Kawasaki
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KAWASAKI TECHNICAL REVIEW

Special Issue on Plant & Infrastructure





Kawasaki Heavy Industries, Ltd.

No.176
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For a comfortable, prosperous, and sustainable future

Plant & Infrastructure Company brings together advanced technologies in a wide range of fields.
As a member of the Kawasaki Group, we are working to create new value to help build a bright and prosperous future that is in harmony with the environment.

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Eiji Inoue
Senior Vice President
President, Plant & Infrastructure Company

Can you tell us about recent developments in the plant & infrastructure business?

Orders for new products were up in fiscal year 2014. That's including the U-KACC boiler, which generates electricity using difficult-to-burn petroleum coke and residues (for Fuji Oil Company, Ltd.), a gas-to-gasoline (GTG) plant (for State Concern Turkmengas, a state-owned company in Turkmenistan), and an ultra-large earth-pressure balanced shield machine (for Kajima Corporation), with a diameter of 16.1 m, which will be used to construct Tokyo Outer Ring Road.

The U-KACC boiler is equipped with a burner in the upper part of the combustion chamber. It's a unique design that makes it possible to efficiently burn solid residues (such as petroleum coke) left over from the oil refining process, which are more difficult to burn than other types of fuel. We worked with the Corporate Technology Division in conducting repeated combustion tests and simulation analyses. These joint R&D efforts really paid off with one of the results being this latest order.

In October 2014, Kawasaki became Japan's first private corporation to build a fertilizer plant in natural gas-rich Turkmenistan. The President of Turkmenistan himself attended the ribbon cutting ceremony that marked the opening of the plant. This major project should pave the way for other Japanese companies looking to make inroads into the country. Our success in Turkmenistan is owed in large measure to Kawasaki's excellent track record in fertilizer plant construction.

We are expecting to see a flood of orders for large shield machines in Japan up until 2020. The manufacturing technology we are working on for the Tokyo Outer Ring Road project will enable us to deliver high quality shield machines with a short lead time.

What is your outlook for the future?

We relocated our engineering department in Tokyo, consisting of about 210 employees, to Kobe in April 2015 and finished consolidating our engineering operations in Kobe. Since Kawasaki Plant Systems, Ltd. (K Plant) was launched in 2005, we have been working on ongoing reform initiatives with a focus on four areas (organization, awareness, operations, and technologies / products). We see the recent consolidation of engineering operations in Kobe as the culmination of our organizational reform efforts. Now that our engineering operations are all based in Kobe, we will combine and leverage our company-wide technological capabilities to spark synergy and realize the following objectives: 1. Enhance cooperation among the Energy plant BU, Environmental Plant BU, Industrial Plant BU, Chemical Plant & Cryogenic Storage System BU, and Production Center with an eye to making our products more competitive; 2. Sign more contracts with independent power producers (IPPs) for coal-fired power plant projects via collaboration between the Ash Handling BU and Materials Handling BU; and 3. Combine the technological capabilities of the Nuclear Plant BU and the R&D BU to expand the horizon of business opportunities.

Looking at current market conditions, we see the economy generally remaining on an upward trajectory despite some uncertainties. We anticipate that energy and environmental projects will continue to grow in resource-rich countries and emerging markets.

More than anything else we are seeing demand for natural gas, which makes a smaller carbon footprint than fossil fuels like coal and petroleum, grow by leaps and bounds. We have already delivered floating liquefied natural gas (FLNG) boilers to be installed on the Prelude, the world's first FLNG plant. Now we are looking to win a contract for the next FLNG project as well as orders for large LNG tanks overseas following on the heels of the order we received from Taiwan's CPC Corporation for the Ichthys LNG Project in Australia.

While the competition is heating up in China and Southeast Asia, we are likely to see orders for waste incinerators and other waste treatment facilities increase there. We are working with our joint venture partner in China to bring in more orders for our existing lines of stoker incinerators as well as the CONCH Kawasaki Kiln (CKK) System. That's our state-of-the-art waste treatment system, a cement manufacturing plant and incinerator in one that cuts energy consumption dramatically.

Is there anything else you would like to add?

In addition to creating synergy via the consolidation of engineering operations in Kobe, we are also actively working on enhancing project profitability while minimizing defects, maintaining and strengthening human resources, which are our core competence, and boosting non-price competitiveness.

Under the initiative to boost non-price competitiveness, we have developed and promoted new lines of high-value added products, such as the GTG plant, U-KACC boiler, FLNG boiler, and CKK System.

In addition to focusing on our existing lines of products, we are cooperating with Kawasaki's group-wide effort to realize the concept of a hydrogen energy supply chain with an eye to creating even more new products.

As always we are moving forward to maintain an optimal balance of established and new products that will continually enhance our corporate value.

Plant & Infrastructure Company products and technologies

Tatsuya Watanabe
Executive Officer and Vice President,
Plant & Infrastructure Company

Preface

In October 2014, Kawasaki announced its Group Management Model 2018 laying out its medium- and long-term goals. In it the Plant & Infrastructure Company has set out its goal of becoming a unique plant manufacturer that provides the energy and environment sector with products and services designed to contribute to environmental conservation while maximizing customer satisfaction. In this effort, the Company will build on a firm foundation of technologies that set it apart from the rest of the pack, a foundation held together by superior product development and engineering capabilities, as well as top-notch quality that customers can count on.

This article takes an up-close look at the outstanding features of the Company's unique product lines and the technologies at work behind them as well as the technological developments on the horizon.

1 About the Company

The Plant & Infrastructure Company has taken over and integrated various Kawasaki projects and technologies focusing on:

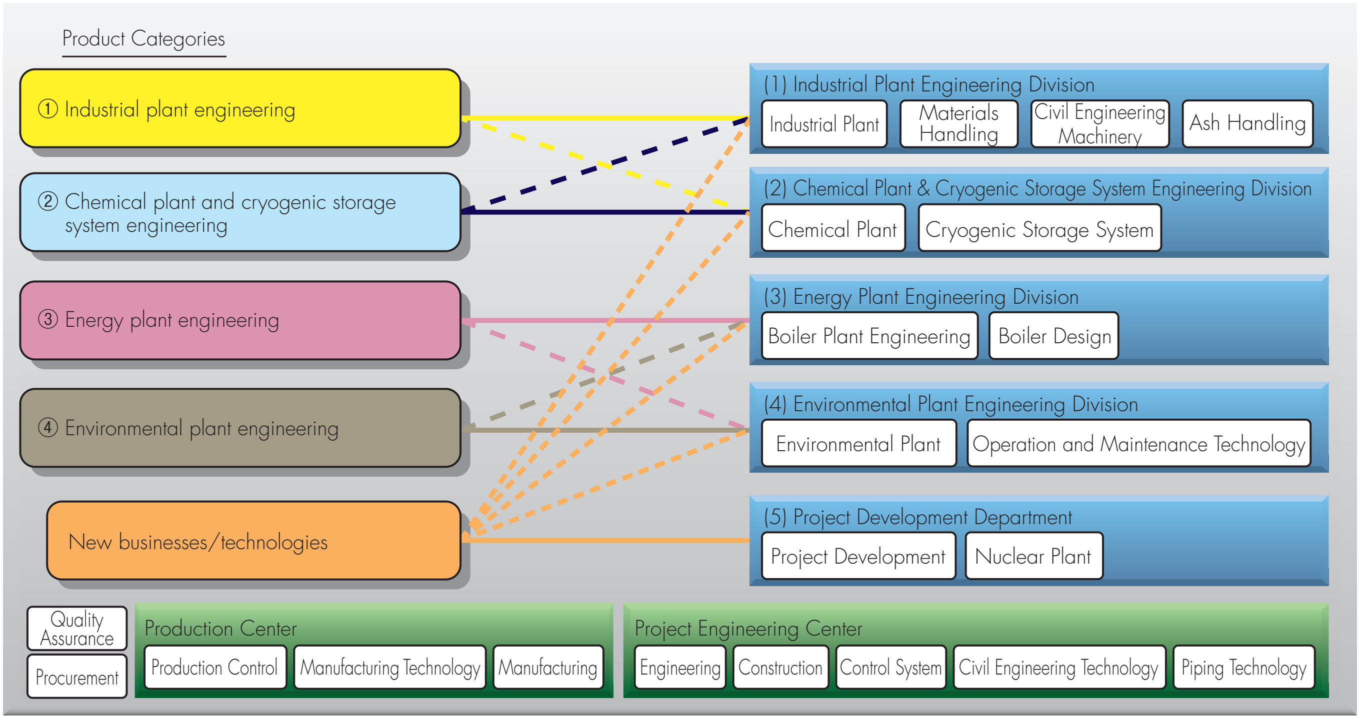


Fig. 1 Product categories and responsible departments

① industrial plant engineering, including cement plants, material handling plants, ash handling plants, and civil engineering machinery;
② chemical plant and cryogenic storage system engineering, including chemical plants and LNG tanks;
③ energy plant engineering, concentrating on boilers and power generation plants;
④ environmental plant engineering, concentrating on waste incinerators and sewage treatment facilities; and
⑤ the Production Center (Harima Works), serving as the Company's mother factory.

Boasting a world of product lines, the Company has had a hand in building industrial and social infrastructures around the globe.

Its extensive line of products spanning a wide range of fields adds a unique edge to its technological development. It can build on the basic technologies it uses in a specific field or integrate technologies employed in different areas to cultivate something new with even greater added value.

The CONCH Kawasaki Kiln (CKK) System that is featured in this issue turns waste into gas, which is then used to fuel a cement plant where the ash from the waste incineration process is used as the raw material to make the cement. The system is the brain child resulting from the marriage of Kawasaki's industrial plant and environmental plant engineering. This kind of dynamic is at work throughout the Company. It not only drives research and development forward but it also enables the Company to incorporate the best qualities of different departments as it creates new value through the overhaul of its business and organizational framework.

Figure 1 provides an overview of the Company's current product categories and the departments handling them.

2 Major products and technologies of each department

(1) Industrial plant engineering

(i) Industrial plants (cement plants)

Kawasaki got its start in the cement machinery manufacturing business back in the 1930s. As Japan's rapid economic growth in the mid 1950s through the early 1970s fueled demand, Kawasaki established itself as an industry leader that could deliver quality on top of quantity. Leveraging the technological expertise in cement plant manufacturing that it gained over the years has enabled Kawasaki to become one of the world's top cement plant manufacturers. Today it provides 360 degree plant engineering services along with a full line of state-of-the-art cement processing equipment built to do everything from mining limestone (a raw material for cement) to shipping finished products.

The Japanese cement industry is working hard to come up with some of the most advanced energy-saving solutions the world has ever seen. Keeping pace with these developments, Kawasaki has engineered a precalciner fitted with a suspension preheater designed to cut fuel consumption. It has also developed the CK Mill, a power-saving vertical roller mill, as well as the CKP Mill, a vertical roller mill designed for use with a pre-grinding system. A number of these products are currently up and running at facilities across the globe. Given a head start on plant exports, Kawasaki's cement plant business has delivered about 90 plants worldwide since 1961.

Harnessing the strength of its cement plant technologies, Kawasaki also supplied a ferronickel smelting plant to Indonesia's PT Antam Tbk in 2007. It then delivered one of the world's largest nickel plants (with a production capacity of 30,000 tons/year) to Korea's SNNC Co., Ltd. in 2009, whose production capacity was upped to 54,000 tons in 2015.

(ii) Material handling systems

Kawasaki's material handling business supplies equipment designed for excavating, stacking and reclaiming, and transporting coal, iron ore, soil, etc. In addition to that it delivers a cohesive running system for unloading, conveyance, storage, and loading anywhere the steel, power, mining, cement, and chemical industries operate. Not only does Kawasaki design and manufacture the main components of these systems, it provides comprehensive material handling engineering services that are all backed up by a solid performance track record and outstanding technical capabilities.

Kawasaki also developed the Flow Dynamics Conveyor (FDC), an idlerless conveyor featuring an air floating belt that cuts the noise and vibration of conventional conveyors while completely eliminating dust emissions for environmentally-friendly and energy-saving operations. A number of FDCs are currently at work across the globe. In 2015, Kawasaki delivered six FDCs to be used for transporting coal at Taiwan's Linkou Thermal Power Plant. Two of these FDCs have a conveyor capacity of 2,000 tons per hour while the remaining four have a capacity of 4,400 tons per hour. Altogether they stretch a total length of four kilometers.

(iii) Ash handling plants

In 1963 Kawasaki formed a technical alliance with United Conveyor Corporation (UCC), a leading manufacturer of ash handling equipment for coal-fired power plants that enjoys a lion's share of the U.S. market. Since then Kawasaki has supplied ash handling plants to the majority of utilities and independent coal-fired power plants in Japan. After a technical alliance with Italy's Magaldi in 1994 to introduce the dry bottom ash handling technology, Kawasaki made improvements to its ash handling equipment and developed peripheral systems based on the newly acquired technology. After building up an excellent track record of delivering state-of-the-art ash handling systems designed to meet customers' exact needs, Kawasaki now enjoys a glowing reputation in the industry plus a huge market share. A flood of orders for ash handling systems are now flowing in as the number of coal-fired power plant projects for independent power producers (IPPs) is growing ahead of the scheduled 2016 liberalization of the electricity market.

(iv) Civil engineering machinery (tunneling machines)
Kawasaki's tunneling machines include shield machines used for underground construction work, tunnel boring machines (TBMs) designed for excavating hard rock, as well as vertical boring machines.

Built for shield tunneling, the shield machine moves forward to excavate the earth, leaving a cylindrical shield (segmented ring) in its path that prevents the newly formed tunnel from collapsing. Kawasaki manufactures all types of shield machines, including slurry, earth-pressure balanced, mechanical, semi-mechanical, and hand-mining shield machines, and leads the industry in the large-diameter category. In 2012, its earth-pressure balanced shield machine with a diameter of 12.55 meters completed excavation for the construction of Tokyo's Central Circular Route Shinagawa North Line (which went into service in March 2015). By the end of fiscal 2014, Kawasaki delivered a total of 35 slurry shield machines to Singapore to be used by Singapore Power as well as to build a subway.

A TBM is a machine designed to bore through hard rock in order to dig tunnels for motorways, railways, headrace channels, as well as water and sewer systems. A pioneer in Japanese TBM technology, Kawasaki boasts an excellent track record when it comes to supplying TBMs for small and medium-scale hydropower development and sewer work, as well as road and rail tunneling such as the Channel Tunnel running beneath the Dover Channel that links France with England. In total Kawasaki has delivered about 1,400 shield machines and TBMs across the globe.

(2) Chemical plant and cryogenic storage system engineering

(i) Chemical plants
The Plant & Infrastructure Company's chemical plant business boasts a wealth of experience and technological capabilities. When it comes to engineering coal-chemical, fertilizer, ethylene, methanol, flue gas desulfurization, petrochemical, and chemical synthetic fiber plants, the Plant & Infrastructure Company has it all covered. On top of that it manufactures all the core components of these plants like reactors, towers, vessels, heat exchangers, furnaces, and more.

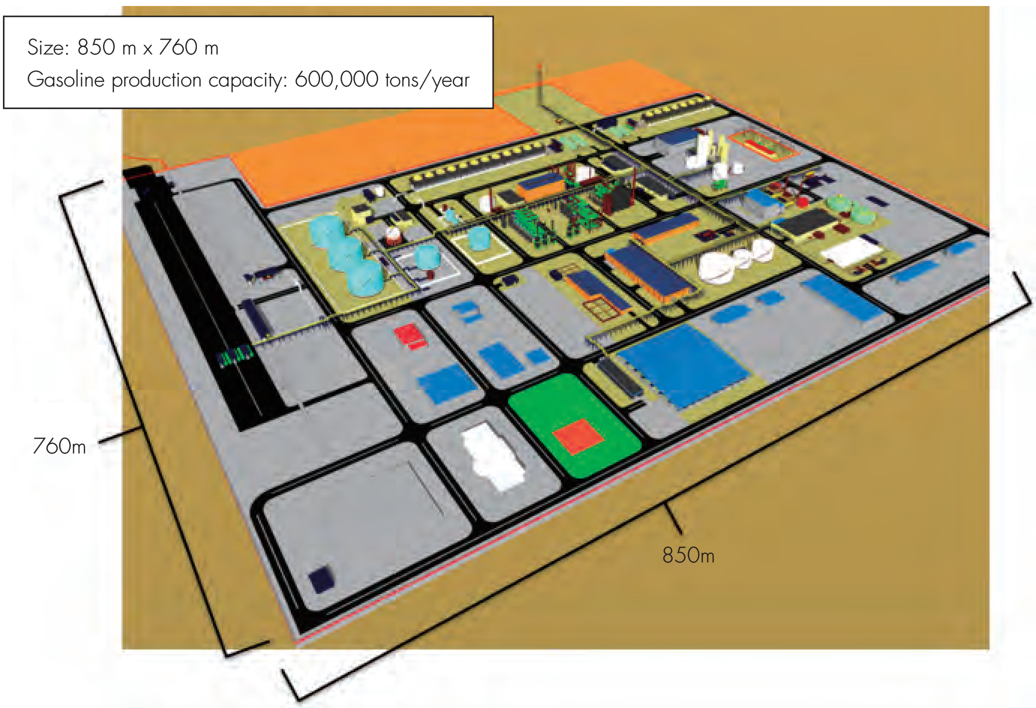


Fig. 2 GTG plant for Turkmenistan

The Company has built up a solid reputation for its fertilizer, ethylene, and methanol related plants. It has delivered seven fertilizer plants, including an ammonia plant to Nigeria's Federal Ministry of Industries in 1981 via a consortium with M. W. Kellogg Limited (now KBR, Inc.). More recently in 2009 it delivered a fertilizer complex to the State Concern Turkmenhimiya, Turkmenistan's state-owned petrochemical company. The fertilizer complex is the largest in the country. In 2014, Kawasaki received an order for a gas-to-gasoline (GTG) plant from Turkmenistan. When completed, it will be the world's largest GTG plant (with an annual production capacity of 600,000 tons), producing high quality gasoline from natural gas (Fig. 2).

The Company's flue gas desulfurization systems employ Kawasaki's proprietary limestone-gypsum process designed for large-scale thermal power plants. It also developed a comprehensive flue gas treatment system for coal-fired power plants as well as its own integrated computer control system, non-leakage gas heater, and new reversal-flow absorber. So far 97 orders have come in from across the globe for Kawasaki flue gas desulfurization systems, including orders from China, Vietnam, and Saudi Arabia.

Kawasaki is currently working on developing a technology to produce bioethanol from non-food soft cellulose. Unlike existing methods, this technology uses hot water in the saccharification process not using sulfuric acid or enzymes. Working jointly with the Akita Agriculture Public Corporation, Kawasaki conducted a demonstration to produce the bioethanol more economically using rice straw and other raw materials under a subsidized Akita soft cellulose utilization project. In the demonstration operation conducted through March 2013, Kawasaki achieved an ethanol production efficiency of 153.5 liters per ton of raw material (dry). Kawasaki is currently working on cutting costs further with a view to commercialization while applying the technology to commercial biochemical plants and more.

(ii) Cryogenic storage systems

Kawasaki has earned high marks for supplying various types of aboveground flat bottom cylindrical tanks with a conical, dome, or floating roof, as well as spherical tanks for storing high-pressure gas such as liquefied or compressed gas. It was one of the first in the industry to explore low temperature and ultra-low temperature engineering and worked on research and development of flat bottom cylindrical low-temperature tanks for LPG and liquefied ammonia as well as land-based LNG storage tanks. Kawasaki has pioneered unique design and construction techniques, including the welding of materials with superior cryogenic toughness.

Most notably it boasts enormous experience in supplying all types of large-scale LNG storage tanks. These include double-containment in-pit tanks whose inner tank is made of 9% nickel steel and aluminum alloy, full containment LNG storage tanks outfitted with a prestressed concrete (PC) dike, in-ground membrane tanks made of thin stainless steel, and more. Kawasaki now claims more than 50% of the Japanese market for large-scale LNG storage tanks. Overseas, it recently brought in an order for four full containment cryogenic tanks to be employed in Australia's Ichthys project, which is being headed up by INPEX Corporation, along with an order for three LNG storage tanks to be constructed at the Taichung LNG plant of CPC Corporation, a state-owned oil and gas company of Taiwan.

Demand for LNG is soaring across the globe as an alternative to petroleum, and Kawasaki is keeping pace as it works hard to expand the scope of its operations to include not only storage tanks but also the construction of LNG terminals.

Kawasaki developed the containers used to transport liquefied hydrogen and the compressed hydrogen trailers, by applying its advanced insulation technology accumulated over the years. It is an investment that has made the dream of transporting large quantities of hydrogen a reality and laid the foundation for a hydrogen energy supply chain. The widespread use of fuel cell vehicles and hydrogen power plants is expected to usher in the era of hydrogen energy, and Kawasaki is poised to leverage its technological expertise in producing, transporting, storing, and using hydrogen as it zeroes in on realizing its concept of a hydrogen energy supply chain.

(3) Energy plant engineering

Since its beginning Kawasaki has manufactured extensive lines of unique thermal power plant products for both land and marine applications. Designed to meet a world of customer needs, these products have been delivered to markets across the globe. These power plants can be applied to various types of fuels, including heavy oil, coal, LNG, biomass (like wood chips and "black liquor" discharged from pulp plants), petroleum residue, waste fuel, as well as other types of special fuels. Kawasaki offers a wide range of combustion boilers designed to make optimal use of each fuel type and best meet each customer's individual needs.

(i) General fuel-fired boilers

Across the industrial spectrum there is strong demand for coal and petroleum residue fired boilers to use in-house as cogeneration systems that can supply businesses with the large amount of electricity and steam they need. Kawasaki has provided these boilers to businesses that produce everything from chemicals to paper and more. In recent years the Company has been working with a keen focus on marketing the U-KACC, an ultra-low NOx, low dust emission boiler that uses solid asphalt pitch produced in the oil refinery process. More information about the U-KACC boiler can be found elsewhere in this issue.

(ii) Fluidized-bed boilers
Kawasaki has developed proprietary fluidized-bed boilers designed to efficiently recover heat from the process of burning woody biomass and waste fuel. Kawasaki's internal circulating fluidized-bed boiler (ICFB) employs a superior combustion technology that enables it to burn multiple types of fuels with varying calorific values along with corrosive fuels altogether. Today there are three Kawasaki ICFBs currently in use, including one at Tokushu Tokai Paper Co., Ltd.'s Shimada Mill, with orders from South Korea for two more refuse paper and plastic fuel (RPF) fired ICFBs in the works. Since the ICFB cuts down on greenhouse gas emissions, demand for this viable green energy solution is expected to increase.

(iii) Marine boilers
Kawasaki has over a century of experience in supplying marine boilers used on power-driven vessels. Drawing on this depth of knowledge, Kawasaki developed a new boiler in 2013 for the Prelude, the world's first floating liquefied natural gas (FLNG) facility. Seven marine boilers (Fig. 3), each with a steam generating rate of 220 tons/hour, have been delivered to the new FLNG that is being built off the coast of Australia by the Dutch petroleum giant, Shell. As plans to develop new gas fields off the coast of Australia take shape and the appetite for LNG continues to grow, Kawasaki expects to see more orders begin flowing in.

(iv) Waste heat recovery boilers
A waste heat recovery boiler recovers waste heat from steel, nonferrous metal, chemical, and cement manufacturing facilities as well as waste incinerators and converts it into usable thermal energy. It helps boost thermal efficiency, saves energy, and prevents pollution all at the same time.

Over the years Kawasaki has supplied numerous waste heat recovery power generation systems that apply waste heat boilers to recover waste heat from cement production process and generate electricity. Working with our joint venture partner in China, we have delivered a total of 1,041 units to China, Europe, and Turkey.

(4) Environmental plant engineering
Working in light of mounting concerns over global warming and with an eye to the 3R (reduce, reuse, and recycle), Kawasaki is moving forward to meet the public's growing demand for more efficient waste-to-energy solutions. At the same time Kawasaki is zeroing in on ways to minimize and eliminate harmful substances like dioxins that may be released into the atmosphere during the waste treatment (incineration) process.

Japan's leading waste treatment facility manufacturer,

Fig. 3 Shell's Prelude FLNG fitted with seven 220 t/h boilers

Kawasaki supplies waste treatment plant solutions that combine incinerator, exhaust gas and waste water treatment, power generation, and other related technologies all in one. As of the end of fiscal 2014, Kawasaki received a total of 175 orders for its plant solutions (some of which are under construction) from around the world.

(i) High efficiency power generation plants

As of the end of fiscal 2014 Kawasaki delivered 43 waste incinerators equipped with waste heat power generation systems and received orders for 12 of its high efficiency power generation plants. These power plants employ the same technology that is behind the Kawasaki Advanced Stoker System to raise the steam pressure to 4 MPa and the steam temperature to 400°C.

(ii) Waste treatment and biogas generation complex

Kawasaki has developed a waste treatment complex that is providing a renewable solution to the world's growing energy problems. The complex combines biogasification and waste incineration facilities for high efficiency power generation while reducing greenhouse gas emissions. It mechanically separates out combustible waste suitable for biogas generation, which is then converted into biogas via a dry thermophilic methane fermentation process in the biogas generation facility. The generated biogas is used as a heat source for superheating the steam generated by the waste heat boiler. Unused waste and methane fermentation residue are incinerated at a high temperature and low air ratio in a parallel flow type incinerator with a mechanical stoker for efficient energy recovery. The construction of the first waste treatment complex was completed in the city of Hofu, Yamaguchi Prefecture, in 2014. It earned the distinction of being named one of the year's ten best new products by the Nikkan Kogyo Shimbun Ltd.

(iii) Waste treatment system using a cement kiln

Kawasaki recently developed the CKK System, a new type of waste incineration system that combines a cement manufacturing facility and waste incineration, and started selling it in China and other emerging markets. This revolutionary system features a fluidized-bed type gasification furnace where waste is gasified. The resulting pyrolysis gas and unburnt char are fed into the cement production facility along with ash to be used as fuel and raw material for cement manufacturing. So far Kawasaki has received orders for 19 of its CKK Systems, including one with a waste treatment capacity of 300 t/d that was delivered to Tongling City in China's Anhui Province in 2010. This and four more CKK Systems are currently in operation there, processing 200 to 400 t/d. We are also working on commercializing the Zero Emission Eco Town (ZEET) System, which integrates sewage sludge and sewage treatment functions into the CKK System.

(5) Production Center (Harima Works)

The Harima Works is the Company's mother factory. Everyone working there is committed to steadily manufacturing its products, such as large-scale boilers, aboveground/in-ground LNG storage tanks, and large diameter shield machines, maintaining short lead time and high quality. Furthermore, the Harima Works is making the most of its toolbox full of advanced manufacturing technologies to set Kawasaki far apart from everyone else. Currently, it is shaping up its comprehensive manufacturing capabilities with a focus on production technology and control, response capability to the challenges of globalization, and the power of worksites in manufacturing operations. For example, it is focusing on making its laser cutting technology more sophisticated than ever, enhancing bending technique for large tank heads, expanding the scope of applications for its high-efficiency welding technique, honing the vacuum technology used in the production of large capacity liquefied hydrogen storage tanks, and putting 3D inspection and measurement technologies to practical use.

Closing

The Plant & Infrastructure Company offers extensive lines of products designed to meet the needs of a diverse spectrum of business categories and is continually working to find innovative solutions to the challenges that lie ahead. Offering products that meet the needs of a number of different industries gives the Company a big leg up. The ability to harness different technologies to create new ones while incorporating the best qualities of different departments has been a source of new growth.

Demand for electricity and energy is expected to be fueled by emerging markets around the globe, and Japan is moving forward on the deregulation of electricity market. Working against this backdrop, the Company will continue to leverage its diverse product lines and technologies as well as its plant engineering capabilities to bring products to the world as it helps fulfill Kawasaki's commitment to working as one for the good of the planet.

Liquefied natural gas (LNG) tank – Optimizing quality and cost with automation technology for the world's largest class LNG tank

Kawagoe Thermal Power Station LNG tank Nos. 5 & 6 for Chubu Electric Power

LNG tanks require high standards of safety and quality as they store natural gas liquefied at a cryogenic temperature of –164 °C.

Kawasaki has been developing automated welding technology as part of an effort to ensure consistent quality. For aboveground LNG tanks, an automated welding robot was developed for the processing of knuckle plates to ensure consistent quality and high efficiency. For in-ground LNG tanks, a new automated welding technology was developed for membrane panels. By applying this technology to block welding in shop fabrication, Kawasaki has achieved both excellent quality and an automation rate of 95%.

Preface

Liquefied natural gas (LNG) emits less carbon dioxide than any other fossil fuels when burned, and as such, it has been attracting considerable attention as a clean energy source. Particularly in Japan, the 2011 Great East Japan Earthquake triggered a surge in demand for LNG as fuel for thermal power generation, and usage has been increasing steadily since.

Against this background, LNG storage tanks are being constructed around the country to ensure a steady supply of LNG, and Kawasaki is keeping pace by offering various types of storage tanks that incorporate the latest technology.

1 Overview of aboveground and in-ground LNG storage tanks and Kawasaki's development efforts

(1) Overview of aboveground LNG storage tank

Figure 1 gives an overview of our aboveground LNG storage tank. This storage tank consists of an inner tank that ensures liquid- and gas-tightness and earthquake resistance, an insulation layer that provides thermal insulation, an outer tank that prevents leakage of the nitrogen gas filling the insulation layer, and a protective dike that ensures liquid-tightness in the event of LNG leakage from the inner tank.

The inner tank is made of 9% Ni steel for cryogenic strength and toughness as well as weldability.

(2) Overview of in-ground LNG storage tank

Figure 2 gives an overview of our in-ground LNG storage tank. This storage tank consists of a membrane that ensures liquid- and gas-tightness, an insulation layer that provides thermal insulation and transfers the pressure from the membrane, a tank body that provides resistance to liquid and earth pressure and protection against the ingress of groundwater, and a steel roof that ensures gas-tightness and load resistance. The membrane is made of corrugated stainless steel sheets that absorb thermal shrinkage.

(3) Kawasaki's development efforts

To date, Kawasaki has received an order for a total of 32 aboveground LNG storage tanks (of which 7 are under construction) and 12 in-ground LNG storage tanks (of which 1 is under construction) around the world. We are currently developing automated welding technology to respond to increased demand for larger LNG storage tanks, shorter construction periods, and reduction of construction costs seen in recent years.

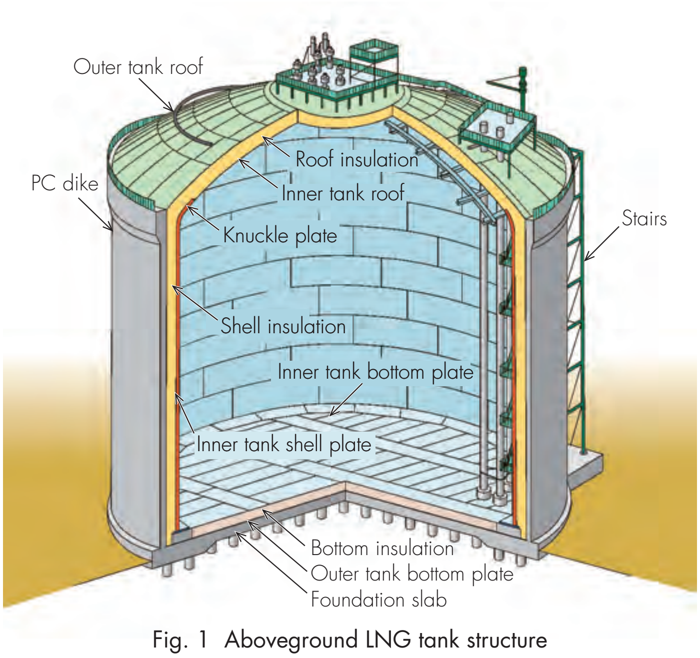


Fig. 1 Aboveground LNG tank structure

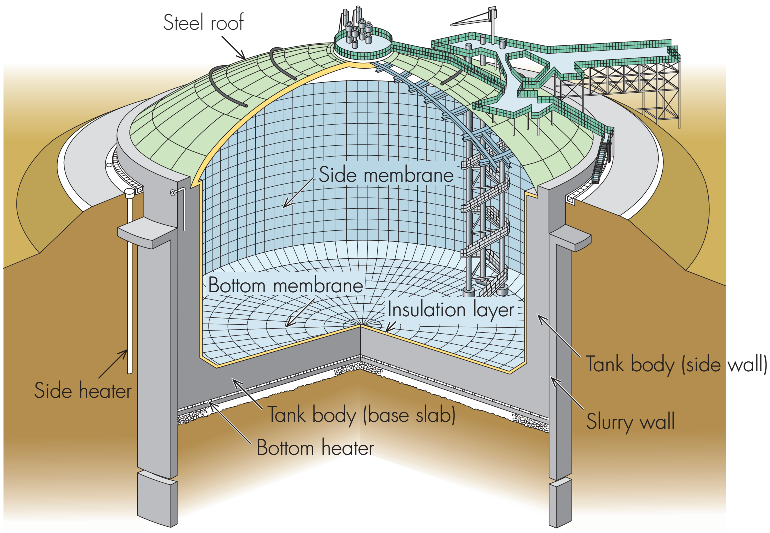


Fig. 2 In-ground LNG tank structure

2 Automated welding in shop fabrication

Kawasaki's LNG storage tanks feature a modular design in which critical structures such as the roof, side walls, and bottom slabs are shop-fabricated in large blocks (modules) by assembling and welding a number of components. In the modular construction method, further automation can be introduced to improve quality, thereby minimizing factors that contribute to variations in quality and processes compared to the on-site construction method, which relies more heavily on the skill level of the operator and is therefore more easily influenced by the work environment. In addition, by moving work off site, construction can be carried out more safely and in a shorter period of time, achieving greater stability in quality as a result. We will now take a look at our automated welding technology in shop fabrication.

(1) Automated welding of aboveground LNG tank knuckle plates

As shown in Fig. 3, knuckle plates (thickness: max. 50 mm) are critical parts that join the roof and side wall of the inner tank of an aboveground LNG storage tank. To shorten the construction period and achieve stable quality, we adopted a modular design in which two to three knuckle plates are welded together in shop using automated welding robots.

The joint welding of knuckle plates is a highly demanding task requiring continuous welding of three-dimensional curved surfaces of 9% Ni steel plates in a vertical or upward-facing position for an extended length of time.

To overcome these challenges, we developed an automated knuckle welding robot described below.

(i) High-functional remote monitoring system

Figure 4 gives an overview of the high-functional remote monitoring system developed to ensure stable quality in continuous knuckle plate joint welding. This system features a laser sensor for the automatic recognition of groove shapes and an arc monitor camera for the remote monitoring of arc conditions, enabling simultaneous operation of multiple welding robots by a single welder.

(ii) Application

Multiple automated knuckle welding robots have been employed to streamline the welding process, shorten the overall construction period, and achieve stable quality. Figure 5 shows an automated knuckle welding robot equipped with this system at work.

(2) Automated welding of in-ground LNG tank membrane panels

Kawasaki is currently constructing a 220,000-kl in-ground LNG storage tank in Japan scheduled for completion in 2016. The in-ground storage tank also uses the modular construction method to optimize quality and the construction process. At our dedicated plant, we construct prefabricated modules combining a number of membrane

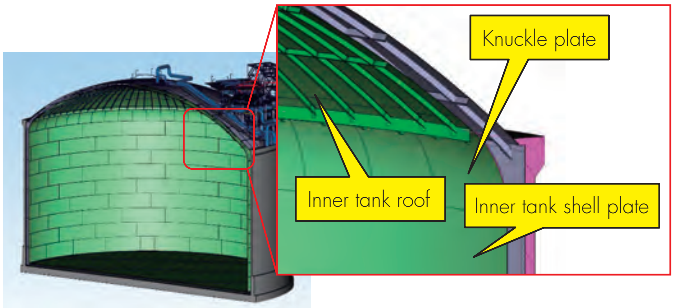


Fig. 3 Knuckle plate

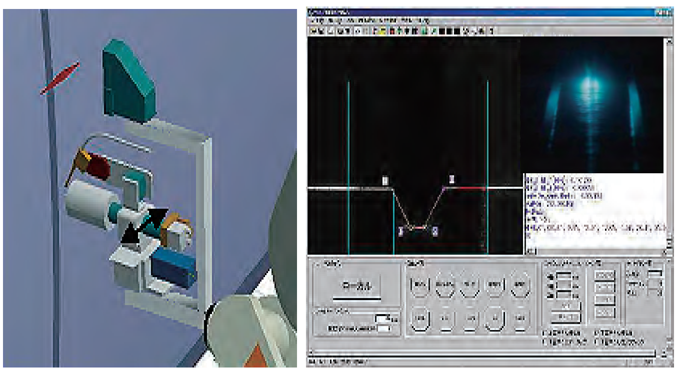


Fig. 4 High-functional remote monitoring system

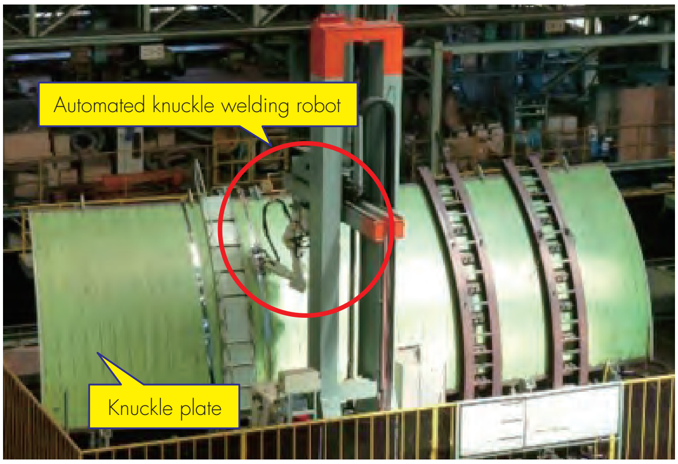


Fig. 5 Automated knuckle welding robot

panels made of stainless steel sheets (SUS304; thickness: 2 mm) machined with a corrugator (Fig. 6).

In the past, the membrane panels of in-ground LNG storage tanks were welded by skilled welders using automated TIG welding equipment. They corrected the position of the welding torch and made fine adjustments to welding conditions in response to the distortion of components due to welding.

To increase the reliability of welding operations, we developed a new automated membrane panel welding system that can perform welding operations without human supervision and does not rely on the skill level of the operator.

(i) Automated welding technology

Mainly the following issues were faced when welding membrane panels with the previous equipment.

① The target position of the welding torch (electrode) would change due to weld distortion. For this reason, the operator had to constantly monitor the condition of the arc and adjust the position of the welding torch.

② Occasionally, the stainless steel sheets warped significantly during welding, bringing the welding equipment to a halt. This would result in welding defects, making repair welding necessary.

To address the above issues, we applied Kawasaki's automation and robot technologies and developed an automated membrane panel welding system that can operate without the supervision of an operator, and also ensures stable quality. Main features of the newly developed system are outlined below.

(ii) Automated weld seam tracking system

To achieve high quality welding of membrane panels, the target position of the welding torch had to be corrected as necessary relative to the weld distortion. Therefore, we developed a sensing system that can measure the position of the weld seam and gap between welded components with a laser sensor in real time, and automatically correct the target position of the weld torch. Figure 7 gives an

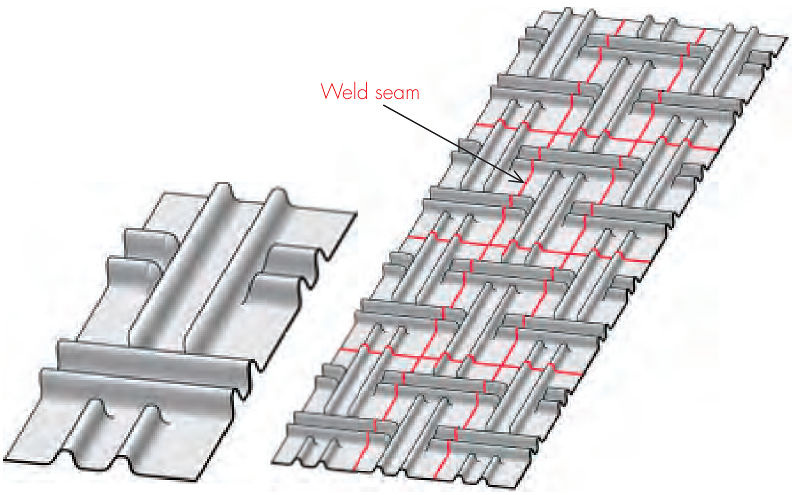


Fig. 6 Membrane panel of in-ground LNG tank

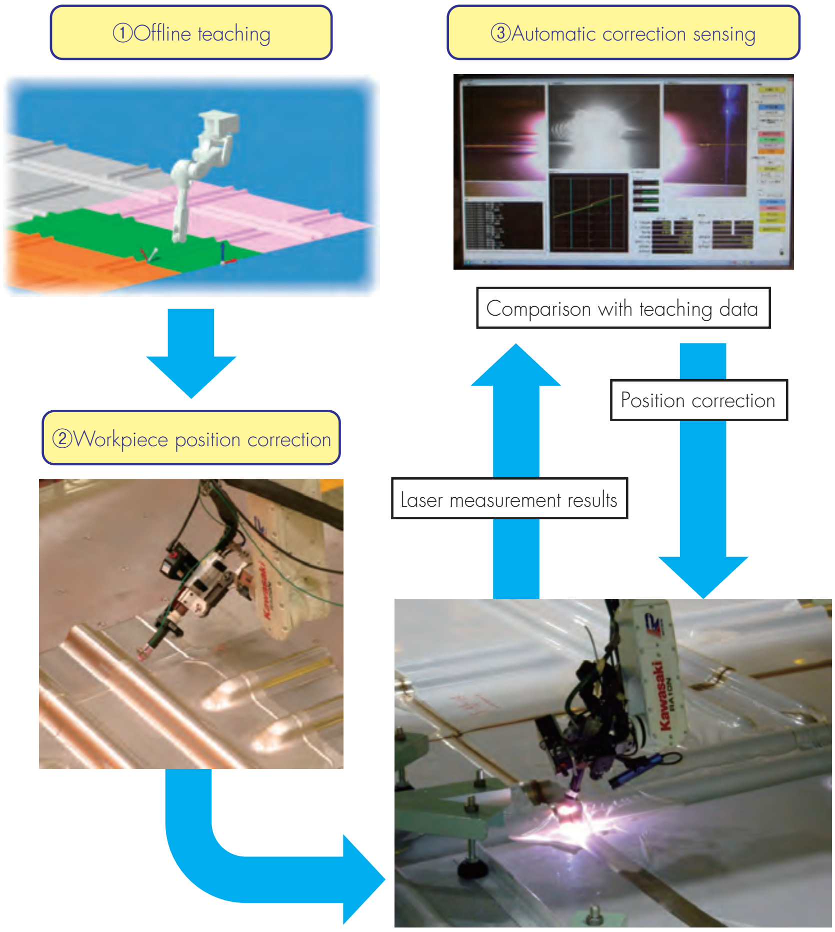


Fig. 7 Automated weld seam tracking system

overview of the automated weld seam tracking system.

