# Development of High Efficiency Lignite-Fired Boiler for Commercial Use


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The utilization of low grade coal is expected to increase in the future as the main source of coal fuel for coal fired power plants. The market for low grade coal firing power station equipment is expected to expand especially with the spread of the use of lignite-firing due to the low fuel cost, as it is not being utilized at the moment, and because it can be produced locally for mine-mouth power plants. IHI has a market entry strategy for lignite-fired power plants. That is why IHI is developing distinctive technologies to establish lignite firing technology and develop high efficiency/low cost lignite-fired power plants. As part of our strategic plan, IHI became shareholders of Steinmüller Engineering GmbH, a German company with rich experience in lignite-fired boilers in Europe. This paper introduces IHI's strategy for entering the market of lignite-fired power plants.


## 1. Introduction

Half of the mineable coal in the world is low-grade coal including lignite. The market for lignite-fired power generation facilities is expected to expand due to increasing requirements for reduction in fuel costs and local consumption of locally mined coal.

Lignite is low carbonized coal that is characterized by various properties, such as high moisture content, low carbon content, high oxygen content, and a small heating value. Since it generates heat and spontaneously ignites due to low temperature oxidation when dried, it is unsuitable for transportation and often used for mine mouth power generation. Some lignite contains a lot of low-melting-point ash content, and special considerations are needed in designing lignite-combustion facilities.

To make our way into the market for lignite-fired power generation facilities, we are working toward establishing technologies for a high-efficiency lignite-fired boiler on the basis of the core technologies that we have developed for designing, manufacturing, and installing bituminous coal-fired and subbituminous coal-fired USC (Ultra Supercritical) boilers. To establish lignite-fired boiler technologies, not only we will perform tests using our combustion testing facility that is one of the largest in Japan and evaluate them based on the latest CFD (Computational Fluid Dynamics) technology, but we will also make full use of the knowledge accumulated by Steinmüller Engineering GmbH (hereinafter, referred to as SE; details described later). SE is a German company with a wealth of knowledge about lignite-fired boilers that became a member of the IHI Group in June 2014. We will thereby ensure the design reliability of lignite-fired boilers.

In Europe and Southeast Asia, the major markets for lignite-fired power generation facilities, the lignite-fired combustion technologies that have been used are raw lignite combustion systems, which use high temperature flue gas from a furnace and a centrifugal type mill to simultaneously dry and pulverize lignite, for large boilers, and circulating fluidized bed combustion systems for middle and small-sized boilers. The biggest issue with these conventional technologies is that the large heat loss due to the high moisture content in lignite prevents high-efficiency power-generation facilities from being realized with conventional technologies. Since the efficiency of power-generation facilities can be increased by predrying lignite with high moisture content before combustion, many manufacturers are working on developing a lignite predrying technology.

We also are enthusiastically advancing development of a lignite predrying system based on our fluidized-bed technology in order to establish a distinctive technology for realizing high-efficiency power-generation facilities. This article introduces the details and progress of the IHI Group's concrete activities for commercialization in this market for lignite-fired power-generation facilities.

## 2. Ensuring of reliability of lignite-fired boiler technologies

To establish highly reliable lignite-fired boiler technologies at an early stage, we welcomed SE, an engineering company with rich experience in lignite-fired boilers, into the IHI Group from Siemens AG in June 2014. The following sections outline SE and the business cooperation we have with them for lignite-fired boiler technologies.

### 2.1 Outline of SE

SE was established in April 2003 as an engineering company based in Gummersbach near Köln, Germany. Their major activities are ① consultant business, ② engineering business, and ③ engineering and major equipment supplying business related to combustion facilities, such as power boilers, heat exchangers for chemical plants, and burners for power boilers, and environmental equipment, such as desulfurization equipment and denitration equipment. Their business covers not only Germany but also East Europe, Turkey, South Africa, and other countries of the world.

Raw lignite combustion system has been developed mainly in Germany, where there are lignite coal mines. The former L. & C. Steinmüller GmbH (hereinafter, referred to as the former LCS), a German boiler manufacturer, delivered many lignite-fired boilers both domestically and internationally. SE employs many engineers from the former LCS and, as described later, implements burner modifications, etc. for lignite-fired boilers on the basis of their rich technical experience and know-how concerning lignite-fired power-generation facilities.

