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

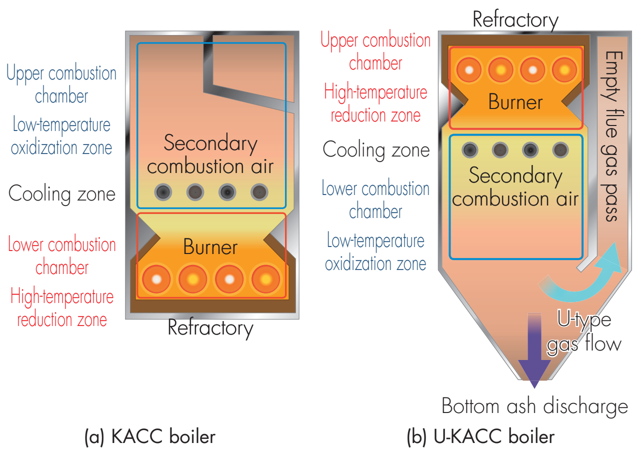


Fig. 1 Comparison between KACC boiler and U-KACC boiler

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

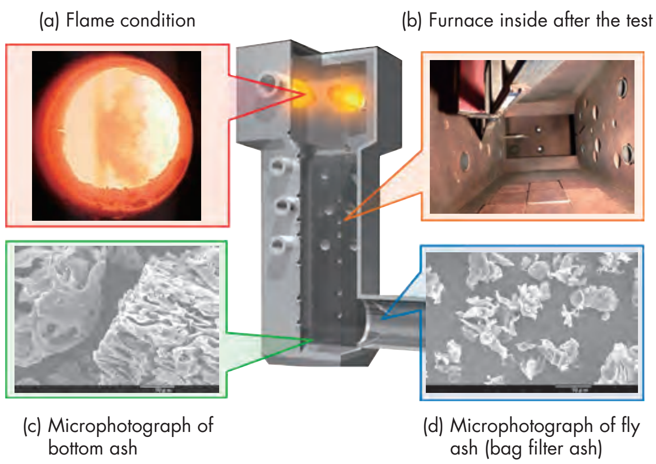
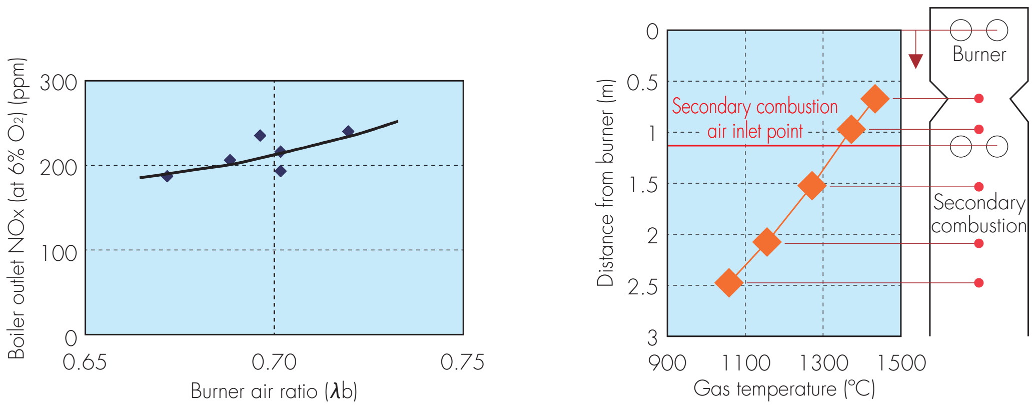


Fig. 2 Combustion condition, test furnace inside after the test and microphotograph of ash



(a) NOx concentration

(b) Gas temperature

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.