① Offline teaching

Teaches welding robots offline (feeds CAD-based weld seam data on a computer, without using the actual robot).

② Workpiece position correction

Corrects the welding position of membrane panels using the touch sensing function of the welding robot.

③ Automatic correction sensing

Measures the position and height of lap joints as well as gaps in real time during welding operations using a laser sensor. Calculates the amount of correction based on the difference with teaching data, and automatically corrects the welding target position to an accuracy of 0.1 mm.

(iii) Weld distortion prediction technology

Membrane panel modules are fabricated in shop by combining 18 panels into a block of approximately 5 x 11 m. To maintain the quality of the modules and shorten the time required for installation on site, it is important to minimize the weld distortion of the overall modules. However, when seam welding multiple joints, it used to be difficult for the operator to accurately predict the amount of weld distortion in the finished work. We sought to solve this issue by simulating the weld distortion of sheet metal membrane panels and determining the optimal welding procedure to minimize distortion.

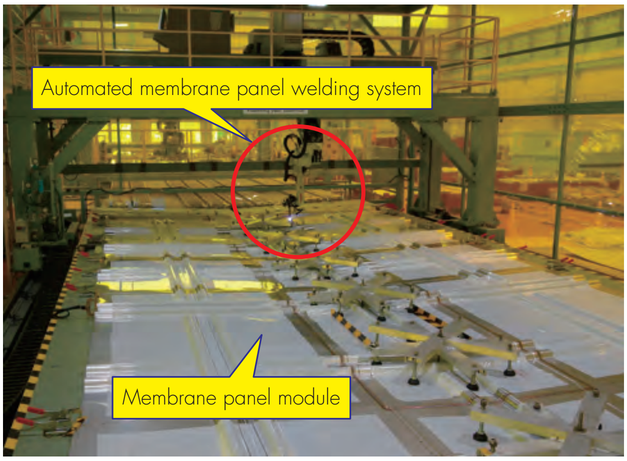


Fig. 8 Automated welding of membrane panels

We verified the simulation results by testing the procedure on a mockup and comparing the weld seams with those welded by a skilled welder using the conventional procedure. This test demonstrated that the new procedure can reduce the amount of weld distortion by half. We applied this procedure to the actual shop fabrication of modules and successfully minimized weld distortion.

(iv) Application

We were able to achieve excellent weld quality by applying an automated membrane panel welding system featuring an automated weld seam tracking system and a welding condition database to in-shop module fabrication. We also achieved an automation rate of approximately 95% for the welding of prefabricated modules by eliminating the need for an operator to monitor the process. Figure 8 shows an automated membrane panel welding system in operation.

3 Development of streamlined welding technology for on-site fabrication

Welding operations at construction sites of aboveground LNG storage tanks overseas can be faced with such issues as difficulty securing skilled welders with the required skill level for nickel steel welding, or inability to use special automated welding equipment due to obstacles related to construction site facilities or environmental factors. To address these issues, the use of flux-cored arc welding (FCAW) has been required in pressure-resistant components of the inner tank. FCAW is a highly efficient welding method that does not rely heavily on the skill level of the operator, and can also help shorten the construction period. Kawasaki has been applying FCAW to non-pressure-resistant components of storage tanks in Japan from about 10 years ago. With a view to applying the process to pressure-resistant components of the inner tank, we evaluated the weldability and joint performance of FCAW materials. As a result, we were able to confirm that the process fully satisfies the performance requirements of LNG storage tanks, and offers excellent fracture toughness as well as joint strength and toughness that are at least equal to the level achieved by the shielded metal arc welding method currently used. We have also established appropriate welding conditions that ensure crack resistance. Therefore, we have started applying the process to the fabrication of pressure-resistant components of the inner tank in LNG storage tanks currently under construction overseas. We are working with an eye to applying the process to the pressure-resistant components of LNG storage tanks in Japan as well, once we have accumulated sufficient technical data and experience.

Professional Engineer (Civil Engineering)
Akira Umeda
Cryogenic Storage System Department,
Chemical Plant & Cryogenic Storage System Engineering Division,
Plant & Infrastructure Company

Mitsuhiro Miyazaki
Cryogenic Storage System Department,
Chemical Plant & Cryogenic Storage System Engineering Division,
Plant & Infrastructure Company

Professional Engineer (Civil Engineering)
Masahiro Tsunekawa
Cryogenic Storage System Department,
Chemical Plant & Cryogenic Storage System Engineering Division,
Plant & Infrastructure Company

Professional Engineer (Mechanical Engineering)
Masahiko Akamatsu
Production Control Department,
Production Center,
Plant & Infrastructure Company

Kenichiro Niimi
Production Control Department,
Production Center,
Plant & Infrastructure Company

Professional Engineer (Mechanical Engineering)
Atsuhito Aoki
Manufacturing Technology Department,
System Technology Development Center,
Corporate Technology Division

Concluding remarks

LNG continues to be in high demand around the world as an environmentally-friendly, clean energy source. As part of its ongoing contribution to society, Kawasaki is working to develop products that help ensure a steady supply of energy through lower cost, higher quality, and more efficient processes.

One of the world largest autoclave facility – High-precision composite curing oven for Boeing 787 Dreamliner

In May 2015, Kawasaki installed an autoclave facility designed to meet the specification requirements of the Boeing 787-10 at Nagoya East Plant. This facility is identical in diameter to the autoclave (designed for the Boeing 787-8 and 787-9) installed at Nagoya North Plant in 2007. The increased length of the 787-10, however, requires some relater structural changes such as strengthening in some area. This called for further performance improvement in terms of temperature distribution inside the oven. Kawasaki used thermohydraulic analysis and other approaches to optimize the specifications and operating conditions, and achieved uniform temperature distribution with the world's largest-class autoclave.

Preface

Today, structural parts made of composites are being increasingly adopted in various fields, including the aerospace and automobile industries, to meet the growing needs for further weight saving. The increased use of composites has given rise to the need for higher-quality parts and processes. Production of composites entails a firing process; in order to achieve high-quality firing with a large composite structure like an aircraft, an autoclave capable of high-precision pressure control and uniform temperature distribution is necessary.

1 Background

The Kawasaki Group has participated in the international project to develop the Boeing 787 airplane shown in Fig. 1 from the outset. It is responsible for developing and manufacturing the forward fuselage, fixed trailing edge, and main landing gear wheel well (Fig. 2) —all critical components of the airplane. The forward fuselage in particular is unique in that it is molded in one piece from composites. In 2007, an autoclave facility designed for the Boeing 787-8 and 787-9 was installed at Nagoya North Plant. With further ramp-ups and the start of production of the 787-10 around the corner, a new autoclave facility that is the one of the world largest was built at Nagoya East Plant to boost production capacity. Given the increased length as well as thickness of the composite structure to

Fig. 1 The Boeing 787 Dream liner family

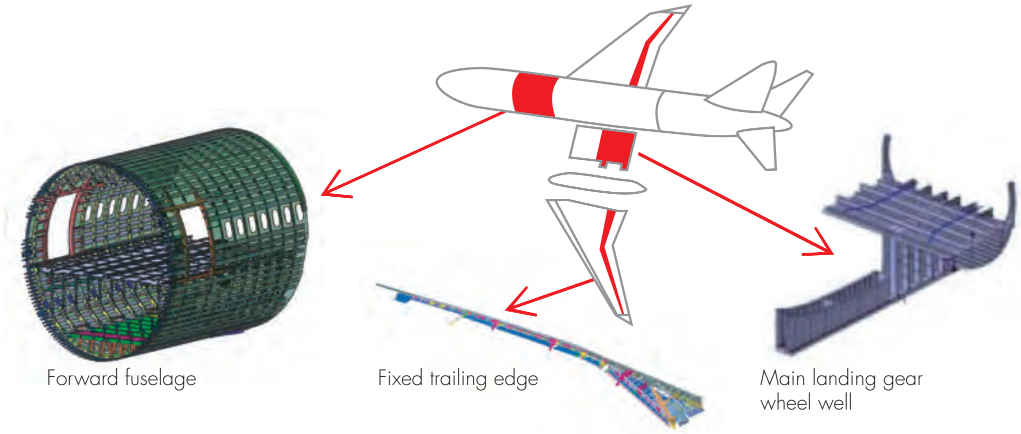


Fig. 2 Sections of the Boeing 787 family supplied by Kawasaki (sections in red)

be molded for the longer variant, the conditions that needed to be overcome were even more stringent than for the previous autoclave.

2 Manufacturing process of the forward fuselage

The forward fuselage is manufactured as a composite component molded in one piece, according to the following procedure.

① Pre-preg lamination

An automated fiber placement (AFP) machine is used to lay up prepreg carbon fiber material, bundled into a certain width and in a precured pliable state, around a huge core (fuselage mold) with the same diameter as the aircraft.

② Curing

The composite layup is placed inside an autoclave to be cured by chemical reaction under high temperature and pressure. Figure 3 shows the cured forward fuselage being taken out of the autoclave.

③ Cutting the outer periphery and drilling holes

Special equipment is used to cut the edges and window openings and drill holes for inserting bolts.

3 Autoclave facility

(1) Required specifications

The autoclave needs to be able to consistently produce high-quality products out of a workpiece that is the world's largest class in terms of both inner diameter and length. Achieving this requires a capability to precisely follow a

Fig. 3 Forward fuselage cured in an autoclave

Table 1 Equipment specifications

Autoclave vessel	Outer diameter (m)	9
	Length overall (m)	30
	Weight (ton)	920
	Material	SFVC2A, SB480
	Applicable regulation	Class–2 pressure vessel

fixed temperature and pressure pattern so that uniform curing is achieved with even strength throughout the structure. The autoclave also must be able to perform two operations a day.

(2) Design specifications

The design specifications shown in Table 1 were adopted in order to fulfill the required specifications. Inside the main unit of the autoclave, which is designed as a pressure vessel, the gas filled inside the vessel is heated and cooled using a heater and coolant, then the gas is circulated with a fan as the workpiece stored inside the muffle furnace (internal cylinder) is fired. The overall flow is shown in Fig. 4. Circulation. The gas blown out from the fan passes along the outside of the muffle furnace and reflects off the outer wall of the door. Then it is led inside the muffle furnace through a screen that regulates the flow. The gas passes through the workpiece, cooler, and heater before being drawn in by the fan and circulated.

The gas filling the autoclave was enriched with nitrogen for increased stability and safety of the molding process. For this reason, a membrane-separation nitrogen generation process was introduced.

The main unit of the autoclave is shown in Fig. 5.

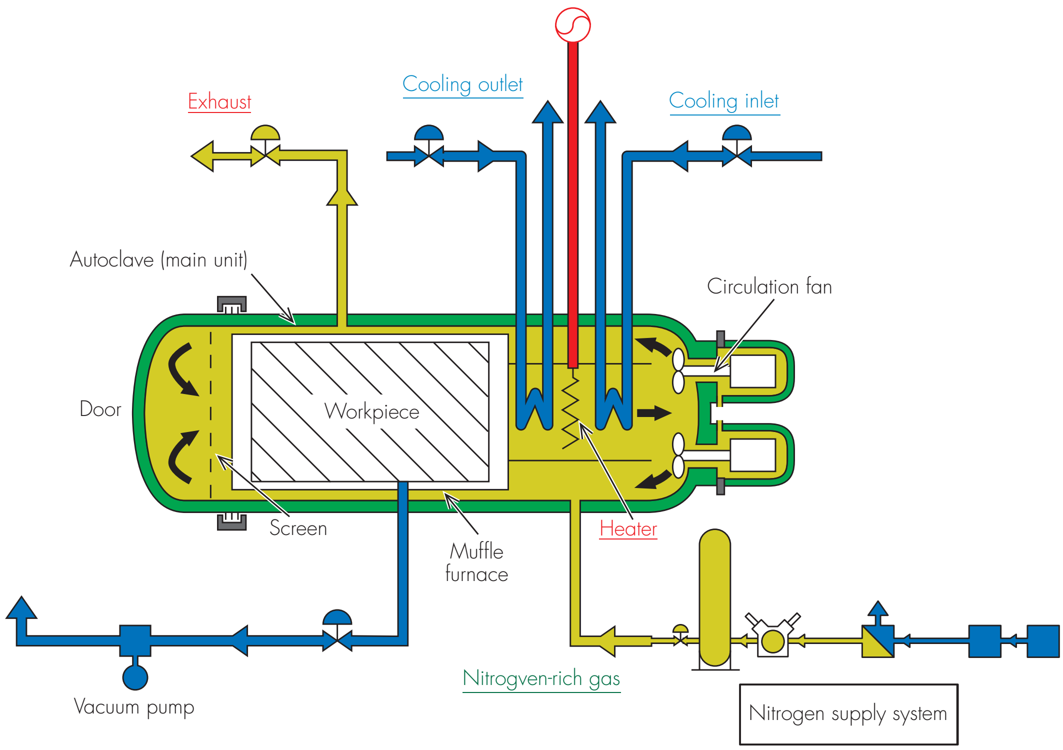


Fig. 4 Overall flow

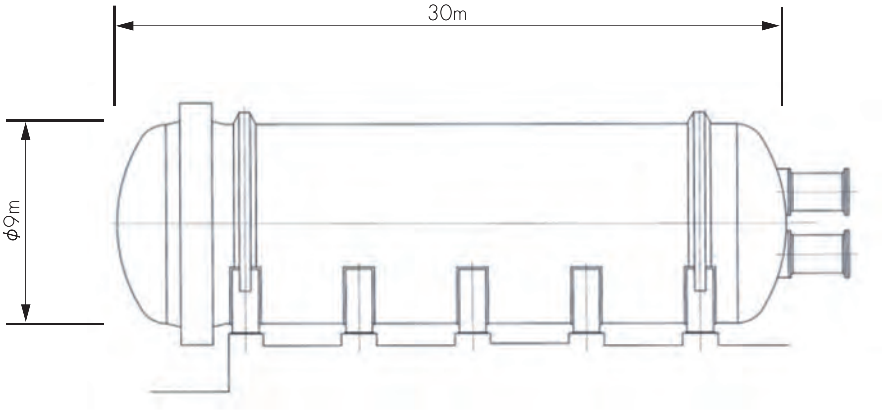


Fig. 5 Main unit of autoclave

(3) Operation pattern of the autoclave

The autoclave is operated in the following process. An example of the temperature and pressure control pattern is shown in Fig. 6.

(i) Pressurization process

The workpiece is placed inside the autoclave, and the door is closed and sealed tight. Then the circulation fan is turned on to start circulating the internal gas.

Next, pressurized nitrogen gas is supplied inside the autoclave, adjusting the pressurization rate with a control valve, until the pressure reaches a fixed level.

(ii) Heating

The heater is turned on, and the output level is adjusted to heat the circulation gas inside the autoclave at a fixed rate. During this process, a thermocouple placed at top center controls the thermocouples mounted in various places of the workpiece so that they are kept within a fixed temperature range for over a fixed length of time.

(iii) Retention and cooling

After a certain length of time has elapsed with the temperature kept within a fixed range, a coolant is drawn regulating the flow to keep the temperature drop at a fixed rate, until the ambient temperature inside the vessel reaches a certain temperature.

(iv) Decompression and ventilation

Once the temperature drops below a fixed point, the pressure inside the vessel is reduced at a fixed rate using a control valve, until it reaches atmospheric pressure. The circulation fan is stopped, and after checking that the oxygen concentration inside the vessel is above a fixed level, the door is opened and the workpiece is taken out.

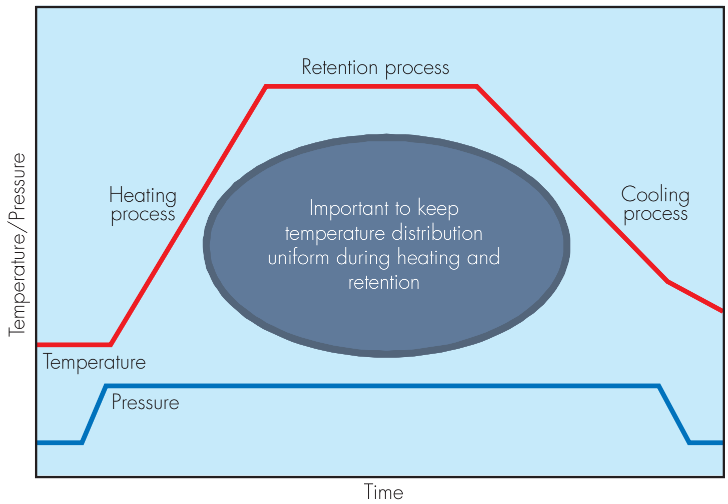


Fig. 6 Control pattern

4 Increasing uniformity of oven temperature

Carbon fiber composites used for airplanes must be cured uniformly so that the strength is kept even throughout the structure. The autoclave used to cure the molded composites must ensure uniformity of temperature in a steady state, as well as in the temperature distribution during temperature rise, and the time taken to reach the prescribed temperature. In order to determine the molding conditions to achieve that capability, the optimal operating method was studied by performing thermohydraulic analysis.

(1) Creating and validating an analytical model for study

The structure inside the autoclave was modeled as in Fig. 7, then simulation was performed under the operating conditions of the existing autoclave to determine the temperature distribution inside the oven. When the results were compared with actual measurement results in representative measurement positions inside an autoclave, a congruence was observed as shown in Fig. 8.

Through an analysis using this analytical model, it was confirmed that the temperature distribution inside the oven can be sufficiently reproduced to study the optimum operating method.

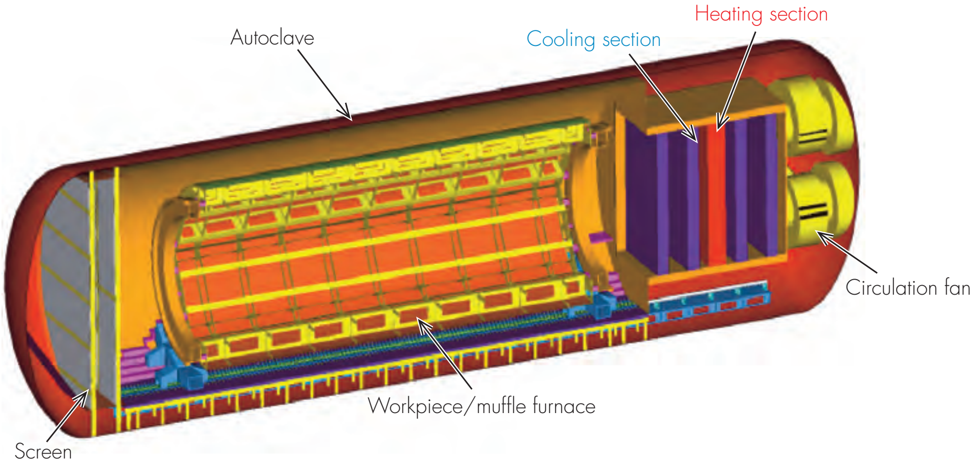
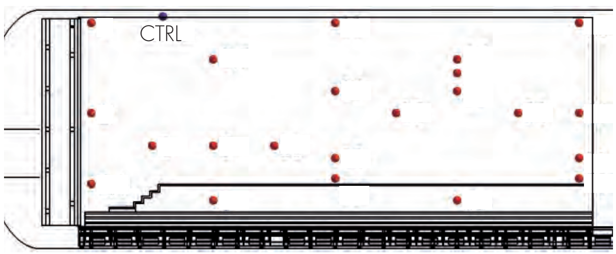
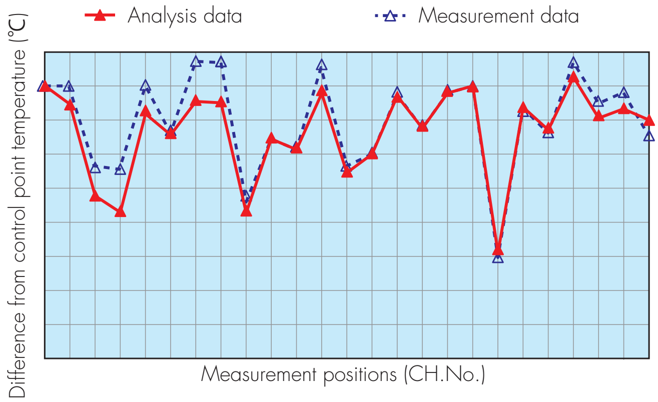


Fig. 7 Analytical model

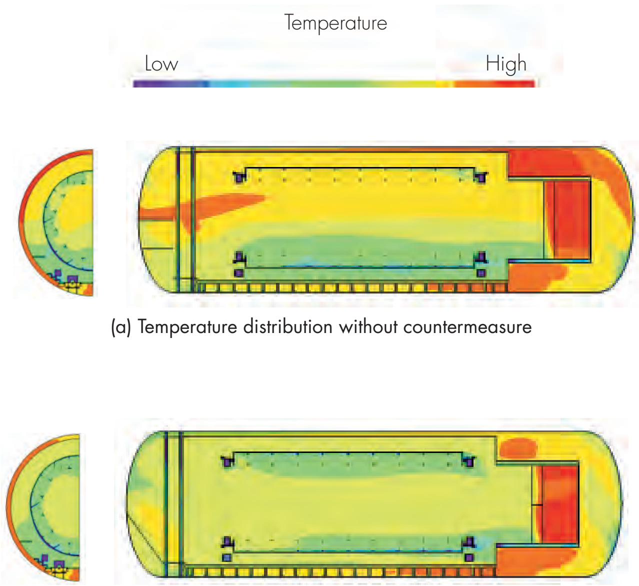


(a) Temperature at each measurement position



(b) Temperature at each measurement position

Fig. 8 Validation of analytical model



(a) Temperature distribution without countermeasure

(b) Temperature distribution with countermeasure

Fig. 9 Comparison of temperature distribution


Kanji Maekawa
Industrial Plant Division,
Kawasaki Engineering Co., Ltd.


Masayuki Shimizu
Industrial Plant Division,
Kawasaki Engineering Co., Ltd.


Satoru Anami
Industrial Plant Division,
Kawasaki Engineering Co., Ltd.

(2) Issues in achieving uniform temperature

Due to the structural members (with a large heat capacity) forming the rail laid under the floor of the autoclave for moving workpieces in and out, the temperature under the floor is less responsive to heating. Further, relatively cold air flows out through gaps provided to accommodate thermal expansion on the floor surface for operators to work on. For these reasons, the measurement positions on the bottom side may register lower temperatures. In the new autoclave, we sought to address this issue to achieve an even more uniform temperature distribution.

(3) Countermeasures

(i) Addressing heating issue under the floor with a large heat capacity

① Optimization of the structure of the straightening vanes (screen) for drawing hot gas inside the vessel

② Addition of an auxiliary duct for hot gas

(ii) Reducing the outflow of air from the gaps in the floor surface

③ Reducing the gaps between the floor boards

(4) Verification of the improvements

Analyses were performed to study the three items above and verify their efficacy. Figure 9 shows the temperature distribution during the heating process. Without the countermeasure, gradients are seen in temperature distribution both at the top and bottom. On the other hand, no gradients are seen when the countermeasure is implemented, indicating that a sufficiently uniform temperature is achieved. Thus, we were able to confirm that with the set equipment specifications, heating at a set rate of temperature rise can be achieved while maintaining a uniform temperature distribution under appropriate operating conditions.

With the above study, we were able to confirm that we would be able to manufacture high-quality products under firing conditions that satisfy the required specifications.

Concluding remarks

The autoclave facility examined in this paper was installed at Nagoya East Plant in March 2015, and is now being used for prototyping and process review to prepare for the manufacture of composite parts. By conducting preliminary studies using thermohydraulic analysis and other approaches to examine the equipment specifications and operating conditions, we were able to meet the tough requirement of achieving uniform temperatures inside one of the world's largest autoclaves. We will continue to endeavor to make significant contributions to aircraft production of the Kawasaki Group.

CKK System
– New waste treatment system that achieves waste reduction, energy use and recycling

The CKK System is a new waste incineration system jointly developed by Kawasaki and the Anhui Conch Group, its joint venture partner in China. This innovative system achieves hygienic waste treatment at low cost, and also makes effective use of the energy and ash content of waste as fuel and raw material for cement production. Orders for the CKK System are steadily increasing in China.

Preface

China is faced with serious environmental pollution and waste treatment issues as a result of its rapid economic development. The Chinese government has made it its highest national priority to develop a "system capable of sanitary waste treatment at a low cost." Kawasaki's new waste treatment system does just that.

1 Background

Kawasaki and the Anhui Conch Group, its joint venture partner in China, have jointly developed a new type of waste incineration system that combines a cement manufacturing facility and waste incineration facility. Called the CONCH Kawasaki Kiln System (CKK System), it enables sanitary waste treatment at a low cost. The first CKK System (300 t/d × 1 furnace) was constructed next to the cement manufacturing facility of Anhui Tongling Conch Cement Co., Ltd. in Tongling City, Anhui Province. The plant has been in operation since April 2010.

2 Advantages of the CKK System

The CKK System (Fig. 1) features a fluidized-bed type gasification furnace where waste is gasified. The resulting pyrolysis gas and unburned char are fed into the calciner on the cement manufacturing side along with ash. The system is designed to harness the energy and ash content of waste as fuel and raw material for cement manufacturing. The CKK System offers the following advantages.

① Reduced fuel consumption
By harnessing the energy contained in waste to manufacture cement, the amount of fuel used for cement manufacturing can be reduced.

② High clinker quality
Heavy metals contained in waste are separated from clinker as chlorides during cement calcination. Heavy-metal concentration in clinker remains relatively stable even with mixed-combustion of waste.

③ Minimal harmful substances in combustion gas
The amount of dioxins and other harmful substances in the combustion gas of waste can be minimized as the combustion gas can be kept at a high temperature for a sufficiently long time in the cement manufacturing facility. HCl and SOx in the combustion gas can be separated through reaction with the calcium contained in cement materials.

④ Smaller initial investment
By utilizing the existing cement manufacturing facility, initial investment costs can be significantly reduced compared to when a new waste incineration facility is built.

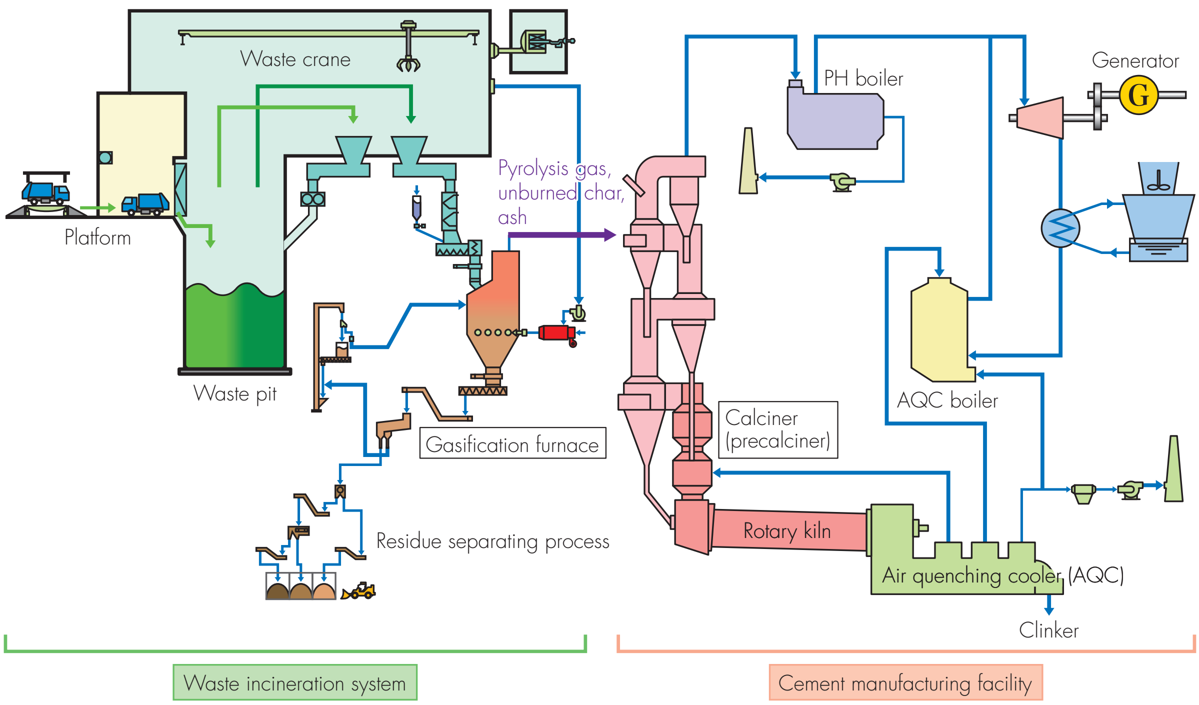


Fig. 1 CKK system flow

3 Development of the CKK System

(1) Basic concept

- Build a waste incineration facility next to a cement manufacturing facility, and continue cement (clinker) manufacturing
- Make full use of the components of the existing cement manufacturing facility in constructing the waste incineration facility
- Minimize impact on cement (clinker) quality by building the waste incineration facility next to the cement manufacturing facility

(2) Selecting the waste incineration technology

In selecting a waste incineration technology, we considered the type of incinerator to use based on Kawasaki's proprietary technology.

As a result, we adopted the fluidized-bed type gasification furnace, which boasts minimal gas volume and low gas temperature at the furnace outlet, a characteristic that makes it possible to reduce the furnace size (Table 1).

(3) Determining the pyrolysis gas injection point

The pyrolysis gas generated in the fluidized-bed type gasification furnace can be injected into the cement

Table 1 Comparison of waste incineration system

Incinerator type	Fluidized-bed type gasification furnace	Fluidized-bed type incinerator	Stoker type incinerator
Incinerator outlet gas volume	Low	High	High
Incinerator outlet gas temperature	Low	High	High
Handling of incinerator ash	Easy	Easy	Difficult (dry ash removal)
Evaluation	◎	○	△

Table 2 Comparison of pyrolysis gas injection positions

Pyrolysis gas injection point	Calciner	Kiln
Gas temperature (max. temperature)	Approx. 900°C	Approx. 1,800°C
Furnace pressure	−0.8 to −0.9 kPa	Approx. −0.2 kPa
Impact of moisture contained in waste on clinker property	No	Yes
Evaluation	◎	△

manufacturing facility either at the calciner (precalciner) or rotary kiln. As shown in Table 2, we chose the calciner due to the large negative pressure inside the furnace, which is an advantage in drawing in pyrolysis gas, and because the moisture content of waste does not impact clinker property in the calciner.

Furthermore, exhaust gas generated in the cement kiln changes the direction of flow from horizontal to vertical at the kiln inlet as it flows into the calciner. We ran a number of simulations to derive the optimal injection point and angle for feeding pyrolysis gas to this gas flow to achieve full combustion inside the calciner.

Specifically, we created an analytical model in which pyrolysis gas is fed from a horizontal direction into an upward flow of gas inside the calciner. We studied several patterns of injection points and angles to examine how they affect the gas temperature, oxygen concentration, and gas flow rate.

The analytical shape model is shown in Fig. 2, and sample simulation results of gas temperature distribution and oxygen concentration distribution are shown in Fig. 3. ① to ④ in Fig. 3 indicate the following areas.

① High-temperature area generated by the combustion of pyrolysis gas
② High-temperature area generated by the combustion of pulverized coal
③ High oxygen concentration area due to the passage of combustion air
④ Low oxygen concentration area due to the passage of kiln gas

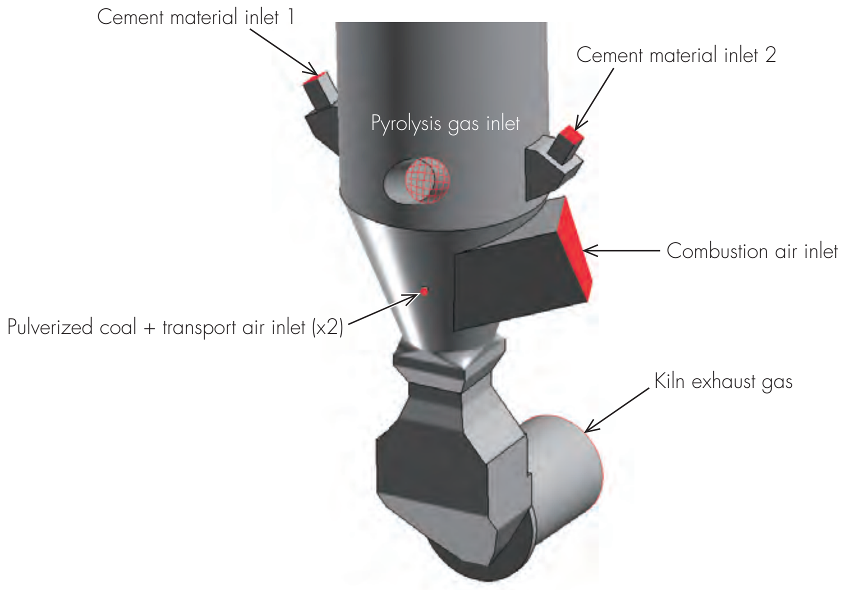
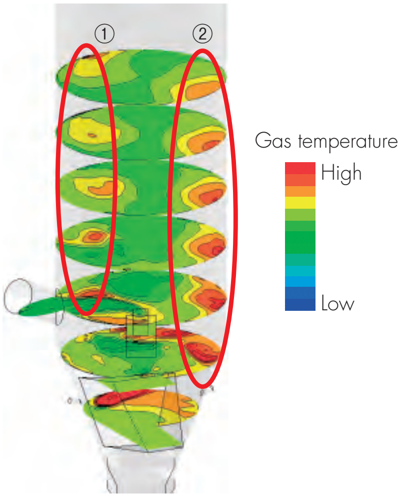
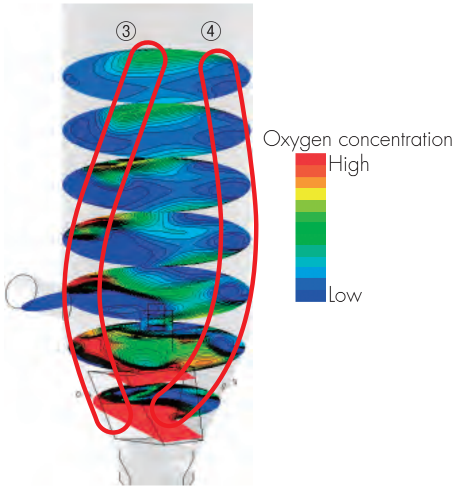


Fig. 2 Geometric model for analysis



(a) Gas temperature distribution



(b) Oxygen concentration distribution

Fig. 3 Simulation results

The following two points transpired as a result of these simulations.

- Inside the calciner, the combustion air causes a rotational flow, and oxygen concentration is distributed. These conditions create a high oxygen concentration area suitable for the combustion of pyrolysis gas.
- Pyrolysis gas is agitated and mixed inside the calciner by the effect of the rotational flow. Therefore, a cross-sectional view of the top section of the calciner shows a roughly even distribution of gas temperature and oxygen concentration.

Based on the above, the injection point and angle of pyrolysis gas were determined so that the gas can be fed to the high oxygen concentration area inside the calciner, and the mixture of the gas can be promoted inside the calciner.

(4) Maintaining stable cement manufacturing operation and high clinker quality

To ensure stable operation of the cement manufacturing facility and high clinker quality, it is important to minimize coating due to concentration of chlorine (and alkali).

Therefore, we studied an effective way to reduce chlorine concentration in the clinker calcining system, based on the chlorine concentration in waste and in the clinker produced by the existing cement manufacturing facility. As a result, we adopted a chlorine bypass system (patent held by Taiheiyo Cement Corporation) as a measure against chlorine concentration in the CKK System, based on cost and effectiveness in reducing the occurrence of coating and chlorine concentration in clinker.

(5) Handling odors and waste pit drainage

We have studied measures to handle the odors and waste pit drainage generated as a result of waste treatment.

(i) Odors

- An airtight waste pit will be adopted. Flowing air will be drawn from the pit to create a negative pressure environment inside, thereby preventing odor leakage. The odors in the fluidized air will be burned and decomposed in the calciner.
- As a measure against the suspension of the gasification furnace, a deodorizing equipment will be installed. Otherwise, air will be drawn from the waste pit and then blown over the high-temperature clinker in the air quenching cooler to decompose and eliminate the odors.

(ii) Waste pit drainage

- Waste pit drainage will be sprayed into the gasification furnace freeboard to be vaporized.

(6) Minimizing environmental impact through mixed combustion of waste

Primary environmental impacts of the mixed combustion of waste in a cement manufacturing facility include the following.

① Increased concentration of CO and dioxins in exhaust gas

② Increased concentration of heavy metals in clinker

These two points have been theoretically examined, which led to the conclusion that neither is a significant issue.

- While the pyrolysis gas and unburned char generated in the gasification furnace are burned in the calciner of the cement manufacturing facility, the gas temperature inside the calciner is maintained at roughly around 900 °C for the removal of carbon dioxide (endothermic reaction) from cement raw material.

・In addition, gas is kept inside the calciner for at least four seconds, minimizing increase in the concentration of CO and dioxins.

・Most heavy metals contained in waste are separated from clinker as chlorides during the calcining process. As a result, heavy-metal concentration in clinker remains relatively stable.

4 Tongling CKK plant operation results

The following is an overview of the operation results of the CKK plant in Tongling City.

(i) Waste status

The analysis results of waste in Tongling City are summarized in Table 3. The lower heating value was approximately 5,900 kJ/kg, which was equivalent to the standard waste at the time of planning. While sulfur concentration is considerably higher than that of the standard waste, this is presumably because briquettes made of coal are used in large amounts as fuel in Chinese households.

(ii) Waste treatment capacity

Transition in waste treatment capacity as of March 2011, about one year after the start of operation, is shown in Fig. 4. The capacity had stayed at around 300 t/d, indicating stable operation.

Table 3 Analysis results of waste in Tongling city

Item		Summer waste	Winter waste	Standard waste
Lower heating value (kJ/kg)		5,760	5,920	5,900
Three components (%)	Moisture	56.34	57.11	60.18
	Combustibles	30.93	34.18	34.30
	Ash	12.73	8.71	5.51
Elemental composition of combustibles (%)	Carbon	60.88	57.85	52.94
	Hydrogen	8.52	8.08	7.82
	Oxygen	25.49	30.72	37.62
	Sulfur	2.97	1.68	0.08
	Chlorine	1.08	0.84	0.70
	Nitrogen	1.06	0.84	0.85

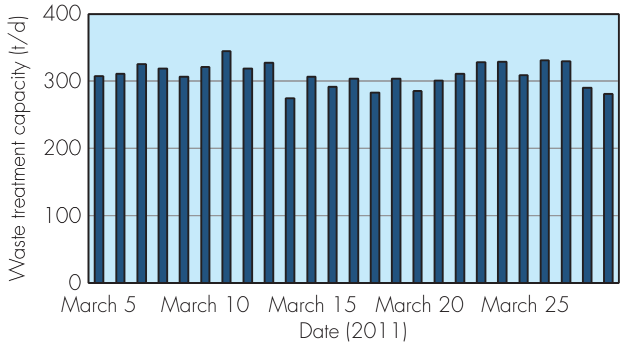


Fig. 4 Amount of waste treated

Table 4 Analysis results of dioxins

Measurement results (stack inlet)		Regulation values
1st	2nd	
0.008	0.033	0.1

Unit: ng-TEQ/m^{3}N: at 11% O_2

(a) Non-combustibles

(b) Material recycled with magnetic separator

Fig. 5 Non-combustibles discharged from gasification furnace

(iii) Concentration of dioxins in exhaust gas
Measurement results of dioxins at the stack inlet of the cement manufacturing facility shown in Table 4 demonstrate that regulatory values are fully met. Incidentally, this plant does not incorporate spraying of activated carbon to reduce dioxins in exhaust gas.
(iv) Non-combustibles discharged from gasification furnace
Non-combustibles discharged from the bottom of the gasification furnace as shown in Fig. 5(a) have been confirmed to be usable as cement material. Iron as shown in Fig. 5(b) has been confirmed to be recyclable in an unoxidized state.
(v) Clinker quality
Ever since it started operation, the plant has never experienced any suspension of the cement manufacturing facility due to low clinker quality. This shows that mixed combustion of waste has no negative impact on the quality of clinker.
(vi) Mixed combustion of dewatered sludge
In China, the increasing number of sewage treatment facilities has made detoxification of sewage sludge (dewatered sludge), which is generated in huge quantities, an issue of great importance. To test whether it is possible to treat dewatered sludge with the CKK System, we had conducted mixed combustion of dewatered sludge starting at the plant in November 2011. As a result, we found that there is no problem if the amount of dewatered sludge is kept within the range of 10-20%.

Concluding remarks

Orders for the CKK System have been steadily increasing in China, where a total of 8 plants are in operation, and 10 plants are under construction as of the end of September 2015.

