New Ash Handling System That Makes It Possible to Recover Energy from Combustion Ash and Convert It into Valuable Resources

The Japanese government announced its policy for achieving carbon neutrality by 2050. We believe that we could contribute to society by reducing environmental impact, including lowering CO_2 emissions and recycling energy with technologies to make effective use of ash generated in power plants using coal and biomass as fuels. We established recycling technologies to make effective use of bottom ash, which is combustion ash discharged underneath the boiler, and fly ash, which is collected from combustion gases, and conducted bench testing and demonstration testing to verify their effectiveness.

Introduction

In Japan, efforts are underway in various industries to achieve carbon neutrality by 2050. These efforts include approaches to energy recovery and CO_2 reduction.

1 Background

In the combustion ash of coal or biomass fuels, there is "unburned carbon" that ideally should have been combusted in the boiler. A high amount of unburned carbon in ash can lead to energy loss. Additionally, an increased quantity of ash that becomes industrial waste is directly associated with increased environmental loads and rising costs for end-users in ash disposal. Moreover, from the perspective of utilizing ash effectively, the amount of unburned carbon in ash must be decreased.

Combustion ash consists of bottom ash, which is discharged underneath the boiler after combustion in the boiler, and fly ash, which is contained in the boiler combustion gas and collected by the dust collector from combustion gas before discharging the gas to the atmosphere.

Regarding bottom ash, more than 60% of coal-fired power plants currently in operation in Japan have been running for more than 20 years since commissioning. Many are using wet processing methods, and they have aged significantly. Because of this, it is expected that there will be increased demand for retrofitting to dry processing facilities, which enable energy recovery and reduce environmental impact.

Regarding fly ash, a significant portion of the domestically generated quantity is recycled as a substitute for clay as a cement material, but CO_2 is emitted during the cement manufacturing process. However, cement blended with high-quality ash, known as fly ash cement, which meets the specified criteria for unburned carbon content in ash, has the potential to reduce CO_2 emissions during production compared to manufacturing an equivalent amount of regular cement. Therefore, given the social backdrop of the desirability of a recycling-based society, demand for fly ash cement is expected to increase.

In response to this situation, we have established recycling technologies for the combustion ash of coal and biomass fuels, which can potentially reduce environmental impact and enable energy recovery.

2 Overview of the ash handling system

Typical handling systems for bottom ash and fly ash are illustrated in **Figs. 1** and **2**, respectively. Bottom ash is conveyed while being air-cooled through a dry bottom ash conveyor and a bottom ash cooling conveyor. After passing through a crusher, it is temporarily stored in a tank and then transported by truck or sent to downstream

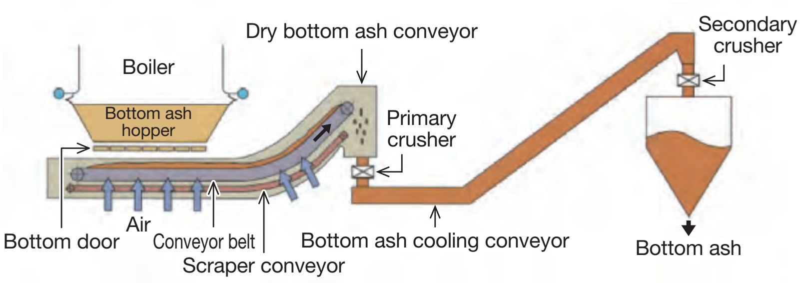

Fig. 1 Bottom ash handling system (dry)

