, et al.: “Development of KX040-4, a Mini Backhoe for North America,” Kubota Technical Report No. 48 (2014)
3) Standard Division, Japan Construction Mechanization Association: JCMAS H020: 2010 Earth-moving Machinery Test methods for energy consumption - Hydraulic excavators

Utilization of Waste Polyvinyl Chloride in the Volume Reduction of Radioactive Waste Using Melting Technology

Water and Environment R&D / KUBOTA Environmental Service Co.,Ltd. / Kubota ChemiX Co.,Ltd.

Kubota's melting technology has been utilized for the recycling of various solid wastes, and it can also be applied as a volume- reduction (Cs separation) technology of radioactive waste by the addition of chloride. Since the Fukushima nuclear accident, we have carried out demonstration test as volume-reduction technology. Calcium chloride has been used as chloride, but if waste polyvinyl chloride (PVC) can be used, other effects can be expected and the recycling of vinyl chloride will be promoted. Therefore, in this report, melting plant test was conducted using waste PVC, and it was demonstrated that the Cs separation effect of waste PVC was as high as that of calcium chloride.

[Keywords]
Melting, Radioactive Waste, Volume Reduction, Waste Polyvinyl Chloride

Related SDGs

7 AFFORDABLE AND CLEAN ENERGY · 11 SUSTAINABLE CITIES AND COMMUNITIES · 12 RESPONSIBLE CONSUMPTION AND PRODUCTION · 3 GOOD HEALTH AND WELL-BEING · 14 LIFE BELOW WATER · 15 LIFE ON LAND · 16 PEACE, JUSTICE AND STRONG INSTITUTIONS · 17 PARTNERSHIPS FOR THE GOALS

1. Introduction

Kubota's melting technology can detoxify and recycle solid wastes such as incineration ash of domestic wastes (municipal wastes), industrial wastes and sewage sludge by melting them into a magma-like state in a high-temperature furnace at 1,300 to 1,400°C. Since the 1970s, 31 facilities have been introduced in Japan and utilized for environmental restoration, environmental conservation, and creating a recycling-based society, including illegally dumped waste treatment project in Teshima, Kagawa Prefecture (2003 to 2017, total treatment amount of 911,000 tons). Regarding the SDGs, Target 12.5 clearly states to "substantially reduce waste generation through prevention, reduction, recycling, and reuse" in relation to wastes. There are also many other closely related targets, and thus this technology is considered the one which can contribute directly to achieving the SDGs.

Since melting technology also has the function to separate alkali metal elements such as cesium thermochemically in the furnace, it can be applied to volume reduction process of radioactive wastes generated in the decontamination of Fukushima Daiichi Nuclear Power Plant accident. By adding a chloride agent to the radioactive waste and melting it, cesium (Cs), a radionuclide, can be changed into cesium chloride (CsCl) which volatilizes (chlorination volatilization) in the furnace. As the exhaust gas is cooled, CsCl is then condensed and precipitated in molten fly ash to be collected (Fig. 1).

We have conducted basic tests and plant tests repeatedly since 2011, and verified that Cs can be separated with high efficiency from various solid wastes[1].

While we had used calcium chloride ($CaCl_2$) as the volatilization accelerator (chloride agent) in our previous study[1], if we can use waste polyvinyl chloride (hereinafter referred to as "waste PVC") as the accelerator, we can expect not only the promotion of Cs volatilization but also the reduction of melting fuel usage and contributions to waste polyvinyl chloride recycling. As a result, we can make further contributions to achieving the SDGs.

In this report, in order to develop a process to recycle waste PVC as a volatilization accelerator in the melting treatment of radioactive waste, we conducted basic tests and plant tests to comparatively evaluate the effects of waste PVC and $CaCl_2$ as the volatilization accelerators.

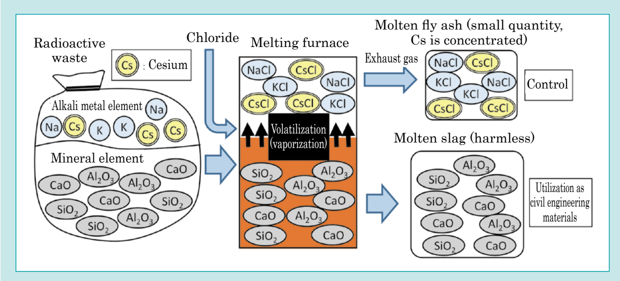

Fig. 1 Conceptual Diagram of Cs Separation Using the Melting Technique

2. Development concept and goals

2-1 Expected effects of waste PVC

Waste PVC is one of chlorinated organic compounds, so it has the properties of both chloride and organic substance. The following five effects are expected when waste PVC is used in the melting treatment of radioactive waste:

(1) Promotion of chlorination volatilization of Cs by contained chlorine

By reacting Cs contained in radioactive waste with the chlorine content of waste PVC, chlorination volatilization reaction will be promoted.

