

Design and Operating Experience of Supercritical Pressure Coal Fired Plant

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Abstract

The Hitachi group (Hitachi, Ltd. and Babcock-Hitachi K.K.) is one of a few companies that manufacture steam turbine generators, boilers, and plant systems for the electric generation market. This paper describes Hitachi's design and operating experience of supercritical pressure, coal fired power plant focusing on recent improvements to accommodate higher temperature steam conditions on both the turbine and boiler.

Keywords

Coal Fired Plant, Boiler, Steam Turbine

1 INTRODUCTION

The recent global energy situation strongly requires environmental preservation and cost competitiveness, therefore, the development efforts toward high temperature steam conditions for fossil power plant have become more important. Coal is still the key fuel for power generation from the view of "best-mix" energy policy. In order to meet the requirements, Hitachi, Ltd. and Babcock-Hitachi K.K., have developed state-of-the-art technologies for supercritical pressure, coal fired plant. The results to date lead to more than 5 units of design and supply experience of steam turbine generators and boilers adopting 1112 deg F class high temperature steam conditions. Hitachi's over 30 years accumulated knowledge and leading technology for supercritical pressure plants are now being noticed by international markets because of their high efficiency, flexible operation, high reliability and economic competitiveness.

2 EXPERIENCES

2.1 Supercritical Pressure Plant

Table 1 shows Hitachi's experience in supercritical pressure plants. Over 30 years experience, up to 1,050 MW unit size, including double reheat systems have

been designed and built. Although the steam temperature was maintained at 1000/1050 deg F for the first 20 years, updated technology improvements have been continuously incorporated. Fuel conversions from oil to coal, sliding-pressure operation for improving the partial load efficiency and operability, thermal efficiency improvement and cost reduction efforts are just a few of the more significant improvements.

Table 1: Experience in Supercritical Pressure Plant

	Steam Turbine & Generator	Boiler	Remarks
Unit Size	Number of Units	Number of Units	
350 MW	1	-	
450 MW	2	2	2 DRH
500 MW	4	5	
600 MW	11*2	11	2 DRH
700 MW	5	6	
1,000 MW & over	5	9	
Total Units	28	33	
Total Capacity	18,350 MW	23,250 MW	
First Unit in Service	1971	1967	

Note: DRH is for double reheat system

2.2 Recent Large Capacity Coal Fired Plant

Table 2 shows Hitachi's recent large capacity supercritical pressure coal fired plant experience. After 1998, 3556 psig – 1112/1112 deg F class high temperature steam condition has become the standard in Japan. Efficiency improvement can be as high as 3% compared to conventional supercritical pressure power plant steam conditions of 3500 psig – 1000/1050 deg F. Compared to conventional sub-critical pressure plants with 2400 psig – 1000/1000 deg F steam conditions, the efficiency improvement is reached at around - 6%.

As a proven steam condition, 3500 psig with 1000-1050 deg F class steam temperature has been used for IPP (Independent Power Producer) and overseas projects.

The features and topics of recent plants are introduced and described below.

Haramachi No.2/The Tohoku Electric Power Co. ^[1,6,9]

This is the first 1112/1112 deg F unit Hitachi supplied the plant and entered commercial operation in July 1998. Fig.1 shows the plant view. A remarkable high gross plant efficiency of 44.76% (HHV basis), auxiliary power consumption ratio of 4.3% and minimum stable load of 14.5% have been achieved during commissioning.



Fig.1 Haramachi Thermal Power Station, Unit No.2

Tomato-Atsuma No.4/The Hokkaido Electric Power Co. [2]

This is the largest tandem-compound steam turbine of 3,000 rpm in service commercial operation in June 2002. The newly developed 12Cr steel 43-inch last stage blade and three casing (HIP, 2 x LP), are used. Fig.2 shows the outline of the steam turbine generator. Hitachi supplied Unit 2, a 600MW TC4F-40 steam turbine at the same site, has been operated since 1985.



