Operation results of power station with petroleum coke firing boiler

YASUNORI HIRAYAMA*1 SHUJI MAKIURA*1
MASASHI HISHIDA*1 YOSHIHISA ARAKAWA*1
YOSHIHISA YAMAMOTO*1 AKIYASU OKAMOTO*2

Petroleum cokes (PC) is a by-product from the oil refining process. In recent years, deep drawing oil technology has been developed and surplus PC with low volatility and low quality is increasing in the market. If the surplus PC could be used as the main fuel for thermal power stations, it will become most economical fuel in the next 5 to 20 years. Mitsubishi Heavy Industries, Ltd. constructed the thermal power station with a 100% PC firing boiler for Frontier Energy Niigata Co., Ltd. Commercial operation started in July 2005. This power station is highly praised both in Japan and foreign countries as a large boiler with the stable combustion of 100% PC, while most of the boilers with PC firing needs heavy fuel or other fuels for stable combustion. This report states the distinctive technology for a thermal power station with a 100% PC firing boiler, including the results of continuous operation and first maintenance in April 2006.

1. Introduction of petroleum coke

Petroleum coke is a by-product produced in the process of refining petroleum (**Fig. 1**). Vacuum residue (VR) obtained after refining major fuels such as gasoline and heavy oil is processed in a coking machine, where kerosene and diesel oil are extracted from gas. The residue from this process is referred to as PC.

Table 1 is a comparison of the general properties of PC, typical bituminous coal, and VR. PC has a heating value about 1.24 times higher than bituminous coal. According to a provisional estimate based on the heating value, it can be assumed that the amount of PC required for electric power generation will be 80% (1/1.24) of that of bituminous coal. However, due to PC's higher sulfur and heavy metal and less volatile matter content in comparison with general fuels, reduction corrosion by hydrogen sulfate and high-temperature oxidation corrosion tend to occur on the heat transfer surface, causing difficulties in stable combustion and operation. Because of these, PC is classified as a poor quality fuel, whose cost is generally lower than bituminous coal. In view of the power generation cost, therefore, the PC firing power plant is sufficiently competitive with bituminous coal-firing power plants.

Focusing on this point MHI built a power plant which fires PC which was lower in cost than bituminous coal-fired power plants and which contributes to the effective use of resources.

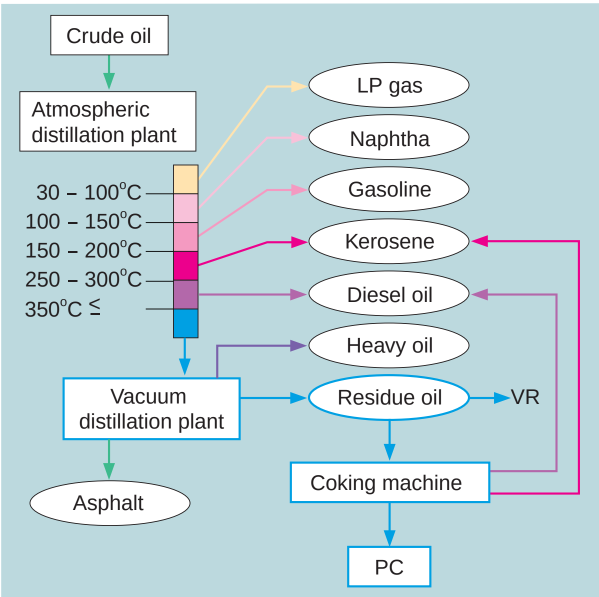


Fig. 1 Outline of PC generation process

2. Toward realization of commercial operation for PC firing power plant

In view of the stable supply of this cost-effective fuel, the use of PC with higher sulfur/higher vanadium was assumed as the premise of this project. Therefore, stable combustion technology and countermeasures against reduction corrosion by hydrogen sulfate and high slagging caused by vanadium are both necessary meaning that the following technological problems had to be solved. In this section, each technological issue for designing a PC firing power plant is stated below.