Our boiler plant division and SE have had worker exchanges since the days of the former LCS, through which we have been mutually enhancing technical capabilities in a friendly rivalry. The two companies continuously cooperate in technical development and human resources with each other. For example, SE provides support for a power-generation facility project (the 813 MWe boiler for Trianel's Lünen Power Plant) that we carried out in Germany.

### 2.2 Past lignite-fired facility projects implemented by SE

Europe has a long history of lignite use in power-generation facilities, and has developed to reach over 90% of availability and up to 43% of plant efficiency (at low heating value basis) for row lignite units. Southeast Asia also has an enormous potential market for lignite use, but circumstances for its effective use in power-generation facilities are still unfavorable.

As described above, SE has advantages in raw lignite combustion power-generation facilities. **Table 1** lists the major lignite-fired facility projects that SE has implemented. In particular, SE has retrofitted many power-generation facilities — totaling 18 000 MWt — to meet the latest environmental regulations by applying lignite-combustion technologies using Steinmüller RSM® burners.

**Table 1 Steinmüller Engineering's track record with lignite technology**

| Project title and target | Client |
|---|---|
| Combustion system modification work for $NO_x$ reduction for a 320 MWe lignite combustion boiler<br>Kostolac PS B1, PE Industry, Serbia | PE ElectricPower Industry, Belgrade, Serbia |
| Lignite-combustion system improvement work for 4 × 227 MWe lignite combustion boilers<br>Maritsa East 3 PS Unit 1-4, Maritsa, Bulgaria | Contour Global,Sofia, Bulgaria |
| Combustion system modification work for 2 × 600 MWe lignite combustion boilers<br>Niederaußem PS Unit G and H, Germany | RWE AG, Essen, Germany |
| Detail design of the wall-air system for 11 × 250 MWe lignite combustion boilers<br>Jänschwalde PS, Germany | Vattenfall Europe Generation AG & Co KG, Cottbus, Germany |
| Basic plan of the low-$NO_x$ combustion system for 11 × 250 MWe lignite combustion boilers<br>Jänschwalde PS, Germany | Vattenfall Europe Generation AG & Co KG, Cottbus, Germany |
| Estimation plan of a 500 MWe lignite combustion boiler<br>Turow PS, Poland | Doosan Babcock Energy Ltd, West Sussex, UK |
| Conceptual design of modification for low-$NO_x$ burners for 2 × 640 MWe lignite combustion boilers<br>Neurath PS, Unit D and E, Germany | RWE Power AG, Essen, Germany |
| Examination of the possibility of $NO_x$ reduction for a 345 MWe lignite combustion boiler<br>Sostanj PS Unit 5, Slovenia | Siemens d.o.o. Bratislavska 5, SI-1000, Ljubljana, Slovenia |
| Examination for estimation of a 330 MWe lignite combustion boiler<br>Turceni PS Unit 6, Romania | Doosan Babcock Energy Ltd, West Sussex, UK |

This section describes the building of a lignite-fired combustion system for Maritsa East (227 MWe for each of its four units), the second item of **Table 1**, and engineering service for Units G and H of Niederaußem Power Station (600 MWe for each unit), the third item of **Table 1**.

#### 2.2.1 Maritsa East 3

The Maritsa East 3 Thermal Power Plant is located in the southeast of Bulgaria. It is equipped with 4 × 227 MWe units and is one of the largest power-generation facilities in Bulgaria. Its Russian boilers were constructed in the latter half of the 1970's. Lignite produced in the Maritsa East mine adjacent to the power plant is used as its fuel. This lignite is characterized by high moisture content, high sulfur content, high ash content, and a small heating value, compared with ordinary lignite. This type of coal requires due consideration in boiler planning and performance evaluation. This power plant was privatized at the beginning of this century. After that, large-scale renovation work was planned, and the reduction of $NO_x$ emissions was worked into the plan in order to meet the expected environmental regulatory values (specified in Directive 2010/75/EU). For this work, the following concrete requirements and purposes were indicated by the client.[2]