Fig.2 Tomato-Atsuma No.4 Steam Turbine Generator

Tachibanawan No.2/Electric Power Development Co. [10]

Fig.3 shows the outline of the plant. Unit No.2 is shown at the right side. The boiler has the world's record

capacity of 1,050 MW and steam conditions of 3627 psig – 1112/1130 deg F. The boiler entered commercial operation in December 2000.



Fig.3 Tachibanawan Thermal Power Station

Genesee No.3 /EPCOR Power Development Corporation

Genesee No. 3 unit is Hitachi's first overseas supercritical sliding pressure coal fired power plant located in Alberta, Canada. A 10% net plant efficiency improvement will be achieved compared with existing units. The TCDF-40 steam turbine contributes to the compact building design. The boiler design is based on the proven and experienced 500 MW class boiler design and for North American sub-bituminous coal.

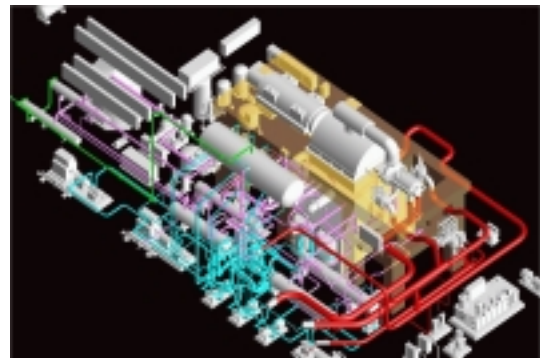


Fig.4 3D Engineering Model for Genesee No.3

Table 2: Recent Large Capacity Supercritical Pressure Coal Fired Plant

Customer, Unit	Hitachi Supply	Unit Output (Gross, MW)	Steam Condition (at Turbine Inlet)	Cycle	Operation Year	Turbine Type	Boiler Type
Kyushu Electric Power Co., Matsuura 1	TG	700	3500 psig 1000/1050 deg F	60 Hz	1989	TC4F-33.5	-
Electric Power Development Co., Matsuura 1	B	1,000	3500 psig 1000/1050 deg F	60 Hz	1990	-	UP
The Chubu Electric Power Co., Hekinan 2	BTG	700	3500 psig 1000/1050 deg F	60 Hz	1992	TC4F-40	Benson
The Tohoku Electric Power Co., Noshiro 1	B	600	3500 psig 1000/1050 deg F	50 Hz	1993	-	Benson
Soma Kyodo Power Co., Shinchu No.1	BTG	1,000	3500 psig 1000/1050 deg F	50 Hz	1994	CC4F-41	Benson
The Hokuriku Electric Power Co., Nanao-Ohta 1	B	500	3500 psig 1050/1100 deg F	60 Hz	1995	-	Benson
Electric Power Development Co., Matsuura 2	B	1,000	3500 psig 1100/1100 deg F	60 Hz	1997	-	Benson
The Tohoku Electric Power Co., Haramachi 2	BTG	1,000	3556 psig 1112/1112 deg F	50 Hz	1998	CC4F-41	Benson
Shikoku Electric Power Co., Tachibanawan 1	B	700	3500 psig 1050/1100 deg F	60 Hz	2000	-	Benson
Electric Power Development Co., Tachibanawan 2	B	1,050	3627 psig 1112/1130 deg F	60 Hz	2000	-	Benson
The Hokkaido Electric Power Co., Tomato-Atsuma 4	TG	700	3627 psig 1112/1112 deg F	50 Hz	2002	TC4F-43	-
Tokyo Electric Power Co., Hitachinaka 1	BTG	1,000	3556 psig 1112/1112 deg F	50 Hz	2003	CC4F-41	Benson
Kobe Steel Ltd., Kobe 2	TG	700	3500 psig 1000/1050 deg F	60 Hz	2004	TC4F-40	-
EPCOR, Genesee Phase 3, Alberta, Canada	BTG	495	3500 psig 1050/1050 deg F	60 Hz	2005	TCDF-40	Benson

Notes: Supply Code; B: Boiler, TG: Steam Turbine and Generator, BTG: Boiler and Steam Turbine Generator

3 STEAM TURBINE TECHNOLOGY

Hitachi is committed to supplying steam turbines with high efficiency and reliability since the first unit was manufactured in 1933. This article describes the technologies employed for the state-of-the-art steam turbines with 1112/1112 deg F class high steam temperature, long blade structure improvements and the development of 1000 MW tandem-compound type.