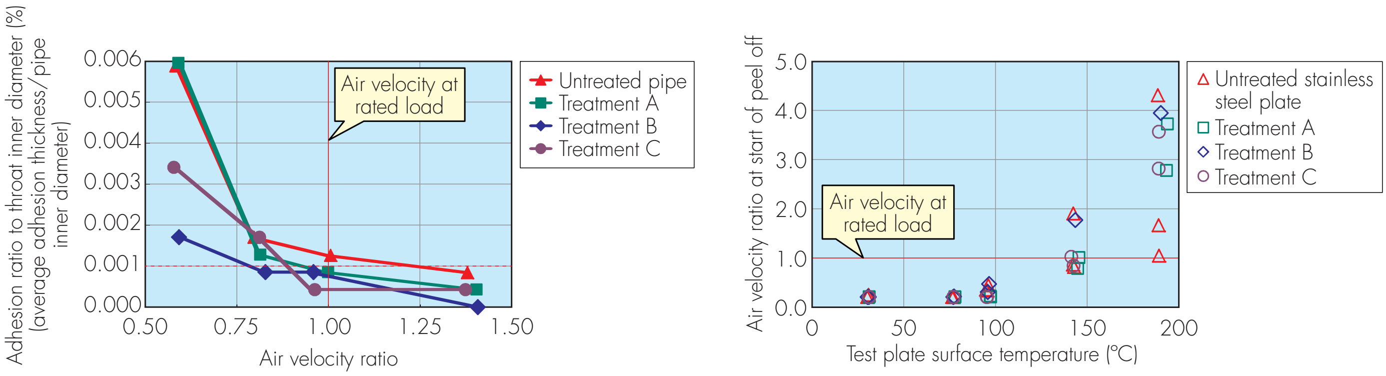
Table 2 shows a comparison of characteristics of asphalt pitch (ASP), petroleum coke, bituminous coal, and vacuum residue (VR).

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.

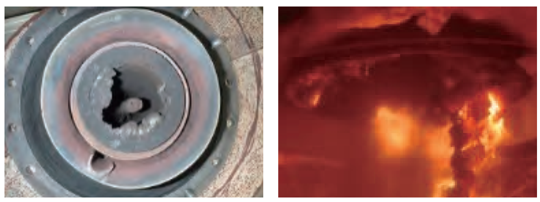
(2) Design properties

(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)

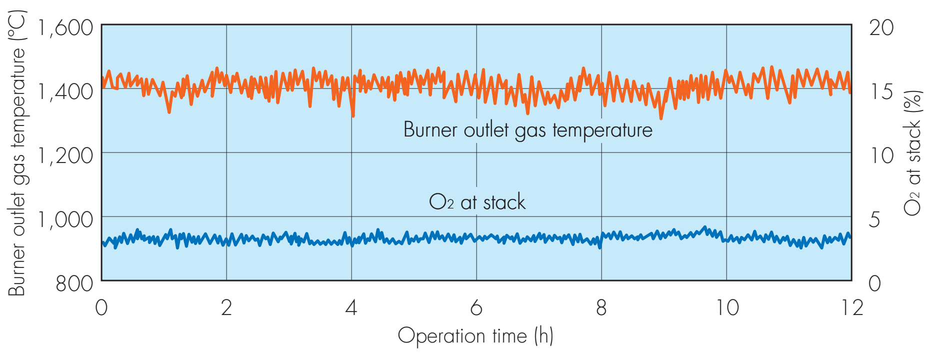


Fig. 6 Results of ASP combustion test (gas temperature and O_2 concentration)

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.

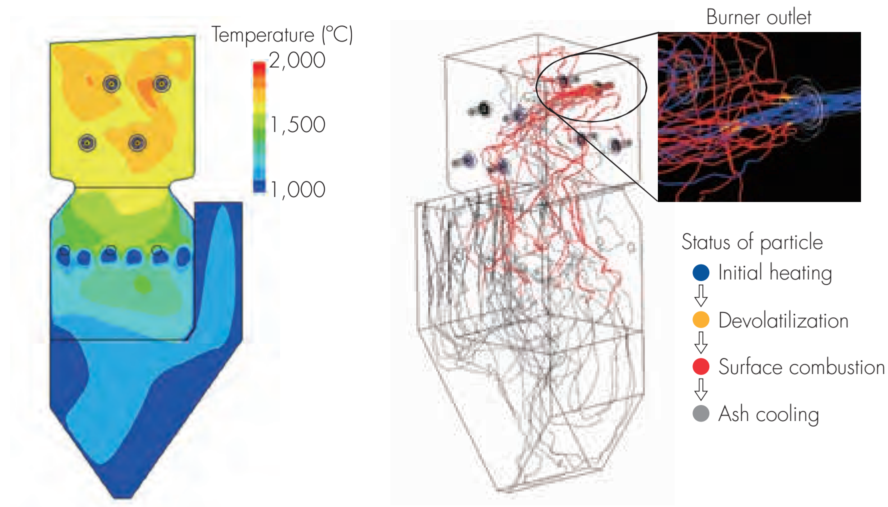
Referring to the gas temperature distribution in the U-KACC furnace shown in Fig. 7 (a), high temperature regions of over 1,500°C are formed in the upper reduction chamber, and the temperature is found to gradually drop in the lower oxidation chamber.

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.

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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