(1) Reducing the $NO_x$-emission concentration from 400 mg/Nm$^3$ to 180 mg/Nm$^3$ (6% $O_2$ on a dry basis)
(2) Reducing the excess air ratio at the boiler outlet from 1.2 to 1.15 in order to increase boiler efficiency
(3) Keeping the CO-emission concentration at 180 mg/Nm$^3$ or lower (6% $O_2$ on a dry basis)
(4) Preventing furnace corrosion
(5) Preventing ash deposition (slagging) and making steam conditions and other process values equivalent to those achieved before the combustion improvement

To achieve the above targets, SE drastically reviewed the combustion system.

For the burners, a plan for introducing Steinmüller RSM® burners to produce a large flow-velocity difference between combustion air and coal was formulated in order to accelerate mixture between them. Combustion stability would be ensured with flame stabilizers. In addition, applying an overfire air system was planned in order to reduce $NO_x$ emissions while preventing increase in CO concentration. Furnace wall corrosion and slagging would be prevented by installing an air-supply nozzle (Side Wall Air system: SWA) on each wall.

The new combustion system optimized the residence time of coal by lowering the primary burner belt zone near the burners and expanding the secondary zone over the top burner level, which achieved the desired reduction in $NO_x$ emissions and prevention of an increase in CO concentration (ensuring of combustibility).

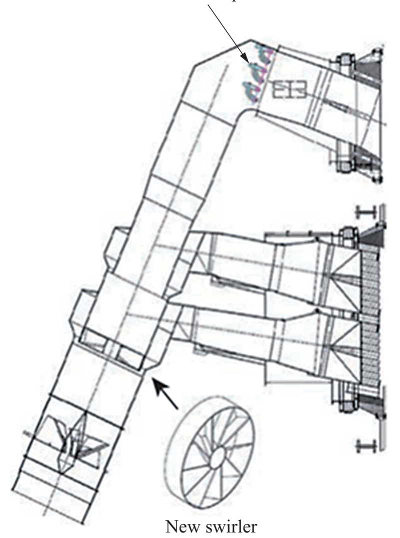
For the fuel supply system for burners, pulverized-coal and air injection was optimized by reviewing the duct shape and installing a new swirler and a new damper. **Figure 1** shows the new swirler and damper. Confirmation of the adequacy of this plan and optimization of the relevant facilities were done by performing combustion simulation (hereinafter, referred to as combustion CFD) in cooperation with RECOM Service GmbH (hereinafter, referred to as RECOM), a company with rich experience in combustion CFD for power-generation and industrial boilers.

In addition, solutions obtained by 3D CFD were applied to verification tests on a physical model burner (one-tenth scale) in order to determine an optimum solution to the design. **Figure 2** shows this model, and **Fig. 3** shows the result of the CFD. The result of the model test and that of the CFD calculation are in good agreement. This simulation was useful not only in the planning stage but also in preliminary understanding of combustion behavior which varies depending on all the different kinds of adjustments in the trial run of the actual system.

The following is an example of the results of combustion CFD. **Figure 4** compares the isothermal surfaces of furnace-gas temperature on the burner level. The results suggest that the gas-temperature distribution becomes uniform by the modification (**Fig. 4-(b)**).

**Figure 5** shows the distribution of CO concentration. It is generally known that reduction in the excess air ratio increases CO concentration. However, it was confirmed that this modification allows a CO concentration as low as the pre-modification level to be achieved even if the excess air ratio is reduced from 1.2 to 1.15.

The delivery periods for this modification work were very short with only five months from the contract award to the start of work. The work was however completed without any problems, and it was confirmed that the modified system delivered the required performance. **Table 2** compares the boiler performance of before and after the modification.