(2) Further promotion of chlorination volatilization by the combustion of organic substances contained

When waste PVC combusts, partial pressure of oxygen in the vicinity of the treated matter will decrease, making it easier for Cs to bind with chlorine than oxygen, so that chlorination volatilization of Cs is further promoted.

(3) Reduction in melting fuel consumption

Waste PVC will act as a substitute for melting fuel, reducing the use of fossil fuels such as natural gas and kerosene.

(4) Inhibition of solidification of radioactive waste

Since $CaCl_2$ is a highly hygroscopic and deliquescent substance used in snow-melting agents and so forth, there is a concern that problems such as stops in equipment due to excessive load caused by its adhesion and solidification may occur in the conveyor line after its addition. However, this risk can be minimized by using waste PVC.

(5) Contribution to waste PVC recycling

Vinyl chloride is produced in quantity of 1,706,000 tons/year (FY2017) to be used in pipes and joints, wire covering material, floor material, wallpaper and so forth[2)]. While material recycling (utilization as a material), chemical recycling (utilization as a chemical raw material), and thermal recycling (heat utilization) are promoted for waste PVC[2)], composite products with other materials are difficult to recycle, and further utilization is desired. Fig. 2 shows photographs of waste PVC (pulverized material) as examples. (B), (C) and (D) are difficult to recycle since the floor material in (B) also contains strings to increase the strength, the credit cards in (C) have paints, metals and so forth adhering on the surface, and the PVDC sheet in (D) has a high chlorine concentration.

If we could utilize these types of waste PVC as a volatilization accelerator in melting treatment, we would be able to improve the chemical recycling rate of waste PVC and further contribute to the achievement of SDGs.

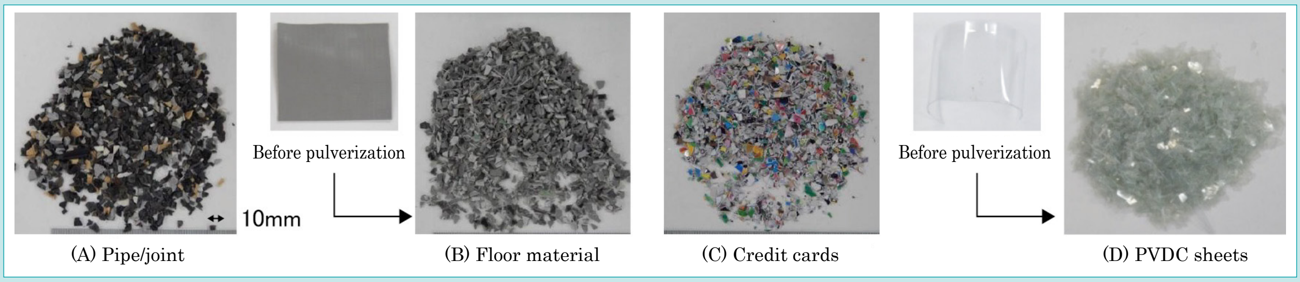

Fig. 2 Picture Examples of Waste PVC (Pulverized Material)

2-2 Development target value

In the melting treatment of radioactive waste, it is important that what percentage of Cs contained in the waste at the beginning can be volatilized and transferred to the molten fly ash. Therefore, our development goal was to achieve 95% or higher of Cs volatilization rate (ratio of Cs which is volatilized by melting treatment), the equivalent level as $CaCl_2$, in plant tests where waste PVC is added as the volatilization accelerator.

3. Development outcomes

3-1 Basic tests

3.1.1 Test method

As a simulated radioactive waste (hereinafter referred to as "simulated waste"), we assumed incineration residue of combustible decontamination waste, and used incinerated ash from a woody biomass power plant (fluidized bed type) with addition of 0.5% non-radioactive Cs_2CO_3 reagent. Table 1 shows its composition. Basicity (CaO/SiO_2 weight ratio) and Cl concentration, which affect the Cs volatilization rate considerably, were 0.29 and 0.67%, respectively. Both values were lower than those of the municipal solid waste incineration ash, for which there are many records of treatment. As waste PVC, we used recycled waterworks pipes from within the city, which were pulverized to sizes smaller than 2 mm. Table 2 shows its composition. The value of inorganic ash content was 1.3%, and the organic matters had a composition which generally matched the chemical formula of vinyl chloride.

Table 3 shows the test conditions. We added $CaCl_2$ or waste PVC so that the same Cl concentration (7%) was delivered, and prepared a total of 22 conditions by varying the basicity in 11 different levels with addition of $Ca(OH)_2$.

The test procedures are described below:

(1) The sample is loaded into a porcelain boat (Fig. 3).

(2) The sample is inserted into an electric muffle furnace (Fig. 4) which is adjusted to 1,350°C in advance to be heated for 15 minutes.

(3) The sample is removed from the furnace and allowed to cool naturally in air.

(4) The Cs volatilization rate is calculated based on the weights and Cs concentrations before and after heating to be evaluated by comparison.