3.1 Materials for High Temperature

9Cr - 1Mo forged steel is applied to the valves and the leading steam pipes which are exposed to 1112 deg F steam and 12Cr cast steel is applied to the internal casing of IP No.1. Cr-Mo-V-B cast steel is used for the HP internal casing. 12Cr rotor and blade material for the HP and the IP turbine are also applied.

3.2 Structures for High Temperature

New design criteria are applied along with the high temperature materials described below.

(a) Overlay welding for the bearings

The overlay method is applied to the main bearings instead of the usual sleeve method.

(b) Steam cooling technology

The structural welding between 9Cr-1Mo forged leading pipes and the Cr-Mo-V casted outer casing are cooled by low temperature steam. The cooling affect is confirmed by analysis and actual operation.

(c) High efficiency nozzle

An Advanced Vortex Nozzle (AVN) is used to improve turbine efficiency to all the stages except for the first stage.

The new technologies applied for 1112/1112 deg F class high temperature plant, are shown in Fig. 5 [6]. The following is a reference from Haramachi No.2 unit HP and IP steam turbine sections.

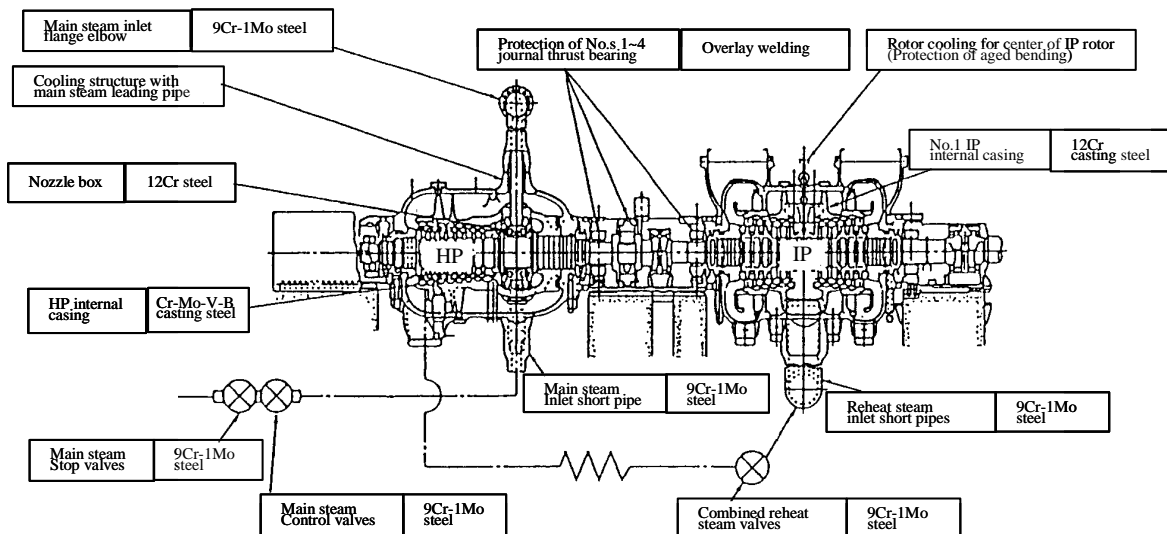


Fig. 5: The New Technology of the Haramachi No.2, 1,000MW Steam Turbine (HP & IP Sections) [6]