Furthermore, growing population and rising standard of living in the emerging economies of Southeast Asia as well as India and Brazil have led to increased demand for the hygienic treatment of municipal waste in these countries and regions. The low cost of the CKK System will make it an ideal solution to meet their needs.

The CKK System is also effective in reducing greenhouse gas emissions, a pressing issue across the globe. We will continue to further refine the system to contribute to a healthier planet.


Professional Engineer (Environmental Engineering)
Tadashi Katahata
Environmental Plant Department,
Environmental Plant Engineering Division,
Plant & Infrastructure Company


Hiroaki Osawa
Industrial Plant Department,
Industrial Plant Engineering Division,
Plant & Infrastructure Company


Sadafumi Katoh
Operation and Maintenance Technology Department,
Environmental Plant Engineering Division,
Plant & Infrastructure Company


Mitsuru Kikkawa
Environmental Plant Department,
Environmental Plant Engineering Division,
Plant & Infrastructure Company


Professional Engineer (Environmental Engineering)
Atsushi Hashimoto
Environmental Plant Department,
Environmental Plant Engineering Division,
Plant & Infrastructure Company


Jun Toshihiro
Anhui Conch Kawasaki Engineering Co., Ltd

U-KACC Boiler
– Technology to effectively utilize residual fuel from oil refinery

Kawasaki has developed the Upgraded Kawasaki Advanced Clean Combustion (U-KACC) boiler, which displays great ability to utilize petroleum coke and other residues effectively as a fuel and achieves low-NOx, low-dust combustion. Kawasaki is currently designing and manufacturing an asphalt pitch-fired U-KACC boiler for Fuji Oil Company, Ltd.'s Sodegaura Refinery, which will feature a new burner and other improvements to overcome some new technological issues. Kawasaki will continue to improve its expertise and develop boilers that consume less energy and resources.

Preface

Solid residues such as petroleum coke and asphalt pitch (ASP) generated in the process of oil refining have conventionally been difficult to handle as fuels. However, demand for the practical use of these as a boiler fuel has been growing in recent years consequent on the promotion of effective energy use. Such petroleum residues contain little volatile matter, which makes stable mono-fuel combustion of them difficult. The ash generated also has high vanadium content, frequently leading to trouble due to ash adhesion and fusion, and making continuous long-term operations difficult with existing types of boiler.

In this report, we describe the features of the U-KACC boiler developed to efficiently utilize such residues as a fuel. Furthermore, we outline the design of the ASP-fired boiler ordered for Fuji Oil Company, Ltd.'s Sodegaura Refinery in October 2014, detail the development of the dedicated ASP burner, and introduce points taken into account when designing the plant.

1 Features of the U-KACC boiler

Kawasaki possesses the Kawasaki Advanced Clean Combustion (KACC) boiler as an existing technology, which can cleanly burn asphalt and other liquid residues. Based on this boiler technology and with added improvements, the Upgraded-KACC (U-KACC) boiler was newly developed in order to burn petroleum coke and other solid residues containing ash.

Figure 1 shows a comparison between the KACC boiler and U-KACC boiler. The KACC boiler has a particular form, in which the furnace is constricted in the middle and separated into an upper and lower chamber (venturi

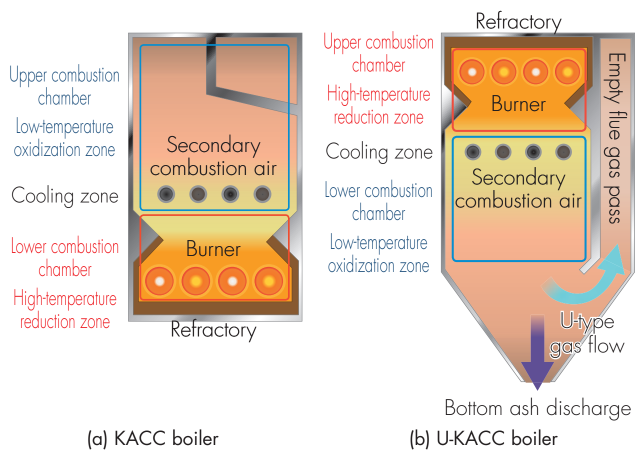


Fig. 1 Comparison between KACC boiler and U-KACC boiler

configuration). In the lower combustion chamber covered with refractory material, NOx generation is reduced through high-temperature reduction combustion by restricting the air supplied to the burner. In the upper chamber surrounded by water wall tubes, combustion is completed through a low-temperature oxidation process in which secondary air is optimally mixed. This two-chamber construction enables low-NOx, low-dust combustion even with difficult-to-burn liquid petroleum residue fuels such as asphalt.

Although the KACC boiler can be continuously operated over the long-term with fuels containing no ash, it has the weakness of being unsuitable to continuous long-term operation with petroleum coke, ASP, and other fuels that contain ash due to accumulation or adhesion of ash in the furnace.

In order to overcome this issue, while maintaining the advantages of the KACC boiler, the combustion chamber section of the KACC boiler is given an inverted form in the U-KACC boiler, and a hopper is installed at the bottom of the furnace, which makes the continuous discharge of ash and the firing of solid petroleum residue fuels possible.

The concept of combustion technology of the U-KACC boiler is identical to that of the KACC boiler, which shows superior performance in low-NOx/low-dust combustion. Further, the U-KACC boiler has a function to exhaust ash from the bottom of the furnace by making U-type flue gas flow there. In this way, the U-KACC boiler minimizes dust adhesion on boiler tubes and thereby prevents troubles caused by high draft loss and/or clogging of flue gas duct.

2 Verification of U-KACC boiler performance

In order to validate the performance of the U-KACC boiler, we first verified basic combustion characteristics by conducting a combustion test using a test furnace. Then, we performed a computer simulation analysis using an actual-size U-KACC boiler model based on the data acquired in the combustion test.

(i) Combustion test

The combustion test was carried out using difficult-to-burn petroleum coke with a volatile matter content of under 10%. As shown in Fig. 2 (a), it was confirmed that ignition and combustion were satisfactory with high flame luminescence and low NOx in a high-temperature reduction atmosphere of a burner air ratio of around 0.7 (Fig. 3).

As shown in Fig. 2 (b), the inside of the furnace was in a clean condition with no ash adhesion observed on the furnace walls after a long-term test operation. This is considered to be a result of the proper combustion method

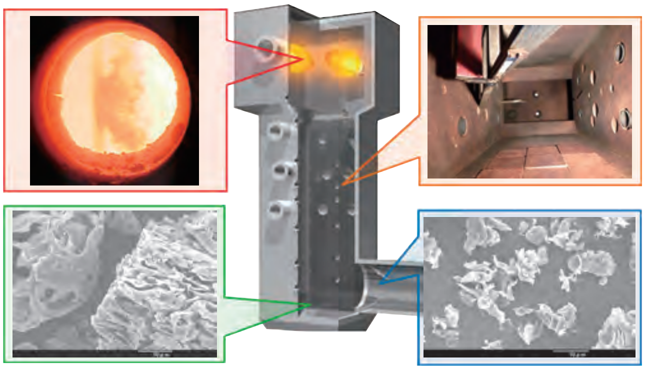


Fig. 2 Combustion condition, test furnace inside after the test and microphotograph of ash

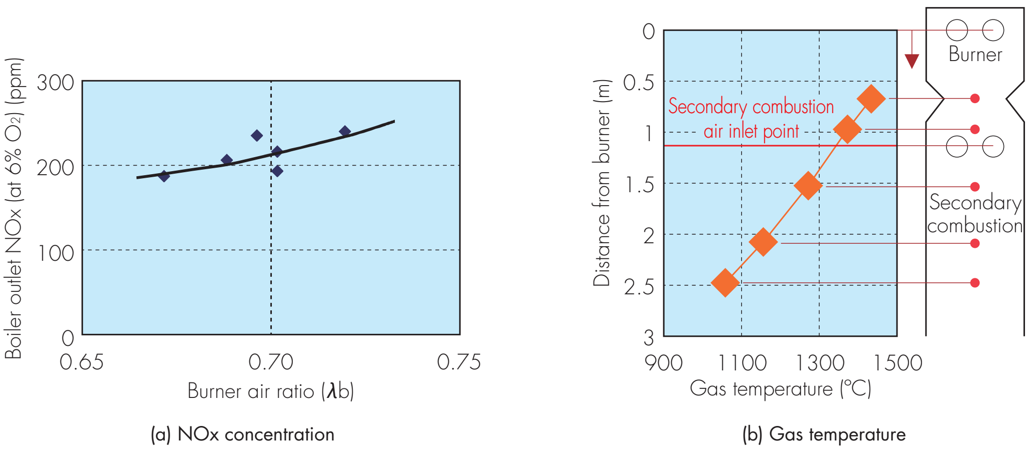


Fig. 3 NOx concentration and flue gas temperature of the U-KACC test furnace

of the U-KACC. In the reduction atmosphere of the upper combustion chamber, the vanadium ash is in a state of vanadium oxide with a high fusion point (e.g., the fusion point of V_2O_3 is 1,970°C, and that of V_2O_4 is 1,640°C). Therefore, it is guided to the outlet of the upper combustion chamber without fusing and then is gradually oxidized by cooling with a low-temperature oxidation process. Furthermore, as shown in Fig. 2 (c), the collected bottom ash has a porous form, from which it is found that the combustion is good leaving almost no unburned carbon. Concerning the fly ash collected in the bag filter, bonding between ash particles is not observed as shown in Fig. 2 (d), and the ash was confirmed to have low adhesiveness[1].

(ii) Combustion simulation analysis

Based on the data acquired in the combustion test, we conducted a computer simulation analysis by modeling the actual size U-KACC boiler. To determine the optimum design, the simulation was carried out by changing various operational conditions, such as the size of the fuel particles, swirling direction of air flow in the burners, etc., and the results were analyzed from various viewpoints, such as combustion gas temperature distribution, gas flow pattern, time in the furnace, combustion reaction behavior, etc.[2].

As a result of the above, it was verified that the U-KACC boiler demonstrated a fixed level of performance, and ability to effectively utilize difficult-to-burn petroleum residue as a fuel.

3 The U-KACC boiler for Fuji Oil Company, Ltd.'s Sodegaura Refinery

(1) Outline of design conditions

This new installation of a boiler-turbine generator facility at the Sodegaura refinery is expected to greatly contribute to energy cost reductions by using the solid ASP produced in the refinery as a main fuel to generate electricity. The primary specifications of the boiler are shown in Table 1.

The design must take various considerations into account due to the difficulty of handling ASP as a fuel.

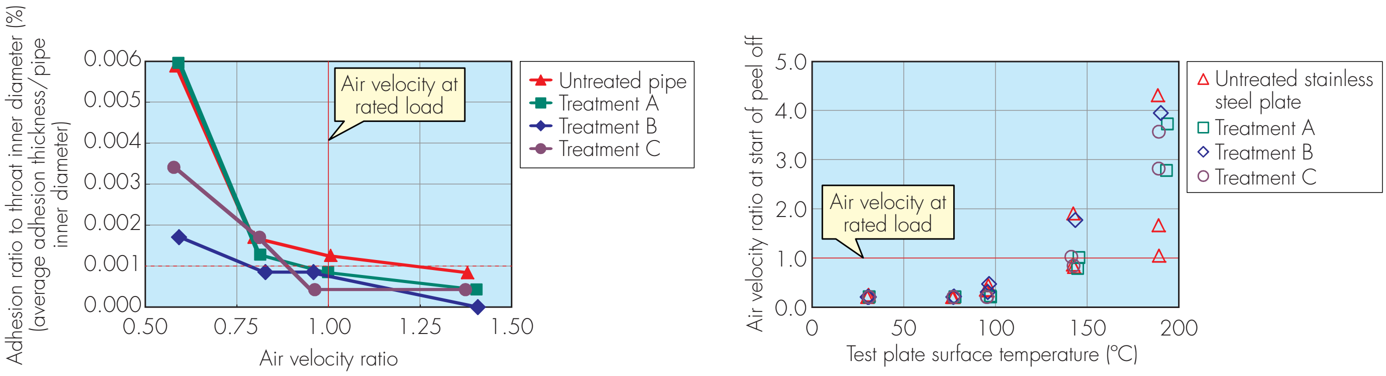
Table 2 shows a comparison of characteristics of asphalt pitch (ASP), petroleum coke, bituminous coal, and vacuum residue (VR).

Table 1 Boiler specifications

Boiler type	U-KACC mono-drum natural circulation boiler
Steam flow (t/h)	295
Steam pressure (superheater outlet) (MPaG)	10.3
Steam temperature (superheater outlet) (°C)	503
Draft system	Balanced draft
Main fuel	Asphalt pitch (ASP)

Table 2 Comparison between ASP and other fuels

Item	ASP	Petroleum coke	Bituminous coal	VR (Vacuum Residue)
Higher heating value (MJ/kg)	7,960	8,300–8,500	4,000–6,000	9,500–10,000
Volatile matter (wt%)	40.6	10–13	30–40	–
Fixed carbon (wt%)	59.1	87–90	45–55	20–30
Nitrogen (wt%)	1.4	1–3	2	Up to 1
Sulfur (wt%)	6 (Max. 8)	4–7	Under 1	4–6
Vanadium (ppm)	600–900	< 1,500	–	< 250
Ash (wt%)	0.3	0.2–1.0	Approx. 10	0.03



(a) Influence of surface treatment and flow velocity on adhesion amount

(b) Influence of surface treatment and temperature on peel off air velocity

Fig. 4 Results of ASP adhesion test

The characteristics of ASP are as follows.

- High sulfur content—Measures against corrosion and desulfurization of high SOx concentration gas are necessary
- High vanadium content—Measures against high-temperature corrosion and measures against ash adhesion to boiler tubes are necessary
- High ash content (around 10-times that of VR)—A bottom ash discharge function is necessary to prevent ash accumulation in the furnace
- Low softening point of around 180°C and high adhesiveness—Anti-adhesion/clogging measures are necessary for the fuel feed system and the burner

Optimal design and planning were carried out taking these characteristics into account.

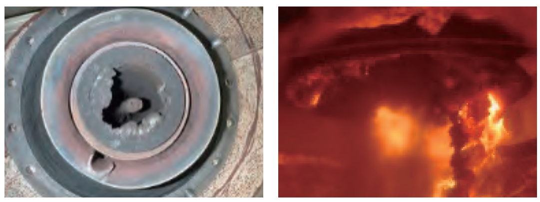
(2) Design properties

(i) ASP burner and combustion in the furnace

The ASP used as a fuel in this project is a solid at room temperature and can be pulverized and pneumatically transported. However, it begins to soften at approximately 180°C and becomes adhesive. This necessitates a cooling structure of the burner to prevent adhesion to the inner surface and clogging of the fuel pass.

Firstly, we conducted a fundamental test with the aim of evaluating ASP adhesion to the burner inside and verified adhesion characteristics with respect to various surface treatments and at different air velocity and temperatures. As shown in Fig. 4, it was possible to suppress adhesion thickness to under 0.001% of the throat inner diameter with surface treatment at the air velocity at rated load. Adhesion was also found not to develop when the surface temperature was kept under 100°C.

Then, based on these results, we investigated an anti-adhesion burner equipped with a cooling structure, and conducted a combustion test by mounting a prototype burner onto the test furnace. Fig. 5 shows the ASP combustion conditions during the test. In the case of a burner without a cooling structure, clogging as shown in Fig. 5 (a) occurred in around 30 minutes and continued combustion became difficult. However, the provision of an appropriate cooling structure suppressed adhesion to the burner surface and enabled continuous operation without clogging. As a result, favorable combustion performance as shown in Fig. 5 (b) was demonstrated. Figure 6 shows the operation data during the combustion test with the anti-



Clogging at burner outlet

Flameout due to clogging

(a) Ordinary burner

Clean burner inside with no clogging

Long-term continuous combustion with favorable flame

(b) Anti-adhesion burner

Fig. 5 Results of ASP burner test (comparison of combustion conditions)

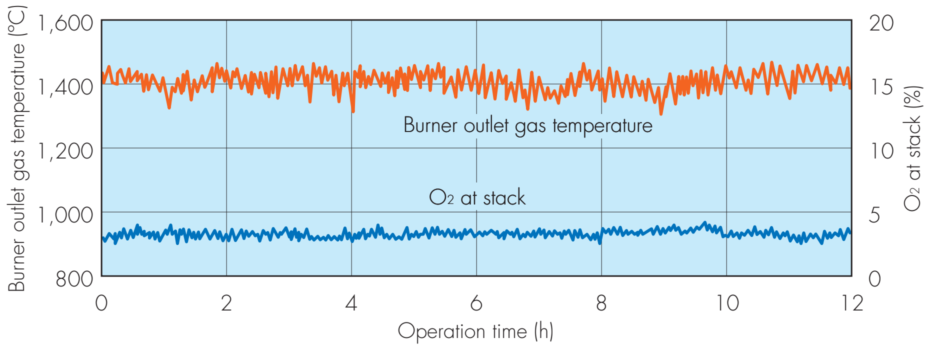


Fig. 6 Results of ASP combustion test (gas temperature and O_2 concentration)

adhesion burner. The gas temperature and O_2 concentration are stable over a long period, demonstrating that long-term continuous stable operation with highly adhesive ASP is possible with this newly developed anti-adhesive burner.

By the computer simulation, it was also verified that ASP combustion was performed appropriately and a high-temperature reduction zone and a low-temperature oxidation zone were formed in the U-KACC boiler as we intended.

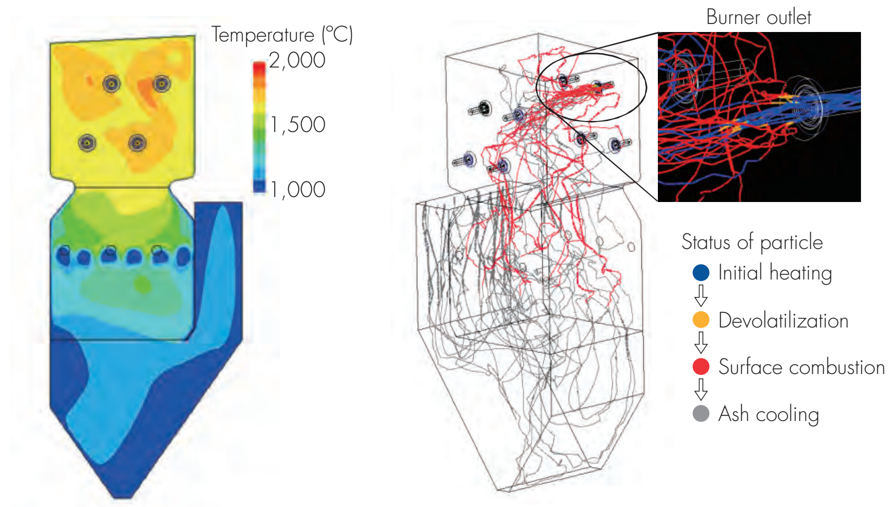
Referring to the gas temperature distribution in the U-KACC furnace shown in Fig. 7 (a), high temperature regions of over 1,500°C are formed in the upper reduction chamber, and the temperature is found to gradually drop in the lower oxidation chamber.

Figure 7 (b) shows the traces of fuel particles emitted from the burner, with the changing status of the particle illustrated by color. The fuel particles being rapidly heated at the burner outlet release their volatile component, and combustion commences. After becoming char the particles start surface combustion and then eventually burn out. The diagram shows that almost all the particles that became char in the upper combustion zone are burned out in the lower combustion chamber. Accordingly, the particles transported to the back pass are mainly composed of ash.

(ii) Fuel pulverization and supply system

ASP has a low hardness with a Hardgrove Grindability Index (HGI) of 158 and is adhesive, so an impact mill was employed instead of the roller mill generally used in pulverized coal fired boilers. Also, the number of hammers and mill speed were optimized through an ASP pulverization test.

The pulverized ASP is fed to the burner by pneumatic transportation, and the appropriate air-fuel ratio, feed pipe route, and form of bend pipe were selected to prevent adhesion or clogging in the feed pipes.



(a) Gas temperature distribution in furnace (b) Traces of fuel particles (Colors illustrate particle status)

Fig. 7 ASP combustion simulation of U-KACC

(iii) Furnace anti-corrosion measures
In the U-KACC boiler, high temperature reduction combustion is carried out in the upper combustion chamber. Sulfurization reduction corrosion due to high sulfur content of the fuel is a concern in the zone before where secondary combustion air is introduced and the oxidization process is completed. For this reason, the water wall tubes of the reduction section combustion chamber employ composite tubes (clad tubes), the outer layer of which is made of stainless steel as an anti-corrosion measure.
(iv) Measures against ash adhesion to the boiler tubes
In conventional boilers, the fusion point of ash containing vanadium is lowered in the high-temperature oxidation combustion, and slagging, fouling, corrosion, and other adverse effects occur due to ash adhesion to the furnace water wall, superheater tubes, and the like. Accordingly, in many cases a magnesium-based additive is mixed into the fuel to address these issues. However, the combustion method of the U-KACC reduces unburned fuel and has the effect of raising the fusion point of vanadium ash in a high-temperature reduction atmosphere, so there is little ash adhesion to the furnace water wall.

Furthermore, ash adhesion to boiler tubes in the downstream of the furnace is also drastically reduced by discharging the bottom ash from the furnace bottom, and by sufficiently lowering the gas temperature in the empty flue gas pass. For this reason, it is unnecessary to use a fuel additive to raise the fusion point of the ash, which contributes to a reduction in operating costs.
(v) Flue gas treatment (environmental measures)
The installation of a state-of-the-art flue gas treatment system is planned in order to comply with the strict environmental regulations of the Sodegaura area.

① In addition to the low NOx performance of U-KACC, an ammonia injection selective catalytic reduction system will be installed as a DeNOx system. U-KACC is less prone to denitrification catalyst clogging due to low unburnt fuel content of ash and low ash adhesiveness.
② A high-efficiency wet type DeSOx system (magnesium hydroxide process) will be installed as a desulfurization system, in which a multistage tray type absorber is adopted considering the lower possibility of clogging. Light-burned magnesium will be used as a desulfurization agent from an economical point of view.
③ A dry type electrostatic precipitator is adopted as a dust collector.
④ A wet type electrostatic precipitator is installed on the downstream side of the wet DeSOx system as an anti-SO_3 measure.


Hiroyuki Mori
Boiler Plant Engineering Department,
Energy Plant Engineering Division,
Plant & Infrastructure Company


Shin-ichi Toda
Boiler Design Department,
Energy Plant Engineering Division,
Plant & Infrastructure Company


Tomoyuki Ogino
Thermal System Research Department,
Technical Institute,
Corporate Technology Division

Concluding remarks

The design and construction of the ASP-fired U-KACC boiler for Fuji Oil Company, Ltd.'s Sodegaura Refinery is proceeding as planned, and it is expected that successful performance will be confirmed through commissioning and performance tests that will be conducted in 2017.

Moving forward, Kawasaki aims to respond to customer needs by promoting the development and marketing of effective energy solutions such as the U-KACC and other boiler facilities that reduce environmental load.

References

1) Patent No. P5496862, Combustion Method to Prevent Contamination of Combustion Chamber of Petroleum Residue Fired Boiler
2) Patent No. P5501198, Low NOx/Low Soot Combustion Method and Boiler Combustion Chamber

RDF-fired internal circulating fluidized-bed boiler
– Longer operating life achieved with improved structure and operating conditions

Kawasaki's internal circulating fluidized-bed boiler (ICFB) that runs on refuse-derived fuel (RDF) has achieved high efficiency by adopting an embedded tube structure, which generates high-temperature, high-pressure steam in heat-recovering cells. The operating life of this boiler is largely affected by the corrosive abrasion of embedded tubes. In the boiler delivered to South Korea in 2012, Kawasaki significantly improved the operating life of embedded tubes by rearranging their layout to minimize abrasion, and optimizing the fuel to alleviate its corrosive properties.

Preface

The national government of South Korea has been promoting the use of recycled fuel for power generation, and in 2012 it put into effect a law that corresponds to the Special Measures Law Concerning the Use of New Energy by Electric Utilities (commonly referred to as RPS Law) in Japan. The ever increasing amount of CO_2 emissions due to the burning of fossil fuels and other social impact of industrial activities continue to pose a major challenge. In an effort to offer a viable solution to this problem, work is underway to construct a facility for converting waste into solid fuel (Refuse Derived Fuel) suitable to stable combustion and a cogeneration facility capable of using this fuel.

1 Objective

In 2012, Kawasaki delivered an internal circulating fluidized-bed boiler (ICFB) to Commerce & Industry Energy Co., Ltd. (Iksan City, South Korea), a special power supplier founded by Korea Midland Power Co., Ltd., engineering manufacturer Halla E&E, and Korea Development Bank.

This paper will discuss enhancements made on the ICFB boiler, which is capable of RDF mono-firing and mixed combustion with coal, and technology employed to reduce the thinning of embedded tubes.

2 Boiler specifications

The main specifications of the boiler are shown in Table 1.

This boiler uses 215 t/d of RDF as main fuel and 65.5 t/d of coal as auxiliary fuel (ratio of 80 to 20 in heat quantity) to generate 75 t/h × 6.37 MPa × 450°C of steam and 6.0 MW

Table 1 Main specifications

Item		Design value
Fuel	RDF (t/d)	215*1)
	Coal (t/d)	65.5*1)
Boiler	Type	Kawasaki FB-75U type Internal Circulating Fluidized-bed Boiler
	Steam generation (t/h)	75
	Steam condition	6.37MPa × 450°C
Environmental regulation value	NOx (ppm)	< 70*2)
	SOx (ppm)	< 30*2)
	HCl (ppm)	< 20*2)
	Dust (g/Nm³)	< 0.02*2)
	Dioxin (ng-TEQ/Nm³)	< 0.1*2)
	CO (ppm)	< 50*2)

*1) Co-firing of RDF and coal
*2) Dry gas at 12% O_2

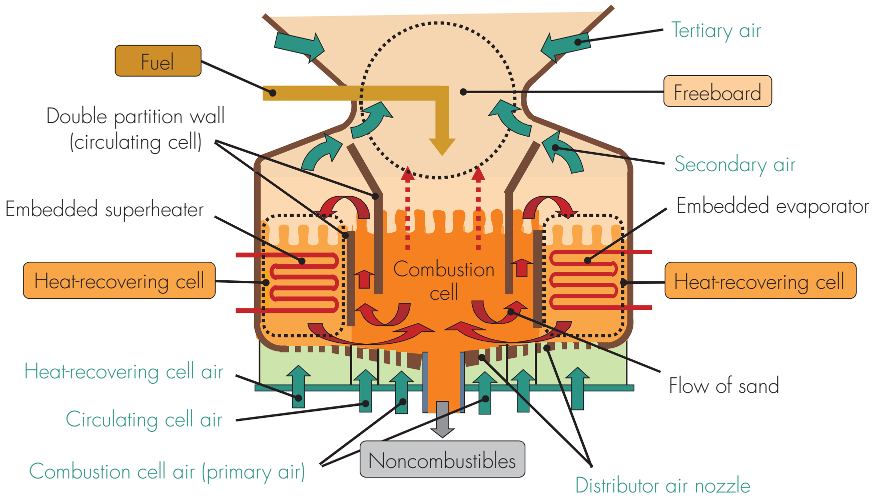


Fig. 1 Conceptual diagram of ICFB

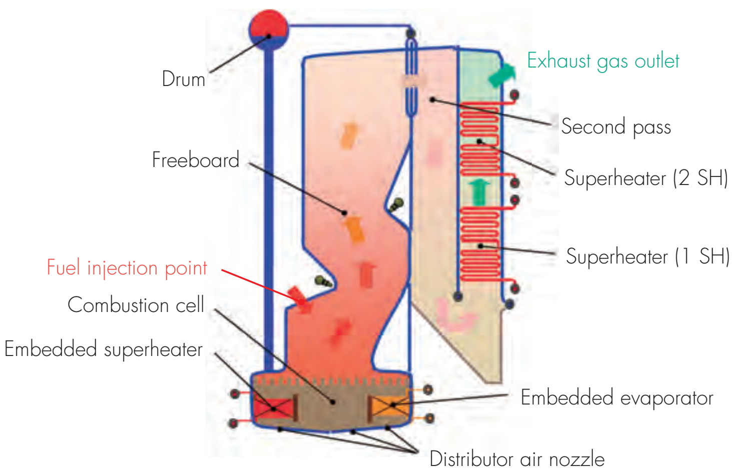


Fig. 2 Overall view of ICFB

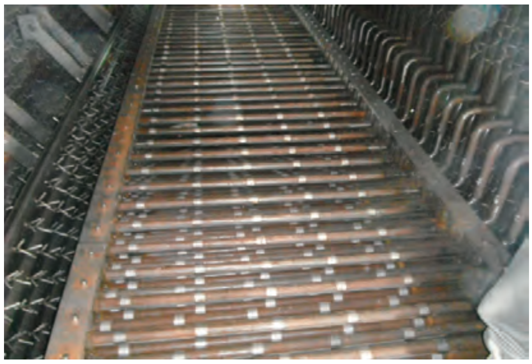


Fig. 3 Embedded tubes

of electricity (gross power output). The generated steam is supplied to an adjacent factory.

This boiler burns fuel in heated sand called bed material and efficiently recovers heat with a heat exchanger embedded inside a fluidized bed. As illustrated in Fig. 1, the fluidized-bed furnace is divided into a combustion zone and a heat recovery zone with a double partition wall. This structure is designed to reduce the infiltration of corrosive gas such as HCl into the heat-recovering cells and minimize the load placed on the heat exchanger. The bed material (sand) is circulated between the combustion zone (combustion cell) and heat recovery zone (heat- recovering cells) to transfer heat inside the fluidized-bed furnace, hence the name “internal circulating fluidized-bed boiler.”

The overall view of the ICFB is shown in Fig. 2.

3 Measures against the thinning of embedded tubes

While this ICFB normally co-fires waste-derived RDF and coal, it is also capable of mono-firing RDF. Accordingly, it features an anti-corrosion measure based on the operating data of the RDF mono-firing fluidized-bed boiler which Kawasaki has delivered to the Omuta Recycle Power Plant. However, the unique corrosive environment created by waste incineration is tough to address, and further measures are required to minimize the thinning of boiler water tubes. For this project, we carried out further R&D and testing on embedded tubes, which among boiler water tubes are particularly in need of extension of service life, to study measures to reduce thinning. Figure 3 shows the embedded tubes placed inside the heat-recovering cells in the fluidized bed at the bottom of the furnace.

(1) Pitch of embedded tubes in tube banks

Traditionally, it has been considered that the amount of abrasion varies in direct proportion to the gas flow rate inside the tube bank. To minimize thinning caused by abrasion inside the embedded tubes, we have therefore adopted a tube bank pitch that also took heat-transfer efficiency into consideration. The embedded tubes of the ICFB have traditionally been designed to minimize gas flow rate within an extent that enables heat transfer to take place as a fluidized bed (superficial velocity ratio*: Ut/Umf = 2.0-3.0). The philosophy behind this design is to slow the rate of thinning due to abrasion compared to conventional fluidized-bed boilers.

However, more recent abrasion tests and analysis of bubble behavior inside tube banks (Fig. 4) have pointed to a stronger correlation with the rising velocity of bubbles than with the flow rate inside embedded tube banks. In addition, it became evident that the rising velocity of bubbles increases in proportion to the diameter of the bubbles. Accordingly, the rate of thinning is significantly affected by the diameter of bubbles inside the tube banks. As a measure to keep the bubble diameter from becoming too large, we came up with the following approaches.

① Employ a structure that facilitates the breaking up of bubbles (make the bubbles smaller)
② Employ a structure that makes it difficult for the bubbles to coalesce (keep the bubbles from becoming larger)
③ Employ a structure that makes it difficult for the bubbles to grow in size (narrow the pitch)
④ Reduce the amount of air supplied (reduce superficial velocity)

Meanwhile, by studying the relationship between the pitch of the embedded tubes and the amount of thinning caused by abrasion (Fig. 5), we also found that abrasion can be minimized by further narrowing the tube pitch, and keeping the bubbles jetting forth from the distributor air nozzle** from coalescing and becoming larger. Furthermore, by examining the relationship between the horizontal pitch of the embedded tubes and the amount of thinning (Fig. 6), we also found that the amount of thinning can be reduced by making the ratio (c/d) between the tube pitch (c) and outer tube diameter (ϕd) smaller. As a result, we narrowed the horizontal pitch in the tube banks and adopted a structure that reduced the clearance to about 70%.

*Superficial velocity ratio:
The ratio between the flow velocity at the time when fluid sand first begins to flow (Umf) and the flow velocity of the fluid sand during actual operation (Ut)

**Distributor air nozzle:
A device for supplying air uniformly inside the fluidized bed to cause the fluid sand to flow

(2) Impact study of corrosive environment

The corrosive environment is affected by the type of fuel, steam temperature and pressure of the tubes, and the state of combustion. Therefore, we studied the relationship between the environment inside the fluidized bed and thinning based on past data. As for the impact of fuel on

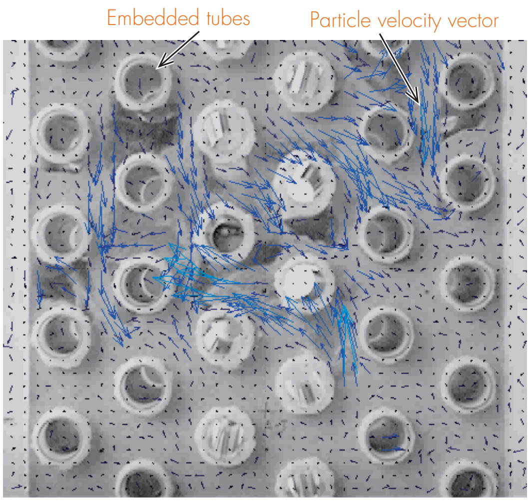


Fig. 4 Velocity analysis of bubbles inside the tube bank

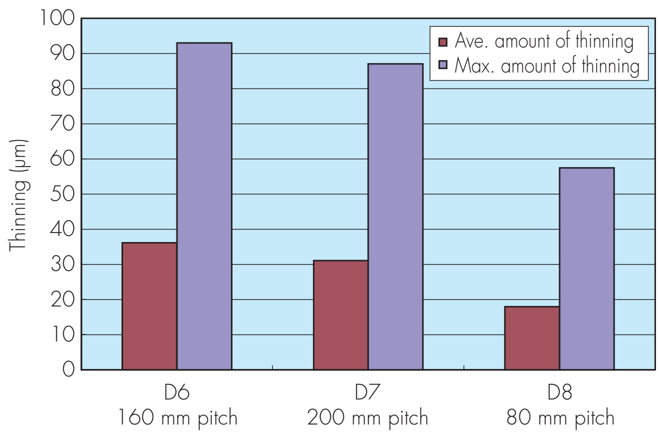


Fig. 5 Relationship between furnace width pitch of embedded tubes and tube wall thinning

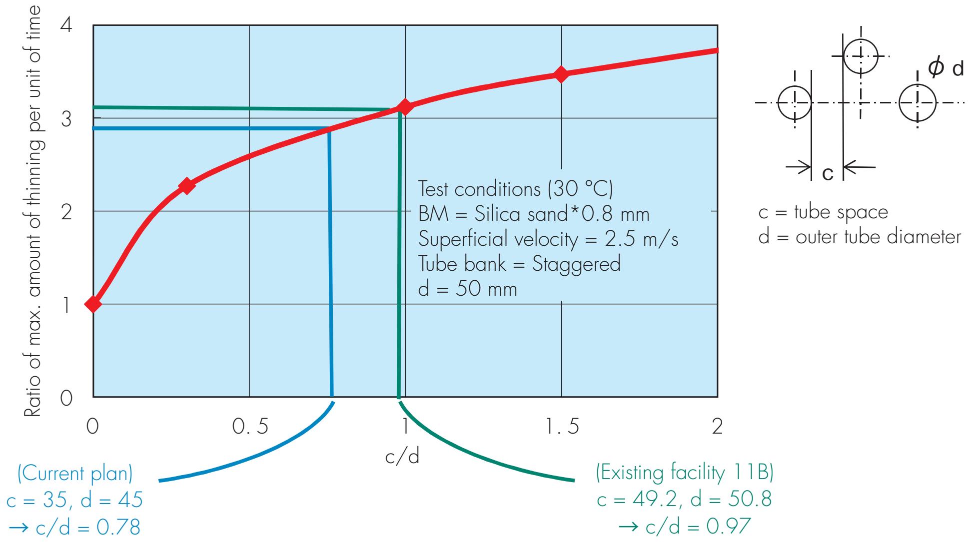


Fig. 6 Relationship between horizontal pitch of embedded tubes and thinning due to abrasion

the environment, the corrosive environment differs significantly between fluidized-bed boilers fired with coal and those fired with corrosive fuels such as RDF* and RPF**. Between these two types of boilers, those fired with corrosive fuels are far more likely to cause thinning, and the effect is multiplied through a combination of corrosion and abrasion. Due to the nature of fluidized-bed combustion, a certain degree of thinning cannot be avoided. However, we will need to mitigate the corrosive environment in order to reduce the impact of corrosion.

Based on a study of past literature, we found that sulfur dioxide (SO_2) changes chlorides into sulfates, which are less corrosive. For instance, 2(K, Na)Cl+SO_2+O_2 is altered to (K, Na)2SO_4+Cl_2. As for hydrogen chloride (HCl), a corrosive gas generated inside a boiler furnace, and SO_2, if SO_2 and HCl exist in equal amounts, or if the concentration of the former is more than double that of the latter, chlorides are changed into sulfates, mitigating the corrosive environment as a result.

The relationship between the HCl/SO_2 molar ratio and the fuel and exhaust gas characteristics of a conventional type of fluidized-bed boiler is shown in Fig. 7. The area in the lower left of the graph, where the HCl/SO_2 molar ratio is small, corresponds to the occurrence of minor corrosion,

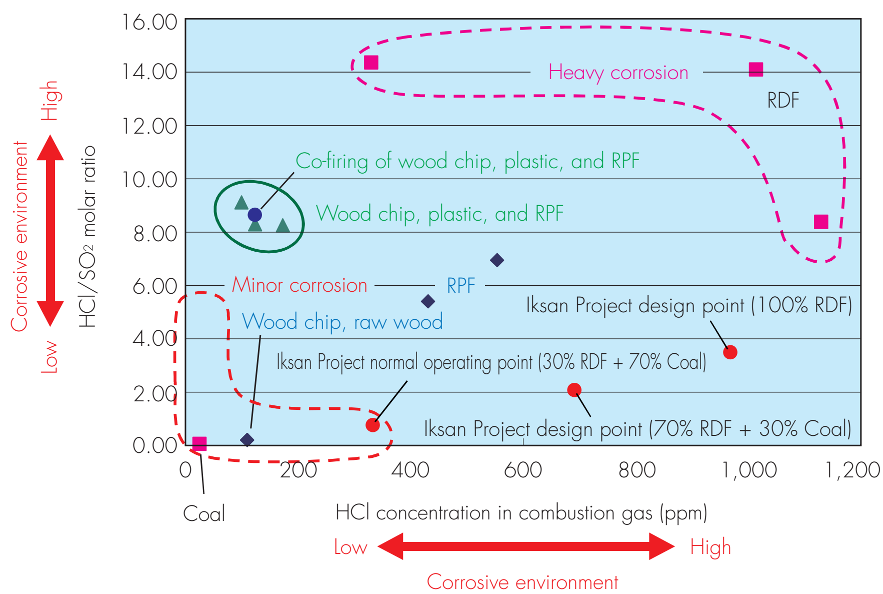


Fig. 7 Impact of HCl/SO_2 ratio in combustion gas on corrosion

whereas the area in the upper right, where the HCl/SO_2 molar ratio is large, corresponds to the occurrence of heavy corrosion. This indicates that in fluidized-bed boilers, sulfates are less corrosive than chlorides as in normal boilers.

As a result, we concluded that it would be possible to reduce thinning by mixing sulfur-containing fuel with corrosive fuels, and that ordinary coal is effective for this purpose.

*RDF: Refuse Derived Fuel
**RPF: Refuse Paper and Plastic Fuel

4 Embedded tube wall thinning in RDF and coal-fired boiler

We implemented the measure discussed above and conducted a study to identify the amount of thinning inside the embedded tubes of the boiler delivered to the Iksan plant (Fig. 8).

Commercial operation was started in January 2012, and measurements were taken at the end of September 2013 and early in June 2014. The cumulative operating time was about 14,400 hours when the first measurement was taken, and about 20,160 hours at the time of the second measurement. In terms of the amount of thinning in a single location, it was 0.42 mm/20,160 hours on average for the embedded superheater tubes (SH: stainless steel). This came to 0.17 mm per 8,000 hours of operation annually. The maximum amount of thinning observed was 2.4 mm/20,160 hours. The locations where we observed maximum thinning were dispersed instead of always occurring in the same place.

On the other hand, the average amount of thinning was 0.40 mm/20,160 hours (0.16 mm/8,000 hours) for embedded evaporator tubes (EVA: carbon steel), the maximum thinning 2.9 mm/20,160 hours. Figure 9 shows a comparison with the data (i.e., average amount of thinning) for Kawasaki's conventional type boiler organized in terms of HCl/SO_2 gas molar ratio. A comparison between the average annual thinning of embedded superheater tubes (SH: stainless steel) and embedded evaporator tubes (EVA: carbon steel) of Kawasaki's conventional type boiler and the results of the improved type that was tested this time indicate a reduction of some 90% in the average amount of thinning, achieved by improving environmental conditions.

It should be noted that the existing boiler and the boiler recently delivered differ in the surface temperature of the embedded tubes. In particular, the temperature is approximately 30°C lower in the embedded evaporator tubes, which also contributed to the reduction of the rate of thinning.

