# RDF-fired Internal Circulation Fluidized Bed Boiler
# – Longer operating life achieved with improved structure and operating conditions

*Kawasaki's Internal circulation fluidized bed boiler 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 circulation fluidized bed boiler 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 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% $O_2$

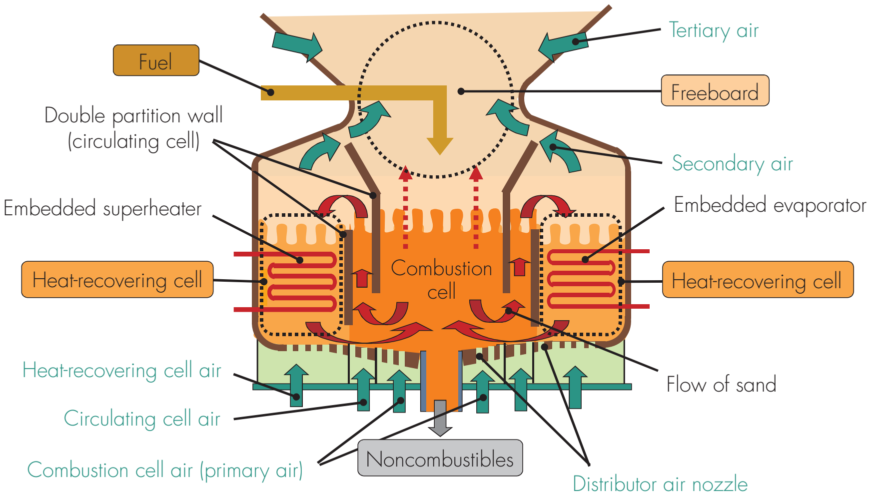


Fig. 1 Conceptual diagram of internal circulation fluidized bed boiler

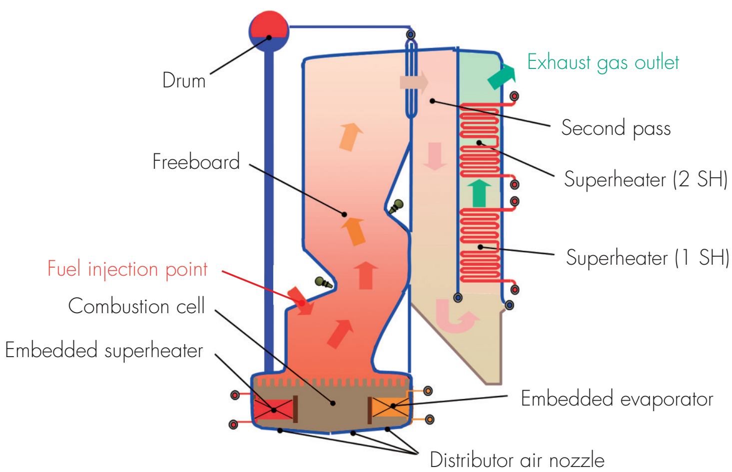


Fig. 2 Overall view of internal circulation fluidized bed boiler

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 circulation fluidized bed boiler."

The overall view of the internal circulation fluidized bed boiler is shown in Fig. 2.

## 3 Measures against the thinning of embedded tubes

While this internal circulation fluidized bed boiler 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 internal circulation fluidized bed boiler 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