3.3 Continuous Cover Blade (CCB)

The last stage blade of a steam turbine is one of the most important components to determine the overall turbine performance and reliability, because it generates about 10 % of the entire output and is operated at severe centrifugal forces. The longer last stage blade yields higher velocity, larger centrifugal force and a lower natural frequency, so a highly advanced design technology is required to develop the last stage blade from the standpoint of performance, strength and vibrational characteristics. Hitachi has been developing long blades and adopting the CCB structure, having a high rigidity and dampening effect at the specified rotational velocity, and incorporates the latest aerodynamic blade profile based on three-dimensional stage flow analysis. Fig. 6 [4] shows blade structure concept for CCB. Table 3 [4] shows the line-up of current last stage blades with the CCB structure, which performed the rotational test. Not shown blades were also completed the design and are now available. These have already been adopted and are operating successfully worldwide for both new installations and retrofit applications.

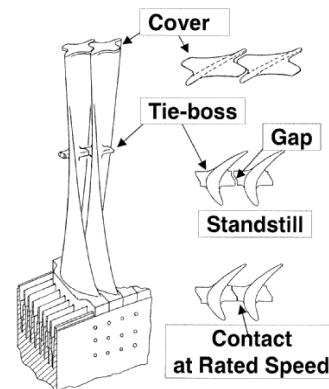


Fig. 6: Continuous Cover Blade (CCB) Structure [4]

Table 3: Line-up of LSB with CCB Structure [4]

Rotational Speed	Last Stage Blade Length
3600 rpm	26 in., 33.5 in., 40 in., 46 in.
3000 rpm	26 in., 33.5 in., 43 in.
1800 rpm	48 in.

3.4 Tandem-Compound 1,000 MW STG

Although Hitachi's largest tandem-compound machine to date experience is 700MW, Hitachi has already developed technology applicable to tandem compound configurations of 1,000MW steam turbine generators. The technology responsible for such improvements include longer last stage blades, larger diameter journal bearings and improved components.

The correlation between unit output and turbine exhaust annulus area is shown in Fig.7^[5]. The tandem-compound four-flow type with Ti-alloy 40-inch or 46-inch last stage blades (TC4F-40 or TC4F-46) and improved high strength 12Cr steel 43-inch last stage blade (TC4F-43) can be applied to 60Hz and 50Hz operation respectively. The described machines are based on 3556 psig – 1112/1112 deg F advanced steam condition design.

Fig.8^[5] shows the sectional arrangement of TC4F-40, 1,000MW steam turbine for 60 Hz use.

Fig.9^[5] shows the sectional arrangement of TC4F-43, 1,000MW steam turbine for 50 Hz use.

The tandem-compound 1,000MW generator design has been completed. The design of the large-diameter rotor was verified by performing tests using an actual section sized model of the 60Hz machines, which sustains greater centrifugal forces compared to the 50Hz machines. The strength against fatigue caused by the start-stop operation and extended running was evaluated to verify reliability. In addition, an improved ductility high-strength shaft material was developed to further enhance the design.