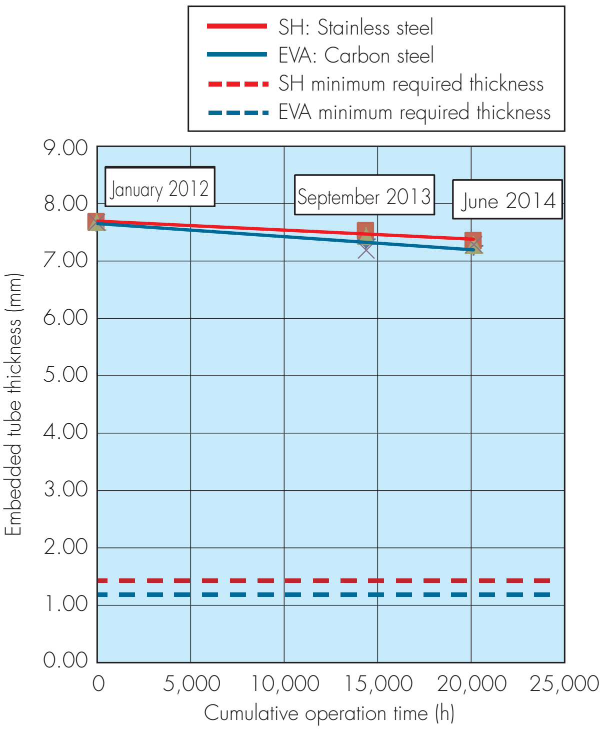


Fig. 8 Cumulative operating time and embedded tube thinning in ICFB for South Korea

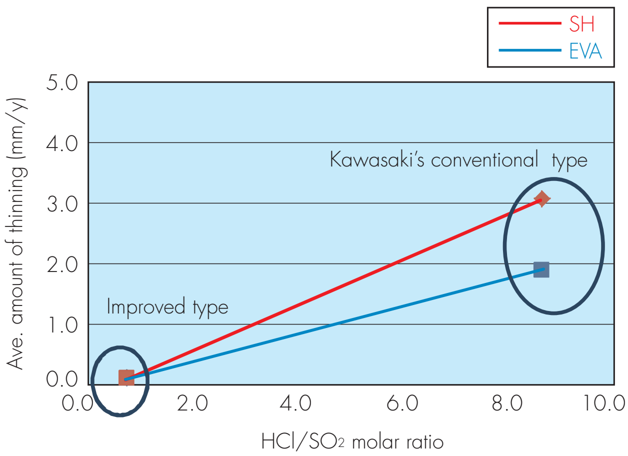


Fig. 9 Comparison between HCl/SO_2 gas ratio and annual embedded tube corrosion amount

5 Summary

With the test data we obtained using an actual boiler in operation, we were able to verify that three approaches are effective in reducing thinning in embedded tubes.

① Narrowing the pitch of tube banks

② Promotion of the vitrolization of chloride salt with SO_2 gas

・Reduce the HCl/SO_2 molar ratio. In ICFB, mixed combustion with coal for a period of time is also effective.

③ Reduction of metal temperature

Although the measures implemented this time were effective in extending the service life, we will still need to consider the following in order to address other conditions (fuel circulation and steam conditions).

① Use of an auxiliary fuel containing sulfur as a substitute for coal (e.g., paper sludge) or an additive to mitigate the corrosive environment

② Method to break up the bubbles into even smaller bubbles

・Improving the injection conditions of the distributor air nozzle

・Further distribution of fluidizing air inside the fluidized bed

③ Reduction of flow velocity

・Impact of further reduction of the superficial velocity ratio on heat transfer

Concluding remarks

It is expected that demand for boilers capable of co-firing RDF or biomass and coal will continue to grow in emerging countries as well, as they are faced with an increased amount of waste to handle due to urbanization. The increasing number of power plants co-firing excess biomass from biomass power plants and cheap coal is also likely to fuel this growth. We will build on the success of the recent project to achieve further extension of service life and cost reduction with an eye to tapping this demand.

As for the RDF-fired ICFB for South Korea, the success of the Iksan project led to two additional projects, for which construction is currently underway.


Sadayuki Mutoh
Boiler Design Department,
Energy Plant Engineering Division,
Plant & Infrastructure Company


Hiroyuki Mori
Boiler Plant Engineering Department,
Energy Plant Engineering Division,
Plant & Infrastructure Company


Hironori Shimizu
Boiler Design Department,
Energy Plant Engineering Division,
Plant & Infrastructure Company


Koya Takeda
Environmental Plant Department,
Environmental Plant Engineering Division,
Plant & Infrastructure Company

Waste incineration and biogas generation complex
– New waste treatment system compatible with the feed-in tariff scheme

In March 2014, Kawasaki completed the construction of Japan's first waste incineration and biogas generation complex called Hofu City Clean Center. The facility converts municipal waste into biogas via a methane fermentation process. The biogas is used to superheat main boiler steam for high-efficiency power generation. Kawasaki has adopted the proprietary Parallel Flow Type Incinerator for this facility, enabling low-emission combustion with a low excess air ratio. This resulted in a system that is both energy efficient and environmentally friendly.

Preface

Expectations towards waste as an energy source have steadily grown in recent years based on the perspectives of global environmental conservation and energy issues, and waste incinerators and biogas generators are now attracting attention.

1 System overview

From the first facility Kawasaki developed, we have delivered various incineration facilities from the perspective of sanitary waste treatment, responding to the needs of the times. We have also worked to increase generation efficiency from the 1990s.

With this as a background, Kawasaki recently delivered the Hofu City Clean Center, adopting a complex of waste incineration and biogasification—the first of its kind in Japan. The combustible waste treatment facility combines our propriety waste incineration technology with biogasification technology that ferments methane from municipal waste in a complex system to realize a generation efficiency of 23.5%, the highest level for a facility of its scale. The plant also has a recycling facility.

The combustible waste treatment facility is a complex facility combining a waste incineration system and a biogasification system, which have the following capacities.

① Combustible waste treatment facility
- Waste incineration system 150 t/24h (75 t/24h × 2 furnaces)
- Biogasification system 51.5 t/24h (25.75 t/24h × 2 tanks)

② Recycling facility 23 t/5h

Figure 1 shows the treatment flow of the complex facility. Combustible municipal waste is treated according to this flow.

(1) Waste incineration system

① Waste collected from households is stored in a waste pit, after which part of it is supplied to the incinerators for treatment. After combustion, the heat of exhaust gas is recovered by the waste heat boiler.

② The harmful substances contained in the combustion exhaust are decomposed and removed by non-catalytic denitration equipment and bag filters.

③ The bottom ash from incinerators and fly ash from bag filters are used as cement raw material.

(2) Biogasification system

① Some of the waste stored in the waste pit is supplied to a sorting system for shredding, magnetic separation, mechanical separation, and other forms of preprocessing. The waste suitable as material for biogasification is stored in a sorted waste pit and other waste is returned to the waste pit.

② The waste in the sorted waste pit is further shredded

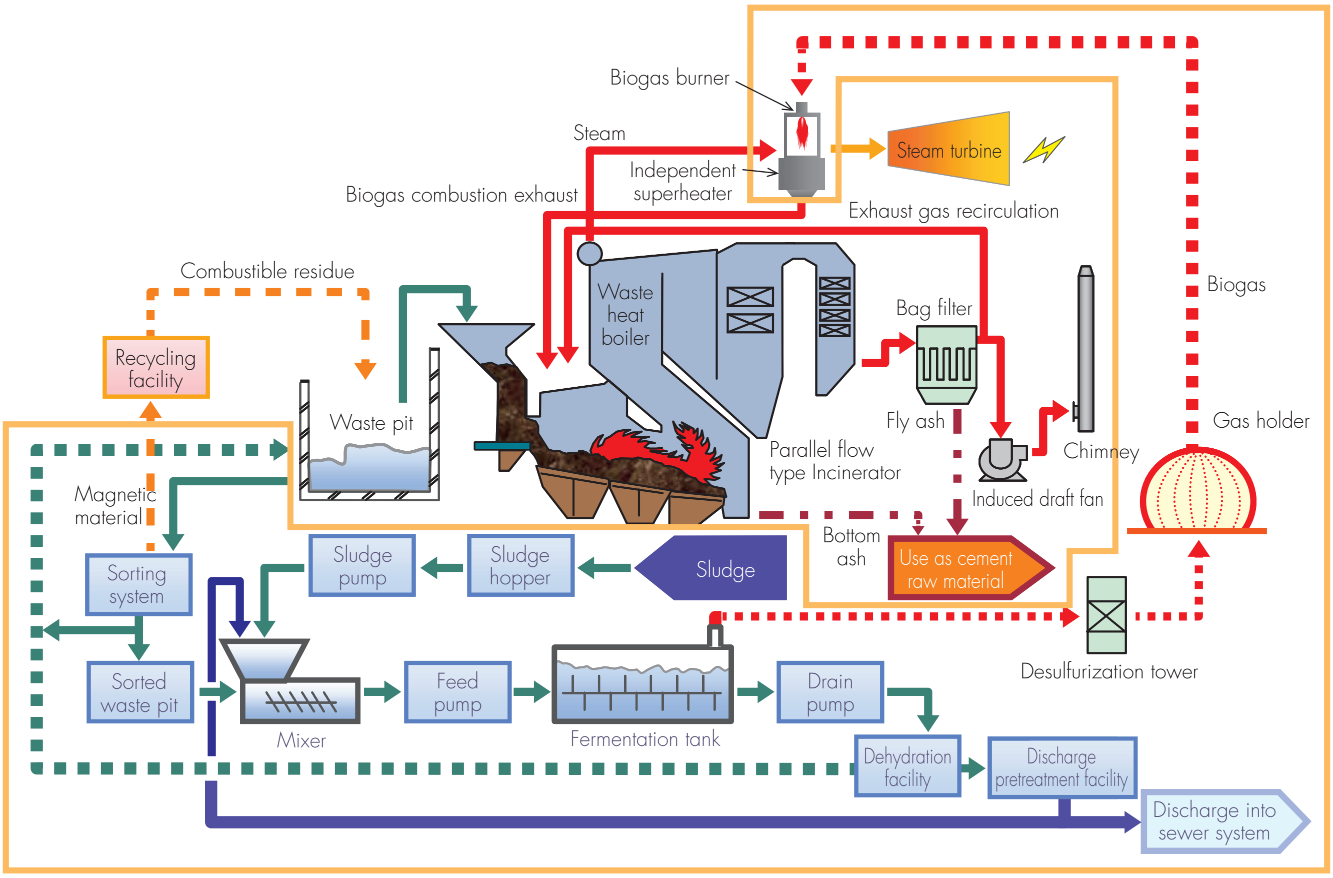


Fig. 1 Complex facility treatment flow

and mixed with dilution water and sewage sludge received from an adjoining facility. It is then made a solid concentration suitable for biogasification and fed into a fermentation tank by a feed pump.

③ Biogas including methane is generated in the fermentation tank by decomposing the organic matter in the raw material. Hydrogen sulfide is removed from the generated biogas in the desulfurization tower, after which the biogas is stored in a gas holder.

(3) Complex

① The fermentation residue generated in the fermentation tank of the biogasification system is dehydrated and returned to the waste pit for incineration with the waste.

② The biogas generated in the biogasification system is burned in the biogas burner and used as a heat source for an independent superheater that further superheats the steam generated by the waste heat boiler.

③ The biogas combustion exhaust from which the heat has been recovered by the independent superheater is fed into an incinerator and the heat it still retains is recovered in the waste heat boiler in order to maximize the rate of heat recovery.

2 Design and operation of each element

(1) Parallel Flow Type Incinerator

Kawasaki has adopted the proprietary Parallel Flow Type Incinerator (Fig. 2) in the facility, realizing a high energy recovery rate and low emissions through low air ratio combustion. Its properties are as follows.

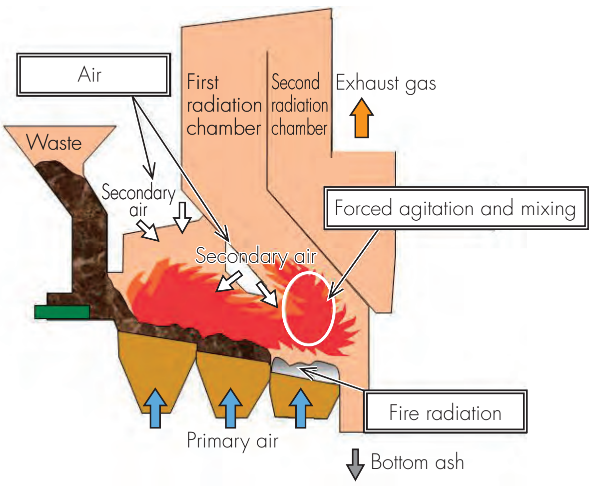


Fig. 2 Prallel Flow Type Incinerator

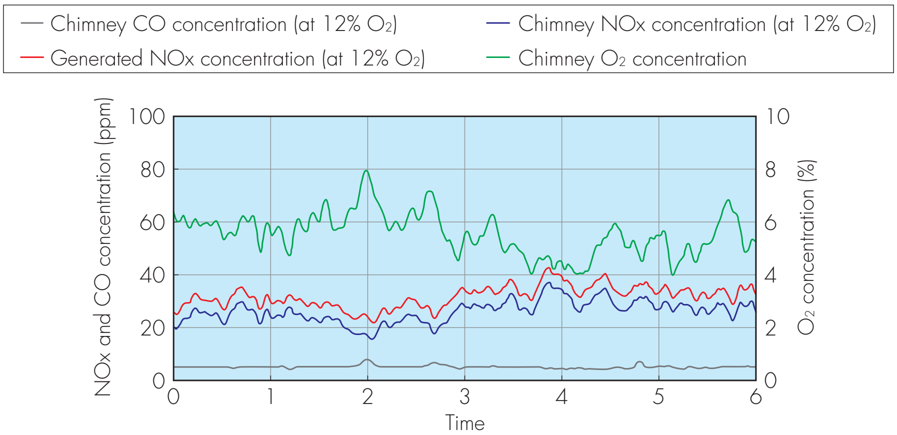


Fig. 3 Trends in exhaust gas emissions

① The form of the parallel flow reverses gas flow at the incinerator outlet, enabling efficient and low air ratio combustion due to the forced mixing and agitation of the air.

② The establishment of multiple secondary air feed points allows the introduction of suitable volumes of air at suitable nozzles, enabling decreased air intake and low air ratio combustion.

③ Staged combustion with secondary air homogenizes the temperature in the furnace and eliminates isolated regions of high temperature, suppressing the generation of thermal NOx and enabling low NOx combustion.

④ The structure makes fire pass through above the ash, enabling combustion by radiation heat, which can burn out combustibles.

Figure 3 shows the trends in exhaust gas emissions realized at the Hofu City Clean Center by the above design. From this the facility is found to be operating at a low air ratio and with low emissions at an average of 5.6% O_2 and 32 ppm NOx.

(2) Sorting system

It is necessary to sort the waste gathered in the facility into waste suitable for biogasification and that not suitable. In addition to decreasing the efficiency of the fermentation process, improper sorting is a cause of pipe blockage around the fermentation tank.

Sorting can be performed at the collection stage or mechanically after dumping into waste pit, and this facility adopts the latter method, which does not require waste to be presorted in each household. Figure 4 shows the flow of mechanical sorting.

The waste accepted is around 500 mm in size. This is coarsely shredded to around 150 mm by a primary

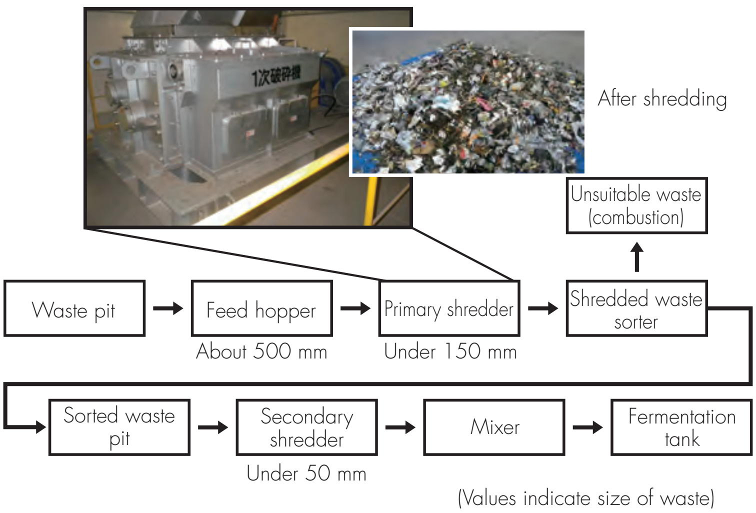


Fig. 4 Mechanical sorting flow

shredder and turned into sorted waste by mechanical sorting. This reduces the volume of large or long vinyl and cloths unsuitable for methane fermentation, and sorts the kitchen waste and paper, enabling a good fermentation material.

(3) Methane fermentation system

High-temperature methane fermentation is employed, in which the inside of the fermentation tank is heated to approximately 55°C to decompose the organic matter. The material remains inside the fermentation tank for around 20 days.

(i) Strength evaluations of tank

The fermentation tank is a horizontal steel-plate cylinder with a diameter of 6.8 m, length of 34 m, and volume of 1,000 m^3. Paddles are installed to constantly agitate the material and efficiently expel the gas generated inside the tank.

The fermentation tank needs to be strong enough to retain its contents and biogas even during an earthquake. Accordingly, Kawasaki performed an analysis of stress (Fig. 5) along with an analysis of deformation conditions during operation in the event an earthquake, and reflected the results in the strength design of the tank. The same analysis was also performed concerning deformation conditions during normal operation to verify that there are no design issues.

(ii) Operation status

The sorted waste is shredded to under 50 mm by a secondary shredder, mixed with regulating water and sludge, and fed to the fermentation tank. The system has maintained stable operation to date, indicating that this fermentation technology has a high tolerance to the inclusion of debris. Also, the system has enough capacity for stable biogasification without having municipal waste presorted in each household.

Figure 6 shows the biogas generation status. The biogas generation rate exceeds 250 m^3 N/ton waste, demonstrating a performance greatly surpassing the 150 m^3 N/ton waste, which was a condition for a 1/2 subsidy rate for a

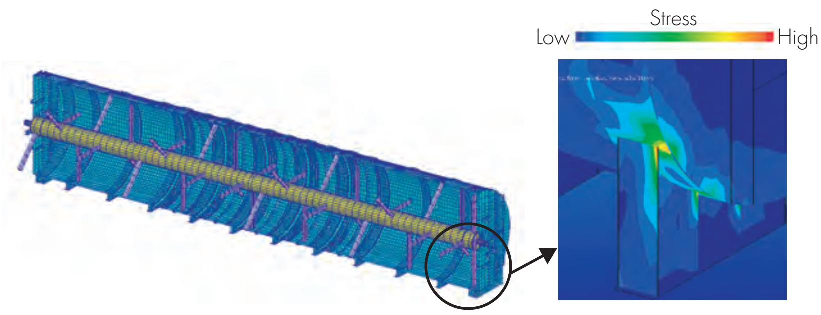


Fig. 5 Structure and stress analysis results of fermentation tank

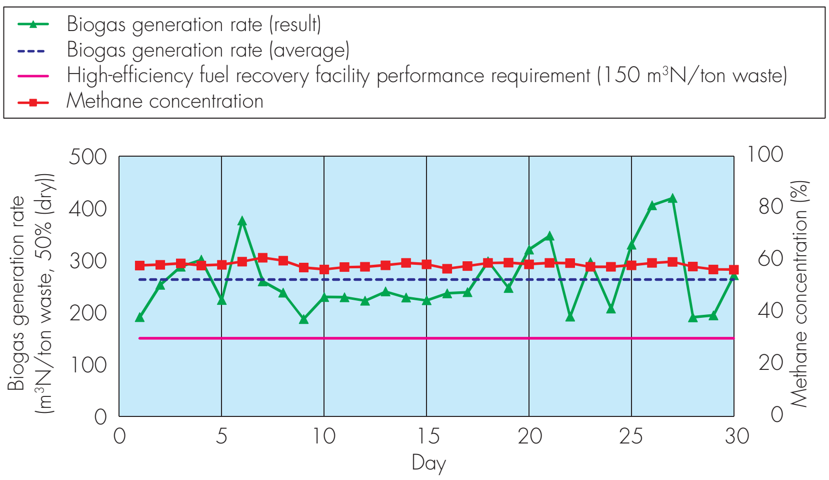


Fig. 6 Biogas generation status (December 2014)

high-efficiency fuel recovery facility. Also, the methane gas concentration was higher than the planned value of 54% at about 58% on average.

(4) Complex of waste incineration and biogas

At the facility, the steam condition for the waste heat boiler is 4 MPaG×365°C. However, the steam acquired by the waste heat boiler is further superheated to 415°C by the independent superheater (Fig. 7) using the high-temperature gas obtained by burning the biogas.

(i) Operation of the independent superheater

Figure 8 shows the operating status of the biogas burner and independent superheater. In the graph, "Before superheating by biogas" indicates the main steam temperature at the boiler outlet and "After superheating" indicates the main steam temperature at the independent superheater outlet.

It was possible to stably superheat the main steam with the load of biogas burner at 100% and at 50% of its rated value. A stepped change was implemented at about 20 hours, but the load following was extremely quick and operational adjustments were verified to be simple.

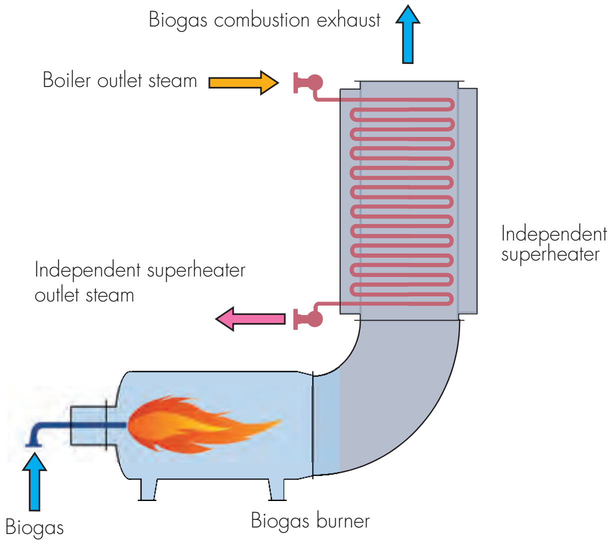


Fig. 7 Independent superheater

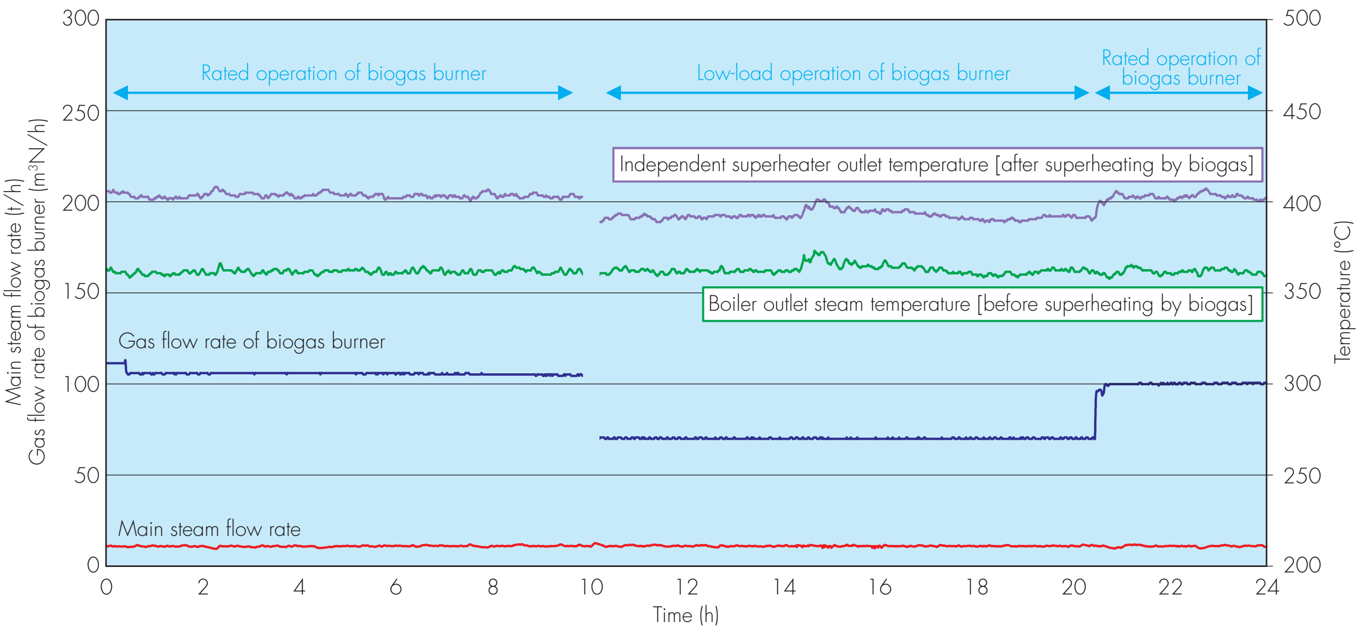


Fig. 8 Operating status of biogas burner and independent superheater

Table 1 Power generation efficiency

Independent superheater	During operation	During suspension
Power generation (KWh)	3,545	3,584
Waste heat input (MJ/h)	62,429	63,202
Biogas heat input (MJ/h)	3,885	0
Generation efficiency (%)	23.6	21.0

(ii) Improvement of power generation efficiency

In a comparison of power generation efficiency when the biogas burner is in operation and when it is suspended, an improvement of over 2% in efficiency was achieved (Table 1).

Concluding remarks

This complex system equipped with an independent superheater fueled by biogas can contribute to the improvement of power generation efficiency in comparison to a simple waste incineration power generation facility of the same scale. Furthermore, the system is approved for the feed-in tariff. Moving forward, Kawasaki intends to promote complex system using an independent superheater, which is a simple system providing both ease of operational adjustment and simple maintenance.


Hiroyuki Uchida
Environmental Plant Department,
Environmental Plant Engineering Division,
Plant & Infrastructure Company


Professional Engineer (Environmental Engineering)
Hideaki Murata
Environmental Plant Department,
Environmental Plant Engineering Division,
Plant & Infrastructure Company


Katsuhisa Usui
Environmental Plant Department,
Environmental Plant Engineering Division,
Plant & Infrastructure Company


Nobuki Uehara
Environmental Plant Department,
Environmental Plant Engineering Division,
Plant & Infrastructure Company


Hideo Sugihara
Environmental Plant Department,
Environmental Plant Engineering Division,
Plant & Infrastructure Company


Professional Engineer (Environmental Engineering)
Nobuko Taniguchi
Environmental Plant Department,
Environmental Plant Engineering Division,
Plant & Infrastructure Company

Cellulosic ethanol production system
– Energy creation from non-food sources

Kawasaki constructed a demonstration plant of bioethanol production in Akita Prefecture in FY2009 and demonstrated its operation until FY2012 under a subsidized project of the Ministry of Agriculture, Forestry and Fisheries. With a view to commercialization, we developed our technologies based on demonstration to produce the bioethanol more economically and make our process compact by increasing the concentration of raw material in hot-water saccharification.

Preface

Resource depletion and global warming caused by CO_2 emissions have been pointed out as the likely scenario of our continued use of fossil fuels, and reducing our reliance on them has become a matter of global concern. On the other hand, in the world of plants, a carbon-neutral system in which carbon circulates without either increasing or decreasing is established. By using plant resources which have such properties as an alternative energy source, we will be able to reduce CO_2 emissions. Ethanol is one such fossil-fuel alternative that has been attracting much attention. In particular, hopes are running high for the practical application of bioethanol that is manufactured from non-food sources.

1 Objective

One of the ways in which non-food biomass resources can be converted into a liquid fuel that is easy to handle is to manufacture ethanol from the cellulose contained in plants. Various methods have been developed to saccharify cellulose—the key element in this approach—including a method that uses sulfuric acid and one that uses enzymes.

With an aim to establish a low-cost manufacturing process for cellulose-derived ethanol to make it sufficiently price competitive, Kawasaki has been developing a saccharification technology that uses hot water instead of sulfuric acid, and a high-efficiency fermentation technology for the resulting saccharification liquid. This approach aims to increase saccharification yield and minimize fermentation inhibition (due to excess decomposition products) by setting the reaction time precisely and preventing the excessive decomposition of sugar. While this approach yields lower saccharification rates than methods using sulfuric acid and enzymes, it will keep down the total cost of manufacturing ethanol, including running costs.

In a joint study conducted with the New Energy and Industrial Technology Development Organization (NEDO) of Japan from FY2006 to FY2008, Kawasaki developed the technology to manufacture ethanol from bagasse, the fibrous matter that remains after crushing sugar cane. Then in the second half of FY2008, Kawasaki constructed a demonstration plant for the production of ethanol from rice straw, and demonstrated its operation until FY2012 under a subsidized project of the Ministry of Agriculture, Forestry and Fisheries (MAFF), in cooperation with Akita Agriculture Public Corporation and the government of Akita Prefecture.

2 Overview of the demonstration of ethanol production technology

In this demonstration project, Kawasaki was responsible for the demonstration of biofuel (ethanol) production and a driving test using the manufactured fuel. The manufacturing facility of biofuel covered the entire process from the reception of the raw material (rice straw) to the production of dehydrated ethanol. Kawasaki was

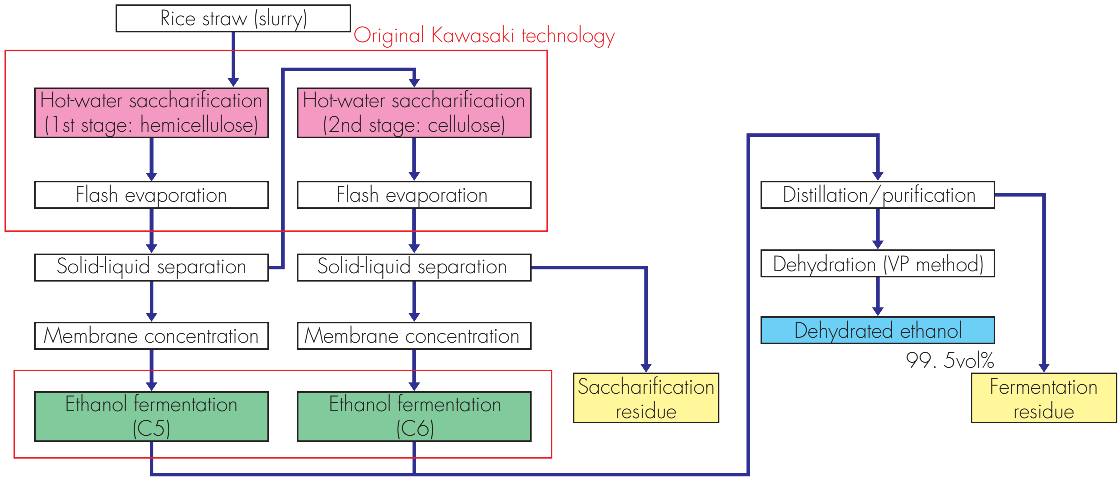


Fig. 1 System flow overview

responsible for the design, construction, and operation of the plant, as well as the demonstration of ethanol production technology and identification of issues to be addressed in commercializing the technology.

(1) Demonstration facility

In FY2009, Kawasaki constructed the facility shown in the photograph above in an industrial park in Katagami City, Akita Prefecture for the demonstration of biofuel production.

The ethanol production flow in this facility is shown in Fig. 1. After receiving rolls of rice straw, they are crushed and slurried, then they undergo saccharification, concentration, fermentation, distillation, and dehydration processes before turning into ethanol.

A notable characteristic of this facility is that hemicellulose and cellulose—main ingredients of rice straw—are saccharified separately by changing the hot-water condition during the saccharification process. The two types of saccharification liquid obtained are fermented using yeast that has not been genetically modified. Then the fermentation liquids are mixed together and distilled. When the resulting product is dehydrated through vapor permeation (VP) using a zeolite membrane, dehydrated ethanol with a concentration of 99.5 vol% is obtained. Products obtained in each process are shown in Fig. 2.

(2) Hot-water saccharification technology

The hot-water saccharification technology adopted in this facility uses the property of water molecules under high temperature, high pressure conditions to enter into the binding sites of organic macromolecules and break them into smaller molecules in a process called hydrolysis.

As shown in Fig. 3, this system breaks hemicellulose into xylose and xylooligosaccharide in the first stage hot-

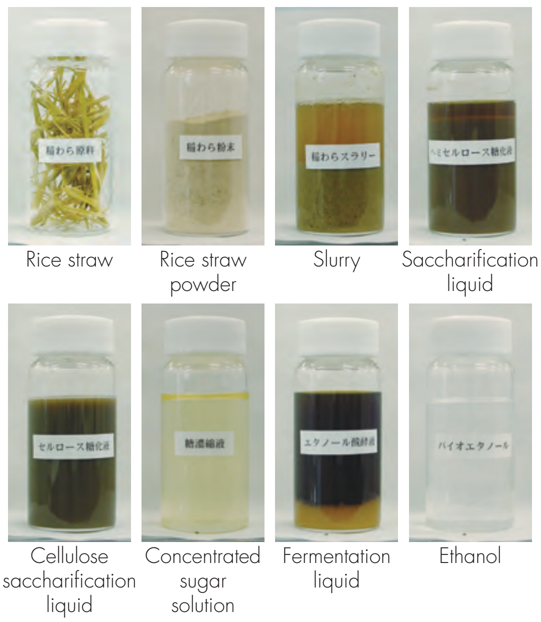


Fig. 2 Products of each process

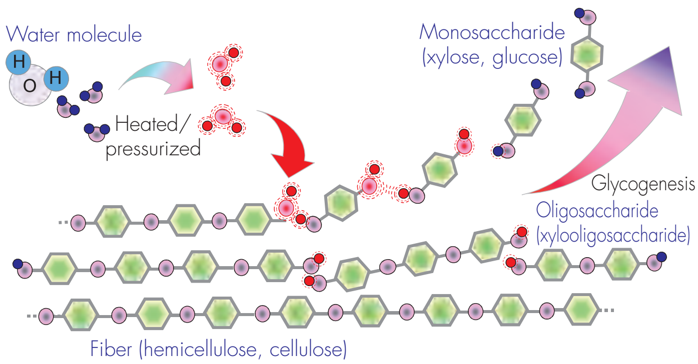


Fig. 3 Concept of saccharification process

water saccharification (150-200 °C, 0.5-1.2 MPa), and cellulose into glucose in the second stage hot-water saccharification (220-260 °C, 2-5 MPa). The saccharification reactor of the demonstration facility employed a shell and tube system in which slurried rice straw is passed through the tubes and heated to a given temperature by applying steam from outside the tubes, then rapidly cooled via flash evaporation.

(3) Fermentation process

In the joint study with NEDO conducted prior to the demonstration operation, a special yeast developed with Kobe University was used for the fermentation process. This microorganism was given the ability to simultaneously convert two types of sugar—xylose and glucose—that are obtained by saccharifying bagasse into ethanol through genetic modification.

Since this genetically-modified yeast could not be used for the demonstration, Kawasaki made improvements to a non-genetically modified yeast for the fermentation of hemicellulose saccharification liquid, which cannot be fermented using the yeast normally used to produce alcohol.

For the base yeast, we used Pichia segobiensis (JCM No. 10740), which has the ability to take up xylose as a nutrient, and improved it using a unique mutant selection method to enhance the ethanol fermentation capability.

As a result, we obtained the mutant strain K5-611⊿ shown in Fig. 4. Fig. 5 shows that the ethanol yield of the mutant strain K5-611⊿ is more than 20 percentage points higher than the yeast (wild strain) before mutant selection was performed.

(4) Results of biofuel production demonstration

The saccharification rate, fermentation efficiency, and manufacturing efficiency obtained in the final year are shown in Table 1. C5 and C6 in the table refer to saccharification liquids obtained from hemicellulose and cellulose, respectively. While the saccharification rate of cellulose was slightly lower than the target value, overall more than 150 liters of ethanol was produced from 1 ton of dry rice straw, demonstrating the effectiveness of Kawasaki's technology.

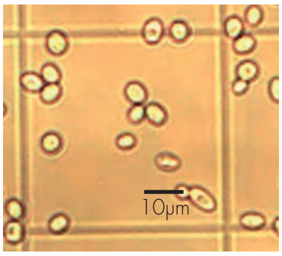


Fig. 4 Mutant strain K5-611⊿

Table 1 Saccharification rate and fermentation efficiency (raw material: rice straw)

Item	Target values	FY2012 results
Hemicellulose saccharification rate (%)	70	70
Cellulose saccharification rate (%)	50	46
C5 fermentation efficiency (%)	70	88
C6 fermentation efficiency (%)	80	91
Manufacturing efficiency* (L/t-dry)	150	153

* Loss from distillation and dehydration not included in manufacturing efficiency

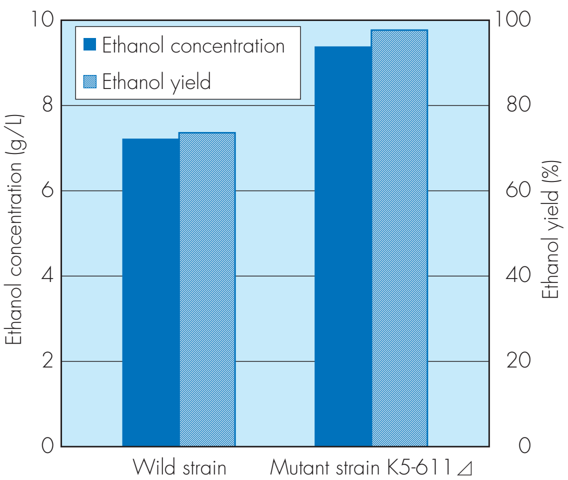


Fig. 5 Fermentation test results

Table 2 Ethanol quality analysis results

Item	Results	JIS standard
Appearance	Colorless	Colorless, transparent
Ethanol content (vol%)	99.8	≧ 99.5
Methanol content (g/L)	1.0	≦ 4.0
Water content (Wt%)	0.35	≦ 0.70
Organic impurities (g/L)	5.6	≦ 10
Electrical conductivity (μS/m)	10	≦ 500
Residue on evaporation (mg/100mL)	0.2	≦ 5.0
Copper content (mg/kg)	< 0.10	≦ 0.10
Acidity (wt%)	0.0031	≦ 0.0070
pHe (reference)	5.2	(*)
Sulfur content (mg/kg)	< 1	≦ 10

* To be agreed between relevant parties

The quality analysis results of the manufactured ethanol are shown in Table 2. The quality of ethanol to be used as automobile fuel is stipulated by the JIS standard. Our manufactured ethanol met this standard.

3 Technological improvements toward commercialization

In the demonstration project performed in Akita Prefecture, we also sought to identify issues that needed to be addressed to realize operation on a larger scale. The biggest issue was reducing facility and running costs, which we aimed to achieve by increasing the concentration of processed materials to enable making the facility smaller. While the concentration of slurry in the hot-water saccharification process was 5% in the demonstration, we were able to raise this to 30% in the component test facility by adopting a high-concentration continuous two-axis paddle system in the saccharification reactor (Table 3). This reduced the facility size and the amount of heat required for heating to one-sixth. As a next step, we are studying a technology to produce enzyme on-site as a way to reduce enzyme costs. In the enzyme method for improving the saccharification rate of cellulose, the high price of enzyme is a major factor that is driving up the cost.

(1) High-concentration processing in hot-water saccharification

When the concentration of processed material is increased, the frequency of contact between the material and hot water decreases, slowing the hydrolysis reaction. As a measure to address this issue, we adopted a two-axis paddle type saccharification reactor (Fig. 6) that is capable of agitation in the vertical direction to enable the material and hot water to come into contact in a uniform manner, and also form a plug flow (in which the material is pushed in one direction to prevent the mixture of material in the back and front) to keep the reaction time constant. This reactor also comes with a self-cleaning function. The saccharification reactor used in the component test facility is shown in Fig. 7.

Table 3 Transition of saccharification reactor

Item	NEDO joint study	Akita-MAFF demonstration facility	Akita component test facility
Development period	2006–2008	2008–2012	2011–2015
System	Medium-concentration batch	Low-concentration continuous	High-concentration continuous
Equipment type	Vertical vessel	Shell & tube	Two-axis paddle
Concentration	5–10%	2–5%	25–30%

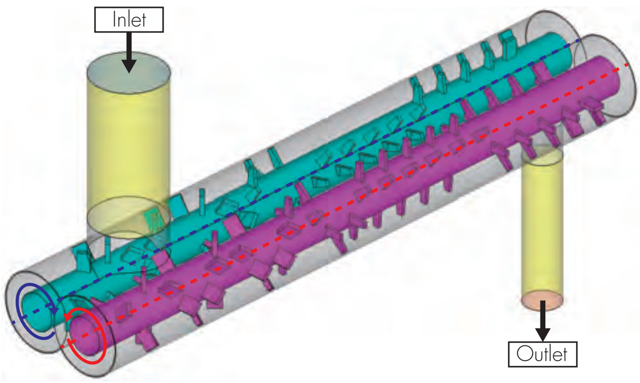


Fig. 6 Schematic diagram of a high-concentration continuous two-axis paddle-type saccharification

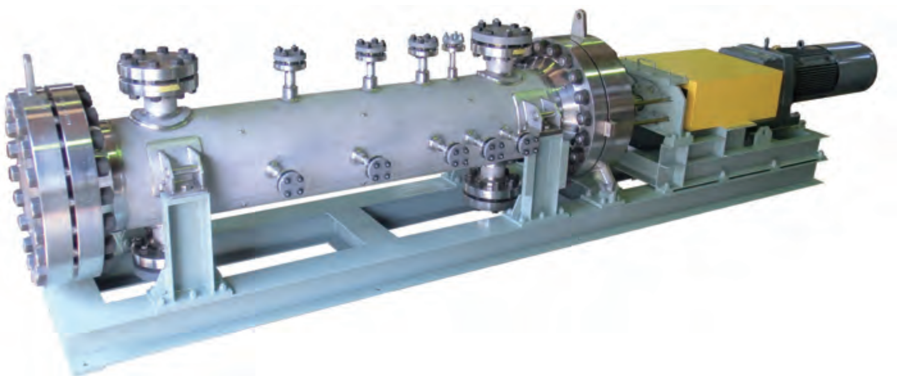


Fig. 7 Saccharification reactor used for the demonstration test in Akita

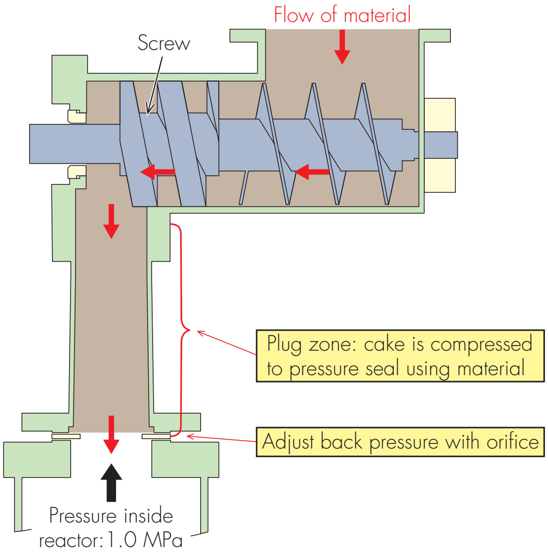


Fig. 8 First-stage plug screw pump for hemicellulose

For feeding material into the high-pressure saccharification reactor, we adopted the plug screw pump shown in Fig. 8. As the material to be fed has high solid-liquid separability, we could not use equipment such as the mohnopump and kneader that used to be employed for feeding high-concentration material. Therefore, we made improvements on a two-axis screw pump (a non-contact positive displacement pump normally used for food applications) and succeeded in pumping the material while it got separated into solid and liquid. Since the solid and liquid are separated while being pumped, the liquid enters the reactor first, followed by the solid. The lower water content causes the material at the inlet of the reactor to be further compressed, serving as a plug that prevents the reflux of high-pressure steam from inside the reactor and enabling continuous feeding.

