For Earth, For Life
Kubota

KUBOTA TECHNICAL REPORT

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Our Efforts to Address the SDGs

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

What are the SDGs?

These are 17 goals set jointly by the nations around the world as issues to be tackled cooperatively.

The goals were adopted at the United Nations Summit in 2015 with 2030 set as the target for their achievement.

"Sustainable Development Goals" is abbreviated as SDGs, which is translated as “Jizokukanona Kaihatsu Mokuhyo” in Japanese.

Association between the published articles and SDGs

Primarily related field		Closely related: ★ Related: ● / Published article
Food	Water Environment	
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■		Development of Green Soybean Combine Harvester
■		Development of Corn Harvesting Header CH70 for DC70 Combine Harvester
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	■	Development of the Mini Excavator RDL3 Series for European Market
■		Development of Slope Grass Cutter “GC-M500”
	■	Development of Micro Flow Rate NX Feeder
	■	Development of Water Work Information System for Water Pipe Construction
	■	Development of Highly Accurate Method for Predicting the Degree of Deterioration in Water Pipes
	■	Development of Manhole Pump AI Abnormal Operation Detection System
■	■	Development of “WATARAS” (LTE-M), Water Remote Management System in Paddy Fields without Gateway Device
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	■	Introduction of Technique Effectively Using Byproduct Salt in a Landfill Disposal Site

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

	SDG goals																
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An "Essentials Innovator for Supporting Life," Committed to a Prosperous Society and Cycle of Nature

President and
Representative Director
Yuichi Kitao

Due to economic stagnation caused by the spread of infections with COVID-19, our company's business, too, faced a dire situation. However, thanks to our customers and all our other stakeholders involved in our business, we managed to get through those difficult times. I feel this was a period in which we firmly reaffirmed our recognition that Kubota's businesses are essential and necessary for a great number of people even amidst the COVID-19 crisis.

In 2021, we launched our newly formulated long-term vision "GMB2030." As environmental issues, such as climate change and oceanic pollution, natural disasters and pandemics, population and resources problems, as well as issues in world politics, are complicatedly intertwined, social issues are becoming increasingly difficult. I had come to have a sense of crisis that if society continued as it currently was, society would not be able to go on eternally. But I now feel strongly that the COVID-19 crisis has made it a common understanding worldwide.

GMB2030 was established as a guidepost to show what Kubota should do to deal with various issues that may arise over the next ten years in order to build a sustainable society.

Becoming an "'Essentials Innovator for Supporting Life,' Committed to a Prosperous Society and Cycle of Nature," which is the type of company Kubota is aiming to be in 2030 as envisioned in GMB2030, means that Kubota must transform itself from being a company that mainly engages in the sale of products and after-sales services for those products to being a company that can offer comprehensive solutions that can solve customers' problems, from upstream all the way to downstream. By achieving this transformation, it is our hope that Kubota will contribute to building a new, enriched and sustainable society; in other words, achieving SDGs (17 sustainable development goals) in the areas of "food, water, and the environment."

In this issue, No. 55 of the Kubota Technical Report, readers will find descriptions of Kubota's technologies that are making contributions in the areas of "food, water, and the environment." In the area of "food," the state of agriculture, which is closely connected with local culture and climate, differs greatly for each region around the world. For example, in India, with the largest market for tractors in the world, tractors must haul grain or transport people in the off-season, so greater importance is placed on multipurpose functionality than on performance in cultivated fields. Furthermore, dry-field farming requires different functions for each type of crop, and mowing, which is labor intensive, must be done frequently. This report describes research and development results produced by listening thoroughly to the voices of the people at various farming worksites all over the world.

In the area of "water," Japan is facing such issues as the updating of water infrastructure, improving the performance of water treatment facilities, and countermeasures to deal with weather-related disasters, such as floods and violent wind and rain storms. Globally, there are important issues such as access to safe drinking water and the spread of water treatment facilities. This report describes the deterioration evaluation and streamlining of installation management of water pipes; membrane bioreactor, which makes it possible to increase sewage water processing capacity without enlarging the existing sewage treatment facility; manhole pump management that makes use of AI; and overseas cases, with the introduction of a water treatment facility in Myanmar as an example.

In the area of "the environment," the use of methane fermentation in waste treatment, which contributes to the reduction of CO_2 emissions by generating electricity from biogas; and engines and construction machinery that are compliant with exhaust gas regulations; and other topics are described.

It is impossible to create truly useful products or solutions without understanding the site where they will be used. The hands-on approach, which has been continuously handed down throughout Kubota's R&D since the company was founded, is now being put into practice on a global scale. This hands-on approach is indispensable not only for grasping the immediate needs but also for forecasting the future. It is my hope that we will contribute to building a sustainable society by creating new value through innovation, which is necessary for changing society, and realizing a prosperous society and cycle of nature on a global scale.

In the spirit of "On Your Side," which calls for standing by our customers' side, finding the issues that concern our customers, and delivering success to our customers, the entire Kubota Group will strive to work together as "One Kubota." I would be deeply grateful for your continued support as always in the future.

Development of Tractors for Local Production in India

Compact Tractor Engineering Dept./Materials & Castings Center
Analysis Center/KUBOTA Research and Development Asia Co., Ltd

Kubota started selling MU series tractors to India in 2015 with the MU5501 followed by the MU4501 in 2017, but at the time, Kubota did not have a production base in India and was exporting tractors from its plant in Thailand. As a result, parts procurement and logistics costs were reflected in the sales price, making the products more expensive than those of local manufacturers despite their good performance. Given these circumstances, Kubota established a tractor manufacturing company in India in 2019 as a joint venture with Escorts Limited, a major Indian tractor manufacturer, and started production of MU4501 tractors at the Indian plant in 2020. In this paper, we will focus on the technologies, especially transmission parts, to maintain the quality level cultivated through the development of tractors for local production in India, and to procure and produce these parts locally in India.

【Key Word】
Tractor, Multi-purpose, India, Material Evaluation, Noise Analysis

Related SDGs

1. Introduction

Kubota started selling multipurpose tractors, MU series tractors applicable to varied purposes including towing to India, the largest market of tractors in the world, in 2015 with the MU5501 followed by the MU4501 in 2017. At that time, Kubota did not have a production base in India and was exporting tractors from its plant in Thailand. Moreover, parts procurement centers on Thai suppliers and a limited number of India suppliers, which can meet the high quality requirement of Kubota played a key role. Therefore, procurement of parts and logistics costs were reflected to the sales price, and the products became relatively higher than those of local manufacturing companies, although the performance was superior. Kubota established a tractor manufacturing company Escorts Kubota India Private Limited (EKI) in India in February 2019 as a joint venture with an India major tractor manufacturing company, Escorts Limited (EL), and started the local production of MU4501 since September 2020.

EKI not only manufactures tractors but also procures parts by the superior procurement ability of EL from many new India local suppliers that had no business transaction with Japanese companies in the past. Prior to the procurement of parts from new suppliers, EKI changes parts to conform to the actual status of material procurement and equipment at site while securing good quality. Especially, manufacturing of TM parts (parts comprising a transmission) requires technical skills for materials, machining, heat treatment, and surface treatment. Since it greatly depends on the experience of suppliers, the quality of these parts are difficult to secure. This time, prior to quality verification, production transfer procedures including the localizing of parts procurement had been completed in a short period, one year and a half, by dividing factors comprising quality into material, heat treatment, surface treatment, and reliability of bearing and thoroughly evaluating the factors influencing the strength and durability of parts. We are going to introduce the issues in the promotion of TM parts procurement in India and the approach to them through the development.

Fig. 1 Multi-purpose Tractor (MU5501)

Fig. 2 First Tractor off the Line at EKI

2. Concept and target of development

2-1 Concept of development

With regard to the procurement of parts from new Indian local suppliers, it was difficult to procure parts whose materials and machining were the same as those of conventional suppliers who had business transactions with Japan and Japanese companies, and we needed to suitably respond to Indian local procurement and manufacturing environment. Conversely, for even parts to be newly procured, we aimed at achieving Kubota quality to secure the performance and durability as in the past as the concept of development.

2-2 Development target

In India, procurable materials and machining method are limited. To procure parts from new suppliers, we aimed for the following targets.

(1) Parts procurement from Indian local suppliers

For Indian local suppliers, JIS are not popular. Though materials conforming to JIS can be procured, suppliers are limited to those whose scale is large enough to have business transactions with Japanese manufacturing companies. Therefore, we will replace them with materials conforming to the Indian standards that are widely usable in India. In a similar manner, we are going to achieve the procurement of parts from Indian local suppliers by making the evaluation method appropriate for the actual status, considering matters that can be materialized by Indian local technologies.

(2) Adoption of gears procured from India

In MU series, Japanese tooth-ground gears whose tooth faces were ground were adopted to some cases to reduce gear noise. Since tooth-ground gears were hard to be procured from India, for the gears without tooth grinding procured from India, secure the same silent property as the conventional gears to achieve the adoption of gears for MU series procured from India.

3. Technological issues to be solved

3-1 Change of parts materials for Indian local suppliers

In the case of parts procurement in Japan and Thailand, Kubota generally uses materials conforming to JIS (Japanese Industrial Standards). This time, prior to the procurement of parts from Indian local suppliers, it is necessary to conform to the procurable materials by respective suppliers without limiting standards, including Indian industrial standards, IS (Indian Standard), standards of SAE (Society of Automotive Engineers) in US, and EN standards (European Standards) of EU. For many parts of materials that have not been handled by Kubota in the past, including steel materials, cast materials, and bearings, evaluation of materials that allows the adoption at once is an issue.

3-2 Noise reduction by using gears without tooth grinding

Users in the northern area in India have a high level of requirements for the reduction of noise from the transmission of tractor. For this reason, the standards for gear noise of MU series, stricter than those for other models, were established. It is the issue of whether gears without tooth grinding procured from India can satisfy the noise standards that have been satisfied by gears with ground tooth by reviewing the specifications and structure of gears.

4. Skills of solving issues

4-1 Change of parts materials for Indian local suppliers

4.1.1 Steel materials

Chemical components, contents, and the hardenability of steel materials used for gear shaft are minutely determined depending on the standards including JIS. Hardness of surface after heat treatment was conducted and the depth of hardening are influenced depending on the contents of chemical components and hardenability. The control of components and hardenability is very important, since it greatly influences on the strength and durability of parts. These values are specified by the standards and slightly differ depending on the standards in respective countries, such as JIS, IS, SAE, and EN. In the past, Kubota has been using materials conforming to JIS when parts are procured in Japan or Thailand. To secure quality, Kubota separately exchanges the specifications and procures parts with the allowable range further narrowed down. This time, when adopting steel materials conforming to the standards that have not been adopted by Kubota, including IS standards, which can be procured by local suppliers, adoption of them has been carried out by exchanging the specifications in a similar manner.

4.1.2 Evaluation results of steel materials

Table 1 shows the results of rotary bending fatigue test on the steel materials from eight Indian steel materials manufacturing companies. The results are comparable to those of steel materials manufactured in Japan, and it was confirmed that the quality was free from problem in the adoption, in terms of nonmetallic inclusion. Other items were also evaluated, and for the 30 types of steel materials in total, considering the combination of the primary supplier and steel material manufacturing companies, to the seven steel types shown in Table 2, it was confirmed that the quality is worthy of adoption. Based on the results of the evaluation, specifications to procure steel materials were determined, and 30 copies of specifications for the procurement of steel materials were newly exchanged.

Table 1 Results of Rotary Bending Fatigue Test

Steel materials manufacturing company	Steel types	Fatigue strength of 10^7 times
Materials procured from Japan	SCM420H	898 MPa
Eight Indian steel materials manufacturing companies	SCM420H	880 to 933 MPa Ratio compared to materials procured from Japan: −0.2 to −0.4%
	21Cr4Mo2	

Table 2 Examples of Possible Substitutions During Indian Procurement

Procured from Japan and Thailand		Procured from India	
Standards	Steel types	Standards	Steel types
JIS	SCM420H	JIS	SCM420H
		IS	21Cr4Mo2
JIS	SNCM420H	JIS	SNCM420H
JIS	SCM435H	SAE	SAE4137
JIS	SCM440H	IS	42Cr4Mo2
		EN	42CrMo4H
JIS	S45C	SAE	SAE1045

4.1.3 Cast iron material

To secure quality, cast iron material was also evaluated as a single material. In the flow of normal quality verification, specimens were taken for each lot that was being mass-produced and materials were checked. The number of specimens is approximately two (each one for structure and component evaluations and strength evaluation) for each lot, and they are frequently casted into molds at once at the end of the lots. This time, the number of samples needed to be increased to evaluate materials accurately, and many more specimens were required than those during mass production. Since it takes time for casting into molds of specimens, the components or temperature of molten metal in a ladle may be changed halfway if specimens are molded into molds at once in the end of a lot in the same way as the mass production time. Additives to be used for the adjustment of structures with ductile cast iron materials tend to be influenced by them especially, and in some cases, the metal structure of a specimen was influenced and an appropriate specimen was not produced. To prevent faults shown above, the method of taking specimens was specified and it was used as the flow at the time of the evaluation of cast iron materials together with the method of evaluation. Furthermore, in the future, it will be developed as the index of evaluation of new cast iron material in the development of other models manufactured by EKI.

4.1.4 Heat treatment

Since gears and shaft parts need to be contained in a limited space including a transmission case, their sizes are limited. In this situation, the ability of withstanding to load and wear to allow to transmit the driving force of tractor is required, and thus, heat treatment including high-frequency hardening and carburizing is conducted aiming to improve strength and wear resistance. Heat treatment needs strict quality control, since it may cause fragility, liability of wear, or the degradation of performance depending on the treatment method. Therefore, Kubota established the control standards using the inspection standards besides drawings. Although the inspection standards specify the control value related to the quality of heat treatment and the measurement method, inspection equipment owned by suppliers is varied depending on respective suppliers in India, and thus, sometimes it could not be handled by the common inspection standards. New standards conforming to the equipment of respective suppliers were established to allow to supply parts of stable quality.

4.1.5 Surface treatment

At the portions where rotating parts such as gears and shaft parts are supported, components including rolling bearings are used in general to reduce wear, seizure, or rotation resistance. However, there are some portions including differential gear inside where the metal surfaces are slid due to the structural limitation. Manganese phosphate coating treatment (hereafter referred to as PHAM treatment) is used to prevent wear or seizure of the sliding surfaces at these portions. PHAM treatment is the surface treatment method that the target parts are immersed in treatment liquid for chemical treatment to form crystalline nonconducting coating on their surfaces, and it allows to prevent the direct contact of metal surfaces and improve the resistance against wear and seizure. In the procurement of parts with PHAM treatment from India, there were some issues in the evaluation method. The coating formed by PHAM treatment is crystalline as described above. Since the size of the crystal grain influences the performance of coating, the grain size needs to be controlled. For the measurement of grain size in Kubota, SUMP (Suzuki's Universal Micro Printing) method is used. In the method, the crystal surface is transcribed onto preparations by using special treatment liquid, called SUMP liquid, and observed with an optical microscope. The method has merits including the inspection at low cost with simple equipment by allowing nondestructive inspection and measurement with an optical microscope without using an expensive electron microscope (hereafter referred to as SEM). However, prior to localization of the treatment, standards to evaluate with SEM needed to be established because of the following two reasons: (1) Indian suppliers cannot procure the SUMP liquid. (2) In the measurement with an optical microscope without using the SUMP method, parts need to be observed directly. On the other hand, the curved surfaces including cylindrical surfaces cannot be measured precisely due to the insufficient depth of subject (range to be in focus).

4.1.6 Establishment of new method to evaluate surface treatment

As the conventional method to evaluate surface treatment, it was specified that the treated surface was compared with the boundary sample that has been controlled by Kubota uniquely for the measurement of grain size and evaluated with "grain numbers" classified into some levels. The boundary sample is the standard specified for microscope photos with using SUMP method, and the results confirmed with SEM cannot be directly applied to the boundary sample. Fig. 3 on the right side shows some of the measurement results. (A) shows the coating surface observed by the inspection method of Kubota (SUMP method), whereas (B) shows the coating surface observed with SEM. The same part is measured with the same magnification. While the form of grain transcribed onto a preparation is observed in the SUMP method, the part surface is directly observed with SEM. Prior to the localization of PHAM treatment this time, the evaluation results of the specified boundary sample was correlated with the measurement results with SEM, and the inspection standards for measurement with SEM were established.

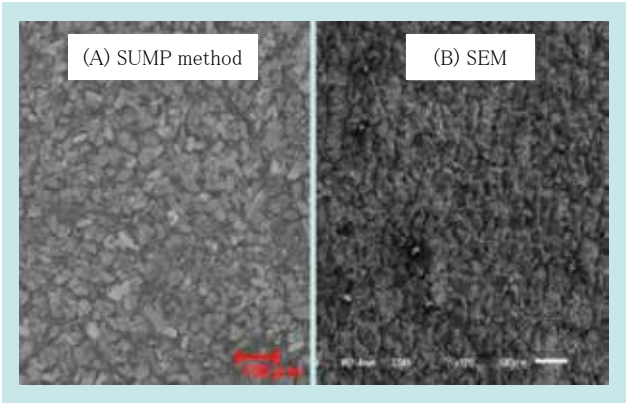

Fig. 3 Measurement of Particle Size (×100)

4.1.7 Rolling bearing

Rolling bearings are used for varied machines in the world, and the sizes, types, rated loads, and the life calculation formulae have been unified by the international standards. Rated life of rolling bearing (L10 life), used as the index of the durability performance of rolling bearing, is defined as "Total number of rotations or total time without breakage of 90% bearings due to fatigue when many identical bearings are operated under the same conditions." 1)For example, in the case of the calculation of the rated life of deep groove ball bearing, which is the most popular rolling bearing, the rated life depends only on the conditions including the type and size of rolling bearing in the formula, and the L10 life in the calculation is the same for rolling bearings of any supplier. However, in reality, quality that cannot be included into the formula, including the machining precision of parts and the quality of materials, has influence and the life may be changed. Thus, even in the case of rolling bearings of the same size, the actual life is varied depending on suppliers, and difference in the reliability of products appears. For these reasons, the selection of bearing is important for securing the durability quality, considering both the life calculated from the rated load, load, and the number of rotations and the reliability of bearings of respective suppliers. Prior to the procurement of bearings from new suppliers this time, the unit test was conducted with the size of bearing narrowed down to define the reliability first, and the reliability of respective suppliers was evaluated and the standards for adoption were determined.

4.1.8 Evaluation results of rolling bearings

Reliability was evaluated to determine the adoption standards for rolling bearing. Table 3 shows the evaluation results of the L10 life of rolling bearing procured in Japan and that from India, obtained by the test. It was found that the L10 life of rolling bearings from two India companies, evaluated this time, was approximately 50% of that from Japan. Based on the results, the adoption standards for the calculated life were established, and the rolling bearings that can be changed to products from India were shifted to those from India. The product from Indian company A was evaluated in 2013 too, and the rolling bearing evaluated this time has the L10 life approximately double compared with the life estimated at that time. It was found that the L10 life has been improved significantly for six years.

Table 3 Evaluation Results of L10 Lifetime Obtained by Experiments

Suppliers of rolling bearings	L10 life compared with that of product procured from Japan
[Standard] Products procured from Japan	100%
Indian company A (2019)	57%
Indian company A (2013)	30%
Indian company B (2019)	55%

4-2 Noise reduction by using gears without tooth grinding

4.2.1 Mechanism of gear noise generation and promotion of development

Mechanism of gear noise generation comprises three steps, (1) Vibration, (2) Transmission, and (3) Emission. As summarized in Table 4, the fixed parts always give influences on the respective steps. Eventually, a mix of multiple factors of parts causes gear noise. In the beginning of the development of MU series, tooth ground gears were adopted for some gears to adjust the tooth surface configuration and reduce vibration and gear noise. To reduce gear noise actually this time, the development was promoted while confirming the effect by the simulation in the case that the respective parts which influence each step are modified.

Table 4 Mechanism of Gear Noise Generation

Items	Parts	Phenomena	Measures for reduction
(1) Vibration	Gear	Rotational fluctuations generated by the tooth face profile and the tooth rigidity cause the vibrating force.	The vibrating force was reduced by reducing the tooth tilt and changing the tooth width to improve the gear mesh ratio.
(2) Transmission	Shaft	Vibration is transmitted to the case through the shaft and holder supporting the gear.	Rigidity was increased and the displacement at the mesh part was reduced to prevent the resonant frequency of shaft from the tooth mesh frequency.
	Holder		With regard to the resonant frequency of holder whose rigidity was increased by a newly added holder, the frequency band of the force acting on bearing was prevented.
(3) Emission	Case	Vibration of the case is transmitted to the air, and gear noise is generated.	Ribs were added to the case to increase the rigidity, reduce the vibration displacement, and decrease the sound emission power.

4.2.2 Gear noise reducing method and achievement of noise reduction

As shown in Table 4, 3D model for which measures against gear noise were provided was created for the respective parts that give influences on gear noise, and the effect was verified by simulation. In the simulation, acoustic emission power was found according to the mechanism of noise generation to compare the level of gear noise. (1) As for vibration, Fourier transformation was conducted on the transmission errors that occur with the progress of tooth mesh found by quasi-static analysis, and the transmission error for each number of rotations or frequency was found. (2) As for transmission, response characteristic for each frequency was found by the finite element method. (3) As for emission, the acoustic emission power for each number of rotations was analyzed by multiplying the results in steps (1) and (2) above. As an example, the comparison results before and after the provision of the measures for gear noise reduction at 2,000 rpm of engine speed at which gear noise is especially increased are shown in the upper part of Fig. 4. The analysis results of the acoustic emission power of gear noise are shown on the right side, whereas the gear noise results of actual measurement are shown on the left side. Gear noise actually measured before and after the provision of measures is shown in the lower part of Fig. 4. Especially, the gear noise value was reduced substantially within the range in which gear noise was an issue, and the gear noise standard values defined for each frequency band were satisfied. Gears without ground tooth surfaces procured from Indian manufacturing companies were able to be adopted by providing the measures for gear noise whose effectiveness was verified by the simulation.

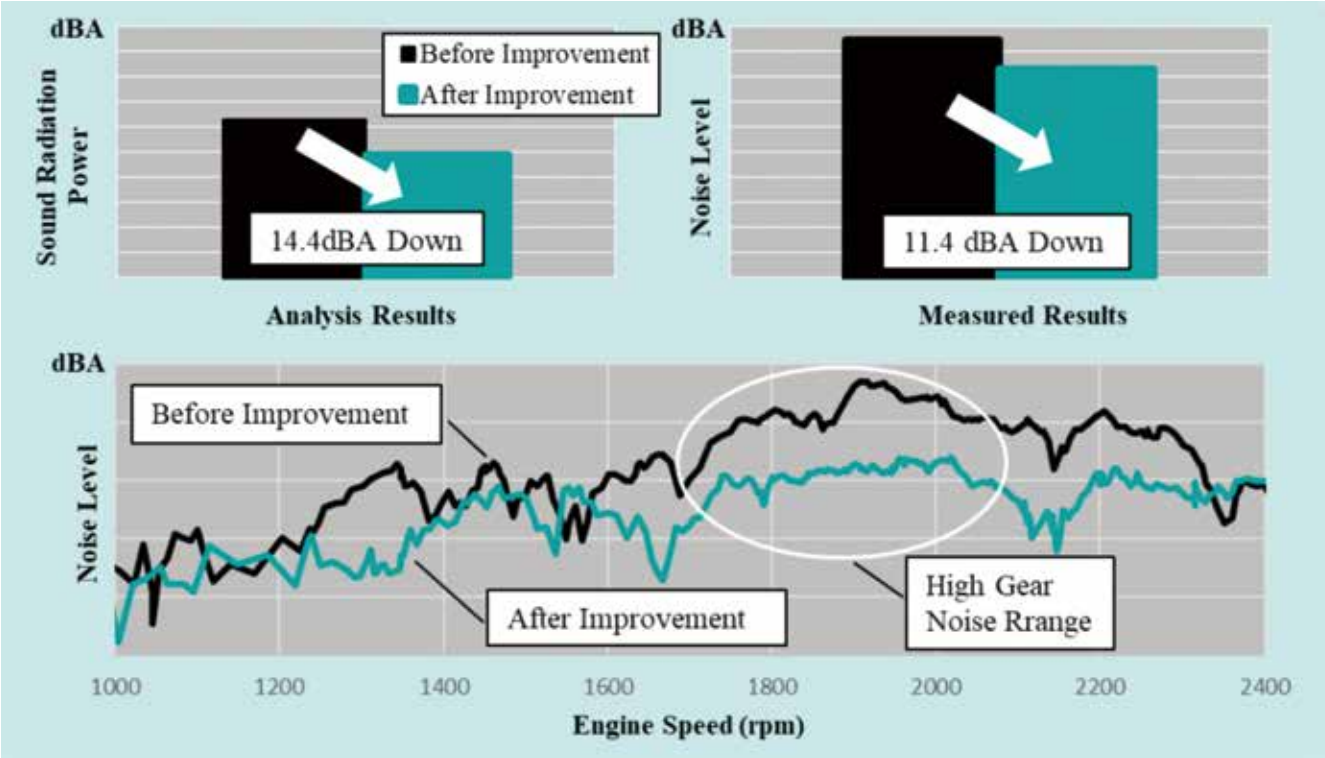

Fig. 4 Comparison of Gear Noise

5. Conclusion

We have presented the issues in the promotion of TM parts procurement in India and the approach to them through the development of Kubota's first local production machines in India. Procurement of parts from India was promoted with a good quality secured by establishing the inspection method and evaluation method that are appropriate for the equipment and production ability with collaborating with local suppliers. We satisfactorily localized the production of tractors for India that have been produced in Thailand and it led to the generation of economic cycle in India and the reduction of transportation energy. Consequently, we could contribute to the economy in India and the manufacturing of tractors with less environmental load. Although there are many remaining issues, we are additionally going to increase the number of parts to be procured locally and models locally produced and achieve the optimum procurement and production to contribute to the realization of the sustainable recycling society and reduction of the environmental load.

Contribution to SDG targets

9.b Technology development, research, and support to innovation in developing countries
Technological support to Indian local suppliers

12.1 Sustainable consumption and production
Contribution to economic circulation in India by local procurement and local production

Reference
1) JIS B 1518:2013 Rolling bearing-Dynamic rated load and rating

Development of M6002 Series Tractor for Europe

Agricultural Tractor Engineering Dept./
Farm and Industrial Machinery R&D Dept. Ⅲ Hydraulic Equipment Engineering Dept./Analysis Center

A growing world population has resulted in a rapidly increasing demand for food. Thus, the need for agricultural machinery has increased, given that it plays an important role in stabilizing the food supply. A key feature of European agriculture is the use of cutting edge technology to attain high crop yields. Kubota had already introduced the 97-127 kW rated M7 series tractor in response to these needs for large row-crop operations. The majority of medium sized operations in Europe are mixed farmers who both produce crops and raise livestock, sometimes using the crops as feed. Among these farmers, high yield per-hectare and ease of use are important. In addition to the M7, Kubota has now developed the 91-106 kW rated M6002 series tractors for the European market with a particular focus on being a good fit for mixed farmers.

【Key Word】
Control Lever Layout, Closed Center Load Sensing Hydraulic System

Related SDGs

1. Introduction

In Europe, mixed agriculture, in which upland farmers also produce feed and are engaged in livestock, is popular and features varied work operations from tillage, seeding, and transportation for crop production to feeding and excretion treatment around a cowshed. Since many types of implements are used and the work load is significantly fluctuated, many of the farmers own several tractors in general. In the M6002 tractor, the transmission, cabin, and hydraulic system were renewed, and it was developed aiming at a tractor allowing a wide range of work for farmers of mixed agriculture. In addition, higher versatility may lead to longer time of use, and thus, approach to the improvement in comfort was taken as an important issue.

Fig. 1 Appearance of M6002 Series Tractor

2. Concept and target of development

2-1 Concept of development

Farmers of mixed agriculture are also engaged in upland farming, livestock, and dairy farming, e.g., production of grains for feeding. In many cases, work required by respective farmers is conducted using multiple tractors. The typical tractors comprise the first tractors to be used for ploughing and seeding; the second tractors to be used for transportation, pest control, and pasture work; and the third tractors to be used for light load work among pasture work (Table 1). Roles (operations) shown in the table are as shown in the pictures (Fig. 2, Fig. 3).

For the second tractors of 75 to 104 kW (100-140 HP) aimed with M6002, operations intended for the first tractors are also required to be covered in busy seasons, and thus, high versatility is necessary. In addition, due to the high versatility, the operating time is the longest, and thus, comfort is also focused on.

Therefore, in the development, the best matching to the market of mixed agriculture was targeted with the following concepts.

(1) Improvement in the compatibility to mixed agricultural work

While securing the vehicle weight, vehicle rank, and vehicle frame strength appropriate for the ploughing type implement, also secure high mobility of existing models and low vehicle height, and aim at the compatibility of work in upland farming and livestock.

(2) Improvement in comfort of long-time work

Targeting the operation of loaders and trailers which are especially used for the second tractors for a long time, achieve the effective reduction of stresses by aiming at improvement in the functions and operability.

Table 1 Tractor Work on a Mixed Farm (example)

Positioning	Power (Horse-power)	Role	Main implement
1st	104 to 149 (140-200)	-Ploughing, seeding, etc. -Towing, etc.	Plough, harrow, cultivator, subsoiler, large baler, manure spreader., Trailer, combination seeder, etc.
2nd	75 to 104 (100-140)	-Ploughing, seeding, etc. -Towing, etc. -Transportation, pasture work, etc.	Harrow, cultivator, plough,. Combination seeder, sprayer Trailer, mower, loader, round baler, spreader, tedder, rake, etc.
3rd	60 to 75 (80-100)	-Transportation, pasture work, etc.	Loader, round baler, spreader, tedder, rake, feeder, etc.
4th	37 to 60 50-80	-Transportation, pasture work, etc.	Loader (light work including cleaning in a cowshed), etc.

Letters in red: ploughing, seeding, etc., letters in black: towing, etc., letters in blue: transportation, pasture work, etc.

Fig. 2 Plow / Trailer Transportation

Fig. 3 Loader Transportation / Round Baler

2-2 Development target

To achieve the two concepts described above, the transmission, cabin, and the hydraulic system were renewed and the achievement of the following functions was set as the development target.

a) Matters related to transmission
- Vehicle weight and vehicle frame strength to allow heavy towing work
- New eight-stage transmission power shift to reduce speed change shock and improve comfort and operability
- Hydraulic transmission-type three-stage auxiliary transmission allowing remote operation
- Automatic clutch operating function allowing stop and start by brake operation only
- Engine boost to secure the acceleration during travel at a high speed
- Shuttle sensitivity adjustment to achieve the favorite workability and comfort

b) Matters related to cabin
- New operation system layout to improve operability
- New multifunctional arm rest to achieve remote intensive operation
- Wide sunroof to increase the upward visibility during loader operation
- Cabin suspension to reduce load during long-time work

c) Matters related to hydraulic system
- Closed-center-load-sensing hydraulic system allowing multiple operations at a time
- Large-capacity pump discharge to improve the workability of loader

d) Others
- Engine output curve to improve the fuel consumption during upland farming work and acceleration performance during travel
- Optional 360° working light to improve nighttime workability
- VT monitor and ISO-BUS options for precision farming

This article describes the following three development targets that need to be tackled intensively for the entry into the market of mixed agriculture.
- Vehicle weight and vehicle frame strength to allow heavy towing work
- New operation system layout to improve operability
- Closed-center-load-sensing hydraulic system allowing multiple operations at a time

3. Technological issues to be solved

Issues in the three development targets described above are specifically shown as follows.

(1) Optimization of vehicle weight and vehicle frame strength

The second tractors for the target market of mixed agriculture are required to cover the heavy towing work to be performed by the first tractors. Since the implement to be installed is large and it leads to high load work, rigid vehicle frame strength applicable to such work is required. Among the main implements, the reversible plough, combination seeder, and front loader were selected as the targets to secure the strength of the vehicle frame.

Conversely, in livestock and dairy farming work, mobility is required for the control work around cowsheds, and thus, lightweight and compactness are also necessary. In the development of M6002 tractors, securement of both lightweight and the strength of vehicle frame appropriate for heavy load work was an issue.

(2) New operation system layout in which operability is improved

In European market, right-handed centralized operation style is popular in tractor operation. In the quality machines of premium type common in the large-scale upland farming market, the fully electronic operation system and large arm rest are adopted, and these features are the selling points of respective companies. To M6002 tractors, the standard specifications in which a mechanical operation lever is provided for the right console are adopted. Achievement of high workability and operability close to the premium specifications by the integration and combination with a newly adopted multifunctional armrest is the issue.

(3) Closed-center-load-sensing hydraulic system allowing multiple operations at a time

Since many of varied implements used in the market of mixed agriculture are hydraulically driven, the high-flow-rate hydraulic system allowing the simultaneous operation of multiple actuators is required. However, increasing the flow of the open center (hereafter referred to as “OC”) hydraulic system adopted to conventional Kubota tractors to high level may cause faults such as an increase in loss horsepower or oil leak, clutch seizure, or faulty lubrication due to worsen heat balance, and it was hard to achieve. Thus, M6002 tractors have the issue of the establishment of the closed-center load sensing (hereafter referred to as “CCLS”) hydraulic system unique to Kubota by the development of the optimum hydraulic equipment.

4. Development technology

4-1 Optimization of vehicle weight and vehicle frame strength

4.1.1 Optimization of vehicle frame strength

Since the vehicle frame is composed of large castings and its trial production and change in the shape are difficult, highly precise review is required from the initial stage of development. Especially, faults in endurance tests necessitate major rework. Therefore, standards for the following three faults that occurred in the high-load endurance test (steep turn test by offset implements) were established respectively, based on the analysis evaluation results of the past models, and verified through analysis (Fig. 4, Fig. 5).

- Insufficient strength of cases
- Oil leak from case mating surface
- Decreased torque of bolts at case joints

Consequently, risks of the broken cases of prototype (clutch housing, mid case, transmission case, brake case, and rear axle case), bolt loosening at joint face, or oil leak were able to be removed early.

4.1.2 Optimization of vehicle weight

With regard to the weight, the precision was improved through continuous adjustment to match the stress measurement result to the analyzed result and the excessive metal parts that do not contribute to the strength of the vehicle frame were actively identified. This allowed the satisfaction of the stress standards in respective test modes and the reduction in weight without decrease in the entire strength of the vehicle frame.

By these approaches, strength to withstand the target, implement operation, was secured and weight reduction was also achieved.

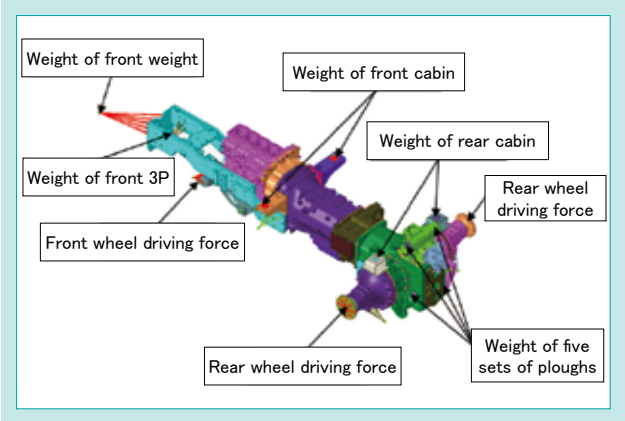

Fig. 4 Analysis Model of High Load Durability Test Mode

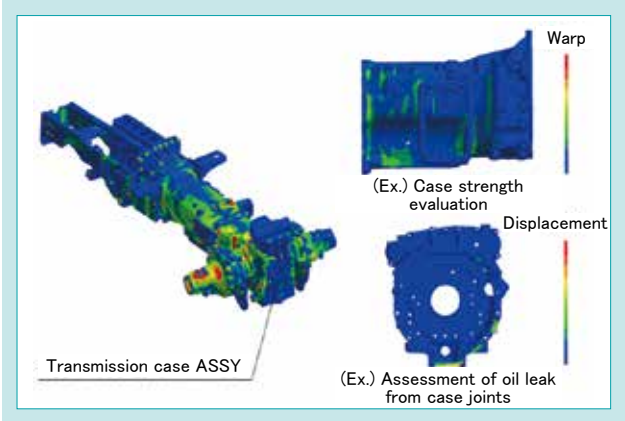

Fig. 5 Results of Strain Analysis

4-2 New operation system layout in which operability is improved

4.2.1 New operation system layout

The optimum operation system layout depends on the target main implement. In the development of M6002 tractors, which targets the mixed agriculture work, the layout was re-optimized based on the concept of ergonomic design.

(1) Operators can understand the operation intuitively

(2) Operators can operate the machine according to their physical constitutions and motions

4.2.2 Development of operation system layout

(1) Achievement of intuitive operation

With regard to the operation levers and switches, the layout allowing operator's intuitive operation by the functional classification and blocking was reviewed. Specifically, considering the level of frequency in use of the centralized operation with right hand for mixed agriculture, functions were classified into those used highly frequently, including "shuttle, speed change" and "raising and lowering farm machinery by one-touch operation"; those used intermediately frequently, including "acceleration, travel, and turning," "3P operation system," and "PTO on and off"; and those with low frequency, including "sub function" and "engine 3P setting." Although they were laid out on the arm rest incorporated in the seat, functions highly frequently used were consolidated to a multifunction lever. Additionally, functions immediately frequently used and those with low frequency were divided into blocks by functions to prevent confusion in operation and allocated with similar functions consolidated (Fig. 6).

(2) Achievement of operation layout according to physical constitutions and motions

Considering the operation areas, "regular working area," in which operators can work without stretching their arms, and the "maximum working area," in which operators' hands can reach by stretching their arms, layout allowing operators to operate according to their physical constitutions and motions was reviewed (Fig. 7).

As for the specific design, the size of the armrest was set within the normal working area, and the multifunction lever, PTO switch, and acceleration dial were arranged diagonally for the motion of the arm to allow the operation with natural action. Also, the position of the arm rest was allowed to be set according to the physical constitutions and working postures of operators by allowing the adjustment of the bracket fixing the seat and arm rest front and back and up and down, respectively. Additionally, the layout in the maximum working area was achieved and operators were allowed to operate the virtual terminal monitor with sitting down by positioning the virtual terminal monitor at the arm rest bracket as the additional display.

Levers on the right console were positioned on the arc in the maximum working area centered on an operator to allow to align their operating directions with those of the motions of the operator's arm (Fig. 8).

Consequently, intuitive operation and operations according to the physical constitutions and working postures of operators were allowed, and the operability was improved in conformity to the market of mixed agriculture.

Fig. 6 Multi-Function Armrest

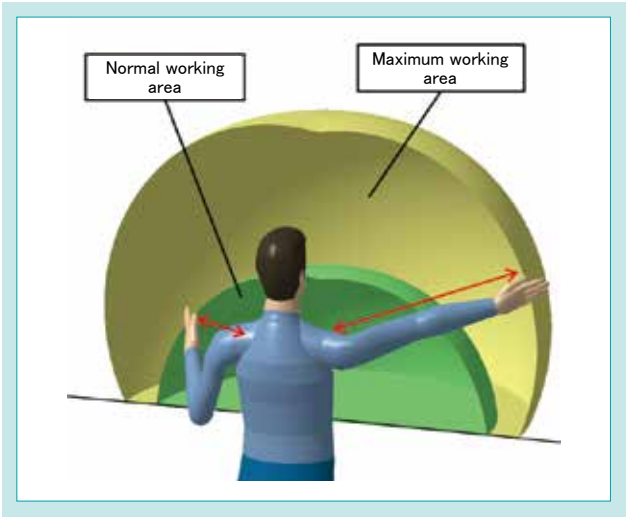

Fig. 7 Working Area

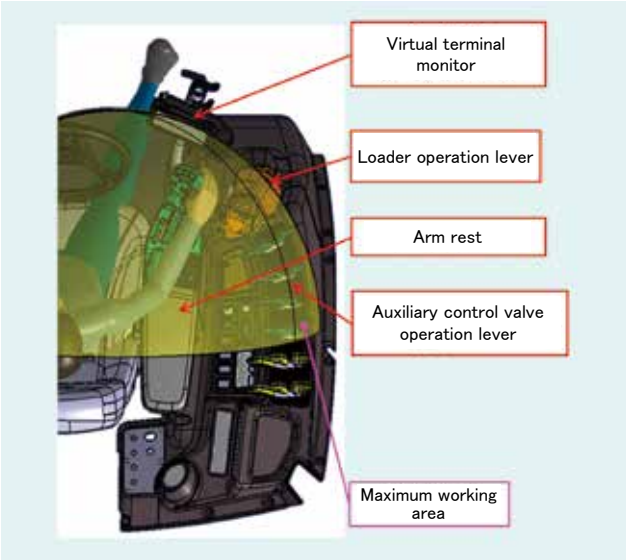

Fig. 8 Control Lever Layout and Maximum Work Area

4-3 CCLS hydraulic system allowing simultaneous multiple work

4.3.1 Development of CCLS hydraulic system

The hydraulic circuits of tractors are roughly divided into three types, namely, the operation system circuit, including the 3P hitch control valve (hereafter referred to as "3P valve"), auxiliary control valve (hereafter referred to as "AUX valve"), and the front loader valve; the steering system circuit for steering controller; and the travel system circuit including the transmission system. In many system structures, CCLS hydraulic system was adopted to the operation system circuit or the operation system and the travel system circuit. The OC hydraulic system was adopted to the steering system (Table 2). With regard to the steering that needs highly reliable operation, the performance can be easily secured by controlling with the OC hydraulic system. However, increase in loss horsepower and decrease in the freedom of layout were issues, since the fixed capacity pump were needed to be mounted for steering.

As for M6002 whose vehicle body is compact and the mobility is needed to be secured, the unique CCLS hydraulic system moving all the hydraulic equipment with a piston pump using the unique priority valve system to solve these issues was developed.

Table 2 Overview of Hydraulic System and Function

Items		Competitor A	Competitor B	M6002
Pump 1	CCLS	Operation system	Operation system	Operation system Steering system
			Travel system	Travel system
Pump 2	OC	Travel system	Steering system	–
Pump 3	OC	Steering system	–	–
Cost		Not bad	Good	Better (in-house production)
Size		Not bad	Good	Better
Technological difficulty		Good	Good	Not bad

:High pressure circuit
:Low pressure circuit

4.3.2 Construction of hydraulic system and development of hydraulic equipment

The most important factor in the construction of the hydraulic system is the securement of the stable flow rate in the steering system. In the hydraulic circuit comprising the operation system and the steering system placed in parallel, when operating simultaneously, the flow in the steering circuit runs short depending on the pressure in the operation circuit or the discharge from the pump, resulting in a fault of heavy steering. To prevent such a fault, priority order of the equipment needs to be determined, and when the delivery flow is saturated, the priority valve to supply oil to the equipment of higher priority needs to be provided for the hydraulic circuit. Therefore, M6002 was provided with the structure allowing the diversion of supplied flow from the piston pump by the three priority valves. Specifically, to secure the safety of the tractor, it was decided that the equipment to be prioritized first is the steering system; next is the trailer brake, followed by the travel system, and then the operation system (3P control valve, AUX control valve, front loader valve) (Fig. 9).

Additionally, to achieve the unique CCLS hydraulic system, the piston pump, 3P control valve, priority valve, front suspension valve, power shift valve, GST, and PTO valve were newly developed (Fig. 10).

Additionally, with regard to the installation of the piston pump, the pump was positioned as compact as possible with the overall length of the pump limited by integrating all the functions into a pump (Fig. 11). Consequently, the handling of piping was simplified and the maintainability was also improved.

Using the approaches above, the CCLS hydraulic system and the hydraulic equipment that realize high flow and simultaneous operation were developed.

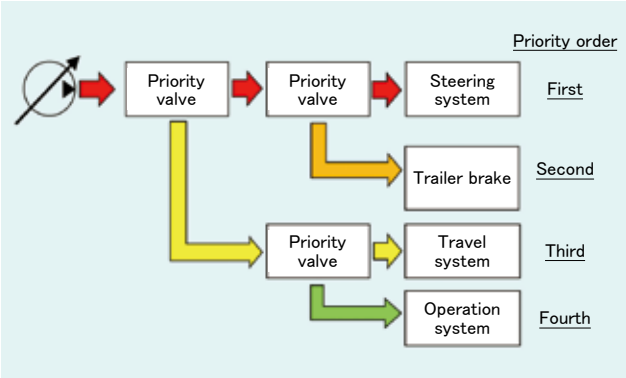

Fig. 9 Schematic Diagram of Hydraulic System

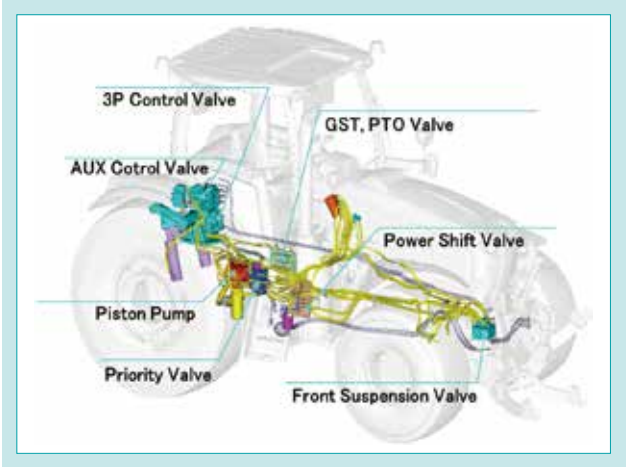

Fig. 10 Newly Developed Hydraulic Equipment

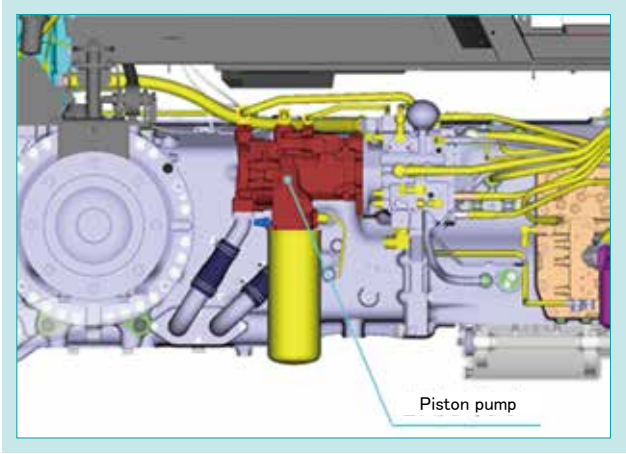

Fig. 11 Piston Pump Layout

5. Conclusion

In this development, to improve the conformity to the market of mixed agriculture in Europe, many functions including the transmission, operation system layout, and CCLS hydraulic system were newly designed. Consequently, M6002 with improved work efficiency and productivity, compared with the conventional model, was developed.

Hereafter, in reply to the evaluation and requests from customers, Kubota's advantage to become the global major brand will be further pursued, the brand value will be increased in the market of the upland farming in which competitors are competing fiercely, and we are going to establish our position securely.

Contribution to SDG targets

2.4 Achievement of sustainable and tough agriculture
Improvement in operation efficiency and productivity, compared with the conventional model

8.2 Improvement in productivity by innovation
Improvement in operation efficiency and comfort to contribute to the energy saving of agricultural workers

Development of Green Soybean Combine Harvester

Combine Harvester Engineering Dept.

In recent years, the production of green soybeans has been increasing because of the conversion from rice cultivation in Japan. Kubota sells walk-behind green soybean pulling machines, but an additional threshing machine is necessary, and low efficiency is a bottleneck. There is increasing demand for a harvester having both high precision and high efficiency. Kubota has developed "high-precision, high-efficiency green soybeans combine" with the cooperation of the Akita Prefectural Agricultural Experiment Station, which is situated in the main production area for green soybeans in Japan. This paper introduces the development technology that achieves both high accuracy and high efficiency.

【Key Word】
Green Soybean Combine, Vegetable Harvester, Feed Chain, Pass, High Accuracy, High Efficiency

Related SDGs

1. Introduction

1-1 Background

In Japan, although the production of rice has been decreased, green soybeans are selected as the crop substituted for rice growing. The crop acreage in Japan in 2019 was 13,000 ha, the yield was 66,100 tons, and the production has been stabled in these years[1]) (Fig. 1). Yamagata Prefecture and Akita Prefecture, major production areas, are dedicating themselves to the increase in the production of green soybeans, and the subsidy system to equipment for green soybeans is enhanced. In terms of gross income, since green soybeans are highly profitable crops compared with rice, the scale will be widened, and the crop acreage and the yield will be increased in the future.

Work flow to the delivery of green soybeans comprises the following: (1) ridging and fertilization; (2) seeding and transplanting; (3) intertillage; (4) pest control and watering; (5) harvesting and threshing, separating, and delivery, and the steps of (5) occupy major parts of working time. Also, since the freshness is important for green soybeans, harvesting in the early morning is specified in many areas. In these areas, harvesting is started from the middle of the night, and thus, even though farmers have harvesters, long working time causes the increase in a burden to farmers and the inhibition of the expanded production scale.

1-2 Characteristics and issues of current harvesters

The current harvesters are divided into two types of machines, namely, pulling machines intended for pulling only and threshing harvesters intended for threshing (Fig. 2).

(1) Harvesting system by pulling machine

Green soybeans need to be pulled by walk-behind pulling machine, transported to the working site, and manually loaded one by one into the stationary type threshing machine for threshing. Although both the pulling precision of pulling machine and the threshing precision of stationary type threshing machine are high, work efficiency is low because of many manual operations, and there is a time-consuming demerit of disposing branches, stems, and leaves after threshing.

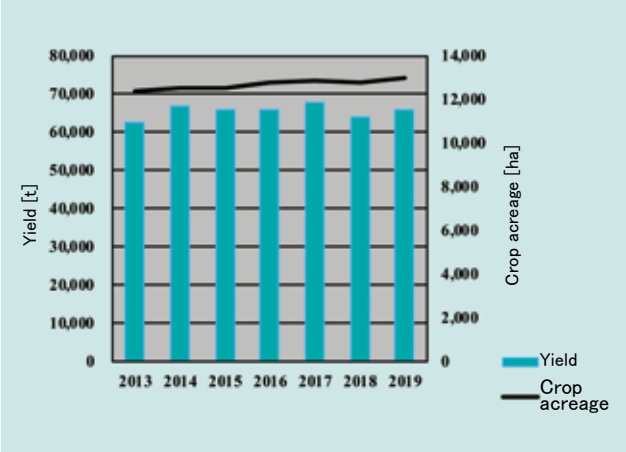

Fig. 1 Green Soybean Planted Area / Yield Transition[1)]

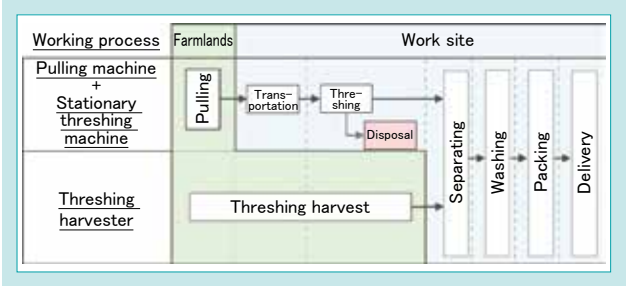

Fig. 2 Work Process of the Current Harvest Systems

(2) Harvesting system by threshing harvester

Since only shells are harvested by the rotary type tine without pulling stems, time and efforts of threshing and disposal at the work site can be reduced, the work efficiency becomes higher than that of pulling machine, and additionally, no stationary type threshing machine needs to be purchased. However, the machine, raking up crops with the metal tine, has the demerits of many losses and damages and less harvesting precision (Fig. 3).

Although the threshing harvester of higher efficiency may be selected in the case that the scale needs to be expanded and profits need to be increased, the harvest accuracy is poor, and needs for a harvester satisfying both high accuracy and high efficiency have been increased. Fig. 4 shows the developed machine.

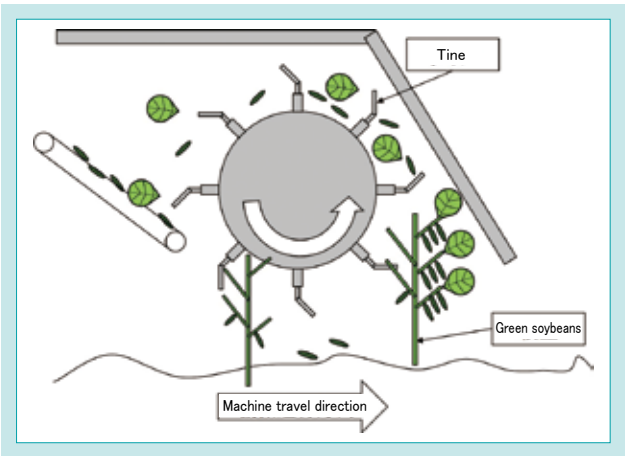

Fig. 3 Schematic Diagram of the Threshing Harvester

Fig. 4 Development Machine

2. Development concept and target value

2-1 Concept of development

In the market of green soybeans harvesters, there is a request for the compatibility of (1) less damages and crop loss (high precision) and (2) high work efficiency (high efficiency). To meet this request, the development concept of the unprecedented "Highly accurate and efficient single-row pulling type riding green soybeans combine allowing the continuous operation from pulling to transportation in a single process by a single operator" was adopted. Furthermore, compact machine size was the important factor, taking into consideration the performance of loading to a truck during moving and transportation.

2-2 Target value

The target value of accuracy was set to the harvest accuracy or better in the working system where the pulling machine and the stationary type threshing machine were combined. The target value of efficiency was set to the working efficiency or better of the threshing harvester. The target machine size was set to that allowing the loading to a 2 ton long truck.

3. Technological issues to be solved

3-1 High precision

To achieve high precision, it is important to pull the stems of green soybeans from the ground one by one and thresh them carefully one by one (system in which the pulling machine and stationary type threshing machine are combined). However, if the pulling machine and stationary-type threshing machine are connected simply, threshing in the posture remained after pulling will be difficult, because green soybeans grow vertically to the ground. During the passing from the pulling part to the threshing part (hereafter referred to as "passing"), threshing needs to be conducted after changing the posture of a stem by 90° so that it is parallel with the ground and the change of posture without an error at high speed and continuously was an issue. Additionally, since a lot of wastes including leaves and stems are included immediately after threshing, improvement in the separating of wastes to achieve high precision was also an issue.

3-2 High efficiency

With regard to the storage of harvested shells, if they are stored in a small plastic container used for the harvest of green soybeans in general, the machine needs to be stopped frequently to replace the storage container during harvest, and thus, this was an issue to achieve high efficiency.

4. Development technology

4-1 Passing technology

4.1.1 Issues in passing technology

In the threshing system of green soybeans in the developed machine, pulled green soybeans are fed rearward by the feed chain, whereas shells, leaves, and stems are threshed by the threshing part at the central section of the machine. When green soybeans are pulled, they are held by the pull-out belt. However, during the passing, the held stems need to be released, and thus, issues of decreased feeding force and the tendency of the worsening of green soybeans feeding posture occur. Since the reduction of feeding force causes the stagnation of stem flow, and the worsen feeding posture may lead to the decreased threshing precision, the securement of feeding force during passing and the passing with accurate posture was an issue.

4.1.2 Solutions of passing technology

To feed green soybeans smoothly from the pulling part to the threshing part without the stagnation of green soybeans and the worsen posture, high speed and accurate passing were achieved by taking the following measures.

(1) Optimization of machine layout

When green soybeans are harvested, since the height of the pulling part needs to be adjusted point by point depending on the field conditions and crop conditions, the pulling part is provided with the structure lifted by the hydraulic cylinder. By placing the revolving fulcrum, which raises the pulling part, near the inlet of the threshing part in the upper section of the machine, change in the distance between the feed chain in the passing part and the pulling belt that is generated when the pulling part is lifted or lowered can be limited to the minimum and the smooth passing is allowed (Fig. 5).

(2) Using two step pull-out belts

Adopt the structure of the upper and lower two steps for the pull-out belts, and exchange them during feeding. During threshing after passing, the space between shell and the feed chain can be secured by moving the holding position downward during feeding. Therefore, pinch of shells by the feed chain is reduced, and threshing near the root can be made effectively (Fig. 6).

(3) Movable circle stick guide

The movable circle stick guide is set along with the feed chain. By the structure in which fed green soybeans are followed by the circle stick guide and are pressed against the feed chain side face by pressing load of the spring, the posture of green soybeans can be continuously changed by 90° with the feeding force kept even after them leaving from the pull-out belts (Fig. 7).