Table 1 Composition of Simulated Waste

Item	SiO_2	CaO	Al_2O_3	FeO	Na	K	Cs	Cl	S	Basicity
Unit	%(dry)	%(dry)	%(dry)	%(dry)	%(dry)	%(dry)	%(dry)	%(dry)	%(dry)	–
Analysis value	48.0	13.8	14.9	5.7	2.5	3.8	0.46	0.67	0.44	0.29

Table 2 Composition of Waste PVC

Item	Inorganic substance	Organic substances					
	Ash content	C	H	N	O	S	Cl
Unit	%(dry)	%(dry)	%(dry)	%(dry)	%(dry)	%(dry)	%(dry)
Analysis value	1.3	38.7	4.6	<0.01	7.1	0.02	48.3

Table 3 Conditions of Basic Test

No.	Classification	Ratio mixed in sample by weight				Sample properties after mixing	
		Waste %	$Ca(OH)_2$ %	Waste PVC %	$CaCl_2$ %	Basicity –	Cl concentration %(dry)
1	Addition of waste PVC [11 Conditions]	88→38 [5% increments]	0→50 [5% increments]	12	–	0.3→2.2	7
2	Addition of $CaCl_2$ [11 Conditions]	90→40 [5% increments]	0→50 [5% increments]	–	10	0.4→2.4	7

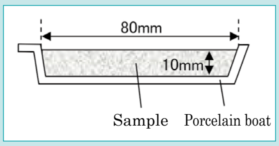

Fig. 3 Filled State of the Sample

Fig. 4 Picture of an Electric Furnace

3.1.2 Test results

Fig. 5 shows the relationship between basicity and Cs volatilization rate under each condition with addition of waste PVC or $CaCl_2$. Cs volatilization rate with waste PVC addition was equivalent to or higher than the values when $CaCl_2$ was added, regardless of the basicity, indicating that waste PVC had the equivalent Cs volatilization promotion effect as $CaCl_2$. Our development target value was achieved with Cs volatilization rate reaching 95% or higher, when basicity was 0.74 or higher.

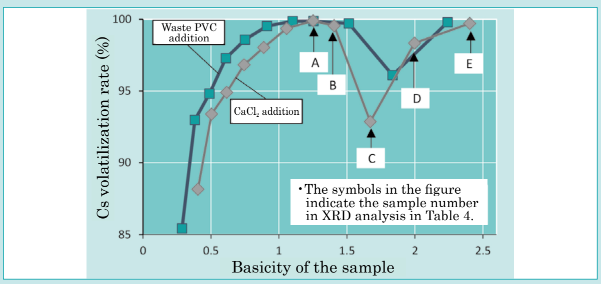

Fig. 5 Relationship Between the Basicity of the Sample and Cs Vaporization Ratio

Although Cs volatilization rate was higher when the basicity was higher regardless of the type of chloride, our results showed that Cs volatilization rate slightly decreased in the basicity range from 1.5 to 2. It is assumed that Cs volatilization rate grew higher as the basicity was higher because more CaO, which has ionic bonding, was contained in slag as its basicity was higher, causing the Si-O covalent bond to be weaker (as the Si-O bond distance became longer), and weakening the slag structure and the Cs capturing force as a consequence.

As to the fact that Cs volatilization rate slightly decreased in the basicity range of 1.5 to 2, we conducted an X-ray diffraction analysis on the Slags A to E shown in Fig. 5 and studied their crystal structures. Table 4 shows the results of the analysis. Slag usually forms amorphous glass due to rapid cooling. However, it was assumed that Cs volatilization rate decreased as a part of Cs atoms were taken into the crystals, since the slag had crystallized at basicity of 1.5 and higher, and KCl crystals containing K, which has a high tendency for isomorphic substitution with Cs, were identified albeit in a trace amount in Slag C.

Table 4 XRD Analysis Results of Slag A to E [$CaCl_2$-added Condition]

Item		A Basicity 1.2	B Basicity 1.4	C Basicity 1.7	D Basicity 2.0	E Basicity 2.4
Degree of crystallinity (fraction crystallized)		Amorphous	60%	90%	95%	95%
Identified crystalline phase	$Ca_2(Al_{0.65}Mg_{0.35})(Al_{0.65}Si_{1.35})O_7$	−	◎	−	−	−
	Ca_2SiO_4	−	○	○	◎	◎
	$Ca_2(Al_{0.92}Mg_{0.08})(Al_{0.92}Si_{1.08})O_7$	−	−	◎	○	−
	KCl	−	−	△	−	−
	$Ca_{12}Al_{14}O_{32}Cl_2$	−	−	−	◎	−
	$Ca_{14}Mg_2Si_8O_{32}$、$Ca_2Al_2SiO_7$	−	−	−	○	−
	$Ca_{12}Al_{14}O_{33}$	−	−	−	−	○

◎ : Present (in a specially large quantity),
○ : Present,
△ : Trace amount,
− : Not identified