Table 1 Comparison of general properties between planned PC and other fuels

		PC	Bituminous coal	VR
Higher heating value (air-dried)	(kJ/kg)	34 893	28 180	41 850
Volatile matter content (air-dried)	(wt%)	9.9~13	26.2	-
Fixed carbon (air-dried)	(wt%)	87~90	56.3	20~30
Sulfur content (dry ash-free)	(wt%)	<6.5	0.40	4.0~6.0
Vanadium	(ppm)	<1 500	-	<300

*1 Nagasaki Shipyard & Machinery Works
*2 Nakasaki Research & Development Center, Technical Headquaters

2.1 PC combustion technology with Direct Mill System

One method of stably burning solid fuel is to pulverize the fuel into fine particles, blow them into a furnace together with air for combustion, and make them self-ignite by the radiant heat of the furnace. This technology has already been put to wide practical use in coal-firing boilers, and when decreasing the ratio of the air for combustion and transportation to the fine pulverized fuel, which is known as A/C (air by coal), – the fuel density becomes higher, and ignition more stable. Therefore, the A/C is set to a low level for lower ignitability solid fuels.

The bin system which collects and delivers pulverized fuel into a bin is well known as a system which can easily reduce A/C (**Fig. 2**). The PC firing boiler which was first introduced in the 1980s also used this bin system.

On the other hand, because there is no need for devices such as a cyclone and a pulverized fuel storage bin, the direct mill system (**Fig. 3**) is advantageous because of its smaller space requirements and less operation and repair costs. However, the direct mill system has a higher A/C lower limit than the bin system and has some remaining technological problems for stable ignition.

From the point of view of reducing the construction and power generation costs, MHI conducted a technological study of PC firing technology with the direct mill system. As a result, we decided that it was possible to solve the problems and the PC firing technology using the direct mill system was adopted.

In order to compensate for the difficulties in reducing A/C, the following techniques were adopted to improve the stable ignition of PC.

2.1.1 Optimization of burner locations

Figure 4 is a comparison of burner and flame locations of the CCF (circular corner firing) system which is adopted for bituminous coal-fired boilers and the CUF (circular ultra firing) system.

In the CUF combustion system, the burners are located near the center of each furnace wall with a high radiation intensity so that circular firing is formed by the burner flame from each furnace wall and lower ignitability PC can be ignited stably at low load. MHI adopted this CUF combustion system.

2.1.2 Development of a special burner for PC firing and PC pulverization technology

A special burner for firing PC was adopted (**Fig. 5**). Its separating performance for concentrated and weakened fuel flows was enhanced as well as its flame stabilization performance. This burner was developed by modifying the latest model burner which has a reputation as a low NOx, coal-fired combustion burner.

Also for the mill (fuel pulverizer), in order to achieve the high fineness of "#200 pass 95% or above" for improvement combustion performance, we adopted the latest model of vertical mill with a built-in rotary separator.

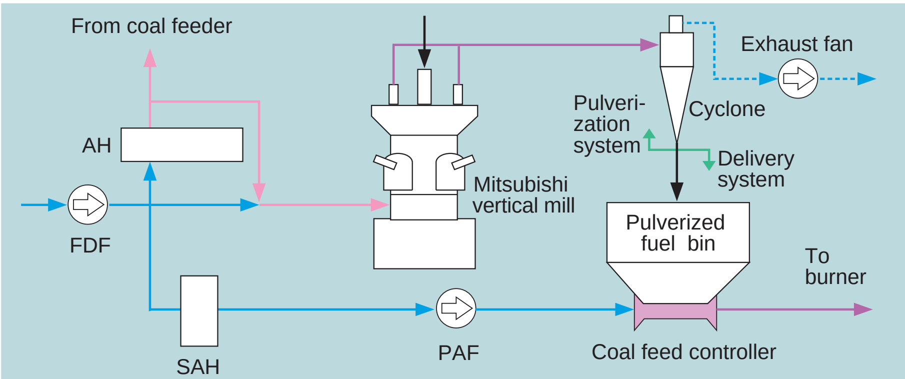


Fig. 2 Bin system (indirect combustion system)