(4) Extension of the pin of feed chain

Until the change of the posture is completed after green soybeans are released from the pull-out belts, the force of feeding green soybeans depends on the feeding force on the side face of the feed chain only, and the force of feeding green soybeans is reduced and stagnation tends to occur most easily. To solve this issue, the pin of the feed chain was projected out of the external plate. Then, feeding force to stems was increased, stable feeding force was secured without depending on the diameter or shape of stem, and the precision of passing was improved satisfactorily (Fig. 8).

(5) Vehicle speed interlocking drive of pulling part and threshing part

During harvesting, the vehicle speed always changes depending on the field conditions and crop conditions. Therefore, after the drive (driving force) at the pulling part and threshing part is directly taken out from the engine, the machine rotates at a fixed speed by engine running regardless of the vehicle speed, and speed difference from the vehicle speed is generated. Because of this speed difference, the posture of green soybeans during passing becomes bad and smooth delivery is difficult. It causes the stagnation of green soybeans and the reduced threshing precision. To prevent them, drive of the pulling belt and the feed chain was taken out from the transmission and the rotating speed was interlocked with the vehicle speed. Then, the stable posture during pulling and passing was achieved.

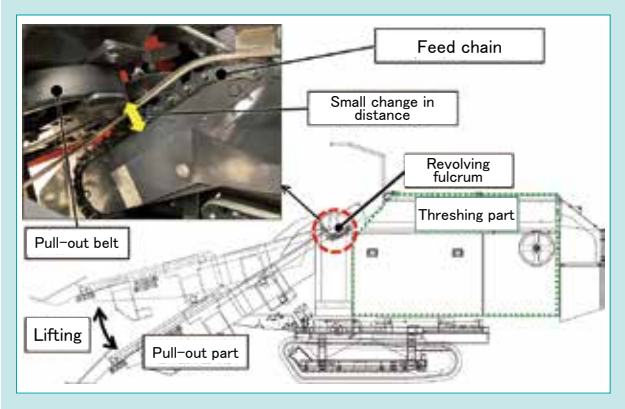

Fig. 5 Machine Layout

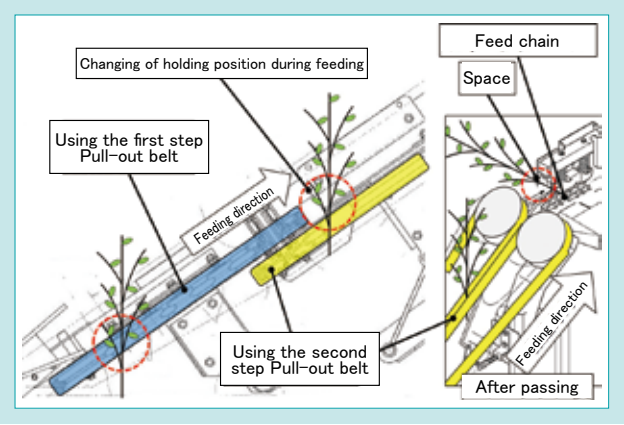

Fig. 6 2-Stage Pull-out Belt

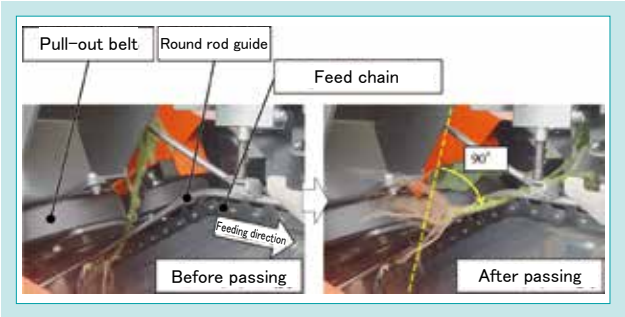

Fig. 7 Movable Circle Stick Guide

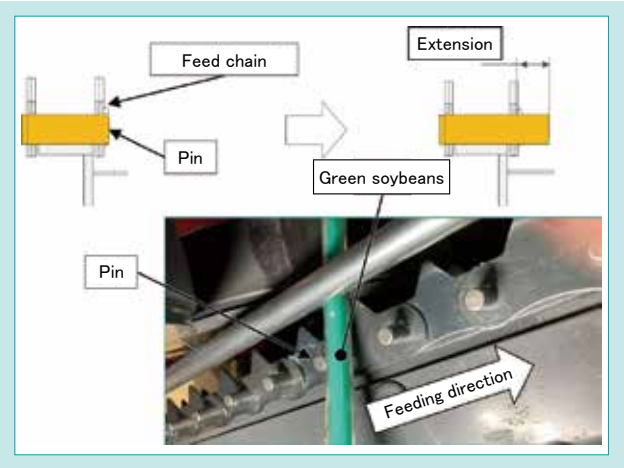

Fig. 8 Extension Feed Chain Pin

4-2 Separating technology

4.2.1 Issues of sorting technology

For the separating of green soybeans, the method to separate refuse by the wind from the grain fan is generally used. The separating precision is reduced by the remained refuse and discharge of shells out of the machine at that time. For the improvement in the precision of separating, precise separation of shells from other refuse was an issue.

4.2.2 Solutions of separating technology

The feeding route of threshed subjects has the two step conveyor structure with the fall distance provided, and the separating is conducted with the wind by the crop fan when the crops are fallen between the conveyors. The separating principle is as follows: light-weight refuse, which is liable to receive the wind, is discharged by the wind force out of the machine, and heavy-weight shells, which are hard to receive the wind, are fallen onto the conveyors for sorting (Fig. 9). However, with regard to small refuse including broken branches whose area receiving the wind simultaneously with shells at the threshing part is small, it is hard to sort them by the wind only. Thus, the crops can be sorted efficiently by rotating the sorting cylindrical drum with projections on the leeward side (Fig. 10). This allows the easy separation of shells from refuse including leaves and the improvement in the separating performance even when morning dew is attached or crops are wet at rainfall time, by bumping against the sorting drum. Furthermore, the crop fan is equipped with the wind volume and wind direction adjuster mechanism to allow it to adjust to varied crop conditions.

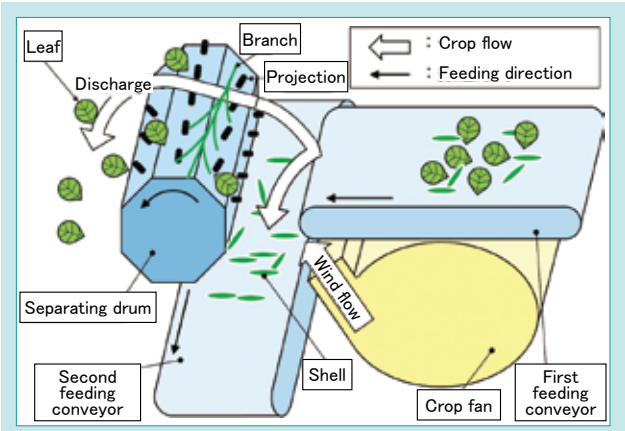

Fig. 9 Schematic Diagram of Separating Part

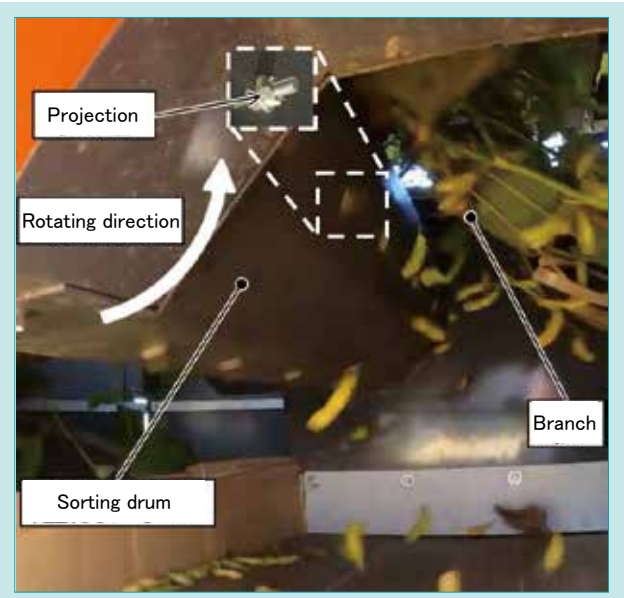

Fig. 10 Separating Part During Harvesting

4-3 Storage technology

4.3.1 Issues of storage technology

In many cases, in the harvesting of green soybeans, harvested crops are stored in plastic small containers. The storage weight of a container is approximately 10 kg, and frequent replacement work is required. Thus, in the case of work by a single person, the machine needs to be stopped for the replacement of the container. Additionally, if the container is filled in the middle of the row, move in the farmlands is required for discharge work, and the work efficiency is substantially decreased. For higher efficiency, the achievement of a large capacity storage method allowing the continuous storage without stopping the machine even when working by a single person was an issue. Additionally, the achievement of compact machine size without impairing the convenience of moving and transportation was also another issue.

4.3.2 Solutions of storage technology

To enable the continuous operation at high efficiency by only a single operator, the belt conveyor type automatic bean tank of a large capacity allowing the storage of shells was provided (Fig. 11).

(1) Tank capacity

With regard to the tank capacity, by adopting the 60 kg tank allowing the storage of 100 m per row, which is the standard green soybeans farmlands, harvesting a row without stopping or moving the machine was allowed.

(2) Compact machine size

By adopting the folding type tank in vertically long shape, considering the convenience of moving and transportation, the machine size stackable to a 2 ton long truck was achieved (Fig.12).

(3) Automatic transportation, full detection sensor

Threshed and separated green soybeans are loaded from the feeding conveyor into the bean tank for storage. By providing the photoelectric sensor to detect stored green soybeans at the feeding conveyor end, green soybeans are stored in the tank, and when the sensor is shut off, the belt conveyor is automatically fed forward the machine by a fixed distance. This allowed the non-necessity for leveling shells in the tank, and continuous operation was also enabled even during the working of only one person. Furthermore, the full detection sensor is mounted to the front side of the tank, and when the tank is filled, the operator is notified by the buzzer. Thus, the operator can concentrate on the driving operation only.

(4) Discharge work

After harvesting, shells stored in the tank can be discharged to small containers at arbitrary places including the end of farmlands by making the tank rear side into the type of opening and closing and reversing the belt conveyor by operating the switch. This reduces the labor of discharging harvested crops from the farmlands.

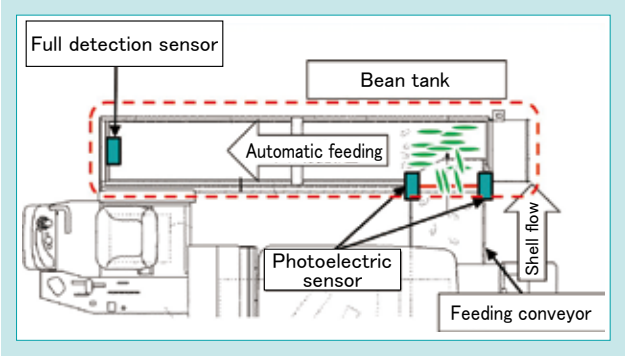

Fig. 11 Schematic Diagram of Bean Tank

Fig. 12 Comparison of Bean Tank Folding / Working Condition

4-4 Development results

Fig. 13 shows the comparison of harvest accuracy[2] among the developed machine, threshing harvester, and the harvesting system comprising the pulling machine and stationary type threshing machine. Fig. 14 shows the comparison of the work efficiency of the above. As for the harvest accuracy (ratio of shells collected without damage or loss), the target of development, i.e., accuracy of the harvesting system comprising the pulling machine and the stationary threshing machine or better, was achieved by mainly the establishment of passing technology and separating technology. Although a 2 ton truck can load it, work efficiency of the threshing harvester or better was achieved mainly by establishing the storage technology, and "Highly accurate and efficient single-row pulling type riding green soybeans combine allowing the continuous operation from pulling to transportation in a single process by a single operator" was realized.

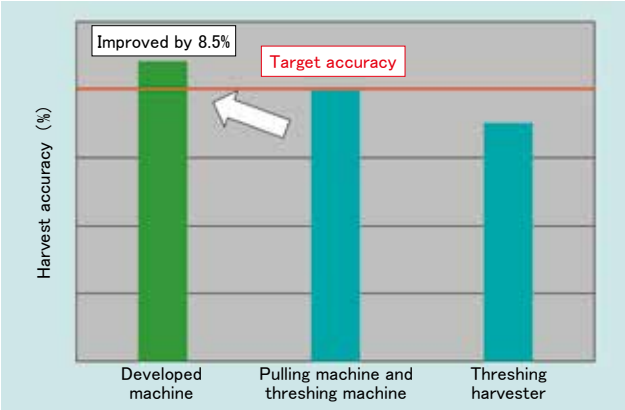

Fig. 13 Comparison of Harvest Accuracy[2]

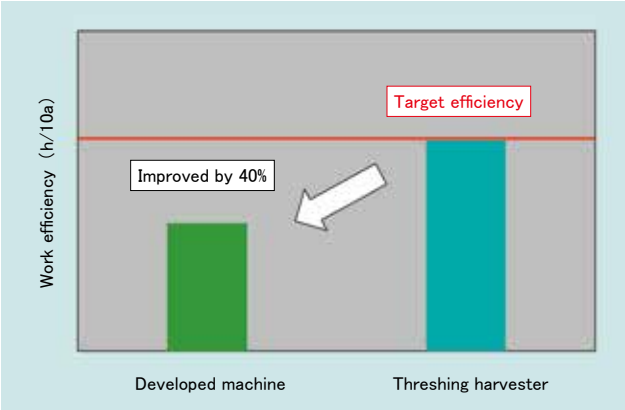

Fig. 14 Comparison of Work Efficiency

5. Conclusion

By establishing the passing technology, separating technology, and the storage technology, green soybeans combine satisfying the market needs was developed with unprecedented high accuracy and high efficiency, and the contribution to energy saving of green soybeans farmers was achieved. In the future, based on the evaluation results and requests from the market and users, we are going to promote improvement additionally and contribute to the manpower reduction and labor reduction for green soybeans farmers.

Contribution to SDG targets

2.3 Increase in agricultural productivity and income
Reduction of loss during harvest

8.2 Improvement in productivity by innovation
Reduction of harvest time by improving work efficiency

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Development of Corn Harvesting Header CH70 for DC70 Combine Harvester

KUBOTA Research and Development Asia Co., Ltd.

There is growing demand within ASEAN countries for better harvesting performance for grain corn along with the growing market for this product due to government-supported policies to achieve self-sufficiency through domestic production and reducing imports. The customer need perfect harvester that can be enhancing about working capacity, low fuel consumption, low header loss, lodged corn harvesting ability to support working. Corn header is one of solution of the enhance requirement.

Kubota Research and Development Asia (KRDA) developed corn header CH70 focusing on greater compactness & flexible size, a header that is lightweight and easy to install, that supports the global policy of zero burn after harvest, has a reasonable price, and with performance superior to all other competitors. Due to its special features, corn header CH70 helps the customer to reduce operational costs and generate a higher income compared to the harvesters of competitors. CH70 can meet the above requirements and can also increase the market share of Kubota's harvesting machines in ASEAN countries, as well as increasing sales and expanding marketing networks to support the future business growth of both customers and Kubota.

【Keyword】
Corn Header, Combine Harvester, Compact, Blade shape, Zero burn

Related SDGs

1. Introduction

Total corn grain market in ASEAN is about 10.2 Million ha. It is second popular plant from rice and it still rising. It makes demand of corn harvesting machine also rising.

Present, selling of DC70 (multipurpose combine harvester) on rice market is full. Increasing of combine harvester DC70 sale volume was on limited. Most of customer buy only for replace the old machine.

KRDA see the chance to develop Corn Header CH70 to catch both rising of demand on high performance harvester and energizing ASEAN sale volume of DC70 with corn, by developing CH70 as a best implement of harvesting machine and making better performance from competitor. We can make both DC70 and CH70 to be the market leader within the small combine harvester market.

When we use DC70 in corn harvesting, first, corn stalk will cut by Header. Second, separated corn pods are conveyed by feeder and transfer to thresher. Then, Corn is threshed in the thresher, only corn grain is separated and sent to product grain tank. Corncob is rejected out from thresher after threshed.

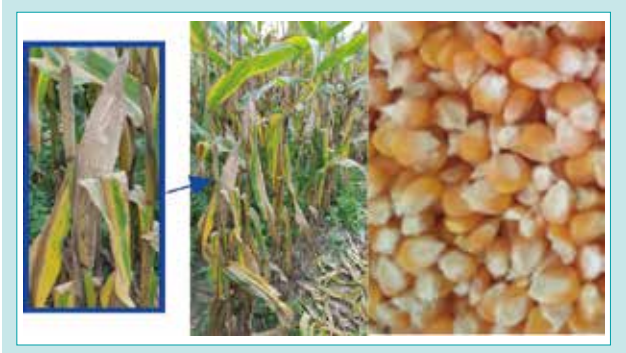

Fig. 1 Corn and Corn Grain

There are two types of corn harvester for DC70. First one is cutting type that is Kubota corn kit CK70. CK70 was developed based on original combine by replacing the minimum parts. So Customer can harvest corn with a small investment. However, since the CK70 harvests the stems, leaves, and Pods and put all into the threshing section, the working load is heavy, the work efficiency is low, and the dust mixing rate is high, so there is a high demand for performance improvement in the market.

Fig. 2 Corn Kit CK70 Attached to DC70

Second one is pod separate type, competitors have launched this type harvester already. This type has high performance than cutting type basically, because can separate only corn pod within header section, and can thresh without stems and leaves. However, competitor header have some big problems, these are heavy weight and large header size. Both problems make customer inconvenient to use or transportation, and cause shorter lifetime of combine harvester.

KRDA decided to develop new machine that has better performance compared to cutting type (CK70) and a competitor corn headers, can have an overwhelming impact on the market and contribute to the expansion of Kubota's business.

2. R&D Concept and Target Value

2-1 R&D Concept

Development of CH70 focus to get achieve with two key design concept

1)"Flexible in using"
2)"High performance"

2-2 Target Value

To make CH70 to the best of new corn harvesting header for customer with below item.

a.) No need to change hydraulic cylinder and no need to install rear balance weight
b.) High working capacity
c.) Low fuel consumptions
d.) Low harvesting header loss (Header loss : Falling crops out of the header)
e.) Support zero burn after harvest

3. Technical Challenge to be Solved

1)"Flexible in using"

The competitor's corn header has two major problems: "too heavy" and "too big". If it is "too heavy", an unbalance will occur during the operation of the combine, making the operation difficult. In addition, extra parts such as special cylinders and rear counter weights need to be used to prevent unbalance. If it is "too big", it will be difficult to transport the combine on the truck, and will occur a problem.

The themes to be challenged when developing the new corn header CH70 are "lightening" and "compactification".

2)"High performance"

Even if the header is compact and lightweight, it cannot be allowed to be inferior to the competitor header in harvesting performance and working performance.

The themes to be challenged when developing the new corn header CH70 is "Ensuring high work performance".

4. Developed Technology

4-1 Lightening Technology

4.1.1 Technical Challenge

Achieving both lightweight structure and durability

4.1.2 Solution of Challenge

A structure using a thin plate was adopted, and a structure with sufficient strength with a minimum weight was designed. Structural analysis was performed using analysis techniques(Fig3). The stress was measured and the durability test was performed on the actual prototype product. We have completed an overwhelmingly lightweight header compared with the competitor header.

As a result, we achieved the front-rear balance of the machine without adding a rear counterweight. In addition, due to the effect of the lightweight header structure, the original combine hydraulic cylinder could be used as it is. Therefore, the product has good operability and easy assembly performance without using extra parts (Fig4).

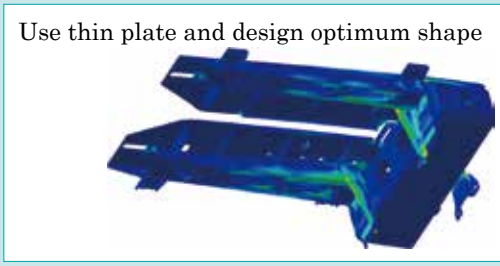

Fig. 3 Structure Analysis

Fig. 4 Counterweight & Hydraulics Cylinder

4-2 Compactification Technology

4.2.1 Technical Challenge

Design optimal relation of unit harvester speed in compact header

4.2.2 Solution of Challenge

Unit harvester is sub assembly part of corn harvester header. Use a harvester unit per a row of corn harvesting. CH70 install for three unit to make three rows harvesting ability and matching for width of combine harvester.

Pod separating process are 3 steps.

Step 1 : Corn pod with corn stalk is pushed by [A] Gathering chain and come into Unit harvester.

Step 2 : Corn is still pushed by gathering chain and low stalk is more pushed by [B] Screw feeder to push the corn into separating zone.

Step 3 : [C] Stalk roller will pulldown only corn stalk while corn pod is left on frame in separating zone. Only corn pod is separated and pushed by gathering chain to convey only corn pod to thresher sction.

Fig. 5 CH70 Header & Unit Harvester

Fig. 6 CH70 Unit Harvester for Corn Pod Separating Process

Three main component of unit harvester must have operation speed in the same relation and matching with harvesting speed(V) of the combine harvester. If not, corn pod will drop out of the header and appear header loss.

A. Gathering chain ; Use for convey corn stalk come into unit harvester for pod separating process and convey separated corn pod to the rear side.

● Speed calculation.

$$N = \frac{60V}{\pi D} \quad [1]$$

N : Drive Sprocket rotation speed (rpm)
V : Harvesting speed (m/s)
D : P.C.D. diameter drive sprocket(m)

● Quantity of finger attach to gathering chain. Find quantity suitable of corn stalk frequent.

$$f = \frac{V}{Cp} \quad [2]$$

$$n = \frac{f}{(\frac{V}{Lc}) \times Cq} \quad [3]$$

f : Corn harvesting frequency (Stalk/s)
V : Harvesting speed (m/s)
Cp : In row corn pitch (m)
n : Finger attached quantity (Pc.)
Lc : Circumference of gathering chain (m)
p : Pitch of corn planting (m)
Cq : Quantity of gathering chain per a unit harvester (Pc.)

B. Screw feeder ; Use for convey corn stalk from gathering chain to feeding into stalk roller or pod separating process.

● Pitch length of screw feeder

$$P = \frac{60V}{Ns} \quad [4]$$

P : Pitch length of Screw feeder (m)
V : Harvesting speed (m/s)
Ns : Screw rotation speed (rpm)

C. Stalk roller ; Use for pull corn stalk down in pod separating process.

● Separating pull velocity
note : Prevent corn pod be bounce after pull, velocity should lower 7.2 m/s

$$Vp = \frac{(Ch - Uh) \times V}{Ls} \quad [5]$$

Vp : Velocity of corn pulling (m/s)
Ch : Height of corn stalk (m)
Uh : Height of unit harvester at harvesting position (m)
V : Harvesting speed (m/s)
Ls : Design long length of Stalk roller (m)

By setting the optimum parameters, the corn header CH70 has been completed as a product that both a compact structure and the required performance in the header.

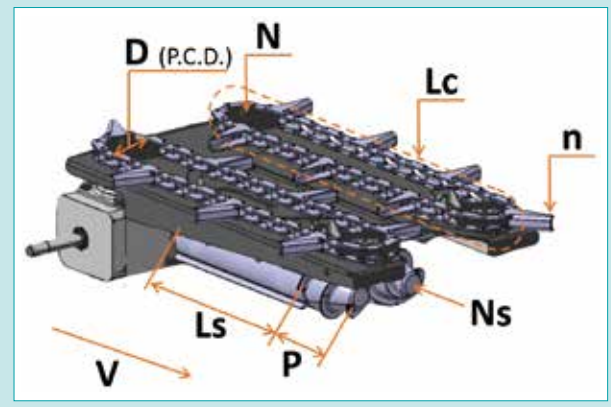

Fig. 7 Parameter of Unit Harvester

4-3 Ensuring high work performance Technology

4.3.1 Technical Challenge

Optimal Stalk roller design to achieve all performance in high level

4.3.2 Solution of Challenge

For enhancing of low fuel consumption performance & high working capacity, the most important part is Stalk roller. Function of stalk roller is pull stalk down for separating only corn pod to reduce load of thresher system by no corn stalk mix in thresher section. Blade is a part attached with stalk roller to improve separating performance.

We considerate two parameters in stalk roller design on separating performance development.

● Rate of complete separating. (Fig. 8)

Only corn pod separating out rate (%) from stalk. If this parameter is not good, not only the pod but also the stalk will be transported to the thresher section, which will increase the load on the thresher section.

● Ability to cut corn stalk. (Fig. 8)

Blade must able to cut pulled stalk to small piece.

If pulled stalk was not cut to small piece, farmer must have to burn remain stalks after harvesting for preparing soil for next crop. Because, long stalk will always jam to plow or Rotary (Fig. 9) when prepare the soil for next crop. It is a special competitive advantage with regard to saving the environment and make easier of soil preparation merit for farmer.

Corn harvesting header CH70 blade of stalk roller design are concern on three parameters. (Fig. 10)

D. Clearance between stalk rollers ; Design for every corn stalk size able to pull pass.

E. Quantity of attached Blade ; Design blade quantity to cover circumference of stalk roller for anti-slip when pull the stalk.

F. Height of Blade ; Find suitable length on test machine for this length on both rate of complete separating (%) and ability to cut corn stalk after harvest. (Fig. 11)

We have realized a structure that achieves the performance of both “Corn pod separating” and “Stalk cutting” at a high level. In addition, the load on each part of the machine has been reduced, and good results have been obtained in terms of fuel efficiency and work capacity.

Fig. 8 CH70 Unit Harvester for Corn Pod Separating Process

Fig. 9 Pulled-up Stalks Jamming into Rotary Machine

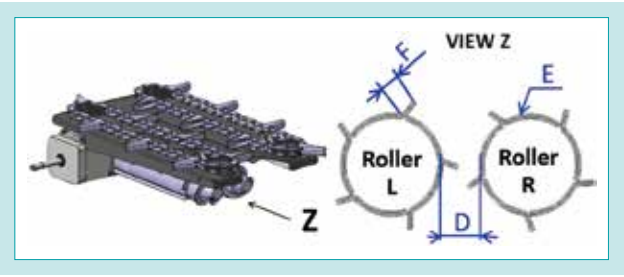

Fig. 10 Blade Shape Layout

Fig. 11 Height of Blade Testing Result

5. Conclusion

With all developed technical innovations CH70 can meet all targets and much better than CK70 and competitor as shown below Table 1.

Table 1 Performance Comparison CH70, Competitor

Specification	Result		
	CH70	Better Competitor	Competitor CH
"High Performance"			
HEADER LOSS [%]	0.21	CH70 Better 33 %	0.33
HARVEST LODGE CORN ≥ 10 Degree [%]	96	=	96
WORKING CAPACITY [ha/hr.]	0.54	CH70 Better 13 %	0.48
FUEL CONSUMPTION [L/ha]	15.62	CH70 Better 10 %	17.5
"Flexible in Using"			
HEADER WEIGHT [kg]	487	○	670
COUNTER WEIGHT [kg]	No	○	Need (100)
HYDRAULIC CYLINDER CHANGE	No	○	Need

○: Better =: Equal

CH70 was first launched in March 2021 in Thailand,and then it will be expanding to ASEAN and around the world from 2022.

CH70 is ready to be the best corn harvesting header in the world. CH70 can contribute to the expansion of Kubota's small combine business and to improve the workability and profitability of users.

Fig. 12 Corn Header CH70 Attached to DC70

Contribution to SDG Targets

2.3 Increasing agricultural productivity and income
Contribution to the increase in income of farmers and contractor in ASEAN through improvement in work efficiency and reduce header loss during corn harvesting.

8.2 Improvement in productivity through innovation
Development a lightweight and compact corn header to save next crop productivity by low ground pressure from combine harvester during corn harvesting.

12.3 Reduction of food loss in production and supply chains
Contribution to reduce the loss during corn harvesting process through development in suitable speed of unit harvester.

13.b Capacity building for climate change planning and management in developing countries
Contribution to reduce CO_2 from burning process after corn harvested and save the earth through development with corn stalk cutting after harvest ability on unit harvester of corn header.

[Reference]

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Development of Ride-on Two-row Fully Automatic Vegetable Transplanter

Transplanter Engineering Dept.

In domestic agriculture, rice farmers who are accustomed to ride-on machines are stepping up their efforts to grow highly profitable vegetables due to the slump in rice prices. In addition, the scale of farms is increasing, and there is a growing demand for a highly efficient and easy-to-use fully automatic ride-on vegetable transplanter. On the other hand, Kubota did not have a line-up ride-on machines that could meet this demand. Given these circumstances, we have developed a new two-row fully automatic ride-on vegetable transplanter. This paper describes the technology we developed made possible "high planting performance" and "easy handling performance", which are in especially high demand.

【Key Word】
Vegetable Transplanter, Planting Performance, Handling Performance, Structure for Controlling Planting Depth

Related SDGs

1. Introduction

In Japan, by the reduction of farmers due to aging, excess farm lands are collected to the large scale farmers, and the scale of such farmers has been increased much more. Additionally, farmers engaged in rice-growing who are familiar with the light-labor riding type machines have launched vegetable growing for the effective use of excess rice paddies because of the reduction in demands for rice and the introduction of highly profitable vegetables due to the reduction in the price of rice, and this trend has been enhanced [1]. Based on these backgrounds, additional high efficiency and reduction of the labor of vegetable planters have been requested.

Conversely, Kubota has been dedicating oneself to the high efficiency of the walk-behind type full-automatic vegetable planting machine (hereafter referred to as a “walk-behind type machine”). However, needs for high efficiency and the reduction of labor in recent years have not been satisfied enough. Therefore, to satisfy such needs, riding two-row full-automatic vegetable planting machine was newly developed (Fig. 1).

Fig. 1 Two-row Fully Automatic Ride-on Vegetable Transplanter

2. Development concept and target value

2-1 Concept of development

Planting performance is the most important performance of vegetable planting machines. As missing plants increase, replanting needs longer time and the efficiency decreases. If the planting posture or planting depth deviates from the setting, decreased growth is caused and the quality is degraded. Naturally, users place the utmost importance on planting performance that directly influences their income. The walk-behind type machine (Fig. 2) enjoys a high reputation of the planting performance, and the developed machine also was required to have the same superior planting performance as that of the walk-behind type machine. Additionally, since the developed machine is newly introduced into the market, it has never been used by anyone. Therefore, easy-handling performance was required.

From the above, "superior planting performance" and "easy-handling performance" were adopted as the development concepts.

Fig. 2 Fully Automatic Vegetable Walk-behind Transplanter

2-2 Development target

(1) Superior planting performance

Achievement of superior planting performance of a walk-behind type machine enjoying a high reputation was a goal.

(2) Easy-handling performance

The vehicle body is applicable to vegetable planting in which sowing is conducted across ridges of height, maximally 30 cm, and the wide step is required, considering the supply of seedlings on the seedling placing stand. The vehicle body of rice transplanters was the most applicable to these conditions. Also, rice-growing farmers who try to grow vegetables are familiar with the handling of the vehicle body of rice transplanters. Thus, the development of a vehicle body based on the vehicle body of rice transplanters was aimed at.

Easy adjustment of the transplanting part depending on the planting conditions improves the handling performance significantly. To achieve superior handling, we targeted the development of the structure allowing the main adjustment of row clearance, planting depth, and root clearance with the minimum work loss.

3. Technological issues to be solved

(1) Superior planting performance

The full-automatic vegetable transplanter performs all processes up to planting by setting the cell tray (Fig. 3) to the machine. The planting part comprises the seedling-extractive tine (A), planting cup (B), press wheel (C), and seedling placing stand (D), and planting is conducted according to the following process (Fig. 4).

(i) A seedling is taken out by the seedling-extractive tine (A) from the cell tray mounted to the seedling placing stand (D).

(ii) The seedling is passed to the planting cup (B).

(iii) The planting cup (B) is stuck into the farmlands, opened in the ground, and the seedling is planted.

(iv) Immediately after that, the seedling is covered with soil with the press wheel (C) for fixing.

To achieve the planting performance equivalent to that of the walk-behind type machine, it is necessary to have the layout with the same positional relation of components from (A) to (D) of the planting part as the walk-behind type to the riding type machine having the different structure.

Fig. 3 Transplanted Seedlings (Broccoli) Cultivated in Cell Trays

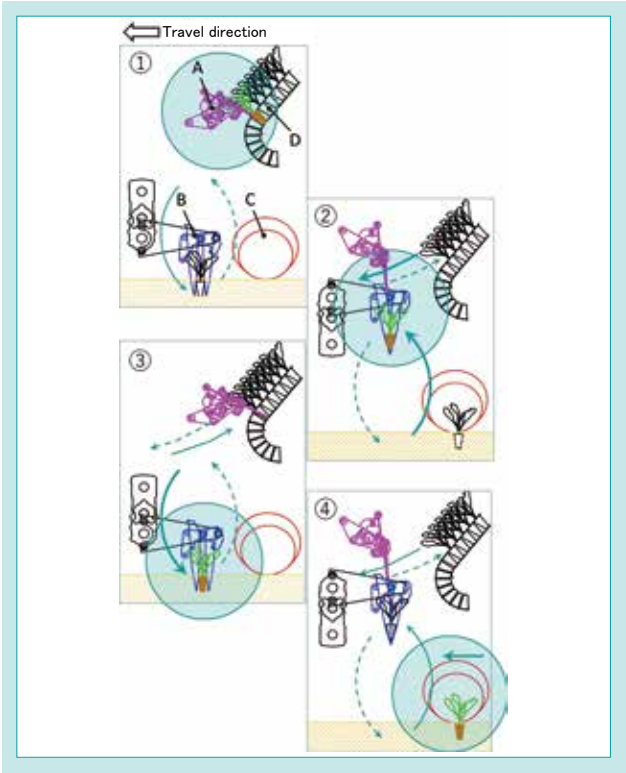

Fig. 4 Planting Process

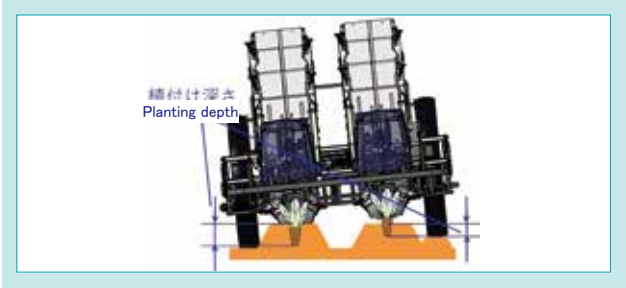

Fig. 5 Planting Depth

The developed machine is of the two-row planting type. Unlike in the case of the walk-behind type machine of the single-row planting type, if the machine body is tilted or there is any difference between the right and left ridges, the planting depth of the right ridge differs from that of the left ridge, and the depth deviates from the target depth (Fig. 5). Therefore, the control technology to maintain the planting depth on the right and left sides uniformly regardless of the tilt of the vehicle body or the difference in the height of the right and left ridges is needed to be developed.

(2) Easy-handling performance

To minimize work loss, easy and quick adjustment of row clearance, planting depth, and root clearance is important. Development of the adjustment structure to achieve them was required (Fig. 6).

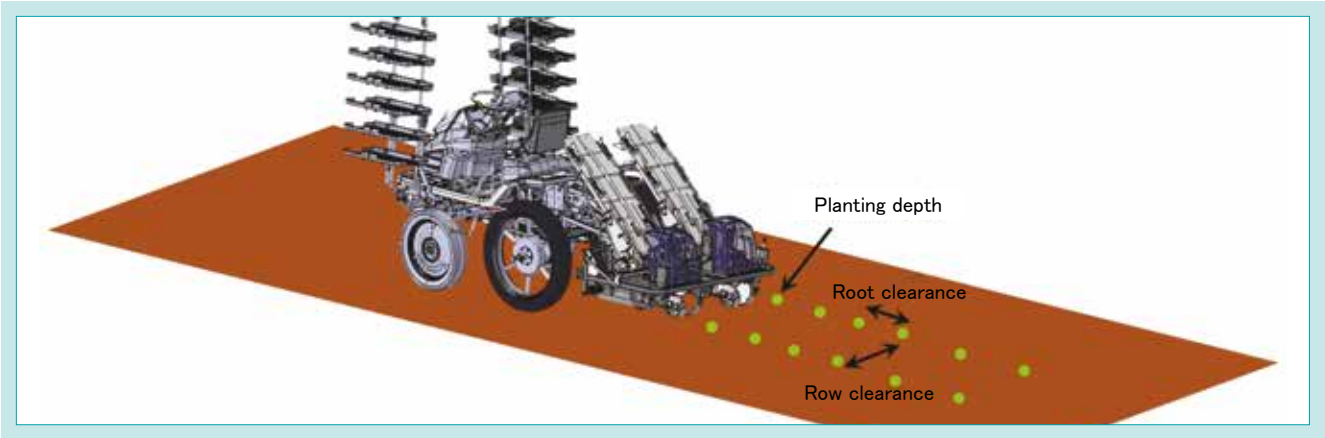

Fig. 6 Various Adjustments

4. Development technology

4-1 Superior planting performance

4.1.1 Development of planting part for riding type machine

The operator of the walk-behind type machine operates the machine behind the machine body. Since the operator supplies seedlings forward, the seedling placing stand is located in front of the operator. Thus, the planting cup is located forward the seedling placing stand (Fig. 7). Conversely, in the riding type machine, the operator is on the forward side of the machine body. Since the operator supplies seedlings from the machine, the seedling placing stand is located behind the operator. Therefore, the planting cup is located behind the seedling placing stand (Fig. 8).

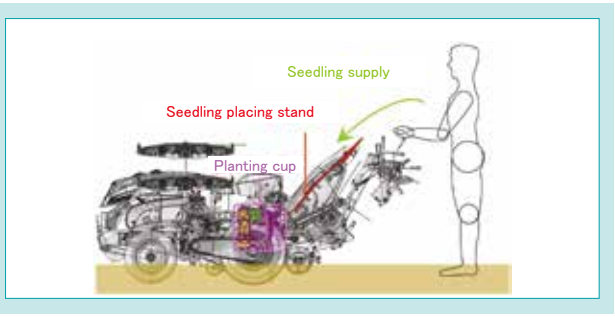

Fig. 7 Arrangement of Walk-behind Type

In this manner, the layout of the riding type machine needs to be changed substantially, compared with the walk-behind type machine. To place the components of the planting part within the layout of the riding type machine with the same positional relation as that of the walk-behind type machine, the size of the planting cup needs to be decreased, since the space in the back of the seedling placing stand to lay out the planting cup was narrow.

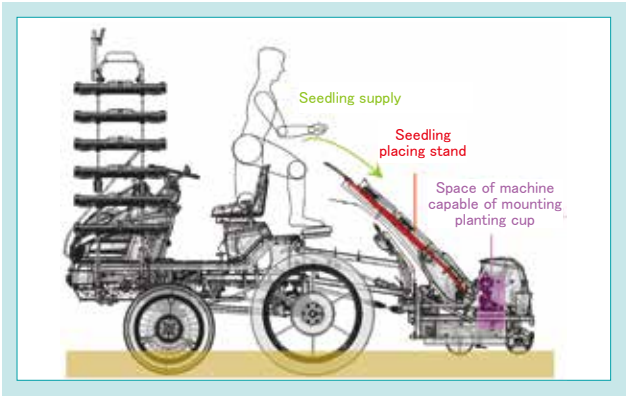

Fig. 8 Arrangement of Ride-on Type

To downsize the planting cup, the structure of the holder connecting the cup to the drive case was reviewed, and the planting cup reduced to 140 mm for the riding type machine was developed, compared with the overall length (305 mm) of the walk-behind type machine (Fig. 9). This allowed the planting cup of the riding type machine with the same layout as that of the walk-behind type machine.

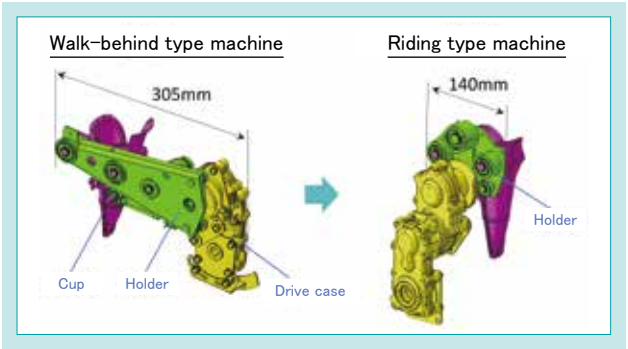

Fig. 9 Planting Cup Structure

4.1.2 Development of ground-Monroe mechanism

"Monroe mechanism," adopted to rice transplanters, is known as the mechanism to control the planting depth. This is the function to maintain the transplanting part horizontal even when the vehicle body is tilted by rolling the transplanting part to the vehicle body. As for rice transplanters, for transplanting seedlings onto the mud face made horizontal by ploughing and irrigating the fields, the transplanting part is controlled horizontally and the planting depth is kept constant based on the information from the angle sensor mounted to the transplanting part. Conversely, vegetable transplanters transplant seedlings into nonhorizontal ridges. To uniform the planting depth of the right and left sides, the height of the right and left planting parts to the ground needs to be equally controlled (Fig. 10). In this development, the Monroe mechanism of rice transplanters was adopted to a vegetable transplanter, and the technology to detect the height of the right and left planting parts to the ground is needed to be developed.

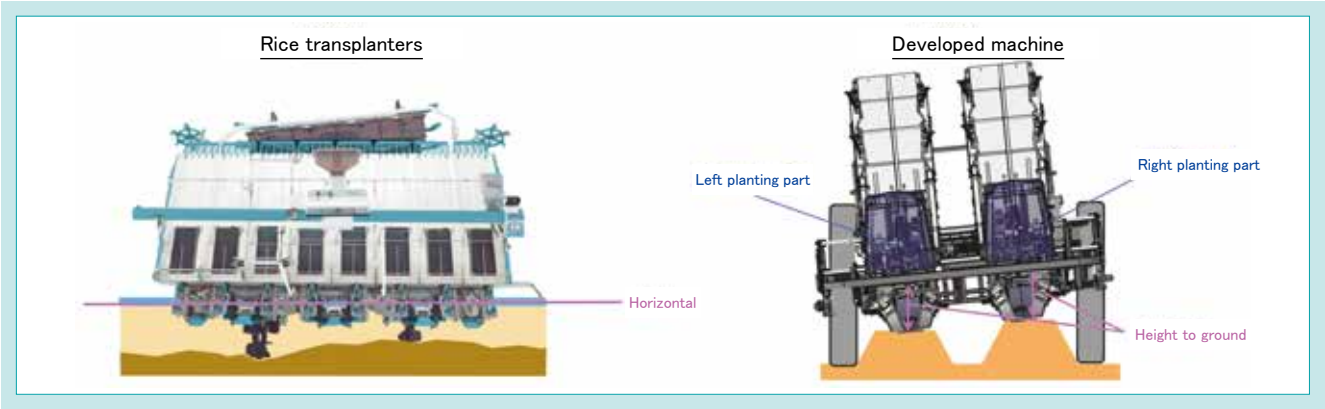

Fig. 10 Planting Depth Control

Then, the sensing roller following the ridge faces was developed. The sensing roller was moved up and down according to the changes in the height including ruggedness on the ridge faces to detect the changes in the angle of the revolving fulcrum, and the ridge height is recognized (Fig. 11). The height of right and left planting parts to the ground is found by the sensing rollers installed to the right and left planting parts. The transplanting part is tilted in the direction filling the gap to maintain the height of the right and left planting parts to the ground equal. The first "ground-Monroe mechanism" in this riding type full-automatic vegetable transplanter allows the highly accurate planting depth control equivalent to that of the walk-behind type machine.

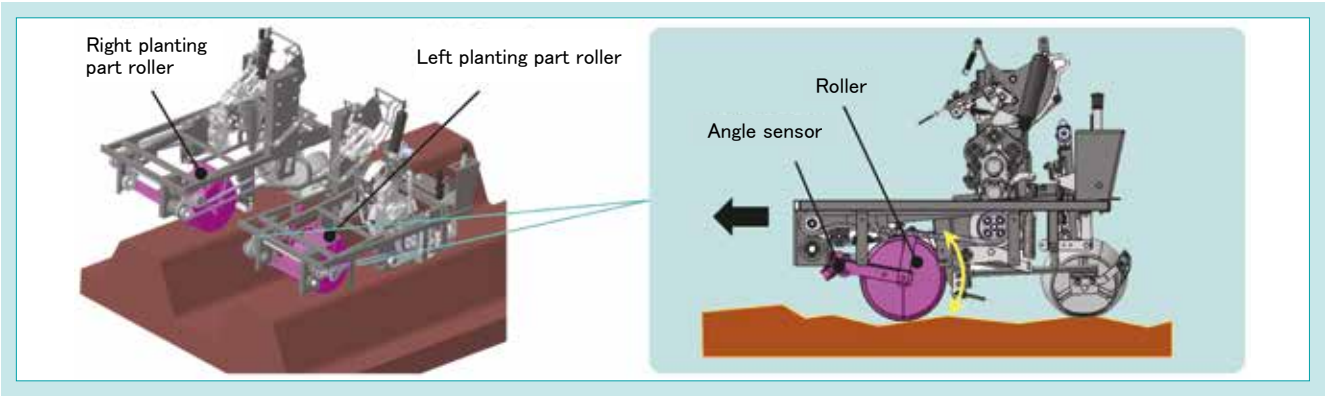

Fig. 11 Ground Height Detection Structure

4-2 Easy-handling performance

4.2.1 Utilization of the vehicle body of rice transplanters

The vehicle body of a rice transplanter was applied to a vegetable transplanter by installing the spare seedling placing stand capable of carrying 12 seedling boxes, structure allowing the change of tread depending on the ridge system, wide tires to secure the driving characteristics in fields, and the provision of electromagnetic clutch to control the root clearance. Although the electronic up lever, mounted to Kubota's rice transplanters, allowing the lifting and planting operations of the transplanting part at hand and enjoying a high reputation, and the four-wheel vehicle suspension, contributing to comfortable work, were remained, the machine body of high operability was newly developed.

4.2.2 Development of easy row clearance adjustment structure

When adjusting row clearances, the clearance of the right and left planting parts is changed according to the clearance between the planting rows. To simplify the adjustment of row clearances, respective blocks comprising the planting part, seedling placing stand, seedling-extractive tine, and planting cup, were integrated as much as possible, and the portion for adjustment was designed to be composed of three units (Fig. 12). Thanks to the adjustment mechanism sliding the three units, easy adjustment of the clearance between rows was achieved.

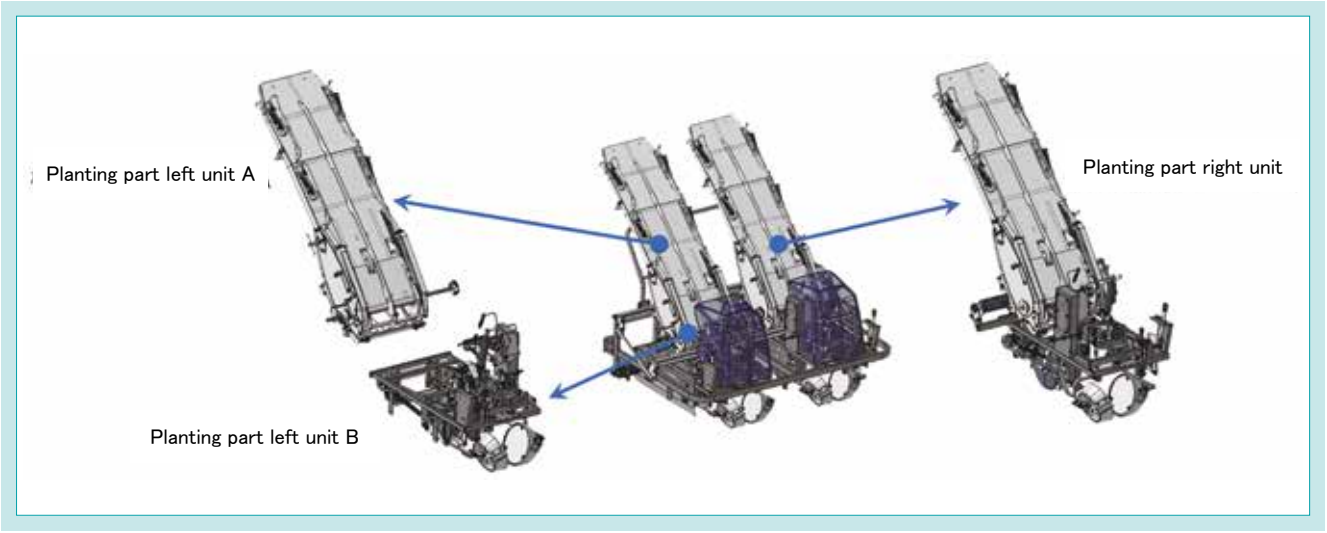

Fig. 12 Unit Structure of the Transplant part

4.2.3 Development of easy planting-depth-adjustment structure

To achieve the structure allowing easy adjustment at hand, the planting-depth-change-structure was electronized, and the adjuster volume was placed at hand. Easy and quick adjustment during operation is enabled through the adjustment of the volume at hand (Fig. 13).

Fig. 13 Planting Depth Adjustment Structure

4.2.4 Development of root clearance mechanism

The root clearance control structure adopted to the walk-behind type machine was incorporated into the riding type machine too. The structure allows the intermittent drive of the planting drive shaft by the electromagnetic clutch to control the stop time to change the root clearance. To widen the root clearance, extend the stop time, and shorten the stop time to narrow the root clearance (Fig. 14). Also, the operation panel for adjustment comprises the root clearance indicator and the push switch to allow the accurate adjustment by 1 cm while checking the indicated root clearance (Fig. 15).

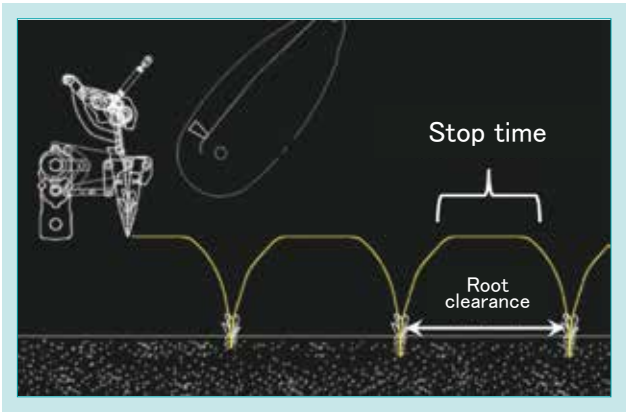

Fig. 14 Hill Space Control

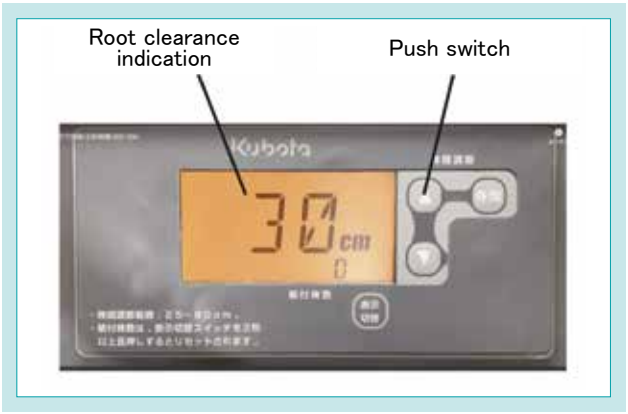

Fig. 15 Control Panel

5. Conclusion

To meet needs for the high efficiency of domestic farmers and the reduction of labor, the riding type two-row full-automatic vegetable transplanter achieving “superior planting performance” and “easy-handling performance” was developed.

1) The planting cup structure for the riding type machine was developed, and superior planting performance equivalent to that of the walk-behind machine was achieved.
2) By the development of “ground-Monroe” mechanism, accurate planting depth control during planting into two rows was achieved.
3) Easy-handling performance was achieved and work time loss by adjustment was minimized using the vehicle body of rice transplanters, the unit structure of the row clearance adjuster part, and operation at hand by the electronization of planting depth control and root clearance control.

In addition to the matters described in this article, high efficiency and convenience were considered for this developed machine by the factors including the maximum work speed in the industry, transplanting part capable of replacing with the weeder by the adoption of multipurpose hitch. Additionally, this developed machine was applied to the row clearance from 40 cm to 66 cm, and thus, the applicable range of cultivating conditions was wider than that of competitor’s machine (row clearance: 45 cm to 65 cm). The approach to widen the applicable range will be promoted additionally. Also, approach to the application to multiple rows aiming at higher efficiency will be promoted.

Contribution to SDG Targets

2.3 Increase in agricultural productivity and income
Improvement in productivity by improving planting performance
2.4 Achievement of sustainable and rigid agriculture
Even elderly people can work easily by the reduction of labor by the riding type machine
8.2 Improvement in productivity by innovation
Work efficiency is significantly improved by riding and two-row planting type machine

Reference
1) Ministry of Agriculture, Forestry and Fisheries: Documents related to rice (July, 2020)

Development of DPF Regeneration System Under All Operating Conditions for Generators

Engine Engineering Dept. Ⅰ

As the global emission regulations have become more stringent recently, a DPF that filters PM in exhaust gas is becoming essential for diesel engines. Engines equipped with a DPF must carry out DPF regeneration that burns and removes PM, but generator engines that operate unmanned cannot be stopped during DPF regeneration. Therefore, it is required that a DPF can be regenerated under all operating conditions even where the exhaust temperature is low. In this study, the development of Kubota's original exhaust gas heating system using an exhaust heating catalyst and exhaust throttle enables regeneration under all operating conditions. In addition, this study solved the problem that low load operation sometime causes both white smoke and DOC clogged during generator use.

【Key Word】
Diesel Engine, Electrical Generator, PM, DOC, DPF, Exhaust Heating Catalyst, Exhaust Throttle Valve

Related SDGs

1. Introduction

In the EU Stage V and China Tier 4 Emission Regulations enforced in recent years, a number of particles as well as the particle matters in emissions (Particle Matter, hereafter referred to as PM) are regulated. Therefore, diesel engines gradually need to be equipped with diesel particulate filter, hereafter referred to as DPF, which collects PM. If a diesel engine is equipped with DPF, reproduction of the DPF, a control to burn and remove the collected PM, is required. DPF is reproduced in the following process: reacting fuel with the diesel oxidation catalyst in the upstream of DPF (hereafter referred to as DOC) shown in Fig. 1, increasing the exhaust temperature, and burning PM.

Since the generator engine is continuously operated in an unmanned state, the operation cannot be stopped to reproduce the DPF. Thus, DPF is required to be reproduced under any operating conditions when PM of the fixed amount or more is accumulated onto the DPF. Additionally, in many cases, a generator is operated in the standby status before the power supply load is applied. It features the long-time operation under a light load at a low exhaust temperature. Therefore, even at a low exhaust temperature that PM combustion and removal are difficult, the system allowing the reproduction of the DPF is required.

Generation of white smoke and clogging at the DOC end face are other issues of the generator engine. Since the exhaust temperature during light-load operation of a generator is low, hydrocarbon (hereafter referred to as HC) caused by unburned fuel and oil is exhausted from the engine and accumulated in the DOC. White smoke is generated when HC accumulated in the DOC for a long time is emitted at a time from the DOC at high load and high temperature. In this situation, HC acts as glue, PM is aggregated, and the DOC end face is clogged (Fig. 2). This technical report presents the DPF reproduction technology applicable to generator engines and the technology to prevent white smoke and DOC clogging.

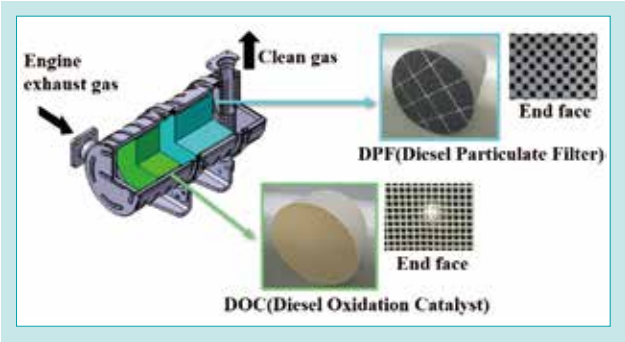

Fig. 1 Schematic of DOC and DPF

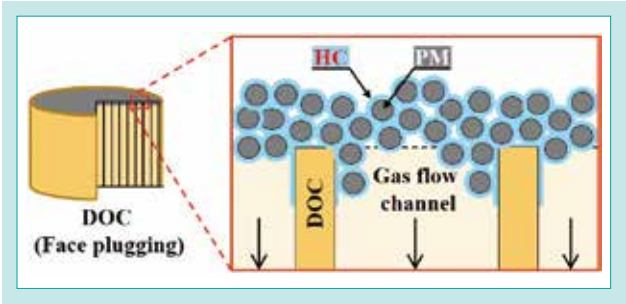

Fig. 2 Schematic of DOC Face Clogging

2. Development concept and target value

2-1 Concept of development

As a generator engine conforming to the emission regulations including the regulation for the number of PM, the DPF reproduction system equipped with DPF applicable to light-load operation, one of the characteristics of generators, needs to be developed. Temperature increase in emission accompanied with the combustion of fuel in the DOC is used for the reproduction of DPF. Thus, the temperature of DOC higher than the activation temperature that the DOC is combustible is a prerequisite. Therefore, the exhaust heating method is required to reach the activation temperature of DOC during light-load operation at a low exhaust temperature. Additionally, white smoke and the clogging of DOC end face are caused by HC accumulated in the DOC at a low exhaust temperature less than 200°C. To reduce the accumulation of HC, temperature of the DOC needs to be increased to 200°C or more where the oxidation and removal of HC are allowed. Thus, the exhaust heating catalyst, hereafter referred to as EHC, metal carrier carrying precious metal catalyst and the exhaust throttle were provided in the upstream of the DOC as the devices to heat the DOC (Fig.3). EHC is capable of increasing the exhaust temperature by catalytic reaction. The restrictor of the exhaust throttle also can increase the exhaust temperature by increasing the fuel injection amount with the compression of exhaust gas and the increase in exhaust resistance. By establishing the exhaust heating method with these devices used, the reproduction of DPF was allowed even at a low exhaust temperature, and the development of high performance and highly reliable engine capable of preventing white smoke and clogging of DOC end face was targeted.

