Mine-mouth Power Generation System Based on Upgraded Brown Coal (UBC®)

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Currently, the use of lignite (also referred to as "brown coal") is limited to mine-mouth power generation. The high moisture content in lignite causes its power-generating efficiency to be considerably lower than that achieved by bituminous coal. Kobe Steel has developed a process for producing Upgraded Brown Coal (UBC®) by applying a unique slurry dewatering technology. A study has been conducted using the UBC made from Indian lignite to verify its applicability in improving the efficiency of mine-mouth power generation. The results confirmed that UBC-based power generation is superior to the existing lignite-fired power generation.

Introduction

Among the various coals, lignite has a less complete level of coalification, as well as much retarded dewatering and decarboxylation, compared with high-grade coals such as bituminous coal. It contains as much as 30% to 65% of moisture and 20% to 25% of oxygen. Thus, when compared with other coals with the same mass, lignite, containing a large amount of moisture, has a substantially smaller proportion of organic matter (to be converted into heat) and a lower calorific value. When dried, lignite becomes prone to spontaneous combustion, making its handling difficult. For these reasons, for over 20 years the production of lignite has plateaued at a level of approximately 900 million tonnes, with almost no increase in consumption, despite its plentiful reserves (approximately 200 billion tonnes, which accounts for 23% of the total proven reserves of coal).

Lignite is relatively young in geological age and is generally deposited near the earth's surface. This decreases the stripping ratio and enables open-pit mining, which is advantageous because the coal can be mined more economically. In addition, most lignite contains low sulfur and low ash. It is attracting increased attention due to its higher environmental suitability compared with bituminous coal and sub-bituminous coal.

In light of these aspects, several countries are eager to develop technologies for upgrading brown coal (lignite) to increase its calorific value and stability so as to exploit it more effectively.

Kobe Steel developed a process for producing Upgraded Brown Coal (hereinafter referred to as "UBC®" note)). This process features a dewatering method for efficiently removing the large amount of moisture contained in lignite, thus increasing its calorific value.

The UBC process has many applications; this paper focuses on mine-mouth power generation based on UBC powder.

1. Development of UBC process

1.1 Development history

Kobe Steel had worked on the development of the liquefaction process for lignite since the 1970s and had cooperated with several other Japanese companies to conduct a pilot project in Victoria, Australia, under a consignment arrangement of the New Energy and Industrial Technology Development Organization (hereinafter NEDO) since 1981. The extensive knowledge on lignite acquired through this project led Kobe Steel to develop the UBC process. After the liquefaction project ended, the company started working on the development of the UBC process and saw its completion in a large-scale demonstration project[1] conducted in Indonesia from 2006 to 2011.

The following outlines the progress achieved thanks to this project.

1.2 Plant construction and operation

In the early 1990s, a bench-scale plant (product-base capacity; 0.1t/d) was built in the Kakogawa Works of Kobe Steel, in which the technical advantage of UBC was confirmed. This was followed by projects involving a pilot plant (product-base capacity; 3t/d) and a demonstration plant (product-base capacity; 600t/d), both constructed in Indonesia, one of the countries producing lignite. These projects have verified the technical effectiveness and economic feasibility of the UBC process. The demonstration test in Indonesia was subsidized by the Japan Coal Energy Center (JCOAL), the Ministry of Economy, Trade and Industry (METI),

note) UBC is a registered trademark of Kobe Steel.

under the cooperation of an Indonesian government organization, the Mineral & Coal Technology Research & Development Center (tekMIRA). **Table 1** shows outlines of the pilot plant and demonstration plant. A general view of the demonstration plant is shown in **Fig. 1**.

1.3 UBC process outline

Fig. 2 outlines the flow of the UBC process. Raw material lignite is pulverized into pieces of 5mm or smaller using a mill (Coal Mill). These are mixed and agitated with light oil, used as a heating medium, to form slurry. The slurry is heated in an evaporator so as to evaporate moisture in the lignite. This process enables the efficient dewatering of lignite with high moisture content under relatively mild process conditions of approximately 140℃ to 150℃ at 3atm. The moisture steam evaporated from the lignite is separated from the slurry by a gas-liquid separator (Flash Drum). The by-product steam is compressed by a compressor (Recycle Vapor Compressor) into high-temperature steam and is reused as the heat source for the evaporator. Thus the latent heat is effectively exploited and the thermal efficiency is improved. The coal/light-oil slurry separated by the gas-liquid separator is collected in a centrifuge (Decanter) and is separated into light-oil and coal cake. The light oil is reused as the heating-medium oil for slurrying. The coal cake is transferred to a dryer (Dryer) where the light oil, still remaining in the coal cakes, is collected further. Circulating gas (Recycle Gas) is supplied inside the dryer to increases the oil collection rate of the dryer and to