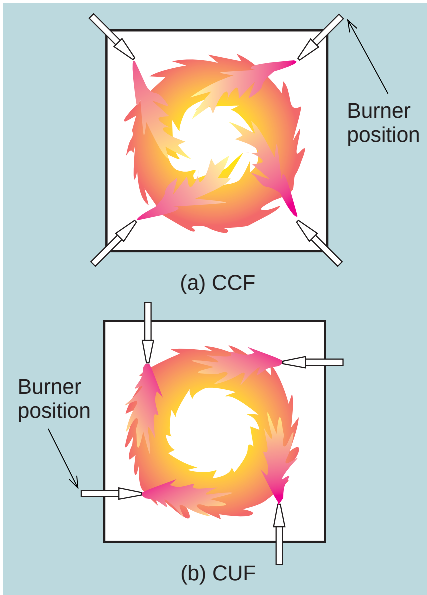


Fig. 4 Comparison of CCF and CUF

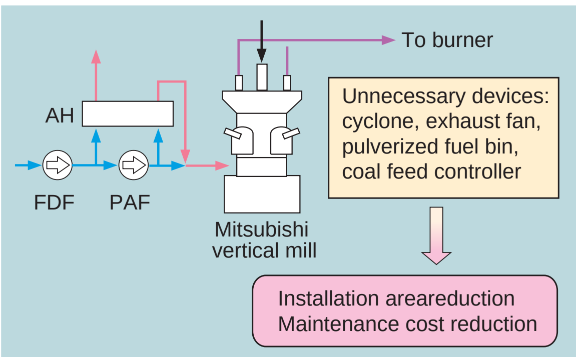


Fig. 3 Direct mill system (direct combustion system)

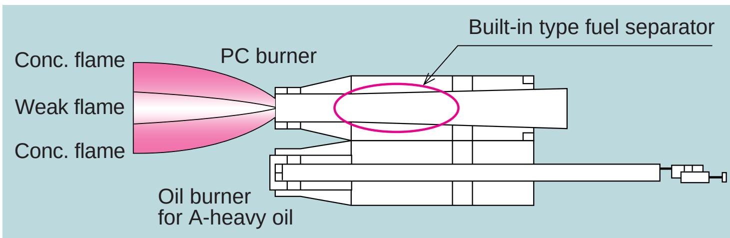


Fig. 5 PC burner

2.2 Technologies for molten ash caused by high vanadium content

As shown in **Table 2**, vanadium oxide may form low melting point ash depending on its combined oxygen weight and other fuel properties, causing problems in the continuous operation of the boiler due to slagging and fouling.

Table 2 Vanadium oxide compounds

Compound	Melting point (°C)	Compound	Melting point (°C)
V_2O_4	1970	$Na_2O \cdot 3V_2O_5$	560
V_2O_5	690	$10Na_2O \cdot 7V_2O_5$	573

In order to solve this problem, we built a test device which is simulates the actual boiler, and investigated the ash deposition and stripping characteristics. Finally, we optimized the tube pitch as well as the sootblower location. Further we succeeded in reducing the generation of molten ash on the heat transfer tube surface by feeding an MgO fuel additive to increase the ash melting point.

2.3 Technologies against corrosion caused by high sulfur and high vanadium content

Anti-corrosion technologies differ by location, from the furnace to the rotary air preheater (AH), which can be summarized as follows:

2.3.1 Furnace waterwall/burner zone

High Cr sprayed film, which has good anti-corrosion performance in VR firing boilers, is coated on the water cooling wall to protect it.

2.3.2 Superheater

High Cr stainless steel pipe is used for the high-temperature parts to prevent thickness reduction caused by corrosion.

2.3.3 Dinitrification system

A catalyst with a large pitch is used to prevent ash deposition. Also the sootblower does not use a steam as the blowing medium but a sonic wave to remove deposited ash.

2.3.4 Rotary air preheater (AH)

To prevent corrosion of the low-temperature element caused by sulfated ash, a steam heating type air preheater (SAH) is mounted on the air inlet of the AH, which maintains the exhaust gas temperature at the AH outlet above the acid dew point. In addition, by using ceramic for the low-temperature elements, we reduced the corrosion of the elements and ash clogging.