(Note) PF : Pulverized Fuel

**Fig. 1** New PF concentrator (New swirler) and vapor dampers

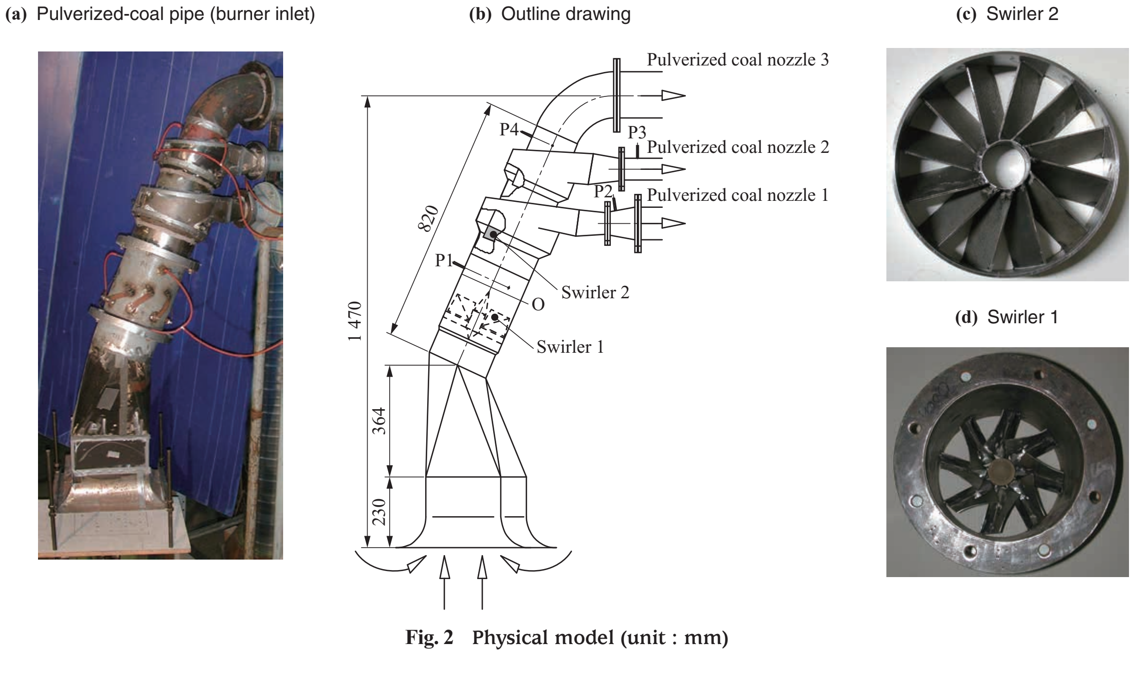
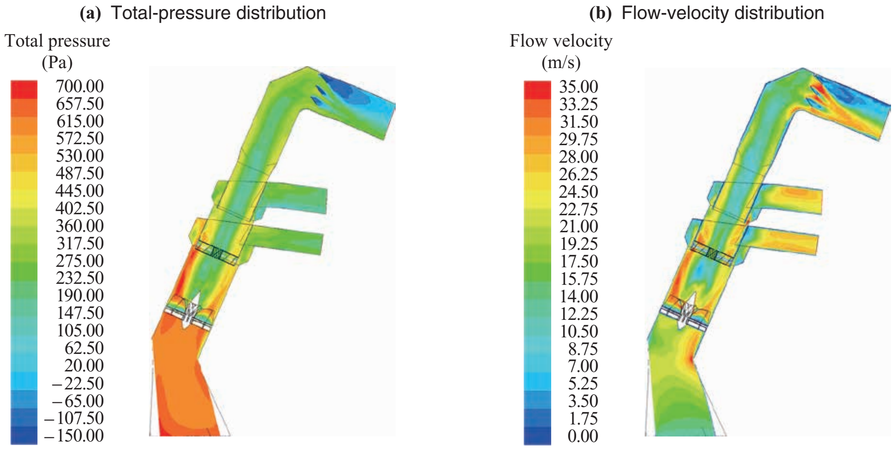
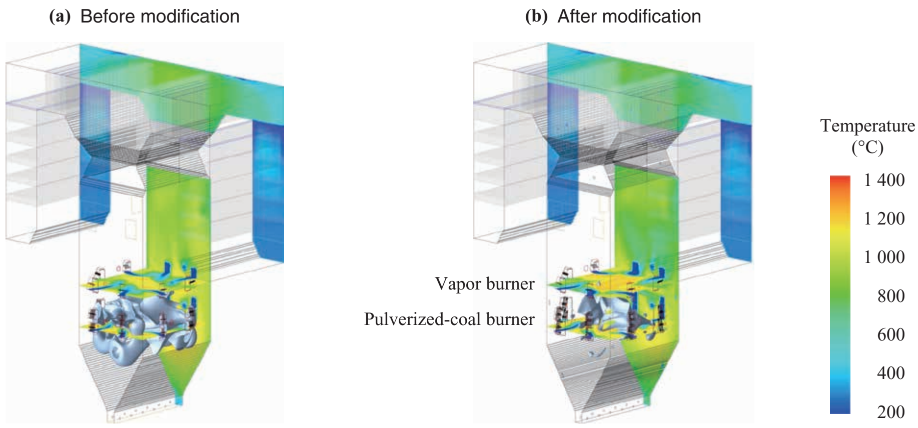