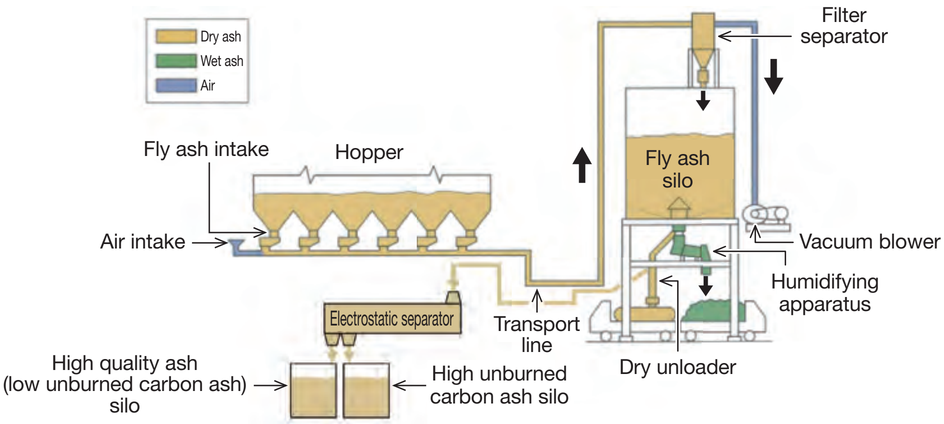

Fig. 2 Fly ash handling system (vacuum conveyance)

facilities by a pneumatic conveying system. In contrast, fly ash is vacuum-conveyed by a blower, collected through a filter separator, and then stored in a fly ash silo. There are two methods for discharging ash from the silo to trucks: when discharging as dry ash, dry unloader is used, and when discharging as wet ash, a humidifying apparatus is used.

3 New dry bottom ash handling system “KACE” (Kawasaki Ash Cooling / Conveying Extractor)

(1) Development background

A dry bottom ash handling system discharges bottom ash as dry ash; therefore, it has advantages such as increased opportunities for effective utilization and the potential for reducing utility usage in facilities. On the other hand, when low grade coal such as sub-bituminous coal is used, problems may occur in downstream transport of ash with the method currently in use if excessively large lumps of bottom ash are formed within the boiler. To address this issue, we have developed the new bottom ash handling system “KACE” (Kawasaki Ash Cooling/ Conveying Extractor), which can mitigate problems in downstream equipment by discharging large lumps of bottom ash in an intact state.

(2) Equipment concept

(i) Discharge of big lumps from the system

Fig. 3 shows an overview of “KACE”. Bottom ash generated in the boiler passes through the bottom ash hopper located at the bottom of the boiler, and it is next separated into big lumps and fine particles in the grizzly[1),2)]. Big lumps are manually deposited into the big lump collection box by manually opening the big lump gate. Subsequently, they are manually transported to ash disposal sites or other designated locations. Small particles are transported to the downstream facilities by the dry bottom ash conveyor. By enabling the discharge of big lumps from the system, the following can be expected:

① prevention of dry bottom ash conveyor shutdowns caused by clogging due to big lumps; and

② reduced installation costs attributable to the reduction in size of the under- boiler conveyor.

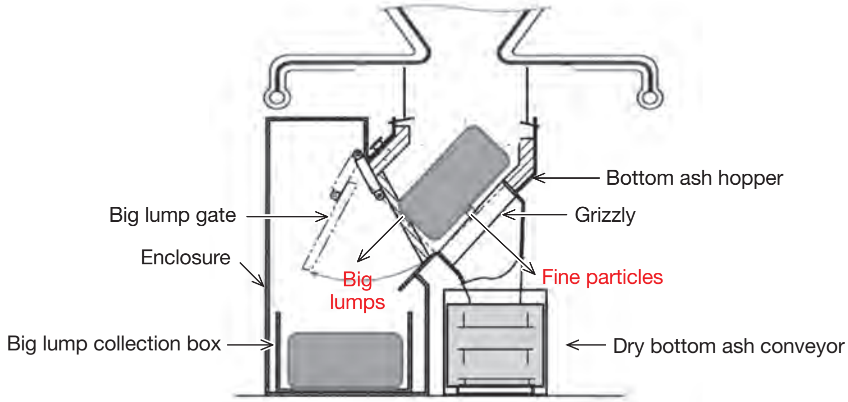

Fig. 3 Schematic of KACE

(ii) Energy recovery from unburned carbon (unburned biomass)

Compared to coal firing boilers, boilers for coal and biomass mixed firing and dedicated biomass firing boilers have a significantly higher proportion of unburned carbon in their bottom ash. For example, while coal-firing boilers may have around 5%, biomass co-firing boilers can have proportions ranging from 40% to 50%. Using a wet system results in the disposal of a large amount of unburned carbon, preventing energy recovery. Additionally, increasing the biomass co-firing rate for the purpose of reducing CO_2 emissions leads to a corresponding increase in unburned carbon—in other words, an increase in the amount of industrial waste.