3. Outline of system and operation results

3.1 Specifications of major equipment and schematic diagram of system

(1) Boiler

- Type: single drum natural circulation type
- Boiler Maximum Continious Rate: 428 tons/hr
- Steam condition: 12.95 MPa x 541°C
  (This system has no reheater.)
- Fuel: PC firing (normal operation)/A-heavy oil(Note) (during unit start-up, and combustion stabilizer)
  Note: Kinetic viscosity (cSt, mm^2/s): 20 or less
  See JIS (Japanese Industrial Standards) K2205.
- Number of burner stages: PC 3 stages (direct ignition)/A-heavy oil (2 stages)
- Main steam temperature control: feed water spray type (1 stage only)
- Draft system: balanced draft system (furnace draft control: −0.2kPa)

(2) Turbine

- Type: single cylinder, single flow, impulse type, condensing turbine, axial exhaust, indoor type
- Steam condition: 12.45 MPa x 538°C
- Rated speed: 3,000 min^{-1}
- Exhaust condition: −93.3 kPa
- Number of turbine stages: HP 13 stages/LP 3 stages
- Number of bleed stages: 5 stages

(3) Generator

- Output (generator terminal): 122,223 kVA/110,000 kW

Figure 6 is a schematic diagram of this power plant.

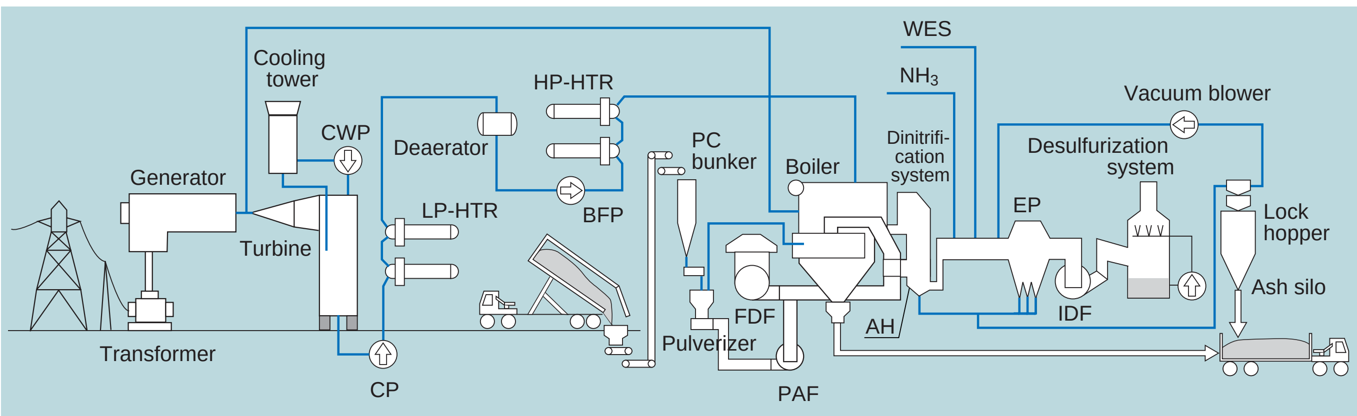
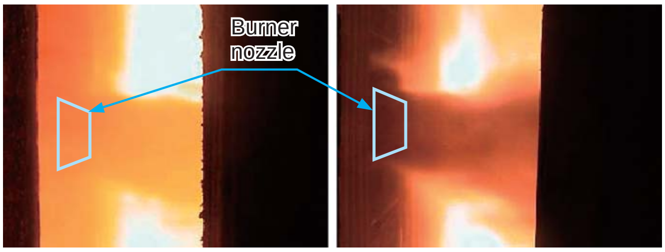


Fig. 6 Schematic of system

3.2 Operation results

It was confirmed that PC firing is stabilized from 35 to 100% of the boiler load the same as the boiler design. This means that this PC firing boiler has a performance as good as the ordinary bituminous coal-fired boilers.

Figure 7 shows the PC burner flame of the actual equipment. Combustion was stable both for 100% and 35% boiler loads, showing the intended good results of stable combustion technology for lower ignitability PC.



(a) 100% load operation

Radiation intensity is comparable with that of a pulverized coal firing boiler and the furnace is filled with flame.

(b) 35% load operation

Flames are formed beside of the burner nozzle to the injected fuel outer circumferences. Combustion is also stable.