**Fig. 2** Physical model (unit : mm)




(Note) PF : Pulverized Fuel

**Fig. 3** CFD results for the new PF concentrator and the vapor dampers




(Note) Isothermal-surface gas temperature : 1 200°C

**Fig. 4** Comparison of isosurface temperature

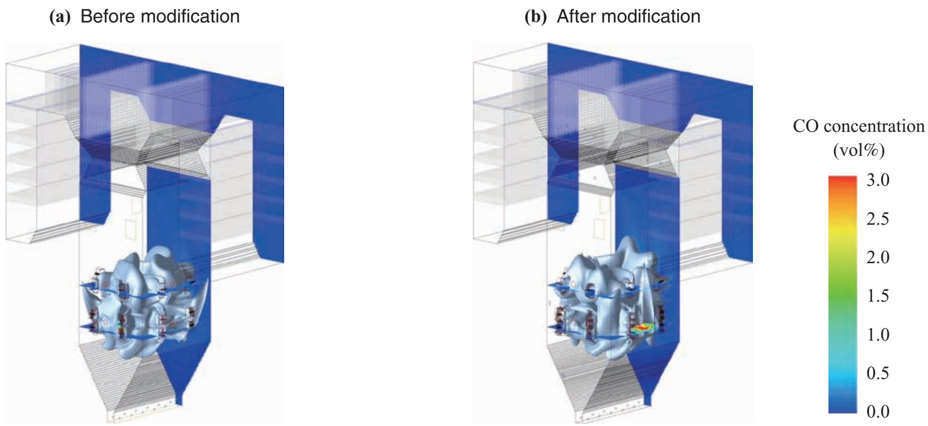



**Fig. 5** Comparison of CO-production

### 2.2.2 Niederaußem Power Station Unit G and H

The Niederaußem Power Station is located in the middle west of Germany. It is owned and operated by RWE AG Corporation (hereinafter, referred to as RWE), one of the four largest electric power companies of Germany. The power station is operated with Rhenish lignite, which is produced in a nearby area. It generates electricity at low fuel cost and is therefore regarded as an important power source.

Lignite-fired power-generation facilities have conventionally been regarded as base-load power sources. Against the backdrop of the recent rise of renewable energy, however, they are increasingly forced to implement partial load operation.

Units G and H of the Niederaußem Power Station are relatively large-scale lignite-fired power-generation facilities

Table 2 Boiler performance parameters before and after modification

| Item | Unit | Before modification | After modification (Target value) | After modification (Actual value) |
|---|---|---|---|---|
| $NO_x$ | mg/m³ *1 | 350 to 400 | < 180 | 150 to 180 |
| CO | mg/m³ *1 | < 60 | < 180 | 30 to 80 |
| Excess air ratio (furnace outlet) | — | 1.2 | 1.15 | 1.1 |
| Boiler efficiency | % | to 83.5 | — | to 83.5 + 1.0 |
| Ratio of the region with an $O_2$ concentration lower than 0.5% near the furnace wall | % | — | 30 | < 5 |

(Note) *1: Normal state, 6% $O_2$ on a dry basis

generating a power output of 600 MWe. Their planned excess air ratio is 1.35, and this relatively high value contributes to high $NO_x$ concentration and delayed ignition in the burner belt area. They have therefore had issues with high $NO_x$ concentrations during rated-load operation, frequent shutdowns due to slagging and ash removal work, and constraints on partial-load operation due to the high $NO_x$ concentration.