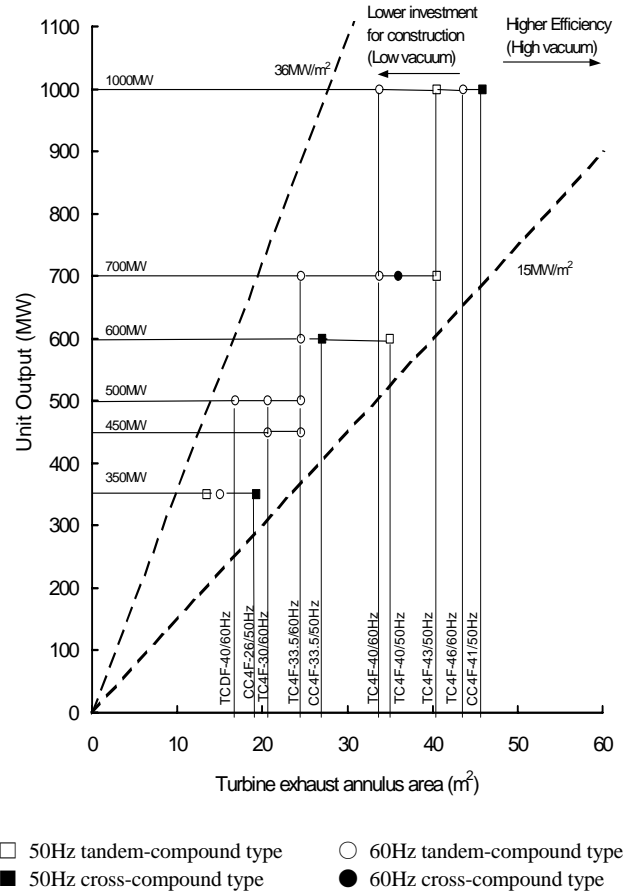


Fig. 7: Correlation between Unit Output and Turbine Exhaust Annulus Area^[5]

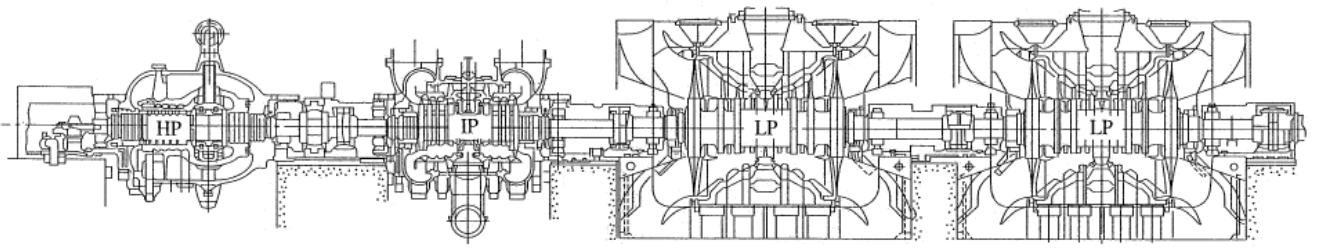


Fig. 8: Sectional Arrangement of TC4F-40 1,000 MW Steam Turbine for 60 Hz Use^[5]

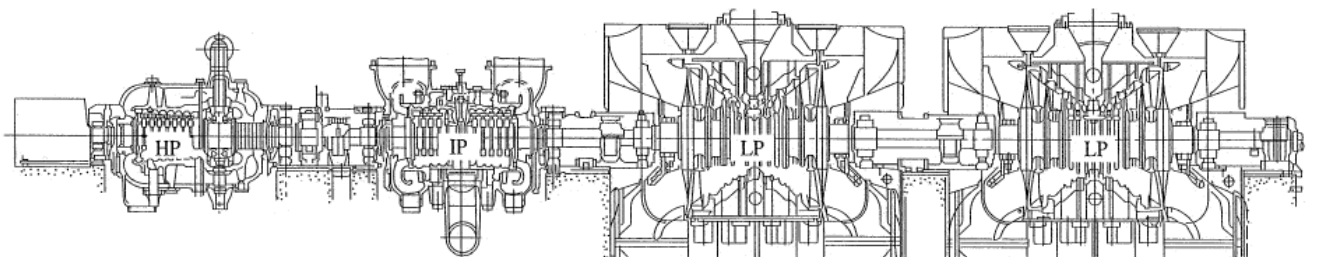


Fig. 9: Sectional Arrangement of TC4F-43 1,000MW Steam Turbine for 50 Hz Use^[5]

4 BOILER TECHNOLOGY

To satisfy the need for higher efficiencies and flexible operation, a sliding-pressure Babcock-Hitachi K.K (BHK) type Benson boiler with the standard spirally wound furnace walls, has been designed. To accommodate higher steam temperatures, and the applications of 1112/1112 deg F, the boiler design uses high-strength materials and optimizes furnace volume.

This article describes the design criteria used for the latest boiler technology using 1112/1112 deg F high steam temperature shown below as the Haramachi No.2 boiler.

4.1 Boiler Structure

Fig. 10 ^[9] shows a side view of the boiler, where the amount of superheaters and reheaters are increased to achieve the required higher steam temperatures. However, an increase of the heating surface is kept to a minimum by optimizing the furnace size so that the boiler dynamic response is improved. A multi-stage superheater spray system is applied for the main steam temperature control while gas recirculation and gas biasing dampers are both included to overcome performance differences when firing different coals.