3-2 Plant verification tests

3.2.1 Test conditions

We conducted the tests using a rotary surface melting test plant (3 t/day, furnace inner diameter 1.8 m). Fig. 6 shows the overall flow of the plant, and Fig. 7 the structure of the rotary surface melting furnace. The melting furnace has a double cylinder structure consisting of the outer cylinder and the inner cylinder, and the material is fed into the supply cylinder between them. The outer cylinder rotates slowly in the horizontal direction at 0.5 to 1 rph while the fed material is supplied to the main combustion chamber from the entire circumferential direction in concurrence with it to be melted into slag. The slag flows down toward the center of the furnace, falls into the slag pit water to be rapidly cooled, and is discharged. Cs volatilized in the furnace becomes a part of the combustion exhaust gas, and is introduced into the exhaust gas treatment equipment, where it is cooled to 200°C or lower by water spraying in the gas cooling tower. It condenses and solidifies to form molten fly ash, and is collected and discharged by the bag filter (hereinafter referred to as “BF”). BF has two stages, and only the molten fly ash is collected in No. 1 BF as a small amount of calcium carbonate ($CaCO_3$), a filter cloth protective agent, is blown into it. In No. 2 BF, acidic gas is neutralized as slaked lime ($Ca(OH)_2$), an alkali agent, is blown in to collect neutralized substances. The purpose of this two-stage BF application was to demonstrate the reduction in the amount of No. 1 BF ash, which is the Cs concentrate, and the recycling and reuse of No. 2 BF ash as a volatilization accelerator.

The simulated waste was prepared with composition adjustment by addition of 15% Al_2O_3 and 5% Fe_2O_3 to the incinerated ash from a biomass power generation (fluidized bed type) facility which was different from the facility used for basic tests. Table 5 shows the composition. Its basicity was 0.07 and Cl concentration 0.09%, which were lower than the values of the simulated waste in basic tests. As waste PVC, we used factory residue of pipes and joints which were pulverized to sizes smaller than 10 mm. Table 6 shows the composition. Its ash content of inorganic substances was quite high at 19.8% due to $CaCO_3$ which was used as the filler, and the composition of organic substances generally matched the chemical formula of vinyl chloride. We added nonradioactive Cs_2CO_3 reagent to the material to be fed so that Cs content was 0.2% of the material.