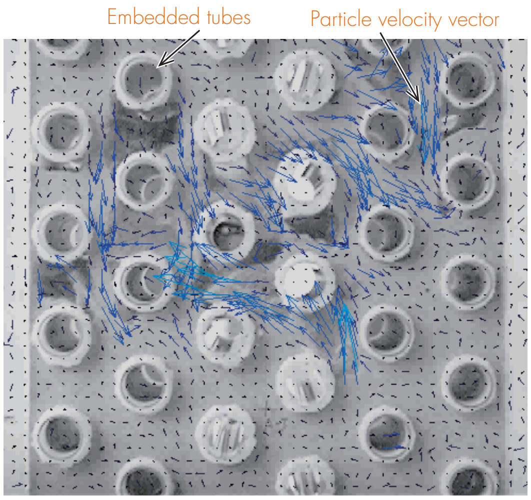


Fig. 4 Velocity analysis of bubbles inside the tube bank

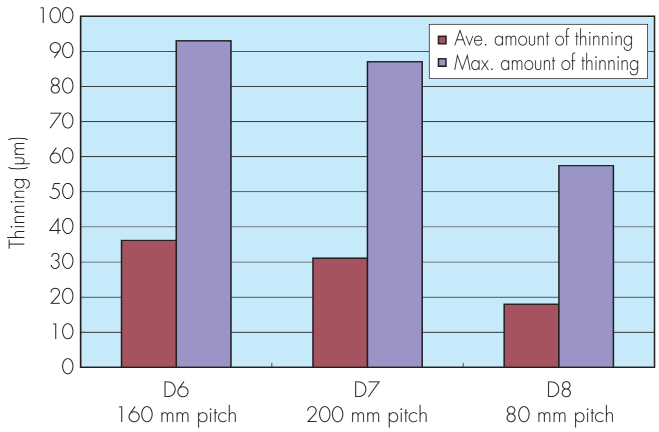


Fig. 5 Relationship between furnace width pitch of embedded tubes and tube wall thinning

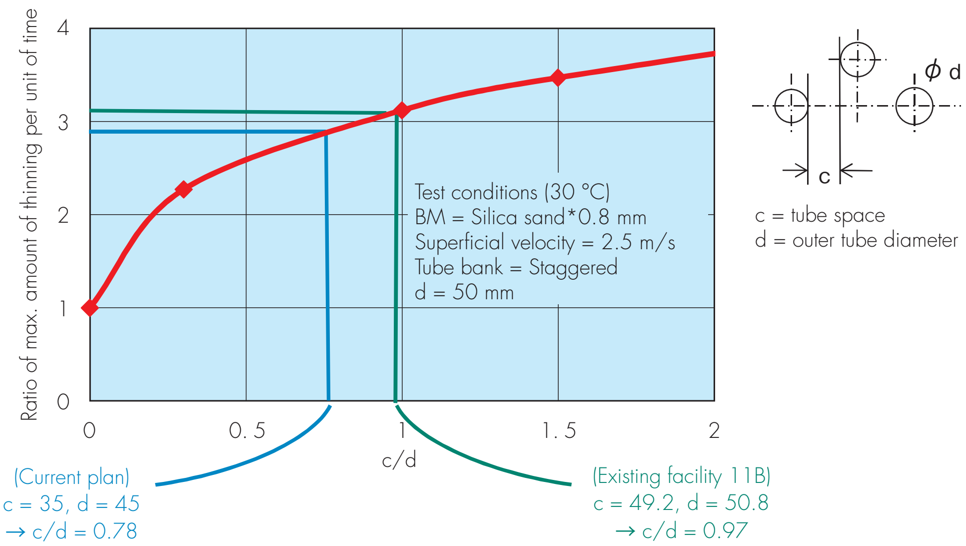


Fig. 6  Relationship between horizontal pitch of embedded tubes and thinning due to abrasion

thinning based on past data. As for the impact of fuel on 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

