PERFORMANCE OF 500 MW COAL FIRED STEAM GENERATORS -

EXPERIENCE OF FIRING INDIAN COALS

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INTRODUCTION

Bharat Heavy Electricals Limited in association with ABB-CE, USA has engineered and supplied twelve 500 MW units. The first steam generator is in service from 1984. The design of these 500 MW steam generators was based on the experience of the 200 and 210 MW units. The Indian coals have high ash content, lower calorific value and high moisture experienced during rainy season. Because of this there were a few performance problems in the first few units. The experience of assessing and improving the performance of these steam generators is the main theme of this paper.

The combustion characteristics of the Indian coals are good. However, the high ash content and low calorific value associated with high moisture required specific changes in steam generator design. Tests done in different units with different coals helped in analysing the problem. The analysis of the test data resulted in engineering changes. The modifications done improved the performance of these units. It also helped in updating design standards and methods. The paper gives an outline of the key aspects to look for in steam generator design for high ash Indian coals. The paper also outlines the testing and performance analysis methods used.

GENERAL DESIGN FEATURES

The design and operating experience covers the following coal fired 500 MW units in India given in Table - I.

These units are of semi out door type, incorporating the following features (Ref.1) - Top supported , Single furnace cell, dry bottom, balanced draft, controlled circulation plus, tilting tangential firing system with bowl mills as shown in Figure-1.

TABLE I : LIST OF 500 MW STEAM GENERATORS

Plant	Customer	Year of operation
Singrauli 6, 7	National Thermal Power Corporation(NTPC)	Dec.86, Nov.87
Korba 4,5,6	National Thermal Power Corporation (NTPC)	May 87, March 88, March 89
Ramagundam 4,5,6	National Thermal Power Corporation(NTPC)	May 88, March 89, Oct.89
Chandrapur 5,6	Maharashtra State Electricity Board (MSEB)	March 91, March 92,

The basic boiler parameters and coal analysis for which the units were engineered are given in Table II and Table III. Since coals for all these units belonged to the bituminous category, same design philosophy was adopted.

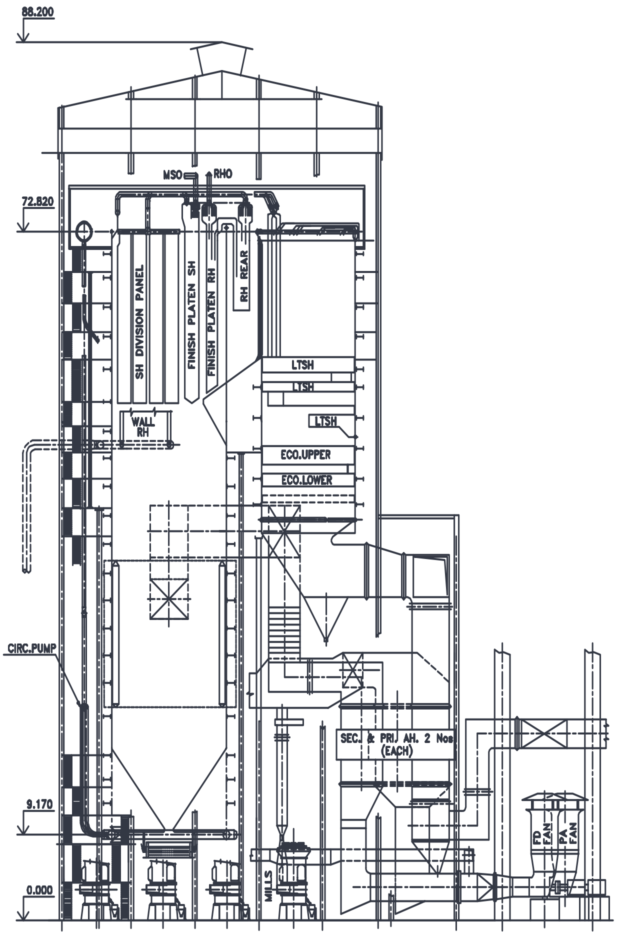


FIGURE 1: GENERAL ARRANGEMENT OF BOILER – TYPICAL

TABLE II : 500 MW - BOILER PARAMETERS

		NTPC (Typical)	MSEB Chandrapur
MAIN STEAM			
Steam flow at SHO	t/h	1725	1681
Pressure at SHO	kg/sq.cm(g)	178	179
Temperature at SHO	Deg.C	540	540
REHEAT STEAM			
Steam flow at RHO	t/h	1530	1430
RH inlet pressure	kg/sq.cm (g)	45.85	44.88
RH inlet temperature	Deg.C	344	343
RH outlet pressure	kg/sq.cm (g)	43.46	42.68
Temperature at RHO	Deg.C	540	540
FEED WATER			
Feedwater temperature	Deg.C	256	255