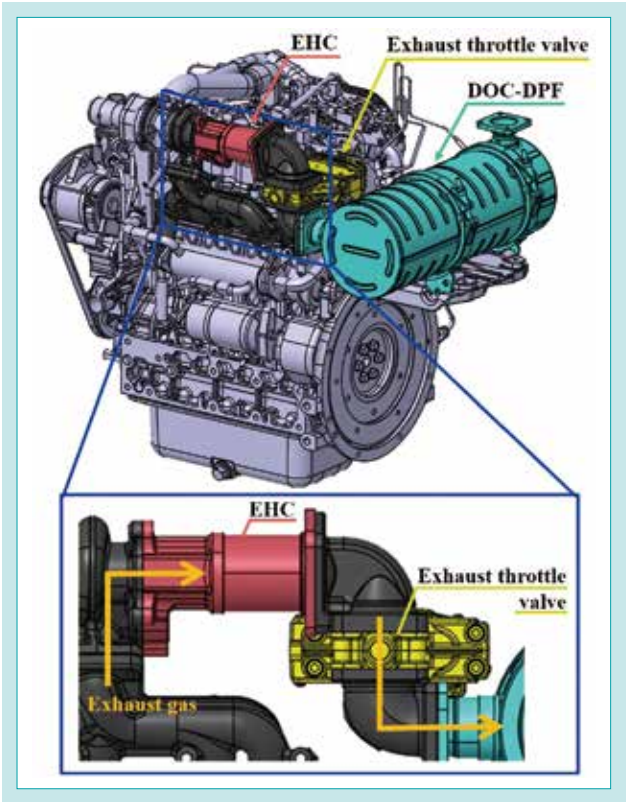

Fig. 3 Schematic of Engine for Generator in this Development

2-2 Target value

Construct the exhaust heating technology allowing the reproduction of DPF and achieve the DPF reproduction system that can be used in all ranges of operating conditions even in the nonload operation in which the exhaust temperature is lowest, approximately 100°C. Establish the method to prevent white smoke and clogging of the DOC end face, and develop the system applicable to continuous light-load operation for a long time.

By the development of technologies above, we aimed to achieve the reduction of PM emission by the DPF and supply of generator engines that are superior in maintainability and reliability.

3. Technological issues to be solved

Exhaust temperature depends on the engine load ratio, since generator engines are operated at the fixed revolving speed depending on the frequency. Fig. 4 shows the relationship between the engine load ratio and the exhaust temperature. In the light-load area in which the exhaust temperature is less than 250°C, DPF cannot be regenerated because the DOC does not achieve the activation temperature. To realize the DPF regeneration system that can be used in all ranges of operating conditions, technology for exhaust heating during light-load operation is required. The technology for heating exhaust is also required to oxidize and remove HC causing white smoke and clogging of the DOC end face. Especially, it is suggested that the HC accumulated in the DOC becomes fire-resistant that does not burn at a temperature less than 400°C[1], and to prevent clogging of the DOC end face, PM including fire-resistant HC needs to be heated to the temperature that allows combustion and removal. To solve these issues, approach to the development of the technology for heating exhaust in the DOC upstream was taken.

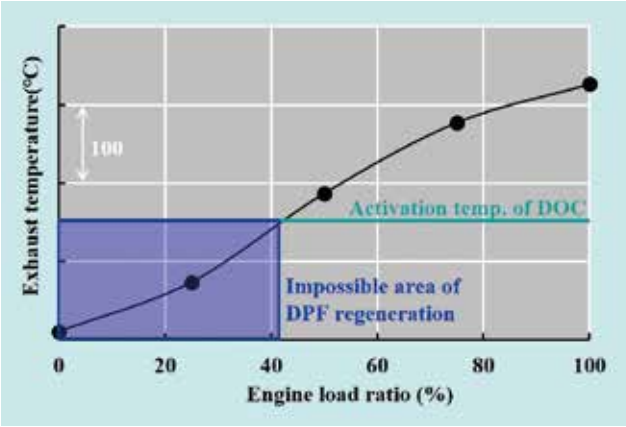

Fig. 4 Correlation Between Engine Load Ratio and Exhaust Temperature

4. Development technology

4-1 No-load DPF regeneration

4.1.1 Issues in the heating technology of multistage injection control

In the past, after-injection and post-injection in the multiple injection control of fuel have been used as the technology to increase the exhaust temperature. Fig. 5 shows the injection process of multiple injection control. The after-injection is performed to increase the exhaust temperature after the main-injection in which engine torque is taken out. Fuel burns again in the engine cylinder by the after-injection, and the exhaust temperature can be increased without giving any influence on the output. However, the combustion temperature is low, and recombustion hardly occurs during no-load operation, so heating effect by the after injection is difficult to obtain. Fuel fed by the post-injection reaches the DOC without burning in the engine cylinder, and the exhaust temperature is increased by the catalytic reaction by DOC. It means that the post-injection allows the supply of fuel required for the regeneration of DPF to DOC and it cannot be performed unless the temperature of DOC is maintained at the activation temperature of catalyst or more.

Therefore, exhaust heating using the after-injection and post-injection cannot be performed at the temperature less than the fixed level, and other heating technologies are required.

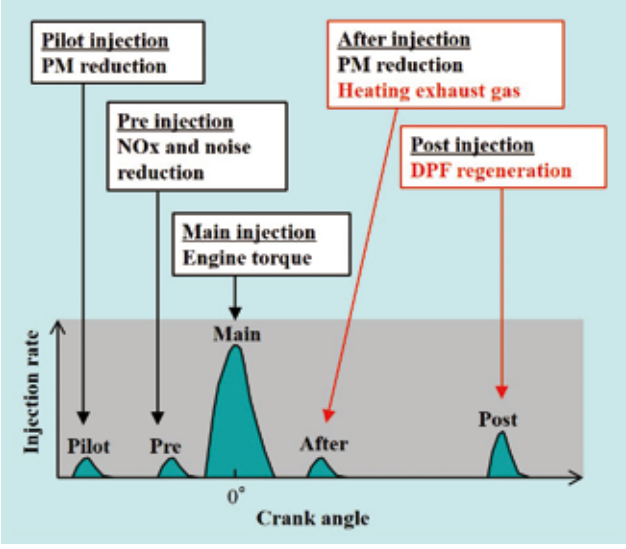

Fig. 5 Process of Multiple Injection

4.1.2 Exhaust heating control using exhaust throttle and EHC

The new device, exhaust throttle, has the function to restrict the exhaust route by controlling the valve opening. The restrictor of the exhaust throttle also can increase the combustion temperature as well as the exhaust temperature by increasing the fuel injection amount with the increase in exhaust resistance. The exhaust throttle control allows the increase in temperature to the level that allows obtaining the recombustion effect in the after-injection (Fig. 6-(1)). However, the use of the exhaust throttle and the after-injection did not reach the DOC activation temperature of 250°C (Fig. 6-(2)). Thus, the additional method, in which unburned fuel is reacted by catalyst in the EHC and the exhaust temperature is increased, was provided. In this system unique to Kubota, unburned fuel is fed to the EHC and reacted to increase the temperature by increasing the after-injection amount, whereas the exhaust throttle is restricted (Fig. 7). By the development of "exhaust heating control" using the exhaust throttle, after-injection, and EHC, the temperature can be maintained to the level exceeding the activation temperature of DOC (Fig. 6-(3)).

DPF was regenerated during no-load operation with the developed "exhaust heating control" applied. Fig. 8 shows the transition of the inlet temperature of the DOC during the regeneration of the DPF and the DPF inlet temperature. The inlet temperature of the DOC was increased by "exhaust heating control" to the activation temperature. Immediately after that, fuel was fed to the DOC by the post-injection. Exhaust gas heated by the combustion of fuel in the DOC to high temperature was fed into the DPF, and the temperature was increased to and maintained at the PM combustion temperature range. By the above exhaust temperature control, it was recognized that the DPF regeneration was allowed at nonload without a problem.

It was recognized that the DPF was regenerated without a problem even in the environment at −25°C expected for the cold area market in Northern Europe by using "exhaust heating control" of this development, and the regeneration of DPF in all areas including nonload operation was achieved.

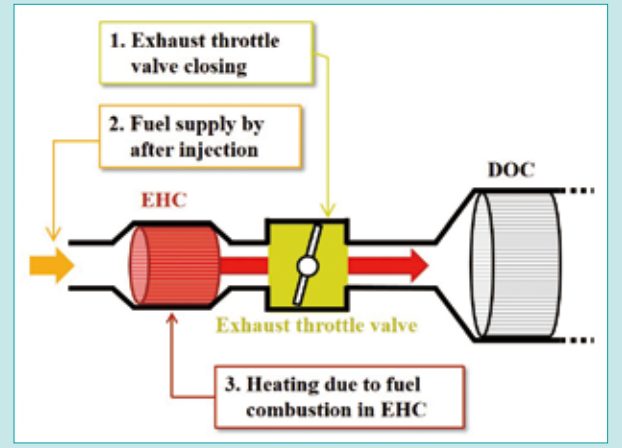

Fig. 7 Mechanism of Exhaust Heating Control

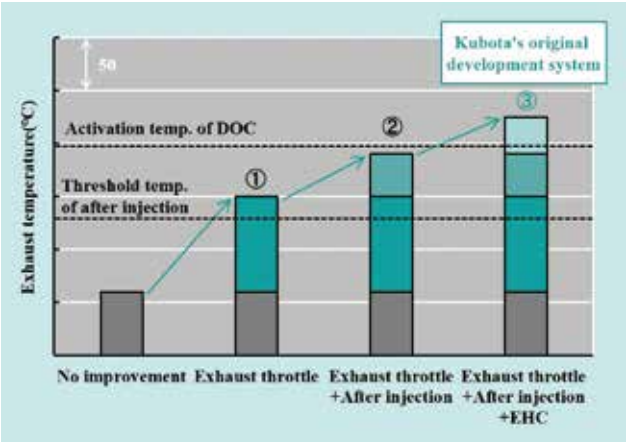

Fig. 6 Comparison of Rising Exhaust Temperature Under no Load Operation

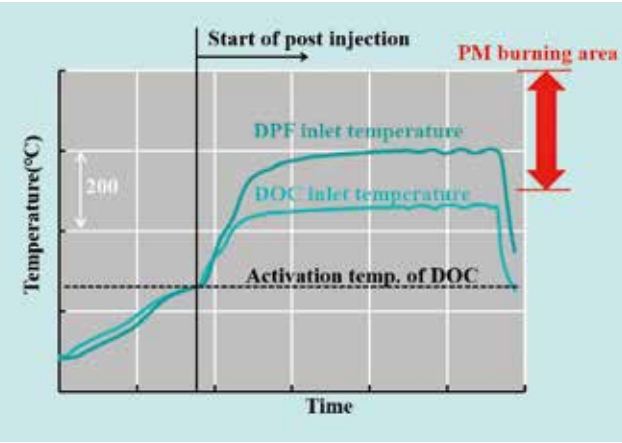

Fig. 8 Exhaust Temperature Profile of DPF Regeneration Under no Load Operation

4-2 Prevention of white smoke by periodic heating

During light-load operation in which the exhaust temperature is low, less than 200°C, HC caused by unburned fuel is emitted from the engine and accumulated into the DOC. HC accumulated in the DOC for a long time is discharged from the DOC under high load and at a high temperature at a time and white smoke is emitted. Therefore, it is necessary not to accumulate HC into the DOC by the fixed amount or more. Thus, "periodic heating system," unique to Kubota, which detects light-load operation and performs "exhaust heating control" periodically, was introduced.

An amount of HC accumulated into the DOC increases suddenly at the temperature less than the fixed level at which failure in the combustion of fuel easily occurs (Fig. 9). The periodic heating system decides that the temperature range in which the amount of accumulated HC increased suddenly leads to light-load operation, and the time is counted. After a fixed time has passed since the light-load operation judgment was given, HC was oxidized and removed by performing "exhaust heating control," similar to 4-1; prevention of white smoke was aimed at by reducing the accumulation of HC (Fig. 10).

Transition of HC emission amount when the maximum load was applied during continuous no-load operation and immediately after that was compared between the case that the periodic heating system was introduced and the case that the system was not introduced (Fig. 11). If the periodic heating system was introduced, exhaust gas was heated during exhaust heating control, HC emitted from the engine was oxidized, and the discharge amount was decreased. If the periodic heating system was not introduced when the maximum load was applied immediately after no-load operation, the peak of HC causing white smoke was observed. Conversely, if "periodic heating system" was introduced, HC in the DOC was oxidized and removed periodically by the exhaust heating control when the maximum load was applied, the peak of HC was not recognized, and white smoke was prevented.

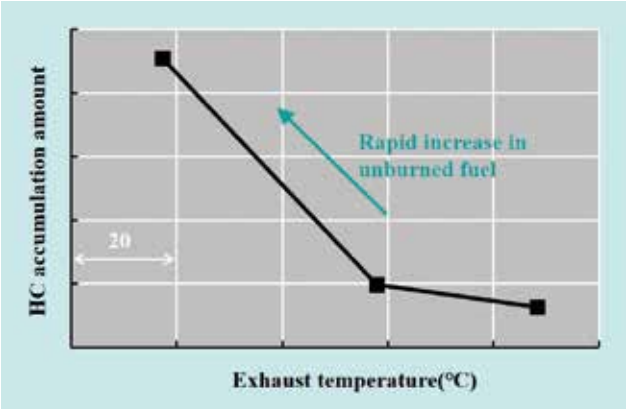

Fig. 9 Relationship Between Exhaust Temperature and HC Accumulation

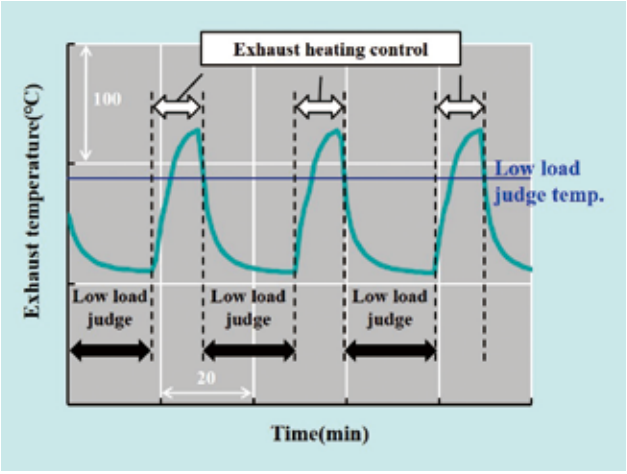

Fig. 10 Pattern of Constant Heating System

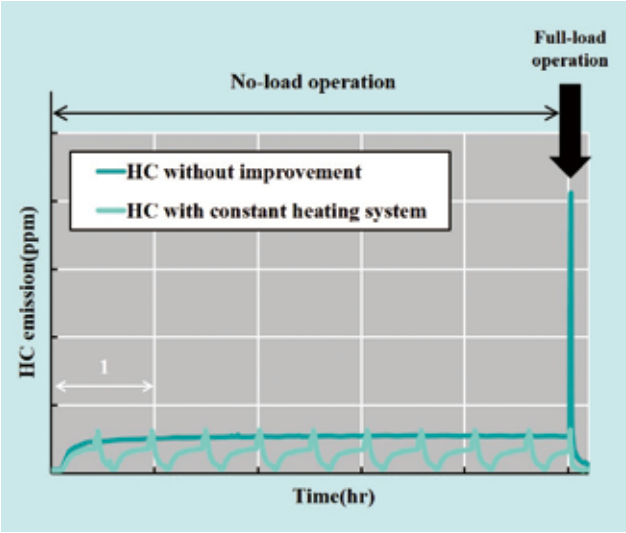

Fig. 11 Comparison of HC Emission Profiles With and Without Periodic Heating System

4-3 Prevention of clogging of DOC end face

HC emitted from the engine during light-load operation, acting as glue, gathers PM on the DOC end face to clogging it. Additionally, it is recognized that HC becomes fire-resistant and does not burn at a temperature less than 400°C on catalyst in DOC. Although the accumulation of HC in the DOC was reduced by the periodic heating system, clogging of the DOC end face could not be prevented. Then, to burn PM including HC accumulated on the DOC end face, "DOC refresh control" that heats the exhaust in the upstream of the DOC was introduced. "DOC refresh control" is the technology unique to Kubota that the exhaust gas fed into the DOC is heated by reacting fuel fed by the after-injection and the post-injection in the EHC with the exhaust throttle restricted. It is aimed that the inlet temperature of the DOC is maintained higher than the temperature during the periodic heating and the regeneration of DPF (Fig. 12).

As a result of "DOC refresh control" performed on the DOC whose end faces are clogged, complete removal of clogging materials was recognized (Fig. 13).

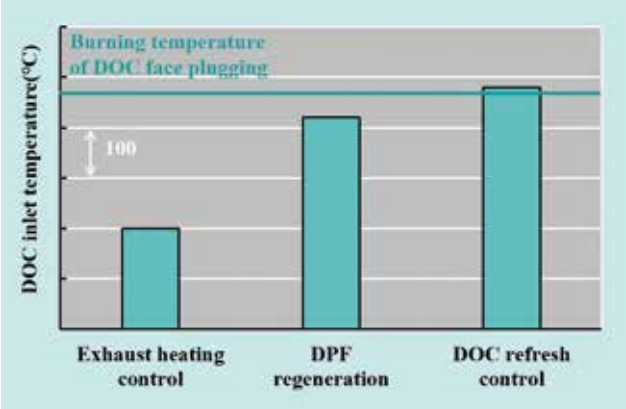

Fig. 12 Comparison of DOC Inlet Temperature for Each Control

The system to perform "DOC refresh control" periodically was incorporated, and the clogging status was recognized in the long-time no-load endurance test by the measurement of the DOC differential pressure (Fig. 14). Although increase in the DOC differential pressure, which is the initial tendency of clogging on the DOC end faces, was observed, it was recognized that the DOC differential pressure decreases to the pressure before the endurance test by the DOC refresh control. "DOC refresh control" allowed the prevention of clogging on the DOC end faces, and the reliability and endurance during light-load operation were increased.

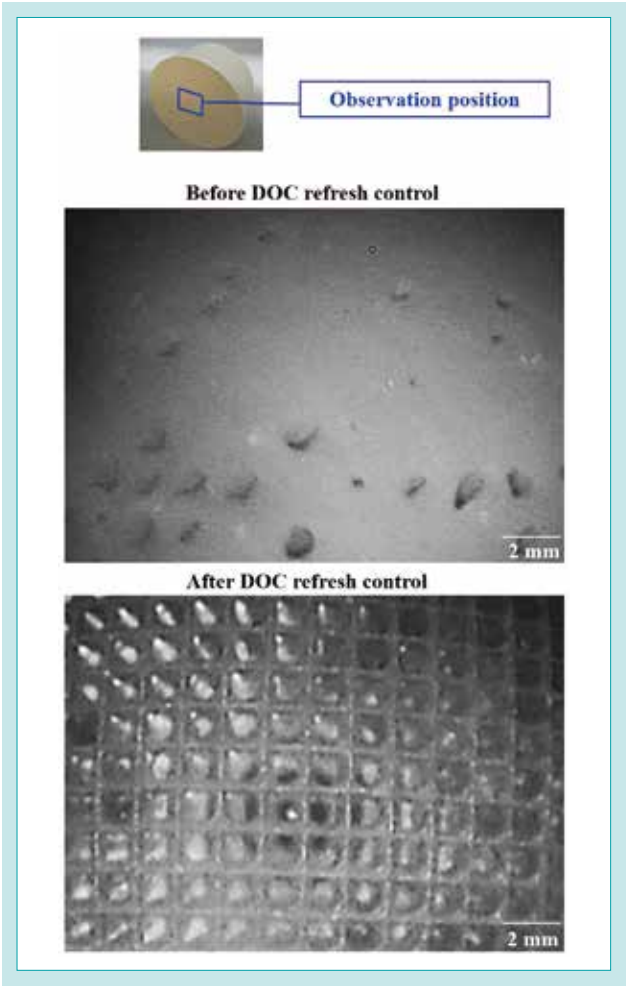

Fig. 13 Micrograph of Inlet End Face of DOC Before and After DOC Refresh Control

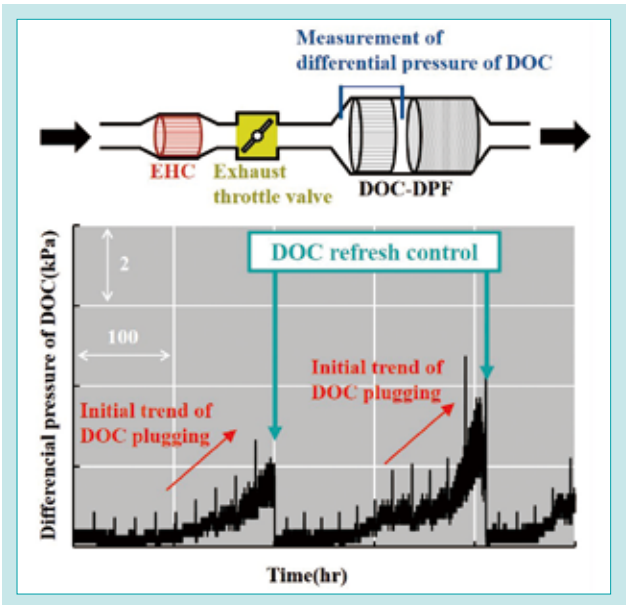

Fig. 14 Differential Pressure of DOC During Long-term no-load Durability Test

5. Conclusion

Kubota's unique technology developed for generator engines is equipped with the DOC and DPF, and their outcomes are shown below.

(1) By "exhaust heating control" using the EHC and the exhaust throttle, the regeneration of the DPF in all ranges including no-load operation was achieved.

(2) Introduction of "periodic heating system" that controls exhaust heating periodically during light-load operation allowed the reduction of accumulated HC during light-load operation and the prevention of white smoke.

(3) Then, "DOC refresh control" that burns PM including HC accumulated on the DOC end face was introduced and performed periodically. It allowed preventing clogging on the DOC end face.

By the results of the development above, the engine superior in maintainability and reliability was realized while reducing PM emissions required for the protection of the global environment.

This development technology can be used for applications other than generators, and the expansion of the operation range allowing the regeneration of DPF and the improvement in reliability of light-load operation are expected. Also, it is suitable for the use at a highland where intake air shortage causes white smoke and use at cold places where the exhaust temperature is low. By the development of technology of these engines equipped with DPF, we further disseminate DPG solutions that Kubota is good at.

Contribution to SDG Targets

3.9 Reduction of deaths and epidemics caused by toxic chemical substances and pollutions of the air, water quality, and the earth
Substantial reduction of the emission of PM causing damages to health

7.1 Securement of universal access to modern energy service
Energy supply by highly reliable generators

Reference

1) Kouta Nakano et al.: "Explication of the mechanism of clogs on DOC end face-Dependency on temperature of HC accumulation-," the 124th Catalyst Review Meeting, 2E08, (2019)

Development of V1505T Engine with Common Rail Fuel Injection System

Engine Engineering Dept. Ⅰ

05 series engines are the leaders in our engine business. They are installed on Kubota's agricultural, construction and OEM machines. The V1505 Turbocharged (V1505T) engine is the high-end model of 05 series having features not found in competitors' products such as low vibration due to its small size and four-cylinder configuration. EU Stage V emissions regulations have been enforced since 2019 and the regulation value has been significantly strengthened. In order to secure business volume and further expand sales in the European market, we have developed the V1505T common rail engine. Here we describe our approach to achieve DI combustion with the smallest cylinder bore and to realize a compactness comparable to a competitor's 3-cylinder engine.

【Key Word】
V1505T, Common Rail System, DI Combustion, Small Cylinder Bore, Compactness

Related SDGs

1. Introduction

05 series mounted to agricultural machine, construction machines of Kubota, and OEM machines play the core role in the business of engines. Above all, V1505T engines perform the maximum output of 33 kW, and it have unique characteristics that no conpetitors have, i.e., small size, and low vibration unique to four-cylinders configuration.

In Europe where 05 series is deployed, since 2019, emission regulations Stage V has been enforced. In the output category of 19 to 37 kW to which V1505T engines, the regulated value was significantly enhanced, the emission of nitrogen oxide (NOx) and hydrocarbon (HC) has decreased by 37%, and the emission of particulate matter (hereafter referred to as PM) has reduced by 97.5%. In Stage V, the regulation for the number of PM (hereafter referred to as PN: particulate number) was introduced in the world for the first time. However, in the mechanical fuel injection system of the current machine (hereafter referred to as mechanical type), precise fuel injection cannot be controlled and thus, the system cannot comply to the regulation[1]. Therefore, to comply to the regulations within the current engine lineup, the current engines are forced to be replaced to the engines of less than 19 kW, or the electronic-control-type engines of the upper class. However, when replacing to engines of less than 19 kW, degradation of the workability of the mounted machine with such an engine due to decreased output is concerned. When replacing to the upper-class-series engines, significant change of the mounting layout is required due to increased engine size. To solve these issues and expand the sales of the engines and machines mounted with them in Europe market, development of the machines complying to the Stage V that succeed the characteristics of V1505T was required.

2. Development concept and target value

2-1 Concept of development

To comply to the regulations, the electronic control common rail system (hereafter referred to as CRS) that has been adopted for the upper class series and improvement for combustion are required[2]. In addition, the exhaust gas recirculation device (hereafter referred to as EGR) reducing NOx emission and the diesel particulate filter (hereafter referred to as DPF) collecting PM need to be added, and emissions need to be purified comprehensively. The following two factors were set as the development concept, taking into consideration them.

(1) Compliance to EU emission regulations Stage V by adopting CRS, EGR, and DPF
(2) Succession of small size and low vibration of the current model V1505T

2-2 Target value

Table 1 shows the specifications of the developed engine. Fig. 1 shows the external view. The following two factors were set as the development targets.

(1) Newly adopt CRS, EGR, and DPF, and develop the engines satisfying the regulation values of EU emission regulations Stage V.
(2) Develop the engines succeeding the characteristics of the current model V1505T, small size and low vibration.

Table 1 Engine Specification

Model	V1505T (current machine)	V1505T-CR (developed machine)
Combustion system	IDI(Indirect Injection)	DI(Direct Injection)
Fuel injection system	Mechanical type	Electronic control system (CRS)
Emission purifier	–	DOC, DPF, EGR
Number of cylinders	4	
Bore × Stroke (mm)	78.0 × 78.4	
Displacement (L)	1.498	
Length × Width × Height (mm)	591 × 433 × 621	591 × 455 × 638 (*787 × 455 × 691)
Rated output (kW/rpm)	33.0/3,000	

*Status when DPF is mounted

Fig. 1 External View of V1505T-CR

3. Technological issues to be solved

3-1 Achievement of DI combustion

In order to adopt CRS, the combustion system needs to be changed from IDI to DI. Fig. 2 shows the shapes of respective combustion chambers. Fig. 3 shows the comparison of cylinder bore diameter and the displacement per cylinder of Kubota's upper-class-series and competitors' common rail engines (hereafter referred to as CR engines). There is no CR engine of small-bore-diameter same of the current V1505T, and every engine has the large bore. Therefore, the developed model with the same bore diameter of the current model is the CR engine of the smallest-bore diameter in the industry. In addition, the volume of the main combustion chamber of a piston is also the smallest in the industry. Thus, the time until the fuel spray reaches the wall of the combustion chamber is short compared with the upper class series with bore diameter is large. Fuel spray is coarsened when it interferes with the wall and does not contribute to combustion. Consequently, it causes a worsened fuel consumption cost and emission gas performance. To achieve DI combustion with the small diameter bore, prevention of the interference of fuel spay with the wall and uniform mixture of fuel and air in a short time are necessary.

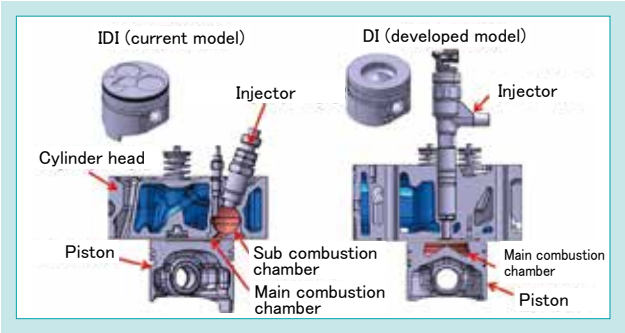

Fig. 2 Shape of Combustion Chamber

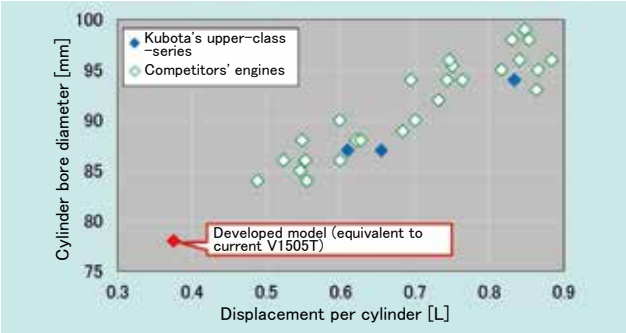

Fig. 3 Comparison of Cylinder Bore Diameter and Displacement per Cylinder of CR Engine

3-2 Maintenance of mounting compatibility

Developed model have many additional parts with the adoption of CRS, DPF, and EGR devices. Fig. 4 shows the layout of main additional functional parts. In addition, additional related parts shown in Table 2 is required. To succeed the small size that is the characteristics of V1505T and maintain the mounting compatibility with the current model, limitation of the increase in the size by the newly added parts is important.

Table 2 Main Additional Rerated Parts

Related device	CRS	EGR	DPF
Required parts	Pulsar gear	EGR pipe	Oil separator
	Pulsar wheel	EGR flange	Differential pressure sensor

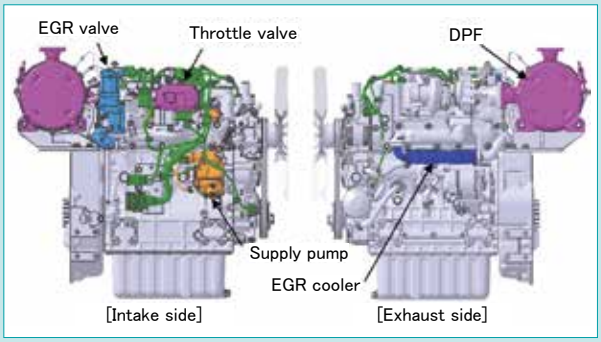

Fig. 4 External View of Main Additional Functional Parts

4. Development technology

4-1 DI combustion technology with small diameter bore

4.1.1 Four-valve CDIS (Center Direct Injection System)

The developed model adopted CDIS in which the injector is vertically located with the center focused on the cylinder bore with the abolished space of the sub combustion chamber. This modification contributed to the equalization of fuel spray into the cylinder and improvement in the mixture with air. Also, to promote the mixture of fuel and air, the air flow in the cylinder is important[3]. Thus, swirl flow (rotational flow around the cylinder center) was strengthened to optimize the air flow by adopting the four intake and exhaust valves (two valves for each). Fig. 5 shows the schematic drawing of the four-valve CDIS.

In the design of the intake port shape of the cylinder head applicable to the four-valves, flow analysis was used for optimization. Fig. 6 shows the analysis results of the intake port of the developed model. Swirl flow was enhanced by the port of the longer route along the cylinder in the two routes of intake port. Shape of the port of the shorter route was made to allow feeding the flow from the port into the cylinder center to prevent interference with swirl flow. By optimizing the two air flows, swirl flow and the intake efficiency that have trade-off relationship with each other were improved at a time.

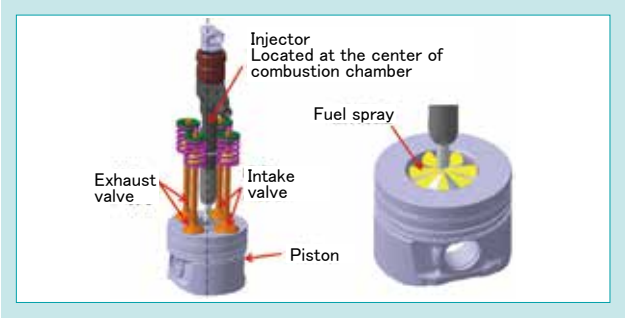

Fig. 5 4 Valve CDIS

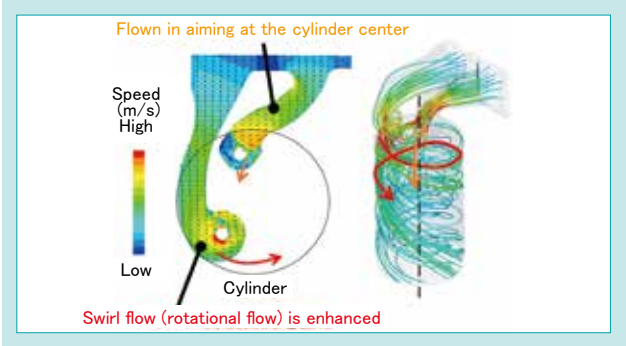

Fig. 6 Analysis Result of Intake Air Flow

4.1.2 Combustion analysis

To prevent interference of fuel spray with the wall and optimize the air flow, the fuel injection angle and the shape of combustion chamber were optimized by combustion analysis. Fig. 7 shows the results of combustion analysis. The flow speed of mixed air in the cylinder is shown on the left side, and the fuel concentration in the mixed air is shown on the right side. At this stage, fuel spray is spread in the combustion chamber, and the flow speed and fuel concentration are increased as the flow is closer from the fuel injection hole to the combustion chamber wall. From the cross-sectional view of combustion chamber, the fuel injection angle that the conic part in the center of the combustion chamber does not interfere with fuel at this timing was estimated. Based on the behavior of the mixed air in the combustion chamber, tendency of the combustion chamber shape to allow using the much more air in the combustion chamber was understood, and it was reflected to the actual enigine.

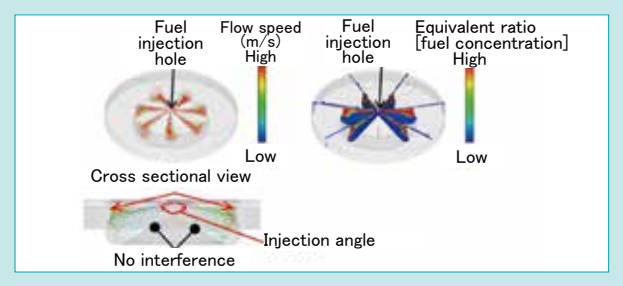

Fig. 7 Combustion Analysis Results

4.1.3 Results of performance measurement

Fig. 8 shows the results of the emission measurement of the developed model. At the initial stage of development, the emission amount of both PM and NOx was large. But the emission amount was reduced and that the swirl flow was improved; the results of combustion analysis were reflected, matching them to the actual machine. By adding the EGR device and DPF, the emission amount was further reduced, and combustion satisfying the regulation values of EU emission regulations Stage V was achieved. Fuel consumption was reduced by 11% from the current model by achieving DI combustion. This achievement also contributed to the reduction of CO_2 emissions that directly influences the fuel comsumption.

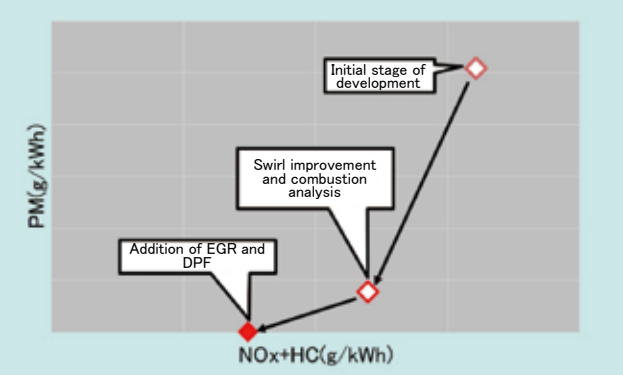

Fig. 8 Measured Result of Emission Gas Level

4-2 Technology for downsizing by parts built in

4.2.1 Built-in pulsar gear

The rotation number sensor (hereafter referred to as NE sensor) and the pulsar gear need to be newly added to the CR engine for sensing the engine rpm and controlling fuel injection. There is a built-in pulsar gear in the upper class series. If space for built-in is newly secured, the engine size is enlarged compared to the current model. In the developed model, a small space in the gear case was focused on, and the pulsar gear was assembled to the crank shaft it to reduce the overall length. However, in the case that the pulsar gear shape and sensor position of the series of the upper level were succeeded, the NE sensor interfered with the internal gear in the developed model. In addition, to secure the robustness of the sensor, the mounting position was limited. Thus, it was difficult only by downsizing and thinning of the pulsar gear. Therefore, the pulsar gear tip was angled shape to improve the the sensor layout. Fig. 9 shows the layout of the pulsar gear. To realize the angled tip shape, sintered material with the higher forming flexiblity and accuracy was adopted. From the above, the structure achieving sensing was established while increasing in size was prevented.

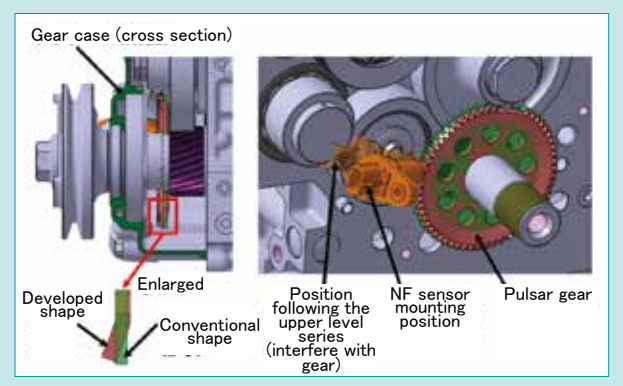

Fig. 9 Shape and Layout of Pulsar Gear

4.2.2 Built-in EGR pipe

To reduce the emission of NOx, the developed model adopted the EGR device. Fig. 10 shows the flow of EGR gas of the series of upper class series and the parts structure. The EGR pipe connecting the EGR cooler and EGR valve is normally located outside of the engine. If the conventional layout is followed, it needs to keep the space between the DPF and cylinder head, and the overall length of engine is increased. With regard to the developed model, the overall length was reduced by the built-in EGR pipe into the cylinder head. Fig. 11 shows the EGR gas route and the parts structure of the developed model. The cooling efficiency of gas in the EGR pipe is improved by not only the built-in EGR pipe but also adopting the structure in which the pipe goes through the coolant route in the cylinder head. Also, by making the cross section of the EGR pipe into a petal shape, the cross-sectional area contacting cooling water was increased to improve the cooling efficiency additionally. Fig. 12 shows the cooling efficiency of gas in the EGR depending on the differences in the layout and shape of the EGR pipe. Compared with the external EGR pipe, cooling efficiency was improved at 18°C by the built-in, and cooling efficiency was achieved at 41°C by making the cross section into a petal shape. The effects given by taking this measure allowed the reduction of the number of layered fins in the main EGR cooler by one layer to achieve downsizing. In addition, by saving space around the starter, the parts layout flexibility was improved.

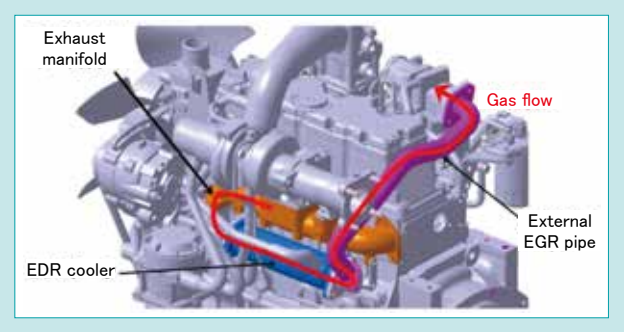

Fig. 10 Conventional Layout of EGR Pipe

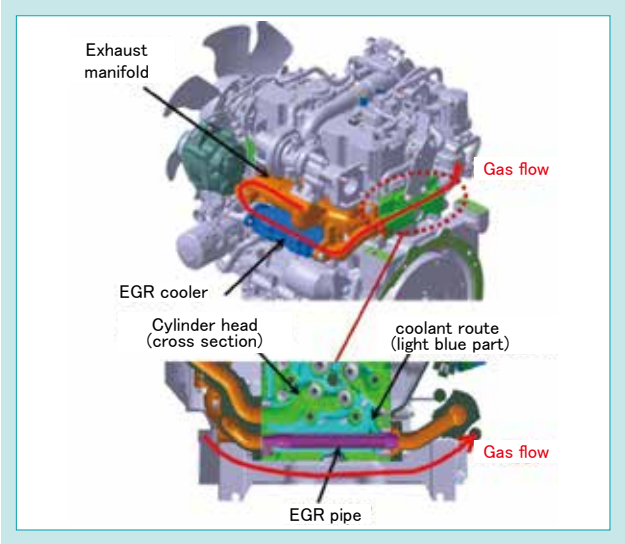

Fig. 11 Built-in EGR Pipe of Developed Engine

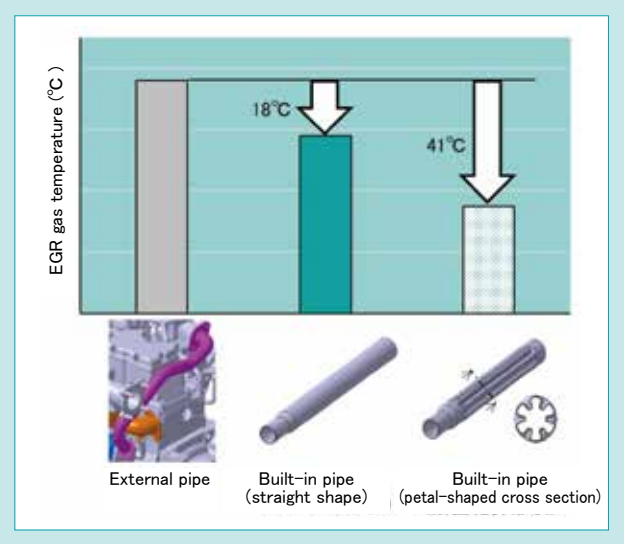

Fig. 12 Improvement of EGR Gas Cooling

4.2.3 Built-in oil separator

The oil separator separating oil from blowby gas (combustion gas leaked from the combustion chamber) is located outside of the engine in the upper class series as shown in Fig. 13. If the conventional oil separator is added, the engine width is increased. Because the rubber hose route connected to the oil separator is long, measures to prevent freezing of the route in the low-temperature environment, including the addition of a heat insulation sheet, were required. With regard to the developed model, increase in the size was limited by built-in as shown in Fig. 14, focusing on the space in the cylinder head cover. It is recognized that the oil separation performance of the built-in small oil separator is equivalent to the conventional external oil separator. Also, for minimization of the rubber hose route, only the connecting part to the intake system was used. In addition, the insulation effect was added and the effect of preventing freezing was increased by providing the air layer between the built-in oil separator and the head cover.

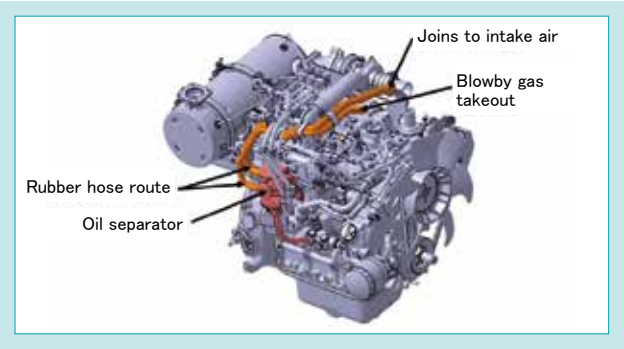

Fig. 13 Conventional Layout of Oil Separator

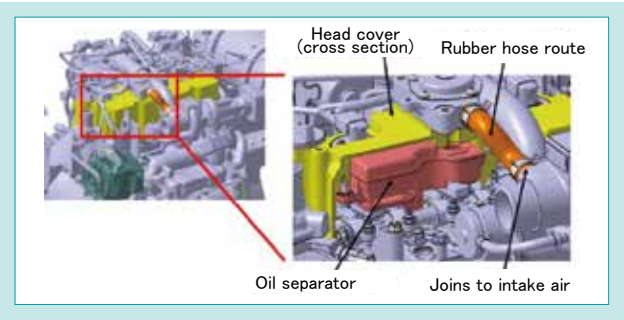

Fig. 14 Built-in Oil Separator of Developed Engine

4.2.4 Engine size of developed model

Increase in the size of an engine was reduced by the built-in parts described above. Fig. 15 shows the effects of the reduction of size increase by the built-in parts. By the built-in oil separator, increase in overall width by 60 mm was reduced, and increase in the overall length by 10 mm was reduced by the built-in EGR pipe. Increase in the overall length was also reduced by built-in pulsar gear into a small space and achieving sensing. Fig. 16 shows the comparison of the displacement and engine size among the developed model, the upper class series, and three-cylinder engines of competitors. The developed model has achieved overwhelming compactness compared with the upper class series and the three-cylinder engines of competitors while the characteristics of four-cylinder engines are maintained. In the status without DPF, the size equivalent to the current model is achieved, and the mounting compatibility with the current model is maintained.

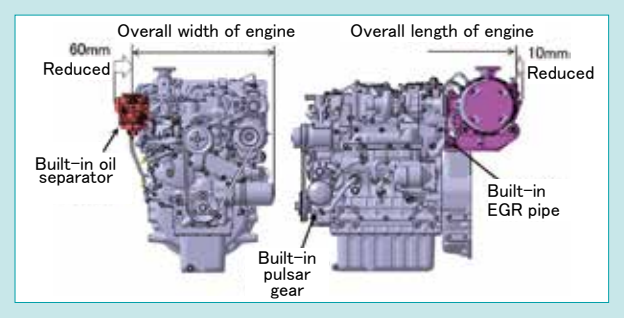

Fig. 15 Effects of Reducing Dimensions by Built-in Architecture

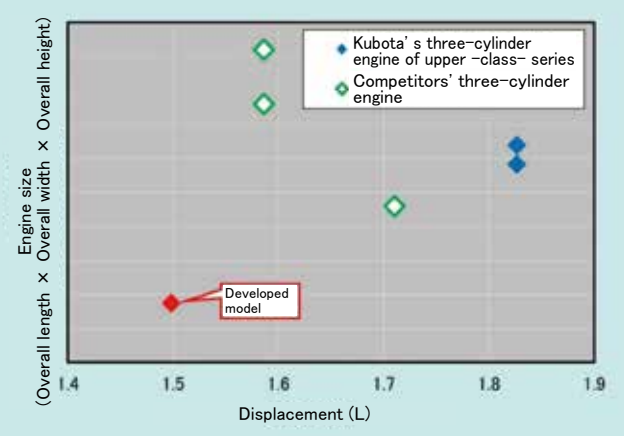

Fig. 16 Comparison of Engine Size and Displacement

5. Conclusion

V1505T-CR engine was developed to comply to EU emission regulations Stage V that has been enforced since 2019.

(1) Combustion satisfying the emission gas performance was achieved by the adoption of four-valve CDIS and the optimization of the shape of the DI combustion chamber and fuel injection angle. By taking them, the CR engine of the smallest cylinder bore diameter in the industry was achieved and it complied to EU emission regulations Stage V. The fuel consumption was reduced from the current model by 11%, and the product competitiveness was enhanced. Additionally, it also contributed to the reduction of CO_2 emissions that directly influence fuel consumption.

(2) Increase in the enigine size was reduced by built-in functional parts that were added according to the compliance to the regulations for emissions. While the characteristics of four-cylinder engines were maintained, compactness than the three-cylinder engines of competitors was achieved.

The developed model mounted to a wide range of Kubota's agricultural machines and OEM machines, contributed to the enhancement of the product performance of machines to which it was mounted. In the future, the sales will be promoted by deploying the technology cultivated in this development to other machines, as well as improving the performance additionally, and enhancing cost competitiveness.

Contribution to SDG Targets

7.3 Improvement in energy efficiency
Fuel consumption ratio reduced by 11% compared with the current model

9.4 Infrastructure improvement and industrial improvement by introducing environmentally friendly technology and industrial processes
Comply to emission regulations by development of DI combustion technology

Reference

1) T.Hasegawa, T.Kuno, K.Kita, A.Kai, Y.Takemura, O.Yoshii, T.Okazaki, H.Miyazaki.Technical concepts on non-road small direct injection diesel engines with common rail system. JSAE 20129035, SAE 2012-32-0035
2) Toshiyuki Yoda, "An Advanced Diesel Common Rail System for Achieving a better Balance between Ecology and Economy," Denso Technical Review Vol.14 (Dec.2009), pp.30-35
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Development of the Mini Excavator RDL3 Series for European Market

Construction Machinery Engineering Dept. for Excavator
Construction Machinery Base Technology Engineering Dept.

The mini excavator RDL3 series for the European market is new model 5 to 5.5t class machine that complies with European Stage V emission regulations. Inheriting the basic performance of the previous model, which was well received by the market, such as operability, stability, durability, lifting capacity, and digging power, the new model delivers the comfort that has been strongly demanded by the market in recent years and upgrades the equipment to increase product competitiveness and expand market share. In terms of comfort, we have achieved the industry's top class quietness (ear noise) for mini backhoes. In the equipment upgrade, we have developed a new user interface (UI) that can be operated intuitively.

【Key Word】
Mini Backhoe, European Emission Regulations Stage V, Ear Noise, User Interface

Related SDGs

1. Introduction

In the mini backhoe market in Europe, 4 to 6-ton class machines constitute the important lineup accounting for 19% of the demand. By the introduction of the current machine in 2009, although the share of 4 to 6-ton class machines have been increased, the share expansion has been dulled since 2015.

The current 5 to 5.5-ton class machines enjoyed a high reputation for the high basic performance and innovativeness of the equipment. Request for comfort including the reduction of ear noise other than the basic performance has been increased every year. Compared with competitors' machines to which model change was completed, disadvantages of the equipment have been pointed out.

To meet the requests from the market and expand the share, we have developed the machine achieving the top-class comfort in the industry with the innovated equipment (Fig. 1).

Fig. 1 RDL3 Tight Tail Swing Excavator U56-5

2. Development concept and target value

2-1 Concept of development

While following the basic performance satisfying the requests from the market, develop the machine having the characteristics shown below to conform to EU new emission regulations Stage V.

(1) Operating space pursuing the comfort of users
 (i) Top-class quietness in the industry (ear noise)
 (ii) Cabin with improved visibility and open feeling by widened glass area
 (iii) Driver's seat equipped with the double adjust mechanism to adjust to the physical status of large users
(2) Equipment innovated in an advanced manner
 (iv) Intuitively operable new user interface (UI)
 (v) Compact and stylish operating device
 (vi) Interior with improved quality

This article describes (i) Top-class quietness in the industry (ear noise) and (iv) Intuitively operable new UI.

2-2 Target value

(1) Top-class quietness in the industry

The target value of ear noise was set to less than 74 dBA, which was the index of the quietness in the operating space.

The value is the result of the review of the top-class quietness in the industry by comparing the quietness with that of the competitors' machines in Europe.

(2) Intuitively operable new UI

UI, contact to connect a user and the machine, constituting a series of mechanism in which the machine conditions are reviewed, setting operation is conducted, and consequently, the machine responses. In the mini backhoe, the meter display and its operation are defined as UI.

While the conventional meter was three-inch monochrome display, a seven-inch color LCD meter was adopted in this development. Since machines with color LCD display produced by competitors have been introduced into the market already, production of new UI, unique to Kubota and superior to competitors, was aimed at.

3. Technological issues to be solved

(1) Top-class quietness in the industry

The ear noise value of the conventional machine was 79 dBA, and reduction of 5 dBA or more noise was an issue.

In addition, while actions against ear noise were taken, a new issue of the prevention of heat conduction to the driver's cab occurred.

(2) Development of intuitively operable UI

Drastic improvement of UI to allow the operator to see and use it easily and operate intuitively was an issue.

Reviewing the elaboration of UI focusing on "visibility" and "operability" and the evaluation method of UI appropriate for the feeling of users were required.

4. Development technology

4-1 Technology to reduce ear noise

4.1.1 Reduction of direct sound

The step of the conventional machine had the structure with many clearances. In RDL3, the step that had been constructed separately in the past was constructed by the incorporated steel plate, the cover was fixed with bolts, a grommet was adopted for the passing part of the pilot hose and wire harness completely blocking the clearances to reduce noises directly (Fig. 2).

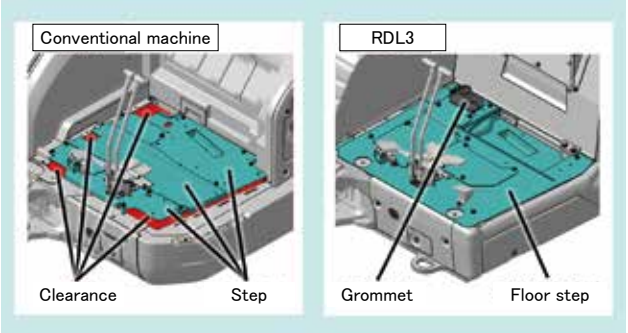

Fig. 2 Steps

4.1.2 Reduction of solid borne sound

The main vibration sources worsening ear noise in the static state are engines and hydraulic pumps.

Measurement of vibrations in the transmission route from the engine and hydraulic pump to the area around driver's seat revealed that ear noise was worsened by the response of the engine bracket and engine support to the excitation frequency 460 Hz of the hydraulic pump.

To increase the resonance frequency of the engine bracket and the engine support, the mount position and shape were reviewed (Fig. 3). Consequently, the engine bracket was removed from the resonance area (Fig. 4), response from the engine support was lost (Fig. 5), and solid borne sound was reduced.

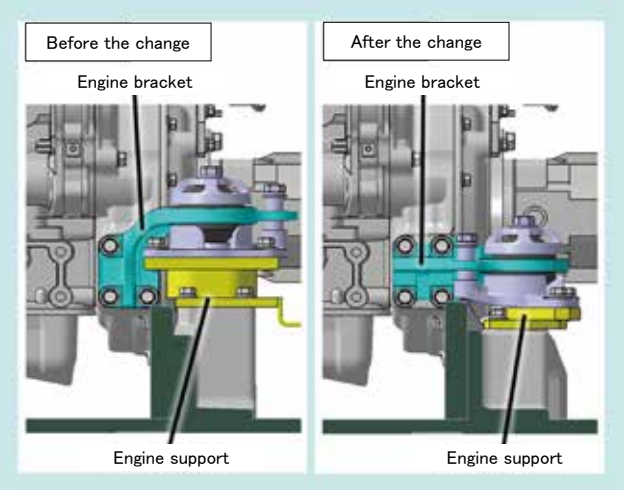

Fig. 3 Engine Mount

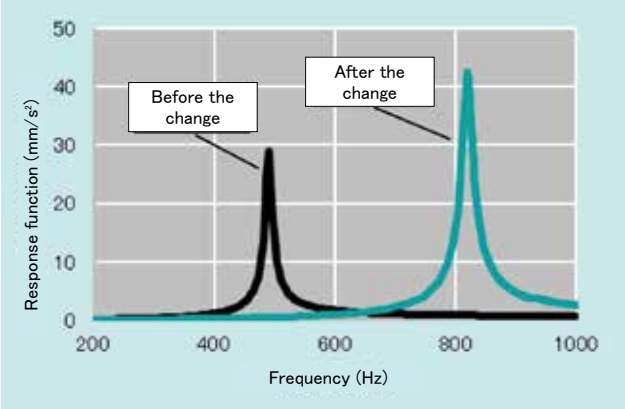

Fig. 4 Frequency Response Function of the Engine Bracket

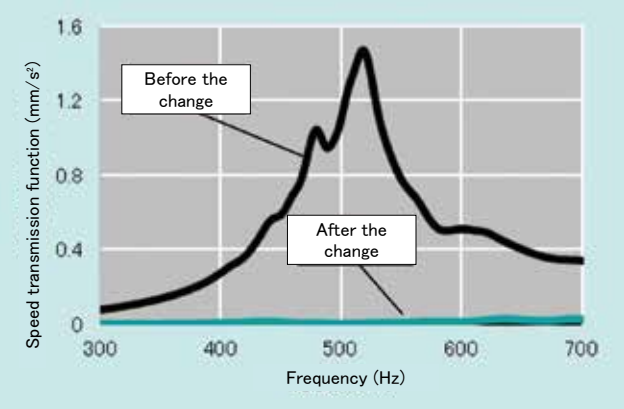

Fig. 5 Frequency Response Function of the Engine Support

4.1.3 Reduction of transmitted sound

A polypropylene (PP) injection molded part was adopted to the partition separating the engine room and the driver's seat of the conventional machine because of the freedom of shaping, superior heat insulation, and cost advantage. However, in terms of sound insulating effect (transmission loss), it is significantly inferior to that of a steel sheet, since mass low is applied (Table 1).