Table 1 Outline of pilot plant and demonstration plant

	Location	Capacity (t/d) (product basis)	Duratio (construction～ operation)	Purposes
Pilot plant	Indonesia (Palimanan, Jawa)	3	2001～2004	Confirmation of technical viability
Demonstration plant	Indonesia (Satui, Kalimantan)	600	2006～2011	Collection of data for design,construction and operation of commercial scale plant

Fig. 1 Outside view of 600t/d demonstration plant

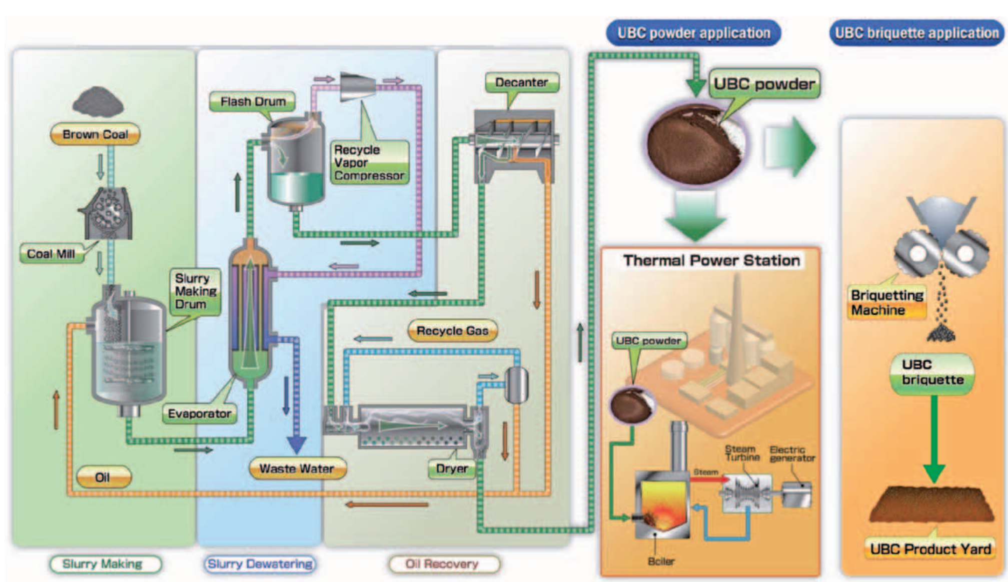

Fig. 2 Process flow of UBC

promote the drying out of the light oil. Then the circulating gas, containing oil vapor, is cooled and condensed so that the light oil can be collected and reused. This produces UBC powder with its residual oil decreased to 0.5% and its moisture to zero.

As a process for dewatering lignite with high moisture content, the UBC process has the following additional features:

(1) High energy efficiency

Compared with other upgrading processes, the process of dewatering slurry in oil operates under milder conditions of temperature and pressure during dewatering. The process allows the vaporizer to run with a higher heat transfer coefficient. High energy efficiency is achieved as a result of compressing the steam generated from dewatering, reusing it as a heat source and collecting the latent heat of the steam.

(2) Enabling the use of inexpensive apparatuses

The process enables the use of inexpensive, general-purpose apparatuses such as a heat exchanger, centrifugal pump and gas-liquid separator.

(3) Low environmental burden

The high energy efficiency results in lower CO_2 emissions than are achieved with other upgrading processes. Involving no chemical reaction, the UBC process generates no effluent contaminated by noxious organic substances, which reduces the burden on waste water treatment.

There are two ways of using the product. One is briquetting the UBC powder with a compacting machine as it exits the dryer. This method is applied to product that must be carried over a long distance in a stable manner. Another way is to directly charge the UBC powder into an adjacent power plant. This method maximizes the UBC process feature of achieving zero moisture and enables highly efficient power generation. The following focuses on this application.

2. Limited application of lignite at present

As described above, there are proven reserve deposits of lignite amounting to approximately 200 billion tonnes. Taken in order by region, from larger to smaller, there are deposits in Europe, Oceania, Asia and North America, while there is nothing to indicate the presence of lignite in Africa, the Middle East, and Central and South America. Currently, lignite is only utilized in very limited regions and countries, and in the least efficient manner.