Fig. 7 PC burner flames during PC firing

3.3 Ash handling

The furnace bottom ash is collected by a water sealed type furnace bottom conveyor and the fly ash (referred below to as FA) is collected by vacuuming. Although the ash handling system is basically the same as that of a coal-fired power plant, the furnace bottom conveyor and the FA handling system are each fitted with the following special technologies to deal with the high sulfur content ash:

- Water sealed bottom conveyor

  Because of using circulated seal water, the seal water tends to become acidic depending on the sulfur content of the bottom ash. Therefore, by injecting sodium hydroxide, the water quality is automatically controlled to neutral.

- FA handling system

  As the temperature inside the ash conveying pipe decreases, sulfuric acid or sulfated compounds in the ash absorbs water from the air and eventually become viscous. To deal with this, SAH is installed at the air intake of the ash conveying pipe. In addition, to prevent temperature drops during winter, a steam trace is mounted on the ash conveying pipe to keep the temperatures inside the ash conveying pipe above the sulfuric acid dew point.

4. System inspection results of the first periodic inspection

The first periodic inspection was conducted in April 2006, lasting about 30 days. Neither the turbine nor the generator were overhauled and the inspection mainly concerned the boiler and its ancillary facilities.

The inspection results of each part are summarized below, based on which the technology adopted in this boiler is evaluated:

4.1 Technologies against molten ash

As a result of the optimum layout of the tube pitch and sootblower based on basic research, it was confirmed that no persistent ash deposits bringing about bridging between tubes were seen and the ash deposits were maintained at an appropriate level for continuous operation. **Figure 8** shows ash deposits on the pressure parts, where both the superheater and the economizer are free of bridges and the conditions are favorable.

4.2 Technologies against corrosion

4.2.1 Pressure parts (furnace, superheater, and economizer)

High-temperature oxidation corrosion was evaluated, for which the residual film thickness of the sprayed film was measured at the furnace bottom and the tube thickness was measured for each pressure part. As a result, it was confirmed that both the sprayed film and the tube thickness were satisfactory and the anti-corrosion technology of the sprayed film and fuel additive were functioning as designed.

(a) Penetrated position of platen superheater to furnace front wall (Gas flow: from the bottom towards the top in the photo)

(b) Tertiary superheater and suspended tubes (Gas flow: from the bottom towards the top in the photo)

(c) Middle-temperature economizer: Spiral fins (Gas flow: from the front towards the back in the photo)

Fig. 8 Ash deposition inside furnace and flue gas duct equipment

4.2.2 Dinitrification system

Of the three catalyst layers, only a slight ash deposit and clogging were observed on the upstream side of the uppermost upstream layer (first layer), which remained within the expected result (**Fig. 9**). These results were attained because the technology to prevent ash deposition caused by the NOx removal catalyst functioned satisfactorily as designed through the combination of the pitch expanding catalyst and the sonic type sootblower.

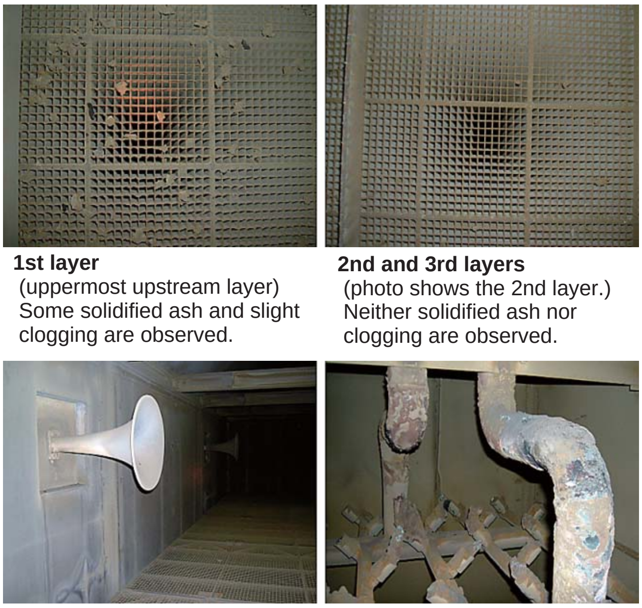
4.2.3 AH (rotary air preheater)

All the elements (high, medium, and low temperatures) of the AH were also free of clogging and corrosion. The same was observed for the basket and seal sections. As an example, **Fig. 10** shows photos of the high-temperature element and the low-temperature element. The AH sootblowers were located on both the high-temperature and low-temperature sides. They were operated as follows:

High-temperature side: 1 time/week

Low-temperature side: 3 times/day

As a result, no significant increase in differential pressure was observed even during continuous operation. Thus, the application of the AH sootblower was judged as appropriate.