Therefore, by changing the bottom ash conveying method from wet to dry, the following become possible from the perspective of energy recovery.

① Heat recovery through continued combustion brought about under the boiler

Cooling of bottom ash on the conveyor utilizes the atmosphere drawn through the air intake using the negative pressure of the boiler. This allows the bottom ash to continue the combustion reaction even after falling under the boiler or the bottom ash conveyor, and the heat energy generated during this process is recovered by the boiler through the inflow of air.

② Recovery of unburned carbon (mainly from unburned biomass) through reintroduction of ash into the boiler

After finely grinding the bottom ash carried by the conveyor, it is reintroduced into the boiler by air transport. This process facilitates complete combustion of the remaining unburned carbon (mainly from unburned biomass) in the bottom ash inside the boiler. This is referred to as "MAR (Magaldi Ash Recycling)", a technology held by Magaldi Power S.p.A., an Italian company with which we have a technological partnership.

(3) Bench testing

We fabricated bench testing equipment and confirmed that the equipment operates smoothly under thermal load and that there are no issues with the separation function of the grizzly.

Based on the findings from the bench test, we incorporated the following aspects into the design of the demonstration unit.

① Enhanced sealing performance between the big lump gate and hopper

To prevent ash from spouting through the gap between the big lump gate and the hopper while the boiler pressure is positive, we modified the gate shape from the one used in the bench test in order to improve its sealing performance.

② Measure to resolve biting with the grizzly

Mid-sized lumps with diameters of approximately φ200 to be separated by the grizzly may become bitten with the grizzly or the shielding (a block that protects the rotary shaft from shocks when big lumps fall), and such biting may not resolve themselves. Therefore, to facilitate ash discharge, multiple protrusions were installed on the shaft to form a shape that resolves biting during shaft rotation. Additionally, the shape of the shielding was modified to facilitate ash discharge.

(4) Demonstration test

We removed the wet conveyor installed under the operating boiler and installed demonstration testing equipment as shown in **Fig. 4**. We then verified the following aspects.

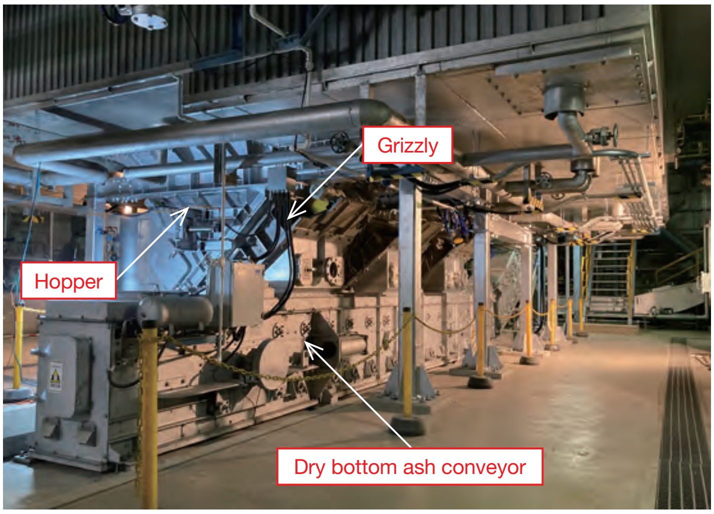

Fig.4 Exterior of demonstration testing equipment (front of boiler side)

(i) Function verification

- Separation function in the grizzly
  While there were instances in which small- to medium-sized lumps accumulated in the hopper chute incline, we confirmed that the majority are discharged after a certain period, and separation was performed without issue.
- Discharge from the big lump gate
  We confirmed that lumps that accumulated in the hopper were discharged without issue.
- Method for dealing with blockages occurring in the grizzly section
  We confirmed that blockages caused by clinker in the discharge outlet can be resolved by pushing from the chute inspection opening.