Furnace and Circulation System

The furnace for these 500 MW units have been designed with conservative heat loadings, taking care of properties of Indian coals, particularly ash and moisture. Typically these units have been engineered with plan area heat loading of 4.75 x10^6 kcal/h.m^2, EPRS loading of 173,000 kcal/h.m^2, Volumetric loading of 87,000 kcal/h.m^3 and burner zone heat release of 1.40x10^6 kcal/h.$m^{2.}$ The distance from top coal nozzle to the furnace arch was set at 1.10 times the average furnace cell dimensions. Controlled circulation is employed with 3 nos. of boiler water circulating pumps, to provide ample head for the engineered selective distribution of fluid by means of orifices located in the furnace wall inlet headers. Two pumps are designed to meet 100% MCR with one pump as standby. The furnace waterwall is made of fusion welded panel with rifled tubes of 51 mm diameter at 63.5 mm pitch. The advantage of using rifled tube over plain tube is that it reduces circulating pump power consumption due to lesser circulation ratio and developed head and has adequate margin on DNB with reference to steam quality.

TABLE III : COAL ANALYSIS

		Singrauli	Korba	Ramagundam	Chandrapur
Proximate Analysis					
Fixed Carbon	%	32.4	25.0	36.54	28.0
Volatile Matter	%	21.6	19.0	21.46	24.0
Moisture	%	16.0	12.0	10.00	8.0
Ash	%	30.0	44.0	32.00	40.00
HHV	kcal/kg	4050	3500	4300	3750
Ash	kg/Mkcal	74.1	125.7	74.4	106.7
Ultimate Analysis					
Carbon	%	43.20	35.60	45.01	40.20
Hydrogen	%	2.50	2.28	2.82	2.80
Sulphur	%	0.27	0.26	0.38	0.40
Nitrogen	%	0.80	0.32	0.95	0.80
Oxygen	%	7.23	5.54	8.84	7.80
Moisture	%	16.00	12.00	10.00	8.00
Ash	%	30.00	44.00	32.00	40.00
HGI		50	58	50	50
Ash characteristics					
Initial deforrn.	Deg.C	1190-1250	1170-1210	1350	-
Softening	Deg.C	-	-	-	-
Hemispherical	Deg.C	+ 1400	> 1400	1390	1200
Fluid	Deg.C	+ 1400	> 1400	1400	-
Ash Composition					
A - SiO_2	%	56.7	60.15	59.00	54.98
A - Al_20_3	%	27.5	27.44	22.15	26.36
B - Fe_2O_3	%	6.4	5.60	8.40	8.40
B - CaO	%	1.8	1.43	7.06	4.45
B - Mgo	%	1.0	0.91	2.05	0.39
B - Na_2O	%	0.4	1.99	-	0.15
B - K_2O	%	2.5		-	0.35
A - TiO_2	%	1.9	1.53	-	1.86
P_2O_5	%	1.1	0.53	-	0.53
SO_3	%	0.3	0.46	1.34	-
Base/ Acid	%	0.14	0.122	0.216	0.165
Fe_2O_3 / CaO	%	3.56	3.92	1.19	1.89
Chloride		-	-	-	-