Mass law related to sound insulation

$TLo = 20 \cdot \log_{10}(f \cdot m) - 43$

TLo: Transmission loss (dB)

f: Frequency (Hz)

m: Area density (kg/m^2)

In RDL3, the partition of the engine room was made of a t3.2 steel sheet to reduce transmitted sound (Fig. 6).

However, it caused the issue of heat transmission to the driver's seat. The measures to be provided for the issue are described in 4-2.

Table 1 Transmission Loss at Each Frequency(dB)

Frequency	pp	Steel sheet	
	t3 (mm)	t1.6 (mm)	t3 (mm)
125 (Hz)	8.1	21.4	26.9
250 (Hz)	14.1	27.4	32.9
500 (Hz)	20.1	33.5	38.9
1000 (Hz)	26.1	39.5	44.9
2000 (Hz)	32.1	45.5	51.0

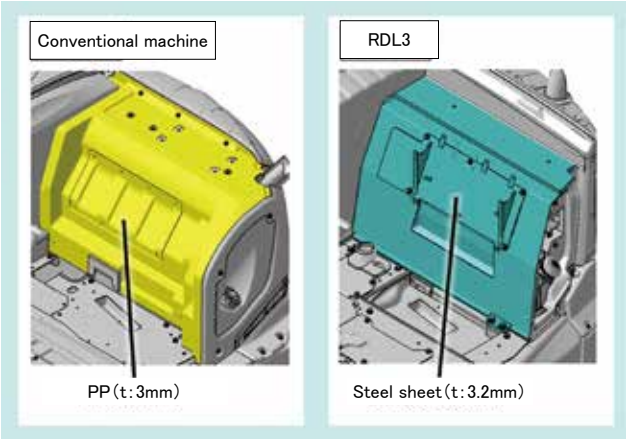

Fig. 6 Engine Room Partition

The above measures for the noise near ears were provided, and consequently, the ear noise value was as shown below, and the target was achieved (Table 2).

Table 2 Ear Noise Measurement Results

Type	Ear noise (dBA)
Small turning machine U56-5 rear RDL3	73.2
RDL3 standard machine KX060-5	72.0

4-2 Cooling system optimization technology (heat reduction)

In the steps described in 4.1.3, the material of the partition separating the engine room from the driver's seat was changed from resin to steel sheet. With this change in material, the issue that the partition was heated and the operator felt hotter compared to the conventional machine, occurred. To solve the issue of heat transmission to the driver's seat, temperature in the engine room needed to be decreased. Thus, the air flow and temperature in the engine room were verified using fluid analysis, and the optimum cooling system was produced (Fig. 7).

By changing the serial layout of the radiator and oil cooler to the parallel layout (Fig. 8), temperature of the air flown into the engine room was reduced, and the performance of heat balance of cooling water temperature and hydraulic oil temperature was achieved.

In addition, the surface temperature of the partition was reduced from that of the conventional machine, and the issue of heat transmission to the driver's seat was solved.

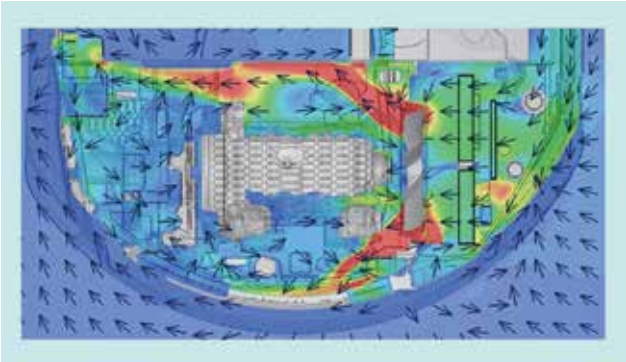

Fig. 7 Fluid Analysis

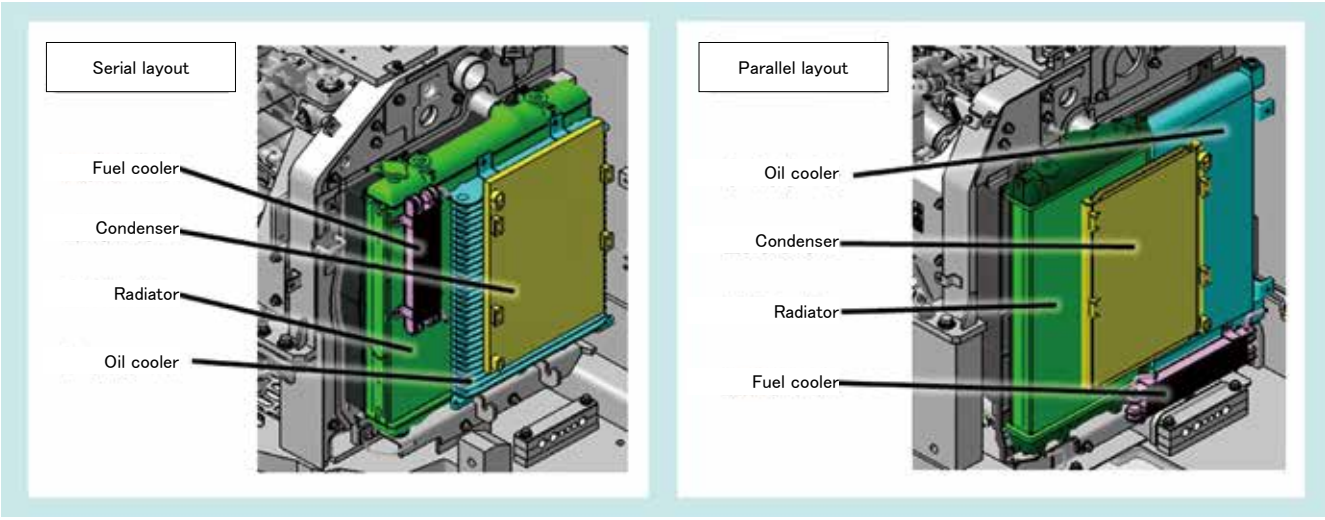

Fig. 8 Cooler Unit

4-3 UI development technology

4.3.1 Investigation of UI in construction machinery industry

To create the UI unique to Kubota, machines produced by competitors in Europe were investigated, focused on "visibility" and "operability."

With regard to "visibility," appropriate amount of information, layout, size of letters and images, and color tones that allow the instantaneous recognition of the display screen were investigated.

With regard to "operability," the switch layout and the matching of meter display with switches to allow smooth operation were investigated.

In the investigation, the track of operator's line of sight was recorded and analyzed by eye tracking with the machine actually operated, and advantages and disadvantages of "visibility" and "operability" from the viewpoint of an operator were extracted, and factors to be introduced into the new UI and those to be excluded were defined.

4.3.2 Review of UI

Based on the results of investigation of competitors, the following two factors were focused on with regard to "visibility."

(1) Determine the size of information and layout according to the importance.

(2) The display should be simple and minimum, and the display and sound feedback hard to be understood by operators should be excluded.

In the investigation, the operator looked at the meter screen for 0.3 seconds each time during operation. Thus, the visibility standard was set to the capability of recognition within 0.3 seconds, and the meter screen was designed according to the standard (Fig. 9).

In addition, move of the line of sight from the working area to the meter was minimized by setting the meter along the cabin column.

With regard to "operability," the jog dial which is simply operated by turning and pushing in was adopted, and smooth operation feeling with higher affinity to the display screen was elaborated to allow intuitive operation.

In addition, improvement in the move of the line of sight to the meters as well as immediate operation in the working posture were achieved by positioning the jog dial beside the operation lever.

The two factors, "visibility" of meters and the "operability" of the jog dial, were provided for the new UI unique to Kubota (Fig. 10).

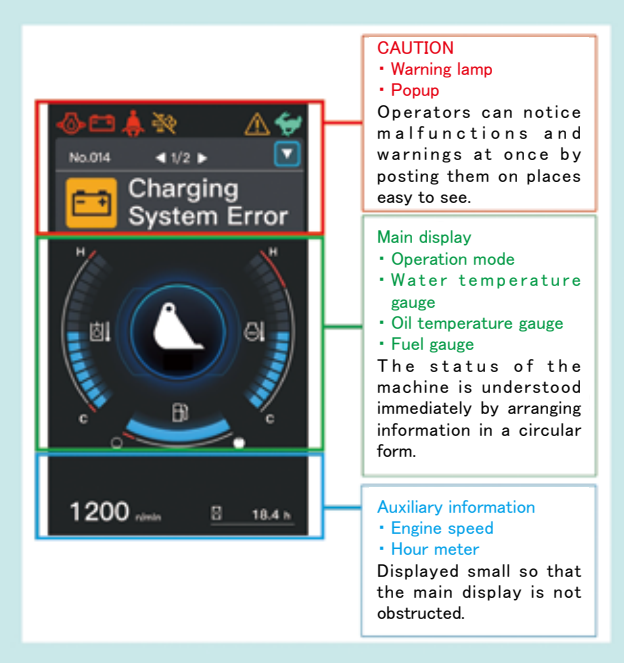

Fig. 9 Meter Display

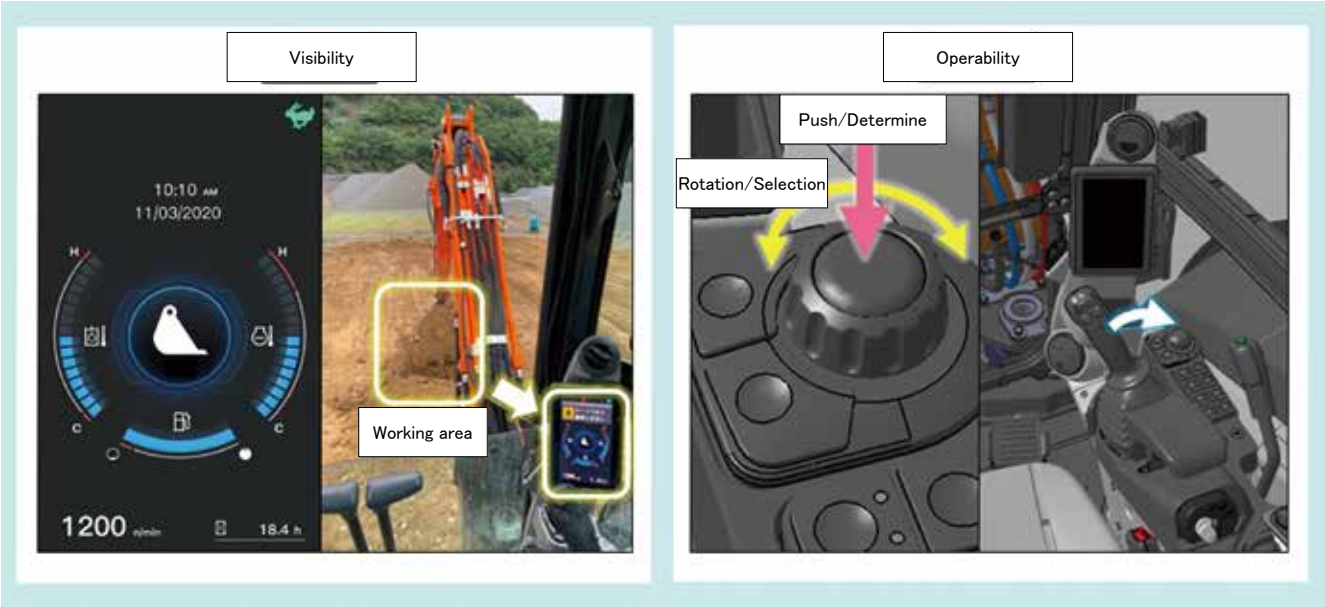

Fig. 10 New User Interface

4.3.3 Evaluation of UI

Usability tests intended for the outside operator of construction machinery was conducted to verify the usability of UI and identify matters to be improved.

The test method was as follows: The operator operated the simulator on the PC with the simulated display and operation of meters and filled the questionnaire about the impression of operation. In another room, observation and analysis about the operation of a user were conducted. After entering the questionnaire, matters to be improved were identified by conducting an interview.

The identified matters to be improved were judged using the judgment criteria for importance (Table 3) based on the hazards and risks with the concept of risk assessment applied.

The judgment result of tests was as follows: no rank A item was found and no critical matter to be improved was identified.

An example of rank B items: although the display of "1/3," indicating the number of messages, means the capability of switching messages by turning dial, the intension could not be conveyed to users, and users did not find how to switch them. We concluded that the display did not match to the feeling of users, and thus, moved the indicated number of messages to the center, added the icons indicating scrolls, "◂ ▸," and created the UI matching to the feeling of users (Fig. 11).

After the improvement, we re-evaluated the feeling of operators by the feeling check in the endurance test. Since no matter was pointed out, we concluded that intuitive and smooth operation was achieved.

Table 3 Importance Criteria

(Difficulty) Hazard	Risk (Frequency in use)		
	High (75 to 100%)	Intermediate (25 to 75%)	Low (0 to 25%)
Difficult (Problems are left even after studying)	A	A	B
Intermediate (Hard to study)	A	B	C
Easy (Problem at the first time only)	B	C	C

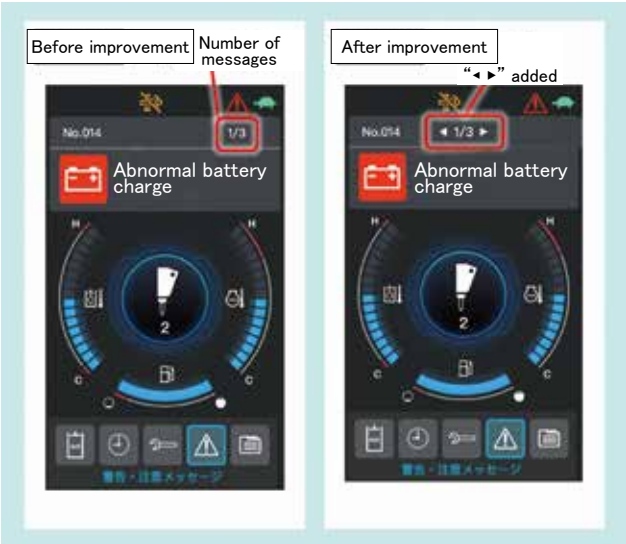

Fig. 11 Improvement of B Rank

5. Conclusion

In RDL3, comfortable operating space and intuitive operation allowed by the top-class quietness in the industry (ear noise) and the initial product concept achieved the new UI unique to Kubota, and it is highly evaluated in European market.

In the future, approach to the environmental problems including the conformity to the emission regulations and the creation of safe and secure operating space for operators, matching to the feeling of operators, and making equipment easy to use will be increasingly important. We further develop the technology cultivated through the development of RDL3, horizontally deploy it to mini backhoes of another class, and contribute to the infrastructure development and city development in the world.

Also, functionality and design concept of RDL3, and the attitude to the social mission of Kubota was evaluated, and the world authority design awards, Red Dot Design Award and iF DESIGN AWARD, and in addition, Japanese Good Design Award were presented, and it contributes to the realization of a global major brand (Fig. 12).

Fig. 12 Awarded Design Awards

Contribution to SDG Targets

7.a Energy-related infrastructure, promotion of investment to clean energy technology
Mounting of engine conforming to EU emissions regulations

8.8 Promotion of safe and secure labor environment
Comfortable operating space was achieved by the top-class quietness in the industry (ear noise)

Development of Slope Grass Cutter “GC-M500”

Farm Machinery Implements and Products Engineering Dept.
Analysis Center

Slope grass cutters have become popular as a product that improves the efficiency and safety of mowing operations. On the other hand, as the number of farmers expanding the scale of their farms is increasing, the operating hours of slope grass cutters is also increasing, and it is necessary to further improve work efficiency and durability. Therefore, we developed the slope grass cutter GC-M500 for professionals. By selecting the maximum engine speed from two stages in the "Master mode", it is possible to work under various conditions. Because of its features, an operator can reduce physical discomfort and the working time. In addition, he can reduce downtime and improve productivity due to the product's high durability.

【Key Word】
Slope grass cutter, Master mode, Blade mounting method, Easy maintenance, Long-life blade

Related SDGs

1.Introduction

Failure in weeding in the farmlands of rice paddies may cause troubles in the rice paddies control, or crop yields may be decreased due to pest damage. Therefore, weeding is required for three to five times in a season and is one of the important operations. However, in the hot summer, weeding is harsh work and it does not directly connect to profits. Therefore, it is said to be the most painful work for farmers. In many cases, footpaths between rice paddies in mesomountainous region have long slope faces, and weeding using a weeder necessitates the standing of an operator on a slope, imposes a burden on the operator, and leads to a hazard. Thus, the self-propelled type slope grass cutter allowing operators to weed with standing on the upper side of footpaths has been penetrating the domestic market as the product enhancing the efficiency and safety of weeding. On the other hand, while large-scale farmers and corporative farmers trying to expand their business are increasing, the farmland area per management body has been increasing every year (Fig. 1)[1], and the annual hours of use of slope grass cutters also has been increasing. In these situations, further improvement in work efficiency and endurance has been required, compared with the conventional machine that was developed based on the assumption of 100 hours of the annual hours of use.

To meet such requests, Kubota developed the professional slope grass cutter whose efficiency and endurance are higher than the conventional machine, “GC-M500” (Fig. 2).

Fig. 1 Cultivated Area per Management Entity

Fig. 2 Development Model GC-M500

2. Development concept and target value

2-1 Concept of development

To deal with long hour use caused by the expanded cultivation area, the development concept was defined as shown below, targeting large-scale farmers that have been increased in recent year.

1) Even in farmlands with a large weed volume, easy work is allowed by mounting a high-power engine. In addition, achieve further improvement in the efficiency of weeding by increasing the working speed.

2) By increasing the endurance and maintainability of respective parts compared with the conventional machine, aim at a machine free of service after sales.

2-2 Target value

1) Highly efficient work

Aim at improvement in the work efficiency, workable area per hour, by 10% higher than the conventional machine by mounting a high-power engine and reviewing the working speed.

2) Improvement in endurance

Because of long working hours due to the expansion of field scale and increase in engine power, endurance of the entire machine body needs to be improved. Above all, increase in the life of a cutting blade by 1.2 times, which is frequently replaced as consumables, was targeted.

3. Technological issues to be solved

3-1 Adaptation to varied working environments

To let the product penetrate into the market as the slope grass cutter for large-scale farmers, not only the handling of high-load farmlands and the achievement of high efficiency, but also the attainment of the optimum workability under farmland conditions of unsteady footing and the adaptation to work in farmlands near residential areas or in the early morning, which needs consideration about noise to the surroundings, and varied work environments are the issues.

3.1.1 Handling farmlands with unsteady footing

In the farmlands of unsteady footing, working at a low speed is favorable for safety. However, the conventional machine does not allow the minute adjustment of revolution numbers by only switching between on and off with the acceleration lever always set to fully opened status (Fig. 3). Simple decrease in the speed at the low-speed stage causes larger difference in the speed between high speed and low speed, and appropriate speed cannot be selected depending on the situation, and thus, it leads to the worse workability. Also, simple increase in the number of speed change stages leads to increase in weight and cost. Therefore, the way to increase the number of speed levels with limiting the weight and cost needed to be reviewed.

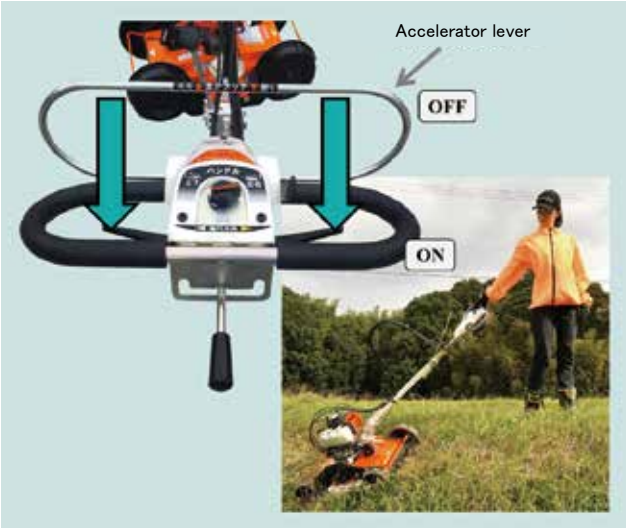

Fig. 3 Accelerator Lever

3.1.2 Reduction of noise

The developed machine is equipped with the engine of larger displacement than the conventional one. Since it is used with the accelerator fully opened, noise becomes louder. To work in the status where consideration about noises to the surroundings is required, noises needed to be reduced. However, change of the muffler to reduce noises and decrease in the maximum speed of the engine will decrease the engine power. The way to perform high power and highly efficient work with low noise was required.

3-2 Improvement in cutting blade and cutting blade setting part

The slope grass cutter has the structure of weeding by the cutting blades set to the rotating cutting blade holder, installed to the bottom of the machine (Fig. 4).

3.2.1 Extended life of cutting blade

It is estimated that the work area per hour increases and the life of a conventional cutting blade decreases by improved work efficiency. For this reason, cutting blades which can be used for a longer time needed to be developed. However, cutting blades are consumable parts, and increase in the unit price of parts due to special machining is a burden for users. Thus, neither expensive machining nor processing was performed, but extending the life was an issue.

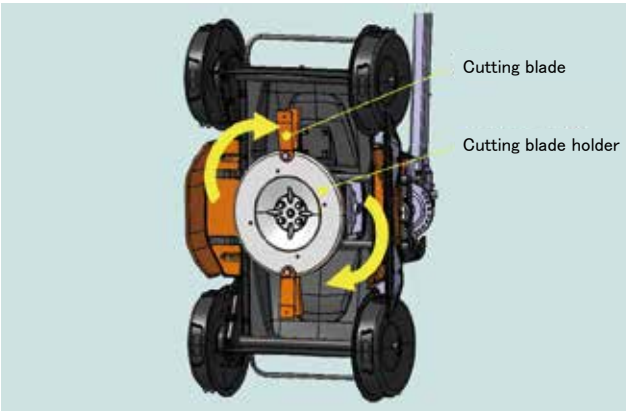

Fig. 4 Grass Cutting Part

3.2.2 Improvement in the maintainability and securing strength in the setting of cutting blades

In the setting method of cutting blades that is adopted to the conventional machines, split pins are inserted from the top and bottom of the cutting blade setting holes, and L-retainers are used for the locking of the split pins. The retainers are locked by bolts and washers (Fig. 5). Although the structure does not have the issue that pins are loosened by being turned themselves until they are removed, some operators had complaints about troublesome replacement because of many parts and working processes for exchanging the cutting blades.

Therefore, improvement in maintainability by changing the setting method of cutting blades and establishment of the setting method to secure the strength of the cutting blade setting parts were the issues.

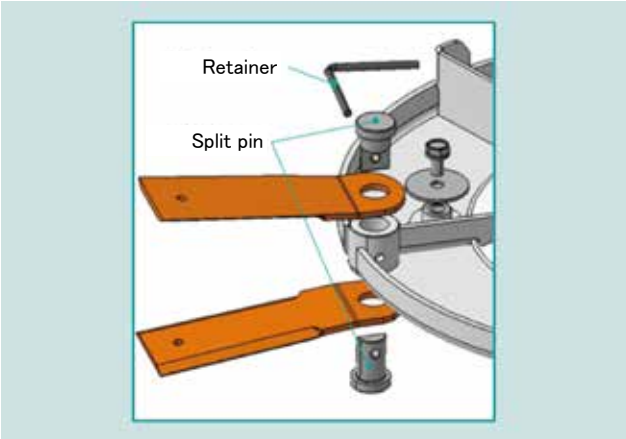

Fig. 5 Conventional Blade Mounting Method

4. Development technology

4-1 Adoption of master mode

4.1.1 Adjustment of the maximum engine speed

To adapt to varied working environments, mechanism allowing the adjustment of the maximum engine speed was reviewed. First, the mechanism allowing the adjustment of the speed by changing the rotation of accelerator lever or pulling of accelerator wire was reviewed. This caused the increase in the number of parts and the complication of operation during work. In addition, it was difficult to adjust the speed to the fixed level with the narrow range of engine speed to be changed.

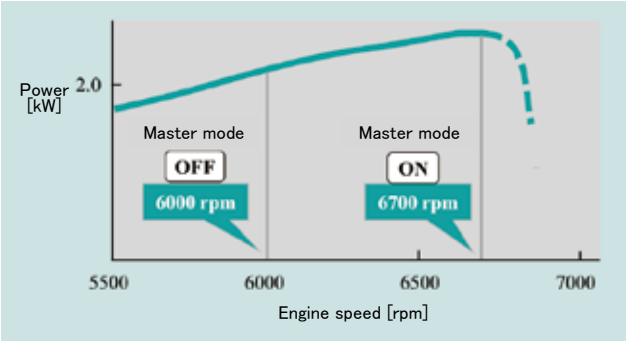

Fig. 6 Engine Performance Curve (Image)

4.1.2 Adoption of master mode

To solve the problems above, a "master mode" in which the maximum engine speed is selected between two speed levels was developed as the method to reduce the complication of operation and increase in costs and weight. In the conventional engines, the ignition timing is controlled by the ignition coil to prevent the maximum speed from being increased above the fixed level for the protection of the machine and the prevention of noises. By modifying the control method to the two-level system, the maximum speed can be switched to 6,700 or 6,000 rpm (Fig. 6). The switching operation allows the speed to be changed by operating only one switch at hand (Fig. 7).

Fig. 7 Master Mode Switch

4.1.3 Vehicle speed setting and work efficiency

By the master mode, for the two levels of maximum speed, choice of the levels of vehicle speed between high and low respectively, i.e., among four speed levels, was allowed (Fig. 8).

Work operation appropriate for the degree of load in farmlands and conditions of footing, while taking into consideration noise, was allowed by the following procedures: for example, in high-load farmlands, if high power is required or highly efficient work at a high speed is required, select 6,700 rpm (master mode on). If low-speed operation is required in light-load farmlands or with unsteady footing, or for the consideration of the surroundings or operation at the speed equivalent to the conventional machine, select 6,000 rpm (master mode off).

Addition of 0.72 m/s, the highest speed in the industry, contributed to the improvement in work efficiency by 11% compared with the conventional machine (*), and thus, the target was achieved.

*Farmland conditions: plant height 0.9 m, weed density 1.0 kg/m^2

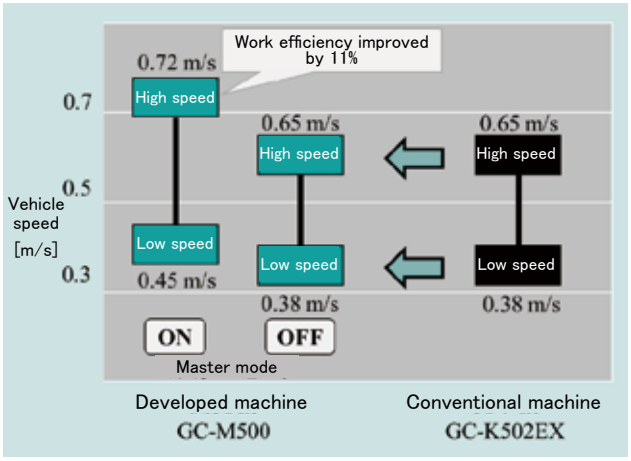

Fig. 8 Vehicle Speed

4-2 Improvement in cutting blades and the setting method of cutting blades

4.2.1 Extended life of cutting blade

With the increase in the power of engine and work efficiency, the available time is shortened if the conventional cutting blades are used. To solve this problem, measures for the life extension of cutting blades were reviewed. First, with regard to the conventional cutting blades, adoption of fan-shaped-blade with wider area for the part prone to easily wear was reviewed, since wear progresses from the corner of the blade tip (Fig. 9). In addition, to extend the life, the thickness of cutting blade was reviewed.

Consequently, it was recognized that the life of a cutting blade was extended in proportion to the thickness by wear acceleration tests, and the head of a cutting blade pin fixing the cutting blade reaches the wear limit early, if the life of cutting blade is extended (Fig. 10). If the head of a cutting blade pin is worn completely, the cutting blade comes off. Therefore, the method to extend the life of the cutting blade pin was reviewed. However, if the hardness of the cutting blade pin is increased, the blade may be broken due to impact, and increase in the thickness of the head of cutting blade pin leads to the shorter distance from the ground, causing the progress of wear, and longer life of the cutting blade pin cannot be achieved.

From the above, the thickness of the cutting blade was set to keep a good balance with the wear of the cutting blade pin, and as a result of checking the life of the cutting blade by the cutting blade wear acceleration test, life extension of the cutting blade by 1.3 times for the developed machine was achieved, compared with that of the cutting blade of the conventional machine (Fig. 11).

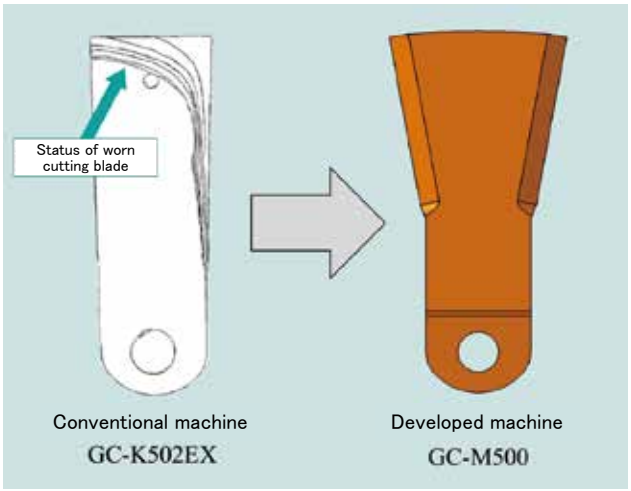

Fig. 9 Shape of the Cutting Blade

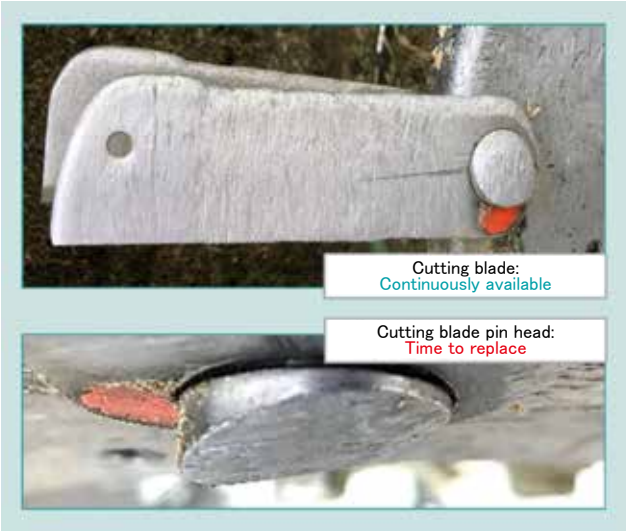

Fig. 10 Wear Status of Cutting Blade and Cutting Blade Pin Head

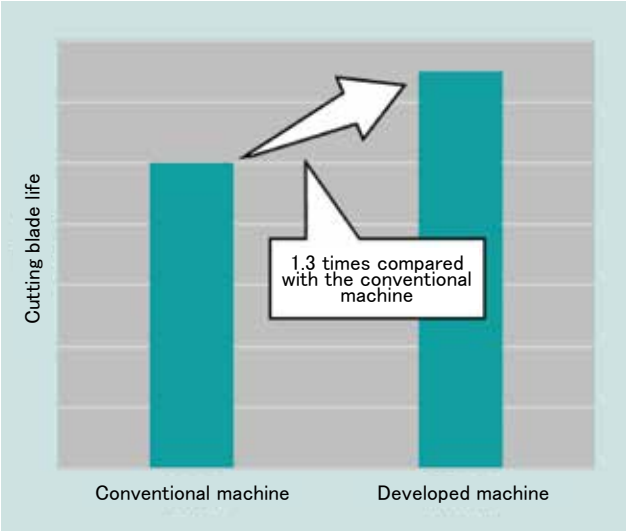

Fig. 11 Improvement of Cutting Blade Life

4.2.2 Securing the strength of cutting blade setting part

To improve maintainability, it was reviewed that the cutting blade setting method was changed from the method for conventional machines in which split pins were used to that using bolts and nuts to reduce the number of parts and working processes for removal of cutting blades. In the bolt-and-nut fixing system, the cutting blade setting bolt might be turned with the turning cutting blade. Thus, the cutting blade pin and setting holes were made into an oval shape to prevent the cutting blade setting bolt from being turned (Fig. 12). In addition, the oval washer to prevent the nut from being turned with the turning cutting blade was added, and safety was secured by applying screw lock agent to nuts.

Fixing of cutting blades is important factor in viewpoint of safety. At the time of the change to the fan-shape cutting blade and cutting blade setting system, the strength when excessive load is applied was verified. Consequently, it was found that a stress was generated at the corner of the cutting blade pin. Thus, the specification was modified to reduce a stress and withstand impact caused by the generation of high power by changing the angle of the oval mounting holes for the cutting blade setting bolt (Fig. 13).

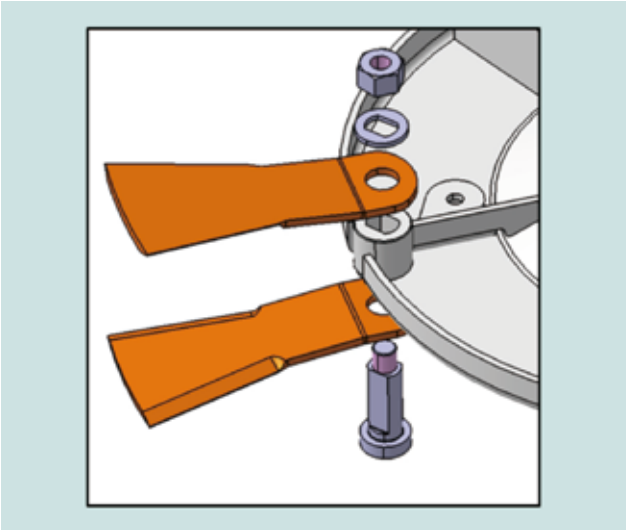

Fig. 12 Method of Mounting the Blade of Development Model

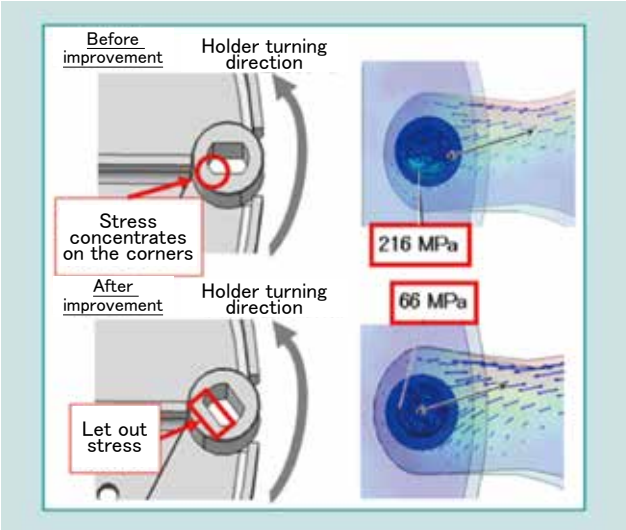

Fig. 13 Strength Analysis Result

4-3 Other improvements

As the slope grass cutter for large-scale farmers, other than the above, varied parts of the product were improved. Two improvements are shown below.

4.3.1 Extension of handle length

The handle of the slope grass cutter is telescopic, and the operator can weed the slope face with the operator standing on the upper side of the slope face by extending the handle depending on the length of the slope face. However, if an operator of the conventional machine works while walking on the upper side of a slope face during weeding on the slope face, a step-wide weeds are left on the lower part of the slope face, and the operator has to stand on the slope face to weed them, and thus, some people say that it is hard work. Therefore, to reduce a physical burden on the operator of the developed machine by weeding on a slope face, working on the remained step-wide weeds in a walking posture on the upper side of slope face was allowed by extending the handle to the maximum length (Fig. 14).

Fig. 14 Extend the Handle Length

4.3.2 Reduction of frame damages

With the increased engine power, impact given by scattered pebbles is also increased, and the frame is liable to be damaged and the endurance is a concern. However, simple increase in sheet thickness causes increase in weight and leads to the poor maneuverability of the weeder. Therefore, increase in the weight was reduced and the endurance of frame was improved by attaching the impact reducing rubber only to the portions which pebbles hit. Even in the case of damage, maintainability was improved by reducing the replacement parts to a rubber only (Fig. 15).

Fig. 15 Frame Protect Rubber

5. Conclusion

With the increase in scale, the area to be weeded by large-scale farmers and corporative farmers is also increased, and work in the heat in the summer is so hard. In these situations, the developed machine which allowed efficient weeding reduces the working time and can save farmers a lot of time, and a physical burden on the operator can be reduced. Thanks to high endurance, downtime was reduced and improvement in productivity was achieved.

By adding the developed machine to the series in 2020, the sales volume of slope grass cutters increased, and we have been enjoying a high reputation from the market. In the future, we are going to contribute to the expansion of business volume by further developing new products satisfying customers' needs.

Contribution to SDG Targets

2.4 Achievement of sustainable and tough agriculture
Operation efficiency and productivity improved by 11% compared with the conventional model

8.2 Improvement in productivity by innovation
Increased work efficiency by 11% compared with the conventional machine

Reference

1) Statistics related to farmlands, Ministry of Agriculture, Forestry and Fisheries
https://www.maff.go.jp/j/tokei/sihyo/data/10.html (date of reference: May 14, 2021)

Development of Micro Flow Rate NX Feeder

Precision Equipment Engineering Dept.

A feeder is a device for continuously supplying a constant flow rate of various powdery and granular materials in order to meet specific resin mixing ratios. Conventionally, resin products have been produced in process by blending a small amount of additives with other materials in advance and supplying them from a feeder to an extruder. On the other hand, in order to improve productivity, there was a need to eliminate the prior blending process and to add a trace amount directly to the extruder. In response, we have developed a new micro NX feeder. The NX feeder series is a proprietary feeder developed by Kubota. In addition to making use of its structural features, we have developed technologies to improve the supply accuracy, expand the flow rate range, expand the range of applicable materials, reduce the installation area, and achieve the target specifications. This paper explains these development technologies.

【Key Word】
Feeder, High Supply Accuracy, Micro Flow Rate, Supply of Very Small Amount, High Accurately Weigh and High Stability, Bridge Material

Related SDGs

1. Introduction

Many resin manufacturing companies in Japan and other countries are manufacturing highly functional resin whose heat resistance and wear resistance are higher than multipurpose resin. Highly functional resin is being widely used in various industry, including automobile and household electric appliances, as the substitute for metal parts, because of its strengths, light weight and capability of being shaped into complicated shapes. Since some materials and additives to add varied functions to resin are supplied in the manufacturing process of highly-functional resin, the number of feeders to be used for the supply of them is being increased. Kubota feeders are necessary for the securement of the quality of resin products and improvement in the productivity by their ability of suppling materials with high accuracy at the fixed flow rate in the manufacturing process of resin.

In recent years, the process of blending additives by a small amount in the upstream process of the extruder in the resin manufacturing process has been eliminated for manpower reduction and reduction of processes in terms of productivity improvement, and the adoption of the direct adding by a small amount to the extruder has been increased (Fig. 1).

Although Kubota has a lineup of feeders applicable to varied flow rate ranges to meet customers' requests, requests for the supply with high accuracy in the micro flow rate range have not been satisfied.

Furthermore, the properties of material used by customers are varied. Some materials are easy to supply stably by feeders, while other materials are hard to do so. To the materials hard to supply stably, bridge, the phenomenon that particles of material form the arch

structure, causing clogs, leading to the impossibility of discharge, may occur, and application to varied materials while coping with such problems must be taken into consideration.

Also, since several feeders are located, the freedom of layout needs to be enhanced, and the size of an installation area must be taken into consideration.

For resin manufacturing companies and extruder manufacturing companies that are not satisfied with the supply accuracy and applicable materials of the conventional Kubota small flow feeder and adopt competitors' feeders, develop the micro flow rate feeder featuring a micro flow rate and highly accurate supply, applicability to varied materials, and space saving to meet customers' requests.

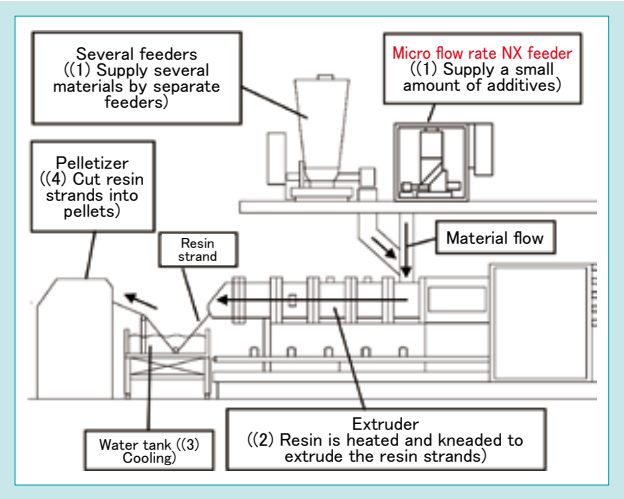

Fig. 1 Micro Flow Rate NX Feeder Installation Example

2. Development concept and target value

2-1 Concept of development

While the developed machine features the high supply accuracy superior to the supply accuracy of the conventional machine, it aims at the expansion of the applicable range to the micro flow rate range exceeding the flow rate rage of the conventional machine.

At present, in the intermediate and high flow rate ranges, conventional machines are being replaced with NX feeder series (hereafter referred to as NX feeders) (Fig. 2). Since NX feeders have high supply accuracy and applicability to a wide range of materials, define the NX feeders as the base of development to realize the micro flow rate NX feeders having those strong points. Then, develop the lineup of NX feeders, and integrate the models of the feeder products group.

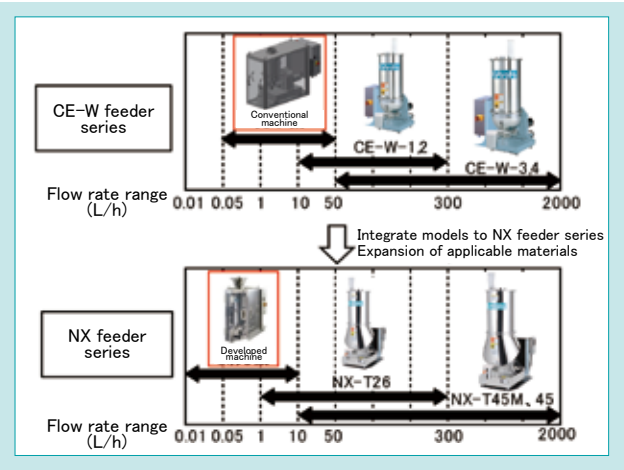

Fig. 2 Weighing Feeder Lineup

2-2 Target value

With regard to the supply accuracy of the developed machine, aim at "100 g/h, 1% or less supply accuracy with 1 min sampling," based on the request from the market. In addition, the flow rate range of the feeder was expanded to the micro flow rate range, and the target minimum flow rate was set to 0.01 L/h. Talc was used for checking them as the standard material.

With regard to the applicable materials, aim at the supply of high bridge materials that was difficult for the conventional machine (liability to bridge is classified into "Low," "Intermediate," and "High" depending on the frequency of occurrence).

As for the installation area of a feeder, reduce by 20% or more compared with the conventional machine for space saving, so that several units of feeders are easily installed.

Table 1 shows the list of the target specifications.

Table 1 Target specification

Items	Developed machine	Conventional machine
Supply accuracy	The supply accuracy is 1% or less with 100 g/h, 1 min sampling. (Low bridge material: talc)	The supply accuracy is 3% or less with 100 g/h, 1 min sampling (Low bridge material: talc)
Minimum flow rate	0.01 L/h (Low bridge material: talc)	0.05 L/h (Low bridge material: talc)
Applicable materials	Low bridge material (Irganox), intermediate bridge material (calcium carbonate), high bridge material (titanium oxide)	Low bridge material (Irganox), intermediate bridge material (calcium carbonate)
Installation area	20% reduced compared with conventional machine	–

3. Development technology

3-1 Micro flow rate feeder utilizing the strengths of NX feeders

3.1.1 Improvement in supply accuracy

Fig. 3 shows the cross-sectional view of a conventional machine and NX feeder. The feeder comprises the weighing part, drive part, and hopper. In the weighing hopper, materials are stored, and in the discharge hopper, the agitator for agitating blades and the screw to discharge materials are rotated. During the control operation, the weighing part detects the materials discharged by the screw, the motor speed is controlled to keep the reduced amount per hour is always constant, and materials are supplied at the fixed flow rate.

Since the up and down motions of materials occur due to the rotation of the horizontal agitator of the conventional machine, the weight tends to be fluctuated easily, and the control status may be disturbed by itself especially at a low flow rate.

In the developed machine, the up and down motions of materials have been reduced and the weight became stable by the diagonal agitator, one of the features of the NX feeders. Consequently, the control status is stable, and the good supply accuracy was achieved.

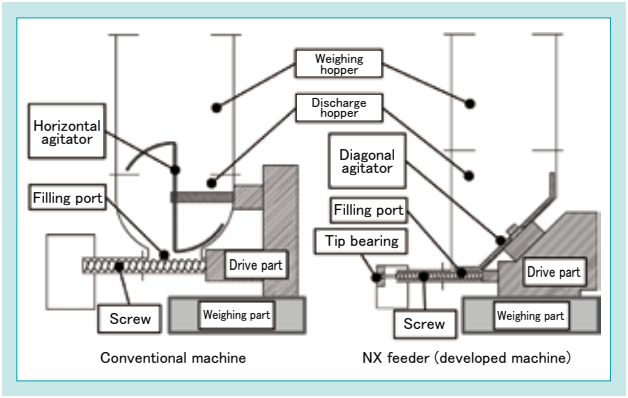

Fig. 3 Conventional Model and NX Feeder

3.1.2 Expansion to micro flow rate range

In the conventional machine, the agitator and screw are closest only at the center of filling port, and spaces are left in the front and rear of the center. For these reasons, performance of filling to the screw is inferior.

As for the developed machine, the micro flow rate screw was newly developed. Performance of filling to the screw is enhanced, since the diagonal agitator, one of the features of NX feeders, passes through while it presses materials against the screw in all ranges of the filling port. Accordingly, even the screw designed for the micro flow rate with shallow grooves and narrow pitches can be controlled stably.

3.1.3 Expansion of applicable materials

In the conventional machine, filling of materials including titanium oxide with high bridge to the screw is unstable and the control status is also unstable, leading to the incapability of supply.

Since the NX feeders have the diagonal agitator, materials in it are moved in varied directions, such as vertical and circumferential directions. Materials with high bridge including titanium oxide are fluidized in this manner and supplied to the screw stably. However, after materials including titanium oxide are supplied to the screw, they are consolidated and a resistance is generated, causing screw run-outs and consequent decrease in the accuracy.

In the developed machine, a tip bearing is added to the screw for the improvement to prevent screw run-outs, and the highly accurate supply of titanium oxide with high bridge is achieved.

3.1.4 Reduction of installation area

Since the conventional machine has the rectangular-box-shape windshield, if several feeders are collectively placed radially, front corners of the feeders interfere with each other (Fig. 4).

To the developed machine, in a similar manner to the conventional machine, the design is provided with a windshield to prevent an influence on the weight by the wind in the environment. To prevent an interference of several feeders collectively placed with each other, the front of the windshield frame was tapered and additionally, the installation area was reduced by 28% (Fig. 5). In addition, the opening space was made by connecting the windshield door on the front tapered part with hinges, and maintainability during the thorough cleaning of the feeder was maintained (Fig. 6).

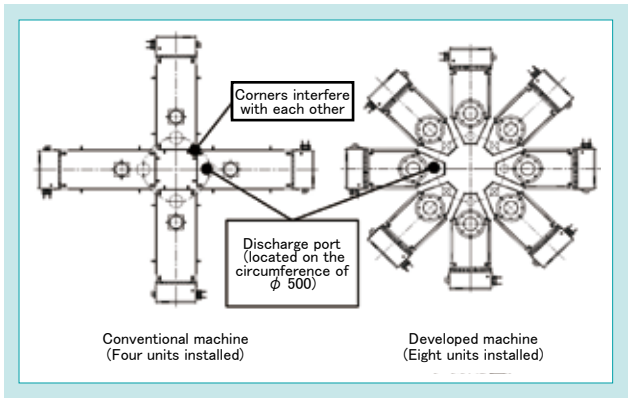

Fig. 4 Collective Installation

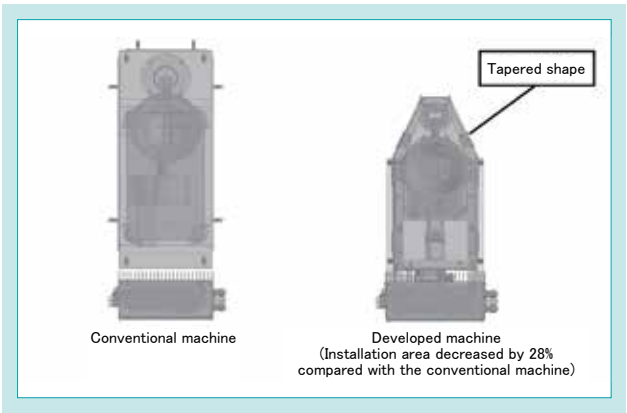

Fig. 5 Installation Area

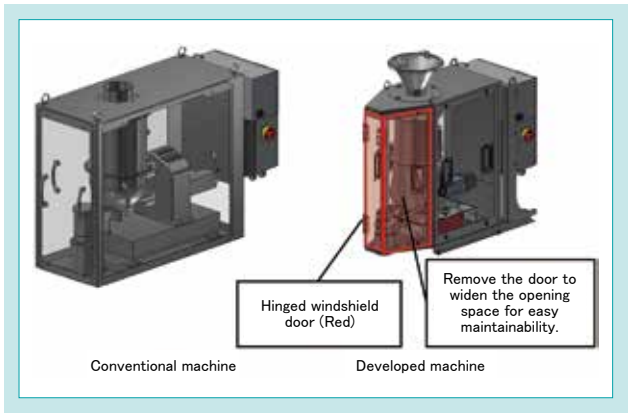

Fig. 6 Feeder Shape

3-2 Technology for improving weighing accuracy

3.2.1 Issues of weighing accuracy

Slight fluctuations in the weight may be a factor to disturb the control status within the micro flow rate range. Therefore, we developed the technologies not to give any influence on the weight. Specifically, we attempted to achieve the high accuracy and high stabilization of load cell and the fixation of the motor wiring route, and develop the flexible tubes.

3.2.2 High accuracy and high stabilization of load cell

For the high accuracy of weight measurement, we improved the in-house load cell in the weighing part. To improve the detection accuracy of a small amount, we focused on the high natural frequency of the load cell. As the natural frequency of the load cell is increased, the rigidity is also increased, the vibration convergence time due to load is reduced, and stable measurement results can be obtained. This time, we adopted the load cell with high natural frequency.

Furthermore, we also focused on the electromotive force of foil materials used for a strain gauge. Among foil materials, the electromotive force of CuNi is high, while that of NiCr is low. It shows the influence given by temperature change by 1°C on the weight as an error. To reduce influence on the weight and enhance the stability by temperature, the load cell with NiCr warp gauge foil used was adopted to the developed machine (Table 2).

Table 2 Load Cell

Load cell	Natural frequency (Hz)	Foil material	Thermo-electromotive force of foil material
Prototype (1)	High	CuNi	High
Prototype (2)	Low	NiCr	Low
Developed machine	High	NiCr	Low

3.2.3 Fixation of motor wiring route

The drive part of a feeder is located on the weighing part, and the drive part has the wiring to supply electric power to the motor. Tension or twist in the motor wiring causes forces on the measuring part, leading to the errors in weight. Therefore, the wiring route and length that will not give any influence on measuring were defined, and for the reproduction of them, influence was reduced by fixing with the bracket and cable ground (Fig. 7).

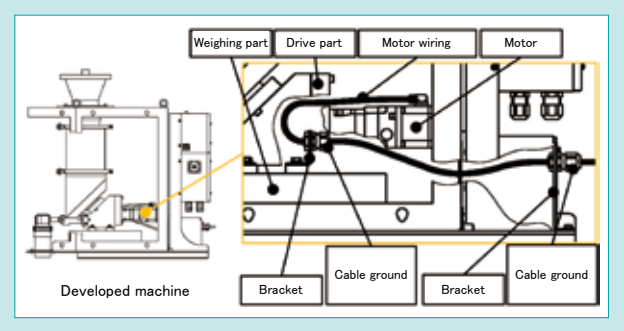

Fig. 7 Motor Wiring

3.2.4 Development of flexible tube not to give influence on weight

The standard conventional machine is not equipped with the flexible tube preventing fluctuations in the weight and separating the weighing side from the fixing side. Thus, materials are scattered, and the cleaning frequency increases. Although the cylindrical flexible tube may be optionally installed according to customers' requests, its accuracy was hard to be secured.

In the developed machine, the flexible tube allowing the prevention of materials scattering and the assurance of accuracy was developed (Fig. 8). Though trial production was conducted with thin silicone rubber used, prior to the determination of shape that does not influence the weight, production of and tests on prototypes for some times were required. Finally, the flexible tube was made into a thin-bellows-shape.

The flexible tube to prevent scattering was installed to the place shown in Fig. 8, and the relationship between the flexible tube and weight was evaluated.

With the flexible tube installed and, talc loaded into the feeder, the feeder was operated with controlled, and fluctuations in weight were measured at respective flow rates. To review the influence given by the diameter of the flexible tube, two types of diameters, 65A (port diameter φ76.3) and 90A (port diameter φ101.6) were tested. With regard to the agitator that seems to be related with the weight change due to the agitation of materials, two types, two-blade, popular in the NX feeders, and three-blade, having different agitation frequency from the type of two-blade, were recognized (Fig. 9).

With the flexible tube of 65A and the two-blade agitator equipped, fluctuations in weight were

large. With the flexible tube of 65A and three-blade agitator equipped, fluctuations in weight were small. In addition, after the flexible port diameter was changed to 90A with the three-blade agitator equipped, it was recognized that the fluctuations in weight were minimum.

If the number of agitator blades is two, the agitation balance in the hopper was uneven due to agitation by the agitator, and the upper flexible tube was pulled by small invisible vibrations, and the weight was fluctuated. The balance seems to become better by changing the number of blades into three. In addition, it seems that the flexibility becomes better as the port diameter of the flexible tube is increased, and small vibrations were absorbed flexibly and thus, no pulling occurred.

In the developed machine, fluctuations in the weight during controlled operation was achieved by the adoption of the three-blade agitator and the flexible tube with a large-diameter port.

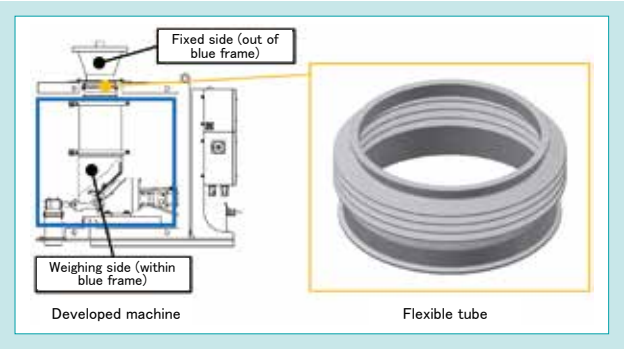

Fig. 8 Flexible Tube

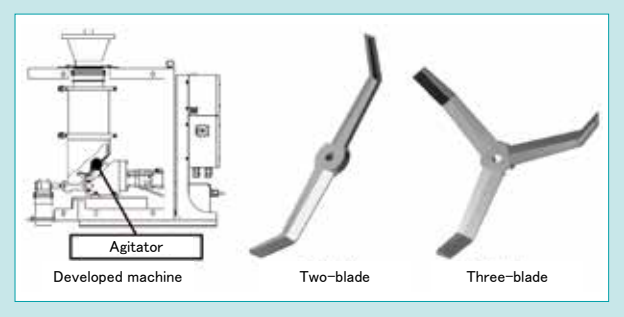

Fig. 9 Agitator

4. Performance verification and technological review

4-1 Confirmation of supply accuracy and minimum flow rate

(1) Test method

As a test material, talc was loaded into the developed machine, and supplied at fixed flow rates, including the target value of flow rate 100 g/h, at 50, 100, 200, 500, and 1,000 g/h.