Transporting lignite to a remote area for consumption suffers from low efficiency due to its high moisture content. In addition, there is a risk of spontaneous combustion during transportation. Therefore, lignite has so far only been used as-is for lignite-fired power generation at mining places. Lignite-fired power generation requires special boilers that are expensive to build. In addition, the low calorific value of fuel lignite decreases its power generation efficiency. As a result, the generated power is costly.

2.1 Lignite-fired power generation systems currently in operation

Lignite-fired power systems have been in operation in lignite producing countries such as Australia, Germany, Poland and India. In general practice, the moisture in lignite is removed by, for example, a flash mill dryer before the coal is burnt in a boiler. A lignite-fired boiler is typically a tower boiler, the flow of which is outlined in **Fig. 3**. In this system, flue gas at a temperature of approximately 900℃ is extracted from the boiler top, where the boiler temperature reaches its maximum, and is introduced into a coal mill. The coal particles pulverized in this mill are transferred into a dryer duct by the flue gas. When passing through the dryer duct, the moisture contained in the lignite is heated and evaporated rapidly within 2 to 10 seconds, producing dry particles of lignite. The flue gas, whose heat is consumed in evaporating the moisture, is cooled rapidly and returned to the boiler along with the moisture evaporated from the coal.

In the end, the water vapor in the flue gas is dissipated into the atmosphere without its latent heat being collected. This significant heat loss causes the power generation efficiency at the sending end

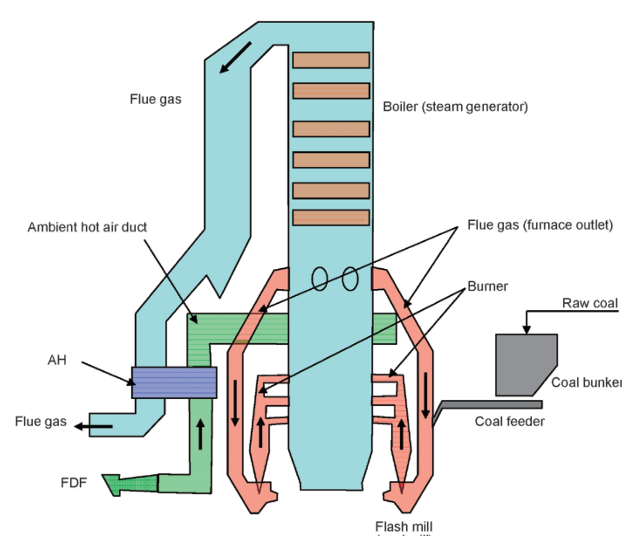

Fig. 3 Schematic flow of lignite-fired boiler (tower boiler)

to be as low as approximately from 20+% to 30%. The high moisture content also decreases the heat density within the boiler. This makes the boiler larger in size and more expensive to build in comparison with the bituminous-coal-fired boiler generally used.

The UBC process developed by Kobe Steel employs a pretreatment based on an efficient dewatering technique, which enables the upgrading of lignite with a high moisture content to coal (UBC powder) with zero moisture content and a high calorific value. This UBC powder is supplied to a high-efficiency power generation system, which significantly decreases the cost of power generation and CO_2 emissions, compared with conventional lignite-fired power generation systems.

Kobe Steel conducted research entitled the "Low CO_2 Emission Type Power Generation Project based on Upgraded Brown Coal (UBC) in India,"[2] which was commissioned by NEDO's 2012 "High-efficiency Clean Coal Technology". As described in Section 3, this commissioned research has clarified the advantages of mine-mouth power generation based on UBC.

2.2 Lignite-fired power generation in India

The Indian lignite used for the NEDO research project has the following characteristics (in average values): moisture 52%, ash 4.5%, volatile matter 25%, fixed carbon 18.6%, and a calorific value of 2,830 kcal/kg (higher heating value: HHV). The lignite-fired power generation plant used as a conventional reference comprises a sub-critical tower boiler with an output of 210MW and has a sending end efficiency of 29.15% (HHV basis).

This lignite is upgraded by the UBC process, and the product UBC powder is charged into a state-of-the-art high-efficiency power plant with an output of 1,000MW to study the comparative advantage. An overview follows:

3. Mine-mouth power generation based on UBC

3.1 Production and combustion tests of UBC

The applicability of Indian lignite to the UBC process was studied by laboratory tests performed on samples of the lignite, as well as by production tests conducted at the pilot plant located in Indonesia. Ten tonnes of UBC powder produced by the pilot plant were sent to a boiler manufacturer in Japan where combustion tests were carried out.