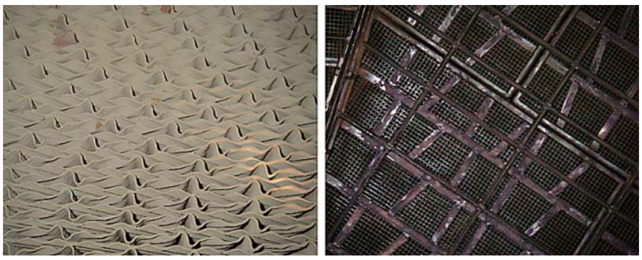
1st layer (uppermost upstream layer) Some solidified ash and slight clogging are observed.

2nd and 3rd layers (photo shows the 2nd layer.) Neither solidified ash nor clogging are observed.

Sonic sootblower (sonic horn)

Ammonia nozzle Only ash deposits. No blockage of nozzle.

Fig. 9 Internal inspection of Dinitrification system



High-temperature side (DU/mild steel) — Low-temperature side (Square/ceramic)

Fig. 10 Clogging of AH elements

4.3 Water washing

There was a worry that corrosion caused by moisture absorption and sulfurization of the high sulfur content ash might occur especially on the equipment in the boiler flue gas line during shutdown of the unit. As a preventive measure, washing the electrostatic precipitator (EP) with water is required during a long-term shutdown (three days or longer, as a rough guide) (**Fig. 11**).

5. Future tasks

As mentioned above, although positive results were obtained with regard to stable operation of the PC firing boiler, tasks to be worked on have appeared in connection with continuous operation and workability during periodic inspection in the FA handling system.

In this section, we would like to take this case as an example and summarize the improvement measures for the FA handling system of the PC firing boiler.

5.1 Blockage of ash handling system (case example during continuous operation)

5.1.1 Outline of FA system

This is a vacuuming FA handling system which uses a vacuum blower (100% capacity machine x 2; 1 machine as a spare), ash is separated from the air through the bag filter and is stored in an ash silo via a lock hopper. It is removed from the silo by trucks at regular intervals.

A lock hopper system has been adopted for the mechanism in which the ash conveying pipe, a vacuum region, is separated from the open-to-air ash silo, and FA, which is separated by the bag filter, is steadily dropped into the ash silo (**Fig. 12**).

Washing AH with water and draining — Washing EP with water and ash discharge

Fig. 11 Washing flue gas duct equipment with water

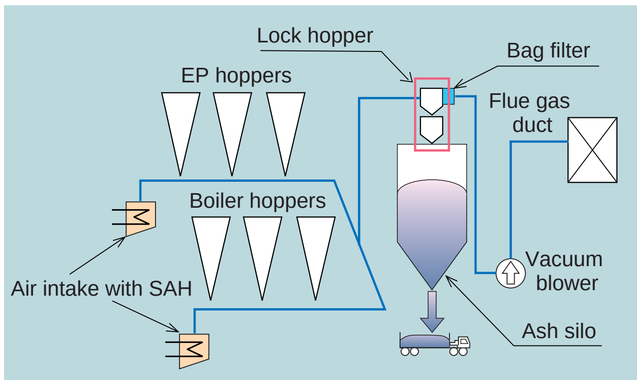


Fig. 12 Outline of FA treatment system

5.1.2 Ash trapping on lock hopper flap valve and line blockage

In the lock hopper system, two tanks are located on top of the ash silo, where the vacuum region and the open-to-air region of each tank are alternately partitioned by valves to convey the FA downward (See (a) to (c) in **Fig.13**). Although various kinds of valve were available for partitioning each hopper, flap valves were adopted in this case.