Table 4 Saccharification and fermentation efficiency (raw material: bagasse)

Item	Target values	C5 hot-water saccharification + C6 hot-water saccharification	C5 hot-water saccharification + C6 enzyme saccharification
Ethanol yield (L/ton-dry)	206	151	242
Saccharification efficiency (%)			
Overall	65	60	72
Hemicellulose	80	80	80
Cellulose	55	50	70
Fermentation efficiency (%)			
Overall	78	60	80
Xylose (C5)	75	60	80
Glucose (C6)	80	60	80

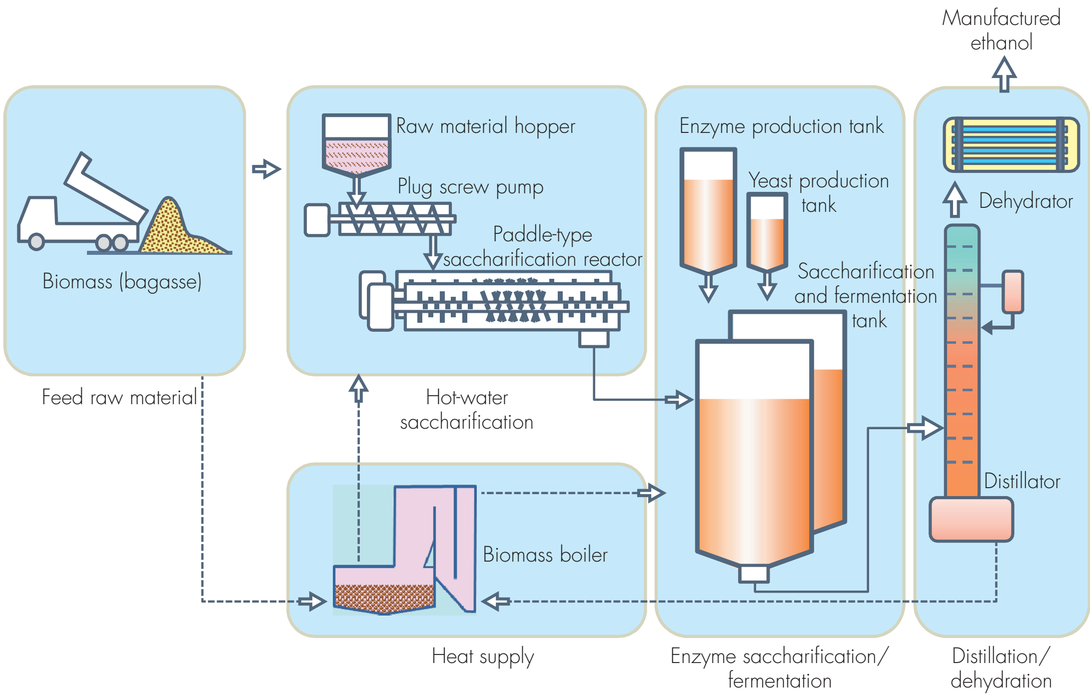


Fig. 9 Outline of cellulosic ethanol production commercial process

(2) High-concentration processing in enzyme saccharification

As for the saccharification of cellulose, there is high demand for enzyme saccharification from users seeking to maximize the ethanol yield per unit of material as shown in Table 4. In response, we are working to improve the enzyme saccharification process that responds to the high-concentration saccharification of hemicellulose mentioned above.

To address the issue of cost with the enzyme method, we have adopted a simultaneous saccharification and fertilization method that can improve the efficiency of enzyme saccharification, and also installed an enzyme production equipment in the ethanol production plant. This will enable the on-site production of enzyme to be directly supplied to the saccharification process without having to purify the solution containing the enzyme, and thus achieve a reduction of enzyme costs (Fig. 9).

Concluding remarks

In the test using the demonstration facility constructed in Akita Prefecture, we consummated the technology for high-concentration saccharification. At present, we are validating the systems for the on-site production of enzyme and simultaneous saccharification and fermentation. We are moving full speed ahead to complete the validation as soon as possible for an early launch of the equipment.

Part of the results of this study has been obtained in the course of the Ministry of Agriculture, Forestry and Fisheries soft cellulose utilization project.

Shoji Tsujita
Chemical Plant Department,
Chemical Plant & Cryogenic Storage System Engineering Division,
Plant & Infrastructure Company

Noriaki Izumi
Chemical Plant Department,
Chemical Plant & Cryogenic Storage System Engineering Division,
Plant & Infrastructure Company

Hironori Tajiri
Chemical Plant Department,
Chemical Plant & Cryogenic Storage System Engineering Division,
Plant & Infrastructure Company

Takashi Nishino
Chemical Plant Department,
Chemical Plant & Cryogenic Storage System Engineering Division,
Plant & Infrastructure Company

Manabu Masamoto
Environmental System Research Department,
Technical Institute,
Corporate Technology Division

Masaki Tsuzawa
Environmental System Research Department,
Technical Institute,
Corporate Technology Division

Technologies of hydrogen liquefaction, transport and storage – Paving the way to a hydrogen fueled future

Demand for hydrogen is expected to increase as we head toward becoming a hydrogen economy. With a view to realizing the Hydrogen Energy Supply Chain Initiative, which envisions importing hydrogen produced in Australia, Kawasaki is developing related equipment. Before commercial operation of the hydrogen energy chain, Kawasaki is planning to implement a small-scale pilot chain around 2020, and a large-scale demonstration chain between 2025 and 2030. When importing hydrogen gas, it will be converted into LH_2 (liquefied hydrogen) suitable for large-scale transport and storage. The technology used for liquefaction, transport, and storage is derived from the cryogenic technology Kawasaki has built up through the development of rocket launch complexes and LNG carries.

Technological development to realize the chain concept is steadily progressing. In terms of liquefaction technology, Kawasaki has succeeded in hydrogen liquefaction using Japan's first large-scale hydrogen liquefier. In terms of transport technology, Kawasaki has obtained approval in principle for the cargo containment system to be installed on the world's first LH_2 carrier.

Preface

Commercialization of hydrogen usage systems and development of infrastructure-related technology are stepping up in Japan and overseas, in a move to build a hydrogen society that will resolve the environmental issues of global warming and resource depletion. Kawasaki proposed the concept of a hydrogen energy supply chain in 2010 and has been working toward its realization. This report discusses the background to the Kawasaki supply chain concept, the predicted expansion of future hydrogen demand, and the state of Kawasaki's achievements and technical developments relating to the liquefaction of hydrogen and the transportation and storage of LH_2 that comprise the supply chain.

1 Background

The Strategic Energy Plan[1)] approved by the Japanese Cabinet in April 2014 stipulated initiatives to realize a hydrogen society. With regards to hydrogen business, fuel cell vehicles (FCV) went on sale at the end of 2014, one year ahead of schedule. Furthermore, in the lead up to COP21 at the end of 2015, the EU announced in February 2015 the long-term target of reducing global greenhouse gas emissions by at least 60% in comparison to 2010 levels by 2050. Amidst such conditions, expectations in the hydrogen society are steadily mounting.

The French science fiction author Jules Verne first predicted a hydrogen society in his 1874 novel, The Mysterious Island. A century later in 1974, the first World Hydrogen Energy Conference (WHEC) was held, and scientific discussion of the subject began in earnest. Since then, hydrogen energy systems have been proposed around the world as a means to complement electric power systems.

In Kawasaki's concept of a hydrogen energy supply chain, hydrogen is manufactured from lignite in Australia, the CO_2 generated is captured and stored on-site, and CO_2-free hydrogen is imported into Japan. Kawasaki has proposed this concept and is working toward its realization in preparation for increased hydrogen demand in the coming hydrogen society.

2 Future hydrogen demand increases

In the hydrogen society, demand for hydrogen will rapidly increase as applications for hydrogen expand from the stationary fuel cells and FCV already at the stage of commercialization, to hydrogen engines and gas turbines for power generation. Japanese research institutions, have predicted hydrogen demand according to various CO_2 restrictions and energy technology evaluation models. For example, The Institute of Applied Energy assumes a CO_2 emissions reduction of 5% of 1990 levels by 2020, and 80% by 2050, and goes on to predict hydrogen demands hypothesizing hydrogen derived from overseas lignite, natural gas, and wind power. The predicted demand reaches 2.5 Mtoe (megaton of oil equivalent) (approximately 9.7 billion Nm^3/y of hydrogen) in 2030 and 57 Mtoe (approximately 219.8 billion Nm^3/y of hydrogen) in 2050.

3 Hydrogen imports from overseas

The idea of importing hydrogen from overseas has been investigated in Japan and other countries for over 20 years[2]. Table 1 shows the transportation route, hydrogen source and form of hydrogen transported for each project. As shown by the table, the form of hydrogen transported is LH_2 in most cases. Two representative projects are the Euro-Quebec Hydro-Hydrogen Pilot Project (EQHHPP, 1986-1998) and Japan's International Clean Energy Network Using Hydrogen Conversion (World Energy Network (WE-NET), 1993-2003), both of which used renewable energy as a hydrogen source. The EQHHPP split water at a 100 MW hydro plant in Quebec, Canada, and transported the LH_2 produced to Hamburg, Germany by sea. The amount of hydrogen transported was 1.5×10^4 t/y (167 million Nm^3/y). The WE-NET adopted LH_2 as the medium for hydrogen transportation in the same way as the EQHHPP, but at a scale of about 10 times larger.

4 The Kawasaki hydrogen energy supply chain concept

In 2010, Kawasaki announced its concept of a CO_2-free hydrogen energy supply chain, by which cheap hydrogen is produced from lignite in Victoria, Australia, and transported for use in Japan. The concept was also specified as a future hydrogen energy chain in the Japanese Ministry of Economy, Trade and Industry's Strategic Road Map for

Table 1 Overseas hydrogen import projects

Project	Transportation route	Hydrogen source	Form of hydrogen transported
EQHHPP	Canada - Europe	Hydro	LH_2, MCH, NH_3
NHGE	Norway - Europe	Hydro	LH_2
EURO-HYPORT	Iceland - Europe	Hydro/geothermal	LH_2
HYSOLAR	Germany - Saudi Arabia	Solar	LH_2
HIHEPP	Hawaii - other countries	Tidal	–
Wind power	Argentina - other countries	Wind	LH_2
Glacier	Greenland	Hydro, glacier	LH_2
WE-NET	Canada - Japan	Hydro	LH_2, NH_3, CH_3OH

Notes: LH_2: liquefied hydrogen, MCH: methylcyclohexane, NH_3: ammonia, CH_3OH: methanol

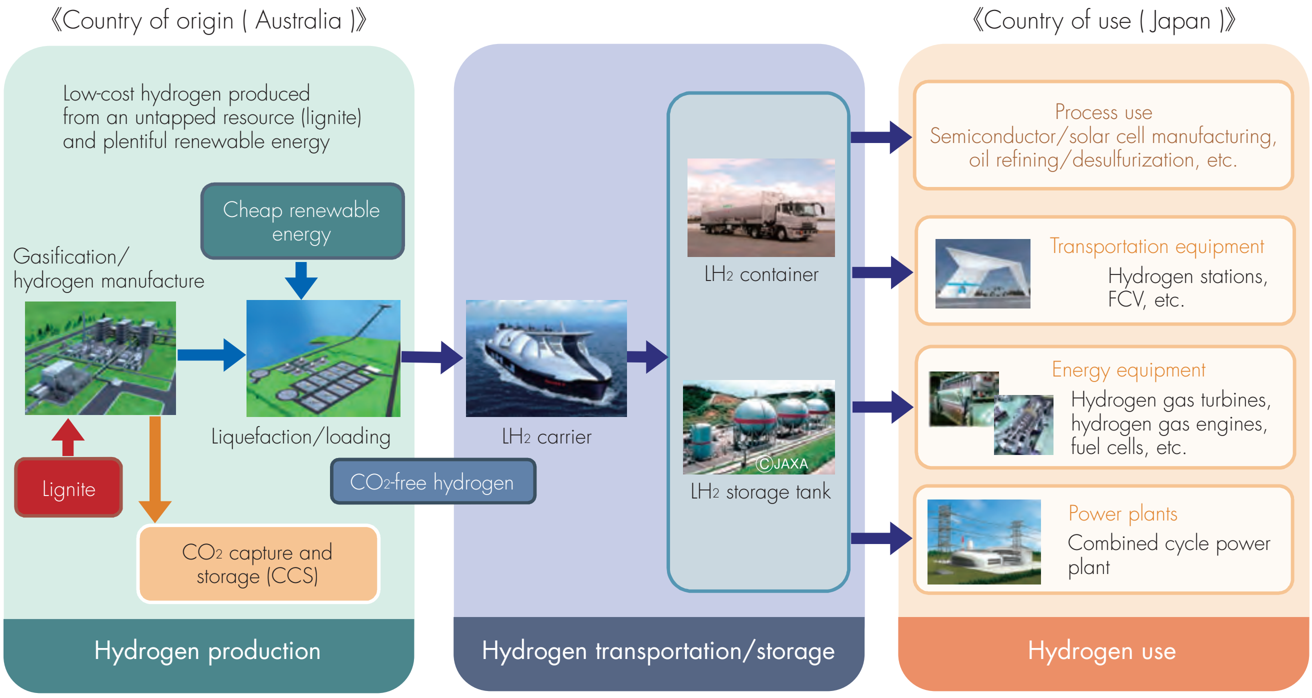


Fig. 1 The concept of a hydrogen energy supply chain

Hydrogen and Fuel Cells published in June 2014. Figure 1 gives a conceptual diagram of the system. Hydrogen is produced from Australian lignite by gasification and purification, after which it is liquefied and transported by ship to Japan. Cheap, CO_2-free hydrogen with no associated CO_2 emissions is imported, because the CO_2 gas produced in the gasification process undergoes CO_2 capture and storage (CCS) in Australia. The imported LH_2 is used as a fuel in a hydrogen power plant adjacent to the receiving terminal and is distributed to hydrogen stations for FCV and to energy equipment such as hydrogen engines in various locations.

Lignite is an underexploited form of coal limited to use in power plants close to the excavation site due to having a high water content (approximately 60%) in comparison to bituminous coal and therefore a low transportation efficiency, and also because it tends to become spontaneously combustible when dry. A vast quantity exists in Victoria, Australia, making hydrogen production possible at an extremely low cost.

5 Hydrogen infrastructure

Kawasaki is promoting the development of a hydrogen infrastructure in a move towards the realization of a hydrogen society. This specifically comprises hydrogen liquefaction systems to convert gaseous hydrogen into a liquid, tanks to store the LH_2, containers and ships to transport the LH_2, and the like.

This infrastructure is highly compatible with Kawasaki's current business, because it can be realized by building on the LNG technology, cryogenic technology, and large-scale construction technology Kawasaki has cultivated to date, such as LNG carriers and the LH_2 tanks of the Japan Aerospace Exploration Agency (JAXA) Tanegashima Space Center.

Of these, we will describe in detail the hydrogen liquefaction system, the first for industrial use comprising entirely Japanese proprietary technologies.

6 Hydrogen liquefaction system

The hydrogen gas produced from lignite is refined to a high purity and pressure-fed to a hydrogen liquefaction system by pipeline. The hydrogen gas is cooled to approximately 20 K (-253°C) and liquefied by a hydrogen liquefier. The LH_2 is loaded into containers and tank trucks equipped with thermal insulated tanks, and transported to the shipping terminal. In a large-scale chain, the hydrogen gas is sent to the shipping terminal by pipeline, and liquefied by a hydrogen liquefier established at the terminal. At the shipping terminal, the LH_2 is temporarily stored in a tank, before being loaded onto a carrier by liquid pump and transported to Japan by sea. After arrival in Japan, it is stored in an LH_2 tank at the receiving terminal and distributed from the tank to hydrogen usage systems at various locations. The scale of the hydrogen liquefaction system from liquefaction to storage and transportation is determined according to hydrogen demand and output volumes and the number of days required for marine transportation. The properties of LH_2 and a description of the hydrogen gas liquefaction and the storage and transportation apparatus for LH_2 in the hydrogen liquefaction system are given below.

(1) Properties of LH_2

Media by which hydrogen can be transported and stored include LH_2, compressed hydrogen gas, hydrogen storage alloys, and chemical media, but only compressed hydrogen gas and LH_2 are developed to the level of commercial application. Hydrogen storage alloys and chemical media require an external source of energy in the dehydrogenation process to retrieve the hydrogen, but LH_2 only requires energy input during liquefaction and does not require any extra energy for gasification in the hydrogen usage system.

Technological development of LH_2 began from bubble chamber experiments in the field of high-energy physics in the 1950s and rapidly developed alongside NASA's rocket fuel technologies. A 30 t/d hydrogen liquefier was constructed in the late 1950s, and a 60 t/d hydrogen liquefier, the largest in the world at the time, and an LH_2 storage tank with a capacity of 3,200 m^3 were constructed in the 1960s. In Japan, LH_2 began to be used primarily as a rocket fuel from the 1980s. Currently, its use is expanding in semiconductor and other industrial fields.

In the hydrogen society, LH_2 will be brought in on a large scale, so technology for liquefied natural gas will be used (LNG; main component: methane), which is similarly a flammable liquefied gas and has been at a commercial level since the 1960s. Table 2 shows a comparison of the properties of LH_2 and LNG. The saturated liquid density of LH_2 (70.8 kg/m^3) is approximately 790 times its gas density at atmospheric pressure and 0°C (0.0899 kg/Nm^3), and approximately 1.7 times its compressed gas density at 70MPa and 0°C (42.1 kg/m^3). Therefore, the volumetric efficiency of LH_2 is extremely high. Also, the boiling point of LH_2 (20.3 K) is around 90°C lower than that of LNG (112 K), and its latent heat per unit volume is small. Thermal insulation technology more advanced than that for LNG and liquefaction technology that reduces power requirements are necessary.

A significant feature of hydrogen is that it exists as high-energy-level ortho-hydrogen and low-energy-level para-hydrogen, according to the spin direction of the nucleus. Hydrogen gas at room temperature is normal hydrogen comprising 25% para-hydrogen and 75% ortho-hydrogen, whereas LH_2 is 99.8% para-hydrogen. In the liquefaction process from normal hydrogen to LH_2, it is important to maintain the equilibrium-state ortho-para composition ratio during the pre-cooling process. Also, the critical pressure for LH_2 (1.28 MPa) is smaller than that of LNG (4.6 MPa), and it is important to take into account significant physical changes near the critical condition.

Table 2 Comparison of LH_2 and LNG

		LH_2	LNG(CH_4)
Boiling point (K)		20.3 (-253°C)	112(-162°C)
Gas density (kg/Nm^3)		0.0899	0.717
Saturated liquid density (kg/m^3)		70.8	442.5
Saturated gas density (kg/m^3)		1.34	1.82
Critical temperature (K)		32.9	190
Critical pressure (MPa)		1.28	4.6
Latent heat	Per unit volume (kJ/L)	31.4	226
	Per unit weight (kJ/kg)	444	510
Lower heating value	Per unit volume (MJ/L)	8.5	22.1
	Per unit weight (MJ/kg)	120	50

Notes: • Physical properties of methane used for natural gas
• Physical properties at atmospheric pressure used for saturated liquid and saturated gas

(2) Liquefaction of hydrogen gas

The minimum liquefaction work required to turn hydrogen gas into a liquid (exergy) is thermodynamically determined by the state quantity at the start and the end of the liquefaction process. Assuming a start point of atmospheric pressure and 300 K and an end point of saturated LH_2 at atmospheric pressure, the minimum liquefaction work is approximately 3.90 kWh/kg (0.35 kWh/Nm^3), around 10 times that of LNG (methane).

The breakdown of the minimum liquefaction work for hydrogen gas is as follows.

① The work to pre-cool the hydrogen gas at normal temperature (300 K) to saturated hydrogen gas (20 K)

② The work to condense the saturated gas into a saturated liquid

③ The work for ortho/para conversion to convert room temperature hydrogen into LH_2 (99.8% para-hydrogen)

The work comprised by pre-cooling is 41%, condensation is 44%, and ortho/para conversion is 15%[3]. In comparison to LNG liquefaction work, the proportion of pre-cooling work is large and ortho-para conversion forms extra work.

Figure 2 shows an example liquefaction system composition (Claude cycle) for a liquefier. The process comprises a refrigeration cycle to produce cold energy and a hydrogen gas supply system that uses the cold energy to cool and liquefy normal temperature hydrogen gas. The cold energy for the cooling cycle is generated by refrigerant (hydrogen, helium, etc.) compressed to a high pressure by a compressor expanding in an expansion turbine (isentropic expansion).

In the hydrogen gas supply system, manufactured hydrogen gas refined to a high purity is compressed by a compressor and gradually cooled by a heat exchanger from normal temperature to around the temperature of LH_2 using the cold energy of the refrigeration cycle. The cooled compressed gas expands to around atmospheric pressure (isenthalpic expansion) and liquefies by means of an expansion valve. The heat exchanger, expansion valve, expansion turbine, and other components are kept in a cold box (vacuum chamber) to isolate them from heat input.

Actual liquefaction work is in the order of approximately 1kWh/Nm^3, and liquefaction efficiency (minimum liquefaction work/actual liquefaction work) is around the order of 30%. This case is based on the raw material hydrogen being at atmospheric pressure and 300 K, but if a high-pressure raw material hydrogen gas is supplied, both the minimum liquefaction work and the actual liquefaction

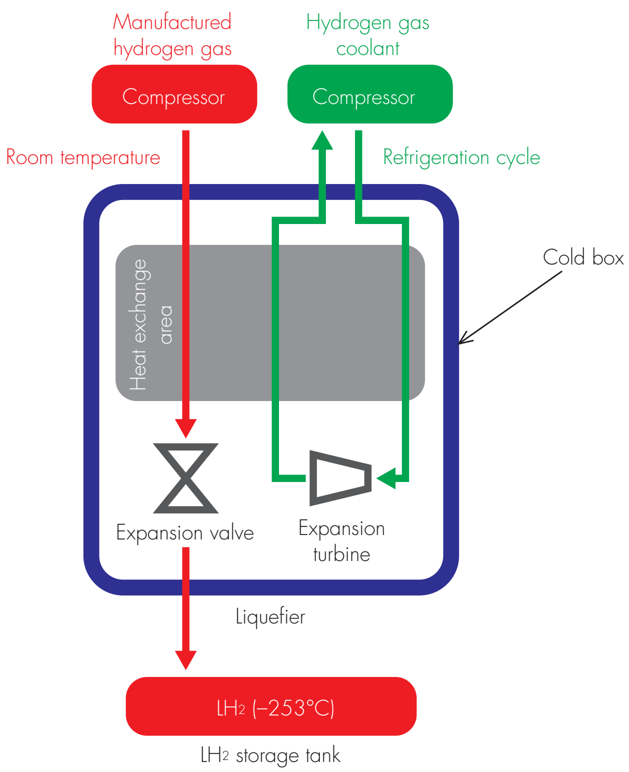


Fig. 2 Composition of hydrogen liquefaction system

Fig.3 Japan's first-large scale hydrogen liquefier

work decrease.

Figure 3 shows the appearance of Japan's first large-scale 5 t/d-class hydrogen liquefier developed by Kawasaki. A gas-bearing expansion turbine was adopted for the expander, and helium liquefier technology (boiling point 4.3 K) developed by Kawasaki in the 1980s was used in the liquefier. The adoption of a gas-bearing expansion turbine enabled high-efficiency liquefaction because high-speed revolution and a high expansion rate are achieved, in addition to it having no system contamination or complexity in restarting, which are issues in oil-bearing expansion turbines. Currently, we are evaluating and testing the components while running test operations.

(3) Storage of LH_2

Thermal insulation technology is particularly important to reduce evaporation in the storage and transportation of LH_2, which has a low boiling point and a low latent heat. A normal pressure solid insulation construction (urethane foam, etc) is adopted for the insulation of LNG tanks, but high-vacuum insulation (under 10^{-2} Pa) is often used with small and medium-size LH_2 tanks (capacity 20-300 m^3) and low-vacuum insulation (under 1 Pa) is often used with larger tanks to drastically reduce the heat input. The input heat flux is approximately 1 W/m^2, but for a larger tank with the same input heat flux, the ratio of surface area to volume decreases and the fluid evaporation rate (%/d) is mitigated. Figure 4 shows the appearance of the largest LH_2 tank in Japan (capacity 600 m^3), which Kawasaki constructed for the Japanese Aerospace Exploration Agency's (JAXA) Tanegashima Space Center. This LH_2 tank has a double-shell construction employing perlite for low-vacuum insulation and an evaporation rate of not more than 0.18%/d. NASA's 3,200 m^3 LH_2 tank, the largest in the world, is also a double-shell tank employing the same insulation method.

The capacity of the aboveground LH_2 tanks for a pilot CO_2-free hydrogen chain and a demonstration chain is planned to be approximately 3,400 m^3 and 50,000 m^3, respectively, and the technologies of the LH_2 tanks

Fig.4 Japan's largest LH_2 tank

Fig.5 Trial manufacture of aboveground LH_2 tank

Kawasaki has constructed will be incorporated.

Kawasaki is currently prototyping an aboveground LH_2 tank at its Harima Works as shown in Fig. 5. This tank brings together the cryogenic technologies and manufacturing capabilities the company has accumulated to date, and Kawasaki is aiming to make it commercially viable at an early stage.

(4) LH_2 transportation

The transportation of LH_2 is categorized as land transportation and sea transportation. Land transportation is generally by trucks with an integrated tank or a separable container. In contrast to stationary tanks, the LH_2 tanks for transportation must have a thin layer of insulation between the inner and outer tanks in order to increase volumetric efficiency to a maximum, and must have a special supporting structure to withstand the weight of the load and reduce heat input.

(i) Land transportation

Figure 6 shows a 40-ft container developed by Kawasaki. The container is made up of a container frame (W2.4 m x H2.6 m x L12 m) housing a tank comprising an inner tank (capacity 46 m^3) and an outer tank. High vacuum insulation using multilayer insulation material is employed. The evaporation rate is 1.0%/d or less. This container is used to transport LH_2 across land from a liquefaction terminal in Japan to semiconductor factories, the JAXA Tanegashima Space Center, and other locations.

Fig.6 LH_2 container

(ii) Sea transportation

There are few instances of transportation of LH_2 by sea. The EU used a large container to transport LH_2 by sea from Louisiana in the US to a rocket launch site in French Guiana, South America. Also, NASA transports LH_2 from Louisiana to a rocket engine test site by barge (capacity approximately 1,000 m^3)[3]. There are no records of the construction of an LH_2 carrier that can transport LH_2 in large volumes and over the long distance from Australia to Japan, which will be necessary in the future.

Kawasaki is developing a small LH_2 carrier for the pilot chain and a large LH_2 carrier (capacity 160,000 m^3) for the demonstration chain in a move towards the establishment of the hydrogen energy supply chain.

Concluding remarks

Government and civilian initiatives for the realization of a hydrogen society are accelerating, with moves such as infrastructure developments and the review of regulations for FCV hydrogen stations, and the establishment of a Council for a Strategy for Hydrogen and Fuel Cells with the aim of formulating a short- to medium-term hydrogen roadmap. The liquefaction of hydrogen and LH_2 transportation and storage technologies that form the foundation of Kawasaki's hydrogen energy supply chain concept for the handling of future large-volume imports of hydrogen will contribute significantly to the realization of the coming hydrogen society. Kawasaki will apply the LNG and LH_2 technologies we have accumulated over many years to promote the technological development of related equipment in a step toward the realization of economical and safe hydrogen liquefaction, transportation and storage systems.

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Doctor of Engineering
Professional Engineer (Mechanical Engineering)
Shoji Kamiya
Project Promotion Department,
Hydrogen Project Development Center,
Corporate Technology Division

Kozo Isano
Technology Development Department,
Hydrogen Project Development Center,
Corporate Technology Division

Daisuke Kariya
Technology Development Department,
Hydrogen Project Development Center,
Corporate Technology Division

Toshihiro Komiya
Project Development Department,
Plant & Infrastructure Company

Akira Yamaguchi
Cryogenic Storage System Department,
Chemical Plant & Cryogenic Storage System Engineering Division,
Plant & Infrastructure Company

Doctor of Engineering
Yukichi Takaoka
Engineering Division,
Ship & Offshore Structure Company

Kawasaki Spouted Bed and Vortex Chamber (DeNOx pre-calciner) — Addressing the global trend of strict environmental regulations

In recent years, industrial plants around the world are increasingly adopting more stringent NOx emissions regulations, and cement kiln systems are no exception. Japanese regulations have set the NOx emissions limit to 250 ppm (at 10% O_2), and an effective countermeasure is to reduce NOx contained in the rotary kiln exhaust gas. Kawasaki has developed a DeNOx precalciner called KSV, which promotes denitration by optimizing the state of combustion and fuel mixture. With outstanding efficiency, KSV has reduced NOx concentration by approximately 70%.

Preface

During its period of rapid economic growth, Japan was faced with serious environmental pollution, and in 1975, the government introduced a new regulation limiting NOx emissions from cement kiln systems to 250 ppm (at 10% O_2) or lower. Industry players responded by implementing measures to reduce NOx emissions from cement kilns.

1 Background

In 1976, Kawasaki developed a DeNOx precalciner called the Kawasaki Spouted Bed and Vortex Chamber (KSV) to reduce NOx emissions from the rotary kiln. It has been demonstrated to effectively remove NOx.

The KSV precalciner has subsequently been upgraded with various improvements designed to further enhance its denitration performance. Since 2000, Kawasaki has delivered 52 suspension preheaters equipped with the KSV precalciner mainly to customers in China, contributing to the global effort to reduce NOx emissions.

2 Mechanism of denitration

NOx is reduced and detoxified with the aid of a highly active hydrocarbon gas that is generated during the combustion process, in a temperature range of 800-1,000°C. NOx is also decomposed through the reaction of gaseous reductants such as CO and H contained in unburned fuel, with cement raw material acting as a catalyst.

Therefore, in order to effectively reduce the NOx concentration in the rotary kiln exhaust gas, the first essential point to observe is to ensure that the raw meal exists and is burned with an excessive amount of fuel injected into the KSV precalciner, and the fuel is adequately mixed with the rotary kiln exhaust gas.

At this time, it is important to ensure that the air-fuel ratio is optimal because while the presence of more reducing gases such as HC (i.e., smaller air ratio in the combustion field) increases the denitration efficiency, NOx is regenerated when unburned fuel is burned. It is also important to ensure that the mixture of unburned fuel remaining after the denitration process and excess air is at an optimal ratio, so that the unburned fuel is completely burned inside the KSV precalciner using a minimal amount of air. These are the second essential points.

3 Structure, features, and advantages

(1) Structure and features

The structure of the KSV precalciner is shown in Figs. 1 and 2.

Each component of the KSV precalciner has the following features.

① Throat

Rectifies the flow of the rotary kiln exhaust gas and leads it directly into the conical portion, which is the main combustion chamber of the KSV precalciner.

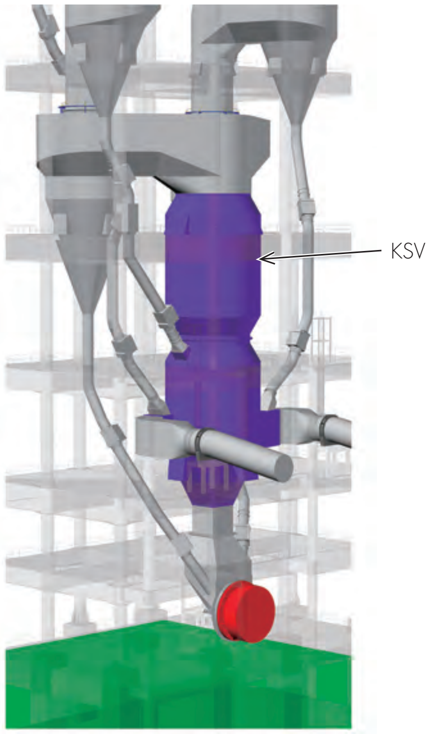


Fig. 1 Overview of KSV (CG)

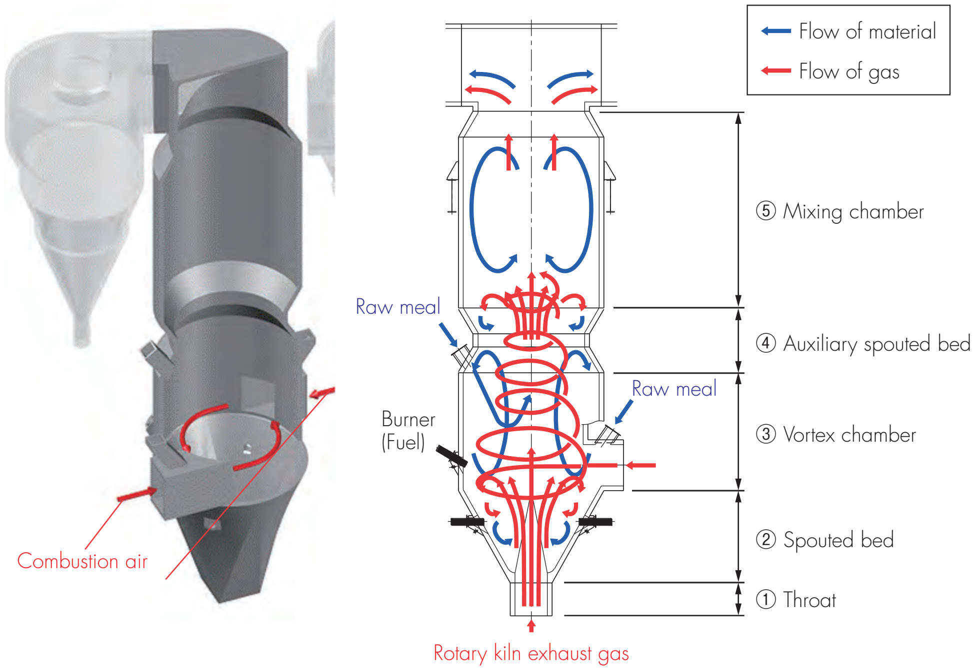


Fig. 2 Structure of KSV

② Spouted bed

Once introduced inside the conical portion, the rotary kiln exhaust gas turns into a jet stream, forming a spouted bed with the raw meal that has been fed.

By injecting some fuel into the spouted bed which has a low oxygen concentration, and burning it in an excess fuel condition, the reducing gas that is generated is efficiently agitated and mixed.

③ Vortex chamber

The combustion air that is introduced in a horizontal direction creates a swirling flow, which promotes the agitation and mixture of the reducing gas in the spouted bed. It also helps the reducing gas to mix efficiently with the rotary kiln exhaust gas and promotes the combustion of unburned fuel.

The remaining fuel is injected into the chamber, where the aforementioned mixing effect helps achieve uniform combustion and efficient heat exchange with the raw meal.

④ Auxiliary spouted bed

The middle portion of the KSV precalciner is narrowed to improve the combustion and mixing performance in the vortex chamber, and also to reduce the amount of gas blowing through, thereby keeping the raw meal inside the chamber for a longer time.

The remaining raw meal is fed directly below the auxiliary spouted bed to prevent the gas from blowing through, and also to form an auxiliary spouted bed above the narrowed portion, further increasing the retention time of the raw meal inside the chamber.

⑤ Mixing chamber

The flow of gas from the narrowed middle portion mixes completely with the swirling flow in the mixing chamber. It provides sufficient internal volume to achieve complete combustion of the unburned gas remaining after denitration at a low air ratio.

(2) Advantages

(i) Energy saving

Fuel consumption is reduced through the synergistic effect of the spouted bed and swirling flow, which combine to achieve excellent efficiency in fuel combustion and heat exchange between the raw meal and hot gas.

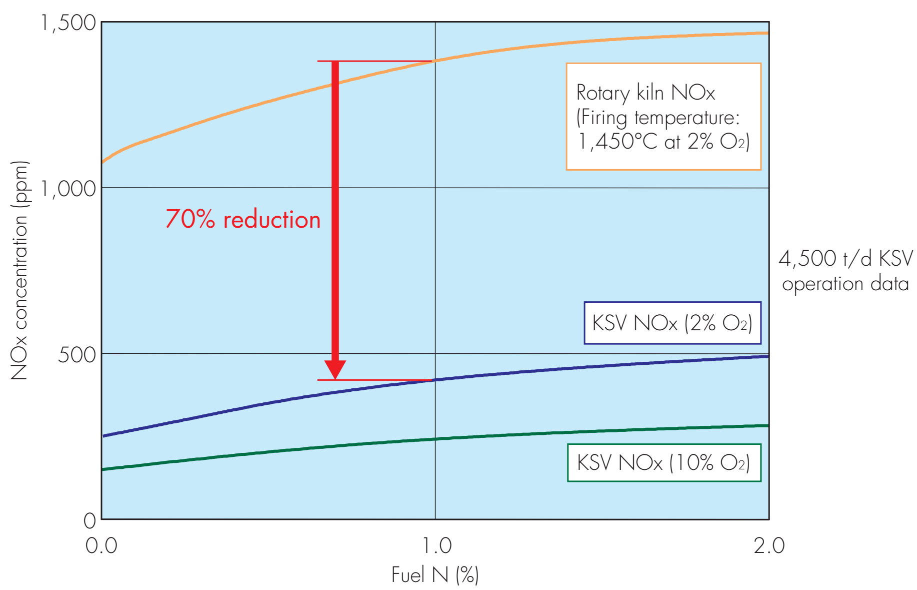


Fig. 3 Denitration effect of KSV

(ii) Stable operation

The temperature distribution inside the KSV precalciner is kept uniform through the distributed combustion of fuel. The wall inside the KSV precalciner is covered with the raw meal due to the swirling flow, which ensures stable operation by preventing the occurrence of hot spots and minimizing coating.

(iii) Low NOx emissions

The generation of HC and other reducing gases is promoted by burning the material in an excess fuel condition within a reduction atmosphere, and these gases reduce the NOx concentration in the rotary kiln exhaust gas by being agitated and mixed together.

4 Dramatic denitration effect of KSV

The NOx generated inside the rotary kiln impacts the ratio of fuel N (proportion of N contained in the fuel), most of which is thermal NOx produced through the reaction of nitrogen and oxygen at a high temperature. Since rotary kilns normally maintain the firing temperature at around 1,450°C, the NOx concentration in a rotary kiln exhaust gas reaches as high as 1,000-1,500 ppm, as shown in Fig. 3.

The precalciner of a suspension preheater, on the other hand, maintains a low combustion gas temperature at around 900°C, which minimizes the generation of thermal NOx and reduces the NOx concentration in the rotary kiln exhaust gas to 40-50% even without the denitration effect. In addition, the KSV precalciner mixes and burns a portion of the fuel with the low-oxygen rotary kiln exhaust gas to generate reducing gas, which removes 40-45% of the NOx contained in the exhaust gas in the process.

Overall, the KSV precalciner reduces the NOx concentration in the rotary kiln exhaust gas by about 70% (at 2% O_2), and has achieved the regulatory limit of 250 ppm (at 10% O_2) as shown by the green line in the figure.

Postscript

As governments around the world are expected to continue to introduce and tighten NOx emissions regulations, we will leverage the KSV precalciner's superior denitration performance to further expand overseas sales.

Akihiro Yoshinaga / Takuya Matsuoka

Contact information
Industrial Plant Department,
Industrial Plant Engineering Division,
Plant & Infrastructure Company
Tel: +81-78-682-5216 Fax: +81-78-682-5539

Ferronickel smelting plant
– Electric furnace off-gas utilization to save energy

In the past, off-gas generated during smelting and reduction of ferronickel ores in electric furnaces used to be released into the atmosphere. By utilizing this off-gas as a heat source for the rotary dryer, Kawasaki achieved highly efficient heat recovery, reduction of environmental impact and increased productivity.

Preface

Ferronickel is an alloy containing iron and nickel and is used mainly as raw material for producing stainless steel. In recent years, the global stainless steel market has seen growth slow down as the market in China, its major growth driver, has reached maturity. However, demand for ferronickel smelting plants remains high in Indonesia, a major raw ore producer where a recent ban on exports of raw ores has led to many new projects in the country.

This report describes the integrated ferronickel manufacturing and smelting plant delivered to SNNC of South Korea in September 2009, and the capacity expansion plant ordered in November 2012. The report will also explain the utilization of electric furnace off-gas in the rotary dryer.