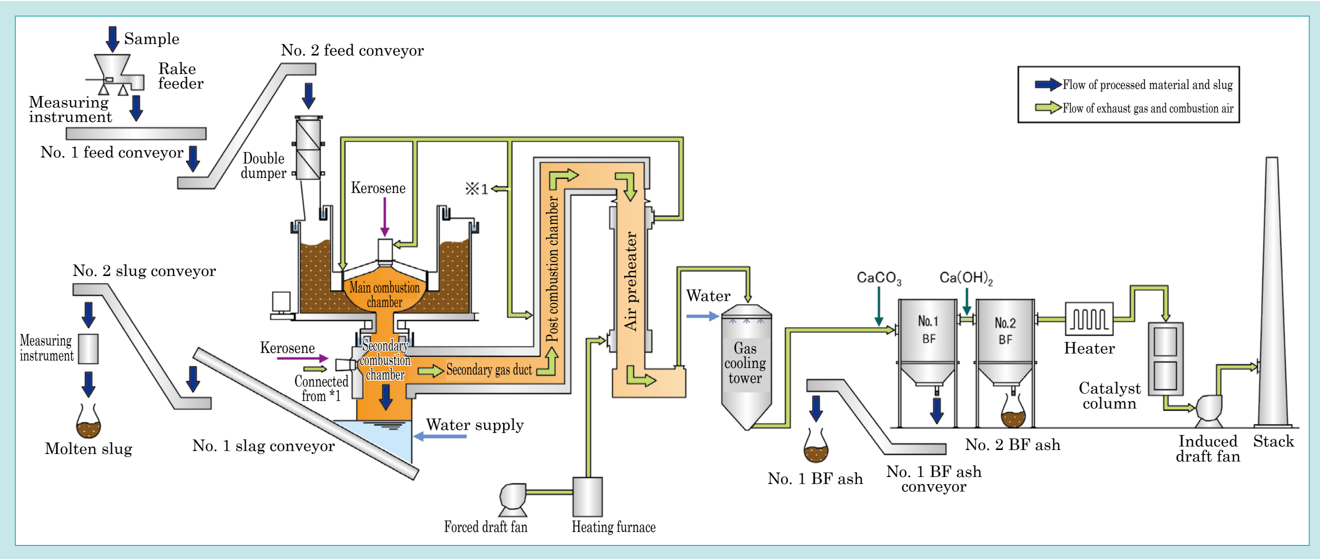

Fig. 6 Flow of the Melting Test Plant

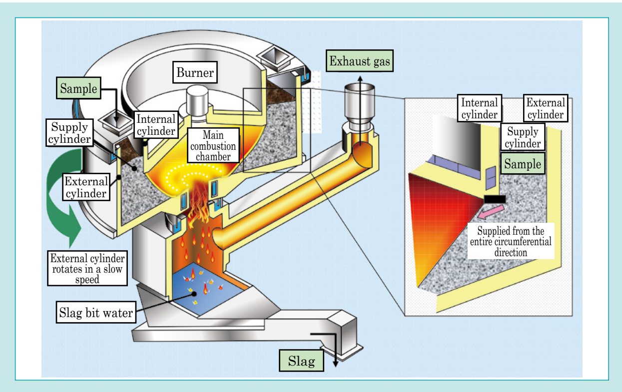

Fig. 7 Structure of a Kubota Melting Furnace

Table 7 shows the test conditions. We prepared 2 conditions by adding waste PVC and $Ca(OH)_2$ reagent or $CaCl_2$ reagent and $Ca(OH)_2$ reagent to the simulated waste to adjust the basicity to 0.7 and the Cl concentration to approximately 7%. The fed material was mixed by first adding the biomass power generation incinerated ash, Al_2O_3, and Fe_2O_3 in a pan-type kneader, followed by addition of Cs_2CO_3 solution by spraying to prepare the simulated waste. The simulated waste was then mixed with waste PVC or $CaCl_2 \cdot 2H_2O$ and $Ca(OH)_2$ in a kneader.

Table 5 Composition of Simulated Waste

Item	SiO_2	CaO	Al_2O_3	FeO	Na	K	Zn	Pb	Cl	S	Basicity
Unit	%(dry)	%(dry)	%(dry)	%(dry)	%(dry)	%(dry)	%(dry)	%(dry)	%(dry)	%(dry)	–
Analysis value	66.0	4.6	16.8	6.1	0.4	2.2	0.016	0.003	0.09	0.21	0.07

Table 6 Composition of Waste PVC

Item	Inorganic substance		Organic substances					
	Ash content	$CaCO_3$	C	H	N	O	S	Cl
Unit	%(dry)	%(dry)	%(dry)	%(dry)	%(dry)	%(dry)	%(dry)	%(dry)
Analysis value	19.8	16.1	34.2	3.2	<0.01	9.0	0.08	33.8

Table 7 Conditions of Plant Test

No.	Classification	Ratio mixed in sample by weight					Sample properties after mixing	
			Cs	Reagent				
		Simulated waste %	Cs_2CO_3 %	$Ca(OH)_2$ %	Waste PVC %	$CaCl_2$ %	Basicity –	Cl concentration %(dry)
1	Addition of waste PVC	52.1	0.2	30.0	17.7	0	0.7	7
					47.7			
2	Addition of $CaCl_2$	59.8	0.2	25.0	0	15.0	0.7	7
					40.0			

3.2.2. Test results

Table 8 shows the outline of the operation data, and Fig. 8 the temperature trends in the exhaust gas from each part under condition in which the waste PVC was added. While we executed steady operation for approximately 9 hours under the condition in which waste PVC was added, the operating conditions for melting remained stable. The temperature of the main combustion chamber remained at a slightly low value of around 1,250°C as the melting point of the fed material was low and the meltability of the slag was high. The amount of No. 1 BF ash in which Cs became concentrated was 13.2 kg/h, which corresponded to approximately 9% of the amount of fed material, and approximately 17% of the amount of simulated waste. Furthermore, in the condition in which $CaCl_2$ was added, solidification was observed in the sample which was cured for a long period after reagent mixture (Fig. 9), whereas this phenomenon was not observed under the condition in which waste PVC was added. It was thus indicated that PVC had an effect to suppress solidification of the fed material.

Fig. 10 shows the volatilization rate of each element in the melting furnace, and Table 9 the composition of the fed material and the product (slag, No. 1 BF ash) under the condition in which waste PVC was added. Volatilization behavior of each element under the condition in which waste PVC was added was similar to that under $CaCl_2$ addition, and alkali metals and heavy metals volatilized considerably well with their concentrations in No. 1 BF ash resulting higher than those in the fed material, while volatilization rate was low for mineral elements and nearly the entire contents were transferred to slag. Cs volatilization ratio was 97.4%, which exceeded the development target value 95%, and was equivalent to the rate under condition in which $CaCl_2$ was added. We were therefore able to verify in the plant test that waste PVC had the same Cs volatilization promoting effect as $CaCl_2$.

Fig. 9 Picture of Solidified Feed [$CaCl_2$-added Condition]

Table 8 Outline of Operation Data

Item		Unit	Addition of waste PVC		Addition of $CaCl_2$	
			Min. to Max.	Average	Min. to Max.	Average
Temperature	Main combustion chamber	℃	1,235～1,274	1,260	1,183～1,253	1,223
Temperature	AH outlet	℃	596～665	629	530～620	584
Temperature	No. 1 BF inlet	℃	188～215	196	171～186	176
Temperature	No. 2 BF outlet	℃	137～145	141	140～146	145
Gas concentration	Secondary chamber O_2	%	3.3～5.4	4.5	2.1～8.3	5.3
Gas concentration	Secondary chamber CO	%	0.0～0.0	0.0	0.0～0.0	0.0
Gas concentration	Secondary chamber CO_2	%	11.8～13.3	12.4	9.8～13.8	11.8
Solid content	Fed material	kg/h(dry)	148.2		188.9	
Solid content	Slag	kg/h(dry)	118.9		165.2	
Solid content	No. 1 BF ash	kg/h(dry)	13.2		17.3	