In 2012, SE received a request from RWE to formulate draft measures for improvement and modification and to implement combustion CFD with the aim of solving these issues.

To improve combustibility, SE implemented optimization using Steinmüller RSM® burners and also formulated measures, such as acceleration of mixture between air and combustion gas by optimizing the secondary-air velocity of the overfire air system and optimization of the geometry of the nozzles.

On the basis of this result, RWE performed the modification work on Unit G and confirmed that the modification produced the required effects. RWE subsequently implemented the same modification on Unit H, which was the same type of unit as Unit G.(3)

### 2.3 Business cooperation in lignite-fired facility projects with SE

#### 2.3.1 Trial design for a project on facilities in Germany

As an example of our activities related to lignite-fired power-generation facilities, this section describes trial designs for a project on facilities in Germany.

With the aim of improving plant efficiency, the client of this project requested not only USC steam conditions but also pre-dried lignite co-combustion for reducing loss due to moisture released during combustion as the specified conditions.

As mentioned above, SE and IHI have been in a technically cooperative relationship since before SE joined the IHI Group. We therefore cooperated with SE in trial design for this project.

Since this project required approaches for both a USC boiler and multi-fuel combustion of raw lignite and pre-dried lignite, we combined the specialized technologies of the two companies, that is, SE's raw lignite combustion technologies and our USC boiler technologies, with the burner for pre-dried lignite (TBK burner) that we had been developing. **Figure 6** outlines the TBK burner. **Figure 7** shows the arrangement of the TBK burner and a burner for raw lignite (RBK burner).

The burner arrangement meeting the new design conditions

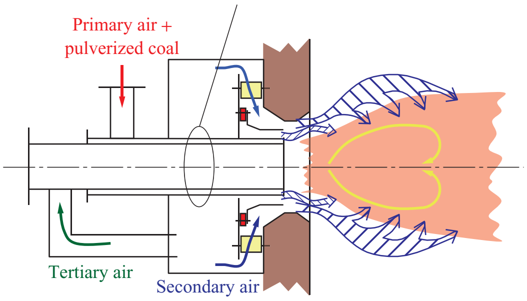



Fig. 6 Burner for pre-dried lignite (TBK burner)

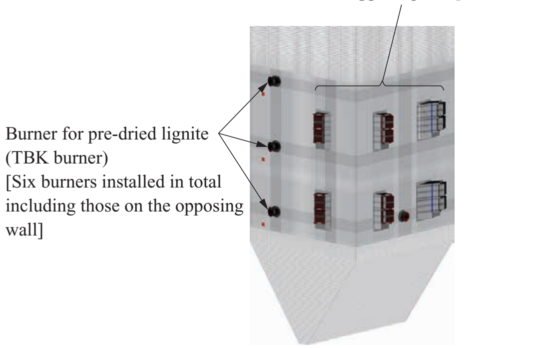



Fig. 7 Arrangement of burners for pre-dried lignite and burner for raw lignite

and the furnace plan were postulated on the basis of data accumulated on the characteristics of co-combustion of raw lignite and pre-dried lignite. In addition, sufficient discussion was held from the perspective of the two companies' boiler design technologies. Since this design coal needed due consideration for problems caused by ash, we shared our knowledge with SE and thereby formulated a basic plan regarding heating surface arrangement and other matters.

To supplement insufficient knowledge on the combustion characteristics of co-combusted raw lignite and pre-dried lignite, we cooperated in combustion CFD with RECOM, verifying the plan while confirming consistency with the postulated basic plan and design. We thereby confirmed that even combustion is ensured, and that the gas temperature profile is in agreement with the plan. **Figure 8** shows an example of the result of combustion CFD on co-combustion of raw lignite and pre-dried lignite.