Compared with a slide gate or a rotary valve, as a flap valve does not have many parts which slide and catch ash, it has the advantage of being less likely to be abraded by ash. On the other hand, if a foreign substance is caught in the flap valve seat, the vacuum region and the open-to-air region cannot be partitioned, and ash clogging may take place. In Fig. 13, (d) to (f) explain this process.

When a clearance is created on the flap valve seat as shown in (d), a flow in the direction of the green arrow in the figure occurs when the lower flap valve is opened. At this time, as FA turbulence occurs in the direction of the gray arrows inside the lower hopper, a portion of the FA remains inside the lower hopper when the lower flap valve is fully closed (e). When the FA is again fed from the upper hopper as shown in (f) in this state, a more than planned amount of FA accumulates in the lower hopper. As this is repeated, the lower hopper is gradually filled with FA up to the level of the upper flap valve. Thus, blockage of the ash handling line takes place, causing problems in the continuous operation of the unit.

5.1.3 Plate-like FA

When a flap valve is examined, a plate of FA is often found inserted in the seat. This phenomenon occurs frequently, particularly during unit startup after EP water washing. This plate-like FA is presumed to be generated when residual FA absorbs moisture after the EP water washing, solidifies, and breaks away in the form of a plate.

The number of EP water washings for the PC firing power plant during its service life is larger than the case of EP for ash from a coal firing power plant. Therefore, additional improvements of the FA handling system are necessary in consideration of the formation of the plate-like ash.

5.1.4 Idea for improvement of FA system

In order to prevent the above problem, we have been studying the following new system (**Fig. 14**).

In the FA handling system, ash is handled according to the following cycle: ash handling at boiler outlet, cleaning the ash conveying pipe, ash handling at EP, cleaning the ash conveying pipe, ash handling at boiler outlet.

In the existing system, as ash is transferred by valves (1) and (2) being alternately opened and closed on a steady basis, the valves are opened and closed many times. The risk of trapping plate-like FA accordingly becomes high.

Meanwhile in the new system being studied, an intermediate hopper, referred to as the "temporary ash-storage hopper," is given enough capacity to store an amount of ash equal to that from one cycle of EP ash handling and the ash in the temporary ash-storage hopper is transferred into the ash silo while the ash conveying pipe is cleaned. This helps reduce the number of times each valve is opened and closed, and is expected to reduce problems in ash treatment caused by trapping the plate-like ash.