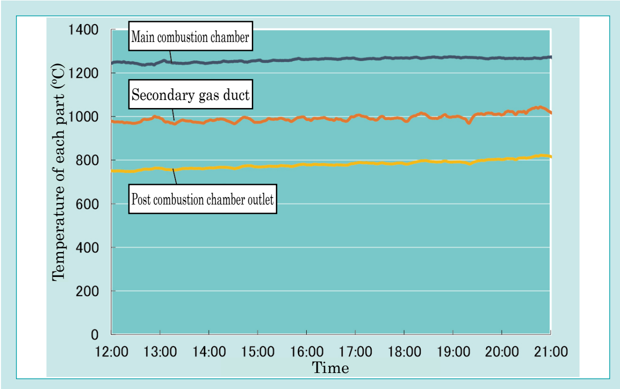

Fig. 8 Temperature Trend of Flue Gas [Waste PVC-added Condition]

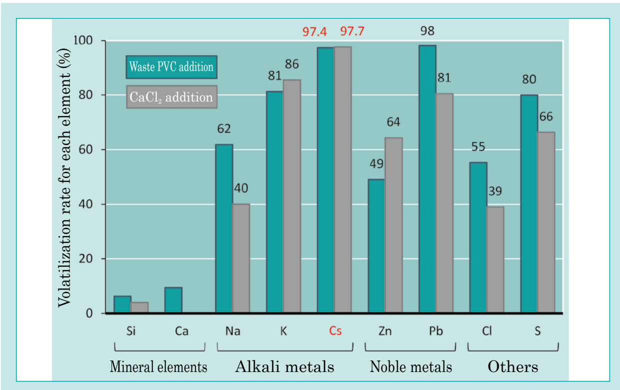

Fig. 10 Volatilization Ratio of Each Element in the Melting Furnace

Table 10 shows the properties of the exhaust gas at No. 1 BF inlet and No. 2 BF outlet under the condition in which waste PVC was added. In this system, hydrogen chloride (HCl) gas is generated at a relatively high concentration due to thermal decomposition of waste PVC, as waste PVC is actively added to volatilize Cs by chlorination volatilization. Therefore, the HCl concentration at No. 1 BF inlet (value converted to 12% O_2) was quite high at 1,860 ppm. Since we execute neutralization and removal of HCl by spraying slaked lime at No. 2 BF inlet, the HCl concentration at No. 2 BF outlet was reduced to 26 ppm.

Since there was a concern that dioxins (hereinafter referred to as "DXNs") may be generated as a result of waste PVC addition, we measured the concentration of DXNs in the exhaust gas at the catalyst column outlet and in the product. Fig. 11 shows the results. Although we did not execute adsorption treatment of DXNs with activated carbon spraying at BF in this test, the concentration of DXNs was 0.033 ng-TEQ/Nm^3 in the exhaust gas at the catalyst column outlet and 0.066 ng-TEQ/g and 0.033 ng-TEQ/g in the BF ash. These values were well below the exhaust gas standard value of 0.1 ng-TEQ/Nm^3 (new constructions, 4 t/h or higher) and the dust discharge standard value of 3 ng-TEQ/g, respectively. It is surmised that DXNs can be dealt with in a similar method to the conventional melting of municipal waste incinerator ash, by taking measures such as suppression of re-synthesis with rapid cooling of exhaust gas, adsorption treatment with activated carbon spraying at BF, and oxidation decomposition at the catalyst column even when waste PVC is added.

Table 9 Composition of Feed and Product
[Waste PVC-added Condition]

Item	Unit	Addition of waste PVC		
		Fed material	Slag	No. 1 BF ash
Si	%(dry)	19.6	22.9	<0.1
Ca	%(dry)	18.7	21.1	23.9*
Na	%(dry)	0.54	0.26	5.6
K	%(dry)	0.83	0.19	6.6
Cs	%(dry)	0.18	0.0060	2.1
Zn	mg/kg(dry)	63	40	1,100
Pb	mg/kg(dry)	1,000	23	7,800
Cl	%(dry)	6.0	3.4	12.3
S	%(dry)	0.12	0.03	0.41

*Ca in No. 1 BF ash was high because $CaCO_3$ was sprayed as the filter cloth protective agent at No. 1 BF inlet.