4.2 Use of High-Strength Materials

For high temperature steam conditions, it is essential to use high-strength materials to reduce wall thicknesses of pressure parts, resulting in low thermal stresses and minimum pressure drops.

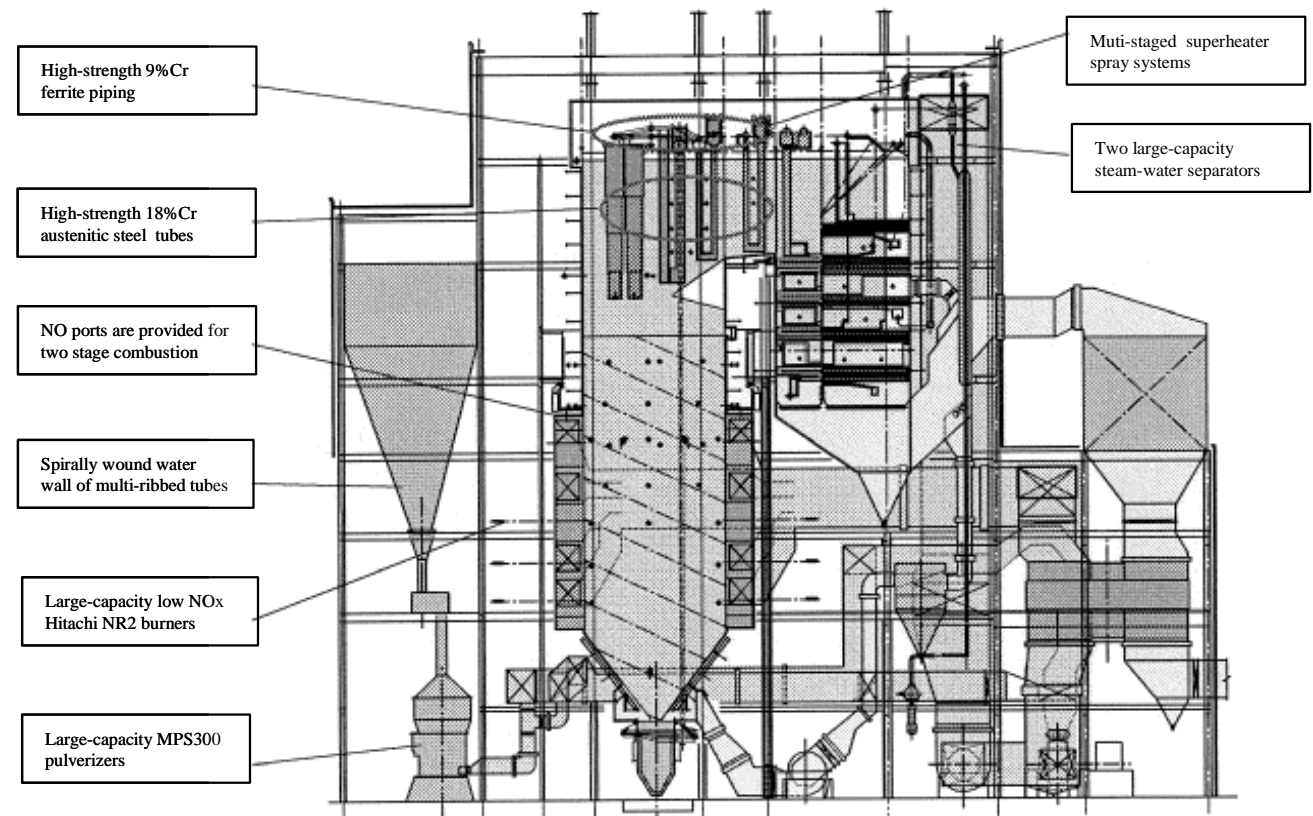


Fig. 10: Technologies Applied to Haramachi No.2 Boiler ^[9]

For pendant superheaters, austenitic steel of 18Cr9Ni3CuNbN, which has significant higher creep strength at the elevated temperature region, was selected.