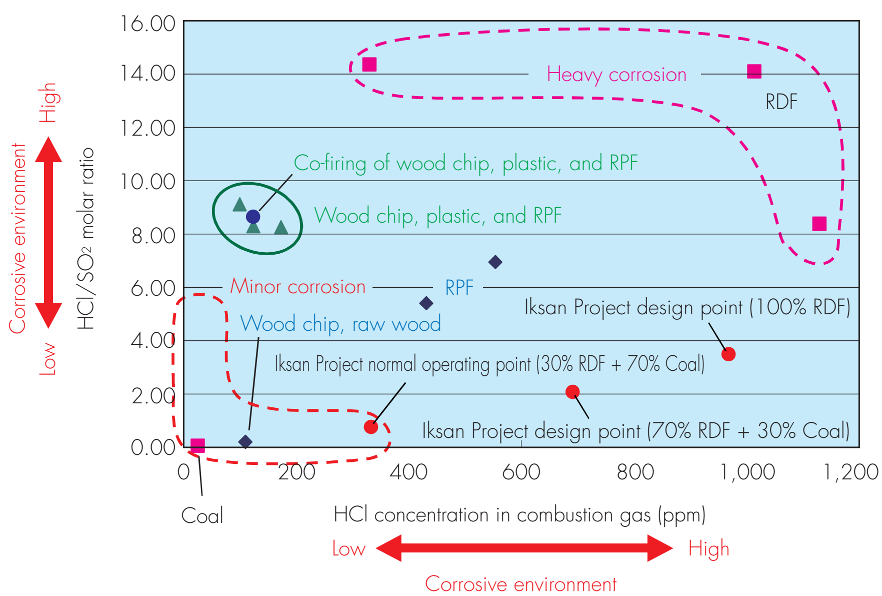


Fig. 7  Impact of HCl/$SO_2$ ratio in combustion gas on corrosion

is small, corresponds to the occurrence of minor 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.

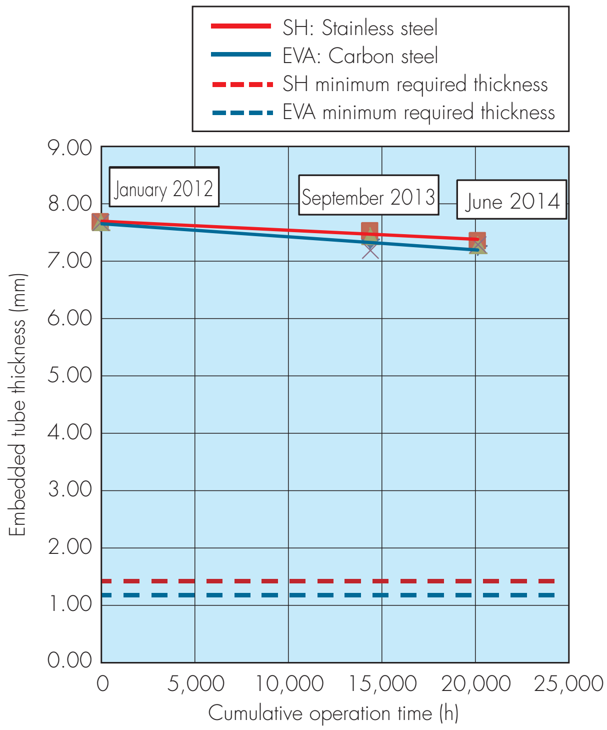


Fig. 8 Cumulative operating time and embedded tube thinning in internal circulation fluidized bed boiler for South Korea

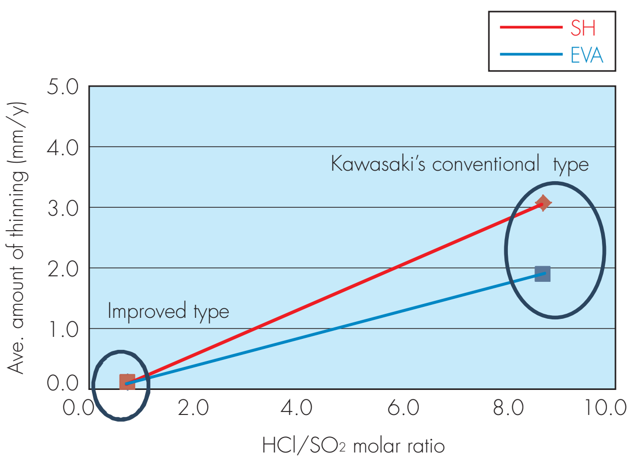


Fig. 9 Comparison between $HCl/SO_2$ gas ratio and annual embedded tube corrosion amount

## 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 internal circulation fluidized bed boilers, 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 internal circulation fluidized bed boiler 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