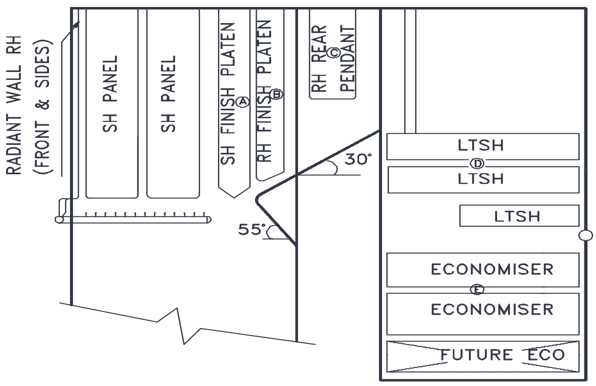
Pressure part arrangement

Typical arrangement of pressure parts is shown in Figure 2. Superheater is equipped with three stages - Low temperature superheater located in second pass, SH division panel and SH finish platen directly located above furnace. Desuperheaters are located in the piping between low temperature superheater section and SH division panel for controlling SH outlet steam temperature.

Reheater is made up of two stages, namely wall reheater located in radiant zone above furnace and finish reheater located in horizontal pass after SH finish platen. Wall reheater is provided in the front wall and a portion in side walls of the furnace.

Plain tubular economiser is provided below the Low temperature superheater.

Considering high ash content and erosive nature of the coal, the pressure parts have been designed for gas velocities in the range of 12 m/s. The gas velocities, transverse spacing, diameter adopted for these units are given in Figure-2. Further, adequate erosion allowance has been considered in the pressure parts design over and above minimum calculated wall thickness.



	ST mm	OD mm	VELOCITY m/s
A	762.0	47.6	8.8
B	381.0	54.0	9.5
C	190.5	63.5	11.9
D	152.4	51.0	11.7
E	114.3	51.0	11.3

FIGURE 2: PRESSURE PART ARRANGEMENT–TYPICAL

Steam temperature control

The boilers have been designed with steam temperature of 540 Deg.C at SH/RH outlet between 56% - 100% BMCR. Over this load range, RH steam temperature is controlled by fuel nozzle tilt and the SH steam temperature is controlled by interstage desuperheating. Positioning of the fuel nozzle between +30 Deg. to -30 Deg. tilt with respect to horizontal, provides a means of automatically adjusting the furnace absorption as required by changes in load or in furnace conditions. The design of the units are such that no reheater spray is envisaged. For controlling RH steam temperature, under any abnormal or emergency conditions, reheater desuperheaters are provided in the cold reheat piping.

Fuel firing system

All the boilers are equipped with 8 nos. of vertical spindle bowl mills except Korba which is equipped with 9 nos. of bowl mills. The bowl mills are located on either side of the boiler in case of NTPC 500 MW units and in the rear of the boiler in case of Chandrapur 500 MW. Since coals for all these units belonged to the bituminous category, same design philosophy was adopted.

All NTPC 500 MW boilers are provided with XRP 1003 bowl mills, Chandrapur 500 MW boilers are provided with XRP 1043 mills. All the boilers are designed to meet 100% MCR with 6 mills in operation for Design coal and one mill is provided as spare to meet 100% MCR while firing worst coal. The pulverisers grind the fuel to a fineness of 70% through 200 mesh. The pulverised fuel is delivered to the furnace through Dia. 610 mm/ 660 mm. pipes and admitted to the furnace through the tilting tangential fuel nozzles located in four corners. The windbox arrangement is shown in Fig.3. Each windbox consists of 8 or 9 elevations of coal nozzles, 4 elevations of oil guns with high energy arc ignitors. Windbox is designed with overfire air ports at 2 levels, located in the upper portion as an integral part of the windbox for controlling Nox emission.