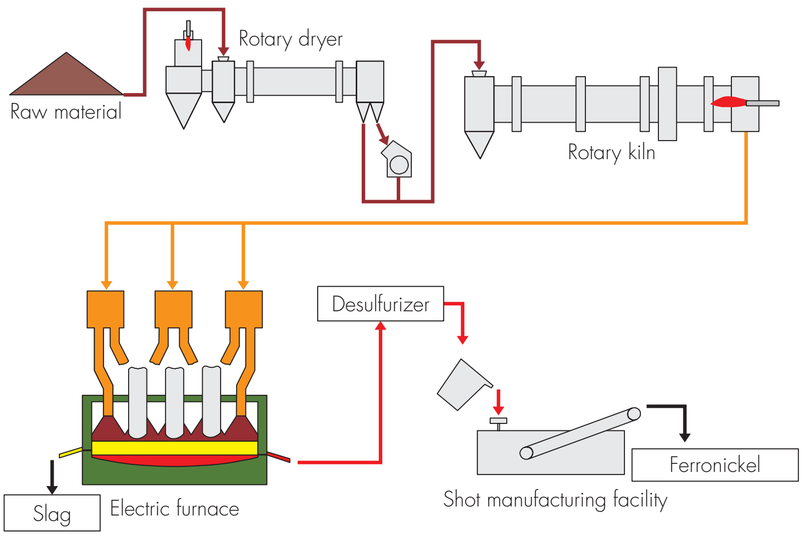


Fig. 1 Flow of ferronickel smelting plant

1 Ferronickel smelting plant and process

Kawasaki's ferronickel smelting plant follows the process shown in Fig. 1. Ferronickel ore with 1.8-2.2% nickel content is first dried in a rotary dryer, then reduced in a rotary kiln. Next, the ore is smelted in an electric furnace and separated into slag and metal (ferronickel) with around 20% nickel content. After the metal is refined in a desulfurizer, it is processed into a product by a shot manufacturing facility. This process makes full use of the technology and experience of Kawasaki, which have been cultivated through years of experience in designing and fabricating cement manufacturing kilns and dryers.

2 Utilizing electric furnace off-gas in the rotary dryer

(1) Material drying facility (rotary dryer)

Ferronickel ore has very high moisture content at 25-30%, making it highly adhesive and difficult to handle. For this reason, the material is dried in a parallel flow type rotary dryer (Fig. 2) to lower the moisture content of the raw material ore to 20-22% and make it easier to handle.

(2) Aim of utilizing electric furnace off-gas in the rotary dryer

In the past, off-gas generated during smelting and reduction of ferronickel ore in electric furnaces used to be released into the atmosphere after complete combustion of the carbon monoxide contained in the off-gas by injecting ambient air.

In the ferronickel plant initially delivered to SNNC, we applied the electric furnace off-gas to the rotary dryer for the following reasons.

(i) Energy saving

By utilizing the electric furnace off-gas as a heat source for the rotary dryer, the amount of fuel consumed by the hot-air generator can be reduced.

(ii) Protection of environment

To minimize environmental impact, dust that used to be dispersed into the atmosphere is collected by a bag filter installed downstream of the dryer.

(iii) Increased productivity

The electric furnace off-gas dust is returned to the process, enabling the nickel contained in the dust to be recovered more efficiently.

(3) Flow of electric furnace off-gas utilization

Electric furnace off-gas undergoes several processes before it can be utilized in the rotary dryer as a heat source. First, it is mixed with ambient air inside water-cooled ducts, and any remaining carbon monoxide is combusted completely. Next, dust is collected in the stabilizer, and the off-gas is mixed with hot air from the hot-air generator in the gas mixing chamber. This mixed gas is used as a heat source in the rotary dryer. After

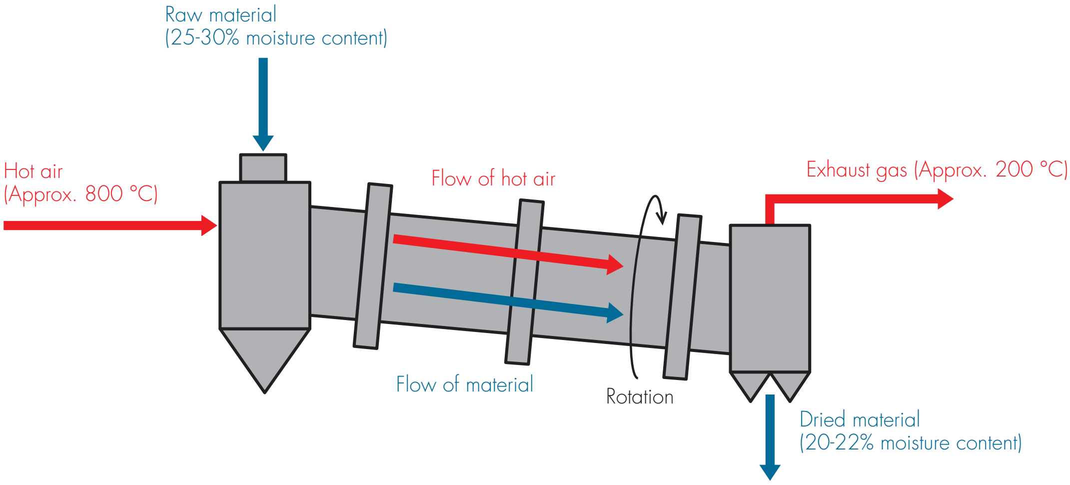


Fig. 2 Parallel flow type rotary dryer

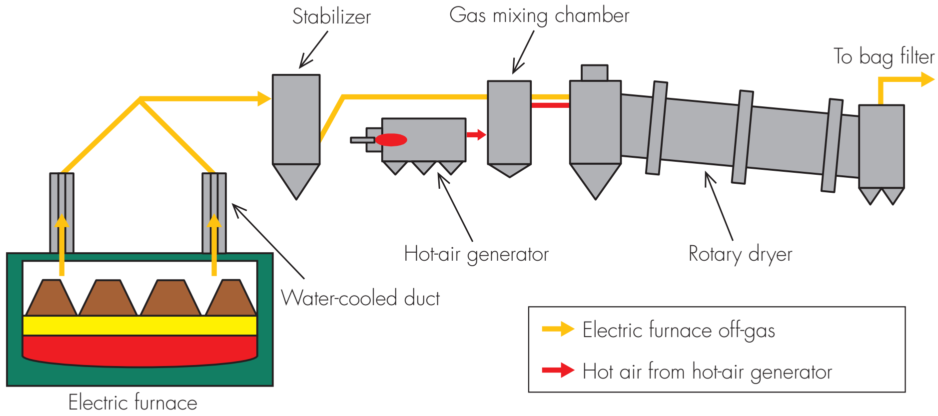


Fig. 3 Flow of electric furnace off-gas utilization

passing through the dryer, the gas goes through a bag filter for dust collection, and then the gas is released into the atmosphere through the chimney (Fig. 3).

(4) Improving fuel efficiency in the dryer by the use of thermohydraulic analysis

In the SNNC capacity expansion project, we did a thermohydraulic analysis (CFD analysis) based on the operational data in the first project to improve the homogeneity of the mixture of the electric furnace off-gas and the hot air from the hot-air generator (Fig. 4).

We applied the optimal arrangement of the hot-air generator, gas mixing chamber, and ducts based on the CFD analysis result. We tried to improve the efficiency of the rotary dryer by making the gas mixture more homogenous. As a result, we achieved approximately 40%

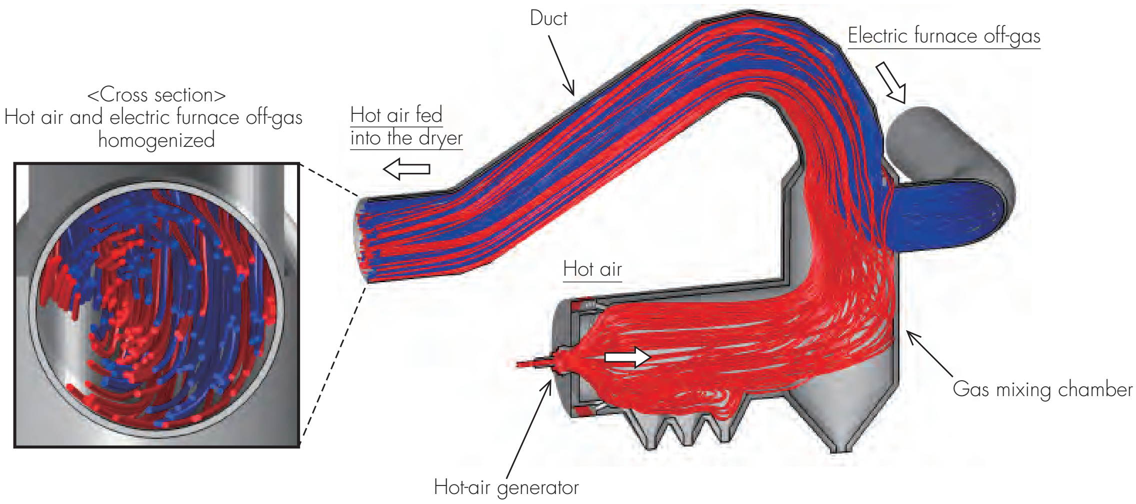


Fig. 4 Mixture of electric furnace off-gas and hot air from hot-air generator (SNNC Capacity Expansion Project)

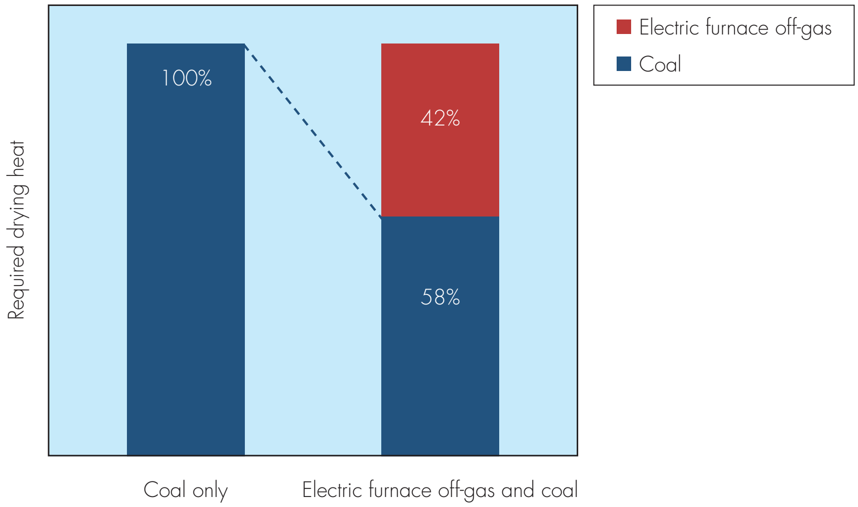


Fig. 5 Reduction of fuel consumption by electric furnace off-gas utilization

reduction of coal consumption on the hot-air generator, compared to without electric furnace off-gas (Fig. 5).

Postscript

In the SNNC project, we achieved a reduction of fuel consumption on the hot-air generator and considerable energy savings by using electric furnace off-gas as a heat source for the rotary dryer.

We will continue to satisfy customer demand for ferronickel smelting plants by making sure our plant design delivers superior performance and efficiency.

Hisatoshi Shigenaga / Shoji Takada

Contact information
Industrial Plant Department,
Industrial Plant Engineering Division,
Plant & Infrastructure Company
Tel: +81-78-682-5216 Fax: +81-78-682-5539

Stacker-reclaimer for conveying coal
— Enabling rapid response to demand for coal yard installation and upgrades

Coal has recently come under renewed attention as fuel for thermal power generation. This has caused a surge in demand for the new installation and upgrade of equipment for conveying coal and other bulk materials. To date, Kawasaki has delivered a significant number of conveyance equipment to customers around the world. These include applications such as excavation, storage, and shipment of coal, ores, gravel, and other bulk materials. Kawasaki has recently delivered a stacker-reclaimer—a type of equipment for conveying coal—to Nippon Steel & Sumitomo Metal Corporation's Hirohata Works.

This equipment features the latest mechanism and systems to enable concurrent operation with existing equipment, secure a wide operating range, offer improved maintainability and energy savings, and reduce total manufacturing costs.

Preface

Bulk materials such as coal and ores are imported from overseas to be used as fuel for power generation or as raw material for making steel. After they arrive at a port on a bulk carrier, they are temporarily stored in a stockyard until ready for use. A stacker-reclaimer is used to stack the material in a stockyard and to reclaim the material from a stockpile. Because stockyards may take different configurations depending on the layout of the port and plant equipment, the equipment must be designed to make the most of the limited space available. When introducing a new machine, its specifications also need to consider coordination with existing machines.

Table 1 Main specifications

Maximum stacking capacity (t/h)	2,000
Maximum reclaiming capacity (t/h)	700
Horizontal length from the slewing pivot to the boom end (m)	Approx. 42
Traveling speed (m/min)	Max. 30
Boom luffing angle (°)	−17 to +17
Boom slewing angle (°)	−136 to +132 (stacking) −148 to +143 (reclaiming)
Power supply	AC440V, ϕ3, 60Hz
Operation	Manual operation by onboard operators

1 Equipment overview

The main specifications of the stacker-reclaimer delivered to Nippon Steel & Sumitomo Metal Corporation's Hirohata Works are shown in Table 1. Its overview and the flow of coal conveyance are shown in Fig. 1 and Fig. 2, respectively. This machine performs two main functions. First, it stacks coal in the yard via a boom conveyor (Fig. 2 blue line).

The coal to be stacked is supplied by a receiving belt conveyor adjacent to the coal yard, and is conveyed uphill by a tripper. Second, it reclaims coal from the yard with the bucket wheel at the end of the boom conveyor, reverses the boom conveyor to discharge the coal onto the reclaiming belt conveyor that runs parallel to the receiving belt conveyor (Fig. 2 red line).

The following points were considered in developing the specifications of the new machine, which was to be installed alongside an existing machine.

- Given only one set of receiving and reclaiming conveyors, positioned in the center of the coal yard, and a number of stacker-reclaimers operating on the same traveling rail, coordination with the existing machine was imperative.
- The coal yard ground was 5 m below the top of the traveling rail, which is deeper than a typical yard. This called for a wider operating range for stacking and reclaiming.

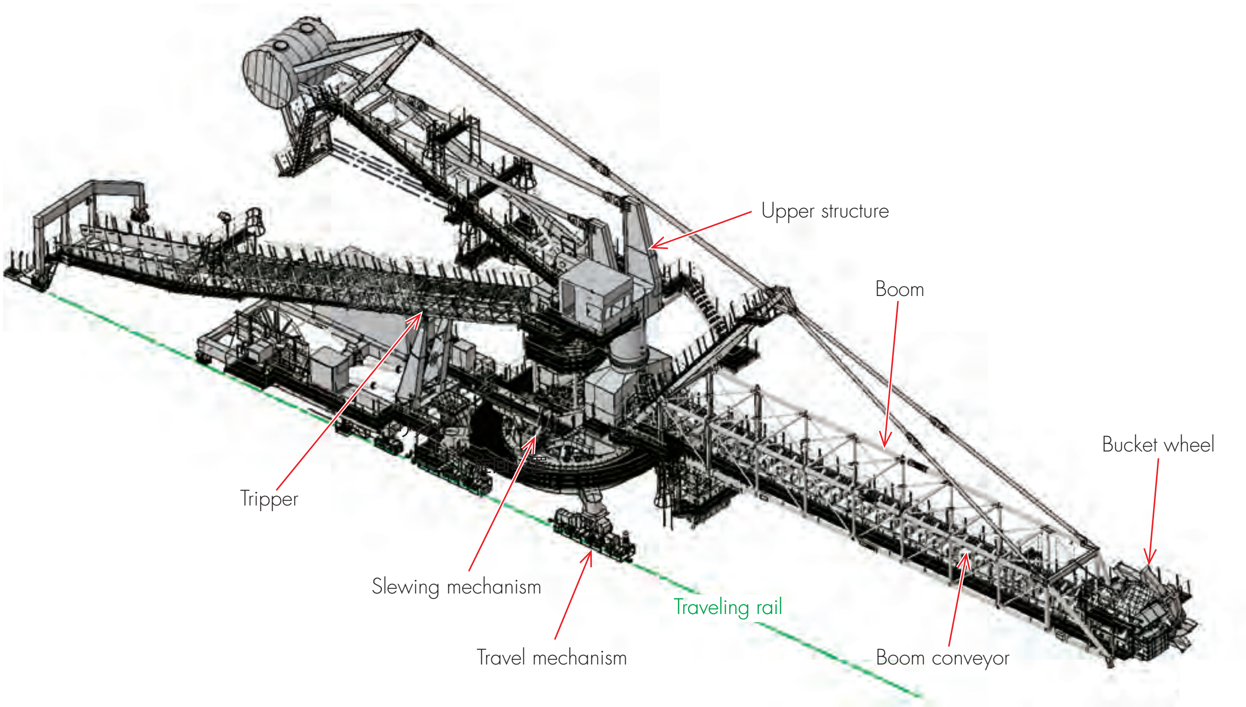
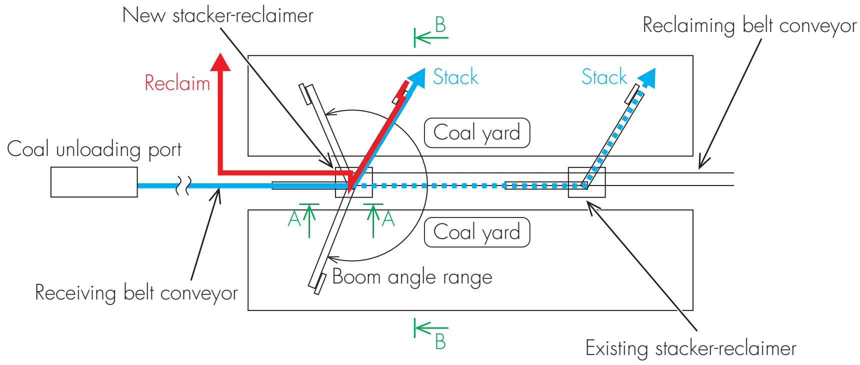
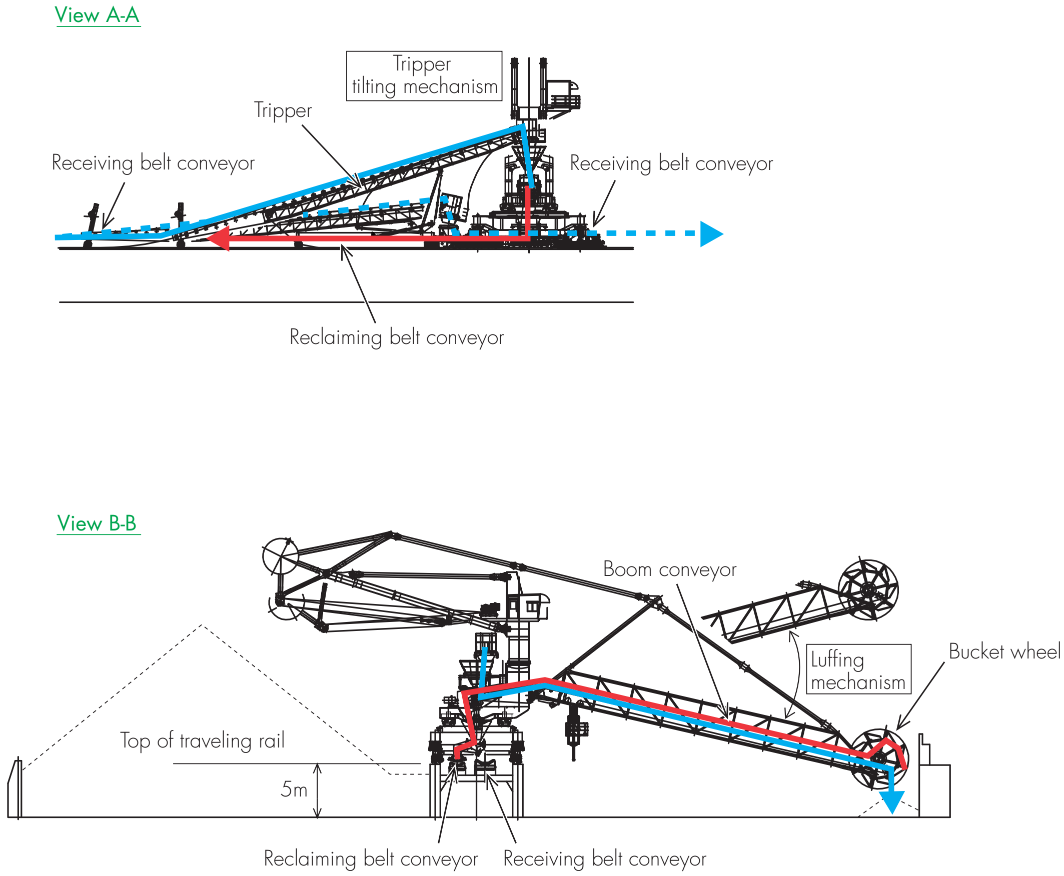


Fig. 1 Stacker reclaimer overview



(a) Flow of conveyance in a yard



(b) Flow of conveyance using a stacker-reclaimer

Fig. 2 Flow of conveyance

2 Structure and features

(1) Tripper tilting mechanism for allowing concurrent operation with existing machines

As the receiving belt conveyor is used by both the existing machine and the new machine, coal to be stacked by the existing machine must pass over the new machine. For this reason, the tripper is inclined at varying angles to allow coal to be conveyed directly to the existing machine (Fig. 2 blue broken line). This tilting mechanism ensures the tripper does not interfere with the slewing motion of the boom during reclaiming operation, and provides enough clearance for slewing toward the back of the machine without uncoupling the tripper.

(2) Upper structure designed to ensure wide slewing range

The tripper tilting mechanism cannot be used to avoid interference during stacking operation. To ensure enough clearance is provided for slewing toward the back of the machine when stacking coal, the central part of the upper structure is supported by a single cylindrical column. This ensures a wide slewing range and also makes space for the walkways along the tripper and boom conveyor.

(3) Use of motor drive system to improve maintainability

We adopted a motor drive system for the bucket wheel, which traditionally has been hydraulically powered in most reclaimers. This change has made maintenance work for hydraulic fluid and equipment unnecessary. Further, we added a protection feature that instantly detects overload based on the measurement of inverter current and automatically stops the machine. The boom conveyor drive unit has also been upgraded. It is inverter driven to ensure smooth operation during startup, shutdown, and reverse rotation. The fluid coupling that used to be provided for cushioned start has been left out to improve maintainability, and the number of times the electric motor can be started and stopped for switching between receiving and reclaiming operations has been increased.

(4) Driving conveyors with regenerative power supply to save energy

Given the unique geometric features of the coal yard (i.e., a low-lying yard ground), we equipped the boom conveyor drive unit with a power regenerative converter to harness the regenerative energy produced when coal is conveyed downward on the boom conveyor during stacking operation. The regenerative current produced is returned to the power source to cut power consumption.

(5) Fabricated overseas to reduce total cost

The structure of the stacker-reclaimer was fabricated and assembled by Shanghai COSCO Kawasaki Heavy Industries Steel Structure Co., Ltd. (SCK), a joint venture between Kawasaki and its Chinese partner, then transported to the delivery site by sea in modules. By handling as much assembly work as possible in the plant, we were able to minimize onsite installation work, improve quality, and reduce the total cost.

Postscript

Currently, there are many plans to upgrade or newly install bulk material conveyance equipment at steelworks and coal-fired power plants in Japan. We will propose and deliver products tailored to the various needs of customers, including stacker-reclaimers for outdoor use and scraper reclaimers for indoor use.

We would like to thank the team at Nippon Steel & Sumitomo Metal Corporation and others for all the support they provided for the recent delivery of equipment.

Fumio Mori

Contact information
Materials Handling Department,
Industrial Plant Engineering Division,
Plant & Infrastructure Company
Tel: +81-78-682-5266 Fax: +81-78-682-5585

Slurry shield machine for Singapore Power – Handling long distance, high water pressure, and curved sections

In 2014, Kawasaki designed and manufactured 6.9-m slurry shield machines that incorporated the technologies of hard-rock tunnel boring machines, and delivered them to Singapore. These shield machines come with such features as a large-diameter roller cutter and an overcutter to enable excavating digging through curved sections and long distances under high water pressure and other challenging conditions.

Preface

Kawasaki has seen growing demand in Singapore for cutting-edge tunneling machines that can handle long distances, high water pressure, and curved sections on top of the conventional function of drilling through hard rock. Kawasaki has been supplying shield machines that can bore through hard rock since 2005. Now it has developed and delivered a shield machine that can handle these requirements. Here we take a look at that machine.

1 History of Kawasaki shield machines

Kawasaki delivered its first shield machine to the Teito Rapid Transit Authority (now Tokyo Metro Co., Ltd.) in 1957. In the 58 years since then, Kawasaki has supplied more than 1,400 shield machines. The original shield machine, which seems primitive now, was essentially a steel cylinder designed to keep soil from caving in during the excavation process and was not even watertight. The steel cylinder served as a protective structure, i.e., a

Table 1 Main specifications

Model		Rear thrust articulated machine
External diameter (m)		6.9
Length (m)		11.65
Cutter head	Power (kW)	1,680
	Rotation speed (min^{-1})	Max. 6
	Torque (kN m)	Max. 6,250
Shield jack thrust (kN)		60,000
Number of roller cutters		46 + 2

shield, which enabled underground excavators to tunnel through the ground, hence the name of the machine. Kawasaki then went on to develop a full-face, closed shield machine equipped with a pressure bulkhead for enhanced energy efficiency and safety, articulated shield machines for excavating curved sections, and other types of machines in response to a range of tunnel construction needs.

To excavate through hard rock, the machine needs to be equipped with a special cutter and structural frame built to take reaction forces. That is why Kawasaki went to work on developing equipment that could cut through hard rock with the focus placed squarely on boring. Taking development beyond shield machines, it expanded into the field of open-face tunnel boring machines.

The shield machine featured here incorporates the functions of both types of machines.

2 Main specifications and structure of the shield machine

The shield machine's main specifications are shown in Table 1. The machine is equipped with a high-speed cutterhead and high thrust shield jacks designed to excavate through hard rock and handle high water pressure.

Figure 1 shows the structure of the shield machine. The shield machine has an inverter motor-driven disk-shaped cutter head at its front end. Built to tunnel through hard rock, the high-speed cutter head is fitted with a number of roller cutters resembling abacus beads which rotate at a maximum speed of 6 min^{-1} (the maximum rotation speed for excavating soil is normally 1-2 min^{-1}). These roller cutters rotate to bore through hard rock as the shield jacks push the cutter head against the hard rock surface to

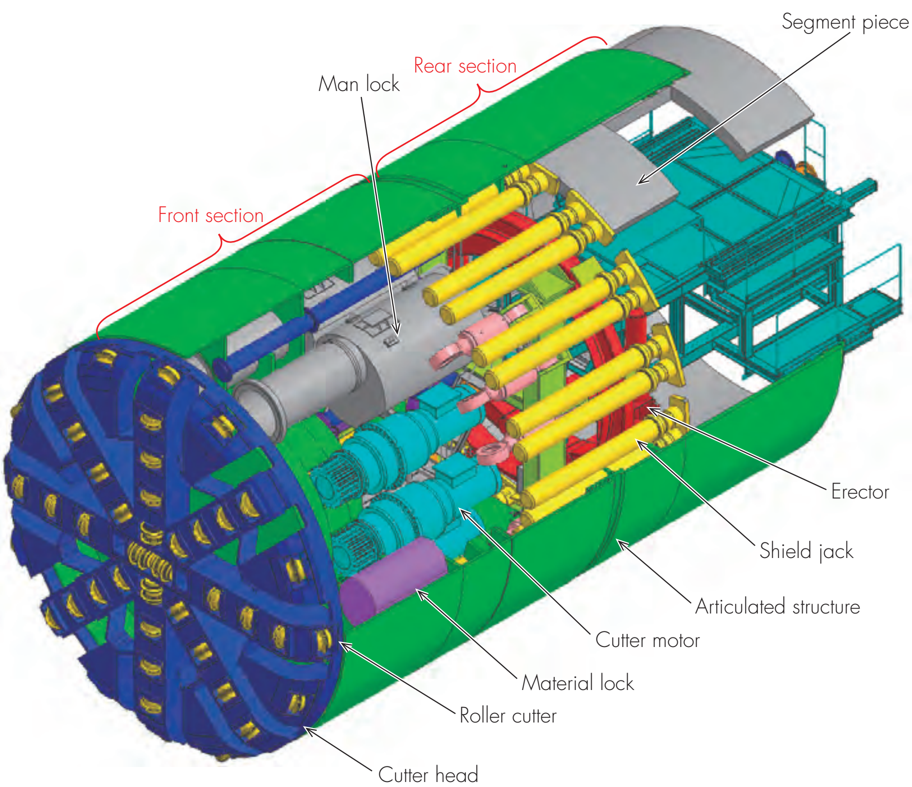


Fig. 1 Shield machine structure

move the machine forward.

The shield machine is divided into front and rear sections. This articulated design enables it to bend at the point where the machine is divided into two in order to excavate curved sections.

The machine's rear section is equipped with an erector used to assemble the segment pieces that line the tunnel.

3 Key features

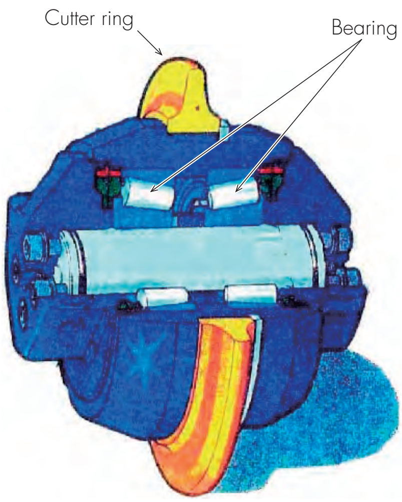
(1) Long-distance excavation

(i) 19-inch roller cutters

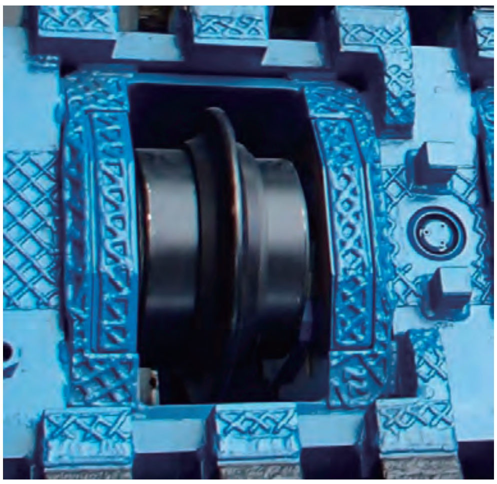
While 6-meter diameter class machines are typically equipped with 17-inch roller cutters, this shield machine employs 19-inch roller cutters to increase excavation speed and reduce the frequency of replacing roller cutters for enhanced tunnel construction performance.

Figure 2 shows the exterior view of the 19-inch roller cutter as well as a picture of the cutter that is mounted to the cutter head. Adoption of the 19-inch roller cutters allows for the use of larger bearings, thereby increasing the pressing force on the hard rock surface for speedier excavation.

The bigger roller cutter also means a larger cutter ring, which results in a higher allowable wear amount and a lower roller cutter intervention (replacement) rate.



(a) Exterior view



(b) Roller cutter mounted to cutter head

Fig. 2 19"roller cutter

(ii) Twin man locks and material lock

Since this shield machine is used for long-distance excavation, the roller cutters will still need to be replaced relatively often. When replacing roller cutters, workers may need to work in a high pressure environment in order to prevent flooding. The workers need to go into a pressure chamber known as a man lock before and after replacing roller cutters so they can acclimate to different air pressures. In order to shorten the time needed for this process, the shield machine is equipped with two man locks. It also has a material lock so roller cutters can be carried into the work area via a separate route that does not use the man locks.

(2) High water pressure capability

Since this shield machine has a closed structure, the seals must withstand an anticipated range of soil and water pressure conditions. Ensuring the performance of the high pressure tail seal that fills the gap between the machine and segments is crucial. The machine employs a four-layer tail seal, which is one more layer than found in conventional tail seals. The final layer is a urethane foam that provides optimal sealing and anti-wear performance.

(3) Ability to excavate curved sections

(i) Overcutting tool

The cutter head is fitted with two overcutting tools which are hydraulically operated by roller cutters in order to bore through curved hard rock sections. These overcutting tools are stored inside the cutter head when the shield machine is excavating straight sections. Hydraulic jacks are extended from the cutter head when excavating curved sections, and the roller cutters attached to the jack ends are used to overcut.

These overcutting roller cutters can also be replaced from the back of the shield machine, which is a huge plus when tunneling long distances.

(ii) Articulated structure

The shield machine features an articulated design with a maximum articulation angle of 3.5 degrees that enables it to handle a curve radius of 120 meters.

Postscript

Shield machines have become vital to infrastructure development across the globe. While their required specifications are getting tougher and more difficult to design, Kawasaki continues to work on developing shield machines with the kind of capabilities that meet today's needs. Kawasaki is moving ahead as it builds on its past successes to engineer better performing and more user-friendly shield machines that will lead to a brighter future.

Yoshio Sakai

Contact information
Tunneling Equipment Department,
Industrial Plant Engineering Division,
Plant & Infrastructure Company
Tel: +81-78-682-5448 Fax: +81-78-682-5096

Dry bottom ash handling system
− Improving maintainability and economic efficiency

Since 2002, Kawasaki has been receiving increased orders from customers around the world for its dry bottom ash handling system, which adopts a new process for handling clinkers in coal-fired power plant boilers.

Following initial deliveries, further improvements have been made to the system, including seals that require no maintenance, reducing its cost of ownership.

Preface

While conventional wet bottom ash handling systems used to process bottom ash, or clinkers, from coal-fired thermal power plant boilers use an enormous amount of water, today we are witnessing a shift to dry bottom ash handling systems designed to meet increasingly strict environmental requirements.

In these systems the bottom ash is air-cooled as it is being removed from a boiler and transported, eliminating

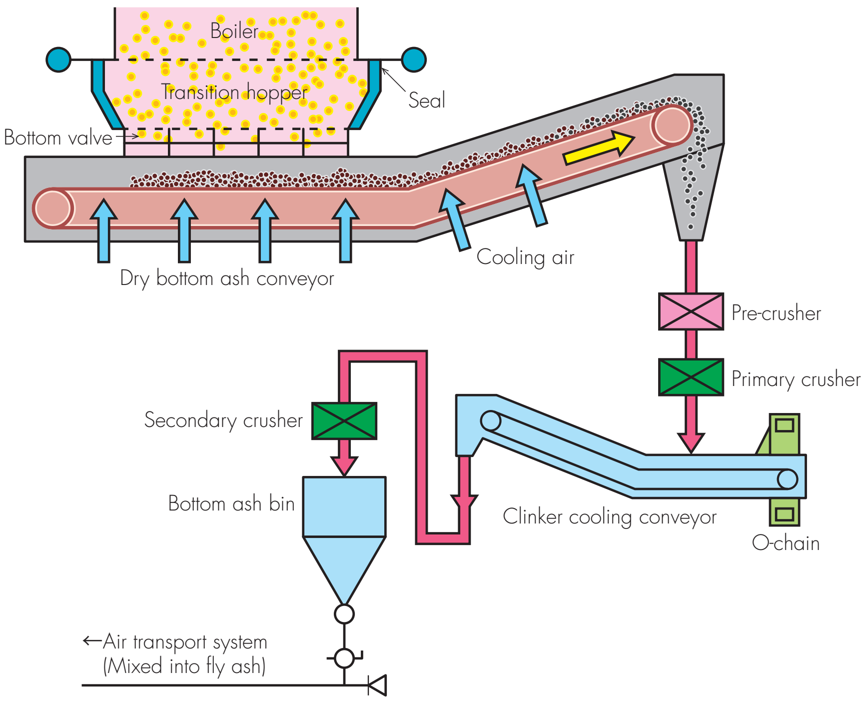


Fig. 1 Overview of dry bottom ash handling system

the need to use water. Kawasaki formed a technological alliance with Magaldi, the Italian firm that developed the dry bottom ash handling system, in 1994 and has been steadily building a solid track record since delivering the first system to a Japanese power plant in 2002.

This paper provides an overview of the system as well as the measures taken after its introduction with the aim of improving maintainability and economic efficiency.

1 Overview of the dry bottom ash handling system

This system, which does not use any water to handle bottom ash, boasts the following advantages over conventional hydraulic transport systems:

- Smaller environmental impact
- Wider and more effective uses of dry bottom ash
- Lower equipment and running costs

Figure 1 shows an overview of the dry bottom ash handling system. Bottom ash that fell from the furnace is cooled as it is transported downstream by a dry bottom ash conveyor. While downstream system components vary depending on user requirements, in the most commonly used system in Japan, bottom ash is transported via a downstream primary crusher, clinker cooling conveyor, and secondary crusher. It is then finally air-blown to be mixed with fly ash.

2 Improving maintainability and economic efficiency

Since launching the dry bottom ash handling system on the market, improvements designed to enhance maintainability as well as economic efficiency have been made. The following section describes three major improvements made to the system.

(1) Maintenance-free seal

Since the dry bottom ash handling system is installed under a boiler, the seal on the interface between the boiler and the system must be resistant to internal boiler pressure as well as thermal expansion.

When the dry bottom ash handling system was first introduced, a water seal similar to those used on conventional wet bottom ash handling systems was used for the boiler interface as shown in Fig. 2 (a), meaning the system was not entirely water-free. With an eye to further improving the system, a new mechanical seal was developed.

Figure 2 (b) shows the structure of the mechanical seal. Composed of a multilayer metal fabric and other materials connecting the bottom of the boiler with the dry bottom ash handling system, the mechanical seal can absorb the thermal expansion of the boiler. Since the

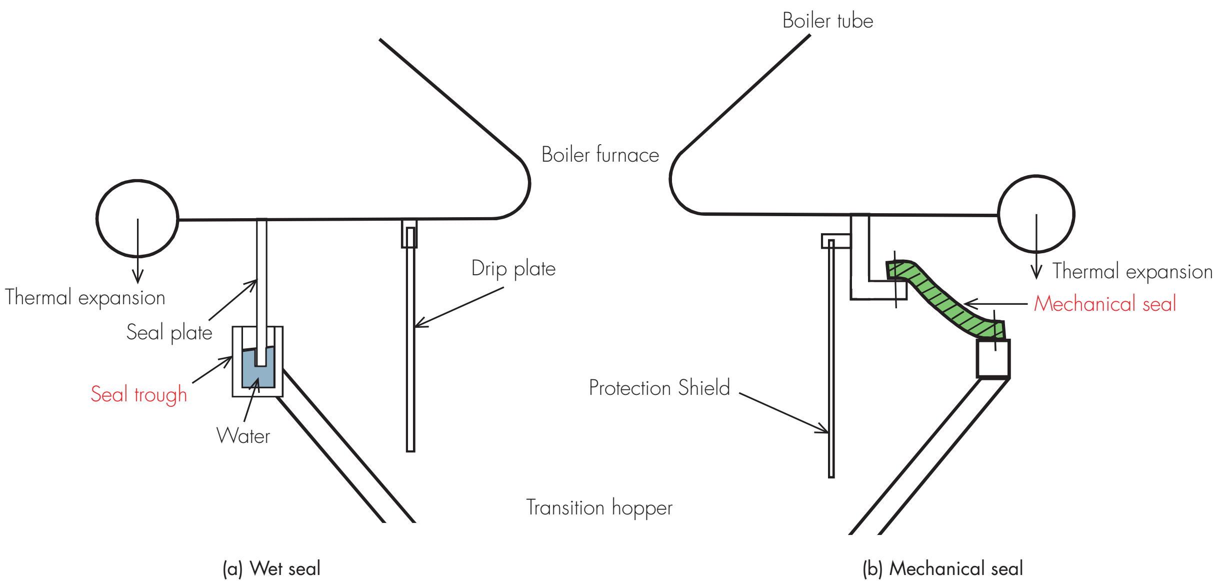


Fig. 2 Boiler interface overview (water/mechanical seal)

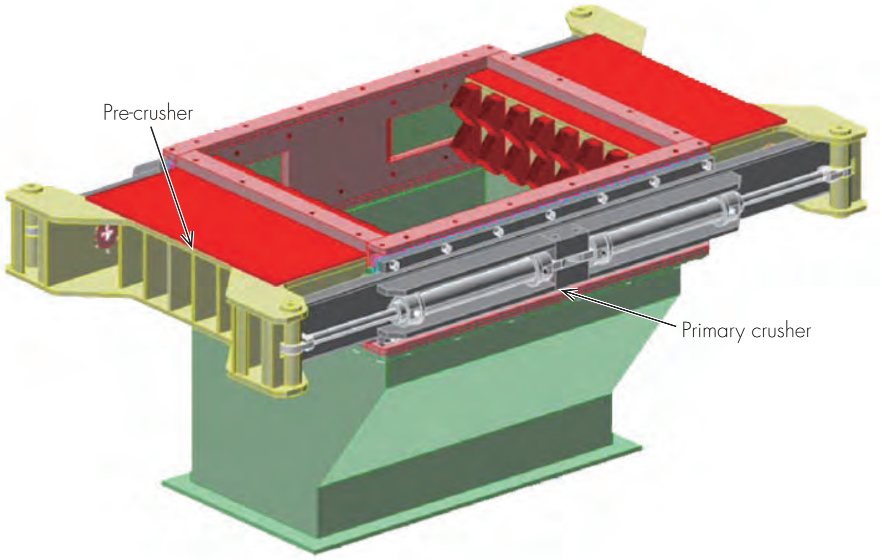


Fig. 3 Hydraulic pre-crusher

mechanical seal is essentially maintenance-free, it eliminates the cost of maintaining and running the kind of circulating water system employed by conventional systems. Replacing the wet seal, it has been adopted as the standard seal since the latter half of 2000.