The supply accuracy for a minute was measured for ten times by using an electronic balance. The supply accuracy (formula (1)) was measured by using the standard deviation of the values measures for ten times and the average. It indicates that the supply accuracy increases as this value is reduced.

Supply accuracy (%) = Standard deviation ÷ Average × 100....(1)

In addition, to improve the reliability of data, the above measurement was continuously conducted for 13 times, and the average of the supply accuracy (formula (2)) was found as shown below.

Average of supply accuracy (%) = Sum of supply accuracy measured for 13 times/13....(2)

This value was regarded as the evaluation value.

In addition, to confirm the flow-rate-range, the control of the minimum flow rate was confirmed at that time. With the flow rate set to 0.01 L/h, if 0.1% of the minimum control output of the motor driving the screw was exceeded or not was confirmed.

(2) Test results

Fig. 10 shows the test results.

It was recognized that the supply accuracy of the developed machine was higher than that of the conventional machine within the entire set flow rate range. The supply accuracy of the conventional machine at 100 g/h was 1.43%, while that of the developed machine was 0.69 %. Additionally, the motor output was 0.18% at 0.01 L/h, and it was confirmed that the screw was rotated without stopping and was controlled without a problem.

(3) Conclusion

The developed machine achieved the target values, “supply accuracy 1% or less with the sampling of 1 min at 100 g/h” and “minimum flow rate 0.01 L/h.”

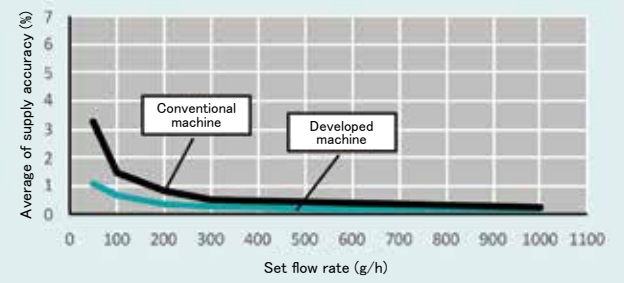

Fig. 10 Supply Accuracy of Talc

4-2 Confirmation of applicable material range

(1) Test object

The supply accuracy of materials other than talc to the developed machine was also compared with that to the conventional machine.

(2) Test method

The test was conducted with using three kinds of typical materials whose properties are different, Irganox (low bridge material), calcium carbonate (intermediate bridge material), titanium oxide (high bridge material).

Respective materials were loaded and supplied at the flow rates of 50, 100, 200, 500, and 1,000 g/h, and the average of supply accuracy was measured.

(3) Test results

Figs. 11, 12, and 13 show the test results. In the case of Irganox and calcium carbonate, the supply accuracy of the developed machine exceeded the conventional machine.

In the case of titanium oxide, by the conventional machine, filling was unstable and the control status was also unstable, leading to the incapability of supply.

(4) Conclusion

In the developed machine, supply of high bridge material, titanium oxide, was achieved.

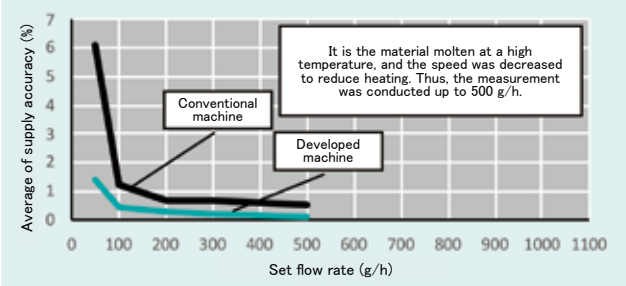

Fig. 11 Supply Accuracy of Irganox

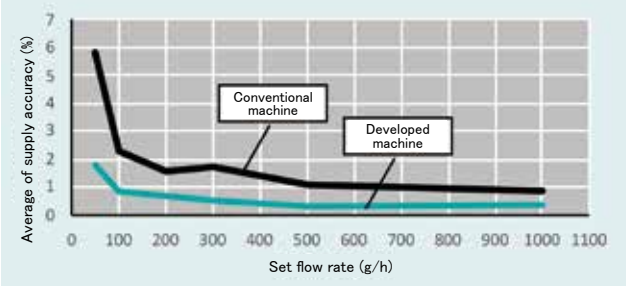

Fig. 12 Supply Accuracy of Calcium Carbonate

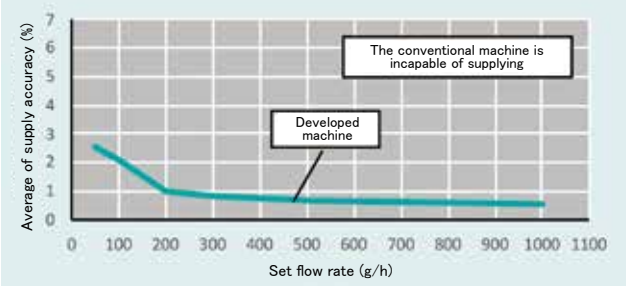

Fig. 13 Supply Accuracy of Titanium Oxide

5. Conclusion

To meet customers' requests for the highly accurate supply within the micro flow rate range, "Supply accuracy of 1% or less with 100 g/h, 1 min sampling" and "Minimum flow rate of 0.01L/h" were achieved. With regard to the applicable materials, supply of high bridge materials including titanium oxide, which were difficult to use with the conventional machine, was achieved. In addition, the installation area of a feeder was reduced by 28% for space saving, so that a shape by which several units of feeders were easily installed was achieved.

This machine was started to be sold in 2020. Its awareness has been increased gradually in the markets in Japan and overseas. It began to be used for the additive supply of a small amount in the resin manufacturing process and has been contributing to productivity improvement.

It can be used for not only the resin manufacturing process, but also trial production in which low volume products are manufactured, research line, or purposes of research and development in varied industries such as industries of batteries, cosmetics, and food, other than resin. In the future, we are going to enter the drug market with strong needs for the supply of a small amount and aim at the contribution to the improvement in the productivity of drugs.

Contribution to SDG Targets

9.5 Promotion of scientific research and innovation
Contribution to the improvement in the ability of research and development in varied industries

12.1 Implementation of sustainable consumption and production
Contribution to the productivity improvement in resin manufacturing

Development of Water Work Information System for Water Pipe Construction

Pipe Systems Networks R&D Dept.

Despite efforts to renew and build earthquake-resistant pipelines, the ratio of aging pipes increases year by year, so acceleration of renewal is required. However, in addition to manpower shortage, construction companies spend a lot of time on various documents to submit. On the other hand, water utilities are concerned about the drop in level of the construction management, and require secure jointing work according to the manual and reliable measurement records. In order to solve these problems, we have developed "Water work information system (WWIS)", "Site Checker" and "Site Angle". WWIS can encourage secure works and automatically create documents using portable terminals, Site Checker can measure positions of a rubber gasket and send to WWIS, and Site Angle can automatically measure joint deflection angles.

【Key Word】
water pipe construction, earthquake-resistant ductile iron pipe, IoT, improvement of quality and efficiency of constructions

Related SDGs

1. Introduction

Despite the requirement of accelerated renewal and building earthquake-resistant pipelines, the ratio of aging pipes has been increasing.[1] (Fig. 1). Even from a viewpoint of the transition of the past piped water supply ratio, the increase in aging pipes is forecast to continue in the future, so additional promotion of the replacement is required.

In the current situations in water pipe construction, construction companies have been spending much labor and time for the control of the worksite and preparation of related documents (Fig. 2), which is said to be one of the factors causing the extension of construction period. On the other hand, water utilities and construction companies suffer from the shortage of manpower, and the approach to skill transfer and the maintenance of construction quality is required.

Therefore, we developed "Water work information system (hereafter referred to as 'WWIS')," expected to solve these issues and improve the productivity of water pipe construction by reducing the labor of persons concerned, and improvement in the construction quality by the unification of construction control, "Site Checker," by which the positions of a rubber gasket are measured and "Site Angle," which automatically measures the joint deflection angle.

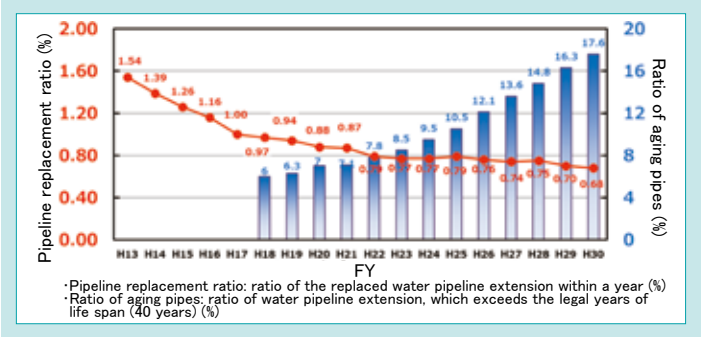

Fig. 1 The Ratio of Aging Pipes is Increasing in Japan

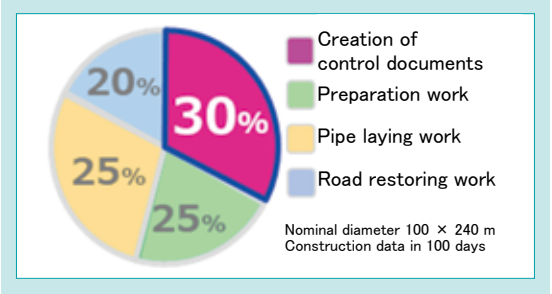

Fig. 2 Construction Works

2. Development concept and target value

2-1 Concept of development

Aiming at the improvement in the construction control level and streamlining of water pipe construction, the development concept was established as shown in Table 1.

Table 1 Development Concepts

Concept	Contents
Promotion of appropriate construction	To exhibit the function of earthquake-resistant ductile iron pipes, appropriate construction and its control are required. Thus, we develop WWIS allowing the guidance to the appropriate construction procedures by inputting the construction information into a smartphone in order at construction site.
Streamlining of the creation of construction control documents	The system should allow the automatic creation of documents related to the laying of pipes among the documents that are required to be submitted to water utilities by construction companies.
Accurate and secure records of the construction control values	As the control values during construction, the confirmation of the positions of a rubber gasket and the measurement of the joint deflection angle are important to confirm that joints are connected appropriately. Conventionally, the measured values have been written at a construction site as memorandums, and then, a fair copy of them has been created. Thus, mis-input or errors in copying may have occurred. For accurate and secure record of these control values, develop the function expansion tool allowing easy measurement of respective values and reflection of them to WWIS.

2-2 Target value

2.2.1 Development of WWIS

(1) The system was designed to allow the application to earthquake-resistant ductile iron pipes of small and middle diameters (GX-type, NS-type E class), as well as NS-type pipes, K-type pipes, and flanged pipes attached to the relevant pipes (Fig. 3).

(2) The system was designed to allow the input of construction control items sequentially according to the input screen on a smartphone at a construction site, the guide to the appropriate construction procedures in accordance with the joint instruction provided by Japan Ductile Iron Pipe Association (hereafter referred to as JDPA), and the judgment of appropriate construction (Fig. 3).

(3) It was also designed so that the joint check sheet, construction daily report, and piping plan diagram, which are needed to be submitted in general to the water utilities from construction companies, are automatically created by inputting required information into a smartphone (Fig. 4).

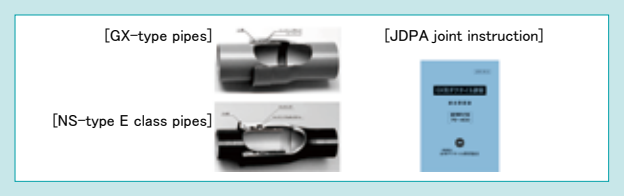

Fig. 3 Application Range and Data Input Procedure of WWIS

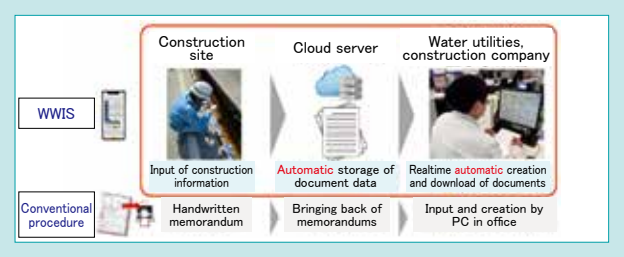

Fig. 4 Water Work Information System(WWIS)

2.2.2 Development of Site Checker

(1) The joints whose the positions of a rubber gasket need to be measured in GX-type pipes and NS-type E class pipes were targeted.

(2) The equipment is designed so that the positions of a rubber gasket can be measured accurately only by operation of a button (Fig. 5), and the measured values can be reflected to the construction information system by radiocommunication.

(3) The system is designed so that it is not influenced by varied conditions in the ditch at site.

2.2.3 Development of Site Angle

(1) The socketed joints whose joint deflection angle needed to be measured in GX-type pipes and NS-type E class pipes were targeted.

(2) The system was designed so that the horizontal and vertical angles and 3D-deflection angles could be calculated within 10 seconds and acceptance judgment was allowed by taking a picture of the joint with the camera incorporated in a smartphone equipped with WWIS (Fig. 5).

(3) The deflection angle performance of eight degrees or less where the joint can bend was adjusted to the applicable range, and the measurement accuracy on a lab basis was adjusted to ±0.5°.

(4) The application was constructed to allow startup by the operation of one switch via WWIS and reflect the calculated values.

(5) The application was also made to allow checking the insertion of the sockets to utilize the earthquake-resistant performance of the joint maximally.

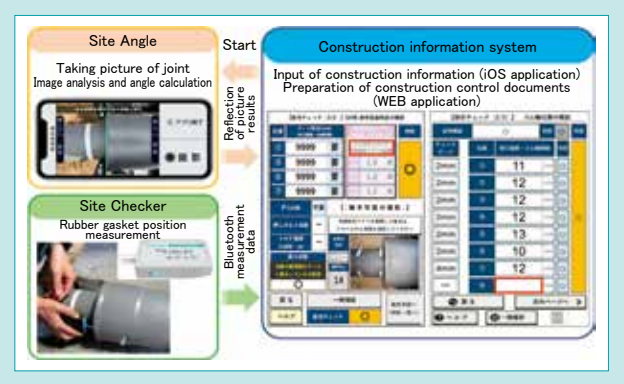

Fig. 5 Enhancement of WWIS

3. Issues to be solved

(1) WWIS

To prevent faulty construction and improve the construction quality, the system design to promote the implementation of appropriate jointing work procedures was required.

Also, for the stable operation of the system at a construction site, the operation system whose parts supplier is fixed and software update is easy to control, and the commercially available application, which is the basis of the system, needed to be selected.

(2) Site Checker

The limited size needed to be satisfied to allow the easy measurement of the positions of a rubber gasket in a narrow place including the pipe bottom.

Since the use in rainy weather or drop into water places are assumed, securement of water tightness was required (Fig. 6).

(3) Site Angle

To calculate the joint deflection angle with high accuracy by the image processing of a picture of joint, the edge lines of the spigot joint needed to be extracted with high accuracy (Fig. 7). Especially, to calculate the angle in vertical direction, minute change in the angle of the edge lines needed to be extracted.

To allow the operation even at a construction site with a bad communication status, the development of applications allowing all processes in a smartphone was required.

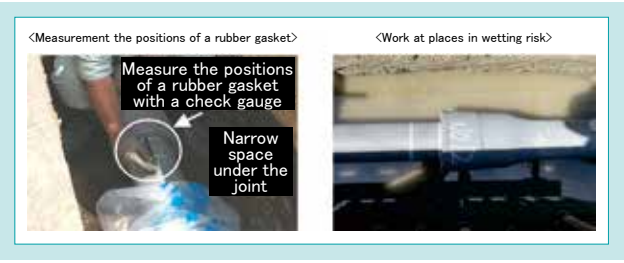

Fig. 6 Checking Positions of a Rubber Gasket

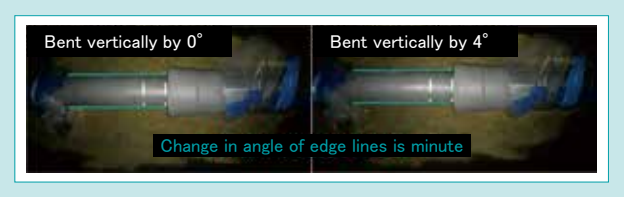

Fig. 7 Checking Joint Deflection Angles

4. Development technology

4-1 WWIS

4.1.1 Selection of terminal and application

As the terminal of the system, iPhone XR was selected because of its wide screen size suitable for outdoor use, the fixed parts supplier, and the easiness of the development of an analysis tool. As the iOS application, the basis of the system, commercially available "i-Reporter" with higher design freedom was selected (Fig. 8).

Fig. 8 Device and Application of WWIS

4.1.2 Development of input system

(1) Input of basic information

The pipe materials to be used for jointing work are input after inputting the basic information including the date of construction and the name of construction and construction companies (Fig. 9). Pipe materials are made to be selectable among all types of straight pipes and deformed pipes shown in the manual of JDPA. Help buttons are provided for the screens appropriately to allow referring to the construction control method according to the joint instruction (Figs. 10 to 12).

(2) Input of joint check items

(i) Check before jointing

Items including the presence of the projection of spigot and the application of pipe joint lubricant that need to be confirmed before the jointings are checked (Fig. 10).

(ii) Check of positions of a rubber gasket

To confirm that the rubber gasket is at the appropriate position after jointing, the acceptance judgment is made automatically displayed by inputting the distance from the socket face to the positions of the rubber gasket (b) with eight equally divided points on circumference (Figs. 11 and 13).

(iii) Check of joint deflection angle and record of joint picture

The acceptance judgment is made automatically displayed by inputting the measurement results of the distance from the socket face to the white line on the spigot pipe (a) with four equally divided points on circumference. The picture of the joint to be recorded on the joint check sheet is decided to be taken (Figs. 12 and 13).

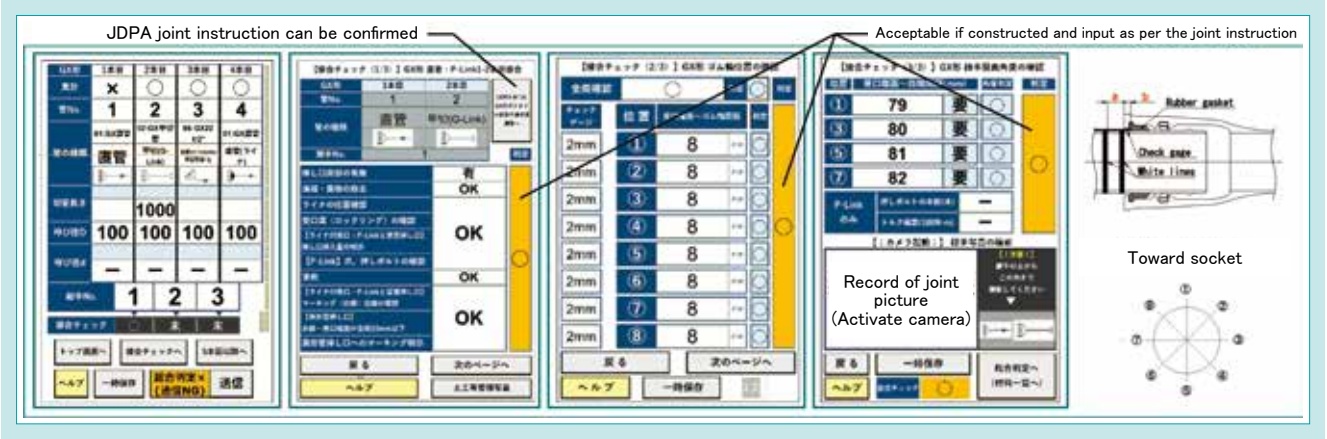

Fig. 9 Information on Pipe Materials

Fig. 10 Check Items Before Jointing

Fig. 11 Positions (b) of a Rubber Gasket

Fig. 12 Distances (a) Between a White Line and the Socket Surface

Fig. 13 Positions(b) and Distances(a)

(3) Creation of construction control documents (as-built drawings)

A web application that automatically creates the documents based on the input information is created, and the automatically created joint check sheet, construction daily report, and piping diagram are allowed to be viewed and downloaded (Fig. 14).

Fig. 14 Output System of WWIS

4-2 Site Checker

4.2.1 Outline of Site Checker

Site Checker is the equipment that can automatically reflect the measurement results of the distance from the socket face to the positions of the rubber gasket to the WWIS via Bluetooth communication by placing the telescoping shaft rod onto the socket face, pushing it until the gauge touches the rubber gasket, and pushing the measurement button (Fig. 15).

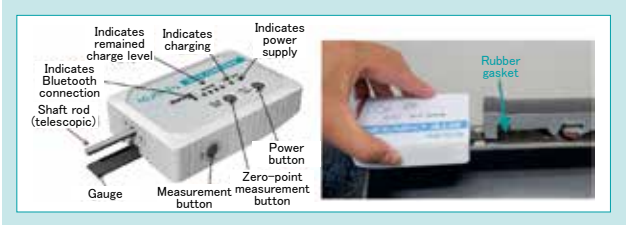

Fig. 15 Image of Site Checker

4.2.2 Performance verification test on Site Checker

As a result of the performance verification test on the Site Checker, it was recognized that no problem was found in the communication to WWIS, waterproof performance and workability. The required performances were satisfied (Table 2 and Fig. 16).

Table 2 Performance Test Results

Performance verification items	Test results	Performance verification items	Test results
Capability of reflecting the measurement results to the WWIS	Satisfied	Having an electric capacity available by charging about once a week	Satisfied
No water infiltration even after submergence into water depth 50 mm for three minutes	Satisfied	Capability of measuring even at the joint directly placed on the ground	Satisfied
Free from problems in sliding performance even after the shaft rod is telescoped for hundred thousand times repeatedly	Satisfied	Capability of measuring even in the case that the position where the Site Checker is inserted is narrow	Satisfied

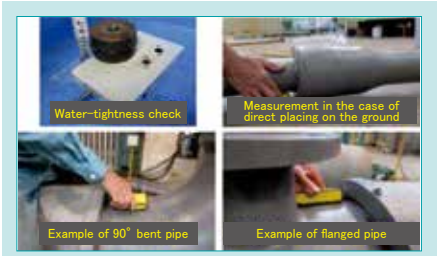

Fig. 16 Performance Test of Site Checker

4-3 Site Angle

4.3.1 Selection of terminal and development of application

The application was designed to allow the operation on the WWIS terminal and the startup by using the custom URL scheme function of i-Reporter. It also allowed for reflecting pictures and the angle calculation results to the WWIS immediately by taking the pictures of a joint with the iPhone-mounted camera.

Also, the image processing algorithm is mounted using the Open CV which is operable on the iOS platform (Fig. 17).

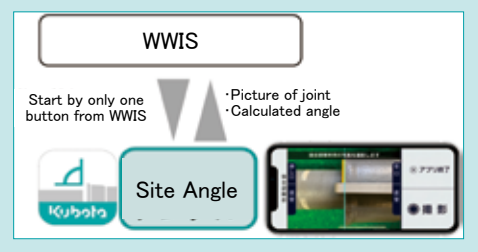

Fig. 17 Image of Site Angle

4.3.2 Development of image processing method

An algorithm that calculates the horizontal angle and vertical angle and finds the 3D-deflection angle by linear algebra processing was developed. To commonize the picture of a joint that is needed to be attached to the joint check sheet and the picture for image analysis, the distance from a pipe to a camera is determined to allow for taking the photograph of the entire joint. The method to calculate the joint deflection angle is as shown below.

Figs. 18 to 21 show the planar schemas showing the top view of joint. Toward the socket, the joint is projected horizontally, to the left side, and it is projected vertically, to the upper side. Therefore, the more the spigot pipe is separated from the socket face, the more the diameter (width) is increased.

(1) Horizontal angle

(i) After binarizing the image and extracting the upper and lower edge lines of the spigot pipe, remove the less accurate profile lines, and roughly fix the center line of the spigot pipe.

(ii) Based on the edge lines of the distances data from the roughly defined center line to the edge lines within ±σ, extract the highly accurate center line of the spigot pipe (Fig. 18).

(iii) Calculate the angle made by the highly accurate center line of the spigot and the socket pipes (Fig. 21)

(2) Vertical angle

(i) After dividing the spigot pipe into four and extracting four edge lines, remove less accurate edge lines and roughly fix the edge lines (Fig. 19).

(ii) After placing the binarized small area over the roughly fixed edge lines and increasing the number of data θ_1 and θ_2, calculate highly accurate θ_1 and θ_2 by averaging the data within ±σ (Fig. 20).

(iii) Convert the calculated result of 180°- (θ_1 + θ_2) into the vertical angle by the function prepared for each nominal diameter and horizontal angle (Fig. 21).

(3) 3D-deflection angle

Calculate the square root of the sum of the squares of horizontal and vertical angles.

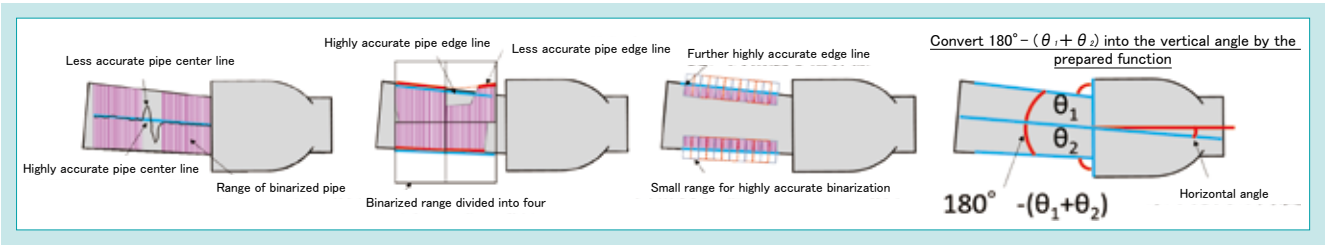

Fig. 18 Calculating the Horizontal Angle Fig. 19 Calculating the Vertical Angle Fig. 20 Calculating the Vertical Angle Fig. 21 Calculating the 3D-deflection Angle

4.3.3 Performance verification test on Site Angle

A built-in joint accurately bent by 8° was produced and the image processing accuracy was verified on a lab basis. From the status with the joint bent by 8° in vertical upward direction, pictures were taken with the joint turned by 10° repeatedly until the joint was bent by 8° in vertical downward direction, and the joint deflection angle was calculated. Consequently, the calculation error was maximally 0.46°, and the target value, ± 0.5° or less, was satisfied (Fig. 22 and Table 3).

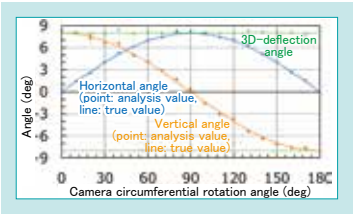

Fig. 22 Results of Analysis and True Values

Table 3 Analysis Accuracies on a Lab Basis

	Average error (deg)	Maximum error (deg)
Horizontal angle	0.13°	0.32°
Vertical angle	0.24°	0.40°
3D-deflection angle	0.18°	0.46°

4.3.4 Development of photographing jig

As a result of CAD simulation, in the case of the joint of nominal diameter 75, the minimum diameter, it was revealed that the difference in the outer diameters of pipe on images was remained approximately 50 pixels even when the joint was bent by the allowable deflection angle (by 4°) vertically, and the camera position and direction needed to be controlled with high accuracy (Fig. 23). Thus, the photographing jig allowing the fixing of camera in tilt within 0.1° or less to the socket pipe by easy operation at site was developed (Fig. 24).

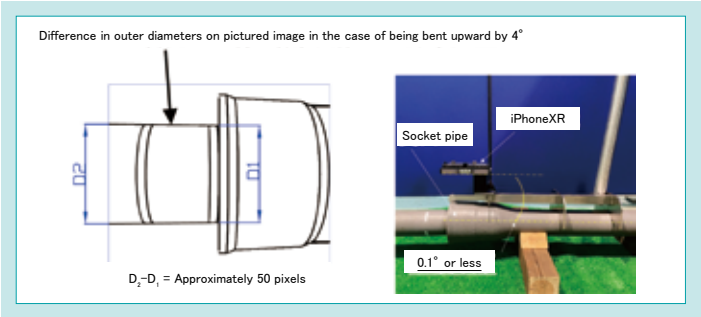

Fig. 23 Difference in Diameters

Fig. 24 Photographing Jig

4.3.5 Development of function to judge the degree of insertion into pipe

In the present situation, whether the degree of insertion into the socket pipe is appropriate or not is confirmed by checking the fit of the socket faces in the width of the white line (1) on the insertion port (Fig. 25), and the difficulty in the under the joint check is an issue. Therefore, marks to allow for checking if the degree of insertion is within the specified range are indicated on the picture of the joint. Then, the operator can easily confirm that the degree of insertion is appropriate by checking the overlap with the white line (2) (Fig. 26).

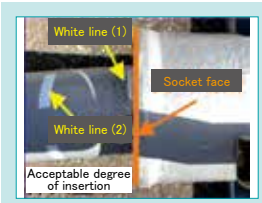

Fig. 25 Checking the Degree of Pipe Insertion by Visual Inspection

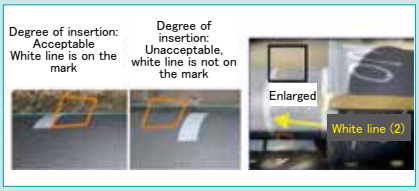

Fig. 26 Checking the Degree of Pipe Insertion Using Marks

4-4 Results of trial operation of respective systems at site

Results of trial operation of WWIS and Site Angle at actual construction sites are shown below. Site Checker is at the stage that the trial construction site is determined, and the trial will be conducted in order.

(1) WWIS

As a result of trials in 66 constructions and 6,250 joints in total, input of information at site was free from problems, and the function to create the documents (joint check sheet, construction daily report, and piping plan diagram) automatically was also free from problems. The time required for input per joint was equivalent to the time required for manual preparation (one to two minutes). It was recognized that the time to create the documents after construction (30 minutes a day on average) was reduced.

(2) Site angle

At the construction site, the trial was conducted on 13 joints in total. Then, the calculation of all joints with an error of approximately 0.5°, and measurement with accuracy higher than the conventional measurement method (error: 0.9°) was allowed, even though there were some environmental conditions worsening the accuracy, including direct sunlight and spring water. The required analysis time is approximately 2 seconds for a joint, and the target value, 10 seconds, was satisfied. Also, it was confirmed that the degree of pipe insertion was appropriate for all joints and visually judged appropriately.

5. Conclusion

"WWIS" for water pipe construction was developed.

"Promotion of appropriate construction" by guiding to the work procedure in accordance with the joint instruction, "Streamlining of creation of the documents" by the function to create the documents automatically, and "Accurate and reliable measurement record of construction control values" by the link of Site Checker and Site Angle are achieved.

Presently, the activity to adopt the system is being deployed as the tool allowing the improvement in quality and streamlining of water pipe construction, and the adoption by several water utilities is being promoted.

We are continuously going to improve the replacement rate of water pipes and develop the products and solutions that can contribute to the construction of safe and secure water pipelines in the future.

Contribution to SDG Targets

6.1 Enhancement of access to safe and low-cost tap water
By improving the pipeline replacement ratio in water pipe construction work to contribute to the improvement in infrastructure of water and sewage

11.5 Reduction of deaths and victims due to injuries, reduction of economical loss
Contribution to the reduction of economical loss by supplying safe and secure water pipes

12.8 Dissemination and enlightenment of sustainable development and life style
Contribution to the achievement of sustainable society by raising the public awareness of water and sewage

Reference

1) Japan Water Works Association: Statistics on waterworks (FY2018)

Development of Highly Accurate Method for Predicting the Degree of Deterioration in Water Pipes

Pipe Systems Networks R&D Dept./Technology Innovation R&D Dept. Ⅰ

There are many domestic water pipes that need to be replaced. Although water utilities need to maintain pipelines to a high standard, pipe replacement has been actually delayed because it is difficult to evaluate the extent to which buried pipes have deteriorated, and there are no clear guidelines on how to evaluate pipe deterioration. Then, as part of an initiative to promote pipe replacement, using approx. 6000 of the accumulated survey data, we have developed a method that can predict the degree of deterioration in water pipelines with high accuracy. The method considers both variation and lag time of corrosion, and predicts pipe deterioration quantitatively as leakage probability (number/year/km).

【Key Word】
Ductile and Cast Iron Pipe, Degree of Deterioration in Water Pipes, Pipe Replacement

Related SDGs

1. Introduction

As many of the domestic water pipes were laid during the period of high economic growth (1954–1973), many of them are now deteriorated and need to be replaced. The ratio of aging pipes, which is the ratio of deteriorated pipelines that have exceeded the legal years of lifespan, continues to increase year by year, whereas the replacement rate is gradually decreasing[1] (Fig. 1). At the current pace of replacement, there is a concern that water leakage accidents will frequently occur in the future and become a social issue all over the country.

Ductile iron pipes, which account for 56.3%[2] of domestic water, transmission, conveyance, and distribution pipelines and are the most often used pipelines, have legal years of lifespan of 40 years (based on the concept of depreciation), but the actual durability varies with the pipe bore diameter and the buried environment and is evaluated to be approximately 60 years or longer. Therefore, it is considered possible to maintain pipelines to a high standard in the future with an efficient budget by replacing them in accordance with the replacement priority judgment, based on correctly evaluating the degree of deterioration in pipelines, instead of replacing them in accordance with their legal years of lifespan.

Some water utilities have difficulty in prioritizing which to be replaced when replacing deteriorated pipelines, and clear evaluation indices had been particularly requested for the degree of deterioration in ductile iron pipes used in major pipelines. Water utilities may set a replacement standard period of 40 to 100 years depending on the bore diameter and buried environment by directly diagnosing the pipe body and soil[3], but particularly, relatively small-scale water utilities often replace from old pipes. Therefore, clear evaluation indices for the degree of deterioration are considered necessary.

Therefore, in order to support the formulation of an efficient replacement plan by water utilities, we have developed a highly accurate method for predicting the degree of deterioration in ductile and cast iron pipes, which are used for main domestic pipelines.

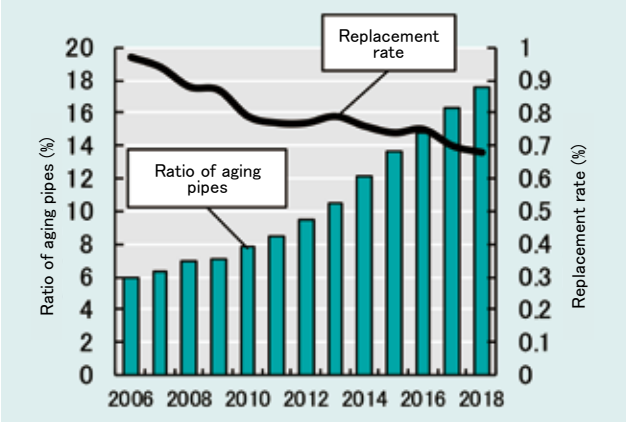

Fig. 1 Transition of Aging Rate and Replacement Rate of Domestic Water Pipes

2. Concept of development

The development concept of a highly accurate method for predicting the degree of deterioration is shown below.

(1) The degree of deterioration can be quantitatively evaluated (for example, calculated as leakage probability (number/year/km)).

(2) The accuracy of predicting leakages is improved compared with the conventional method for predicting the degree of deterioration (hereinafter referred to as the conventional method).

(3) The variation in corrosion and the protection period of the outer coating (hereinafter referred to as lag time) can be considered.

3. Technological issues to be solved

In the conventional method, multiple regression analysis was conducted based on the survey data on buried soil and the corrosion depth of the pipe body, and the obtained logarithmic regression formula was used to classify the deterioration degree rank in 5 stages (ranks I to V) according to the corrosiveness of the buried soil and the buried years of pipes (Table 1). This method had the following issues.

(1) Only qualitative evaluations can be made based on the deterioration degree rank, and it is not possible to make quantitative evaluations, such as the "leakage probability (number/year/km)" requested by water utilities.

(2) Since the accuracy of predicting the corrosion depth is insufficient, the accuracy of predicting leakages is not high either.

(3) Since a prediction is made using the average corrosion depth, it is not possible to make an evaluation that considers the variation in corrosion.

Furthermore, actually buried pipes do not corrode immediately after burying because of the lag time, but the model is based on the concept that corrosion immediately starts after burying, which differs from the actual situation.

Table 1 Corrosion Depth and Deterioration Degree Rank

Corrosion depth (mm)	Deterioration rank	Judgment
6.5<	Ⅰ	Need immediate replacement
6.1～6.5	Ⅱ	Need prompt replacement
5.8～6.1	Ⅲ	Consider replacement depending on the pipeline
2.0～5.8	Ⅳ	Rediagnose within 10 years
<2.0	Ⅴ	Rediagnose within 20 years

*Example of ductile iron pipes (Class D1) with a nominal diameter of 75

4. Development technology

4-1 Construction of a leakage risk prediction model

4.1.1 Construction process of a leakage risk prediction model

Fig. 2 shows the construction process of a leakage risk prediction model. By analyzing approximately 6,000 survey data that Kubota has been accumulating, including 0 mm corrosion depth data, we have constructed a leakage risk prediction model to be used for a new method for predicting the degree of deterioration.

(1) Classify the survey data into four buried environments depending on the difference in soil corrosiveness.

(2) For each of the four buried environments, construct a corrosion depth prediction model that considers the variation and lag time of corrosion.

(3) Using the corrosion depth prediction model, construct a leakage risk prediction model that calculates the probability of corrosion depth reaching the pipe thickness.

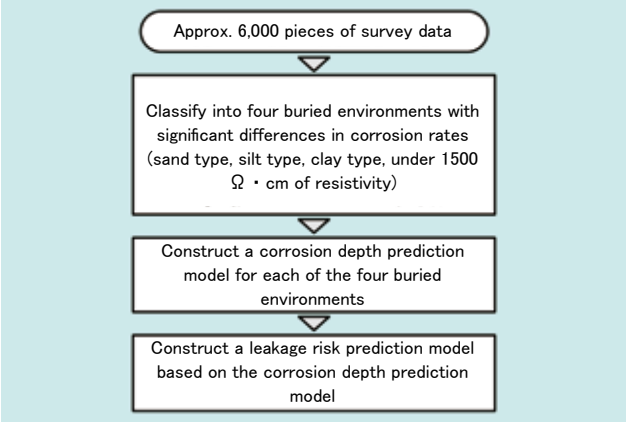

Fig. 2 Construction Process of Leakage Risk Prediction Model

4.1.2 Classification of buried environments

Table 2 outlines approx. 6,000 survey data used in the analysis. First, the buried environment data were analyzed, and among various items, it was found that the soil type and specific resistivity are contributing greatly to the corrosion rate.

Next, buried environments were classified based on soil type and specific resistivity. When classifying, consideration was made while paying attention to the point to ensure that each type has a sufficient amount of data and that a statistically significant difference will be made.

Consequently, as shown in Fig. 3, it was confirmed to be optimal if the buried environments are classified into sand type, silt type, clay type, and under 1500 Ω・cm of resistivity.

Therefore, an analysis was conducted for each of these four buried environment classifications below.

4.1.3 Construction of a corrosion depth prediction model

By investigating the relationship between the buried years and the corrosion depth from the survey data for each of the four buried environment classifications, we constructed a model that can predict the corrosion depth for each buried environment classification, that is, for each soil corrosiveness.

Among the survey data, there are many data with a corrosion depth of 0 mm where corrosion has not started because of lag lime. We were able to estimate the distribution of lag time from the ratio of the data with the corrosion depth of 0 mm, and by subtracting the estimated lag time from the buried years, a clear correlation between the buried years and the corrosion depth was obtained (Fig. 4)[4].

However, even if the buried years are the same, there is still a variation in the corrosion depth. Therefore, we devised a model that can calculate the corrosion depth as a probability value instead of an average value.

Fig. 5 shows the construction process of the corrosion depth prediction model using a corrosion depth histogram (an example with a clay type after 20 to 30 years of burying).

(1) Construct a model for calculating the probability that the corrosion depth exceeds an arbitrary value (exceedance probability of corrosion depth) by utilizing the idea of machine learning (logistic regression).

(2) Construct a corrosion depth prediction model by performing the regression of (1) for each buried period.

(3) Construct corrosion depth prediction models also for other buried environment classifications.

Table 2 Outline of Approx.6000 Survey Data Used for the Analysis

Survey target	Data
Pipe body (ductile iron pipes, cast-iron pipes)	Buried location
	Pipe specifications (bore diameter, pipe thickness, layed year)
	Maximum corrosion depth (mm)
	Corrosion rate (mm/year)
Buried environment (soil is collected and analyzed)	Soil type
	Specific resistivity (Ω・cm)
	Moisture content (%)
	pH(−)
	Presence or absence of sulfide (−) and others

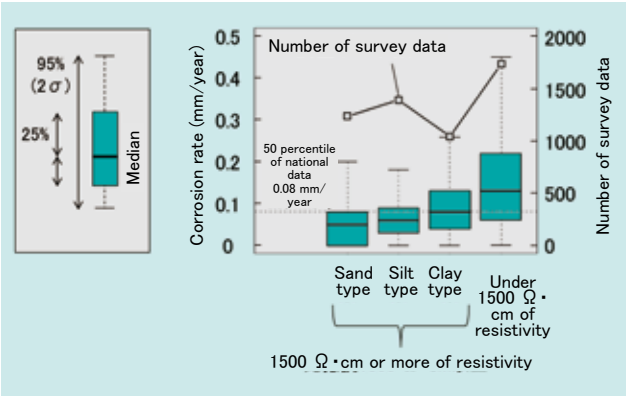

Fig. 3 Box Plot of Corrosion Rate of Each Buried Environment

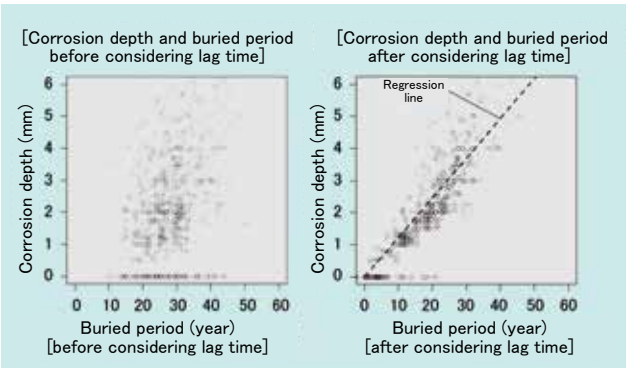

Fig. 4 Relationship between Buried Period (Before and After Considering Lag Time of Corrosion) and Corrosion Depth (Case of Clay Type)

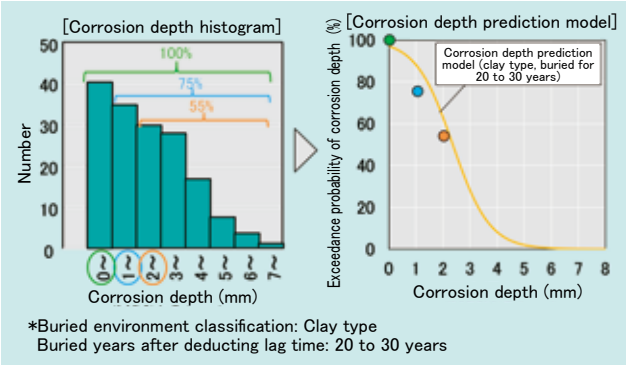

Fig. 5 Construction Process of the Corrosion Depth Prediction Model Using Corrosion Depth Histogram

4.1.4 Construction of a leakage risk prediction model

Considering that water leakage will occur when the corrosion depth reaches the pipe thickness, the corrosion depth prediction model was converted to a leakage risk prediction model applicable to the prediction of the degree of deterioration in pipes. Fig. 6 shows the construction process of the leakage risk prediction model using a corrosion depth prediction model (an example with a clay type and pipe thickness of 7.5 mm).

(1) Using the corrosion depth prediction model, calculate the probability that the corrosion depth exceeds the pipe thickness (7.5 mm for example) (Probability that corrosion depth exceeds pipe thickness (hereinafter referred to as "pipe thickness exceedance probability") for each buried period.

(2) Plot the calculated pipe thickness exceedance probability as the leakage risk for each buried period, and use the obtained relational expression as the leakage risk prediction model.

(3) Construct a leakage risk prediction model also for other buried environment classifications in the same manner.

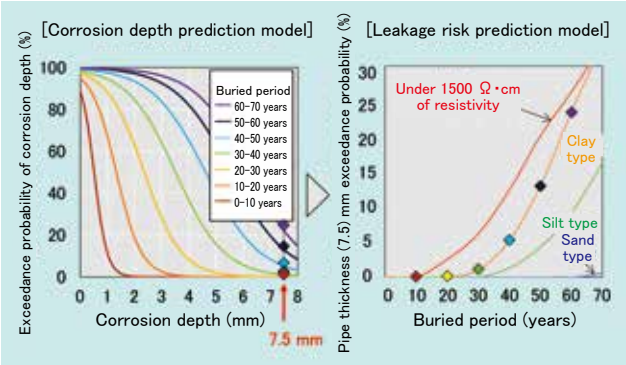

Fig. 6 Construction Process of the Leakage Risk Prediction Model Using Corrosion Depth Prediction Model

4-2 Development of a leakage probability prediction method

In the leakage risk prediction model, the pipe thickness exceedance probability (%) is calculated. To convert this into the leakage probability (number/year/km), it is necessary to understand the frequency of leakages that actually occur (annual number of leakages per pipeline extension) and perform appropriate conversion processing. If the degree of deterioration can be quantitatively evaluated as the leakage probability, it is possible to quantitatively grasp the extent to which the number of leakage accidents (= leakage probability (number/year/km) × pipeline length (km)) can be reduced by first replacing pipelines with a high leakage probability.

Fig. 7 shows a method of analyzing the leakage probability of pipelines using the leakage risk prediction model. By superimposing four buried environment classification maps on the pipeline data, the buried environment classification is defined for each pipeline, and the pipe thickness exceedance probability is calculated from the pipe thickness and the buried years. The buried environment classification map was created by superimposing approx. 6,000 survey data and publicly available national soil and geological distribution data and defining four buried environment classifications with different corrosion rates. Based on the assumption that the leakage probability could be calculated by performing appropriate conversion processing on the calculated pipe thickness exceedance probability, a comparison was made between the pipe thickness exceedance probability obtained by analyzing the pipeline data of multiple water utilities and the actual leakage data.

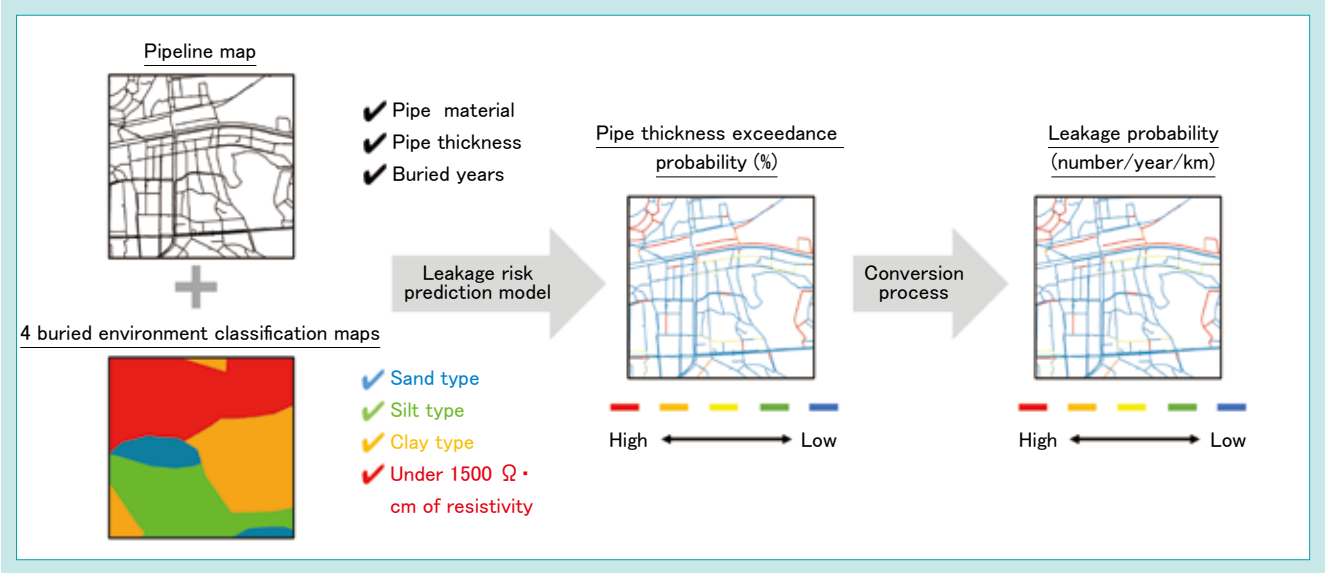

Fig. 7 Method of Analyzing Leakage Probability using the Leakage Risk Prediction Model

Fig. 8 shows the relationship between the analyzed pipe thickness exceedance probability and the actual leakage probability. The pipe extension and the actual number of leakages were aggregated for each pipe thickness exceedance probability to calculate the leakage probability. Consequently, a clear correlation was found between the analyzed pipe thickness exceedance probability and the actual leakage probability. Using the obtained relational expression between the pipe thickness exceedance probability and the leakage probability, it has become possible to calculate the leakage probability from the pipe thickness exceedance probability.

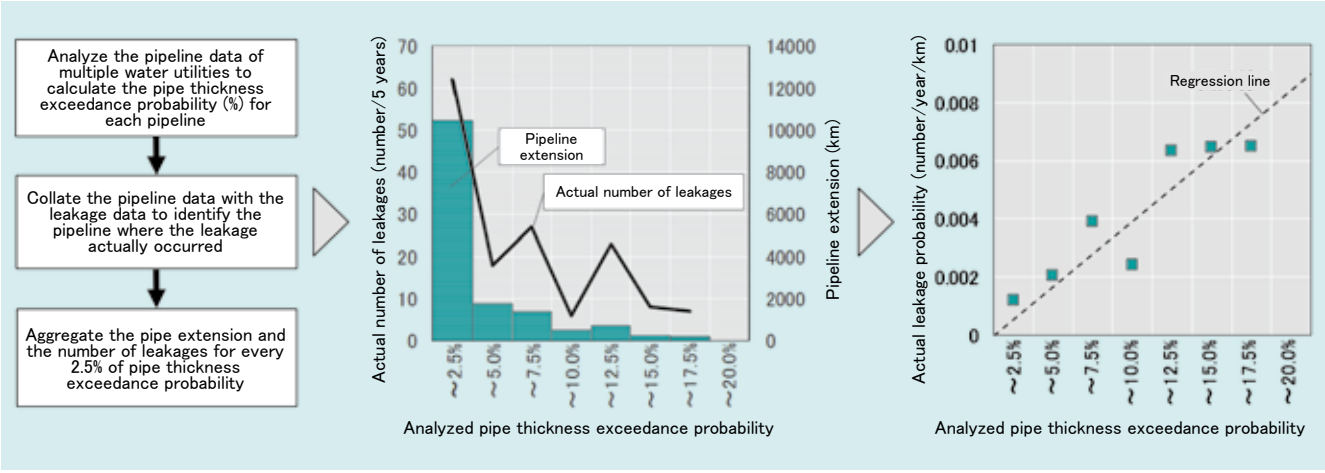

Fig. 8 Relationship Between Analyzed Leakage Risk and Actual Leakage Probability

4-3 Validation of prediction accuracy of leakages

4.3.1 Validation method

Fig. 9 shows the validation method of the accuracy of predicting leakages. By predicting the leakage probability for each pipeline using the pipeline data at some point in the past and by collating it with the leakages caused by corrosion for the following 5 years, we checked whether there were actually leakages in pipelines with a high leakage probability. The same was also checked with the conventional method, and a comparison was made with the new method for predicting the degree of deterioration.

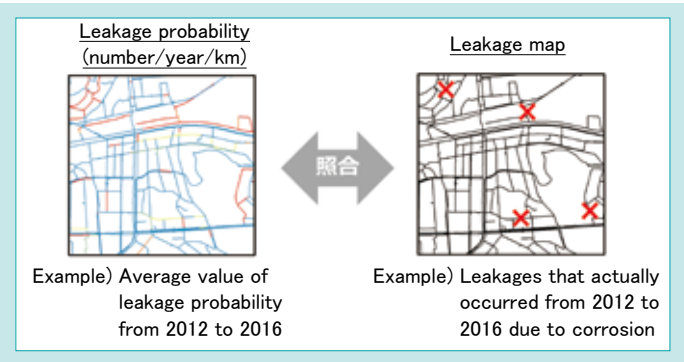

Fig. 9 Method to Validate the Accuracy of Predicting Leakages

4.3.2 Validation results

Fig. 10 shows an example (H Water Utility) of the result of validating the accuracy of predicting leakages. If 10% of the pipelines are replaced in descending order of the predicted leakage probability, the conventional method was able to reduce the number of leakages from 57 to 51, whereas the new method for predicting the degree of deterioration was capable of reducing them to 31. It was confirmed that future leakages can be reduced even with the same replacement extension by replacing pipelines using the new method for predicting the degree of deterioration.

Table 3 shows a list of the results of validating the accuracy of predicting leakages. If 20% of the pipelines are replaced in descending order of the predicted leakage probability, the conventional method was able to reduce the number of leakages to 79 (calculated by the total of 8 water utilities), whereas the new method for predicting the degree of deterioration was capable of reducing them to 39, which confirmed that the leakages can be reduced by almost half compared with the conventional method (Fig. 11).

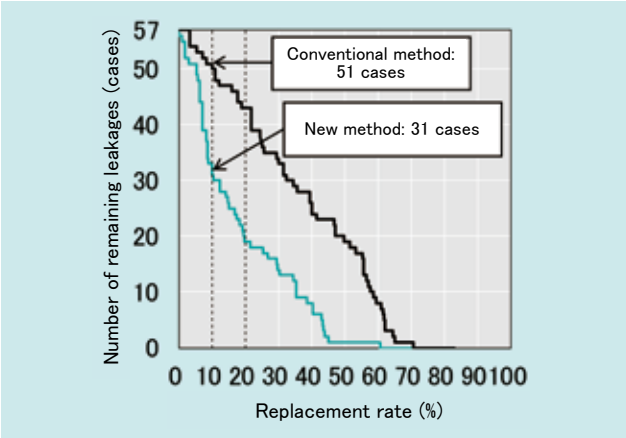

Fig. 10 One Result Validating the Accuracy of Predicting Leakages (H Water Utility)

Table 3 All Results Validating the Accuracy of Predicting Leakages

Water utility	Number of remaining leakages (cases)						
	No replacement	After 10% replacement			After 20% replacement		
	–	Conventional method	New method	Evaluation	Conventional method	New method	Evaluation
A	14	9	3	○	6	1	○
B	27	21	18	○	14	11	○
C	22	12	7	○	5	2	○
D	13	8	6	○	5	4	○
E	4	2	0	○	0	0	—
F	15	6	5	○	6	2	○
G	5	2	0	○	0	0	—
H	57	51	31	○	43	19	○
Total	157	111	70	○	79	39	○

Evaluation standard ○ : The number of remaining leakages smaller than conventional method
— : Not subject to evaluation because of 0 leakage cases

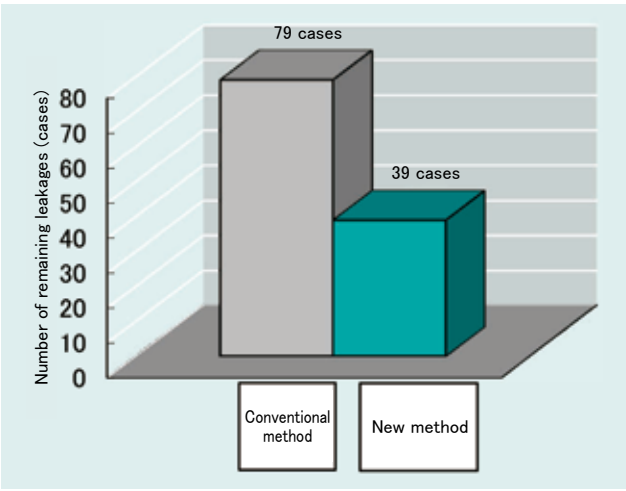

Fig. 11 Results Validating the Accuracy of Predicting Leakages (Top 20% Replace, Sum of 8 Water Utility)

5. Conclusion

We have developed a method for predicting the degree of deterioration that can quantitatively calculate the leakage probability and is more accurate than the conventional method by considering the variation and lag time of corrosion. In the validation using the pipeline and leakage data of multiple water utilities, it was confirmed that the leakages can be predicted with higher accuracy than the conventional method and that the future leakages can be almost halved.