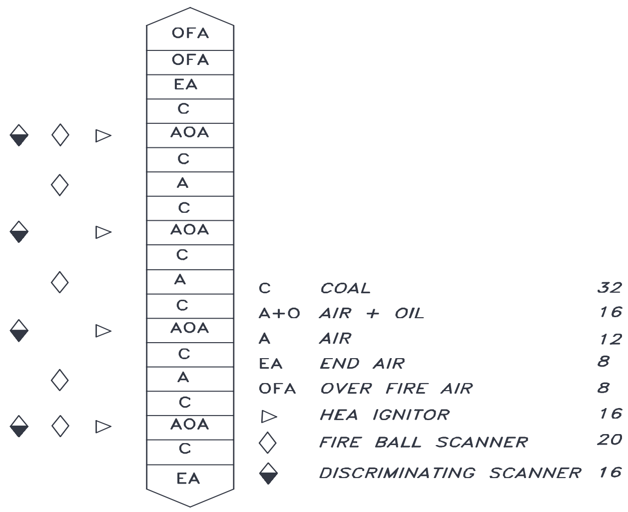


FIGURE 3 : WINDBOX ARRANGEMENT — TYPICAL

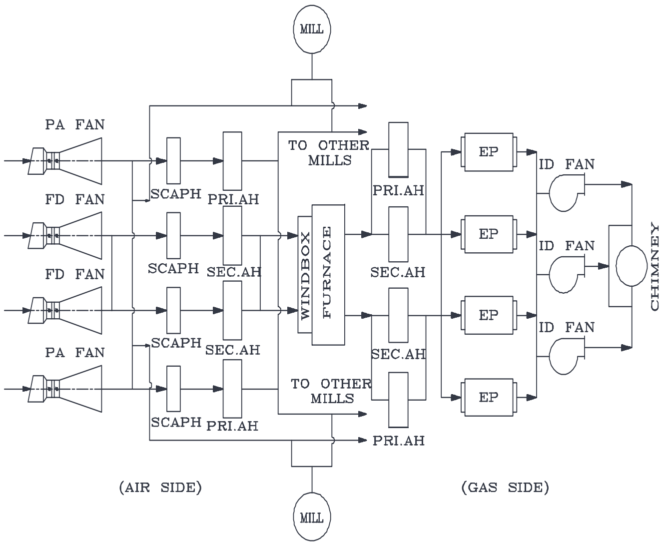


FIGURE 4 : AIR AND GAS SYSTEM - TYPICAL

Airheaters

These units are designed with four bisector regenerative airheater systems, two for primary and two for secondary air arranged in parallel as shown in Fig.4. In this type of airheater system, control dampers are provided at each airheater outlet on the gas side to control flue gas flow in such a manner that the temperature of the gas leaving the primary and secondary airheaters are nearly the same. The airheaters have been designed for gas outlet temperature of 140 °C at 100% MCR.

Fans

Axial reaction/ radial fans have been provided for these boilers as per customer preference. NTPC boilers have been equipped with Axial Reaction type, each of 2x50% capacity FD & PA fans and 3x50% capacity radial backward curved ID fans. Chandrapur boilers are provided with 2x50% capacity radial inlet vane controlled FD/ PA fans and 4x25% capacity radial backward curved ID fans.

Soot blowers

Based on operating experience of 200/210 MW boilers, Indian bituminous coals do not exhibit slagging and fouling tendency. However, the furnace has been equipped with 88 No. wall blowers and for cleaning SH, RH & Economiser 34 nos. Long retractable soot blowers have been provided.

Electrostatic precipitators (ESP)

All the boilers are provided with 4 nos. ESP with 6 or 7 fields per ESP depending upon duty requirements. These ESPs have been sized, duly taking care of the pollution requirements prevalent in India and specific requirement of the customer for each installation.

Controls & Instrumentation

Control systems like Furnace safeguard supervisory system, secondary air damper control, soot blower control, ESP controls are solid state hard wired/ micro processor based as per customer requirement.

OPERATING EXPERIENCE

The first NTPC 500 MW unit at Singrauli was commissioned in Dec.1986. The unit was loaded to full load on March 1987. Table-I gives the commissioning dates of the other units. Ever since the initial commissioning of Singrauli 500 MW, the following problems have been faced while operating the boilers.

- Inability to resort to all mill combinations without danger of exceeding allowable metal temperature in low temperature superheater.
- Excessive spray in SH system, Spray in Reheater system.
- Restriction in operating the burner tilt through its full range ie. +30 Deg. to -30 Deg. tilt .
- High mill wear.

High SH/ RH pick up

Higher SH, RH absorption was noticed in these boilers necessitating higher amounts of SH, RH spray flows for temperature control. SH spray was varying from 1.6% MCR - 13% MCR depending on Bottom 6 or middle 6 or Top 6 mills in service as against predicted value of 1.3% MCR flow with middle 6 mills in service at 90% MCR (500 MW load). RH spray was varying from 0 to 3.9% MCR depending on mill combination, as against predicted value of zero spray at 90% MCR (500MW load). Because of this high amount of spray flows, there were severe restrictions on mill combinations and mostly bottom mills were used with negative burner tilt.