(2) Preventing bottom ash from clogging

The dry bottom ash handling system uses a primary crusher installed downstream from the dry bottom ash conveyor that coarsely crushes bottom ash. Clinkers of certain sizes and shapes would sometimes build up in the

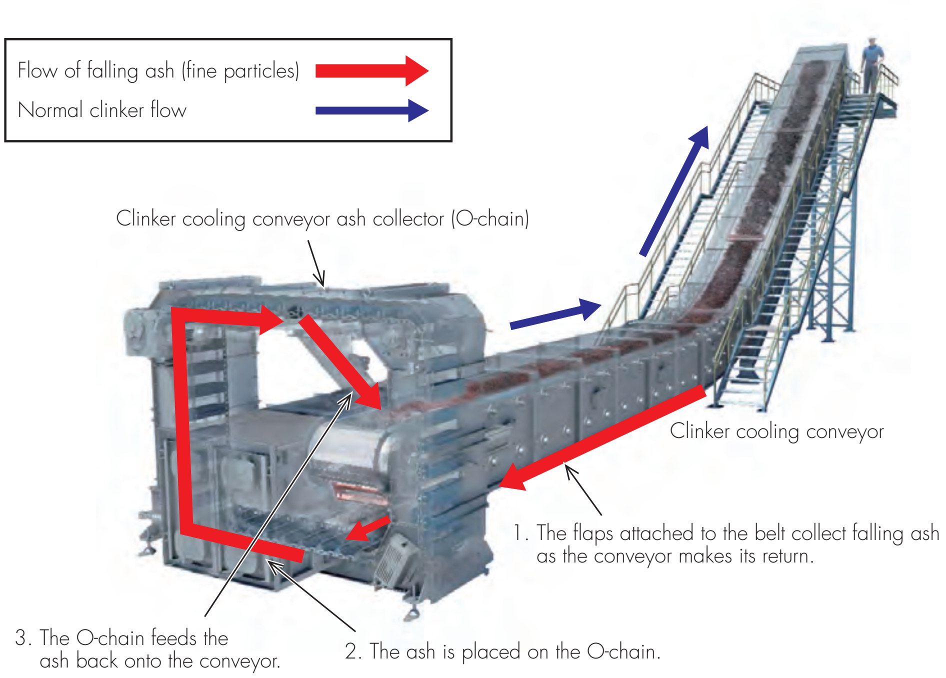


Fig. 4 Clinker cooling conveyor ash collector

primary crusher, blocking the flow and clogging the system. A hydraulic pre-crusher was developed in order to solve this problem. Figure 3 shows a schematic diagram of the hydraulic pre-crusher.

The hydraulic pre-crusher features a set of jaws (the red area shown in Fig. 3) that open and close to crush lumps of bottom ash. It is installed below the outlet of the dry bottom ash conveyor and crushes any ash that accumulates in the primary crusher. Before installing the hydraulic pre-crusher, ash lumps had to be removed manually by operators whenever they clogged the conveyor outlet. The new feature significantly reduces operators' workload and has earned high marks from customers.

(3) Reduced maintenance cost for the clinker cooling conveyor ash collector

The clinker cooling conveyor, a component of the dry bottom ash handling system, originally had a scraper conveyor installed under the main conveyor to collect falling ash. Since the scraper would wear out relatively quickly, it proved to be a major obstacle to providing a long lasting system. As a solution to this problem, a new ash collector (O-chain) was developed to replace the scraper conveyor.

The O-chain is installed at the tail end of the cooling conveyor as illustrated in Fig. 4. Fine ash particles that have collected at the bottom of the conveyor are swept up by the conveyor belt flaps and onto the O-chain, which puts them back on the cooling conveyor. Eliminating the use of sliding parts that can wear out easily, the O-chain will significantly reduce maintenance costs. Furthermore, O-chain has several merit below: increase the clinker cooling conveyor slope, provide a more compact and cost-effective solution, have the possibility to offer longer conveyor etc.

Postscript

Since Japan's first dry bottom ash handling system was installed at Kobe Steel, Ltd.'s Shinko Kobe No. 1 Power Station, the system has been widely adopted by utilities as well as independent power plants across the country and has set a new standard for bottom ash handling systems. As of April 2015, Kawasaki has delivered seven units in Japan and eight units overseas (South Korea and the Philippines). Add in those delivered by Magaldi and the tally comes to over 150 in use around the world.

The system is in high demand due to its clear advantages over wet systems and is expected to remain the coal ash handling equipment of choice. Kawasaki looks forward to harnessing its years of experience as it continues to deliver optimal systems tailored to customers' needs.

Yasutaka Ozeki / Yoshihiko Takemura

Contact information
Ash Handling Project Office,
Industrial Plant Engineering Division,
Plant & Infrastructure Company
Tel: +81-78-682-5057 Fax: +81-78-682-5058

Prelude FLNG boiler
− World's largest off-shore boiler delivered

Kawasaki has completed the delivery of seven boilers for use on the Prelude FLNG facility, developed by Royal Dutch Shell in Australia as the world's first floating LNG facility. Each boiler is capable of producing 220 tons of high-temperature, high-pressure steam per hour, and boasts the world's largest capacity in any other boilers for off-shore use. These boilers feature a robust structure and a furnace optimized to meet special, high-level specifications required for offshore applications. Following assembly at Kawasaki's Harima Works, the seven boilers were delivered on schedule in 2013 (four in August and three in October).

Preface

Across the globe there are a wealth of untapped offshore gas fields, both large and small. While today's changing energy demands are likely to put a greater strain on LNG resources, hopes are running high that offshore gas field development will fill the void. Floating liquefied natural gas (FLNG) is a groundbreaking solution for offshore liquefaction, storage, and offloading of natural gas. All eyes are on the technology as it paves the way to opening up new offshore gas fields at sea that have always been considered too difficult to develop.

1 Background

About 200 kilometers off Australia's north-west coast and 250 meters below the surface of the water lies the Prelude gas field. It is above that gas field that an FLNG facility will remain moored as it operates for a period of about 25 years. The Prelude FLNG will employ boilers designed to generate electricity and process steam even under turbulent offshore conditions triggered by huge typhoons and other natural forces.

Over the years Kawasaki has delivered more than 1,000 land boilers (with a maximum steam flow of 1,200 t/h).

Table 1 Main specifications

Maximum steam flow (t/h)	220
Steam pressure (bar g)	69
Steam temperature (°C)	480
Fuel	Fuel gas or diesel oil
H x W x D (m)	Approx. 20 x 13 x 11
Weight (ton)	Approx. 500

*Figures are for a single boiler.

They have been used to generate the electricity supplied by power companies as well as for industrial and in-house power generation. Kawasaki has also supplied more than 200 marine boilers (with a maximum steam flow of 140 t/h) for LNG carriers and other applications. The boilers to be supplied to the Prelude FLNG project were contracted by the French engineering company, Technip. Kawasaki has incorporated the lessons it has learned over the years in the field of marine boilers with its outstanding land boiler technologies to meet the large capacity requirement.

These marine boilers are the largest ever to be used and each one will generate 220 t/h of high-temperature, high-pressure steam. That is 1.6 times the maximum steam flow of any marine boiler Kawasaki has previously built.

2 Product design, development, and testing

Table 1 provides the main specifications for the Prelude FLNG boiler while Fig. 1 illustrates its general arrangement. The air and gas paths feature a simple design in which air and gas flow downward in a furnace and upward in the second pass, creating a large U-shaped flow path. In the water steam flow, boiler water is heated as it goes through the economizer and is fed to the steam drum. Heat is transferred to the boiler water as it naturally circulates through the steam drum, water drum, and evaporator before turning into saturated steam. The saturated steam flows through a superheater where it becomes superheated steam with the desired pressure and

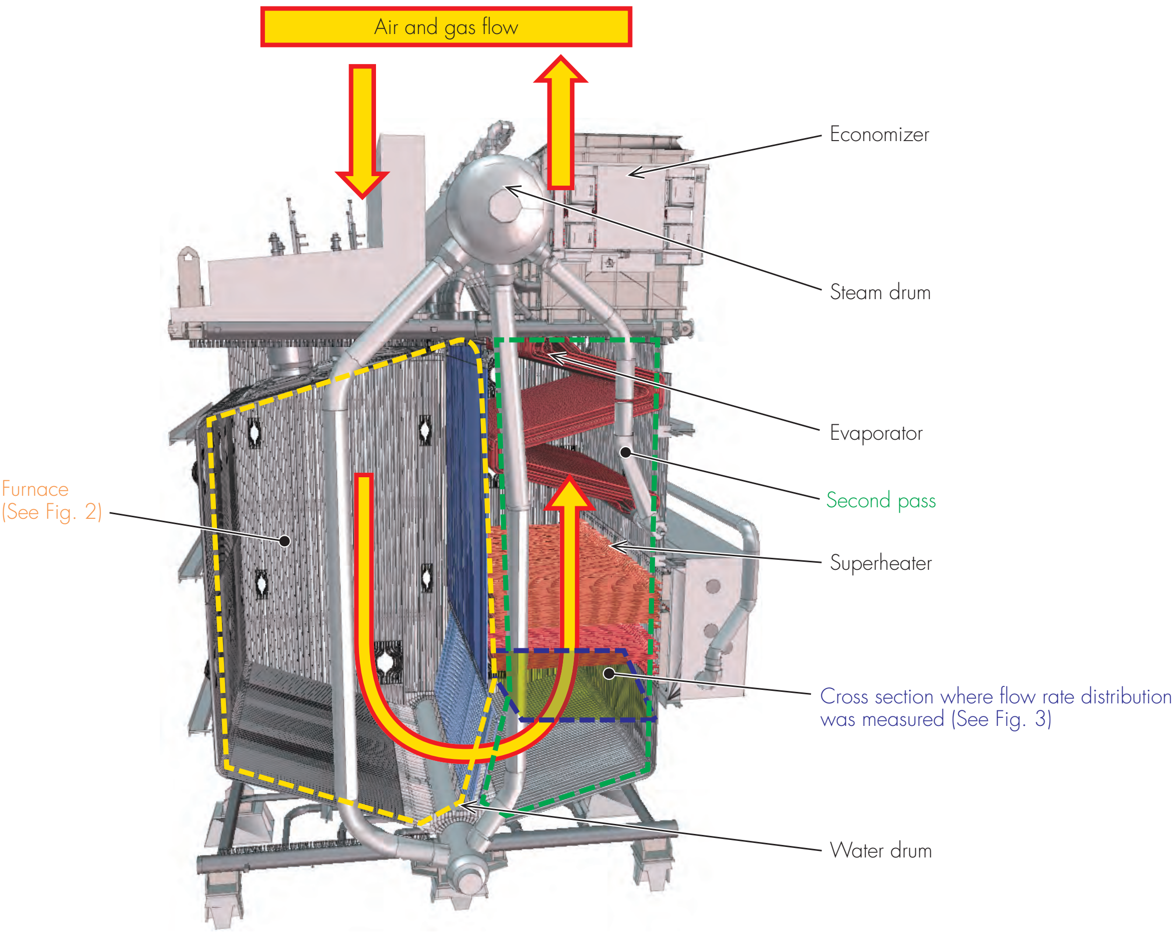


Fig. 1 General arrangement of Prelude FLNG boiler

temperature before being supplied to the user's equipment.

Designed to generate a large amount of high-temperature, high-pressure steam, the Prelude FLNG boiler is almost double the size of standard conventional marine boilers (approx. H13 m x W7 m x D4 m). The boiler was developed with a keen focus on the following two design features.

(1) Optimized furnace

Kawasaki conducted a wind tunnel test using a 1/5 scale model of the actual boiler with an eye to optimizing the furnace. The test examined the burner installation angle and the distribution of gas flow rate through the boiler's second pass.

The burner installation angle was tested in Fig. 2, and the distribution of gas flow rate on the cross section of the boiler's second pass is illustrated in Fig. 3.

The test demonstrated that the burner flames did not touch the furnace walls and that the gas flow rate was distributed within the threshold values. The test results were used to create an optimal design for the actual boiler.

(2) Robust structure

FLNG boilers must be built sturdy enough to withstand the motion and acceleration of FLNG at sea. They must also be built blast-proof since they also serve as a shield for the vessel's accommodation space in the event of an emergency. Keeping that in mind, Kawasaki analyzed blast load from every possible angle to design boilers that were tough enough to meet the customer's requirements.

3 Advantages

The Prelude FLNG boiler offers the following advantages

(1) Short lead time

Kawasaki incorporated designs that would help shorten the production lead time right from the basic engineering

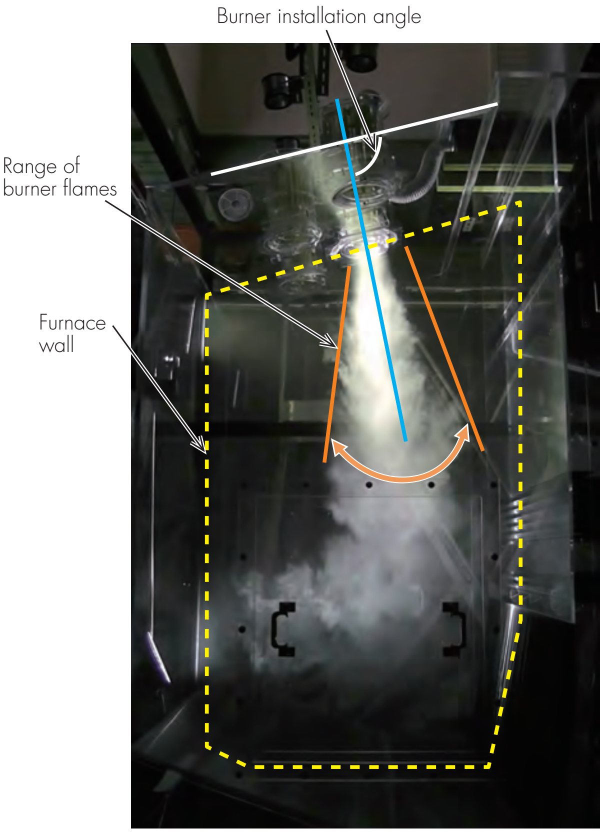


Fig. 2 Evaluation of burner installation angle

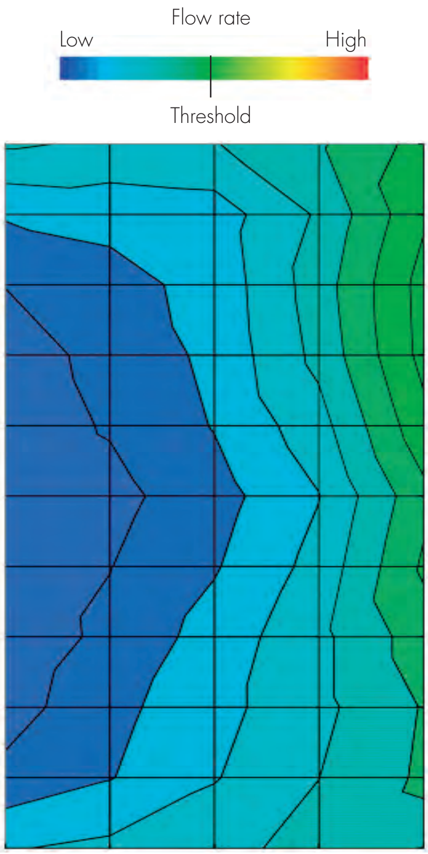


Fig. 3 Distribution of gas flow rate through the 2nd pass of boiler

stage, and constructed an assembly shop dedicated to the final assembly of FLNG boilers at its Harima Works. Teamwork between engineering and manufacturing during planning and design processes cleared away any potential bottlenecks in production and established a one-piece flow manufacturing system in which workers complete assigned tasks at their respective stages of the production line. This enabled Kawasaki to ensure quality every step of the way while shortening lead time.

(2) High quality

The Prelude FLNG project has adopted strict certification requirements set by Lloyd's Register for equipment used in everything from design to inspection. In order to meet these requirements, Kawasaki had about 40 of its Harima Works employees undergo a special training program to acquire the advanced welding skills needed to be Lloyd's Register certified. As a result, Kawasaki was able to achieve an even higher level of welding quality.

(3) Environment resistant

Project specification requirements for the Prelude FLNG boilers include heavy-duty painting and water-tight insulation under harsh offshore conditions. For this reason, painting work was performed under strict oversight by only qualified painters who passed a qualification test conducted in the presence of an inspector from the National Association of Corrosion Engineers (NACE) International. The boilers were insulated in accordance with CINI standards (Netherlands insulation standards) as required by Shell and underwent thorough inspections by Technip and Shell inspectors.

(4) Maintainability

Due to limited deck space, a compact design and ease of maintenance were a must for the boilers. Kawasaki incorporated a maintenance area for pressure parts, burners, etc., in the boiler module blueprints to ensure that maintenance work could be carried out throughout their service life.

Postscript

After winning the contract for Shell's Prelude FLNG project in 2011, Kawasaki assembled the boilers at its Harima Works and delivered a total of seven units to the customer as planned in 2013. Shell plans to build additional FLNG facilities to follow the Prelude, its first FLNG, on an ongoing basis. Other companies also have plans to construct FLNG facilities and the market is expected to really take off.

Using this project as its foundation, Kawasaki is moving forward to supply highly reliable FLNG boilers to the market as a major player in the field of energy production and to help make the world a brighter place.

Seiji Tabata / Keisuke Kurokawa

Contact information
Boiler Design Department,
Energy Plant Engineering Division,
Plant & Infrastructure Company
Tel: +81-78-682-5039 Fax: +81-78-682-5041

Municipal waste carbonization system – Making effective use of carbonized fuel manufactured from waste

At the end of June 2015, Kawasaki delivered a municipal waste carbonization system to Saikai City, Nagasaki Prefecture. This system manufactures carbonized fuel from municipal waste and sewage sludge generated in the city with minimal environmental impact. The carbonized fuel is effectively used at private facilities for mixed combustion with coal. The system features a compact-size carbonization kiln, high-performance exhaust gas treatment system, and desalination and granulation treatment to achieve high efficiency. Therefore, even if the disposal capacity is relatively small, it is possible to maintain high performance.

Preface

While there are many opinions regarding the optimal method of waste treatment, in the case of facilities with a relatively small capacity (less than 100 tons/day), carbonization is an excellent process to be used. It enables excellent thermal energy recovery from waste and effective utilization of biomass resources present in waste.

1 Background

In November 2012, Kawasaki in collaboration with Electric Power Development Co., Ltd. (primary contractor; J-POWER) accepted an order from Saikai City in Nagasaki Prefecture to build and operate an energy recovery facility, and delivered a municipal waste carbonization facility in June 2015. The project's goals included the design, construction and operation of a facility to be used for manufacturing carbonized fuel (charcoal) from municipal waste and sewage sludge generated in Saikai City. The carbonized fuel is effectively used at private facilities for mixed combustion with coal. These activities are part of efforts aimed at realizing a recycling-oriented, low-carbon society.

2 Overview

This facility has a capacity of 30 tons/day (2 processing lines, 15 tons/day each). Built to replace two facilities nearing the end of their service lives—the Seihi Clean Center and Saikai Clean Center—this facility was designed to consolidate waste treatment in Saikai City while also serving as a sewage sludge treatment facility by handling sewage sludge and human waste sludge disposal. Fig. 1 provides a general outline of the treatment processes within the facility.

Waste is transferred from the platform to the waste pit and sewage sludge to the sewage sludge hopper. The waste is reduced to a fine size using the shredder and fed via the waste feeder into the carbonization kiln, where waste is carbonized. Pyrolysis (thermal decomposition) gas produced during carbonization is combusted in the combustion furnace; processed as appropriate via the gas cooling tower, bag filter and other exhaust gas treatment equipment; and exhausted as exhaust gas. Charcoal discharged from the carbonization kiln is desalinated and granulated, then transported to an outside facility for utilization as carbonized fuel.

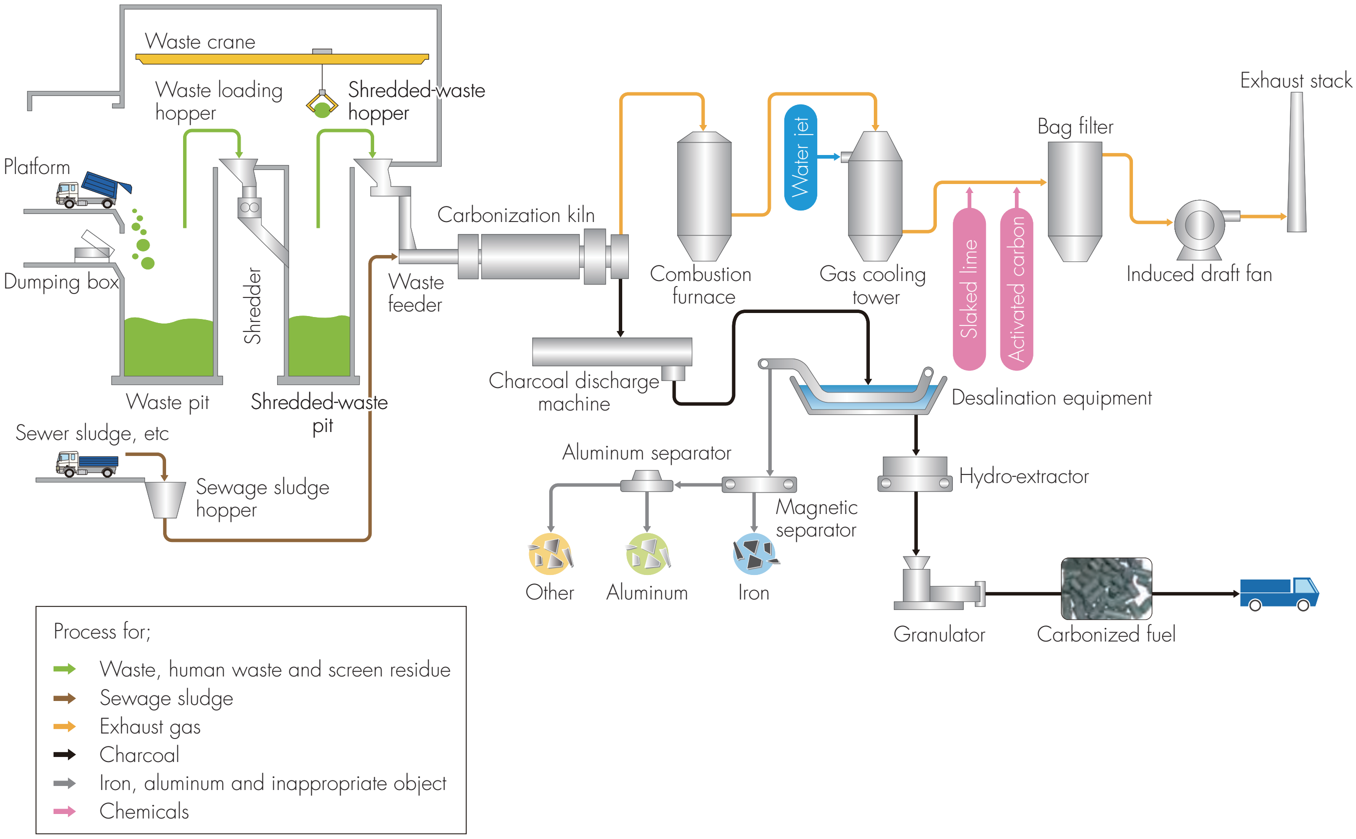


Fig. 1 Flow of municipal waste carbonization system

3 Advantages

(1) Compact carbonization kiln size

The external appearance of the carbonization kiln can be seen in Fig. 2. As shown in Fig. 3, this kiln is an indirect-heating kiln type with excellent airtight mechanism, ensuring both safety and the manufacturing of high-quality charcoal. In this rotary-type kiln with its dual-tube kiln design, waste is fed into the inner tube and heated gas is passed through the space between the inner and outer

Fig. 2 Carbonization kiln

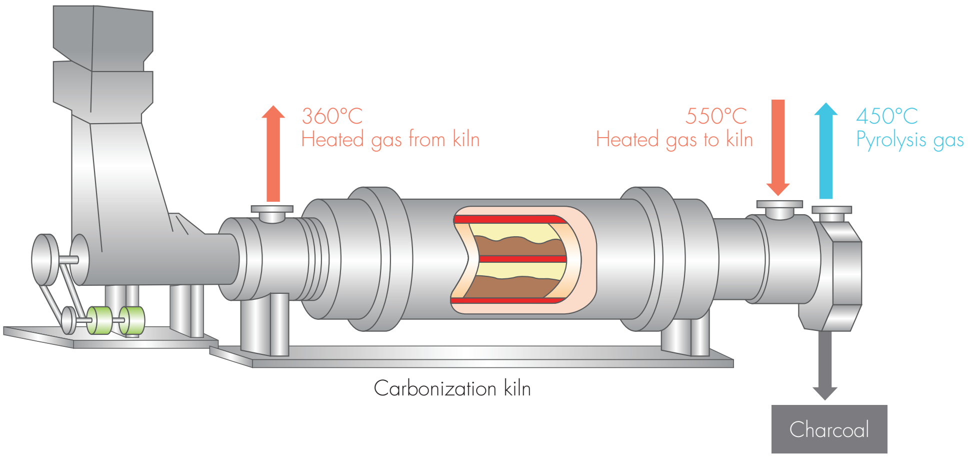


Fig. 3 Schematic view of carbonization kiln

tubes to heat the waste indirectly, producing charcoal and pyrolysis gas. The carbonization kiln's internal structure consists of a cylindrical tube divided into quadrants, which enables efficient carbonization and makes our kiln more compact than simple kiln products consisting of a single tube without internal subdivisions.

(2) Environmentally friendly treatment facility

Pyrolysis gas generated during carbonization is combusted in the combustion furnace, serving as the heat source for the carbonization kiln. Before being exhausted into the atmosphere, exhaust gas passes through a gas cooling tower and bag filter, with chemicals injected in order to thoroughly prevent potential atmospheric pollution. Facility operations have achieved extremely low CO and NOx concentration in exhaust gases.

In addition, in the case of the carbonization process, municipal waste is not incinerated completely. The municipal waste is converted into carbonized fuel (as a fuel resource). This results in low exhaust gas and dust emissions as well as ash quantities that only amount to 20% or less of those generated by a waste incineration process, leading to reduced final disposal quantities and lower environmental impact.

(3) Desalination and granulation equipment to enable use as fuel by private facilities

In order to manufacture low-chlorine carbonized fuel for the purpose of creating coal-mixture fuels to be used by private facilities, we utilize advanced desalination techniques consisting of desalination equipment, hydro-extractor and granulator. Fig. 4 shows the appearance of this carbonized fuel, and Table 1 our manufacturing facility's carbonized-fuel quality specification, in regard to which we have achieved completely satisfying performance.

(4) Advantages of carbonized fuel

When evaluated in terms of the entire process from manufacturing through to usage, the partial replacement of coal with carbonized fuel can reduce overall coal usage quantities and cut greenhouse gas emissions (CO_2).

We do, in fact, possess refuse-derived fuel (RDF) technologies for the conversion of waste for use as fuel; however, in contrast to RDF production, our carbonization process utilizes energy derived from waste itself, meaning that it is possible to reduce the use of fossil fuels. Furthermore, we have innovated desalinization with the goal of further spreading the use of our carbonized fuels. This enables the manufacturing of low-chlorine carbonized fuel, thus ensuring a wider user base.

Fig. 4 Carbonized fuel

Table 1 Quality specification of carbonized fuel

Quality Item	Standard Value
Lower heating value (kJ/kg)*	Approx. 13,000
Chlorine concentration (ppm)	Approx. 3,000
Form	Pellet

*Anhydrous base

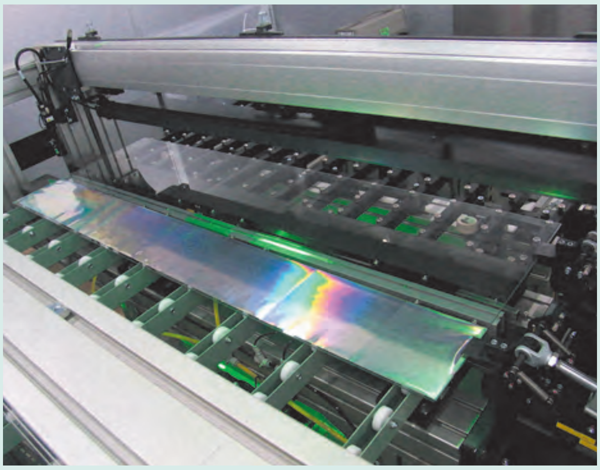
Postscript

In terms of waste treatment technologies, Kawasaki offers the indirect-heating type carbonization kiln described here as well as various other waste incineration technologies. We are actively pursuing technological developments and sales efforts in order to address increasingly severe environmental problems throughout society and respond to the diversifying needs of our customers.

Masato Odake / Shiro Suzuki

Contact information
Environmental Plant Department,
Environmental Plant Engineering Division,
Plant & Infrastructure Company
Tel: +81-78-682-5082 Fax: +81-78-682-5433

Kawasaki High-speed Laser Scanning System – Using differentiation technology to boost the productivity and quality of laser processes



The Kawasaki High-speed Laser Scanning System boasts an overwhelming production capacity compared to competing systems on the market. Initially developed for cutting (patterning) the power generation layer of thin-film solar cells, the system will be used for broader laser processing applications using features not found in competing products.

The system can irradiate workpieces with a laser over a wide area at ultra-high speed during conveyance. The laser processing unit can be customized for various types of laser. By configuring the system so that workpieces pass through the system, it can help improve the quality and productivity of various laser processes according to the user's needs.

Preface

In recent years, laser scanning systems have come to be used in thin-film circuit forming for thin-film solar cells, touch panels and so forth in pursuit of improvements to productivity. Additionally, laser scanning has begun to see applications in areas such as 3D printing and laser coating, and the scope of applications is expected to expand even further in the future.

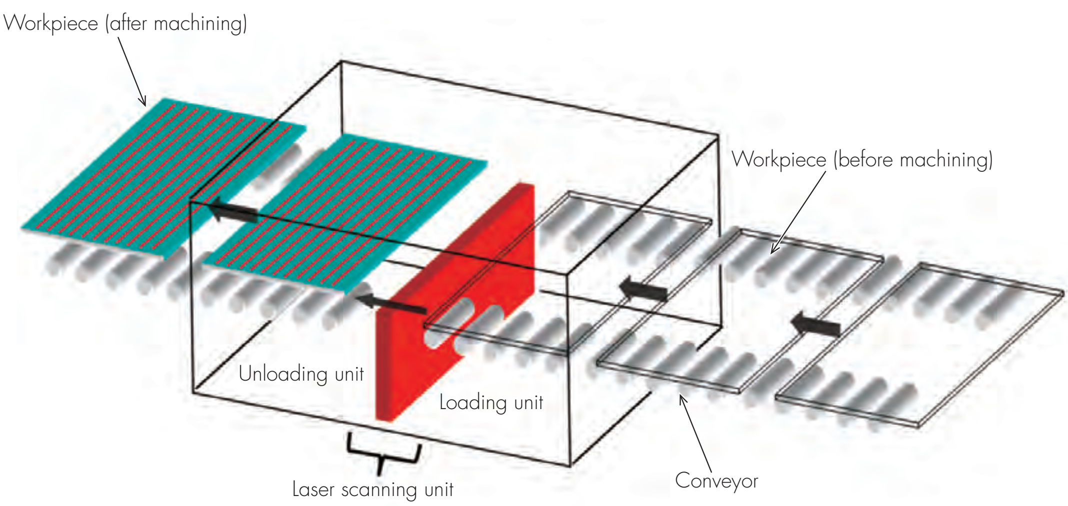


Fig. 1 System configuration

1 System configuration

Figure 1 depicts a simulated system configuration, consisting of a workpiece loading unit, a laser scanning unit and a workpiece unloading unit. Although Fig. 1 places the laser scanning unit below the workpiece, it is also possible to position this section above the workpiece.

2 Advantages

Our system offers the following advantages, which enable a wide range of high-quality laser machining operations and lead to improved productivity.

(1) Workpiece pass-through system with ultra-high-speed scanning

Through the use of ultra-high-speed laser scanning (10,000-20,000 mm/sec.), our system achieves continuous passage of workpieces with simultaneous machining operations. Furthermore, the system's physical footprint is extremely compact, facilitating easy integration into existing production lines.

(2) Wide scanning area and vertical laser-beam projection

Figure 2 compares a standard galvano scanner with our system. The galvano scanner has a small scanning area, and the beam profile becomes warped and less uniform closer to the edges of this scanning area, making it difficult to achieve consistent machining results over a wide area. In contrast, the Kawasaki system has a large scanning area (up to 1,400 mm wide), and because the laser is always projected vertically onto the workpiece it is possible to achieve uniform and consistent-quality laser machining results.

Until now, it has only been possible to handle small workpieces (localized machining) using laser machining processes. However, with our system it is now possible to handle large workpieces (wide-area machining).

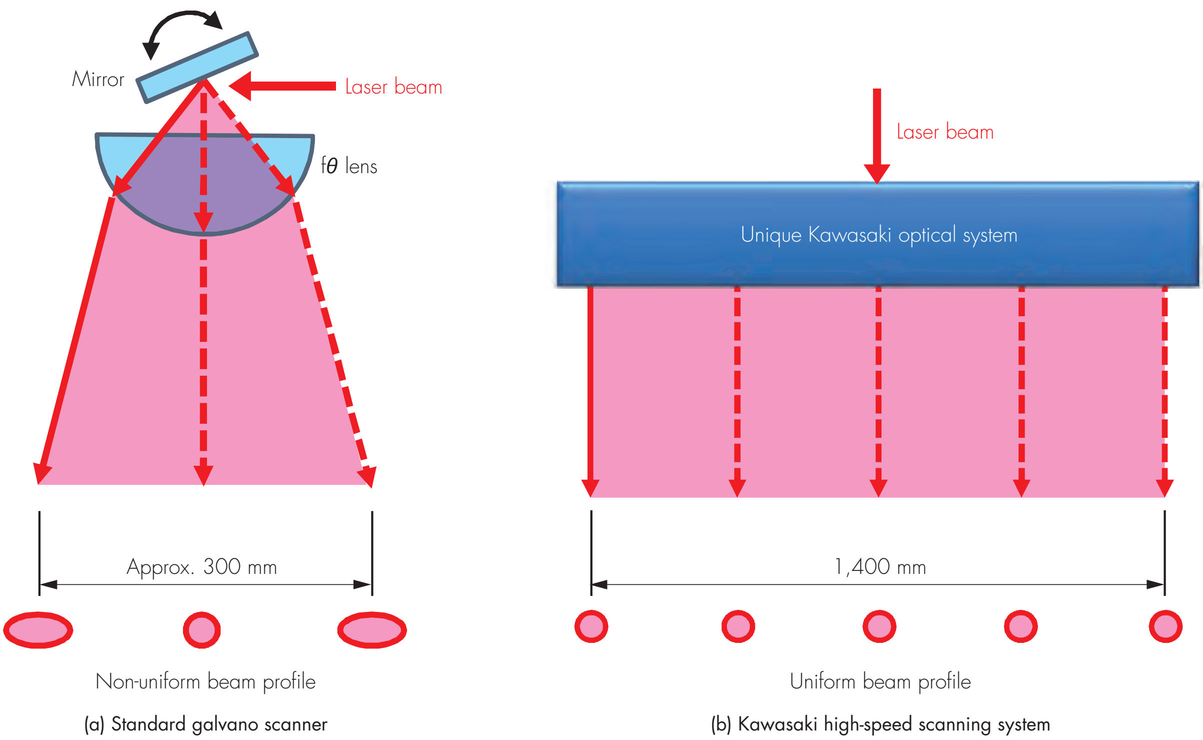
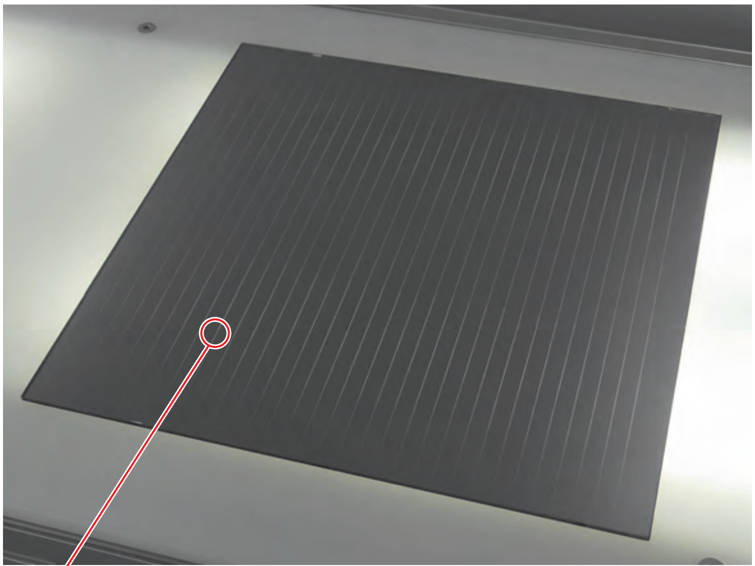


Fig. 2 Comparison with galvanometer scanner

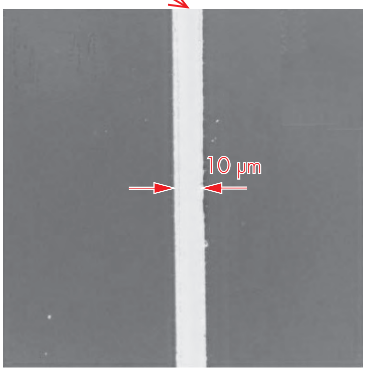
(3) Uniform-width line cutting

Example machining results are shown in Fig. 3(a). The workpiece is a thin-film solar cell substrate: laser cutting has been carried out at 9 mm intervals on a molybdenum (Mo) thin film atop a glass panel. A magnified image of a section machined using our system can be seen in Fig. 3(b), and a magnified image of a competitor company's machined section is shown in Fig. 3(c) for comparison. In contrast to the non-uniform results produced by the competitor's system, Kawasaki's system achieves consistent, uniform-width machining, and does so at ultra-high machining speeds 50 times that of the competitor.

Type of workpiece: thin-film solar cell substrate
(Mo thin film atop a glass substrate)
Size of workpiece: 300×300 mm, 3 mm thickness
Mo film thickness: 400 nm

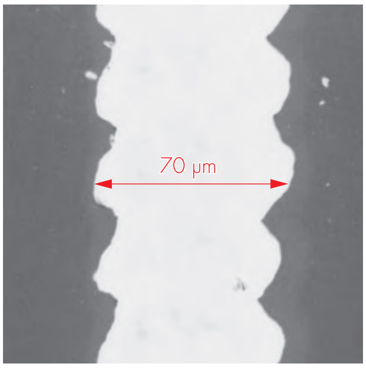


(a) Machining example: workpiece (after machining)



Scanning speed: 15,000 mm/sec.
Uniform machining width: 10 μm

(b) Kawasaki



Scanning speed: 300 mm/s
Non-uniform machining width: 50-70 μm

(c) Competitor company

Fig. 3 Processing example (sample comparison)

Table 1 Main specifications

External form	External dimensions (mm)	L 3,500 × W2,300 × H1,500
	Weight (t)	Approx. 4
Compatible workpieces	Dimensions (mm)	Between 300 × 300 and 1,400 × 1,100
	Board/plate thickness (mm)	1–5
	Additional details	Please consult with us regarding system configurations for use with workpieces that fall outside the above dimensional limits
Laser equipment	Type	YVO4 THG, SHG pulse laser
	Output/wavelength (W/nm)	14/355, 14/532
	Beam direction	From directly below conveyor surface to above
Equipment specifications	Scanning speed (mm/sec.)	Max. 20,000
	Scanning range (mm)	Max. 1,400
	Workpiece feed speed (mm/sec.)	Max. 400
	Feed stroke (mm)	Max. 2,000

3 Demonstration system

We have installed a system for demonstration purposes in our company facilities to respond to requests for sample machining tests. Main specifications of the demonstration equipment are outlined in Table 1.

4 Various fields of application

The system's laser equipment and optical components can be customized to meet user requirements, enabling the use of our product in the following types of applications.

① Circuit patterning: circuit forming (via thin-film cutting) for thin-film solar cell substrates, touch panels, etc.
② Surface modification/treatment: laser hardening and laser annealing (e.g., melt crystallization of amorphous silicon thin films, grain boundary formation in grain-oriented magnetic steel sheets for improved product quality, etc.)
③ Optical fabrication including 3D printing and UV curing of resins
④ Laser coating/cladding (padding)
⑤ Laser cleaning and laser stripping (of layers)
⑥ Laser exposure
⑦ Laser deposition
⑧ Laser cutting and laser beam welding
⑨ Inspection and measurement

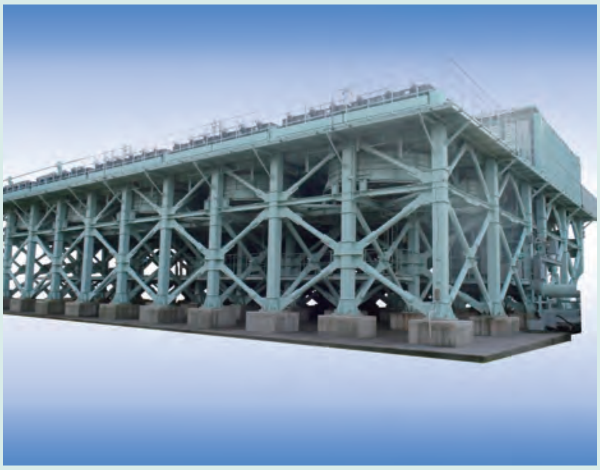
Postscript

In the future, we hope to develop applications in new fields by responding to user requests for sample machining processes while providing higher quality and productivity in laser-based processes in order to assist in the development of new products.