The results confirmed that the Indian lignite can be upgraded by the UBC process without any problems and that the UBC powder has sufficiently high combustibility to be applied to an ultra-super critical boiler without causing any problems. Another confirmed advantage was the fact that the ash contains much less unburned matter.

3.2 Incorporation of UBC plant into power generation plant

Fig. 4 outlines the flow of a power plant incorporating a UBC plant. The UBC powder

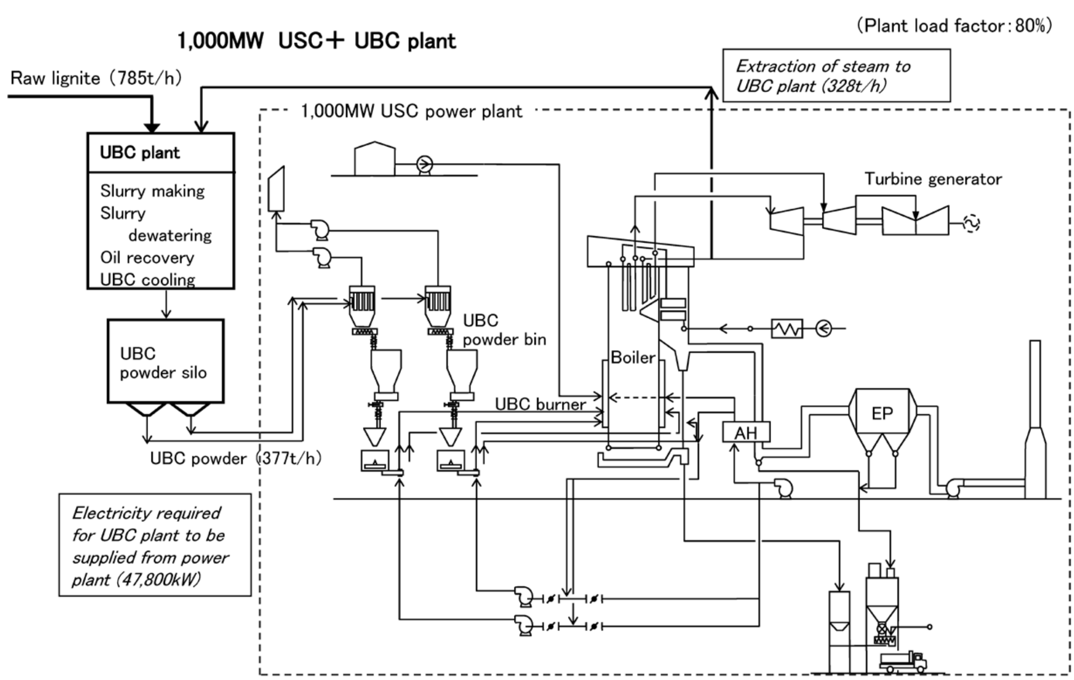

Fig. 4 Schematic flow of UBC based power plant

produced by the UBC plant is cooled to approximately 60℃, stored in silos and, from there, charged as-is into a boiler through UBC powder supply bins. This eliminates the need for a coal pulverizing mill to be installed on the side of the power plant, which would otherwise be required. The UBC plant requires steam and electricity for its energy. The steam is partially extracted from the power generation plant, while electricity is supplied as a part of the auxiliary power. This optimizes the energy efficiency of the integrated system as a whole.

3.3 Improvement of power generation efficiency

The 52% moisture contained in the Indian lignite is decreased to zero by the UBC process, which increases the calorific value from 2,830 kcal/kg (HHV) to 5,900kcal/kg (HHV), enabling the introduction of an ultra-super-critical power generation plant.

The power generation efficiency is compared with that of conventional lignite-fired power generation as shown in **Table 2**. In Case 1, where a UBC plant is combined with a sub-critical power generation plant (i.e., a power generating plant operating under sub-critical conditions, as in the case of a conventional power plant), a power generation efficiency of 32.60% is achieved, with an improvement rate of 11.8% compared with the conventional plant. In Case 2, where a UBC plant is combined with an ultra-super-critical power plant (the major subject of this study), the power generation efficiency reaches 34.45%, with an improvement rate of 18.2%, in comparison with the conventional type. In both Case 1 and Case 2, the steam and power required to run the UBC plant are supplied from the respective power generation plant in the downstream.

In Case 3, which assumes that the UBC product (powder) is charged into an ultra-super-critical power generator and the steam and power required to operate the UBC plant are supplied from other sources, the power generation efficiency becomes 40.63%, with an improvement rate−in comparison with the conventional plant−of 39.4%.