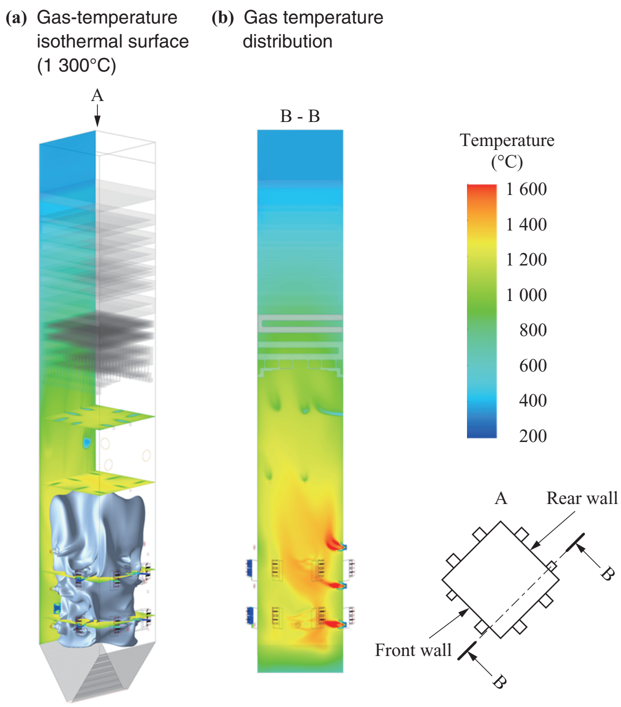



**Fig. 8** Example of CFD result for raw/pre-dried lignite mixed combustion

### 2.3.2 Trial design for a project on facilities in Southeast Asia

Lignite significantly differs in its basic conditions such as its heating value, moisture content, ash content, and ash characteristics according to the area and coal seam from which it is produced. Accordingly, lignite-fired facilities cannot be planned with the standard equipment configuration for bituminous coal-fired power-generation facilities. It is therefore essential to adopt an equipment configuration appropriate for the design coal properties and range of each design project.

SE and IHI implement trial design of optimum equipment configuration, boiler structure, etc. in order to handle raw lignite-fired boilers in projects for lignite-fired facilities in Southeast Asia with consideration given to the properties of Southeast Asian lignite. **Figure 9** shows the overall arrangement of a raw lignite-fired boiler.

## 3. Development of a lignite dryer

The key to realizing high-efficiency lignite-fired power-generation facilities is pre-dried lignite firing technologies. Lignite predrying facilities, which have room for improvement in terms of higher efficiency and cost reduction, will play an important role as will boilers.

We are in the process of developing a lignite predrying system with functions, such as recovery of the latent heat of steam as a heat source, in order to maximize efficiency improvement using the pre-dried lignite.

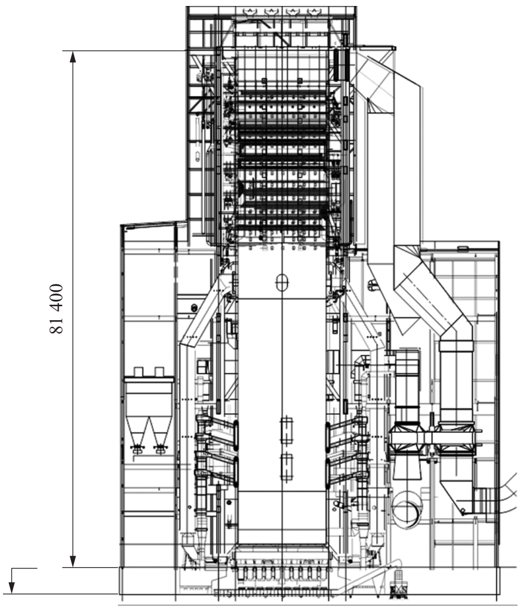



**Fig. 9** Overall boiler arrangement for raw lignite firing (unit : mm)

## 4. Closing remarks

The use of lignite is expected to further increase in the future. We will combine SE's lignite-fired boiler technologies and our high-efficiency and high-quality boiler technologies to establish a highly reliable boiler plan in preparation to partake in lignite-firing projects mainly in Southeast Asia as soon as possible. In order to contribute to meeting a worldwide requirement for $CO_2$ reduction, we will put our energies into realizing a pre-dried lignite-fired plant, which is a high-efficiency lignite-fired plant, while enthusiastically advancing development of technologies including those for lignite predrying system. We will thereby ensure reliability and increase economic efficiency.

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