Table 10 Properties of the Flue Gas [Waste PVC-added Condition]

Item		Unit	Addition of waste PVC	
			No. 1 BF inlet	No. 2 BF outlet
Exhaust gas (wet)		Nm^3/h	1,300	2,400
Exhaust gas temperature		℃	201	142
Dust	O_2 12%	g/Nm^3	3.2	<0.002
SOx	O_2 12%	ppm	3	2
NOx	O_2 12%	ppm	21	19
HCl	O_2 12%	ppm	1,860	26

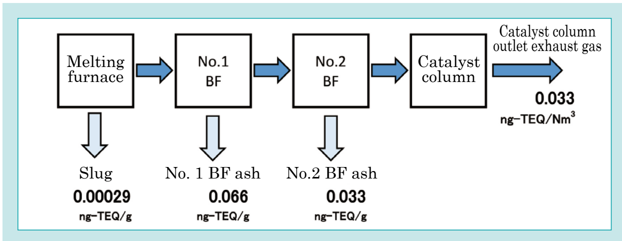

Fig. 11 DXNs Concentration of Flue Gas and Products
[Waste PVC-added Condition]

4. Conclusion

We conducted basic tests and plant tests to compare and evaluate the effects of waste PVC and $CaCl_2$ for the purpose of utilizing waste PVC as a Cs volatilization accelerator in the melting treatment of radioactive waste. As a consequence, we found that the Cs volatilization rate when waste PVC was added was as high as that of $CaCl_2$ addition, and were able to demonstrate that waste PVC had the same effect as $CaCl_2$.

Since 2011, when Fukushima Daiichi Nuclear Power Plant accident occurred, Kubota Group has continued developments and demonstrations of melting technology as a method for waste volume reduction. Our efforts resulted in an order reception for “Waste Treatment Project 1 at Futaba-machi Volume Reduction Facility (intermediate storage facility)” in March 2018. In addition to the fact that execution of this project itself can greatly contribute to the reconstruction of Fukushima and achievement of the SDGs, we will be able to make further contribution to the achievement of the SDGs with promotion of PVC recycling if waste PVC can be utilized. At present, Kubota Environmental Service Co., Ltd. is in the process of designing and manufacturing the system, and we are determined to develop the system by gathering the wisdom of the entire group so that the project can be carried out smoothly.

Contribution to SDG targets

7.3 Improvement in energy efficiency	Reduction in unit fuel consumption for melting by approximately 30% with utilization of waste plastic
11.6 Improvement in urban environment through strengthening of waste management and so forth	Purification of 911,000 tons of illegally dumped waste in Teshima, Kagawa Prefecture
12.5 Prevention and reuse of waste	Contribution to recycling of waste and sewage sludge at 31 facilities in Japan

Literature

1) For example, Kamata, et al.: “Plant Demonstration Test on the Thermal Separation of Cesium by Melting Technique from Soil” Journal of the Society for Remediation of Radioactive Contamination in the Environment, Vol. 3 - No. 2, (2015), pp. 49-64
2) Vinyl Environmental Council Website http://www.vec.gr.jp/index.html, (date of reference: Sept. 27, 2018)

Development of the Compact Johkasou KRZ Type for Large Scale Facilities

Research & Development Group

The installation of Johkasou has spread mainly outside sewer areas, and domestic wastewater from large-scale buildings such as condominiums, hospitals, factories and public facilities is mainly purified by FRP large-scale Johkasou (For 51 people or more). Demand for large-scale Johkasou totals about 1,500 cases / year in Japan, and it is also developing in Southeast Asian countries such as Vietnam, Myanmar etc. One of the biggest demands of customers is compactness. In this paper, we will report on the development of the Kubota Johkasou KRZ type, which achieved the industry's smallest model in medium- and large-scale Johkasou with equalization tanks, incorporating KUBOTA's proprietary technology, maintaining the same performance as conventional models.

[Keywords]
Johkasou, Downsizing, Energy Saving, Renewal, Southeast Asia

Related SDGs

1. Introduction

In the past, Kubota developed compact Johkasou "Z Series," which included Johkasou KZ type for small scale facilities (for 5 to 10 people), Johkasou HCZ type for medium scale facilities (for 12 to 50 people), and Johkasou KTZ type for large scale facilities (for 51 to 2,380 people),[1] and has put them on the market. The KRZ type introduced in this report is the smallest Johkasou for large scale facilities in the medium- to large-scale range in industry with a flow rate adjustment tank, which can accommodate tanks for up to 51 to 10,000 people by expanding the size of the tank for people from that of KTZ type.

While various countries around the world are making efforts to reduce greenhouse gas emissions in various fields, the Ministry of the Environment in Japan has established a subsidy system in relation to the "Project to promote introduction of energy-saving medium and large scale Johkasou systems" and is promoting the replacement of existing large scale Johkasou which conform to the old structural standard with the new types of Johkasou with high energy-saving effect. On the other hand, it is necessary to secure a new installation space for the newly constructed Johkasou because the existing Johkasou must be renewed while continuing treatment of the incoming sewage. Since KRZ tank is compact and can employ a hybrid specification (described later) which can utilize the existing RC tank (reinforced concrete construction), it is possible to renew the existing facility while effectively using it with "small lot installation" and also contribute to the reduction in construction cost even if it is newly installed.

In overseas, KRZ type can also contribute to countries where sewage treatment establishment is slow, including participating countries in Asia Wastewater Management Partnership (AWaP).

We have sold Johkasou for large scale facilities to government-affiliated hospitals in Vietnam from the viewpoint of preventing secondary infection from hospital wastewater. Application of KRZ system is also expected to reduce construction costs and promote more introductions. In Southeast Asia, efforts are being made to strengthen water quality regulations in resort areas and so forth, and KRZ type is expected to play an active role in such areas.