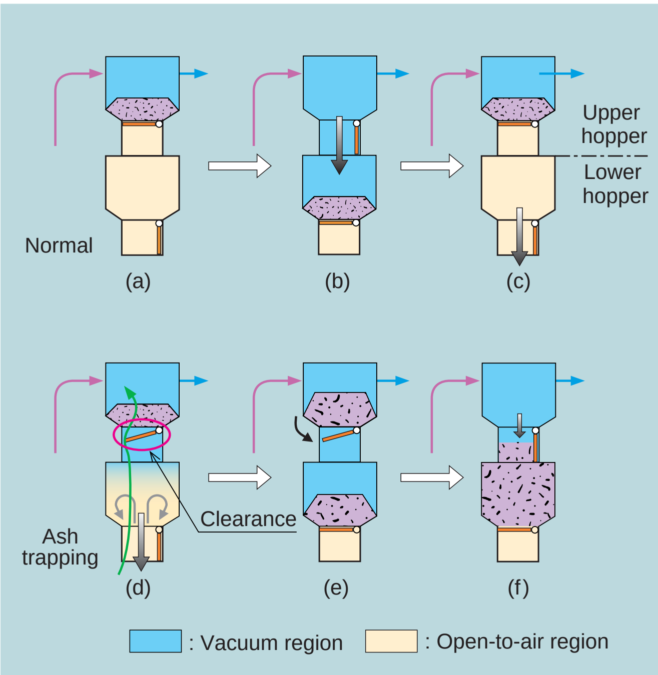


Fig. 13 Lock hopper ash conveying system

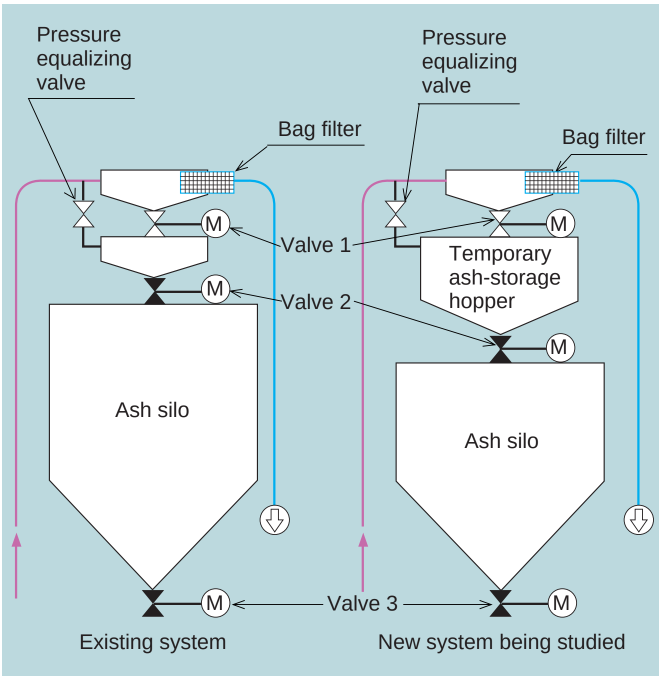


Fig. 14 Suggestions for improvement of FA handling system

5.2 Cleaning of flue gas duct of EP Inlet (case example during periodic inspection work)

In this power plant, a WES (Waste Elimination System) has been adopted, in which waste liquid from desulfurization is sprayed into the EP inlet flue gas duct so that its water content evaporates and its solid content is collected by the EP. Therefore, as ash is deposited in the EP inlet flue gas duct during continuous operation (**Fig. 15**), this needs to be removed during periodic inspection.

To remove ash from the flue gas duct, we have fitted a straight tube chute underneath the flue gas duct. However, if ash clogging occurs in the middle of the chute during ash removal work, there is no measure for removing this. Therefore, it is not used during periodic inspections and ash is removed from the duct manholes.

With regard to similar plants in the future, in consideration of this point, we need improved measures such as optimizing the manhole size and securing a work space on the exterior platform of the duct to increase the efficiency of the ash removal work.

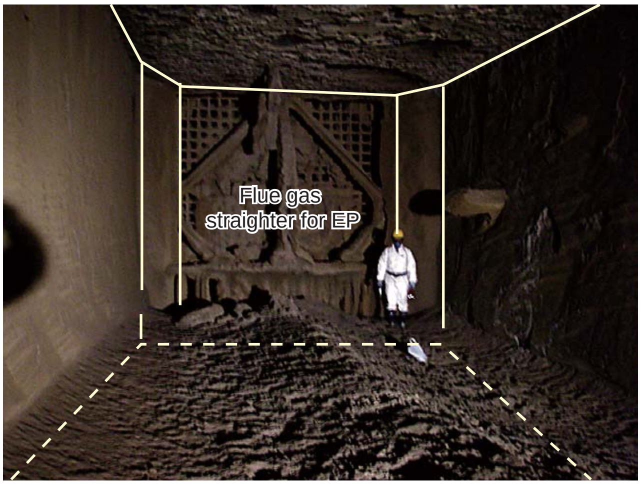


Fig. 15 Ash depositionat the EP inlet flue gas duct

6. Conclusion

After overcoming various challenges such as the stable ignition of lower ignitability fuel, anti-corrosion technologies for pressure parts, and clarification of the ash deposition mechanism, we have succeeded in utilizing PC, which is a poor quality fuel for power generation, and operating a PC power generating unit which is comparable with a coal firing type unit. This technology, we think, is significant not only from the viewpoint of its high competitiveness in power generating costs but also from the viewpoint of the effective use of energy.

Although this power plant has almost reached the level of completion from the technological point of view, there is still possibility for improvement of the system to support boiler operations such as the ash handling system. We would like to work on these improvements, aiming to build a plant which is trusted by our clients as a highly stable power supply facility.

Last but not least, we would like to extend our special thanks to Frontier Energy Niigata Co., Ltd. and the clients concerned for their kind guidance and cooperation.

Reference

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Yasunori Hirayama


Shuji Makiura


Masashi Hishida


Yoshihisa Arakawa


Yoshihisa Yamamoto,


Akiyasu Okamoto