For pendant reheaters, another high-strength austenitic steel of 18Cr10NiTiNb, was selected.

Reliable ferritic piping of 9Cr1MoVNb was selected for main steam piping and high temperature superheater headers. Rolled-plate-type piping made of the same steel was used for reheater outlet headers and hot reheat piping.

The use of the described materials maintains the wall thicknesses in high temperature zones similar to that of conventional boilers.

The advanced steam parameters along with the latest combustion technologies significantly improved plant and boiler efficiency. (Fig 11 ^[9])

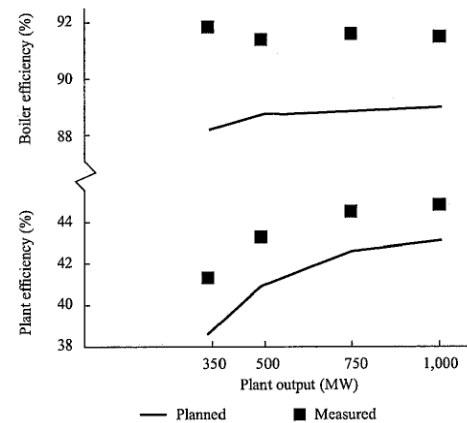


Fig. 11: Performance Test Results for Haramachi No.2 Plant ^[9].

4.3 Combustion System

Following the development of Hitachi NR burner, which is based on the innovative concept of in-flame NO_x reduction, BHK developed the NR2 burner, having strengthened the high temperature reducing flame to achieve extremely low NO_x emissions in addition to improved combustion efficiency. This enables a small amount of excess air at the economizer outlet (15%) when firing various kinds of imported coal. The NO_x reduction principle is shown in Fig. 12^[7].

Another feature of the combustion system is the large capacity roller-type pulverizers (MPS300) with rotating classifiers, which improve pulverized coal finenesses. These combustion system technologies contribute substantially to significantly higher boiler efficiency.

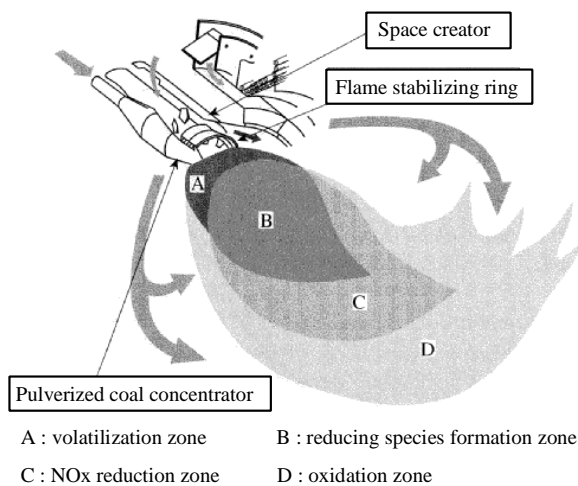


Fig. 12: Frame Structure of Hitachi NR2 Burners^[7]

A third generation burner (NR3), which enhances the reaction of in-flame NO_x reduction, has been developed in response to needs for higher efficiency and lower NO_x combustion. The performance of the NR3 burner has been verified at the Inkoo Thermal Power Station Unit No.3 of Imatran Voima Oy (IVO), Finland. It was confirmed that the NR3 burner had approximately 25% lower NO_x level at the same UBC (unburned carbon) level, than the current NR2 burner^[8]. The NR3 burner equipped boiler is now in the construction stage and will be in commercial operation in 2003.

5 CONCLUSION

The advanced steam condition of 3556 psig – 1112/1112 deg F class has been applied in the recent coal fired plants in Japan and confirmed to their design, performance and operability.

The Hitachi group continues to play a key role in the development of advanced steam turbine generator and boiler to contribute global welfare in the form of better technologies for energy and environmental preservation.

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