3.4 Reduction of lignite consumption and CO_2 emissions

Table 3 shows the reduction in lignite consumption and CO_2 emissions, assuming 1,000

Table 2 Effect of improving power generation efficiency

		Power generation efficiency (%) (sending end, HHV basis)	Improvement from conventional (%)	Remarks
Conventional Power Generation				
	Lignite-fired Sub-Critical Plant	29.15	NA	Data from operating Plant
UBC based Power Generation				
1	Integrated UBC-fired sub-critical plant	32.60	11.8	Energy used for UBC plant is deducted
2	Integrated UBC-fired ultra super critical plant	34.45 (40.90:LHV basis)	18.2	Energy used for UBC plant is deducted
3	Non Integrated UBC-fired ultra super critical plant	40.63 (42.70:LHV basis)	39.4	Energy used for UBC plant is not deducted

* Lignite: total moisture 52%, calorific value 2,830kcal/kg (HHV)
UBC powder: total moisture 0%, calorific value 5,900kcal/kg (HHV)

Table 3 Reduction of lignite consumption and CO_2 emissions

	Study results				Remaks
	Power output	UBC production (Mt/y)	Lignite consumption (Mt/y)	CO_2 emission (Mt/y)	
①UBC-fired ultra super critical plant	1,000 MW (generating end) 891 MW (sending end)	2.64	5.50	5.69	
②Conventional lignite-fired sub-critical plant	957 MW (generating end) 891 MW (sending end)	—	6.51	6.73	・Existing facility is 210MW sub-critical. ・Sending-end output is adjusted to the above ①.
Reduction of lignite consumption and CO_2 emission	—	—	1.01 (②−①) (approx. 16% reduction)	1.04 (②−①) (approx. 16 % reduction)	

<Premises of the study>・Lignite : total moisture 52%, calorific value 2,830kcal/kg (HHV), carbon 28.22%
・Plant load factor : 80% (7,008 h/y)

MW power generation. Comparisons are made with a conventional plant. This comparison assumes that both plants have the same output at their respective sending ends. The CO_2 reduction is attributable to the lignite consumption being decreased (for the same amount of power generated) by improved power-generation efficiency. It is expected that the annual consumption of lignite would be reduced by approximately 1 million tonnes, and annual CO_2 emissions would be reduced by 1 million tonnes, compared with conventional-type power generation.

4. Advantages of mine-mouth power generation system based on UBC

Mine-mouth power generation exploiting the UBC process for pretreatment possesses advantages over lignite-fired power generation. The following is a summary of these advantages:

(1) Realization of highly-efficient power generation:
- Use of UBC powder with a high calorific value for the fuel. (The total moisture content of the lignite, which is higher than 50%, is reduced to 0 %.)
- Burning UBC powder with a high calorific value causes no problems in an ultra-super-critical boiler.

(2) Decreased CO_2 emissions:
- Thanks to the decreased consumption of lignite.

(3) Low operating cost:
- Highly efficient power generation (enabling the introduction of a highly efficient power generating system.)

(4) Extension of mine life:

(5) Low capital investment in power generating facilities:
- No need for a tower boiler that would be large in scale and costly.
- No need for a coal pulverizing machine (because UBC powder is used for the fuel.)

Other advantages include the following:
- Containing zero moisture, UBC can generate power more efficiently compared with other fuel coals of a similar grade.
- UBC powder, with its advantages of high combustibility and lower amounts of unburned constituents in its ash, can substitute for other fuel coals.

Conclusions

Despite its plentiful reserves, the use of lignite is limited. The UBC process is a process for exploiting a so-called unused resource.

As the global demand for energy continues to increase, there is a concern that the supply of high-grade coal will become depleted. Under such conditions, the effective use of lignite by the UBC process is important, as it is currently not fully used. The process enables us to improve power generation efficiency, thus reducing CO_2 emissions better than lignite-fired power generation (still used in certain areas), in which lignite is used as-is. This new technology is expected to prevail in countries such as India, where lignite is available in abundance.

The development of the UBC process introduced in this paper was carried out under the aid of JCOAL, METI of Japan, and the cooperation of the Coal and Mineral Technology Research and Development Centre (tekMIRA) of Indonesia. Furthermore, the study on UBC-based mine-mouth power generation was conducted as a project subsidized by NEDO. We wish to express our special gratitude to all.

References

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2) NEDO Progress Report, FY2012. Project Formation Research on High-efficiency Clean Coal Technology. No. 20130000000625.