Utilizing this technology, it is considered possible to formulate a pipeline replacement plan that can preempt and maximize the investment effect and to support the water supply business.

In the future, we would like to contribute to the water supply business and pipeline management by systematizing the methods applicable to pipeline replacement implementation plans and construction implementation and by streamlining the flow from planning to construction completion.

Contribution to SDG Targets

6.1 Strengthening access to safe and affordable drinking water
Contribution to provision of safe and affordable drinking water by reducing leakage accidents and accompanying repair costs

9.1 Development of high-quality, sustainable, and resilient infrastructure
Contribution to maintenance management of resilient pipelines by supporting the formulation of efficient replacement plans

Reference

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Development of Manhole Pump AI Abnormal Operation Detection System

Water and Environment R&D Dept. Ⅰ / Environmental Engineering Design & Procurement Dept.
Environmental Engineering Dept./EU Innovation Center

For manhole pumps for sewage pumping, which are distributed over a wide area, the adoption of cloud monitoring systems has increased recently in order to improve management efficiency. However, due to the huge amount of operational data acquired, it is difficult for maintenance managers to check daily, and even if an abnormal operating condition occurs, they are not aware of it and are forced to take emergency measures after a failure occurs. Therefore, Kubota has developed an abnormal operation detection system using AI / machine learning technology. Since AI analyzes operation data on behalf of humans and notifies abnormal conditions, maintenance managers can perform efficient preventive maintenance. In this paper, in addition to the details of the two AI functions developed, the effectiveness of these functions demonstrated in the B-DASH project of the MLIT will be described.

【Key Word】
AI, Machine Learning, IoT, Manhole Pump, Preventive Maintenance

Related SDGs

1. Introduction

A manhole pump is a pump facility that collects domestic sewage from households and pumps it to a sewage treatment facility. Pump equipment is installed in a manhole and is installed in a buried form under the road, and usually a set of two submersible pumps are operated and controlled alternately according to the water level (Fig. 1). Since the 1980s, they have been widely installed in line with the popularization of sewage, and are estimated to be located at more than 60,000 places nationwide now. Some local governments own hundreds of them, which are distributed over a wide area within the city depending on the distribution of urban areas and villages, and the terrain such as land undulations and rivers.

Because of a large number of facilities, Kubota is providing a cloud monitoring system by KSIS (Kubota Smart Infrastructure System) to improve management efficiency. A manhole pump has a control panel on the ground, in which the IoT (Internet of Things) communication terminal of KSIS (Fig. 2) is installed, and its operation data are transmitted to the cloud server via wireless Internet communication. Local government officials who maintain and manage manhole pumps as well as maintenance contractors commissioned by local governments can monitor their operating status on the cloud screen (Fig. 3). Additionally, the system is equipped with a form output function as well as an e-mail notification function in the event of a failure.

This time, Kubota has developed an abnormal operation detection function using AI (Artificial Intelligence) technology as a new function of the cloud monitoring system. Through an analysis of operation data by AI on behalf of humans, it is possible to send early notification of abnormal conditions. Consequently, measures can be taken before facilities are brought to an emergency stop, which allows efficient maintenance.

Fig. 1 Manhole Pump Unit and Submersible Pump

Fig. 2 KSIS IoT Terminal MU-1000 Series

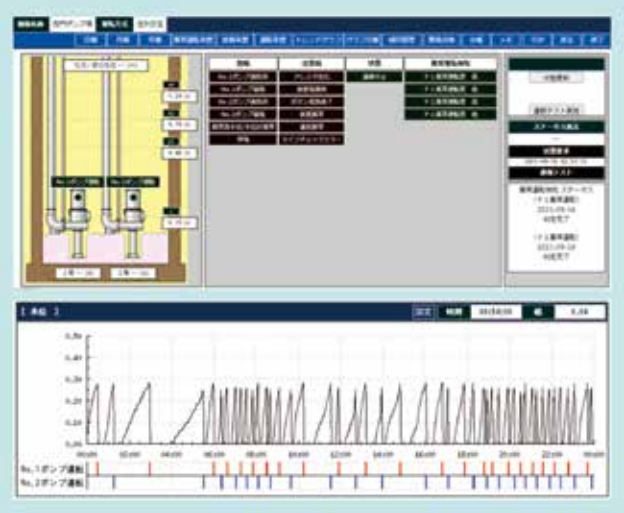


Fig. 3 Cloud Monitoring Screen Example

2. Maintenance management of manhole pumps

Foreign substances often flow into manhole pumps since they handle sewage from households, and failures are likely to occur, such as blockage inside a pump due to accumulation of them and overload because of jamming into rotating parts. If a pump becomes inoperable because of a failure, a maintenance manager visits the site to take measures such as removing foreign substances, but the urgency is required so that sewage does not overflow from a manhole, which has been a burden. Additionally, even in periodical inspection during normal times, many patrol points are scattered over a wide area, which also has been a burden.

The cloud monitoring system described above can be used to check the water level fluctuation graph, pump current value, and trend changes in operating time and the number of operations on a daily basis, which enables managers to notice when there are signs of faults. However, in reality, the monitoring data becomes enormous as the number of target facilities is large, which makes it almost impossible for maintenance managers to check all of them on a daily basis. Furthermore, with a backdrop of a shortage of responsible personnel in recent years, such a situation has been further deteriorated.

Therefore, the current situation is that the condition is first recognized only after receiving the failure report if a malfunction occurs in the pump, and emergency response is provided even at night or on holidays. Even though the cloud monitoring system had been introduced, the data were not used effectively, and there was actually no choice but to rely on follow-up maintenance.

3. Concept of development

The concept of this development was that AI would monitor the operation data of manhole pumps on behalf of humans and notify them of any abnormal operation.

The use of AI technology allows automatic detection of the operation that is different from "usual," that is, abnormal operation, from an enormous amount of operation data. Even the detection of minute changes in operation, which cannot be distinguished unless a person carefully checks facilities one by one, can be automatically handled by AI in large quantities without individual differences in judgement criteria. Maintenance managers check the detailed operation graph of manhole pumps only when the AI notifies the abnormal operation and then consider the content and timing of the response in consideration of the urgency and geographical characteristics. This allows the streamlining of maintenance management since it is possible to respond before a serious failure occurs and also in a planned manner during the daytime on weekdays instead of emergency response at night and on holidays. In other words, the developed AI can realize preventive maintenance (Fig. 4).

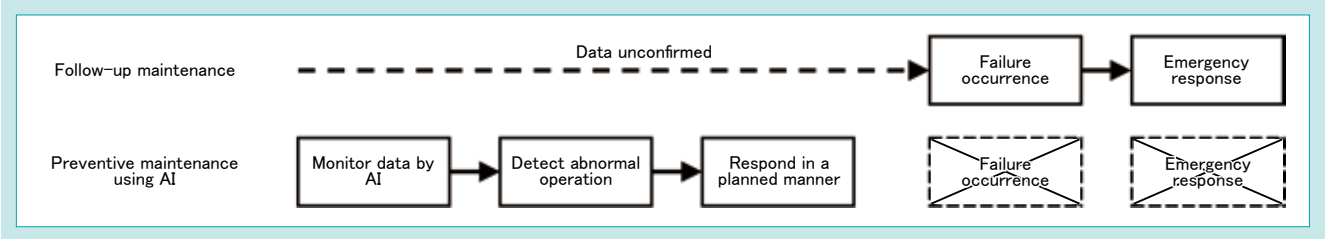


Fig. 4 Flow of Preventive Maintenance Using AI

4. Development technology

4-1 AI that learned the judgment of Kubota engineers

Through machine learning, the developed AI learned the judgment of abnormality/normality of experienced engineers who have been engaged in manhole pumps for many years in Kubota. This creates a borderline between abnormal/normal data in the data space. AI that can reproduce 90% or more of the judgment of Kubota engineers was completed as a result of many trials and errors, such as selection of features (data given to AI), data preprocessing, and tuning of machine learning parameters.

During operation, the newly input data inside the borderline is judged to be normal, and the one outside the borderline is judged to be abnormal (Fig. 5).

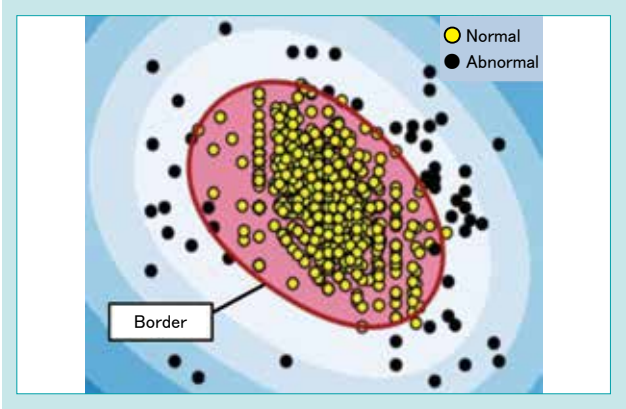


Fig. 5 Image of Learned Border

4-2 Two methods with different features

While sharing the abovementioned concept and the machine learning method, we have developed two methods of abnormal operation detection technology with different features. One uses the data of the water level and the current value, and the other one uses the data of the operating time and the number of operations. Here, the former is called an analog version, and the latter is called a digital version. The names are derived from whether the data signal acquired by the IoT terminal is an analog input (continuous value) or a digital input (contact point).

A comparison table between the analog version and the digital version is shown in Table 1. The characteristic difference between the two is that the analog version requires sensors to measure the water level and current as continuous values. Since AI is provided with data with abundant information, it can estimate the cause of abnormalities in detail, but the introduction cost is high because of the installation of sensors and the large data communication traffic. Therefore, it is positioned as a highly functional type. Conversely, because the digital version does

not require such sensors, the introduction cost is low, and it is positioned as a popular type.

Both versions have the following common points: they have learned the judgment of Kubota's experienced engineers, the range of usual operation is automatically set by AI for each facility based on it, operation is determined to be abnormal if there is out-of-range operation data from usual operation, and the level of abnormality is calculated and presented according to the degree of deviation from the usual range.

Furthermore, they also have in common the point that they present not only the presence or absence of abnormal operation but also an estimated cause of abnormality. However, the analog version presents details such as "clogging" and "water leakage," whereas the digital version only estimates whether the cause is from Unit 1 or Unit 2. Because the probable cause is presented, maintenance managers can easily determine the degree of urgency, select tools to carry for inspection, and prioritize the points to be checked on-site, which allows further streamlining of maintenance work.

Table 1 Table Comparing Analog and Digital Versions

Items	Analog version	Digital version
Data to use	Manhole water level, Pump current value, Pump ON/OFF time	Pump ON/OFF time (⇒ operating time/ number of operations)
Additional sensor	Water level sensor, Current sensor	(Not required)
Abnormal cause estimation	Present detailed cause	Present only the abnormal unit
Installation cost	High	Low
Type	Highly functional type	Popular type

4-3 Analog version of AI abnormal operation detection technology

4.3.1 Concept

The analog version uses the water level and current value data. Based on the data of the time-series change of the manhole water level, the water level lowering rate per pump operation can be calculated, which is an index showing the pump drainage capacity. If the flow path is blocked because of foreign substances clogging the inside of the pump, the drainage capacity declines compared with ordinary times, which allows the detection of an abnormality.

By contrast, the pump current value is an index showing the load state of a pump during operation. For example, when the pump is operated while its impeller is entangled with foreign substances to rub against the casing, increased frictional resistance makes the pump load higher than in the normal state, which allows detection of an abnormality.

These indicators can express the state of pumps more directly, and abnormal operation detection was realized by giving these indicators to AI as features.

4.3.2 Detection case (1)

This is a case where fibrous foreign substances entangled around the impeller inside the pump. Since the pump was operated while rubbing foreign substances, AI detected that the current value of the pump increased because of frictional resistance. The substances were gradually accumulated over a certain number of days because of their properties, and if the accumulation continued as it was, it is presumed that an overcurrent occurred and a failure was reported.

In this case, AI had already detected the abnormal operation since approximately 40 days before the field survey, and abnormality judgments had been continuously made (Fig. 6). Additionally, "rubbish entanglement in the impeller" was also predicted in the cause estimation, which was in agreement with the actual condition. Therefore, in the actual operation, it is considered possible to take a sufficiently planned response by using the said period.

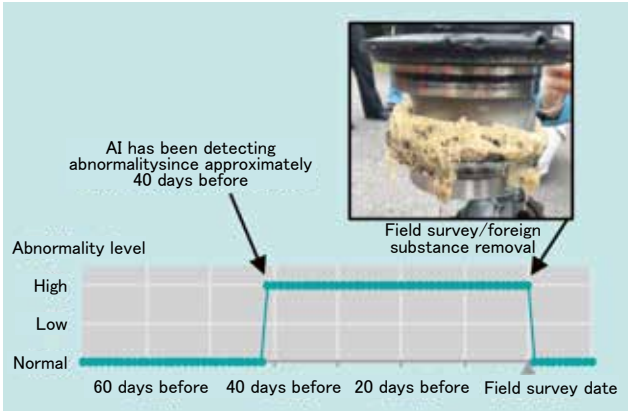


Fig. 6 Detection Case 1

4.3.3 Detection case (2)

This is a case where the piping of the exhaust valve of the Unit 2 pump was clogged with foreign substances. AI detected that the drainage capacity had been decreasing because of the idle operation state since the air pool in the pump was not discharged. This facility had a system where the operation was switched to the other unit after a fixed time during the drainage operation. Therefore, even if water should have been drained by the Unit 2 pump, drainage was completed by the subsequent operation of the Unit 1 pump, and no failure was reported.

AI had intermittently made abnormality judgments since approximately 1 year before this event, and in the latter part of the period, it almost continuously made abnormality judgments (Fig. 7). Additionally, "clogging of the exhaust valve" was also predicted in the cause estimation, which was in agreement with the actual condition. A long period of idle operation leads to wasteful energy consumption and a reduction in equipment life. If the on-site inspection was conducted based on the AI judgment at an early stage during the period, the clogging could have been solved to avoid the long-term abnormal operation.

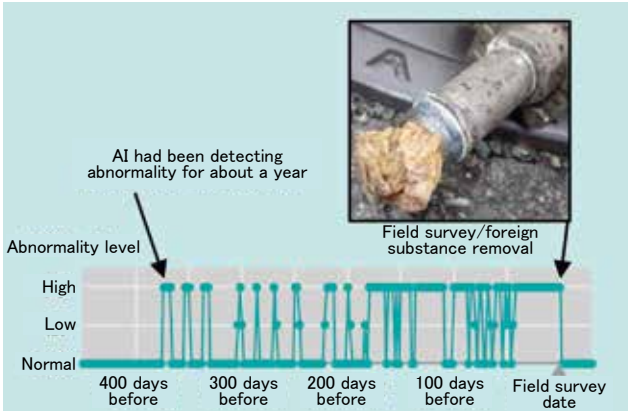


Fig. 7 Detection Case 2

4-4 Digital version of AI abnormal operation detection technology

The digital version uses the data on operating time and the number of operations. The signals to be input to the IoT terminal are only the contact signals of the pump ON/OFF, but since they are acquired as the data with time information, it is possible to calculate the operating time and the number of operations.

Since manhole pumps are basically operated alternately in pairs of two units, the operating time and number of operations per day are usually the same for two units. The balance will be lost if a problem arises in either unit, which allows the detection of an abnormality. For example, if the drainage capacity of Unit 1 declines, the operating time of Unit 1 will be longer.

Although the operating time and the number of operations are indicators that can only indirectly express the state of pumps, we were able to realize the practically sufficient detection of abnormal operations despite at a low cost by using the minimum amount of information.

In the next chapter, the field demonstration experiment using this digital version will be described in detail.

5. Field demonstration by the B-DASH project

5-1 Overview

Using the developed digital version of AI abnormal operation detection technology, we participated in the Breakthrough by Dynamic Approach in Sewage High Technology Project (commonly known as the B-DASH Project) of the MLIT to conduct a demonstration experiment in the actual field. The B-DASH project is led by the MLIT for the purpose of disseminating and expanding innovative technologies in the area of sewage[1]. Kubota's digital version of AI abnormal operation detection technology was adopted as the theme of FY2020 "Efficient preventive maintenance type manhole pump maintenance management technology using IoT and AI," and Kubota is participating as one of the five joint research entities together with Clearwater OSAKA Corporation, Kawachinagano City in Osaka, Imabari City in Ehime Prefecture, and Akaiwa City in Okayama Prefecture. We examined the effects of AI detection performance and streamlining of maintenance management on a total of 194 manhole pumps in three local governments. Here, we report the results obtained by June 2021.

5-2 Demonstration items and results

5.2.1 AI detection performance

A field survey was conducted based on the results of abnormality judgment that is output daily by AI for each manhole pump facility, and the accuracy of judgment by AI was verified by confirming the actual condition. AI detection performance was defined and evaluated based on the concept shown in Fig. 8, which is frequently used in the area of machine learning.

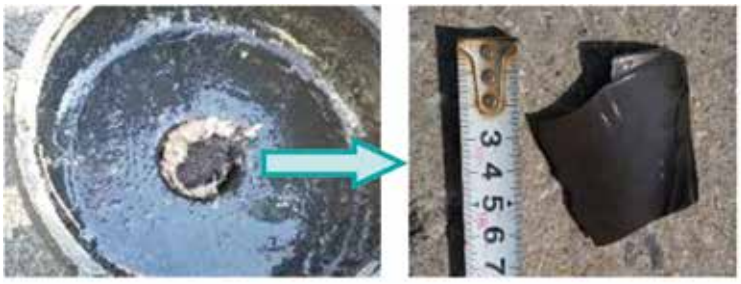
Fig. 8 also shows the results of a total of 531 field surveys. The detection rate was 73.8% against the target value of 70% or higher, and the accuracy rate was 96.0% against the target value of 70% or higher, both of which achieved the targets. It has proved the practical utility of the developed AI. Fig. 9 shows some of the abnormal cases found in the field survey.

		Judgment by AI	
		Abnormal operation	Normal operation
Actual condition	Abnormal	TP (abnormality detection) 31 cases	FN (missed abnormality) 11 cases
	Normal	FP (false detection) 10 cases	TN (normality detection) 479 cases

$$\text{Detection rate} = \frac{TP}{TP+FN} = 73.8\%$$

$$\text{Accuracy rate} = \frac{TP+TN}{TP+FP+FN+TN} = 96.0\%$$

Fig. 8 Evaluation of AI Detection Performance



Pump suction opening clogged with plastic pieces

Pump casing clogged with a towel

Fig. 9 Abnormal Cases Detected

5.2.2 Effect of reducing the number of emergency dispatches

Through a comparison with the past performance before the introduction of AI technology, we verified that the number of emergency dispatches due to failure occurrence is reduced by performing preventive maintenance that uses AI technology. The results are shown in Table 2. Additionally, in the demonstration results, conversion was performed to match the past performance with the calculated period length, and events that could not be predicted in advance even by humans, such as power outages due to lightning strikes, were excluded.

Consequently, the reduction rate of the number of emergency dispatches was 83%, achieving the target of 70% or more. Since emergency dispatch is the type of work involving particularly heavy physical and psychological burden among manhole pump maintenance work, the results showed that the said work was significantly reduced. Consequently, the securing of responsible personnel and reduction of maintenance costs will be expected.

Table 2 Results Showing Reduction in Emergency Dispatches

		Kawachinagano City	Imabari City	Akaiwa City	Total
Number of manhole pumps for demonstration		80 locations	82 locations	32 locations	194 locations
Number of emergency dispatches	Past performance (time/year)	72	52	30	154
	Demonstration results (time/annualized period)	20.8	2.3	2.2	25
Reduction rate of the number of emergency dispatches		71%	95%	93%	83%

5.2.3 Effect of reducing abnormal operating time

Calculation based on the abnormal cases detected during the demonstration confirmed that the period during which manhole pumps are operated in an abnormal state can be shortened by removing the abnormal factors at an early stage through preventive maintenance using AI technology. The operating time may become longer in the event of an abnormality, which indicates that extra operating time is required as compared with ordinary times. If AI has not been introduced, abnormalities will not be found until the next periodical inspection (Fig. 10), so we calculated the total extra operating time required during that period and made a trial calculation by assuming that such duration could be reduced.

Consequently, the reduction rate of abnormal operating time was 22%, which achieved the target of 11% or more. Consequently, suppression of wasteful energy consumption and reduced equipment life are expected.

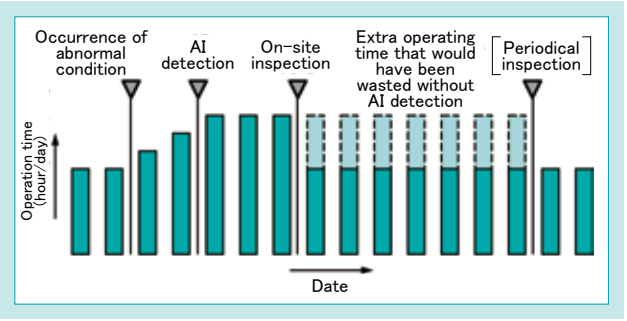


Fig. 10 Image Showing Reduction in Abnormal Operation Time

6. Conclusion

By combining the advanced field of AI technology with the technical capability for products that Kubota has cultivated over many years, we were able to effectively utilize operation data that could not be utilized in the past, leading to the efficient preventive maintenance of manhole pumps. We have developed two types of AI abnormal operation detection functions, namely, an analog version that is a highly functional type and a digital version that is a popular type, both of which have shown their effectiveness in actual detection cases.

At the time of writing this paper, the analog version has already been used by 25 local governments in approximately 700 manhole pumps (including those under preparation). In the digital version, we were able to confirm not only the performance of AI but also the high introduction effect in actual maintenance management through the B-DASH project. Initiatives for the B-DASH project are still underway, and we plan to evaluate its operational usability in the future.

Not limited to manhole pumps, there are common issues in the maintenance management of infrastructure facilities, such as facility deterioration and shortage of responsible personnel. Going forward, we will continue to contribute to solving social issues by quickly incorporating advanced technologies such as AI, putting them into practical use, and promoting their dissemination and expansion.

Contribution to SDG Targets

6.2 Strengthening access to sewage and sanitation facilities
Contribution to the maintenance of sewage infrastructure through preventive maintenance
9.1 Development of high-quality, sustainable, and resilient infrastructure
Contribution to sustainability by substituting AI for the shortage of responsible personnel
11.1 Ensuring access to safe and affordable basic services
Contribution to cost reduction by improving maintenance management efficiency

Reference

1) National Institute for Land and Infrastructure Management, Ministry of Land, Infrastructure, Transport and Tourism: Breakthrough by Dynamic Approach in Sewage High Technology Project (B-DASH Project)
http://www.nilim.go.jp/lab/ecg/english/bdash.htm

Development of "WATARAS" (LTE-M), Water Remote Management System in Paddy Fields without Gateway Device

Water and Environment R&D Dept. Ⅰ /Kubota ChemiX Co., Ltd. R&D Dept.

The water remote management system "WATARAS" can remotely and automatically control the water supply and drainage of paddy fields while monitoring them with a mobile phone or personal computer. The benefits include reducing manhours spent on water management, conserving water resources, and digitizing and utilizing water management. The direct communication (LTE-M: LTE Cat.M1) type reported in this article is a communication method in which the electric actuator installed in the paddy field connects directly to the public radio wave (cellular wave), and it does not require a gateway device that is indispensable for existing products. It can be installed and used in remote or mountainous areas; something that was difficult until now.

【Key Word】
paddy fields, WATARAS, water management, remote area, mountainous area, LTE-M, LTE Cat.M1, IoT, gateway, reducing manhours spent on water management, saving water

Related SDGs

1. Introduction

1-1 What is WATARAS?

WATARAS is a paddy field remote management system based on the technology developed mainly by the "National Agriculture and Food Research Organization" (hereinafter referred to as "NARO") through the "Technologies for creating next-generation agriculture, forestry and fisheries" of the National Research and Development Project "Strategic Innovation Promotion Program." The population of Japanese farmers has decreased by 500,000 in 5 years from 2.61 million (average age: 65.8) in 2010 to 2.1 million (average age: 66.3) in 2015, and the aging of farmers continues to be striking[1]. For this reason, Japan Revitalization Strategy[2] has proposed that the use of agricultural land by large scale farmers be increased from 50% at the end of 2014 to 80% in 10 years.

Of the rice-growing labor, the work related to water management is a daily routine work, but its automation has not progressed. Therefore, this work accounts for approximately 30% of the total working hours, which is a heavy burden, especially for large scale farmers who often manage dispersed agricultural land[1]. Kubota ChemiX Co., Ltd. has participated in the above-mentioned development to solve this issue and commercialized the WATARAS, which has been on the market since 2018. The advantages of introducing WATARAS are the four points of "light labor," "saving water," "timer," and "digitization" shown in Fig. 1. The following are confirmed as the effects of these advantages in the test results by the NARO.

- Approximately 80% reduction in working hours required for water management
- Approximately 50% decrease in the amount of water use
- Maintaining the set water level at a paddy field whose water level is controlled, except during rainfall (comparison between the test field in the NARO and the control field).

Furthermore, this system can contribute to the realization of precision farming by utilizing the scheduled operation function and the acquired data.

Additionally, the product life is designed to be 10 years in consideration of the system adoption in field development projects such as parcellation into a large field. Furthermore, by replacing electronic parts, the system can be used for a long term of over 20 years and accommodate a change of communication method.

It is the fourth year since the launch of WATARAS, and approximately 1,800 electric actuators (as of the end of August 2021) have been installed and operated all over Japan (main devices of WATARAS that enable remote opening and closing of paddy field water supply and drainage facilities).

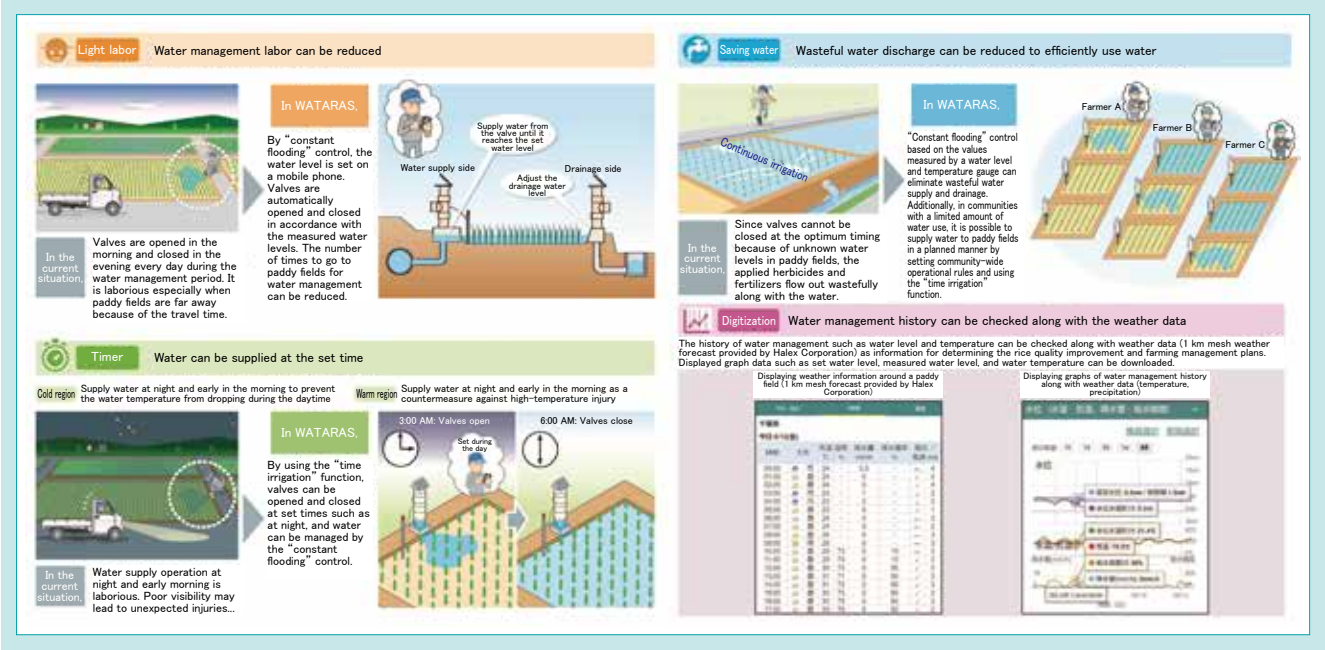


Fig. 1 Advantages of introducing WATARAS

1-2 Existing communication method: Communication aggregation (LoRa) type

WATARAS is operated on a mobile phone or personal computer. The control commands sent from these devices are transmitted to an electric actuator installed at a paddy field via the cloud server. Along with that, the measured values from the electric actuator and the water level and temperature gauge are transmitted and saved in the cloud server, which can be viewed and used on a mobile phone or personal computer.

The communication aggregation (LoRa) type has been adopted as a communication method since the launch of WATARAS (Fig. 2). This method connects a cloud server and an electric actuator via a communication repeater (gateway device) installed in a building near a paddy field, and it is a LoRa type that does not require a license with the characteristics that it uses public radio wave (cellular network) between the cloud server and a gateway device, and long-distance communication between a gateway device and an electric actuator. With this method, up to 40 (or 80 by adding a wireless box) electric actuators can be connected with one gateway device (one line of public radio wave), which provides high economic efficiency of communication costs when managing many paddy fields. Note that the recommended distance between a gateway device and an electric actuator is 1 to 2 km when obstacles are taken into account, and 5 km under favorable conditions.

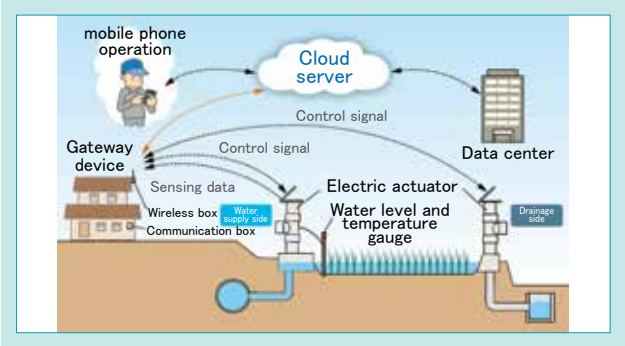


Fig. 2 System configuration: Communication aggregation (LoRa) type

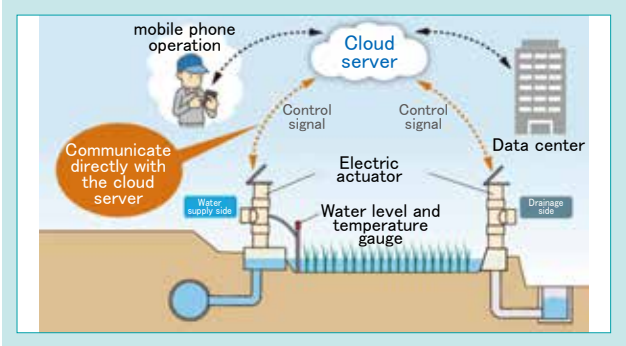


Fig. 3 System configuration: Direct communication (LTE-M) type

1-3 Communication method reported here: Direct communication (LTE-M: LTE Cat.M1) type

The direct communication (LTE-M) type is a method in which communication between the cloud server and an electric actuator is performed directly via public radio wave, and does not require a gateway device (Fig. 3). It has an advantageous system for the installation in a small number of fields in remote locations, in mountainous areas where wireless communication is difficult to reach, and in demonstration tests.

2. Development concept and target value

2-1 Development concept

The concept of developing the direct communication (LTE-M) type is to complement the WATARAS system by enabling the installation and use in remote areas and mountainous areas, which used to be difficult with the communication method of the existing communication aggregation (LoRa) type. The differences between the two communication methods are shown in Table 1.

Table 1 Difference between communication aggregation (LoRa) type and direct communication (LTE-M) type

Items	Communication aggregation (LoRa) type	Direct communication (LTE-M) type
Usage scene	When installing (up to 80 units) at a large number of closely situated paddy fields	・A small number of paddy fields in remote areas ・A paddy field in a mountainous area where LoRa radio is difficult to reach ・Installation of a small number on a trial basis
Communication method	Cloud server ⇔ Gateway device: LTE (public radio wave) Gateway device ⇔ Electric actuator: LoRa	Cloud server ⇔ Electric actuator: LTE-M (public radio wave)
Communication range	Reach of wireless access from gateway device (recommended range: 1 to 2 km)	Coverage area of public radio wave (cellular network)
Gateway device	Necessary	Unnecessary
Economic efficiency	High economic efficiency when introducing a large number	High economic efficiency when introducing a small number

2-2 Target values

Development goals of the direct communication (LTE-M) type were set as shown in Table 2 by meeting the specifications of the existing communication aggregation (LoRa) type, as well as by incorporating the improvements based on the knowledge obtained from the sales of WATARAS in the past.

Table 2 Development goals of direct communication (LTE-M) type

Items	Development target	Special note
Response to nonsunshine conditions	Continuous operation for 5 days or more without charging the battery with sunlight	Operating conditions: Operation of water supply and drainage device twice a day
Electromagnetic interference wave	30 MHz to 230 MHz: 50 dB or less 230 MHz to 1,000 MHz: 57 dB or less	Energization state, measurement distance 3 m (CISPR 22, EN55022, VCCI)
Radiation, radio frequency, electromagnetic field	No breakdown, no abnormal operation	Operating condition, irradiated radio wave: 10 V/m × 3 seconds, 26 MHz to 1,000 MHz (JIS C 61000-4-3, IEC/EN 61000-4-3)
Characteristics of use in mountainous areas	The electric actuator can be connected to the cloud server by itself	Communication established by LTE-M
Maintainability	Device settings can be controlled remotely	The existing communication aggregation (LoRa) type is operated by wire on the device side.
Operability	Installable in the same area as the existing communication aggregation (LoRa) type	Affinity with the existing system

3. Technological issues to be solved

3-1 Securing the number of operable days under nonsunshine conditions

Since LTE-M is a direct wireless communication to the public radio wave, it consumes more power compared with LoRa, a specified low-power wireless station that does not require a license. The communication module installed in the direct communication (LTE-M) type consumes approximately 40% more than the existing communication aggregation (LoRa) type. When the communication condition (control command transmission/reception interval) is set to "short," it is difficult for the direct communication (LTE-M) type to secure the number of operable days (response to nonsunshine conditions) under no charging conditions.

3-2 Reduction of on-site work when setting up devices

In the existing communication aggregation (LoRa) type, the motor settings (current limit value, stroke, and others) and identification number (ID, channel) can be changed by connecting a computer to the substrate inside the electric actuator. When implementing this method, there may be a situation where the upper flange (water-stopping structure) of the electric actuator needs to be removed by the edge of a paddy field, but it should be avoided when handling precision equipment and is the operation that we would like to eliminate also from the perspective of labor-saving.

4. Development technology

4-1 Power consumption suppression technology

With WATARAS, the transmission/reception interval of control commands can be switched to long or short, and power consumption can be suppressed by extending the interval. In the existing communication aggregation (LoRa) type, this interval is manually changed. Even when the transmission/reception interval is "short" (large power consumption), this method does not cause any problems because it sufficiently satisfies the response to nonsunshine conditions in Table 2, but the direct communication (LTE-M) type cannot meet this if it has a "short" transmission/reception interval.

Therefore, in the direct communication (LTE-M) type, the remaining battery power is secured by suppressing the power consumption to the equivalent level as in the case of the communication aggregation (LoRa) type with the "long" transmission/reception interval. This is achieved by switching the transmission/reception interval to "long" to enter the sleep mode upon a fixed time interval after starting the electric actuator, and by devising a way for power saving at the time of startup (Table 3).

Table 3 Battery level : converted value when (LoRa) type transmission / reception interval "long" is 100

Type	Transmission/ reception interval	Current consumption	Remaining battery (after 5 days)
LTE-M type	Short → long, interlocking	115	98 (equivalent to LoRa type)
	Short	690	16
LoRa type	Long	100	100
	Short	213	84

Remarks: Calculated as G valves opened and closed twice a day. Not charged by a solar panel.

4-2 Technology for remote setting of motor

The electric actuator contains two substrates, a "communication substrate" and a "control substrate." Since this development involves a change in the communication method, the control substrate has not changed from the existing communication aggregation (LoRa) type. However, it has an added function that enables the reference and change of control setting values remotely from the WATARAS operation screen. This is achieved by the communication substrate of the direct communication (LTE-M) type that incorporates the motor control setting values stored in the control substrate and sends to/receives from the cloud server (Fig. 4). As a result, the direct communication (LTE-M) type eliminates the need for a computer connection to the substrate inside the electric actuator by the edge of a paddy field in normal operation management.

Fig. 4 Control setting screen (excerpt)

5. Conclusion

The WATARAS direct communication (LTE-M) type started trial operation in the field in September 2020 (Fig. 5) and is proceeding with the extraction and improvement of defects toward the launch of full-scale sales in April 2022. In the future, we are considering the development of a method to compactly store an electric actuator at the catch basin of a paddy field by taking advantage of the communication stability of LTE-M using the public radio wave.

For the development of WATARAS, we have received a great deal of cooperation from the Kubota Water & Environment Sales Promotion Dept., KUBOTA Systems Inc., Kubota Farm and Industrial Machinery R&D Dept. I, and external cooperating companies. We would like to take this opportunity to express our gratitude from the bottom of our hearts.

Fig. 5 Example of trial operation (Ishigaki City, Okinawa Prefecture)

Contribution to SDG Targets

6.4 Resolution of water shortages
Reduction of water use by approximately 50%
7.2 Expansion of renewable energy
Equipment operation by solar power generation

Reference

1) Kousuke Wakasugi, Sho Suzuki: "Remote Automatic Operation System Using ICT for On-farm Water Management in Rotational Paddy Fields" Journal of the Japanese Society of Irrigation, Drainage and Rural Engineering 85 (1), (2017), pp.11–14
2) Cabinet Office: "Japan Revitalization Strategy" revised in 2015, (2015), pp.160–165

Development of High-Efficiency Denitrification MBR (LOOP MBR) that Reduces Costs, Energy, Space

Environmental Engineering Dept.

Sewage treatment plants whose discharge destination includes closed water areas are required to remove nitrogen, and a discharge regulation of <5 mg/L of T-N in treated water is set for some facilities. The conventional advanced treatment process for such high-efficiency denitrification significantly increases the treatment cost, power consumption, and installation space compared to the secondary treatment process, such as conventional activated sludge process. To solve this, we have developed a new MBR enabling high-efficiency denitrification that saves cost, energy, and space. This method enables the denitrification of ≈3 mg/L of T-N using multistep processing that arranges four sets of single-step MBRs in series; each having one anoxic tank and one aerobic tank. By eliminating the need to install a postdenitrification tank and by integrating the aerobic tank and membrane tank, construction costs for civil engineering and blower facilities as well as air diffusion amount can be reduced. Moreover, operating this method with the existing secondary treatment process in the advanced treatment is expected to decrease the cost and construction period required for advanced treatment to comply with the regulation equivalent to ≤10 mg/L of T-N.

【Key Word】
MBR, Cost-Saving, Energy-Saving, Space-Saving, High-Efficiency Denitrification

Related SDGs

1. Introduction

Sewage is an important social infrastructure for improving our living environment and preserving the quality of public water areas, and it has been continuously developed. The sewage treatment population penetration rate reached 80.1% at the end of FY2020[1], and the water quality has been improving in rivers, lakes and marshes, and coastal waters. However, in order to take measures against eutrophication of closed water areas and respond to the reinforcement of water quality environmental standards, switching of secondary treatment centered on the removal of organic pollutants to advanced treatment (removal of inorganic nutrient salts such as nitrogen and phosphorus) is required, but the implementation rate of advanced treatment for creating a good water environment remains at only 56.3% at the end of FY2019[2]. In addition, in lakes such as Lake Biwa and Lake Kasumigaura, a high-efficiency denitrification treatment process with a total nitrogen (hereinafter referred to as T-N) concentration of 5 mg/L or less in treated water is required, but it is extremely costly, and the site area of the treatment facility is also limited. For this reason, the local governments are having a hard time with their response. Therefore, a cost-saving, energy-saving, and space-saving treatment process had been sought after as compared with the conventional high-efficiency denitrification treatment process.

2. Concept of development

2-1 Problems with existing technologies

2.1.1 Conventional High-efficiency denitrification process

As a treatment process capable of achieving T-N ≤ 3 mg/L, a step-feed biological nitrogen removal process (hereinafter referred to as a multistep process) can be listed (Fig. 1). This process enables high-efficiency denitrification by repeating anoxic treatment and aerobic treatment, but it involves a complicated treatment process. For this reason, it is highly costly and requires large space, which creates another issue that it cannot be adopted in a treatment facility with severe restrictions on the site area.

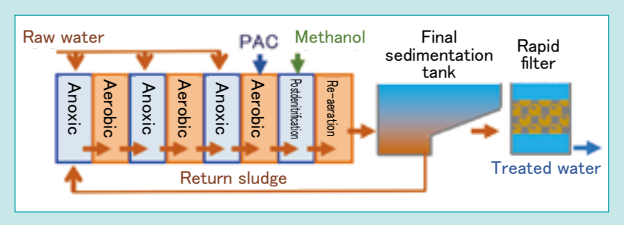


Fig. 1 Conventional High-Efficiency Denitrification Process

2.1.2 Step-Feed Nitrogen Removal MBR

As a means to save space in the above treatment process, a step-feed nitrogen removal MBR combined with the membrane bioreactor (hereinafter referred to as MBR), which can reduce the facility size by using a membrane, has been put into practical use (Fig. 2). This process does not require a final sedimentation tank or a rapid filter, and can maintain a high concentration of activated sludge, which saves space. However, the compactness, which is one of the strengths of MBR, is compromised by the installation of a postdenitrification tank and membrane separation tanks. In addition, since it is necessary to add an organic matter source (methanol) in the postdenitrification process and because the membrane separation is performed at the final stage when the biological treatment is completed, the oxygen supplied by the membrane cleaning aeration performed for the membrane separation cannot be utilized for biological treatment. Therefore, there is also a problem that chemical costs and electric power costs will increase.

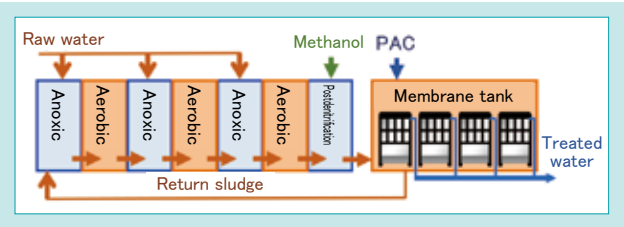


Fig. 2 Step-Feed Nitrogen Removal MBR Process

2-2 Overview of developed technology

As a high-efficiency denitrification MBR that solves the above problems, we have newly developed a "multitank circulating nitrification–denitrification MBR." This process consists of multiple water tanks arranged in a non-terminating loop, and its features are expressed as Low OPEX and Optimized MBR, so LOOP MBR® is used as an abbreviation. In parallel with the development of this process, we also developed the UCT LOOP MBR, in which a biological dephosphorization process is added. Fig. 3 shows the treatment flow of LOOP MBR and UCT LOOP MBR. LOOP MBR is said to be an improved modification of the modified Ludzack-Ettinger MBR (hereinafter referred to as MLE MBR), which is widely used in domestic sewage treatment facilities. The formula below shows the theoretical relational expression of nitrogen removal rate (hereinafter referred to as η_{DN}) and the nitrified liquor recycle ratio R involved in the nitrification–denitrification reaction that is the basis of the nitrogen removal performance.

$$\text{Nitrogen removal rate for nitrification–denitrification reaction } \eta_{DN} = \frac{R}{1+R}$$

As shown in the formula, R and η_{DN} have a positive correlation, and it is possible to improve the nitrogen removal performance by increasing R, but due to the economic efficiency of the nitrified liquor circulation pump, the upper limit of R has been set to about 3 Q in the past. However, in this process, a practical increase of the nitrified liquor circulation ratio was achieved by multistaging of aerobic tanks and anoxic tanks to allow step feeding of raw water into each tank evenly without increasing the circulating nitrified liquor volume. For example, if the circulating fluid volume is three times the raw water inflow volume in the 4-stage LOOP MBR, 3 Q of nitrified liquor will be circulated against 0.25 Q

of raw water per tank, which increases the practical nitrified liquor recycle ratio by 12-fold as shown below. As a result, the nitrogen removal performance can be significantly improved without impairing economic efficiency.

$$\text{Nitrified liquid recycle ratio R} = \frac{\text{Circulating nitrified liquid liquor volume}}{\text{Raw water volume}} = \frac{3}{0.25} = 12Q$$

In addition, the LOOP MBR does not require a postdenitrification tank nor a membrane separation tank required for the step-feed nitrogen removal MBR , and a practically higher recycle ratio will increase the MLSS concentration in anoxic tanks, which reduces the reactor capacity and therefore is space-saving.

Furthermore, since the separation membrane is installed in the aerobic tank, the oxygen supplied by the aeration for membrane cleaning can be utilized for biological treatment, which is energy-saving. Furthermore, it is cost-saving because it does not require the addition of an organic matter source in the postdenitrification tank.

The UCT LOOP MBR is a treatment process in which an anaerobic tank is installed upstream of the LOOP MBR to circulate the denitrified liquor from anoxic tanks to an anaerobic tank. In the conventional activated sludge process, phosphorus is often removed chemically by adding a flocculant (PAC), but since the UCT LOOP MBR process is capable of biologically removing phosphorus, the amount of flocculant addition can be reduced, and a further reduction in the running cost can be expected.

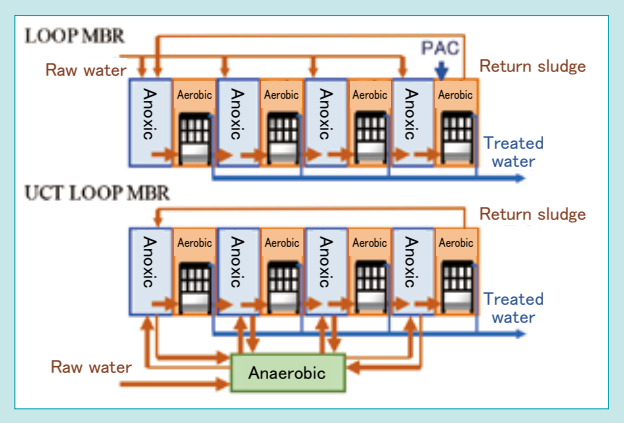


Fig. 3 LOOP MBR and UCT LOOP MBR Process

3. Development target

The basic concept of this development is to realize the MBR capable of high-efficiency denitrification with a cost-saving, energy-saving, and space-saving process, and it was developed through the following two steps.

(1) Confirm treatment performance in a demonstration experiment using a pilot plant

(2) Confirm feasibility derived from the desk study based on demonstration results

Table 1 shows a list of the main development target for the LOOP MBR and UCT LOOP MBR. The target nitrogen removal performance was set as T-N concentration in treated water of ≤3 mg/L or ηDN ≥ 90%, and the target phosphorus removal performance was set as total phosphorus (T-P) concentration in treated water of ≤0.5 mg/L. Note that the following formula was used to calculate η_{DN} based on the verified data.

$$\eta_{DN} = \frac{\text{Denitrification volume}}{\text{Amount of nitrogen to be nitrified}}$$

In addition, compared to the step-feed nitrogen removal MBR process that has been put into practical use as an MBR capable of high-efficiency denitrification, the target was set to reduce the life cycle cost (hereinafter referred to as LCC) by 5% or more, the running cost by 10% or more, the power consumption by 10% or more, and the required space by 10% or more.

Table 1 Development Target

Items	LOOP MBR	UCT LOOP MBR
Nitrogen removal performance	T-N < 3mg/L or η_{DN} > 90%	Same as the left
Phosphorus removal performance	T-P < 0.5mg/L	Same as the left
LCC	95	Same as the left
Running cost	90	75
Power consumption	90	Same as the left
Required space	85	90

The numbers in the table are the ratios with the step-feed nitrogen removal MBR as 100.

4. Development issues

4-1 Collection of demonstration data showing stable nitrogen removal performance

Demonstration of the nitrogen removal performance requires the data showing that continuous and stable treatment was carried out. In the LOOP MBR, the inflow amount of dissolved oxygen (hereinafter referred to as DO) supplied from aerobic tanks increases due to actual circulating nitrified liquor volume that is significantly increased, which had a risk of causing denitrification inhibition in anoxic tanks. In addition, it was assumed that multistaging has shortened the actual retention time in an anoxic tank per aerobic tank/anoxic tank, making it more susceptible to fluctuations in the inflow load. Therefore, it was also necessary to confirm the resistance to load fluctuations.

4-2 Equalization of operating conditions for each water tank

Equalizing the volume of treated water filtered by each membrane unit is effective in suppressing the speed of membrane clogging. In addition, it is important for this process to maintain the treatment status evenly in each water tank in order to stabilize the treated water quality. For this reason, it was necessary to study the design that allows the uniform amount of membrane-filtered water discharged from each aerobic tank and the uniform amount of raw water supplied to each anoxic tank. In addition, it was required to confirm that the effect on the treated water quality is minor even if there is some unevenness.

4-3 Response to the shortage of organic matter in the influent water

In order for nitrogen removal to occur, the influent water must contain more than a fixed amount of organic matter (containing more than three times of T-N, as BOD, an indicator showing the amount of organic matter). An insufficient amount of organic matter may pose a risk of increased concentration of T-N in treated water, which creates concern that the standard for the designed influent water quality will be exceeded. For this reason, the addition of an organic matter source is required when the amount of organic matter in the influent water decreases. As is the case with the conventional process, it was necessary also for this process to confirm that the stabilization of T-N concentration in treated water is possible by adding an organic matter source.

4-4 Feasibility verification in the actual facility of the development process

In this process, it was assumed that the water tank layout would need to be significantly changed because of the multitank structure. By conducting a case study, it was necessary to verify the possibility of designing a facility that can be actually constructed to perform various operations, such as even distribution of sewage, examination of the layout of treated water pipes and air pipes, and securing of maintenance flow lines.

5. Results of demonstration experiment and desk study

5-1 Outline of demonstration plant and experimental conditions

To confirm the treatment performance of LOOP MBR and UCT LOOP MBR, a pilot plant with a treatment capacity of 15 m^3/d was constructed for each process. The demonstration plant for LOOP MBR is referred to as Train 1, and that for the UCT LOOP MBR is referred to as Train 2. The basic operating conditions are shown in Table 2. The amount of supplied water fluctuated at a daily fluctuation ratio of 1.4 (peak/daily average) on the assumption of medium- and large-scale treatment facilities, and the filtration flux was also adjusted to follow it. The demonstration experiment was conducted from June 10, 2019 to July 6, 2021. The operation process is shown in Fig. 4. Note that, of the plant experiment period, an evaluation period was set for each of Trains 1 and 2, and the treatment function and treatment performance were evaluated. The development target was deemed to be achieved if the average value of the effluent water quality during the evaluation period achieved the water quality target. After the start of the operation, nitrification failure occurred due to the insufficient DO concentration in both Trains, and auxiliary air diffusion was added as a countermeasure. Consequently, the shortage of DO was almost eliminated, but the denitrification performance deteriorated because of the effect of DO inflow into anoxic tanks. As a countermeasure, strict DO control was performed by controlling the DO of the auxiliary air diffusion and partially blowing off the membrane cleaning aeration.

In Train 2, we have conducted an experiment to add methanol and Econitrin® for the purpose of ensuring denitrification performance by adding an organic matter source. Econitrin is a product of KUBOTA Environmental Engineering Co., Ltd. and has a proven record as an alternative to methanol in excrement processing facilities. It is expected to reduce CO_2 emissions by approximately 95% compared with methanol by utilizing by-products generated in the manufacturing process of food products. In the process of biological dephosphorization, the phosphorus removal function is known to deteriorate during rainfall, and the same tendency was observed also in this process. In the actual facility, it is common to prevent deterioration of effluent water quality by adding PAC, and to demonstrate whether the same measure can be taken in this process, a PAC addition experiment was conducted only during rainfall. Note that the dephosphorization of Train 1 was based on the constant addition of PAC.

Table 2 Basic Operating Conditions

Items		Summer	Spring and fall	Winter
Amount of treated water		15.0 m^3/d	13.5 m^3/d	12.0 m^3/d
HPT (Train 1)		5.7 hrs	6.3 hrs	7.1 hrs
HRT (Train 2)		6.7 hrs	7.4 hrs	8.4 hrs
Aerobic tank target MLSS	(Train 1)	9000 mg/L	Same as the left	Same as the left
	(Train 2)	10000 mg/L	Same as the left	Same as the left
Membrane cleaning aeration volume		0.1 m^3/min/unit	Same as the left	Same as the left
DO management target value		1.0 mg/L or more	Same as the left	Same as the left
Nitrified liquid recycle ratio		3 Q recycle	Same as the left	Same as the left
Denitrified liquor recycle ratio (Train 2)		1 Q recycle	Same as the left	Same as the left

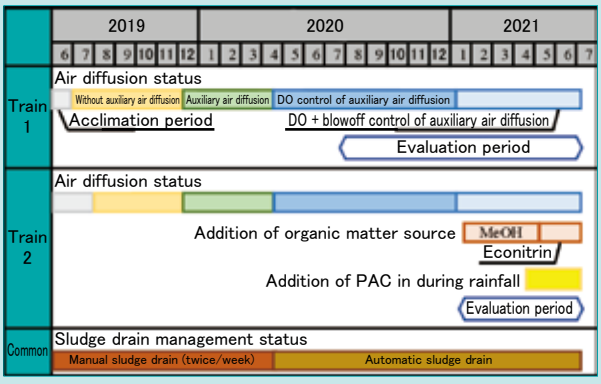


Fig. 4 Operating Mode of Demonstration Plant

5-2 Experimental data

Table 3 shows the operating conditions of Train 1 and 2 during the evaluation period, Table 4 shows the effluent water quality data obtained, and Fig. 5 shows the daily data of nitrogen and phosphorus removal. An analysis of the relationship between the aerobic tank DO and η_{DN} during the peak load showed that η_{DN} tended to worsen when DO at the peak load exceeded 1.5 mg/L. As a result of analyzing η_{DN} in the range where proper DO control was performed (in which the average aerobic tank DO at the peak influent volume was managed to be maintained at less than 1.5 mg/L), the average value of Train 1 was 90.1%, which achieved the development target of 90%.

Table 3 Parameters for Biological Treatment

Items	Analysis/measurement results	
	Train 1 (N = 40)	Train 2 (N = 20)
Aerobic tank MLSS (mg/L)	7,900–11,400 (9,800)	8,000–11,900 (10,000)
Reaction tank Water temperature (°C)	14.8–30.0 (21.8)	14.6–26.5 (20.5)
Supplied BOD/T-N ratio	2.8–5.4 (3.6)	3.7–6.5 (4.7)

Table 4 Influent and Effluent Water Quality

Items		Analysis/measurement results	
		Train 1 (N = 40)	Train 2 (N = 20)
BOD	Influent water	71–184 (111)	72–184 (121)
	Effluent water	0.4–3.6 (1.6)	0.5–2.5 (1.3)
COD	Influent water	39–93 (55)	48–93 (58)
	Effluent water	4.1–6.3 (5.3)	5.0–7.0 (6.1)
SS	Influent water	33–200 (73)	52–177 (84)
	Effluent water	N.D.	N.D.
T-N	Influent water	21–41 (32)	29–39 (33)
	Effluent water	2.3–6.9 (3.7)	3.0–7.6 (4.1)
NH_4-N	Influent water	12–26 (21)	17–26 (22)
	Effluent water	N.D.–1.1 (0.22)	N.D.–0.3 (0.12)
T-P	Influent water	2.8–5.7 (4.1)	3.9–5.7 (4.5)
	Effluent water	0.08–0.47 (0.23)	0.02–0.71 (0.14)

The unit of water quality is all mg/L, and the values in parentheses indicate the average values.

Conversely, the average value of η_{DN} of Train 2 was 88.5%, which was slightly below the development target. This is due to the effect of some data pushing down the average value. The cause of this was considered to be insufficient organic matter source because a fixed amount of organic matter source was added in this demonstration experiment. At a full-scale facility, we believe that a further increase in the η_{DN} is achievable by appropriately adjusting the amount of organic matter added and stabilizing the effluent water quality through monitoring of the influent water volume and the ORP of anoxic tanks. As for phosphorus, the average T-P in effluent water during the evaluation period of Train 1 was 0.23 mg/L, and that of Train 2 was 0.14 mg/L, both of which achieved the development target of T-P < 0.5 mg/L. In the UCT LOOP MBR, the effluent water quality of T-P < 0.5 mg/L was achieved by adding PAC even during rainfall.