(ii) Evaluation by measurement at different points

- Atmospheric temperature in the bottom ash hopper
  We confirmed that it was between approximately 250 and 350°C, which is on the safer side compared to a strength evaluation condition of 450°C or lower.
- Ash temperature inside the dry bottom ash conveyor
  The high-temperature (red-hot) bottom ash at 600-800°C at the inlet showed a temperature decrease of 100-300°C while being transported on the conveyor incline.
  Normally, the temperature of falling ash is 100 to 200°C at the inlet, while it was 100°C or lower at the discharge outlet.
- Measurement of temperature at various sections (hopper, grizzly, gate, etc.)
  We confirmed that the temperatures were on the safer side compared to the temperature distribution obtained by analysis.

(iii) Consideration of energy recovery

An increase in combustion efficiency was observed after installation of the demonstration testing equipment, compared to that during wet conveyor operation prior to installation (prior to installation: approx. 99.3%; after installation: approx. 99.6%). This is believed to be a result of conversion to a dry system, in which the unburned carbon content in the bottom ash continues combustion reactions under the boiler. Additionally, eliminating the need for seal water under the boiler due to the transition to a dry system resulted in the absence of moisture (evaporated seal water) entering the boiler. This absence of moisture is believed to have contributed to the increase in overall boiler temperature, promoting combustion not only of the bottom ash but also of the unburned carbon in the fly ash.

4 System for removing unburned components from fly ash using electrostatic separate technology

As a method of producing high-quality ash, for which demand is expected to increase, we possess electrostatic separate technology. We have been developing this technology since around 2003[3),4)] by confronting challenges such as downsizing the equipment and improving the recovery rate. Most recently, we have been aiming to realize methods that enable us to increase the handling amount.

(1) Separation of unburned carbon and valuable recycling of ash

To turn ash into high-quality ash (valuables), it is necessary to reduce the amount of unburned carbon in the ash to below the specified level. As a method to do so, we have developed the system shown in **Fig. 5**, which uses electrostatic separate technology to separate unburned carbon from ash.

When ash raw powder is introduced to a porous plate and a mesh-like plate is placed above it, applying a voltage between the two results in neutral ash remaining on the porous plate, which serves as a positive electrode, while charged unburned carbon is attracted to the mesh-like plate, which serves as a negative electrode. The movement of unburned carbon is assisted by flowing fluidizing air from the bottom of the porous plate. The separation of unburned carbon from ash achieved by this technology enables conversion of ash into valuable resources, whereas conventionally disposal costs have been incurred.

(2) Reduction in CO_2 emissions during cement manufacturing

Japan's domestic CO_2 emissions from cement manufacturing in fiscal year 2019 totaled 41.47 million tons, accounting for approximately 3.7% of the total direct emissions of 1.10794 billion tons. As mentioned earlier, widespread adoption of fly ash cement could contribute to increased demand for high-quality ash domestically, leading to a reduction in CO_2 emissions. Compared to conventional cement manufacturing, it is possible to reduce CO_2 emissions by approximately 20%.

(3) Bench testing

Fig. 6 is a schematic diagram of the bench testing equipment. In the process of introducing ash onto the porous plate and guiding it to the discharge outlet through the vibrator, a voltage is applied between the high