Osami Oogushi

Contact information
Project Development Department
Plant & Infrastructure Company
Tel: +81-78-682-5411 Fax: +81-78-682-5586

Air fin cooler (AFC) – Excellent earthquake resistance helps make nuclear power station safer



Increased earthquake resistance in nuclear power facilities has been in great demand ever since the Great East Japan Earthquake. In response, Kawasaki has added reinforcements and made structural improvements to its air fin coolers (AFC). Seismic analysis results have shown that these improvements have raised the eigenvalues of major components, attaining sufficient stiffness.

Accordingly, Kawasaki will now be able to provide AFCs with excellent earthquake resistance to help make nuclear power stations safer.

Preface

Following the 2011 Great East Japan Earthquake and subsequent tsunamis, there has been an increasing demand for diversification in nuclear power plant facility cooling methods, and in an increasing number of cases air is being used in place of seawater to cool equipment.

1 Objective

Nuclear power plants are equipped with diesel power generation equipment to be used for emergency power generation in the case of an accident or other such circumstance that prevents the regular provision of electricity, and seawater is often used as the coolant for these diesel generation facilities.

However, in order to diversify cooling methods in pursuit of greater levels of safety, an increasing number of plants have adopted air fin coolers (AFCs). There is a high demand for cooling facilities that remain undamaged even in the event of an earthquake, thus preserving cooling capabilities.

In consideration of such demand, we at Kawasaki have improved the earthquake resistance of our AFCs.

2 AFC structure and specifications

(1) Structure

Our AFC's external appearance and form are shown in Fig. 1. In general, AFCs comprise the following components:

① Tube bundles
② Fan
③ Motor and reduction gear
④ Fan ring
⑤ Framework
⑥ Louvers (upper and side louvers)

Cooling liquid is fed through the tube bundles (heat exchanger tubes) and cooled via air from the fan. Each component device is supported by a highly earthquake-resistant framework, enabling the AFC to continue functioning even in the event of an earthquake. In addition, if the upper louvers become blocked by snow during the winter, air can be exhausted from the side louvers, enabling the equipment to function regardless of snow accumulated on top.

Please note that the AFC depicted in Fig. 1 is of a two-bay design. Our AFCs are divided in units known as "bays," and the number of bays can be increased or decreased as necessary according to heat exchange quantity requirements. Each bay's basic structure adheres to a standardized form, which enables reduction of time normally required for design and analysis as well as cutting of installation costs.

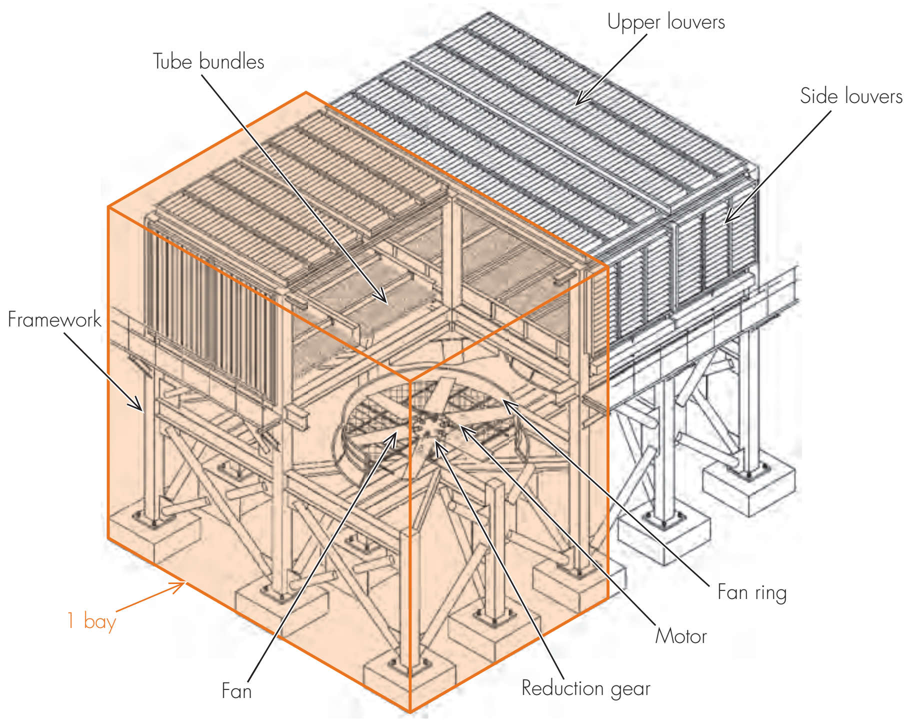


Fig. 1 Air fin cooler outline (2 bays)

Table 1 Air fin cooler specifications

Type	Forced draft
Earthquake resistance rating	S*
Equipment class	JSME** Codes for Nuclear Power Generation Facilities class 3 container
Heat exchange quantity	Approx. 1.3 MW per bay (varies according to temperature conditions)

* S represents the highest class of earthquake resistance.
** JSME: Japan Society of Mechanical Engineers

(2) Specifications

The specifications for Kawasaki's standard AFCs are outlined in Table 1.

3 Improved earthquake resistance

High earthquake resistance is required of AFCs. In the past, the soundness of support frameworks, the fan section and so forth in the event of an earthquake was confirmed via analysis based on specified seismic conditions. In response to increasingly strict requirements regarding seismic force conditions in recent times, we have made improvements to the fan and fan ring (see Fig. 2), tube bundles and other individual components. We have also added ribs, braces and other reinforcing parts to reduce deformation caused by earthquakes, and modified structural forms and increased the numbers of bolts used at joint sections which are subject to greater concentrations of stress.

The presence or lack of sufficient structural rigidity is determined using eigenvalue analysis: requirements as of late call for values exceeding 33 Hz, and through the abovementioned improvements eigenvalues for the fan ring and tube bundle framework have, as shown in Fig. 3, fulfilled structural rigidity requirements.

4 Measures against snow accumulation

Our AFCs are equipped with louvers designed to provide a countermeasure to snow accumulation. In order to enable proper exhaust of hot air generated by the heat exchange process regardless of snow accumulation on top of the equipment during the winter, the upper louvers are closed

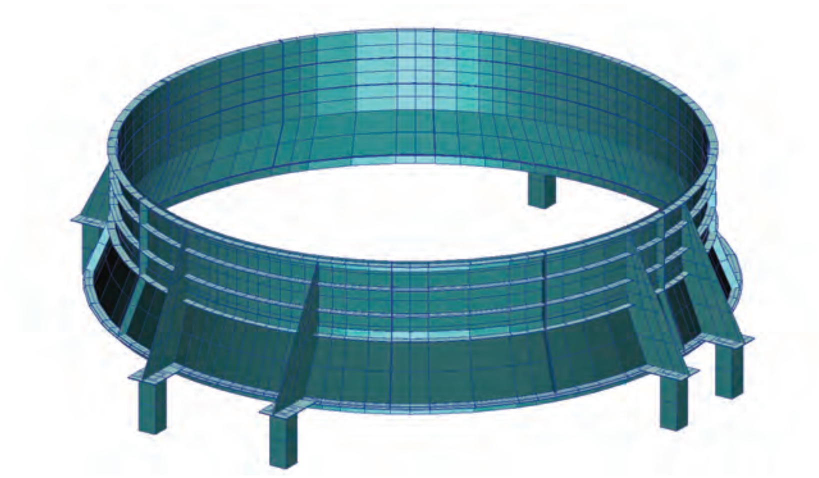


Fig. 2 Seismic analysis model of fan ring

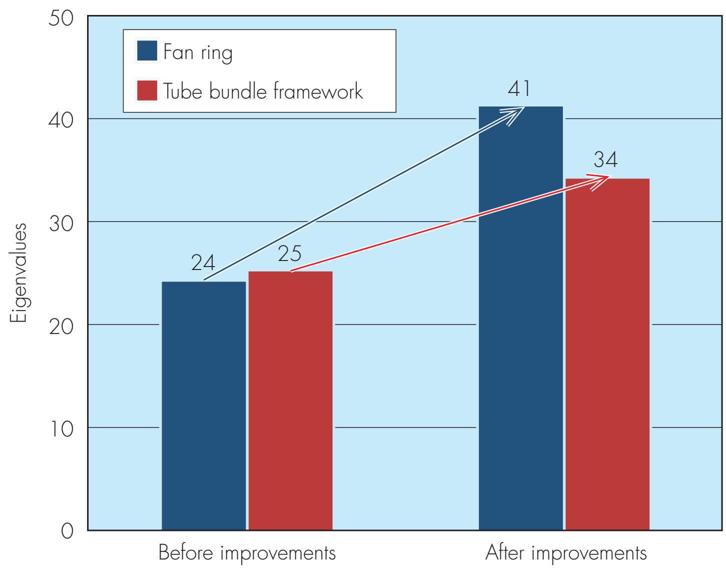


Fig. 3 Rise in eigenvalues after improvement

Table 2 Completed deliveries

Client	Year of installation	Heat exchange quantity	No. of units
Fukushima Daiichi Nuclear Power Station Unit 4, Tokyo Electric Power Company, Inc.	1996	5. 27 MW	1 unit (3 bays)
High Temperature Engineering Test Reactor, Japan Atomic Energy Agency	1996	3.5 MW	1 unit (4 bays)
Shimokita Reprocessing Plant, Japan Nuclear Fuel Ltd.	2002	11. 6 MW	2 units (9 bays each)
		4. 45 MW	2 units (4 bays each)

during the winter and air exhausted from side louvers instead, enabling continued AFC operation. Although it is possible to equip AFCs with snow-melting heaters to prevent snow accumulation on top, the water produced by melting snow may refreeze and hinder machinery operations. Furthermore, because necessary utility supplies such as steam and electricity (for heaters) may be cut off in the event of an earthquake, louvers are suitable as an earthquake safety measure.

5 Past installations of Kawasaki AFCs

We have successfully installed our AFCs in various nuclear-power and related facilities in the past (see Table 2), and we are currently preparing designs for installation of our system at the J-POWER (Electric Power Development Co., Ltd.) Ohma Nuclear Power Station.

Postscript

Following the Great East Japan Earthquake and subsequent tsunamis, demand for increased safety at nuclear power plants has been strong. At Kawasaki, we strive to contribute toward safer nuclear power plant operations through relevant safety measures.

Tatsuya Ozawa / Koji Sato

Contact information
Nuclear Plant Office,
Project Development Department,
Plant & Infrastructure Company
Tel: +81-78-682-5054 Fax: +81-78-682-5055

Fine Sector θ
– Achieving ultrafine powder classification

EarthTechnica Co., Ltd. has developed a new powder classifier, Fine Sector θ, using its technological know-how cultivated through years of experience in developing toner production equipment. Fine Sector θ is capable of eliminating particle size of 4 μm or less, especially the particle size of 2 μm or less, which is defined as ultrafine powders in pulverized toner material. Specially designed classification-rotor and dispersion air enable to achieve this high classifying performance with superb accuracy.

Preface

Demand for higher printing quality in laser printers, copiers and other such devices is growing by the year. In order to meet such demand, it is necessary to reduce quantities of particles with diameters of approximately 4μm or less—especially those with diameters of approximately 2 μm or less, which are known as ultra-fine particles—during classifying processes on toner production lines.

1 Background

EarthTechnica Co., Ltd. is a comprehensive crushing/grinding equipment manufacturer that focuses on crushing, pulverizing and classifying as its key technologies. Their products include crushers and grinders, environmental equipment, and powder processing equipment, which can be utilized to reduce large masses several meters in size to small particles several micrometers in size. EarthTechnica's array of powder processing equipment lines are used in a wide range of powder-based production processes in fields including medicine, chemicals, food products and others. One such product line is the KRYPTRON series of powder processing units—grinders designed for use in toner production—which have received high praise from users over the years.

The standard production process for pulverized toner is outlined in Fig. 1. After grinding, the toner particles have a maximum diameter of approximately 10 μm with an average diameter of approximately 6–7 μm. Particles approximately 4 μm or less in size are separated out during the classifying process, and an external additive (surface coating) is added to the remaining particles to complete the toner product.

During classifying, it is difficult to sufficiently remove ultra-fine particles (those measuring in at approximately

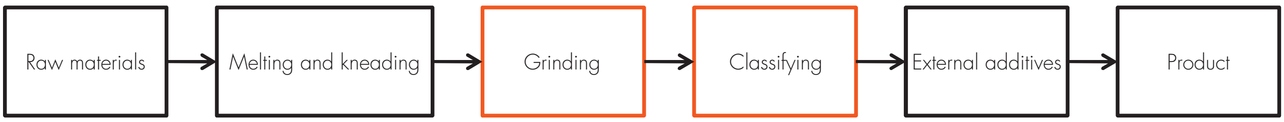


Fig. 1 Manufacturing process of pulverized toner

2 μm), which means that these particles become mixed in with the final product. This is problematic because the use of toner containing large quantities of ultra-fine particles leads to lower printing quality. Therefore, demand for complete removal of these particles during toner production is on the rise, which is why we developed the Fine Sector θ series of fine-powder classifier products.

2 Product lineup

Table 1 provides an overview of Fine Sector θ models. Designed with consideration for market needs and a maximum processing capacity of 200 kg/hour, we have created three production models as well as one laboratory-use model (EFS0Q) for developing powder products.

3 Structure

Figure 2 provides a cross-sectional view of a Fine Sector θ product. It comprises casing elements, which create the overall product form, as well as internal components including a high-speed-rotation classifying rotor in the upper section and louvers in the lower section for the intake of outside air. Raw materials are fed in from the top of the device and move from there to the peripheral areas surrounding the classifying rotor. At this point, which

Table 1 Fine Sector θ models

Model	EFS0Q (laboratory model)	EFS00	EFS10	EFS20
Total airflow volume (m^3/min.)	1.5–2.0	6.0–8.0	15–20	30–40
Max. processing capacity (kg/h)	10	40	100	200

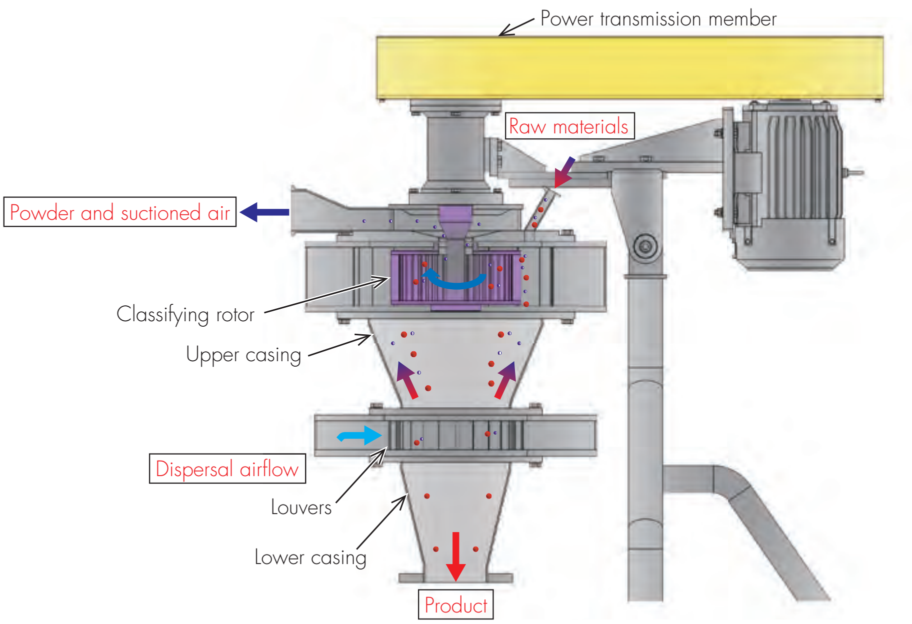


Fig. 2 Cross section view of Fine Sector θ

represents the primary classifying process, coarse and fine powders are separated by the rotor. Ultra-fine particles not separated out due to insufficient dispersal during primary classifying fall down toward the product output end, where they are redispersed by air taken in through the louvers for separating and elimination.

4 Advantages

The Fine Sector θ was designed based on technologies cultivated over many long years in the development of toner production equipment, and the latest in computational fluid dynamics (CFD) analysis technologies have been used to offer the following advantages to users.

(i) Removal of ultra-fine particles

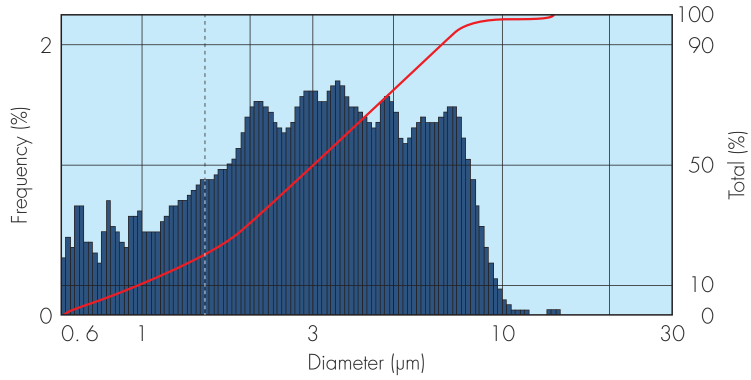
The classifying rotor plays a major role in determining classifier performance, and its form has been optimized to achieve airflow conditions suitable for classification of ultra-fine powders. Excellent classification performance makes it possible to effectively remove ultra-fine particles, which in the past was very hard to achieve.

(ii) Excellent classifying results via secondary dispersions

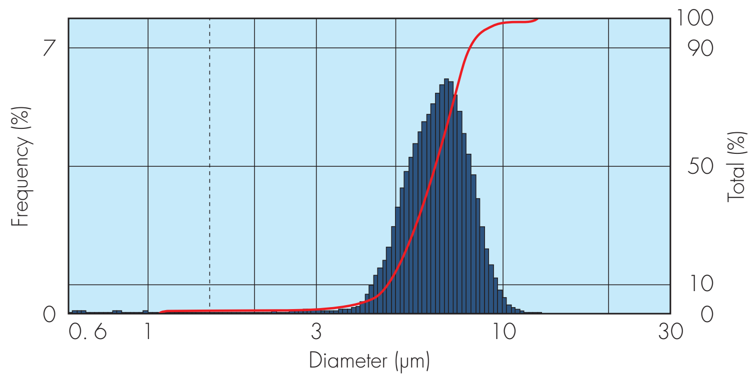
Particles that are not successfully separated fall down toward the product output end where air introduced through the louvers in the lower portion of the device creates an internal rotational airflow to thoroughly redisperse and remove said particles. This redispersal and classifying process helps users achieve high-quality finished products.

(iii) Easy control over particle size

By controlling the rotation speed of the classifying rotor, it is possible to adjust the centrifugal force acting on the particles, facilitating easy control over particle size.



(a) Before classifying



(b) After classifying

Fig. 3 Particle size distribution of classified toner material (based on the number of particles)

(iv) Design that facilitates internal equipment cleaning

Large-sized models from EFS10 upward come equipped with a casing open/close mechanism that can be operated with the press of a single button. Furthermore, the equipment casing is designed to provide easy access to the inside, making for smooth and effective internal cleaning operations when switching between the production of different powder types and so forth.

5 Classifying examples

Figure 3(a) shows number-size distribution measurement results for a standard grinded toner material, and Fig. 3(b) the same results for a classified toner material using one of our Fine Sector θ models. (Results were measured using a Malvern Instruments FPIA-2100). Before classifying, the percentage of grinded particles with diameters of 4 μm or less was 63.9%, and the percentage of ultra-fine particles with diameters of 2 μm or less was 30.2%

After classifying the particles using Fine Sector θ, the respective percentages for particles measuring in at 4 μm or less and 2 μm or less had dropped to 3.5% and 1.7%. The amount of product (classified powder) collected at the end as a percentage of the total amount of raw material loaded into the classifier was 77%, demonstrating that Fine Sector θ products offer excellent classifying performance while efficiently separating out only the ultra-fine particles.

Postscript

Thanks to the development of EarthTechnica's Fine Sector θ series of products, it has become possible to separate out ultra-fine particles with greater efficiency than ever before. These products achieve toner product quality that fully satisfies customer requirements, and we have received much praise from users following new installations of Fine Sector θ equipment in their production facilities. Moving forward, we will strive to improve classifying performance further and meet all of our customers' needs.

Yuko Sakaguchi

Contact information
Engineering Department,
Engineering and Quality Assurance Center,
EarthTechnica Co., Ltd.
Tel: +81-47-483-5817 Fax: +81-47-483-3733

High-pressure hydrogen gas trailer – Japan's first composite tank

Fuel cell vehicles (FCV)—hailed as the ultimate green vehicle—have recently been put on the market. To help keep hydrogen stations replenished with hydrogen needed to power these vehicles, Kawasaki developed a high-pressure hydrogen gas trailer for transporting, storing, and supplying hydrogen gas produced at hydrogen production plants including refineries.

The first of its kind in Japan, this trailer features a light-weight composite tank capable of easily storing high-pressure hydrogen. It is designed to ensure maximum security under emergency situations.

Preface

In response to the increasing popularization of fuel-cell vehicles, hydrogen stations are being established in various locations, leading to increased demand for more economical methods of transporting hydrogen gas produced at refineries and elsewhere to these stations and keeping and storing hydrogen tanks at the stations.

1 Objective

Hydrogen in its pure H2 state can be transported in either liquefied or high-pressure form. Liquefied hydrogen is suitable when transporting large quantities and high-pressure hydrogen when transporting small quantities. At the dawn of this new era for hydrogen-related business, companies do not yet expect great demand for large-scale

Table 1 Main specification of a hydrogen trailer equipped with a 45 MPa class composites tank

Item	Specifications
Trailer type	Flatbed semi-trailer
Axles and suspension	Dual-axle air suspension
Vehicle length and width (mm)	9,670 × 2,490
Hydrogen transport capacity (kg)	260
Keeping method	Ferry hook
Working pressure (MPa)	45
Gas type	Compressed hydrogen
Tank type	Type 3 composite tank
Tank capacity (L)	300
No. of tanks	24
Master valves	Manual valves with fusible-type safety valve
Top side	Opening/closing cover panels
Side	Punching metal doors
Front side	Door-type tank area access hatches
Rear side	Door-type control-station access hatches
Additional equipment	Fire extinguisher, gas detector

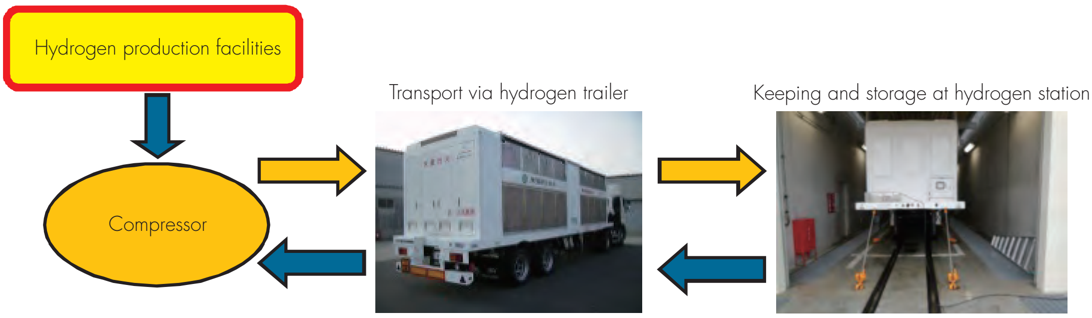


Fig. 1 Use in offsite hydrogen stations

distribution of hydrogen; rather, transport of high-pressure hydrogen is the predicted norm.

Until now, steel tanks loaded onto truck trailers have been used to transport high-pressure hydrogen gas. However, because it was necessary to cut costs in order to make hydrogen a feasible fuel source in our society, companies felt the need to reduce tank weights and enhance transport efficiency.

In FY 2011, the Kawasaki Group started by using composite hydrogen transport tanks and developing its 35 MPa class composite-tank hydrogen transport trailer based on the legally stipulated maximum of 35 MPa at the time. Later, in response to trends toward 45 MPa tank usage, the Group increased tank pressure further and upped capacity by two-and-a-half times, completing our 45 MPa class composite-tank hydrogen transport trailer.

2 Main specifications and operation

Table 1 provides an outline of main specifications for Kawasaki's 45 MPa class composite-tank hydrogen transport trailer.

There are two types of hydrogen stations: an onsite type wherein hydrogen gas or its base ingredients are collected
and high-pressure 40 MPa / 80 MPa hydrogen gas is produced, stored and supplied to vehicles, and an offsite type which does not include hydrogen production facilities. At offsite-type hydrogen stations, 45 MPa class composite-tank hydrogen transport trailers are utilized according to the process outlined in Fig. 1.

① The pressure level of hydrogen produced in hydrogen roduction facilities is increased to 45 MPa using a

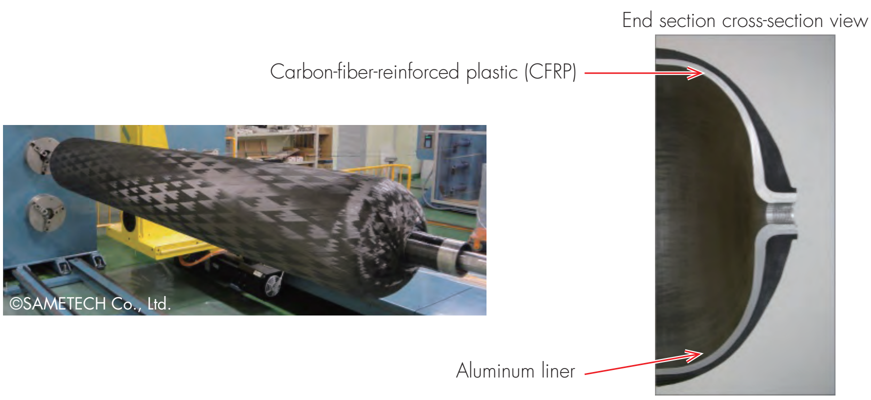


Fig. 2 Composite tank

compressor and transferred to composite hydrogen transport tanks.

② The hydrogen transport trailer is used to take this high-pressure hydrogen gas to the hydrogen station where the entire transport unit is kept and used as a storage/supply facility.

③ When the hydrogen pressure level becomes low, the tanks are taken back to the hydrogen production facility and refilled.

3 Unique product characteristics

(1) Composite tanks enable large-volume hydrogen transport

By making tanks from lightweight aluminum-alloy material wrapped with carbon-fiber-reinforced plastic (CFRP) boasting high tensile strength, we have achieved tank products that are lightweight yet also offer ultra-high pressure resistance (Fig. 2). Furthermore, the use of composite tanks makes it possible to haul more than

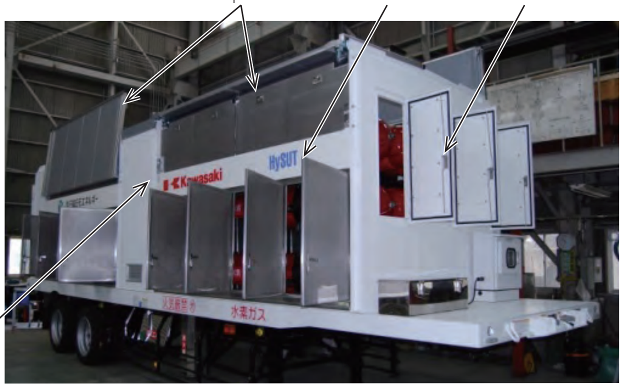


Fig. 3 Roof panels, side doors

Fig. 4 Central tank master valve control room

approximately twice the amount of high-pressure hydrogen than would be possible with traditional steel tanks.

(2) Equipment and features to ensure trailer travel stability

Our trailers feature an electronic braking system (EBS) and air suspension to ensure stable road travel. Furthermore, our anti-lock braking system (ABS) offers the following features:

① Roll stability support (RSS), which detects potential rollovers and automatically activates the brakes to reduce danger

② Load sensing function to adjust braking strength in accordance with load size, and to prevent excessive braking strength when the trailer is empty

③ A function that records travel distance, trailer axle load and other vehicle information and displays it on a smart panel

(3) Structural design enhances safety and ease of operation (Figs. 3 and 4)

① Opening/closing roof panels can be operated with a lever to enable water spraying when high temperatures are detected

② Punching metal opening/closing doors are installed on the side surfaces to facilitate tank inspections and other such operations

③ Front-side access hatches are installed to provide access to the tank area

④ A central control station has been included to facilitate easy opening and closing of the 24 master valves for the tanks when they are being transported or are kept at a hydrogen station.

⑤ Fusible-type safety valves are used for the composite tank master valves to enable safe release of hydrogen should tank temperature become too high

⑥ Nonflammable material has been installed along the ceiling section in order to mitigate internal temperature spikes

⑦ An emergency shutdown valve in the rear-area control station automatically closes when temperatures reach or exceed 100°C (212°F)

⑧ A simple, one-step hose and coupler attachment for connection to hydrogen station supply piping are included in the rear-area control station

4 Commercial vehicle production

Currently, Kawasaki is developing a commercial-use hydrogen transport trailer capable of handling 1.4 times the capacity (34 tanks) of our existing 45 MPa class composite-tank hydrogen transport trailers. It will be shorter in length than the current model and usable at a wider range of hydrogen stations.

Postscript

Kawasaki was contracted research activities for this product by the New Energy and Industrial Technology Development Organization (NEDO), and it was developed in collaboration with Kawasaki Engineering Co., Ltd.

Moving forward, we predict that growing numbers of fuel-cell vehicles will lead to increased demand for our products, and in order to meet customer needs through safe and efficient transport of large quantities of hydrogen gas, we intend to improve ease of product operation while also reducing costs.

Kanji Maekawa

Contact information
Industrial Plant Division,
Kawasaki Engineering Co., Ltd.
Tel: +81-78-612-8585 Fax: +81-78-642-3654

Kawasaki Heavy Industries Group

Main Products and Production Bases by Business Segment

Business Segment	Main Products	Main Production Bases
Ship & Offshore structure	• LNG carriers, LPG carriers, crude oil carriers, bulk carriers, container ships, car carriers, high-speed vessels, submarines, ships for government and municipal offices, offshore structures	Kobe Works (Kobe, Hyogo Prefecture) Sakaide Works (Sakaide, Kagawa Prefecture) Enseada Industria Naval S.A. (Brazil)* Nantong COSCO KHI Ship Engineering Co., Ltd. (China)* Dalian COSCO KHI Ship Engineering Co., Ltd. (China)*
Rolling Stock	• Train cars, integrated transit systems • Gigacell™ (nickel metal-hydride battery)	Hyogo Works (Kobe, Hyogo Prefecture) Harima Works (Harima-cho, Hyogo Prefecture) Kawasaki Motors Manufacturing Corp., U.S.A. (U.S.A.) Kawasaki Rail Car, Inc. (U.S.A.)
	• Rotary snowplows, de-icing vehicles • Rail cars, heavy lift cars	Nichijo Manufacturing Co., Ltd. Head Office (Main Plant) (Sapporo, Hokkaido) Nichijo Manufacturing Co., Ltd. Akebono Plant (Sapporo, Hokkaido)
Aerospace	• Aircraft (fixed-wing aircraft and helicopters), missiles, electronic equipment, space systems and peripheral equipment, simulators	Gifu Works (Kakamigahara, Gifu Prefecture) Nagoya Works 1 (Yatomi, Aichi Prefecture) Nagoya Works 2 (Tobishima-mura, Aichi Prefecture)
	• Aircraft components, rocket components, space equipment, target systems • Aircraft servicing, remodeling	NIPPI Corporation Aerospace Division (Yokohama, Kanagawa Prefecture) and Aircraft Maintenance Division (Yamato, Kanagawa Prefecture)
Gas Turbines & Machinery	• Gas turbine engines for aircraft and ships, peripheral equipment • Gas turbine generators, gas turbine cogeneration systems	Akashi Works (Akashi, Hyogo Prefecture) Seishin Works (Kobe, Hyogo Prefecture)
	• Steam turbines, diesel engines, gas engines, large decelerators • Marine propulsion systems (side thrusters, steerable thrusters) • Natural gas compression modules, air blowers and other aerodynamic machinery	Kobe Works (Kobe, Hyogo Prefecture) Harima Works (Harima-cho, Hyogo Prefecture) Wuhan Kawasaki Marine Machinery Co., Ltd. (China)
	• Air conditioning equipment, general-purpose boilers	Kawasaki Thermal Engineering Co., Ltd. Shiga Works (Kusatsu, Shiga Prefecture) Tongfang Kawasaki Advanced Energy-saving Machine Co., Ltd. (China)*
Plant & Infrastructure Engineering	• Cement, chemical, conveyers, and other industrial plant systems • Industrial boilers for land and marine use • Waste treatment facility • LNG tank and other storage facilities • Shield machines, tunnel boring machines	Harima Works (Harima-cho, Hyogo Prefecture) Shanghai COSCO Kawasaki Heavy Industries Steel Structure Co., Ltd. (China)* Anhui Conch Kawasaki Equipment Manufacturing Co., Ltd. (China)* Anhui Conch Kawasaki Energy Conservation Equipment Manufacturing Co., Ltd. (China)*
	• Crushers, processing equipment for recycling	EarthTechnica Co., Ltd. Yachiyo Works (Yachiyo, Chiba Prefecture)
Motorcycle & Engine	• Motorcycles, ATVs (all-terrain vehicles), recreation ulitity vehicles, utility vehicles, Jet Ski® watercraft • General-purpose gasoline engines	Akashi Works (Akashi, Hyogo Prefecture) Kakogawa Works (Kakogawa, Hyogo Prefecture) Kawasaki Motors Manufacturing Corp., U.S.A. (U.S.A.) Kawasaki Motores do Brasil Ltda. (Brazil) India Kawasaki Motors Put. Ltd. (India) Kawasaki Motors Enterprise (Thailand) Co., Ltd. (Thailand) PT. Kawasaki Motor Indonesia (Indonesia) Kawasaki Motors (Phils.) Corporation (Philippines) Changzhou Kawasaki and Kwang Yang Engine Co., Ltd. (China)*
Precision Machinery	• Hydraulic equipment for construction machines, hydraulic equipment and systems for industrial machines • Marine application machines, deck cranes and other marine deck equipment • Industrial robots • Medical and pharmaceutical robot	Akashi Works (Akashi, Hyogo Prefecture) Nishi-Kobe Works (Kobe, Hyogo Prefecture) Kawasaki Precision Machinery (U.K.) Ltd. (U.K.) Wipro Kawasaki Precision Machinery Private Limited (India) Kawasaki Precision Machinery (Suzhou) Ltd. (China) Kawasaki Chunhui Precision Machinery (Zhejiang) Ltd. (China) Flutek, Ltd. (Korea)

*Affiliated company-equity method

Domestic Offices, Works & Technical Units

Kawasaki Heavy Industries, Ltd.

Tokyo Head Office
1-14-5, Kaigan, Minato-ku,
Tokyo 105-8315, Japan
Phone: 81-3-3435-2111 Fax: 81-3-3436-3037

Kobe Head Office
Kobe Crystal Tower, 1-1-3, Higashikawasaki-cho, Chuo-ku, Kobe, Hyogo 650-8680, Japan
Phone: 81-78-371-9530 Fax: 81-78-371-9568

Corporate Technology Division
1-1, Kawasaki-cho, Akashi, Hyogo 673-8666, Japan
Phone: 81-78-921-1611 Fax: 81-78-921-1867

Sapporo Office
14F, JR Tower Office Plaza Sapporo, 2-5, Kita 5-jo Nishi, Chuoh-ku, Sapporo, Hokkaido 060-0005, Japan
Phone: 81-11-281-3500 Fax: 81-11-281-3507

Sendai Office
Tokyo Tatemono Sendai Bldg., 1-6-35, Chuo, Aoba-ku, Sendai, Miyagi 980-0021, Japan
Phone: 81-22-261-3611 Fax: 81-22-265-2736

Nagoya Office
JR Central Towers, 1-1-4, Meieki, Nakamura-ku, Nagoya, Aichi 450-6041, Japan
Phone: 81-52-388-2211 Fax: 81-52-388-2210

Osaka Office
Furukawa Osaka Bldg., 2-1-29, Dojimahama, Kita-ku, Osaka City, Osaka 530-0004, Japan
Phone: 81-6-6344-1271 Fax: 81-6-6348-8289

Hiroshima Office
12F, Hiroshima Business Tower Bldg., 3-33, Hacchobori, Naka-ku, Hiroshima City, Hiroshima 730-0013, Japan
Phone: 81-82-222-3668 Fax: 81-82-222-2229

Fukuoka Office
Hakata-ekimae Daiichi Seimei Bldg., 1-4-1, Hakataekimae, Hakata-ku, Fukuoka City, Fukuoka 812-0011, Japan
Phone: 81-92-432-9550 Fax: 81-92-432-9566

Okinawa Office
Kokuba Bldg., 3-21-1, Kumoji, Naha, Okinawa 900-0015, Japan
Phone: 81-98-867-0252 Fax: 81-98-864-2606

Gifu Works
1, Kawasaki-cho, Kakamigahara, Gifu 504-8710, Japan
Phone: 81-58-382-5712 Fax: 81-58-382-2981

Nagoya Works 1
3-20-3, Kusunoki, Yatomi, Aichi 498-0066, Japan
Phone: 81-567-68-5117 Fax: 81-567-68-5161

Nagoya Works 2
7-4, Kanaoka, Tobishima-mura, Ama-gun, Aichi 490-1445, Japan
Phone: 81-567-68-5117 Fax: 81-567-68-5161

Kobe Works
3-1-1, Higashikawasaki-cho, Chuo-ku, Kobe, Hyogo 650-8670, Japan
Phone: 81-78-682-5001 Fax: 81-78-682-5503

Hyogo Works
2-1-18, Wadayama-dori, Hyogo-ku, Kobe, Hyogo 652-0884, Japan
Phone: 81-78-682-3111 Fax: 81-78-671-5784

Seishin Works
2-8-1, Takatsukadai, Nishi-ku, Kobe, Hyogo 651-2271, Japan
Phone: 81-78-992-1911 Fax: 81-78-992-1910

Nishi-Kobe Works
234, Matsumoto, Hasetani-cho, Nishi-ku, Kobe, Hyogo 651-2239, Japan
Phone: 81-78-991-1133 Fax: 81-78-991-3186

Akashi Works
1-1, Kawasaki-cho, Akashi, Hyogo 673-8666, Japan
Phone: 81-78-921-1301 Fax: 81-78-924-8654

Kakogawa Works
170, Yamanoue Mukohara, Hiraoka-cho, Kakogawa, Hyogo 675-0112, Japan
Phone: 81-79-427-0292 Fax: 81-79-427-0556

Harima Works
8, Niijima, Harima-cho, Kako-gun, Hyogo 675-0180, Japan
Phone: 81-79-435-2131 Fax: 81-79-435-2132

Sakaide Works
1, Kawasaki-cho, Sakaide, Kagawa 762-8507, Japan
Phone: 81-877-46-1111 Fax: 81-877-46-7006

Overseas Offices

Beijing Office
Room No.2602, China World Office 1, No.1, Jian Guo Men Wai Avenue, Beijing 100004, People's Republic of China
Phone: 86-10-6505-1350 Fax: 86-10-6505-1351

Taipei Office
15th Floor, Fu-key Bldg., 99 Jen-Ai Road, Section 2, Taipei, Taiwan
Phone: 886-2-2322-1752 Fax: 886-2-2322-5009

Bangkok Office
28th FL, Sathorn Square Office Tower, 98 North Sathorn Road Silom, Bangkok, Bangkok 10500
Phone: 66-2-163-2839 Fax: 66-2-163-2841

Overseas Affiliated Companies

Kawasaki Heavy Industries (Singapore) Pte. Ltd.
6 Battery Road, #23-01, Singapore 049909
Phone: 65-6225-5133 Fax: 65-6224-9029

Kawasaki Heavy Industries Management (Shanghai), Ltd.
10th Floor, Chong Hing Finance Center, 288 Nanjing Road West, Huangpu District, Shanghai 200003, People's Republic of China
Phone: 86-21-3366-3100 Fax: 86-21-3366-3108

Kawasaki do Brasil Ind´ustria e Comércio Ltda.
Avenida Paulista, 542-6 Andar, Bela Vista, 01310-000, São Paulo, S.P., Brazil
Phone: 55-11-3289-2388 Fax: 55-11-3289-2788

Kawasaki Heavy Industries (U.S.A.), Inc.
60 East 42nd Street, Suite 2501, New York, NY 10165, U.S.A.
Phone: 1-917-475-1195 Fax: 1-917-475-1392

Kawasaki Heavy Industries Middle East FZE
Dubai Airport Free Zone, Bldg. 6W, Block-A, Office No.709,
P.O. Box 54878, Dubai, U.A.E.
Phone: 971-4-214-6730 Fax: 971-4-214-6729

Kawasaki Heavy Industries (U.K.) Ltd.
4th Floor, 3 St. Helen's Place, London EC3A 6AB, U.K.
Phone: 44-20-7588-5222 Fax: 44-20-7588-5333

Kawasaki Heavy Industries (India) Private Limited
5th Floor, Meridien Commercial Tower, Windsor Place, New Delhi 110001, India
Phone: 91-11-4358-3531 Fax: 91-11-4358-3532

Kawasaki Trading do Brasil Ltda.
Avenida Paulista, 542-6 Andar, Cj. 61D, Bela Vista, 01310-000, São Paulo, S.P., Brazil
Phone: 55-11-3266-2790 Fax: 55-11-3266-2853

Kawasaki Trading (Shanghai) Co., Ltd.
10th Floor, Chong Hing Finance Center 288 Nanjing Road West, Huangpu District, Shanghai 200003 People's Republic of China
Phone: 86-21-3366-3700 Fax: 86-21-3366-3701

KHI (Dalian) Computer Technology Co., Ltd.
Room 205, International Software Service Center, Dalian Software Park, 18 Software Park Road, Dalian, People's Republic of China
Phone: 86-411-84748270 Fax: 86-411-84748275

Kawasaki Heavy Indistires Russia LLC
Office 1206 (12th Floor), Entrance 3, Krasnopresnenskaya nab. 12, 123610, Moscow, Russian Federation
Phone: 7-495-258-2115 Fax: 7-495-258-2116

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www.khi.co.jp

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