Based on the analysis results of the demonstration experiment data, it was found that T-N in effluent water can be stably obtained by controlling the DO concentration of aerobic tanks to 1.5 mg/L or less in Train 1, which confirmed that the management of DO value is more important in the operation management in this process as compared with the conventional MBR. As for T-P in effluent water, stable treatment performance was demonstrated by the addition of PAC. In Train 2, since organic matter is consumed in the anaerobic tank, an organic matter source for removing nitrogen tends to be insufficient, and managing the balance of the BOD and T-N of the influent water was confirmed to be important. Furthermore, it was shown that in a situation with a shortage of organic matter, it is possible to achieve both biological dephosphorization and nitrogen removal by adding an organic matter source as is the case with the conventional technology. It was also confirmed that the dephosphorization performance can be stabilized by adding PAC even during rainfall.

Additionally, to confirm the uniformity of the treatment status of each tank, the membrane filtrate and sludge filtrate in each tank were collected to conduct water quality analysis. Consequently, the difference between the tanks of Train 1 and 2 was small, and the data supporting that the uniform treatment were performed in each tank was obtained.

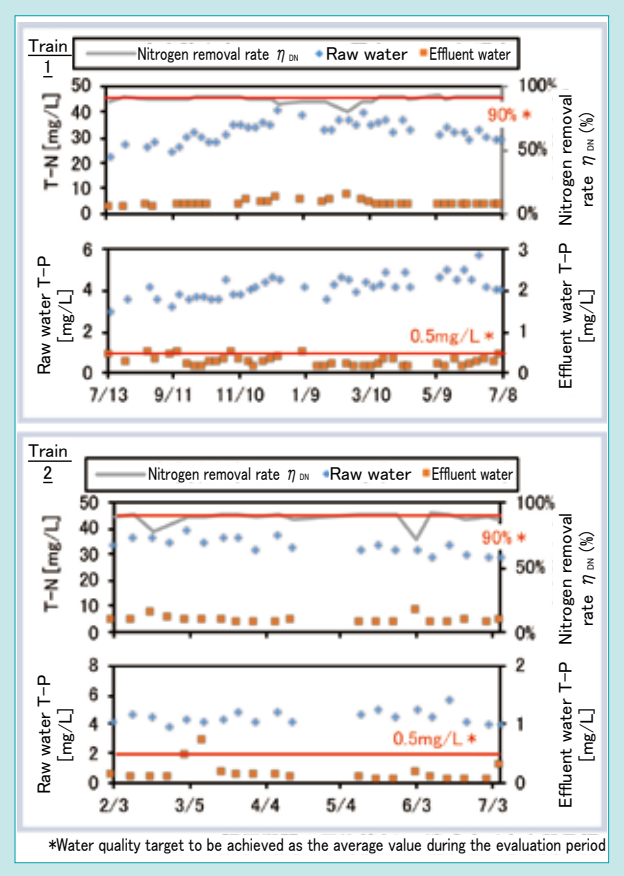


Fig. 5 Time Course of Nitrogen and Phosphorus Removal in Two Trains

5-3 Results of desk study

Based on the results of the demonstration experiment, a case study was conducted to construct a new sewage treatment facility with a treatment capacity of 80,000 m^3/d. Design and construction of the development process were confirmed to be possible through examination of the shape of the sedimentation tank necessary to demonstrate the performance verified by the development process, selection of various equipment, piping, and valves, and examination of facility layout in consideration of workability and maintainability.

6. Effect of introducing the development process

6-1 Cost-saving, energy-saving, and space-saving effects on step-feed nitrogen removal MBR

Table 5 shows the calculation results of the reduction rate of each element for the step-feed nitrogen removal MBR in the previously described case study. The LOOP MBR can be expected to reduce the LCC by 5% or more and the running cost by 10% or more as compared with the step-feed nitrogen removal MBR. Additionally, it is also expected to reduce power consumption by 10% or more and required space by 15% or more. The UCT LOOP MBR achieved the development target for LCC of 5% or more reduction, and its reduction effect was exhibited also for other items.

Table 5 Case Study Results

Items for reduction	LOOP MBR		LOOP MBR	
	Reduction target	Case study results	Reduction target	Case study results
Construction cost	—	98	—	100
LCC	95	95	95	95
Running cost	90	87	75	77
Power consumption	90	89	90	94
Required space	85	83	90	94

The numbers in the table are the ratios with the step-feed nitrogen removal MBR as 100.

6-2 Advanced treatment using the LOOP MBR

There are not many domestic sewage treatment facilities that require the performance of a 90% nitrogen removal rate that is achievable by the LOOP MBR. However, the introduction of this process is expected to significantly reduce the costs required for advanced treatment of other sewage treatment facilities, and an example is shown in Fig. 6. According to the conventional advanced treatment process, when remodeling the conventional activated sludge process (only for organic matter removal) of a total of five series into an advanced treatment process that can handle T-N ≤ 10 mg/L and T-P ≤ 1 mg/L in treated water, it is necessary to add a reaction tank, a final sedimentation tank, and a rapid filter and to remodel the entire series, which also increases power consumption. Therefore, the remodeling cost and the running cost will increase significantly. Conversely, when this process is introduced, an additional civil engineering building is not required, and it is possible to achieve the regulation value of T-N in treated water ≤ 10 mg/L only by remodeling the three series, which also suppresses an increase in power consumption after remodeling.

Additionally, in a normal sewage improvement plan, the same level of advanced treatment is often applied to all sewage treatment facilities under the jurisdiction. In this development plan, delays due to constraints on site and budget and shortage of site for facility expansion have become problems, which have been the cause of delays in advanced treatment. To solve this problem, it is possible to employ a process of meeting the regulation on total volume in the closed water area of the discharge destination; this process introduces the LOOP MBR in some sewage treatment facilities to intensively remove nitrogen and allows other sewage treatment facilities to continue treatment with the conventional activated sludge process or remodel into an anaerobic-oxic activated sludge processthat deals with organic matter and dephosphorization and that can be remodeled without the additional civil engineering building. Consequently, the costs and construction period required for advanced treatment are expected to be significantly reduced or shortened.

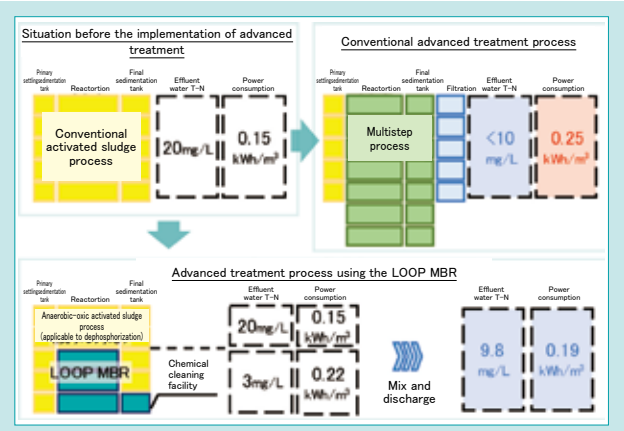


Fig. 6 Comparison of Upgrade Scheme Between Conventional Processes and Present Process with LOOP MBR

7.Conclusion

In the fall of 2021, the MLE MBR with a treatment capacity of 40,000 m^3/d was put into service at the Nakahama Sewage Treatment Plant in Osaka City. As such, the introduction of MBR to large-scale sewage treatment facilities is progressing in Japan in the form of capturing the demand for full-scale renewal of aging facilities. In the future, the popularization of MBR will be expected to accelerate due to the cost, power, and space reduction effects required for advanced treatment by the LOOP MBR and UCT LOOP MBR. There is actually a sequel to this development; it turned out that although the idea of LOOP MBR was proposed twice in the past prior to this development, the idea was not put into practice since it was not able to lead to the development activity. The LOOP MBR is a groundbreaking technology that defies the conventional wisdom in sewage treatment in the past that "realization of high-efficiency denitrification is a trade-off with cost, electric power, and space," and it is a great loss that the technology could not be put into practical use for a long time even though it was invented. We realized the importance of leading ideas to verification and development rather than leaving them as ideas.

Last but not least, this development is the result of a joint research project, "development of cost-saving, energy-saving, and space-saving high-efficiency denitrification MBR" with the Japan Sewage Works Agency. We would like to express our deepest gratitude to everyone involved in this joint research.

Contribution to SDG Targets

6.2 Strengthening access to sewage and sanitation facilities
Achievement of reduction in LCC by 5% or more, running cost by 10% or more, power consumption by 10% or more, and required space by 15% or more compared to the conventional process capable of high-efficiency denitrification

7.3 Improvement in energy efficiency
10% or more reduction of power consumption compared with the advanced treatment process capable of high-efficiency denitrification

14.1 Prevention and reduction of marine pollution
Achievement of nitrogen removal rate of 90% or more, and treatment water T-P < 0.5 mg/L

Reference

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Development of Fermentation Technology for Household Garbage

Water and Environment R&D Dept. Ⅲ /Carbon Neutral Promotion Dept.

The combined system, which recovers biogas by separating garbage and paper garbage from combustible garbage and subjecting it to fermentation, and incinerates nondegradable materials such as plastics and wood has the advantage of being able to effectively utilize the energy of the waste. However, the introduction of the combined system has not proceeded smoothly due to the problem of life cycle cost (LCC) compared with the conventional incineration system. This development aims to solve the problems of existing combined systems by (1) highly efficient pretreatment, (2) an original vertical fermenter, and (3) dewatering residue. As a result, the developed system achieved a lower LCC than the incineration system, making it easier for local governments to introduce the system. By popularizing this system, which can reduce CO_2 emissions by biogas power generation, it is possible to contribute to CO_2 emissions reduction and resource circulation.

【Key Word】
CO_2 Emission Reduction, Resources Circulation, Household Garbage, Methane Fermentation

Related SDGs

1. Introduction

As initiatives have been taken all over the world for CO_2 emissions reduction and resource circulation, there has been a strong demand for such measures in the area of waste treatment (garbage treatment) also in Japan.

The national government has been promoting the waste energy utilization and resource circulation in the past, but many of the small- and medium-sized facilities in rural areas are waste treatment facilities (incineration facilities) that do not have power generation facilities, and energy utilization (≈ CO_2 emissions reduction) has not been sufficiently promoted. Some facilities are promoting energy utilization by introducing a combined system that combines the incineration treatment with methane fermentation, but it has not become popularized due to a high LCC.

Against this background, Kubota has been developing a treatment system that can recover energy and resources while ensuring economic rationality, targeting small- and medium-sized waste treatment facilities. This paper mainly reports on the results of the development undertaken through the consignment of the Ministry of the Environment's "Project for evaluation and verification of leading waste treatment systemization in small- and medium-sized waste treatment facilities" (FY2017–2019) (hereinafter referred to as the "consignment project").

2. Development concept and target value

2-1 Concept of development

The combined system, which combines the methane fermentation treatment and incineration treatment, separates garbage and paper garbage from combustible garbage and performs methane fermentation treatment to recover biogas as renewable energy, whereas nondegradable materials such as plastics and wood are incinerated. Since biogas can be recovered from wet waste unsuitable for incineration, the energy recovery rate is high, which contributes to the reduction of CO_2 emissions. Particularly, it is an effective means in small- and medium-sized treatment facilities (roughly 70 t/day or less) where it is difficult to recover energy by incineration treatment only.

However, the existing combined system has not been introduced smoothly because of a high LCC.

For this reason, as shown in Fig. 1, we have developed an improved combined system that can solve the problems of the existing combined system by combining three technologies: (1) highly efficient pretreatment (crushing and separation) technology, (2) methane fermentation treatment technology using an original vertical fermenter, and (3) residue treatment (dewatering) technology that enables low water content.

Furthermore, through composite treatment of not only combustible garbage but also wet waste such as sewage sludge, it is possible to streamline the entire waste-based public infrastructure, consequently reducing the overall cost.

Note that, in this paper, (1), (2), and (3) are collectively referred to as methane fermentation technology in a broad sense.

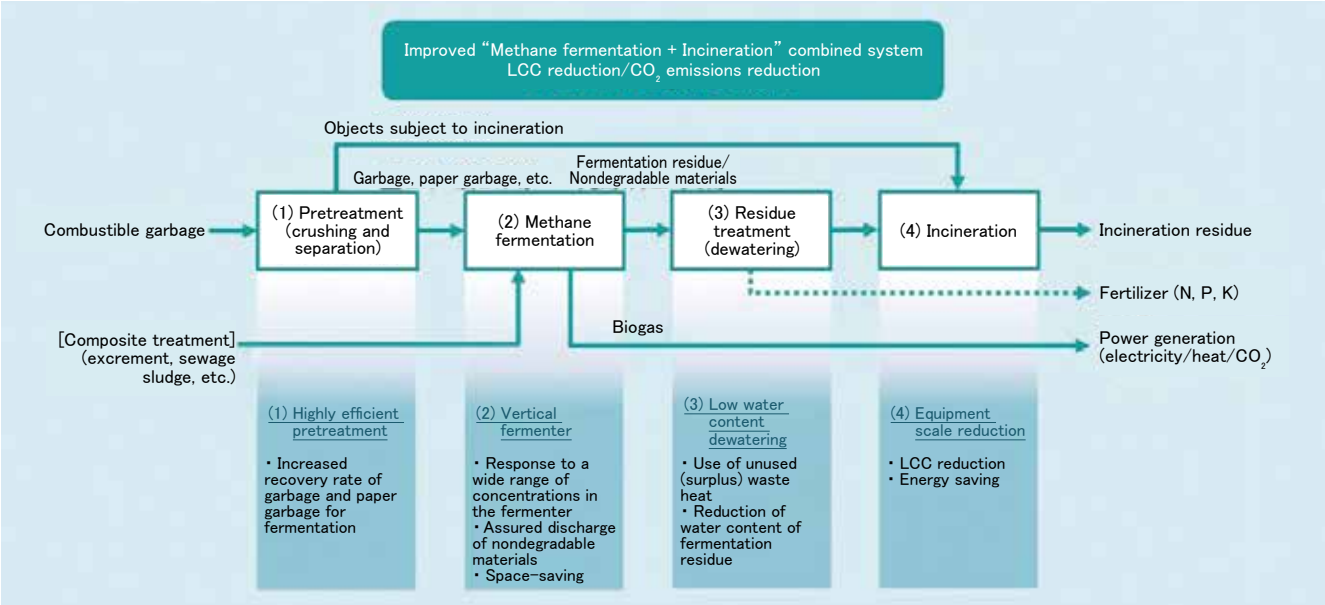


Fig. 1 Concept of the Development System

2-2 Target value

The goal of this development is "to establish a combined system that can achieve both LCC reduction and CO_2 emissions reduction compared to the conventional incineration treatment only."

In the model case (Table 1) presented by the Ministry of the Environment as a standard for small- and medium-sized waste treatment facilities, the target value was set so that the LCC and the CO_2 emissions will be less than those of incineration treatment only (Table 2).

Table 1 Model Case

Items	Condition
Garbage properties	35% garbage, 25% paper garbage, 40% other garbage (of which, 15% plastics)
Garbage amount	50 t/day × 280 days/year

Table 2 Target for Model Case

Items	Condition
Items	542 million yen/year or less
CO_2 emissions[1)]	7,470 t-CO_2/year or less

LCC: calculated independently by the Company

3. Technological issues to be solved

To achieve the development target, the entire system needs to be optimized by solving the problems concerning each component of the system shown in Fig. 1: (1) pretreatment (crushing and separation), (2) methane fermentation treatment, and (3) residue treatment (dewatering). Relevant issues are shown below.

(1) Pretreatment (crushing and separation)

- It is necessary to separate and remove (≈ subject to incineration) nondegradable materials such as plastics while increasing the recovery rate of garbage and paper garbage.

→ Construct a pretreatment system with a garbage recovery rate of 90% or more and a paper garbage recovery rate of 60% or more.

(2) Methane fermentation treatment

- Since garbage has a large solid content and makes its concentration and viscosity high in the fermenter, it cannot be agitated by a conventional pump or blower. By contrast, since the concentration and viscosity may become relatively low, such as during composite treatment with sludge, it is necessary to deal with both cases.

→ Establish an agitation mechanism that can accommodate a wide range of concentrations and viscosities in the fermenter

- Since various nondegradable materials such as plastics and sand are contained, they can be accumulated in the fermenter and block the outlet easily.

→ Establish a mechanism that ensures a discharge of nondegradable materials

- A high level of biogas yield is achieved by proper pretreatment (crushing and separation), agitation mechanism, and nondegradable materials discharge mechanism.

→ Ensure the 210 Nm^3/t or more of biogas generation per waste input to fermenter in garbage treatment only

*Biogas yield by the existing methane fermentation treatment technology: 150 Nm^3/t (Ministry of the Environment, Energy Recovery-type Waste Treatment Facility Manual)

(3) Residue treatment (dewatering)

- The water content of the residue needs to be lowered in order to reduce the amount of residue to be incinerated and reduce the incineration cost.

→ Establish a dewatering technology that achieves a water content of 60% or less

4. Development technology

4-1 Target value

As the first step of development, we first established the basic technology by conducting laboratory experiments using simulated garbage as well as small machine experiments using actual garbage.

However, the actual disposal target is combustible garbage generated from households and business establishments, and its properties are extremely diverse. Additionally, some devices and functions require a certain scale of garbage to demonstrate their performance. Therefore, by utilizing the consignment project by the Ministry of the Environment, a demonstration plant was set up on-site to conduct an experiment with the cooperation of the Funai District Sanitation Management Association (composed of Nantan City and Kyotamba Town) in Kyoto Prefecture. Table 3 shows the outline of the demonstration plant, Fig. 2 shows its flow, and Fig. 3 shows photos of the external view.

Table 3 Outline of the Demonstration Plant

Items	Overview
Objects subject to treatment	Household and business combustible garbage
(for composite treatment with sludge)	Excrement septic tank dewatered sludge, and sewage dewatered sludge
Pretreatment amount	300 kg/d
Fermenter capacity	3 m^3/fermenter × 2 fermenters
Fermentation processing amount	75 kg/(day/fermenter)

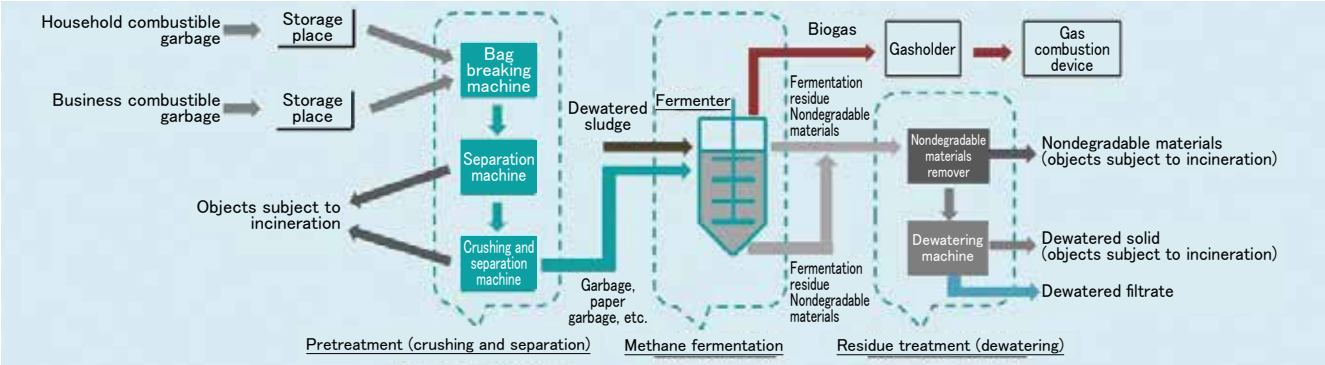


Fig. 2 Flow of the Demonstration Plant

Fig. 3–1 Pretreatment

Fig. 3–2 Fermentation

Fig. 3–3 Dewatering

4-2 Results of demonstration experiment

4.2.1 Pretreatment (crushing and separation) technology

As shown in Fig. 2, the developed pretreatment technology consists of (1) a bag breaking process (breaking garbage bags with a bag breaking machine to remove the contents), (2) separation process (removing relatively large nondegradable materials such as plastic bags and PET bottles as objects to be incinerated via the sieving effect of the separating machine), and (3) crushing and separation process (further removing nondegradable materials by wind separation while crushing with the crush and separation machine).

Table 4 shows the recovery rates of garbage and paper garbage in the pretreatment, and Fig. 4 shows the photos before and after the pretreatment.

Although there were variations in the garbage properties prior to pretreatment, we managed to collect most of the garbage and paper garbage. By contrast, we were able to remove most of the nondegradable materials such as plastics and move them to the objects to be incinerated side.

Table 4 Recovery Rate in Fermentation Object by Composition

Items	Recovery rate
Raw garbage	88–99.9%
Paper garbage	58–81%
Overall	Average 63% (45%–87%)

Fig. 4–1 Garbage

Fig. 4–2 Nondegradable materials

Fig. 4–3 After pretreatment

4.2.2 Methane fermentation treatment technology

In the methane fermentation treatment, garbage, paper garbage, etc. collected in the pretreatment are put into a fermenter, in which biogas (mainly methane and CO_2) is generated by the action of microorganisms, and energy is recovered by power generation or the like.

Fig. 5 shows the outline of the developed fermenter. It takes a shape of an original vertical fermenter, and has a mechanical agitation mechanism that can realize necessary and sufficient mixing for a wide range of total solids (TS) in the fermenter, as well as having a nondegradable material discharge mechanism equipped with the following parts: upper and lower blades that facilitate a discharge of mixed nondegradable materials not removed by pretreatment, a side extracting port for extracting light nondegradable materials such as plastics along with fermentation residue, and a bottom extracting port for extracting heavy nondegradable materials such as sand. With this original vertical fermenter, a stable fermentation treatment was performed for approximately 400 days during the demonstration period.

The results are shown in Table 5. The total solid (TS) in the fermenter differs between the condition of garbage only and the condition of composite with sludge, but proper adjustment of the operation of agitation mechanism enabled to maintain the management Indicators related to fermentation treatment, such as ammonia concentration, organic acid concentration, and pH, in an appropriate range in both Trains, and recovery of biogas with a target value of 210 Nm^3/t or more was achieved.

Fig. 6 shows an example of extracted nondegradable materials. We were able to pull out plastics, etc. from the side extracting port and pull out sand, eggshells, etc. from the bottom extracting port without obstruction, and the nondegradable materials discharge mechanism exhibited the intended function. It was also visually confirmed that there were no nondegradable materials accumulated in the fermenter after the completion of the experiment.

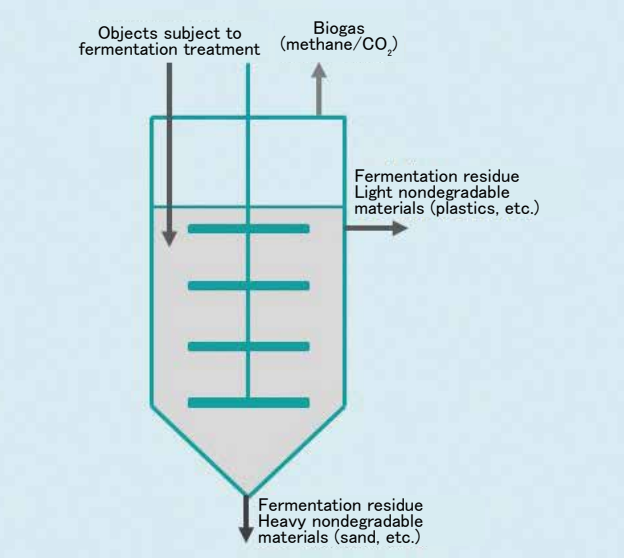


Fig. 5 Diagram of Fermentation Tank

Table 5 Results of Fermentation Experiments

Items	Recovery rate	Recovery rate
Objects subject to fermentation treatment	Pretreatment garbage 100%	Pretreatment garbage 70% + sludge 30%
Dilution	Usually undiluted*	2 times
Total solids (TS) in the fermenter	～12%	～7%
Number of retention days	40 days or less	40 days or less (20 days or less including dilution)
Gas yield	280 Nm^3/t	220 Nm^3/t
Methane concentration	54%	53%
Ammonia concentration	Proper range maintained	Proper range maintained
Organic acid concentration	Proper range maintained	Proper range maintained
pH	Proper range maintained	Proper range maintained

*Only dilution was performed to adjust the pretreatment garbage TS to 40% or less.

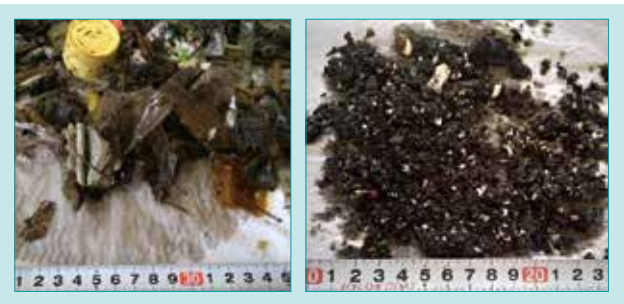


Fig. 6-1 Nondegradable (Side) Fig. 6-2 Nondegradable (Bottom)

4.2.3 Residue treatment (dewatering)

The organic matter decomposed by microorganisms turns into biogas by the methane fermentation treatment, but on the other hand, a residue is also generated, which contains surplus microorganisms, inorganic matter, nondegradable materials, etc. that are mixed with water.

Since this residue is incinerated in a combined system, it is desirable to reduce the water content. The residue treatment is a dewatering treatment for that purpose (Fig. 2).

In the actual facility, surplus waste heat is generated by biogas power generation, so we examined a way to efficiently reduce the water content by using the unused waste heat.

The results are shown in Table 6. By combining the addition of a flocculant and heating, the water content of the dewatered solid was successfully reduced to the target level of 60% or less.

Note that the dewatered solid and dewatered filtrate after removal of nondegradable materials are confirmed to be usable as fertilizer through a component analysis and plant damage test. If they can be effectively used as fertilizer in the communities, they can be adjusted to the required properties by adding a flocculant or adjusting the heating. Since the use of them as fertilizer will lead to the circulation of resources such as nitrogen and phosphorus in the communities, it is desirable to actively secure use destinations.

Table 6 Result of Dewatering (Water Content)

Items	Without heating	With heating
Garbage only	57%	47%
Composite with sludge	64%	59%

4-3 Calculation of LCC and CO_2 emissions reduction effect of the entire system

Through this demonstration experiment, we were able to construct an improved combined system.

LCC and CO_2 emissions reductions were calculated in five cases with differences in waste properties, an amount of waste (≈ facility scale), and the presence or absence of composite treatment with sludge. Table 7 shows the calculation conditions. Condition B is the model case shown in Table 1, and Condition E shows the properties of waste generated by the Funai District Sanitation Management Association.

Table 7 Study Conditions

Items	A	B	C	D	E	Remarks
Garbage properties (%)						
Garbage		35			20	
Paper garbage		25			40	
Other garbage		40			40	
(of which, plastics)		(15)			(20)	
Garbage amount (t/day)	30	50	70	50	30	280 days/year
Sludge amount (t/day)	0	0	0	15	0	280 days/year
Incineration treatment only						
Incineration capacity (t/day)	30	50	70	65 (mixed incineration of garbage and sludge)	30	280 days/year
Combined system						
Incineration capacity (t/day)	16.5	27.5	38.5	32.5	18.7	280 days/year
Methane treatment capacity (t/day)	15.2	25.3	35.4	36.8	13.8	365 days/year

*Number of incinerators: 2 for incineration treatment only, 1 for the combined system (because methane fermentation can process about half of the garbage even when the incinerator is stopped)

*Incinerator operating time: 14 h/day for A and E (semi-continuous furnace), and 24 h/day for B, C, and D (continuous furnace)

Fig. 7 shows the results of the LCC calculations, and Fig. 8 shows the CO_2 emissions (including the reduction effect by biogas power generation).

LCC is calculated independently by the Company. The initial cost takes into account the grant from the Ministry of the Environment (incineration only: 1/3, combined: 1/2) and does not include the land costs or land development costs. The running cost takes into account the expenditure of utility costs, labor costs, facility repair costs, and income from FIT power sales (39 yen/kWh). Additionally, CO_2 emissions are calculated by using the calculation tool in the "Guidebook for calculating the effects of global warming countermeasures project <for subsidy project application>" by the Ministry of the Environment. It is obtained by subtracting the amount of reduction due to biogas power generation from the amount of emissions generated by the combustion of plastics in garbage and the amount of emissions derived from the electricity and fuel used in a treatment facility (CO_2 generated from incineration of garbage, paper garbage, wood, and the like is not counted as emissions).

Under all the conditions examined, the improved combined system resulted in the reduction in both LCC and CO_2 emissions compared with the incineration treatment only, which achieved the target.

As for the LCCs, a higher garbage ratio leads to a greater reduction effect (A > E), and even if sludge is combined, it can be reduced despite small the effect (B > D).

With regard to CO_2 emissions, the high yield of biogas achieved by this improved system has resulted in a reduction effect of over 20% in all cases.

The model case (B) has the LCC reduction effect of approx. 46 million yen/year (approx. 920 million yen for the operation period of 20 years) and the CO_2 emissions reduction effect of 1,940 t-CO_2/year (Table 8).

In the examination of an actual facility, highly accurate calculations are necessary to accommodate individual conditions, but the calculations this time are based on a wide range of conditions, and the LCC and CO_2 emissions of many small- and medium-sized waste treatment facilities are considered to be reducible by adopting the improved combined system as compared with the incineration treatment only.

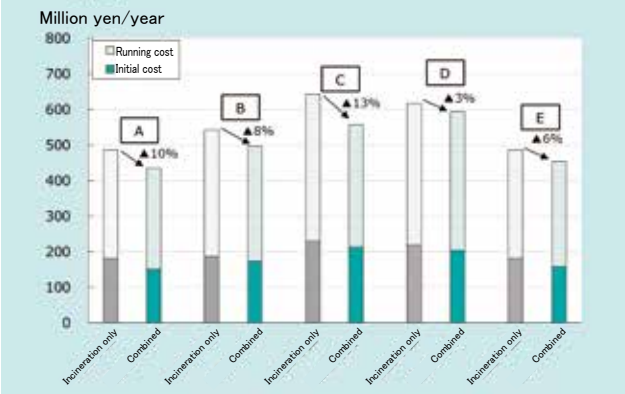


Fig. 7 LCC

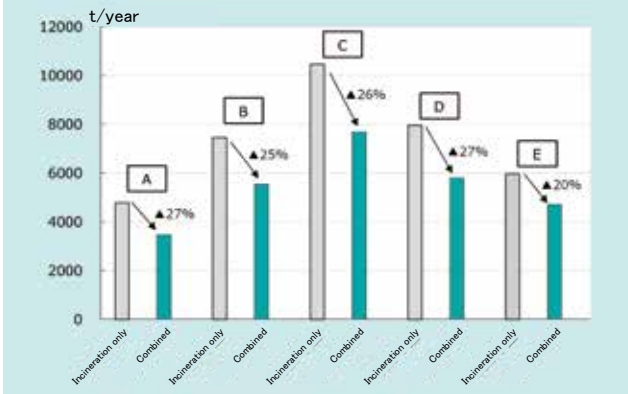


Fig. 8 CO_2 Emissions

Table 8 Evaluation Results in Model Case

Items	Incineration treatment only (target value)	Results of examination	Amount of reduction
LCC	542 million yen/year	496 million yen/year	46 million yen/year
CO_2 emissions	7,470 t-CO_2/year	5,530 t-CO_2/year	1,940 t-CO_2/year

5. Conclusion

We have developed a combined system centered on an original vertical methane fermentation technology that can recover energy and resources while ensuring economic rationality even in small- and medium-sized waste treatment facilities.

If this development system is introduced to all small- and medium-sized waste treatment facilities in Japan, the reduction of CO_2 emissions is estimated to be 1.75 million t-CO_2/year. We would like to continue making efforts to further improve the system and reduce the LCC so that this system will be popularized and significantly contribute to the CO_2 emissions reduction and resource circulation.

Lastly, we would like to express our deep gratitude to the Funai District Sanitation Management Association, Nantan City, Kyotamba Town, the Ministry of the Environment, and other relevant parties for their great cooperation in the demonstration experiment.

Contribution to SDG Targets

7.2 Expansion of renewable energy
Contribution to reduction of GHG (greenhouse gas) emissions

9.4 Infrastructure improvements and industry improvement through introduction of environment-friendly technologies and industrial processes, Introduction of an environment-conscious waste treatment facilities

Reference

1) Ministry of the Environment: "CO_2 emissions: Guidebook for calculating the effects of global warming countermeasures project <for subsidy project applicants>" pp.2–3

Development of Energy-saving Technology Utilizing a Turbocharger for Sewage Sludge Incineration Facility

Environmental Engineering Design & Procurement Dept.

In recent years, there has been an increasing need for energy saving technology from the viewpoint of global environmental conservation, and sewage treatment plants are no exception. Fluidized bed incinerators have been widely used as sewage sludge volume reduction technology, but the high consumption of electricity has been an issue. We developed a method utilizing a turbocharger that significantly reduces the amount of electricity consumed by a sludge incineration facility.

【Key Word】
Energy Saving Technology, Turbocharger, Fluidized Bed Incinerator, Sludge Disposal

Related SDGs

1. Introduction

Currently, the sewage treatment penetration rate in Japan exceeds 90% on a target population basis, and wastewater in urban areas is mostly treated as sewage. At sewage treatment facilities, sludge generated in the process of treating sewage is reduced in volume by concentration treatment and dewatering treatment and then undergoes final disposal upon incineration treatment.

In recent years, from the perspective of global environmental conservation, the amount of electricity used has been required to decrease even in infrastructure facilities such as sewage treatment facilities. Currently, facilities that cannot achieve a certain level of energy saving are excluded from the subject of the national treasury subsidy project, which makes construction virtually impossible, and it was necessary to promptly develop a technology that contributes to power consumption reduction also from the perspective of the need for Kubota's business promotion.

2. Overview of developed technology

2-1 Technical issues

Dewatered sludge prior to incineration has a water content of 70% or more in weight ratio even when using a high-efficiency dewatering machine, but because organic sludge has a large amount of flammable components (= thermal energy), incineration treatment is possible. Generally, a "fluidized bed incinerator" is used to incinerate high-water-content dewatered sludge.

In a fluidized bed incinerator, a fluidized bed is formed by depositing silica sand at the bottom of the incinerator and sending air from the lowest part to fluidize the silica sand. The fluidized bed is kept at a high temperature of approximately 700°C to 800°C, and after evaporating the water in the dewatered sludge and gasifying and incinerating the combustible component, the combustible component is completely incinerated at 800°C to 900°C in the combustion space in the upper part of the furnace. Since a fluidized bed incinerator has a large heat capacity, it can stably and efficiently incinerate dewatered sludge containing a large amount of water.

In the sludge incineration facility, the combustion air is preheated by the waste heat of incineration exhaust gas to efficiently incinerate the dewatered sludge containing a large amount of water. The preheated air temperature reaches approximately 700°C, and dewatered sludge with a relatively low water content can be incinerated by simply using the amount of heat (= thermal energy) possessed by the combustible component of sludge even without supplementary using fossil fuels. However, since a large amount of heat energy is required to evaporate water in the incineration process and because the amount of heat energy left in the exhaust gas is small after waste heat recovery, it is difficult to introduce a steam turbine power generation device that is widely used as a waste heat utilization technology in waste incineration facilities.

Additionally, the blowing pressure becomes high

when blowing combustion air to form a fluidized bed in the incinerator, and the required power of the blower (fluidizing blower) is large. In the current sludge incineration facility, the amount of electric power consumed to incinerate 1 ton of dewatered sludge is approximately 80 to 100 kWh. Of these, the fluidizing blower consumes approximately one-third of the total power consumption of the sludge incineration facility, so if power saving can be achieved for the fluidizing blower, the power consumption of the facility can be significantly reduced.

2-2 Facility configuration

The "turbine assist" system that we developed this time is a power-saving technology for plant equipment that functions by incorporating a "turbocharger" in the blowing passage of combustion air. In the sludge incineration facility, to improve the combustion efficiency in blowing the combustion air to a fluidized bed incinerator by a fluidizing blower, an air preheater (heat exchanger) placed in the blowing passage indirectly exchanges heat with an incineration exhaust gas to preheat the combustion air to about 700°C.

A facility equipped with a "turbine assist" system is comprised of a compressor placed between a fluidizing blower and an air preheater and a turbine placed between an air preheater and a fluidized bed incinerator. Comparison with the conventional facility is as shown in Fig. 1. Although this technology requires modification of an air preheater and duct for the installation of a turbocharger, it is possible to obtain an improvement effect by renovating the conventional facility.

A turbocharger is a device in which a centrifugal compressor and a turbine are connected with a shaft and is used for the purpose of improving the output and efficiency of internal combustion engines (Fig. 2).

"Turbine assist" is a technology that combines a turbocharger driven by thermal energy and a fluidizing blower driven by an inverter. The combustion air blown from the fluidizing blower is first pressurized by the compressor before flowing into the air preheater. Furthermore, the pressurized combustion air is heated by the air preheater and expands to drive the turbine. At this point, the flowing air will undergo pressure boosting in the process of passing through the turbocharger and the air preheater, and this action is brought by thermal energy. The drive status of a turbocharger fluctuates depending on the temperature and pressure of the passing air, but in response to this, the combustion air volume blown to a fluidized bed incinerator can be adjusted to a predetermined value by controlling a load amount of a fluidizing blower with the rotation speed of an inverter in a coordinated manner. As shown in Fig. 3, the load on the fluidizing blower can be reduced by the amount equal to the turbocharger driving force utilized by receiving the waste heat, which results in the reduction of power consumption.

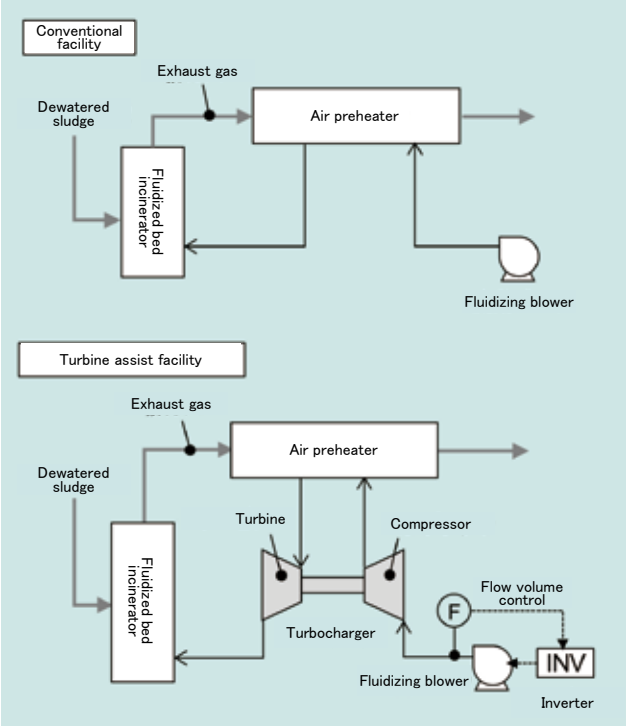


Fig. 1 Configuration of Sludge Incineration Facility

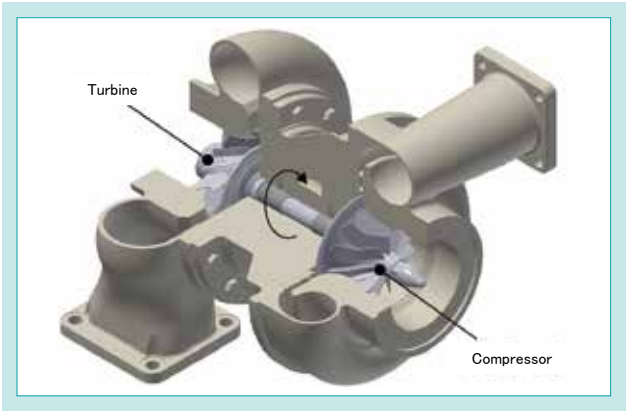


Fig. 2 Structure of Turbocharger

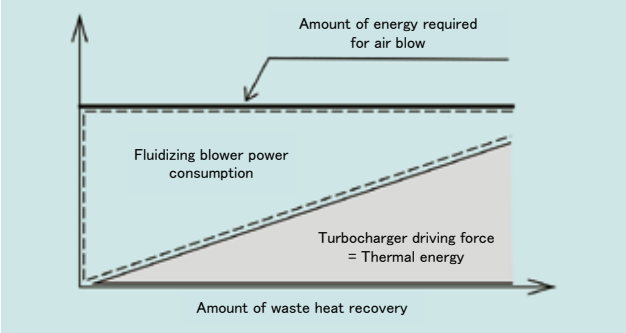


Fig. 3 Principle of Electricity Reduction

2-3 Comparison with a similar technology

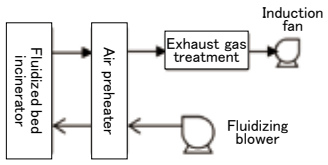
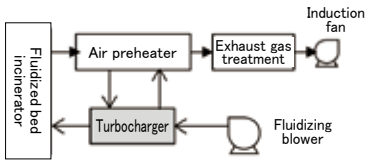
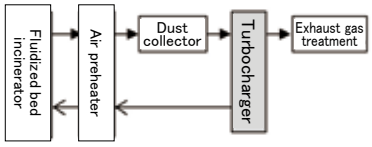
As a power-saving technology using a turbocharger in sludge incineration facilities, there is a "Pressurized fluidized bed (PFB) incineration system" that has been popularized earlier. The "PFB system" is different from the "turbine assist" developed by Kubota in terms of the turbocharger position and the driving principle of a turbocharger, and the differences are shown in Table 1.

A facility equipped with a "turbine assist" system is considered to have the following advantages over a "PFB system" facility.

1) Because the turbine driving fluid of the "PFB system" is incineration exhaust gas, it is necessary to remove the flying ash contained in the exhaust gas before introducing a turbine. Furthermore, dust collection is required at high temperatures, and the risk is high if the dust collector is damaged.
2) Since the "PFB system" does not have a balanced ventilation mechanism and incinerates under pressure, there is a risk that incineration exhaust gas will leak from the incinerator or downstream equipment. Additionally, total renovation including an incinerator is required for its introduction, but "turbine assist" can be introduced also by partial remodeling.

As technology for waste treatment facilities, "turbine assist" is expected to be accepted because safety can be easily ensured.

Table 1 Features of Facilities

	Conventional facility	Turbine assist facility	PFB system facility
Facility configuration			
Power consumption	—	△ : 60%–70% of conventional facility	○ : Approx. 50% of conventional facility
Incinerator internal pressure	Negative pressure	○ : Negative pressure	× : Positive pressure
Turbine inflow gas	—	○ : Air	× : Incineration exhaust gas
Dust collector	Bag filter (negative pressure, approx. 200°C)	○ : Bag filter (negative pressure, approx. 200°C)	× : Ceramic filter (positive pressure, 500°C or higher)
Maintainability	Satisfied	○ : Same as conventional	× : Heavy burden of equipment maintenance

3. Confirmation at a demonstration test facility

3-1 Demonstration test facility

To confirm the function and performance of "turbine assist," the incineration facility delivered by Kubota was remodeled with the cooperation of customers.

For the sake of the demonstration test, of the two air preheaters arranged in series, the No. 2 air preheater on the low-temperature side and the duct attached to it were modified to install a turbocharger (Figs. 4 and 5). Since a turbocharger requires a larger air blow volume to be used in the incineration facility than the car engine, a marine model was selected, and two units were installed in parallel. Additionally, the fluidizing blower was changed to an inverter-driven one, and the method of controlling the air blow volume was changed to the control by the rotation speed of the blower.

Fig. 5 Turbocharger

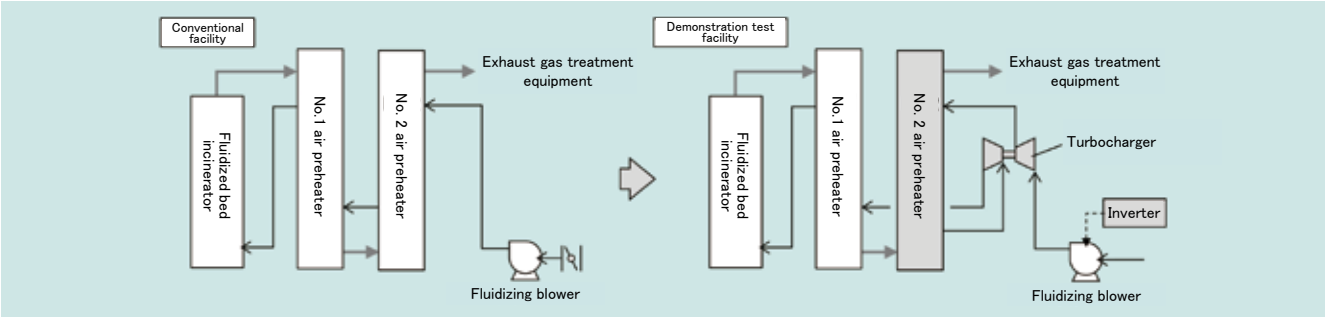


Fig. 4 Configuration of Test Facility

3-2 Test results

By using a turbocharger after the facility remodeling, the fluidizing blower outlet pressure was successfully reduced significantly, which used to be approximately 25 to 28 kPa [G] before the remodeling. When the turbine inlet temperature is raised to 500°C or higher, the fluidizing blower outlet pressure becomes 1 kPa [G] or less, and we were able to reduce the power consumption of fluidizing blower, which used to be 250 kW before the remodeling, to 9.2 kW (−96% compared with the conventional one) (Fig. 6).

As a result of reducing the power consumption of fluidizing blower, we achieved the reduction of power consumption of the entire facility to −29% compared with the conventional one.

The turbocharger is particularly affected by the turbine inlet temperature. For example, when the turbine inlet temperature is raised by using the bypass function of the air preheater, the air blow volume fluctuates (increases) with the temperature change. When this operation was repeated in a short time to change the load applied to the turbocharger, the fluidizing blower driving device (inverter) quickly followed it, which confirmed that the combustion air volume can be stably controlled (Fig. 7).

Note that the power consumption of fluidizing blower is reduced along with a decrease in fluidizing blower outlet pressure due to an increase in the turbine inlet temperature.

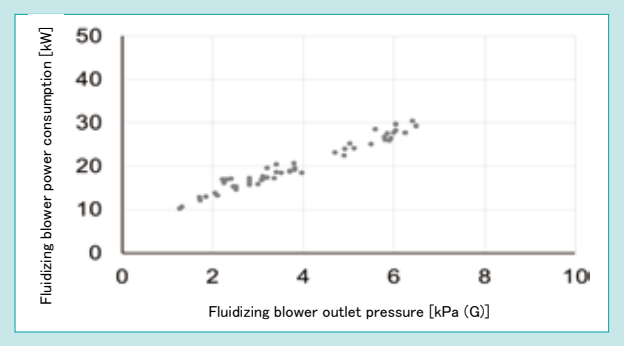


Fig. 6 Relationship between Outlet Pressure and Electricity Consumption

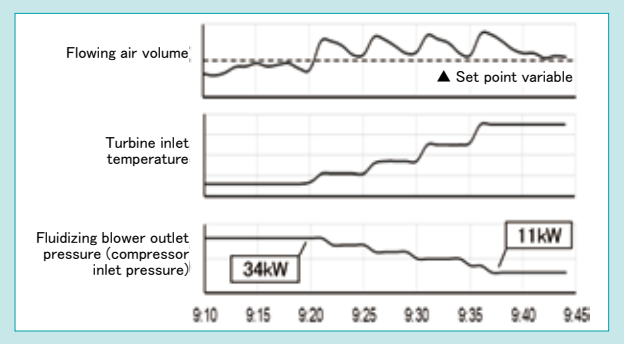


Fig. 7 Changes in Airflow Volume

4. Principle and consideration of this technology

4-1 Brayton cycle

A turbocharger is a heat engine classified into the Brayton cycle. The Brayton cycle is a combination of a heating/cooling (heat dissipation) process in an isobaric state and a compression/expansion process in an adiabatic (isentropic) state. In addition to turbochargers, gas turbines and jet engines are also equipment belonging to the Brayton cycle. The cycle diagram (Fig. 8) shows that the expansion process under high temperature and pressure can function as a heat engine since it has a relatively large amount of change in enthalpy (T) than the compression process under low temperature and pressure.

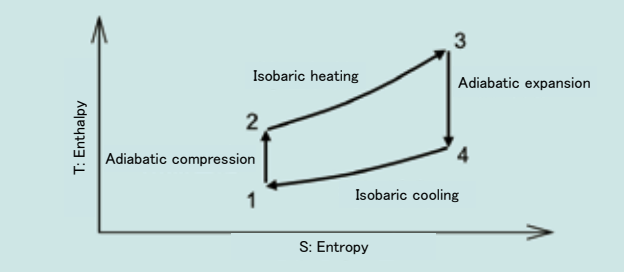


Fig. 8 T-S Diagram of Brayton Cycle

4-2 T-S diagram and pressure change

Because the turbine outlet pressure of the turbocharger rises by the level equal to the blowing pressure to the fluidized bed incinerator, the amount of expansion work is reduced. “Turbine assist” increases the compressor inlet pressure for that loss by supplementarily using a fluidizing blower and gets the driving force of a turbocharger by supplementing the compression work volume. In the “turbine assist” cycle diagram (Fig. 9), the adiabatic compression work volume of the compressor is the same as the adiabatic expansion work volume of the turbine. Under the condition that the fluidizing blower outlet pressure is smaller than the blowing pressure of the fluidized bed incinerator, the power-saving effect of the fluidizing blower can be obtained.

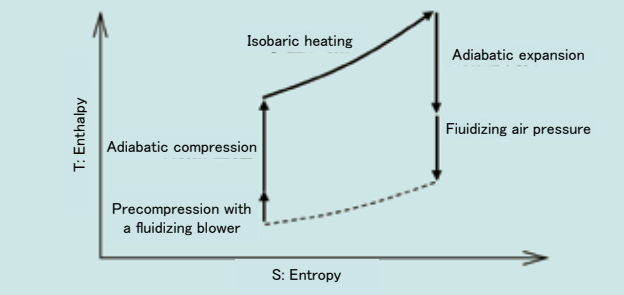


Fig. 9 T-S Diagram with Turbocharger

The pressure change in the blowing passage of the facility equipped with the “turbine assist” system is as shown in Fig. 10. Combustion air blown from the fluidizing blower is first pressurized by a compressor and then heated in an isobaric state to expand. After that, it is returned to the turbocharger, obtains the driving force of the turbocharger when the pressure is reduced by the turbine, and is blown to the fluidized bed incinerator by the residual pressure. In a series of processes, the turbocharger outlet pressure becomes higher than the inlet pressure, which shows that the turbocharger functions as a pressure booster for the combustion air.

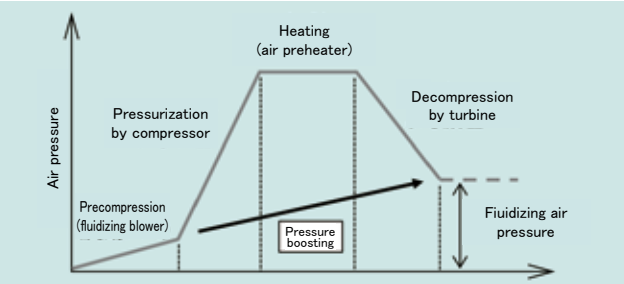


Fig. 10 Changes of Air Pressure

4-3 Behavior

With “turbine assist,” the state change can be estimated by calculation upon an understanding of the Brayton cycle.

According to the knowledge of thermodynamics, regarding the state quantity around the turbocharger (Fig. 11), air blow volume changes as shown in Table 2 depending on the behavior of the turbocharger. In the demonstration test facility, the compressor inlet pressure P_1 is adjusted and controlled by a fluidizing blower. Additionally, in the demonstration test, we have confirmed that the behavior of a turbocharger changed as expected in response to changes in other influencing factors.

The turbocharger used in “turbine assist” is particularly affected by the turbine inlet temperature T_3, and air blow volume becomes greater with the higher the turbine inlet temperature T_3.

By contrast, air blow volume decreases when the compressor inlet temperature T_1 is high (equivalent to the high-temperature state) or when the turbine outlet pressure P_4 is high (equivalent to the state of high blowing pressure = flowing air pressure to the fluidized bed incinerator). For example, in consideration of the influence of air temperature, if there is a temperature difference of 30°C between winter and summer, the compressor inlet temperature T_1 also has a 30°C difference. Therefore, in summer when the air blow volume decreases, it is necessary to increase (raise) the turbine inlet temperature T_3 by approximately 70°C higher than in winter. If the adjustment allowance for the turbine inlet temperature T_3 is insufficient, the expected power-saving effect cannot be obtained in summer, or it may lead to an uncontrollable situation in winter. When constructing facilities, it is necessary to consider the design so that it can be adjusted with a margin upon giving due consideration to the effects of fluctuations in each factor.

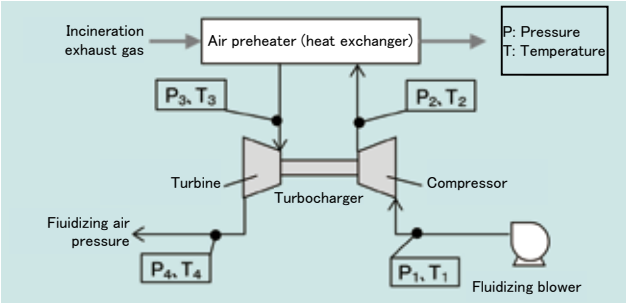


Fig. 11 Factors Influencing Turbocharger

Table 2 Behavior of Airflow Volume

Influencing factor	When increasing	When decreasing
Compressor inlet pressure P_1	Air blow volume increase	Air blow volume decrease
Compressor inlet temperature T_1	Air blow volume decrease	Air blow volume increase
Turbine inlet temperature T_3	Air blow volume increase	Air blow volume decrease
Turbine outlet pressure P_4	Air blow volume decrease	Air blow volume increase

4-4 Energy utilization efficiency

When the gas is compressed or expanded in an adiabatic state, the pressure change causes a temperature change. Specifically, the temperature rises when it is compressed, and it falls when it expands.

When the gas passes through a turbocharger and undergoes a pressure change $P_1 \rightarrow P_2$ in the compressor or a pressure change $P_3 \rightarrow P_4$ in the turbine, the compressor outlet temperature T_2 and the turbine outlet temperature T_4 can be expressed by the following equation with the compressor efficiency η_C and the turbine efficiency η_T.

$$T_2 = \frac{T_1}{\eta_C}\left\{\left(\frac{P_2}{P_1}\right)^{\frac{\kappa-1}{\kappa}} - (1-\eta_C)\right\}$$

$$T_4 = T_3\left\{\eta_T\left(\frac{P_4}{P_3}\right)^{\frac{\kappa-1}{\kappa}} + (1-\eta_T)\right\}$$

This equation indicates that the temperature change accompanying the pressure change is affected by the efficiency of the compressor and turbine. There is a loss in the compression work in the compressor of the actual turbocharger and the expansion work in the actual turbine, and the total efficiency of the turbocharger is about 60% for a marine model. When using an actual turbocharger, the compressor outlet temperature T_2 and the turbine outlet temperature T_4 are higher than when they are subject to an ideal pressure change of η = 1. This can be interpreted as the fact that the loss in the compressor and turbine is stored as thermal energy in the passing gas.

However, since this process also aims to preheat the combustion air, the rise in gas temperature due to the loss of a turbocharger is functionally harmless; therefore, this process can be said to be an extremely efficient system having practically no energy loss.

With the assumption that the turbocharger efficiency η is different, the operating conditions of a facility are calculated as shown in Fig. 12.

The higher efficiency of a turbocharger (upper figure) requires a smaller amount of heat energy to operate the turbocharger, as well as the lower turbine inlet temperature T_3.

However, to improve the combustion efficiency of the fluidized bed incinerator, it is necessary to raise the combustion air temperature with another heat exchanger. Conversely, in the case of a turbocharger with low efficiency (lower figure), the turbine inlet temperature needs to be raised, but the amount of required heat energy is small to raise the temperature to a predetermined combustion air temperature by the heat exchanger on the rear flow side.

Consequently, the amount of heat energy that is recovered by the heat exchanger as the preheating process of the combustion air is the same regardless of the efficiency of the turbocharger. The energy loss in the turbocharger does not impair the waste heat recovery for the purpose of preheating the combustion air, and the thermal energy ends up being converted into the pressure increase of the combustion air without loss.