LTSH Failures

A few tube failures occurred in the LTSH outlet terminal tubes. LTSH outlet temperature predicted is 405 Deg. C, where as steam temperatures as high as 500 Deg. C were observed. The high LTSH temperature restricted the mill combination particularly top mills in service and also the tilt has to be kept in negative direction. Also, LTSH right side assemblies showed higher metal temperature compared to left side assemblies indicating unbalance. This high LTSH outlet steam temperature necessitated reduction in load to contain the same within safe limit considering the materials used in this section.

Mill wear

Apart from the restriction in mill combinations, the availability of mills also posed problems due to high mill roll wear. This is due to high % of ash and abrasive nature of the coals used in the power station. Analysis of bowl mill residues showed a large amount of alpha quartz.

Heat rate deterioration

The heat rate of 500 MW units also deteriorated due to high SH and RH spray. This is because of the regenerative cycle adopted for these 500 MW units is different from normal cycle. The spray tap off is taken before HP heaters for SH and interstage tap off from boiler feed pump for RH. The additional SH, RH spray also increased the heat duty in the boiler

Gas Stratification

There was gas stratification at outlet of second pass. This was physically seen in erosion pattern of ducting leading to airheaters. There was a gas temperature difference of approximately 20 Deg.C was observed between gas entering the secondary and primary airheaters.

All the conventional methods for solving such problems like secondary air damper control adjustment, adjusting combustion regimes, optimised soot blowing etc. were attempted. Unfortunately, these attempts did not result in any appreciable reduction of spray quantities.

The same problems have been faced while commissioning Korba, Ramagundam and Chandrapur 500 MW boilers.

BOILER PERFORMANCE TESTS

The operational feed back of various 500 MW units led to the need for detailed thermal performance testing of the units. Detailed test procedures were finalised jointly between BHEL/ABB-CE and customer. Performance tests were done in all units, at varying loads with various mill combinations and at varying tilts.