2. Description of the technology

2-1 Characteristics of the technology

KTZ type, which is already on the market, has a high capability of capturing and removing suspended solids (SS) through two-stage filtration (first filtration tank and carrier filtration tank), and can set the organic compound pollution load for the biological reaction tank (carrier flow tank) to a high value with adoption of a sponge carrier. We also adopted these technologies in KRZ type (Fig. 1). While the current model (K-HC-R) adopted a mechanical automatic screen for the purpose of removing impurities, we obtained a good balance between lifecycle cost reduction with reduction in the number of facilities and SS removal performance improvement in KRZ type by changing the screen to a solid-liquid separation tank, which can remove not only the impurities but also suspended solids (Fig. 2). By improving the performance of the latter stages of the treatment processes, we were able to increase the instantaneous transfer amount of water from the flow rate adjustment tank, and reduce as a consequence the capacity of the flow rate adjustment tank to 70% compared to the current model and the total capacity to 83% (with a tank for 300 people, 60 m^3/day, 12-hour discharge, BOD: 200 mg/L).

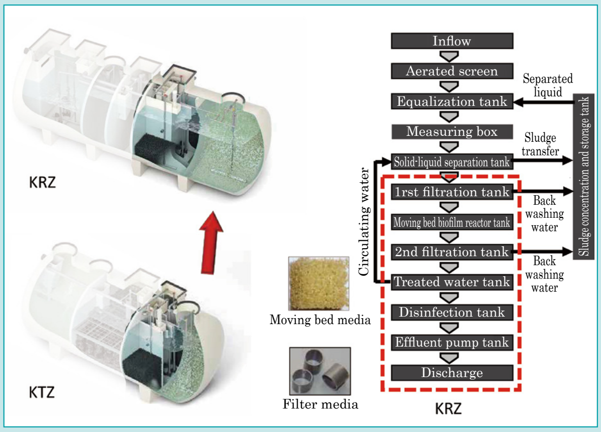

Fig. 1 Adopted KTZ Technology After the 1st Carrier Filter Tank.

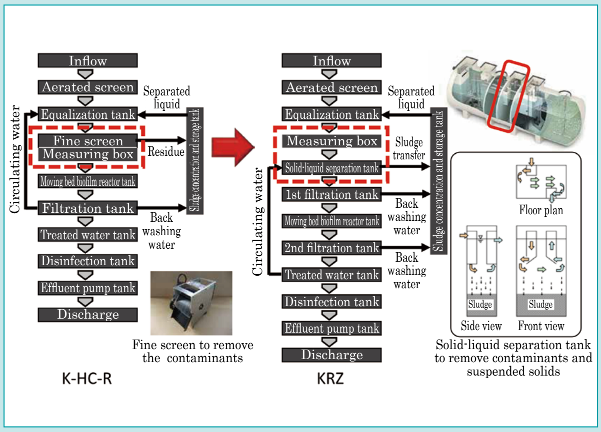

Fig. 2 Change from the Fine Screen to the Sedimentation Separation Tank.

2-2 Selling points

(1) Hybrid specification

We have lined up products with Kubota's original hybrid specification, which combines not only FRP but also RC and FRP tanks. This makes it possible to combine a deep RC flow rate adjustment tank with an FRP tank, making it possible to save space even in large scale facilities. The cost burden for the customer can be reduced dramatically when an RC Johkasou with aging facilities is to be renewed, as the existing RC tank can be utilized as the flow rate adjustment tank.

(2) Compatible with KSIS

By setting up in KRZ type the standard configuration for Kubota Smart Infrastructure System (KSIS), which can monitor the operation status via the internet, we have made it possible for the customers to select whether to install remote monitoring on Johkasou ahead of our competitors. With the adoption of KSIS, it is possible to check the operating conditions at any time from any place by using an information terminal such as a smartphone, thus providing our customers with a sense of security.

3. Conclusion

With market introduction of the KRZ type, our lineup of compact products is now capable of meeting a wide range of customer needs, in addition to KTZ type introduced in the previous report[1]. In particular, the total cost (product price and construction price) is important in expanding the application of the system to Southeast Asian countries such as AWaP participants.

The compactness of the product is effective not only from the viewpoint of reducing construction costs but also from the viewpoint of reducing the transportation costs associated with export. We intend to continue to contribute to the elimination of untreated wastewater discharge in the concerned countries.

Contribution to SDG targets

3.3 Eradication of communicable diseases and response to infectious diseases	Contribution to the development of domestic wastewater treatment facilities at more than 1,000 hospitals in Vietnam
6.3 Improvement of water quality through reduction, recycling and so forth of untreated wastewater	Contribution to the establishment of domestic wastewater treatment facilities in more than 14 countries in the world

Literature

1) Kouichi Fujii and Nobuhiko Nishikawa: "Development of Compact Johkasou KTZ type for Large Scale Facilities," Kubota Technical Report, No. 51, (2018), pp. 108-109