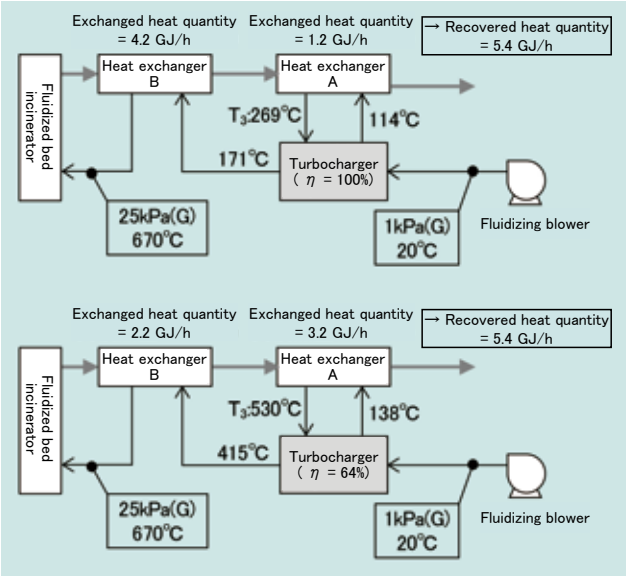


Fig. 12 Comparison of Facilities with Different Turbocharger Efficiencies

4-5 Blowing air by turbocharger only

At the beginning of development, the performance of the "turbine assist" system could not be predicted accurately, so the goal was first set to confirm and demonstrate that a mechanism that concomitantly uses both a blower and a turbocharger would be established.

After the above demonstration test, we had prospects that blowing operation can be performed by the turbocharger alone without the concomitant use of a blower by increasing the air blow volume from the turbocharger through further raising of the turbine inlet temperature. If air is blown only by a turbocharger, power consumption can be reduced as compared with the concomitant use of a blower.

Therefore, at another treatment facility, an additional test was conducted with the goal of blowing air only by a turbocharger without the concomitant use of a blower. In designing the facility remodeling, (1) the turbine inlet temperature was raised (600°C or higher), and (2) an adjustment mechanism was added to bypass the turbine to control the air blow volume (Fig. 13). In this facility, if the air blow volume needs to be increased, the amount of turbine bypass is reduced to increase the driving force of a turbine, and if it needs to be decreased, the reverse operation is done.

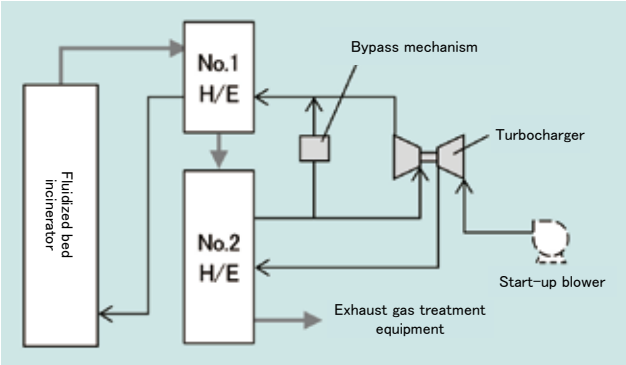


Fig. 13 Configuration of Facility Using Only a Turbocharger

It was confirmed that this method also works without problems.

According to this method, the power consumption can be reduced as compared with the case without the concomitant use of a blower, but it is necessary to consider that the addition of a control mechanism is required for switching between the combined operation with the blower and the single operation of the turbocharger and that the load is applied to the turbocharger by the amount equal to the temperature rise of the turbine inlet.

5. Conclusion

Presently, energy saving in sewage treatment facilities is an urgent issue in response to the trend of environmental conservation on a global scale, and the turbocharger utilization technology that can achieve significant power saving is attracting attention. We have already received an order for a facility that uses this technology as a project for Nagano Prefecture, and we are preparing for construction. Additionally, we are expanding sales activities for further popularization.

Contribution to SDG targets

7.3 Improvement in energy efficiency
Reduction of power consumption to about 2/3 compared to conventional facilities

Development of 45% Nickel-based Aluminum-containing Material for Cracking Tube Market

Steel Castings Technology Dept.

In the cracking tube market for ethylene production, a growing number of customers use materials containing Al (aluminum) which are high value added products. Kubota's Al-containing material is based on 35 Ni (nickel) with high creep rupture strength in order to prevent tube deformation. However, some customers prefer 45 Ni material because carburizing resistance is more important than preventing tube deformation. In order to meet a variety of customer needs, we designed an alloy aiming to improve the carburizing resistance performance required by customers and provide good weldability for on-site welding. Also, we developed a product with the same cost and shorter delivery time as the current 35 Ni based Al-containing material by streamlining a part of the manufacturing process of the current Al-containing material.

【Key Word】
Cracking Tube, Carburizing Resistance, Al-Containing Material, Alumina Forming, Customer's On-Site Welding

Related SDGs

1. Introduction

The cracking tube for ethylene production is a key component in an ethylene production plant (ethylene plant) in the petrochemical industry. It produces ethylene by being heated to approximately 1,000°C to 1,100°C by the heat source on the outer surface side of the tube and by thermally decomposing ethane, naphtha, etc., which are the raw materials that flow down the tube (Fig. 1)[1]. For this reason, high heat resistance and carburizing resistance in a high-temperature environment are required as its characteristics. Generally, a Ni-Cr-Fe alloy called austenitic heat-resistant steel is used. During the operation, carbon is deposited on the inner surface of the tube (coking, (Fig. 2)) because of the thermal decomposition reaction of raw materials and by the catalytic reaction with the Ni and Fe elements that are the main components of the cracking tube. This leads to the blockage due to a decrease in the tube inner diameter and the material deterioration due to significant carburization, which basically limits the product life. Furthermore, since the tube is used at high temperatures, creep deformation and rupture can also be limiting factors for product life.

As one of the solutions to these problems, in 2012, Kubota launched the cracking tube AFTALLOY (35 Ni-based Al-containing material, (Fig. 3))[2] in which an alumina layer is formed on the inner surface of the tube. This technology optimizes the alloy design of the cracking tube material and the formation conditions of the alumina oxide layer that protects the material, and by performing special processing and heat treatment, it forms a dense and uniform high-purity alumina layer on the entire tube inner surface with the minimum amount of Al added. Since the alumina layer is a dense and higher-purity oxide layer than the chromia layer formed on the conventional material (45 Ni, without Al), it prevents carbon from infiltrating from the deposited coke into the tube inner surface. Therefore, the anticarburization property is greatly improved, and furthermore, protection (masking) of the base metal with an alumina layer can prevent the catalytic reaction between the main components of the base metal and raw materials, enabling the suppression of coking during operation. At this point, if more than a certain level of coke accumulates in the cracking furnace, it is necessary to suspend its operation to perform decoking, which burns the accumulated coke. The dense alumina layer of the AFTALLOY reduces the coke deposition and has been establishing a proven record of achieving two to five times more continuous operation days compared with the conventional material that does not contain Al. This effect leads to the improvement of the

operating time rate and ethylene productivity of the customers' ethylene plants and contributes to the improvement of energy efficiency by reducing the number of decoking. In recent years, there are an increasing number of customers who are using this material for cracking furnaces that use ethane, propane, etc. as raw materials (Fig. 4).

Kubota's Al-containing materials are based on a 35 Ni-based material with high creep rupture strength by placing an emphasis on not only coking resistance and carburizing resistance but also tube deformation, and the amount of added Al that reduces creep rupture strength is minimized. By contrast, there are customers who expect further improvement in carburizing resistance rather than tube deformation resistance. These customers specifically desire a material with high Ni content as an element that enhances the carburizing resistance of the base metal itself when the alumina layer deteriorates and cannot protect the base metal, and they also desire a high Al-containing material having an alumina layer that does not easily deteriorate in the first place. Because an increase in the amount of Ni added can suppress the internal diffusion of carbon into the base metal, the life-extending effect of products can be expected by improving the carburizing resistance. An increase in the amount of Al added can reinforce the alumina layer to prevent deterioration, providing the long-term protection of the base metal by the alumina layer to improve the operation efficiency.

Based on the above, to respond to customer requests and expand the product lineup of Al-containing materials, we have developed a 45 Ni-based Al-containing material with enhanced carburizing resistance and alumina layer for the cracking tube market.

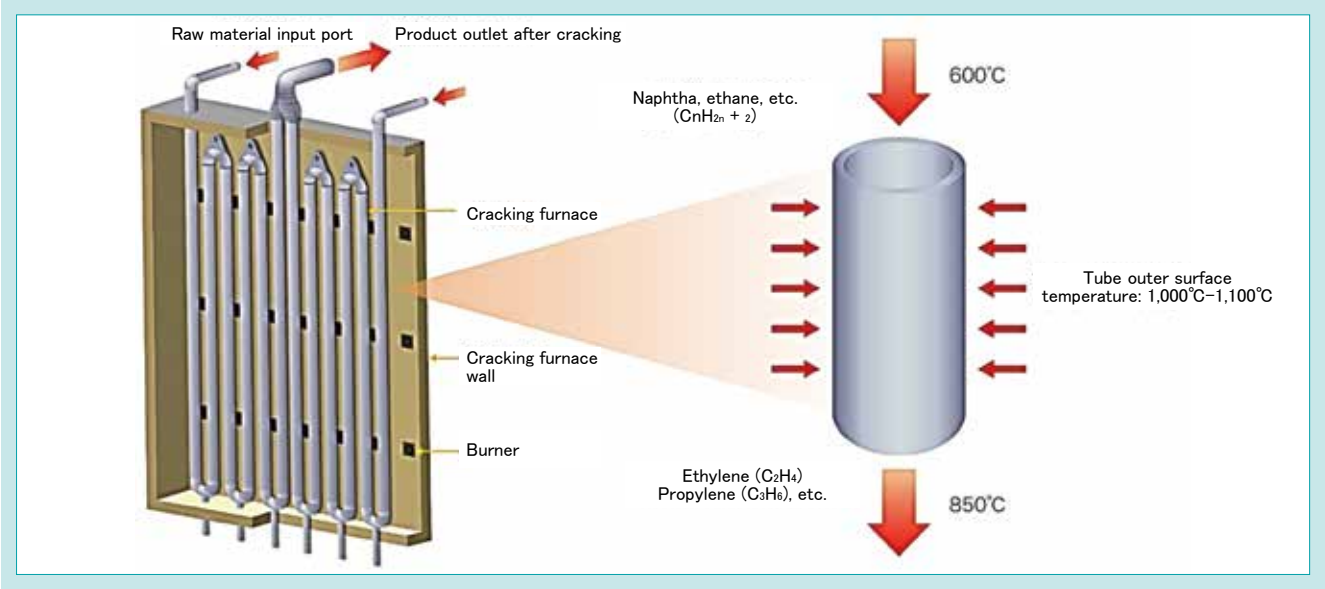


Fig. 1 Cracking Tube in Cracking Furnace for Ethylene Production[1)]

Fig. 2 Coking in Cracking Tube

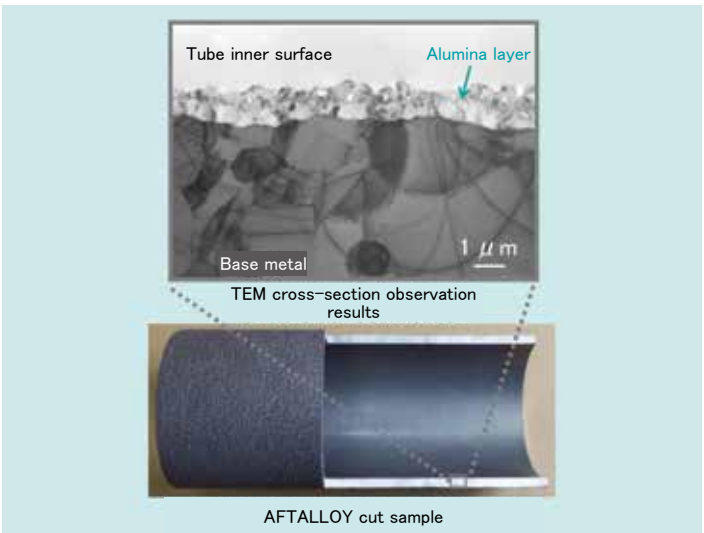


Fig. 3 Overview and Chemical Composition of AFTALLOY Cut Sample and Cross Section View of Alumina Layer

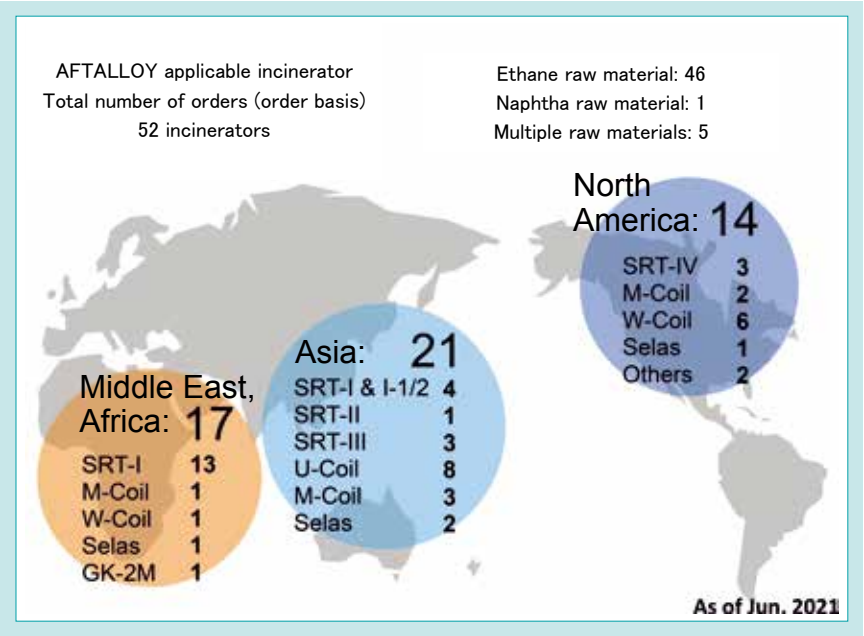


Fig. 4 Number of Commercial Furnaces Installed AFTALLOY as of June, 2021

2. Development concept and target value

2-1 Concept of development

For the 45 Ni-based Al-containing material, we aim to increase the amount of Ni and Al added to improve the product life and long-term operation efficiency. Furthermore, cracking tubes must be welded on-site at the customer's site. Therefore, on-site welding is facilitated if it has good weldability equivalent to that of the conventional material. Lastly, the increase in raw material Ni would normally be added to the manufacturing cost, but the manufacturing cost is reduced to the same level as the conventional material, and the manufacturing period is also shortened. These can be achieved by utilizing the effect of facilitating the formation of alumina layer via an increased amount of Al added, and by aiming for easy manufacturing through simplification of the special manufacturing process that used to be required for the formation of alumina layer in the AFTALLOY.

2-2 Target value

The development targets for the 45 Ni-based Al-containing material have been set as follows.

(1) Improved product life: Carburizing resistance of more than twice that of the AFTALLOY
(2) Improvement in long-term operation efficiency: Alumina layer formed in layers after an accelerated test compared to the AFTALLOY.
(3) Good weldability: No cracks in a welding test
(4) Manufacturing cost: Equivalent to the AFTALLOY

Manufacturing period: 10% shorter than the AFTALLOY

3. Technological issues to be solved

Generally, austenitic heat-resistant steel has improved carburizing resistance because of an increase in Ni and Al content. However, the increased Al content causes a decrease in mechanical properties such as the ductility value because of the formation of an Al compound with high hardness, high strength, and low ductility in its structure. At this point, weldability is affected by other elements contained in the base metal, but a decrease in ductility value will lead to solidification shrinkage cracking during welding. Therefore, it was necessary to optimize the alloy composition itself and develop a material with a ductility value equivalent to that of the conventional material and with excellent weldability even if an Al compound is produced.

4. Development technology

4-1 Alloy design technology

4.1.1 Issues related to alloy design technology

For the 45 Ni-based Al-containing material, evaluation was examined with various component compositions to solve the above-mentioned problems. However, the speed of development did not increase as expected because it was necessary to manufacture a cast product and conduct various tests to make an actual evaluation.

4.1.2 Solutions to alloy design technology

To speed up the development, more than 100 cases of analysis and evaluations were conducted using the equilibrium phase diagram simulation software "Thermo-Calc" for the component composition, precipitated structure, and solid-liquid phase line temperature. By evaluating in analysis in advance, the number of test pieces to be tested was reduced. Then, an appropriate component composition was selected, and static casting and centrifugal casting were performed to actually test and evaluate 20 or more test pieces.

4-2 Evaluation of developed products

For this developed product, a test piece was prepared by using static casting and centrifugal casting. The test piece was evaluated using the developed product of 45 Ni-based Al-containing material (KHR45AH) against the comparative materials of 35 Ni-based Al-containing material (AFTALLOY) and the conventional material 45 Ni + without Al (KHR45A). Table 1 shows the component composition of each material.

Table 1 Chemical Compositions (wt%)

Material			C	Si	Mn	Ni	Cr	Nb	Al	Others	Fe
Developed material	45 Ni-based Al-containing material	KHR45AH	0.4-0.6	<1.0	<1.0	43-47	23-27	<1.8	3-5	<0.5	Bal.
Conventional material	35 Ni-based Al-containing material	AFTALLOY	0.4-0.6	<1.0	<1.0	33-37	23-27	—	2-4	<0.5	Bal.
	45 Ni-based material without Al	KHR45A	0.4-0.6	<2.0	<2.0	40-46	30-35	<1.8	<0.5	<0.5	Bal.

4.2.1 Evaluation of oxide film

Fig. 5 shows the cross-sectional observation results of the oxide film of the test piece. As for the conditions for forming the oxide film in the initial state, since the KHR45AH has an increased amount of added Al compared to the AFTALLOY, heat treatment was carried out with steam by simulating the operation at the customer's site without performing special processing or heat treatment. The KHR45A was also heat-treated with steam by simulating the operation at the customer's site. By contrast, special processing and heat treatment were performed on the AFTALLOY to facilitate the formation of the alumina layer. During the evaluation of aging degradation, an accelerated test was conducted by repeating the process of holding the oxide film in the initial state at a higher temperature than the actual machine operation for a certain period of time and then cooling it to room temperature.

Based on the observation results of the oxide film in the initial state, in both KHR45AH and AFTALLOY, alumina was formed uniformly in layers, which was confirmed to be the alumina layer. Furthermore, by increasing the Al content of KHR45AH more than that of AFTALLOY, a layered film close to an alumina single layer was confirmed without any special processing or heat treatment required for the AFTALLOY in the initial state. In response to this result, the KHR45AH was found to be capable of omitting the special processing and heat treatment compared with the AFTALLOY, achieving the above-mentioned target (4) (manufacturing cost: equivalent to the AFTALLOY, manufacturing period: 10% shorter than the AFTALLOY). By contrast, the KHR45A mainly produced chromia in layers.

Next, as a result of cross-sectional observation of the oxide film after aging degradation, in the KHR45AH, an alumina layer was observed at the bottom of the chromia layer. This is because of the following mechanism. The chromia layer was once formed after the peeling of the alumina

layer, but since the chromia layer is not sufficiently dense, internal diffusion of oxygen occurs, forming alumina under the chromia layer. Furthermore, as the amount of added Al is large, the alumina layer was uniformly formed. Likewise, in the AFTALLOY, alumina was produced at the bottom of the chromia layer, but because the amount of Al added was kept to a minimum to enhance the creep rupture strength, alumina was produced in clumps with many gaps instead of a layered form. Additionally, the KHR45A had an enlarged chromia layer.

As for the evaluation of the aging degradation of the oxide film, the above results have confirmed that the KHR45AH can suppress the deterioration of the oxide film and maintain the layered alumina forming compared to AFTALLOY (achievement of target (2)). The KHR45AH allows the long-term protection of the base metal because of the presence of a layered alumina forming, suppressing the deterioration of coking resistance during use, which is expected to maintain the operation efficiency improvement of customers over a long period of time.

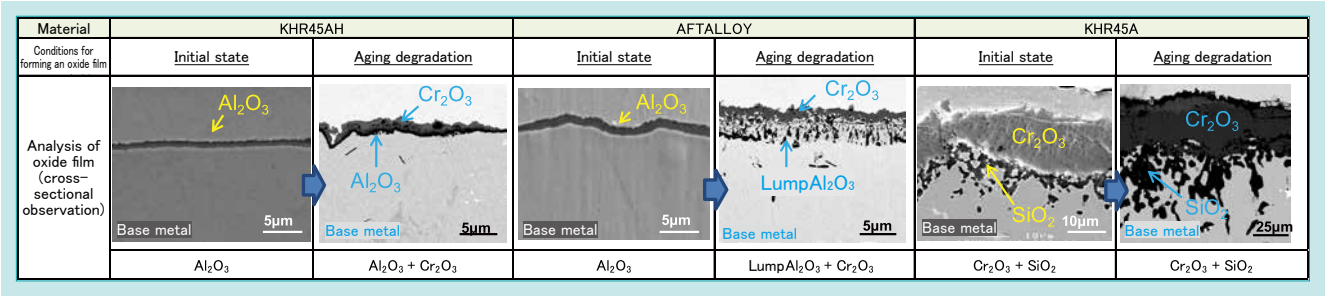


Fig. 5 Comparison of Oxidation Film Formation

4.2.2 Evaluation of carburizing resistance

Fig. 6 shows the results of the carburization test on the test piece observed in Fig. 5. In the carburization test, the carburized depth was measured by observing the cross-sectional surface after holding for a fixed time in a high-temperature heating state using methane gas. Shallower carburized depth indicates a better carburizing resistance to prevent the infiltration of carbon.

As a result of the carburization test in the initial state, carburization was not confirmed in the KHR45AH or AFTALLOY. This suggests that the dense alumina layer prevented carbon from infiltrating into the interior, so that carburization did not occur. By contrast, the KHR45A was confirmed to be carburized. This is because the chromia layer is not as dense as the alumina layer and allows carbon to easily penetrate the inside.

Next, the results of the carburization test after aging degradation confirmed that both carburized parts and noncarburized parts were confirmed in the KHR45AH. In the noncarburized parts, the presence of alumina layer is preventing carburization. As for the carburized parts, the internal diffusion of carbon is less likely to occur compared with the AFTALLOY of 35% Ni-based material because of the effect of an increased amount of Ni in the base metal, and the carburized depth is less than half compared with the AFTALLOY.

It was also confirmed that alumina is formed in the AFTALLOY although it is formed in clumps, that the carburized depth is shallower than that of KHR45A, and that it has excellent carburizing resistance.

Based on the above results, it was confirmed that the carburizing resistance in the initial state is KHR45AH = AFTALLOY > KHR45A, and the carburizing resistance after aging degradation is KHR45AH > AFTALLOY > KHR45A. Then the result of carburized depth confirmed that the anticarburization property of the KHR45AH is more than twice that of the AFTALLOY (achievement of target (1)).

Because of the improved carburizing resistance, the developed product KHR45AH can be expected to have an extended product life compared to the AFTALLOY and KHR45A.

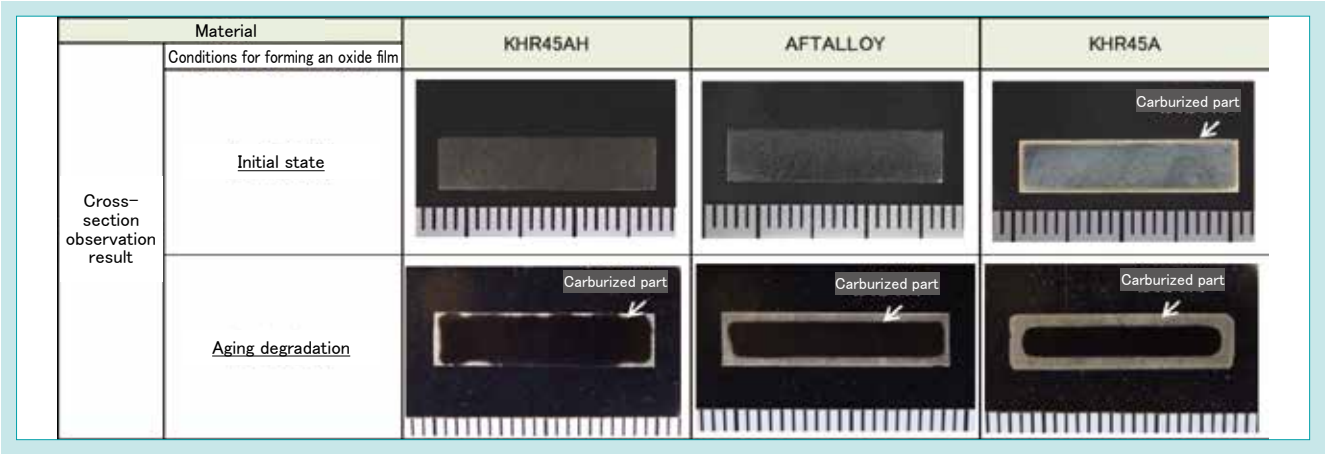


Fig. 6 Anti-Carburization Property

4.2.3 Evaluation of weldability

Generally, austenitic heat-resistant steel is the alloy steel having high-temperature strength such as carburizing resistance and creep rupture strength and is a material also with excellent formability and weldability. Moreover, by adding Al, Cr, Si, and the like, the carburizing resistance can be further improved. However, additives such as Al are known to reduce mechanical properties, particularly creep rupture strength and ductility, by producing a compound having high hardness, high strength, and low ductility as well as a low-melting-point compound. A decrease in ductility can be a cause of cracks along with solidification shrinkage during welding, leading to a decrease in weldability. Furthermore, since the weldability also varies with the balance of each element in the alloy such as the amounts of C, Cr, and Nb, it was necessary to investigate a weldable alloy with improved ductility. Therefore, by analyzing the composition, we searched for the component composition with low precipitation of compounds with high hardness, high strength, and low ductility. Consequently, we found out that Cr was the most influential element. In the KHR45A, 30% to 35% of Cr is added, whereas Ni content is 45%. Cr is an important element for forming carbides to improve the strength of the base metal and forming a chromia layer to improve carburizing resistance. However, the KHR45AH has achieved sufficient carburizing resistance by the addition of a high amount of Ni and Al, so the effect of Cr mainly contributes to the strength. Therefore, the amount of Cr, which has the equivalent strength as the conventional material while having a high ductility value, was evaluated by using an actual cast product.

Fig. 7 shows the effect of Cr on strength and ductility. As comparative materials, the AFTALLOY and KHR45A, are presented. By setting the amount of Cr addition to 25%, higher ductility was obtained compared with the material with 30% Cr content, and the strength was also maintained at the same level as the comparative materials. The carbides produced by Cr have high hardness and high strength and improve the alloy strength by spreading on the network. However, ductility decreases in inverse proportion to strength. In KHR45AH, the Al compound reinforced the matrix and carbides because of the influence of the addition of Al, which improved the strength of the entire alloy and reduced the ductility. Therefore, the strength does not drop significantly even if the amount of Cr is reduced, and ductility is considered to be restored.

Together with these results, a welding test was conducted with components optimized for C, Nb, etc., that affect weldability. Fig. 8 shows a cross-sectional observation photograph after butt welding as a welding test result. There were no defects such as cracks in the welded parts, and good weldability was confirmed for the KHR45AH (achievement of target (3)).

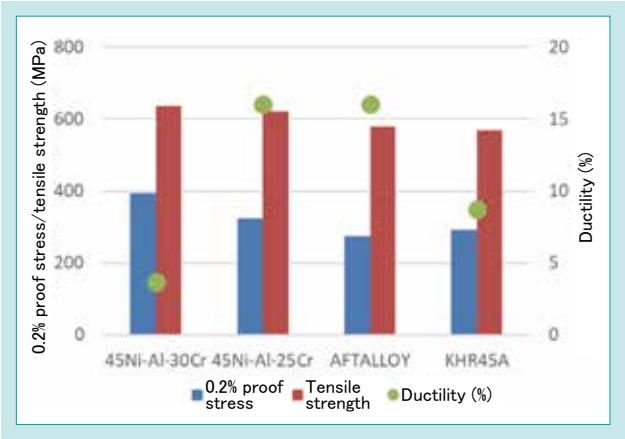


Fig. 7 Tensile Test Results

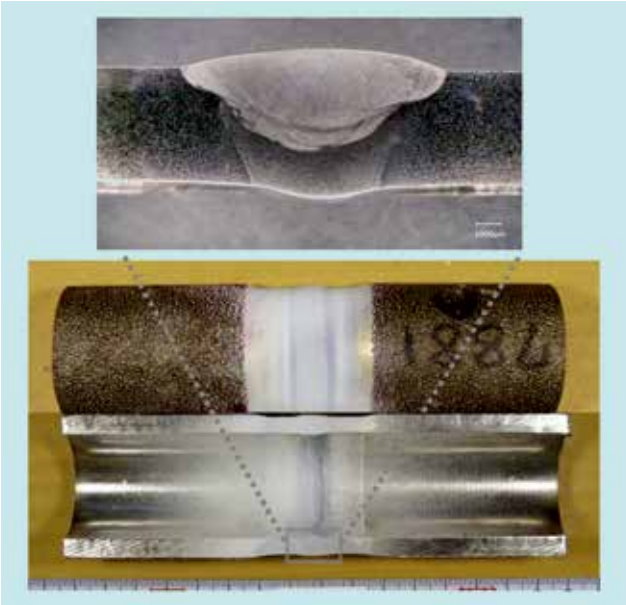


Fig. 8 Welding Test Results

4.2.4 Evaluation of creep rupture strength

Lastly, Table 2 shows the test results of creep rupture strength. Generally, because cracking tubes are used for approximately 3 to 5 years, data of 10,000 hrs or more are required, but the KHR45AH is currently under investigation. Therefore, the evaluation at the present moment is shown. As described above, the AFTALLOY is a material having an alumina layer with excellent creep rupture strength and is the most suitable material for customers whose product life is limited by creep deformation and rupture.

Conversely, the KHR45AH is a material that has a lower creep rupture strength than the AFTALLOY and considers the strengthening of creep rupture strength by optimizing the component composition. Furthermore, it is a material that has an alumina layer and maintains improved carburizing resistance and operation efficiency for a long period of time, which makes it to be the most suitable material for customers whose product life is limited by carburization.

Table 2 Creep Rupture Strength (Reference Example)

(MPa)

Material	Temperature	1,000℃		1,100℃	
	Time to rupture	100hrs	1,000hrs	100hrs	1,000hrs
KHR45AH		29.9	22.5	16.7	11.7
AFTALLOY		30.4	22.9	17.1	12.0

5. Conclusion

The KHR45AH is a product developed to meet the needs for improved carburizing resistance and to expand the product lineup of Al-containing materials. The developed product realized the extension of product life, which is limited by carburization as well as the improvement in the long-term operation efficiency, and further achieved better on-site weldability, manufacturing cost reduction, and shortening of the manufacturing period.

Currently, the adoption of Al-containing materials is accelerating especially in North America. By adding the KHR45AH to the lineup in addition to the current AFTALLOY, it will satisfy the diverse needs of customers, contributing to the improvement of energy efficiency as well as the sustainable management and efficient use of natural resources.

Contribution to SDG Targets

7.3 Improvement in energy efficiency
Improvement in long-term operation efficiency
12.2 Sustainable management and efficient use of natural resources
Reduction of replacement opportunities by improving product life

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Reference

1) Kubota: Cracking tube, https://www.kubota.co.jp/product/materiAls/products/cracking_coil/
2) Kubota: AFTALLOY, https://www.kubota.co.jp/product/materiAls/products/cracking_coil/AFTALLOY.html

Introduction of Water Infrastructure Development Projects in Asia

International Environmental Engineering Dept.

Related SDGs

1. Introduction

Since water infrastructure in society is indispensable for meeting basic human needs and also plays an important role in regional economic development, the SDGs have set it a targets in Goals 6 and 11.

Conversely, in Asia, water infrastructure development has progressed in some major cities, and the service water coverage rate is also rising in recent years, but there are still many emerging nations having a service water coverage rate of less than 50%. Therefore, securing of stable water supply and safe water quality 24 hours a day has been positioned as an important infrastructure development issue in each country. Kubota has been reinforcing its activities by holding a business policy to contribute to the future development of water infrastructure in Asia through the utilization of its experience in supplying water-related products and constructing plants in Japan and Asia. Because the operation for the "Greater Yangon Water Supply Improvement Project (Phase 1)" which was ordered in 2017 was launched, this report will describe the project outline and a case of tackling various issues unique to overseas that are different from those in Japan.

2. Project outline

2-1 Project background

Yangon is the largest city in Myanmar with a population of over 5 million, and its service water has a long history, with the commencement of its development in 1842. However, in recent years, the development has not kept pace with the population increase, and the population receiving water from the Yangon City Development Committee (hereinafter referred to as "YCDC"), which holds jurisdiction over the water supply business in the city, remained only at 35% of the total city population. Additionally, although approximately 90% of the water source depended on the reservoirs whose water quality is far from favorable, two-thirds of them were directly supplied without water purification treatment or chlorination[1]. Additionally, in areas without water supply, citizens' domestic water was obtained either by drawing water from small-scale rainwater reservoirs scattered throughout the city (Fig. 1) or purchasing from "water sellers" who collect and sell such water in carts with tanks (Fig. 2), so it was not always possible to secure safe water.

Under these circumstances, the YCDC has positioned countermeasures against the pressing water demand as an urgent issue and has been taking initiatives by placing a high priority on the improvement of service water system among urban development issues. Additionally, the Government of Japan and JICA also started to provide support for the service water supply in Yangon City based on the "support for the improvement of lives of citizens" and "support for the development of infrastructure and systems necessary for sustainable economic growth" that are the economic cooperation policy for Myanmar enacted in April 2012. Thereafter, upon various preliminary surveys, the Yen loan project "Greater Yangon Water Supply Improvement Project" described in this report was planned and has been implemented since 2017.

Fig. 1 Water Drawing

Fig. 2 Water Seller Cart

2-2 Project outline

In the Greater Yangon Water Supply Improvement Project, for the purpose of supplying safe and secure water, the following facilities were constructed: three water transmission and distribution pump stations for water supply from the Lagunbyin water purification plant constructed by the YCDC, as well as water pipelines; a city water distribution pipeline network to eliminate the communities in the eastern part of the city where water supply system is not developed; and four disinfection facilities using sodium hypochlorite to resolve the unsterilized water supply condition in the entire city. Additionally, one of the major purposes was to stably supply water to the Thilawa Special Economic Zone, which is located in the southern part of the project area and is jointly developed by Myanmar and Japan, as well as to lead it to economic revitalization.

This project is ordered in five packages from the ICB01 to ICB05. In the Kubota Group, Kubota received an order for the ICB01, which deals with the construction of pumping stations and chlorine disinfection facilities by a JV (joint venture) project, and Kubota Construction Co., Ltd. received an order for the ICB02, which deals with the construction of water pipes by a JV project.

The outline of each package is shown in Table 1, and the location map is shown in Fig. 3.

Table 1 Summary of the Project and Each Package

Country name		Republic of the Union of Myanmar	
Project name		Greater Yangon Water Supply Improvement Project (Phase 1)	
Project implementing agency		Yangon City Development Committee (YCDC)	
Donor		JICA	
Total project cost		31.2 billion yen (of which, 23.7 billion yen subject to ODA loan)	
Overview of each package	Package	Contents	Contractor
	ICB01	– Pumping station (3 locations: 17 pumps in total) – Service reservoir (2 locations: 21,000 m^3, 28,000 m^3) – Monitoring and control facility (pumping station) – Chlorine disinfection facility (4 locations) – Water purification plant administration building	JV of POSCO E&C/Kubota Corporation
	ICB02	– Water pipe laying (ductile iron pipes) – ϕ1,000: 14.8 km – ϕ700: 32.5 km	JV of Kubota Construction Co., Ltd./Marubeni Protechs Corporation
	ICB03	– Water pipe laying at the river crossing – Distance: Approx. 820 m – Main pipe bore diameter: 700 mm	Japanese company
	ICB04	– Water distribution pipe laying – ϕ300–ϕ700: 72 km – ϕ100–ϕ200: 224 km – Water meter installation in each house	JV of Chinese/ Myanmar Companies
	ICB05	– Procurement of water meters to be installed in the ICB04	Myanmarese company

Fig. 3 Project Map

3. Initiatives in the project

Between Kubota and its JV partner, POSCO E&C (hereinafter referred to as "P Company"), Kubota took charge of mechanical and electrical facilities while P Company took charge of civil engineering and building facilities. The order for the ICB01 package for this project was received on December 5, 2017, and the construction work started on January 29, 2018.

At Kubota, we successfully handed over the facilities to the YCDC safely without any accident after a construction period of over 3 years by coordinating the processes of a wide range of operations with the P Company, including engineering (detailed design) of each piece of equipment including our own products such as pumps and iron pipes, manufacturing/procurement, transportation (customs clearance)/acceptance inspections, on-site equipment installation, and trial operation, with those operations concurrently proceeded in a timely manner. However, we faced various challenges in engaging in such large-scale facility construction and various work all at local sites. Particularly, in the latter half of the project, it was unavoidable to take countermeasures against COVID-19 and the political change in Myanmar, but we have been steadily progressing the project while solving the issues each time. This chapter describes those initiatives.

3-1 Engineering (detailed design), procurement

The detailed design is created based on the facility specifications and drawings presented by the YCDC, but as the designing process actually proceeded, issues that require various design changes emerged on a daily basis. Many of them were inconsistencies and interferences due to large-scale projects, but to resolve them, approval from the YCDC was obtained one by one, including repeatedly having detailed on-site discussions with the YCDC and P Company on changes after Kubota created a plant construction drawing that includes the scope of civil engineering work, as well as making changes/adjustments to designs and processes with other facility and civil engineering work.

Additionally, for facilities whose required specifications were already outdated, negotiations were held such as by proposing the latest specifications in consideration of the usability by the YCDC, which operates and maintains the facilities.

We strived to procure better quality products at the lowest possible cost, and consequently, this project procured items from eight countries (see Table 2), and the number of items procured ended up with at least approximately 1,400 for major equipment alone. Fig. 4 shows the main equipment, a pump manufactured by Kubota.

Table 2 Procurement Items

Country of origin	Procured equipment
Japan	Water transmission and distribution pumps (made by Kubota), ductile iron pipes (made by Kubota), chlorine tanks, chemical injection pumps, submersible pumps, special valves, electric control panels, water quality analysis equipment
Thailand	Valves, gates, monitoring control devices (SCADA)
Vietnam	Steel pipes , air vessels
China	Pipeline component
Taiwan	Crane, hoist
Korea	Pump motors, pump control panels
England	Special valves (check valves)
Myanmar	Construction materials, etc.

Lagunbyin pumping station
55 m^3/min × 750 kW × 4 units
SR7 pumping station
50 m^3/min × 550 kW × 3 units
24 m^3/min × 270 kW × 2 units
SR8 pumping station
50 m^3/min × 550 kW × 3 units
24 m^3/min × 270 kW × 2 units
14.6 m^3/min × 250 kW × 3 units

Fig. 4 Kubota Pump Used in the Project

3-2 Production/transportation

The number of items manufactured and procured in this project was enormous, and transportation of main equipment alone required ship loading of 52 times and a total number of 152 containers.

We initially planned less frequent ship loading, but due to the limited storage space at the site and from the perspective of unfavorable long-term storage for security reasons, it was necessary to place an order little by little and transport them to the site each time by adjusting to the progress of engineering and the timing of construction.

Note that in addition to transportation restrictions (weight/passage time) and adverse transportation conditions due to obstacles such as rough roads and trees, there were repeated delays in civil engineering work during a half year of the rainy season, so smooth logistics could not be expected at all. However, it gradually became possible to predict transportation obstacles and the progress of construction work, and by carefully coordinating with the site, suppliers, and transportation companies and by adjusting the timing of transportation from each country, we successfully shortened the storage period of the equipment at the site to several weeks to 2 months.

Additionally, these activities not only achieved smooth construction progress and reduced storage warehouse costs but also contributed to the leveling of the manufacturing load of suppliers and zero predelivery failures of electrical and instrumentation devices that are vulnerable to humidity. Fig. 5 shows the acceptance inspection at the storage warehouse, and Fig. 6 shows unloading at the actual site.

Additionally, this project is the first Yen loan project for the YCDC, and the system for paying customs duties and import taxes in the contract with the YCDC was not yet established at the beginning of the project, which frequently led to delays in customs clearance along with delays in the procedures by the YCDC. However, we were able to resolve the delay in customs clearance by having persistent and repeated discussions with the YCDC, submitting a shipment list for the following year to the YCDC, and proposing a method to ask the YCDC to deposit customs duty payment costs based on that.

Fig. 5 Acceptance Inspection (Steel Pipe)

Fig. 6 Unloading at Site (Chemical Tank)

3-3 Installation work/trial operation

In this project, to start from the establishment of a system to proceed with the construction on-site and supervise the construction at 6 locations in Yangon City with two Japanese engineers, we hired eight Myanmarese staff dedicated to this project and then selected and adopted companies having experience in installing pumps and water-related equipment as local contractors.

However, their ability was not for immediate use from the beginning even though construction has been supervised to ensure a similar level of quality as that of Japan, so we tried to let them understand the differences in national character and then understand the concept of construction management of Kubota. For example, Myanmarese people are generally serious-minded and work loyally as instructed once they understand, but they sometimes did not understand the points of work accurately. Therefore, we patiently explained to them while repeatedly checking the work progress with the eyes of Kubota engineers themselves, and we were able to obtain their true understanding.

Additionally, as with all construction sites, safety education was thoroughly conducted in Myanmar as well, and in collaboration with local contractors, we performed the same level of safety control as in Japan, including preliminary risk extraction for each operation, daily morning meetings (Fig. 7), and periodical safety education sponsored by Kubota. Although the project did not proceed as planned because of repeated design changes, the influence of the rainy season, minor troubles, etc., the construction was completed without any accident from a total of more than 28,000 workers.

This was achieved by giving due consideration to measures against heat stroke and infectious diseases (such as chikungunya fever) in the intense heat peculiar to Southeast Asia. Particularly, working in the intense heat while wearing masks as a countermeasure against COVID-19 was harsh, and even under such circumstances, appropriate breaks and replenishment of water and salt were indispensable to proceed with the work.

Fig. 7 Safety Morning Tool Box Meeting

Note that at the final phase of the construction period of this project, we had no choice but to suspend the construction for a total of 108 days due to the influence of COVID-19 in 2020 and the political change in Myanmar in 2021. Furthermore, although Kubota's on-site supervisors and design staff could not visit the site, the instruction given until then was successful, and the Myanmarese staff members alone were able to complete the rest of the construction management.

Even in the trial operation and inspection, essential instructors from the manufacturers could not visit the site, but we were able to complete them safely with Myanmarese staff members alone by remotely providing trial operation instructions from each country after preparing the detailed and concrete written procedures in advance. Figs. 8 and 9 show the construction work in this project.

Fig. 8 Pump Installation

Fig. 9 Ductile Iron Pipe Installation (DN 1600 mm)

5. Conclusion

The project faced unexpected situations such as construction delays because of the rainy season, COVID-19, and the political change, which made us keenly aware of the difficulty in performing the same work as Japan in Asia, but we successfully delivered the Lagunbyin pumping station (Fig. 10) to the YCDC by March 2020 and the other two water transmission and distribution pumping stations by August 2021. Additionally, the chlorine disinfection facilities at four pumping stations in the city were also handed over by February 2020, and some of them have been put into service by the YCDC.

According to the estimation of the project effect by JICA, the water supply population in Yangon City will increase from 1.9 million to 3.3 million (water supply coverage rate: 54.4%) after the full-scale operation of each facility, and the continuous implementation rate of chlorine disinfection will be 100%[1]; therefore, we consider that the goal of contributing to the water infrastructure development in the city has been achieved.

The example of a project in Yangon City was described in this report, but many projects for future service water improvement are also planned in Southeast Asian cities. Furthermore, the sewage development and flood control measures are already being promoted as major issues in the development of water infrastructure. Kubota will contribute to the achievement of our goals for the SDGs by utilizing its experience in Asia, a wide range of water-related in-house products and engineering capabilities, and the construction capabilities to realize it on-site, and through the construction of water infrastructure facilities in close relation to the local situation.

Fig. 10 Lagunbyin Pumping Station

Contribution to SDG Targets

6.1 Strengthening access to safe and affordable drinking water
Contribution to improved service water coverage rate and implementation of chlorine disinfection in Yangon City (service water coverage rate: 35% → 54%, chlorine disinfection: 0% → 100%)

11.3 Strengthening of inclusive and sustainable housing planning and management capabilities
Contribution to the development of the water infrastructure in Yangon City

Reference

1) Project preliminary evaluation table (Greater Yangon Water Supply Improvement Project) (2014)
https://www2.jica.go.jp/ja/evaluation/pdf/2014_MY-P5_1_s.pdf

Introduction of Technique Effectively Using Byproduct Salt in a Landfill Disposal Site

KUBOTA Environmental Service Co., Ltd.

Related SDGs

1. Introduction

In recent years, the introduction of a nondischarge system has become popular in the construction of landfill disposal sites from the viewpoint of environmental conservation and regional harmony. In such a system, the landfill is covered with a roof, and the leachate is reused within the site without discharging. Since the leachate contains high-concentration chloride ions, desalination treatment is required to remove these chloride ions when a nondischarge system is adopted, and in doing so, a method for disposing of concentrated salt water generated as a byproduct will be an issue. Currently, large amounts of fossil fuels are often used to turn concentrated salt water into dry salt, which dry salt is treated as industrial waste. Approximately 100 L of heavy oil is required to turn 1 m^3 of concentrated salt water into dry salt. This time, we explain a technology to produce sodium hypochlorite (hereinafter referred to as "eco sodium hypochlorite") that can be effectively used as a disinfectant by electrolyzing concentrated salt water.

2. Overview

2-1 Technical overview

The principle of this technology is to electrolyze concentrated salt water to produce sodium hypochlorite. The method of electrolysis is the nondiaphragm method; concentrated salt water is electrolyzed, chlorine is mainly generated at the anode while sodium hydroxide is generated at the cathode, each of which is mixed in the electrolytic cell to form eco sodium hypochlorite (Fig. 1). The effective chlorine concentration of eco sodium hypochlorite produced is 1,000 to 4,000 mg/L. This recycling technology can utilize the entire amount of concentrated salt water as a disinfectant, contributing to the circulation of community resources.

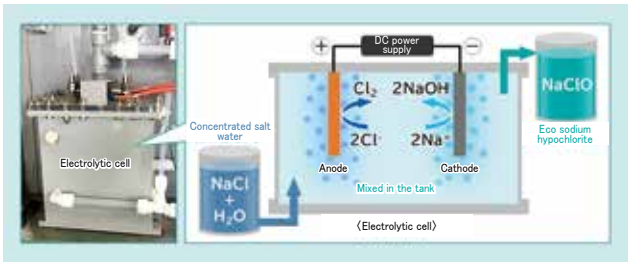


Fig. 1 Figure of Eco Sodium Hypochlorite Generator

2-2 Features of eco sodium hypochlorite technology

2.2.1 Construction of community resource circulation system

Wastewater treatment plants such as nearby sewage treatment facilities are expected as potential user for eco sodium hypochlorite. By constructing a recycling system as shown in Fig. 2 between a landfill disposal site and a wastewater treatment plant, concentrated salt water can be used as an effective resource.

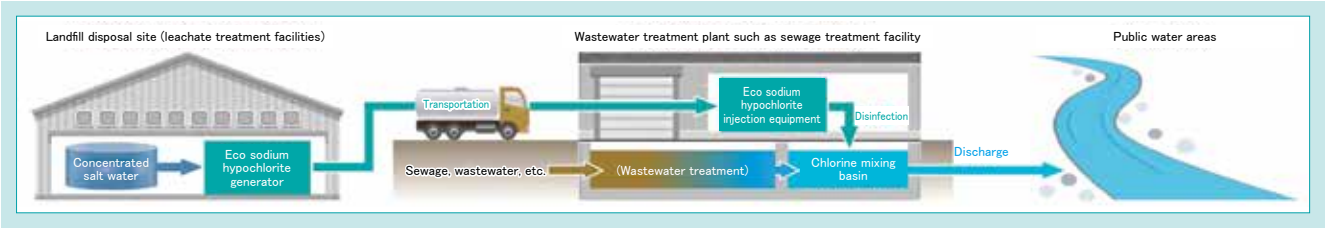


Fig. 2 Recycled Flow of Eco Sodium Hypochlorite

2.2.2 Reduction of CO_2 emissions

The greatest feature of eco sodium hypochlorite is that it eliminates the need for heavy oil.

It does not need to turn concentrated salt water into dry salt, and eco sodium hypochlorite is produced as a liquid form, which allows a significant reduction of CO_2 emissions.

3. Detailed explanation

3-1 Evaluation of eco sodium hypochlorite as a disinfectant

The quality of eco sodium hypochlorite is important to introduce eco sodium hypochlorite. For this reason, we conducted a demonstration test of eco sodium hypochlorite using concentrated salt water derived from general waste. The purpose of this test is to confirm the performance and safety of eco sodium hypochlorite. In the safety confirmation test, a bioassay test was conducted by using three species. As a result of the test, we have confirmed that the performance and safety of eco sodium hypochlorite are equivalent to those of commercially available sodium hypochlorite and that it can be used as a disinfectant. A list of test contents and results are shown in Table 1.

Table 1 Test Contents and Results

	Test name	Test content	Test results
Performance	Stability test	The effective chlorine concentration decreases over time. The generated eco sodium hypochlorite was let for 1 week to confirm the stability of the effective chlorine concentration during storage.	The rate of decrease in the effective chlorine concentration of the eco sodium hypochlorite after one week is about the same as that of the commercially available sodium hypochlorite, which has confirmed the sustainability of the effective chlorine concentration of the eco sodium hypochlorite.
	Disinfection effect confirmation test	Eco sodium hypochlorite was added to the sewage before disinfection to confirm the disinfecting effect against coliform bacteria*. *Drainage standard: 3,000 units/cm^3 or less	The number of coliform bacteria became zero at an addition rate of 1.0 mg/L or more for both eco sodium hypochlorite and commercially available sodium hypochlorite, which confirmed the equivalent disinfecting effect to commercially available sodium hypochlorite.
Safety	Safety confirmation test	We conducted a WET (wastewater management method using biological response) test to confirm the safety of eco sodium hypochlorite. Eco sodium hypochlorite with deactivated effective chlorine was used. – Short-term toxicity test using embryo and larval fish (zebrafish) – Water flea breeding test using Ceriodaphnia dubia – Growth inhibition test using freshwater algae (Pseudokirchneriella subcapitata)	At the addition rate of the sodium hypochlorite to disinfect, there was no effect on living organisms by both eco sodium hypochlorite and commercial sodium hypochlorite, which confirmed the safety of eco sodium hypochlorite.

3-2 CO_2 emissions reduction effect

CO_2 emissions by the eco sodium hypochlorite technology were calculated. The calculation conditions and CO_2 emissions are shown in Table 2. The calculation results showed that the eco sodium hypochlorite technology has a great effect on eliminating the need for heavy oil, and that CO_2 emissions can be reduced by about 95% compared to the conventional technology.

Table 2 Calculation Conditions and CO_2 Emissions

	Calculation conditions	CO_2 emissions
Conventional technology (evaporation treatment → disposal industrial site)	CO_2 emissions from heavy oil required for boiler operation and from industrial light oil for transporting dry salt to the disposal destination	2450 t-CO_2/year
Eco sodium hypochlorite technology (eco sodium hypochlorite → user)	Power consumption required for electrolysis, and CO_2 emissions from light oil for transporting eco sodium hypochlorite to the user	69 t-CO_2/year

*Both technologies do not include CO_2 emissions from maintenance and the like.

4. Introduction of actual achievement

The above test has been issued with the logo mark (Fig. 3) and verification number of an Environmental Technology Verification (ETV) Program conducted by the Ministry of the Environment. We would like to make effective use of them for the dissemination and expansion of the technology in the future. An ETV project supports the popularization of environmental technologies, in which a trusted third party (demonstration organization) demonstrates environmental technologies at actual sites and publicizes the results widely[1]. Currently, we are considering the introduction of eco sodium hypochlorite technology to the facilities under construction.

Fig. 3 ETV Logo

5. Conclusion

In this test, we successfully demonstrated the disinfecting effect and safety of eco sodium hypochlorite. It is expected that the construction of covered landfill disposal site will continue to increase in the future, and the eco sodium hypochlorite technology is considered to be an effective technology from the perspective of establishing a community resource circulation system and reducing the environmental load.

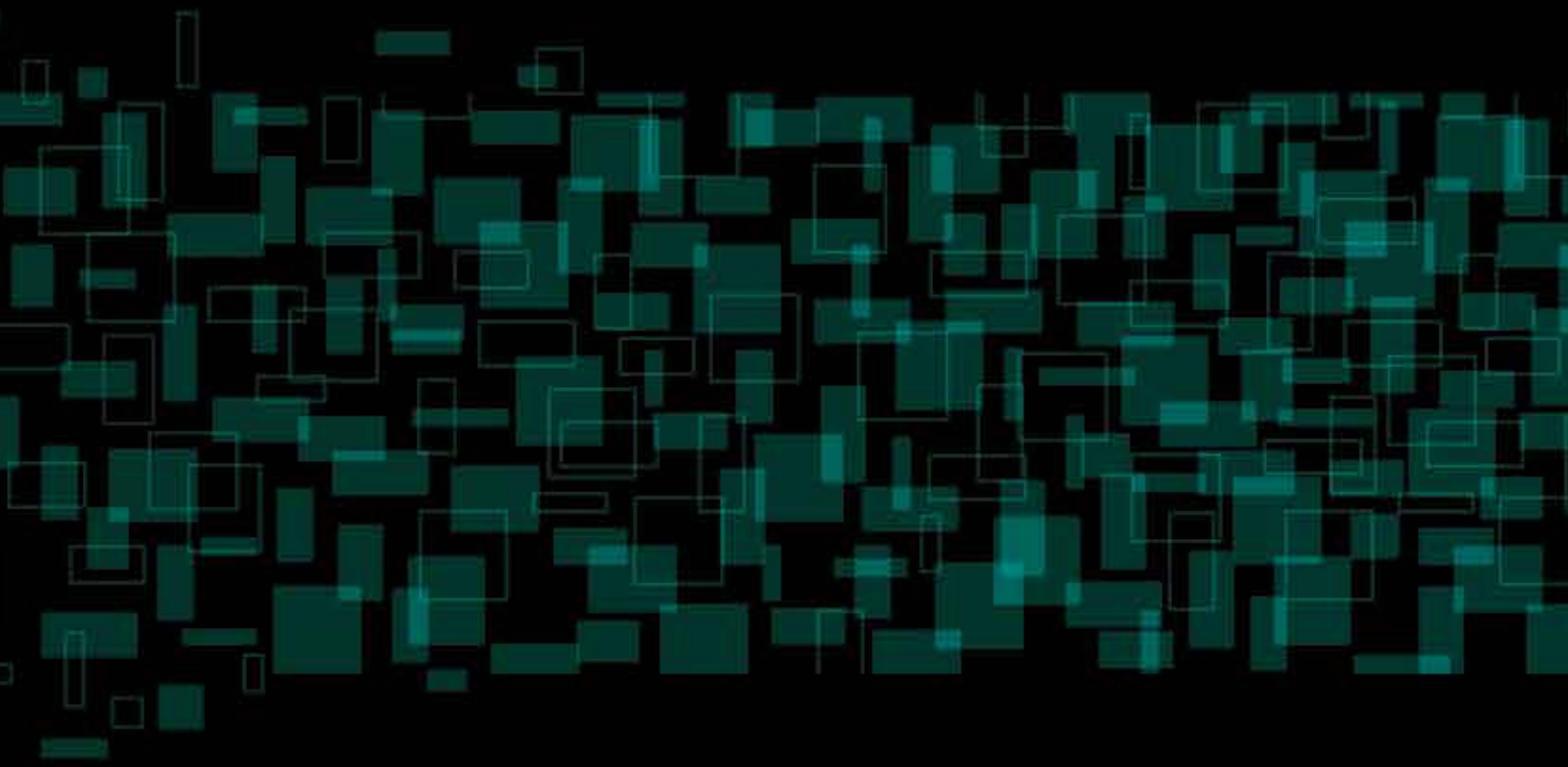
Contribution to SDG Targets

9.4 Infrastructure improvements and industry improvement through introduction of environment-friendly technologies and industrial processes
Reduction of CO_2 emissions by about 95% compared to conventional technologies, environment-friendly technology

12.5 Prevention and reuse of waste 100% reuse of concentrated salt water as a disinfectant, contribution to the prevention of waste generation

Reference

1) Ministry of the Environment:
Environmental Technology Verification Project https://www.env.go.jp/policy/etv/ (reference date: 08/31/2021)



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