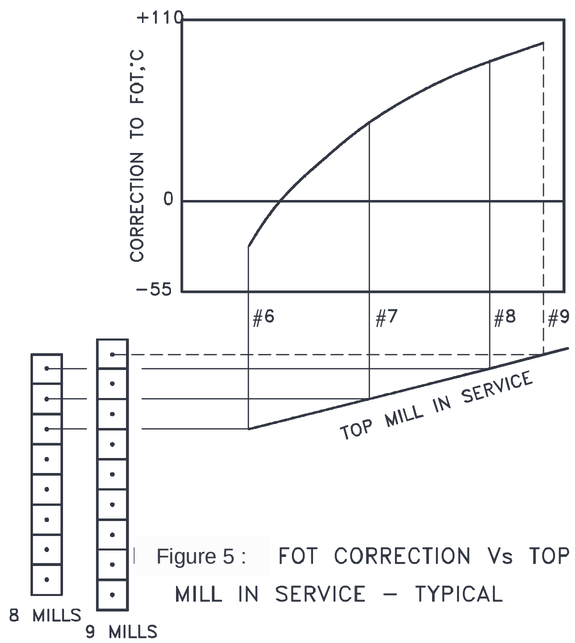


Figure 5 : FOT CORRECTION Vs TOP MILL IN SERVICE – TYPICAL

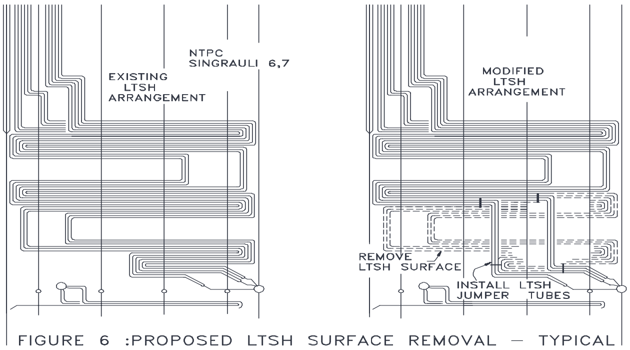


FIGURE 6 :PROPOSED LTSH SURFACE REMOVAL — TYPICAL

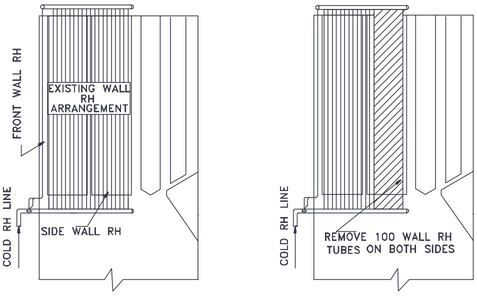


FIGURE 7 : PROPOSED WALL RH SURFACE REMOVAL — TYPICAL

Elaborate field measurements have been done by means of reliable and accurate local instrumentation on water and steam circuit, air , gas & fuel paths. Also where tapping points were not envisaged during design stage special arrangements have to be made to measure steam temperatures at SH division panel outlet, Radiant wall reheater outlet and for collection of coal samples and analysis.

In addition to above , the accuracy of the analysis depends primarily on the accurate measurements of the following:

a) Oxygen content of flue gas at Eco outlet, AH inlet and AH outlet.
b) Flue gas temperature at Economiser outlet.
c) Temperature of air at airheater inlet and outlet, both Primary and Secondary and gas temperature at AH outlet.

Grid measurements totaling to 186 Nos. each for gas temperature and oxygen determination were therefore taken. Coal samples were collected for each test. The analysis of these samples have been used for estimation of operating efficiencies and the air and gas weights. A total of 35 performance tests have been conducted for duration of 59 days at various sites. This consists of 22 tests in Singrauli Unit-7, 8 tests in Korba Unit-6 and 5 tests in Chandrapur-5. Prior to conduct of thermal performance test, windbox damper adjustments for optimised firing, operation of the tilt, mill PF fineness adjustments, operation of wall blowers and long retracts before testing, no oil guns to be in service etc. were ensured. Typical measured values with predicted values at 90% MCR (500 MW load) for Singrauli-7 is given in Table - IV.

TABLE IV : TEST DATA

Test No.		Predicted	Test 1E	Test 3B	Test 1A	Test 2A
Date			19/7/88	8/8/88	17/8/88	21/8/88
Load	%	90	91	93	91	93
SH/RHO Temp.	°C	540/540	540/540	541/527	533/530	537/530
SH spray	%	1.3	7.8	1.6	9.8	10.9
RH spray	%	0	1.4	0	1.2	2.0
Excess air	%	20	22	22	20	20.7
Tilt	Deg	+ 18	+ / -0	-30	-8	-28
Mills in service		2 - 7	1 - 7 (3 out)	1 - 6	2 - 7	3 - 8
Tg lvg. Eco.	° C	369	348	343	351	352
Tg lvg. APH P/S	° C	135/136	146/130	141/129	146/126	146/127
Tg lvg.APH combi	°C	135	137	134	135	135

TEST DATA ANALYSIS

Based on the test data, the steam generator performance was back calculated, using gas temperature leaving Economiser and matching the measured heat pick ups in various sections ahead of economiser , furnace outlet temperature (FOT) was arrived at. This actual FOTwas compared with that of FOT used in design stage as predicted from performance standards. Corrections to furnace outlet temperature depending on mills in service and surface effectiveness factors for SH, RH, Economiser have been calculated for each power station. It was established by test data that for Indian coals, heating surfaces tend to over absorb and hence the surface effectiveness factors shall be more than 1.0. In addition to surface effectiveness factors, it was possible to establish a correlation between corrections to furnace outlet temperatures with fuel elevation in operation as shown in Fig.5. Using this, a computer model was developed to make the prediction close to actual operating values. Table - V gives typical prediction by Computer model Vs. Test data. Based on this, to address the problem of LTSH overheating, high SH/RH pick up, flexibility of mill operation, burner tilt etc, it was basically decided to remove a portion of LTSH and a portion of side wall reheater. The specific action plan for each unit is given in Table-VI. For Ramagundam 500 MW unit, modification in SH/RH sections were decided based on Singrauli 500 MW unit test analysis without doing performance tests after detailed discussions between BHEL, ABB-CE and NTPC.

Fig. 6 & 7 gives typically the existing surface in the design stage and surface removal proposed.