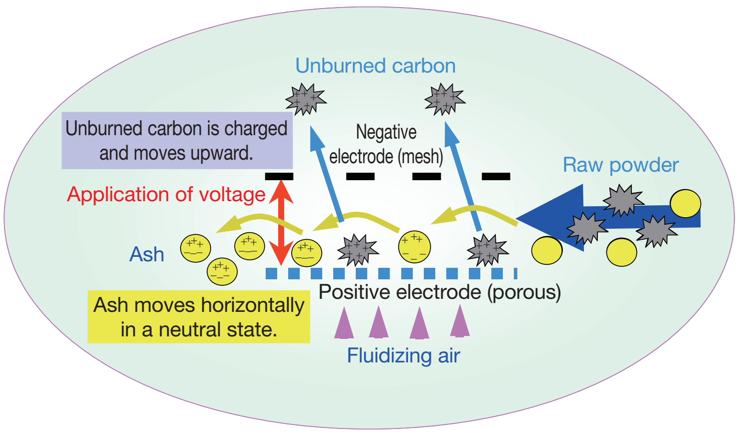

Fig. 5 Principle and concept of electrostatic separate technology

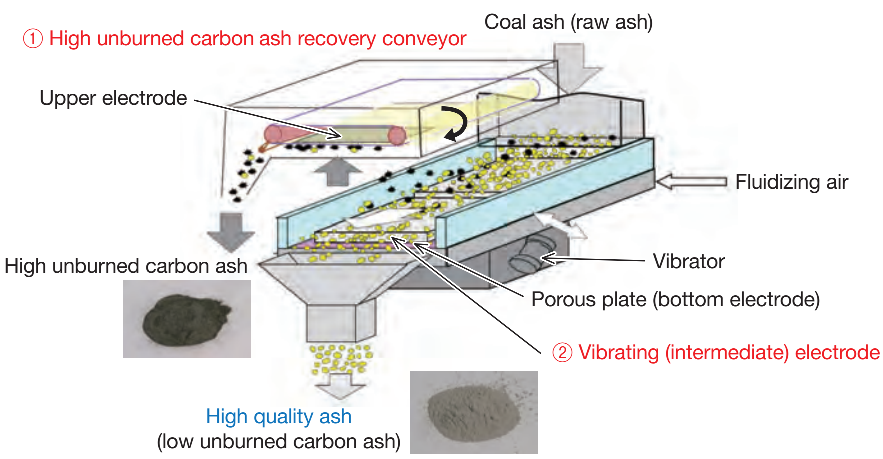

Fig. 6 Bench testing equipment

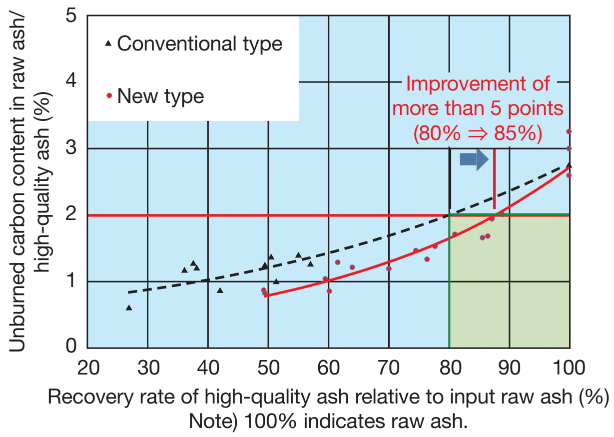

Fig. 7 Bench testing results

unburned carbon recovery conveyor, which serves as an upper electrode, and the porous plate. Fluidizing air is simultaneously introduced from the bottom of the porous plate, allowing the unburned carbon to be collected and conveyed to the recovery conveyor.

The conventional type suctions unburned carbon that has moved to the upper electrode while vibrating the entire apparatus, resulting in an enlarged device. However, in our bench testing equipment, vibration is applied only to the intermediate electrode, and unburned carbon is not suctioned but instead adhered to the belt. This design enables device downsizing and improved recovery efficiency.

Using this system, the unburned carbon separation performance was checked at two power plants in operation. The results of the bench test are shown in **Fig. 7**. In this test, the target performance items were the percentage of unburned carbon in high-quality ash and the recovery rate of high-quality ash relative to the input raw ash. The former was set to the general requirement in cement manufacturing of 2% or less, while the latter was set to 80%, which is the performance of the previous machine, or more. The unburned carbon amount was determined from the mass ratio before and after heating the recovered high-quality ash. In comparing the conventional type with our bench testing equipment, both are capable of reliably separating ash with a varying amount of unburned carbon content. However, our bench testing equipment showed a significant improvement in the recovery rate, exceeding 5 percentage points, indicating high separation performance.

Conclusion

For "KACE", the new dry bottom ash handling system, demonstration testing is complete, and we are now conducting sales activities to obtain commercial orders. As for the system for removing unburned carbon from fly ash using electrostatic separate technology, we have confirmed its high separation performance through bench testing. We are currently planning how to proceed to the stage of demonstration testing. We aim to contribute to achieving carbon neutrality by applying these technologies to recover energy and effectively utilize ash.

References

1) US Patent No. 10712000, "Ash discharge system"
2) US Patent No. 10562072, "Grizzly apparatus and bottom ash discharge system"

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