TABLE V : TEST vs MODEL

Load % MCR		93 %		91 %		61 %	
		Test 2A	Model	Test 1A	Model	Test 5A	Model
SHO TEMP.	°C	537	537*	533	533*	538	538*
PANELOUTLET	°C	466	462	467	461	463	465
PANEL INLET	°C	382	384	385	384	382	387
LTSH OUTLET	°C	431	431	429	425	415	408
SH SPRAY	%	10.9	10.5	9.8	9.4	7.4	4.8
RHO TEMP.	°C	530	530*	530	530*	529	520*
RAD Wall OUT	°C	376	365	384	369	368	381
RH INLET L/R	°C	344/327	344/319	339/329	339/323	323/313	323/323
RH SPRAY	%	2	2.9	1.2	1.9	1.2	0
FOT Ent. platen	°C	1120	1147	1108	1130	1030	995
TG LVG. ECO.	° C	352	351	351	347	307	304

* Given

TABLE VI : PROPOSED MODIFICATIONS OF VARIOUS 500 MW UNITS

Singrauli	Korba	Ramagundam	Chandrapur
Removal of 33% LTSH Horizontal surf.	Removal of 44% LTSH Horizontal surf.	Removal of 43% LTSH Horizontal surf.	Removal of 60% LTSH pendant surface area. Removal of 34% LTSH Horizontal.
Removal of 100 side wall RH tubes	Removal of 100 side wall RH tubes. Removal of 4% RH rear pendant. Addition of 14% Eco.		Removal of 40 sidewall RH tubes. Addition of 10% Eco-nomiser.

POST MODIFIED TESTS & ANALYSIS

After the modifications, detailed performance tests were conducted in Singrauli -7, Korba-6, Ramagundam-6 and Chandrapur-5. A total of 23 tests were conducted in different units. It was found that surface modifications have yielded the desired results of reduced spray levels in both SH, RH & reduced metal temperature levels at LTSH outlet, increased flexibility of mill operation as can be seen from Table-VII.

Design Changes

From the above operating experience, some specific design features have been evolved for our future units as given below.

- Surface effectiveness factors have been updated.
- Depending on coal elevation in service corrections to FOT have been arrived at.
- Furnace shall be sized with reduced plan area loading by 10%.
- Only RH pendant section is to be provided and elimination of Radiant wall reheater is preferred if possible.

We are of the firm opinion that the present units being designed with the above features will perform close to prediction.

TABLE VII : UNIT PERFORMANCE BEFORE & AFTER MODIFICATION

PREDICTED VS. TEST (TYPICAL)

Description	Units	Before Modification		After Modification		
				Prdicted With Composite Model		
		Predicted	Test-1A 17.8.88	Design	Adj. To Test-A	Test-A 3.10.91
Load	MW	500	498	500	483	483
Load	%	90	91	90	88	88
Steam flow	t/h	1530	1570	1530	1514	1514
SHO Temperature	° C	540	533	540	537	537
SH DESH in temperature	° C	405	429	403	407	419
SH DESH out temperature	° C	400	385	388	384	392
SH Spray	%	1.3	9.8	3.9	5.8	5.9
RHO temperature	° C	540	530	540	543	543
RH DESH in temperature	° C	342	339	342	347	347
RH DESHout temperature	° C	342	329	342	345	339
RH Spray	%	0.0	1.2	0	0.2	0.8
Gas temp. lvg.Eco.	° C	369	351	361	358	363
Excess air	%	20	20	20	19	19
Tilt	Deg.	+18	-8	-15	-19	-19
Mills		Mid 6	Mid 6	Mid 6	Mid 6	Mid 6

CONCLUSION

It is evident that properties of coal have a pronounced influence on steam generator design. Eventhough, in the design stage, 500 MW steam generators considering high ash and moisture, have been sized with conservative heat loadings, sufficient height between top coal nozzle to arch, extra thickness for tubes, spare milling capacity etc., certain operational difficulties have been encountered as elaborated in this paper. Through field operating experience supported by extensive research and development facilities, we have established design criteria for future units firing high ash Indian bituminous coals that will permit utility industry to have the steam generating units operating closer to prediction and to achieve their goals of high performance and availability.

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