8.2.2 その他ワークショップとセミナー

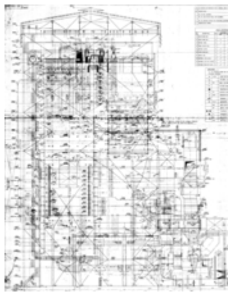
Diagnosis Boiler Problem

Current Boiler Problems for Vindhyachal # 7

- **Vindhyachal Unit 7 Boiler has the problem of lower Main Steam (MS)/High Reheter Steam (HRH) temperature than design value and Left/Right side unbalance in MS/HRH temperature since commissioning.**

Diagnosis Boiler Problem

Vindhyachal # 7 side view



Diagnosis Boiler Problem

The modification history of Boiler up to now is as follows;

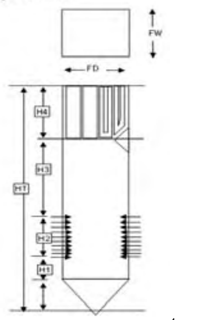
Step I
- **Addition of wall superheater on the front wall (area: 922 m2, consisting of 216 tubes)**
- **Removal of outer tube in each of the 74 reheater (area: 722 m2)**

Step II
- **To reduce the high metal temp of reheater, out of 74 nos, 44 nos. of off-set bend piping (54 mm) in pent house was replaced by 44.5mm piping to avoid the Reheater tube overheating.**
- **75% size orifices were installed at reheater outlet header(LHS) to reduce the Left/right steam temp imbalance.**

Diagnosis Boiler Problem

Table 6.1-9 Boiler Furnace Dimension Comparison Table

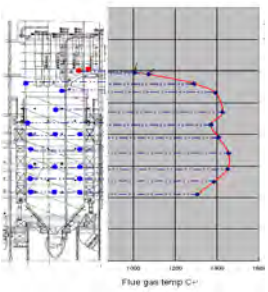
No	Item	Unit	Same type of Boiler in Japan	Vindhyachal Unit 7
1	Rated Output	MW	500	500
2	Boiler High (HT)	m	56	63
3	Bottom of SH Panel to roof (H4)	m	14	16
4	Top Burner level to Bottom of SH Panel (H3)	m	17	18
5	Burner Zone (H2) Burner	m	10 (6 stages)	13 (10 stages)
6	Hopper Bent to bottom of burner (H1)	m	3	5
7	Hopper bend to Bottom of SH Panel (HH (H1-H3))	m	30	36
8	Furnace width (FW)	m	16	19
9	Furnace depth (FD)	m	15	16
10	Furnace Area	m^2	229	303
11	Furnace Volume	m^3	10,700	16,424
12	1st SH Panel (Dev SH)	No.	6	48
13	Panel Pitch (No./FW)	m	2.6	0.40
14	2nd SH Panel (Platen SH)	No.	28	25
15	Panel Pitch(No./FW)	m	0.57	0.76
16	Coal Calorific value	kcal/kg	6600	3700
17	Ash	%	16.6	30



Diagnosis Boiler Problem

Flue Gas temperatures measured with online instruments at Div SH outlet, platen SH outlet etc. However, those are not only one point measurement data.

It is necessary to verification of L & R flue gas temperatures unbalance in across the cross-section considering data with regard to steam temperature, SH/RH metal temperature, mill combination and angle of burner tilt.



Diagnosis Boiler Problem

Cross connection of the left and right side of superheater header connecting pipes

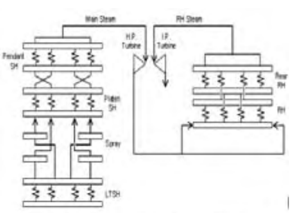


Fig. 6.1-2 Outline of Steam Flow Diagram (Same type of Boiler in Japan)

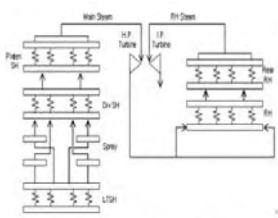


Fig. 6.1-3 Out line of Steam Flow Diagram (Vindhyachal Unit 7)

Diagnosis Boiler Problem

Recommendation

- **Increase in the superheater heat transfer area**

  In order to reduce furnace heat absorption and to increase heat absorption in superheter section, to add wall SH left and right sides of furnace.

- **Cross connection of the left and right side of superheater header connecting pipes**

  Those modification are required to review and re-design of total heat balance of boiler by the original boiler supplier.

Japan International Cooperation Agency

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Combustion Simulation

1. About Combustion Simulation

2. Preparation of Condition

3. Preliminary/Base Case Study
   ＊Cross Connection between Dev SH & Platen SH

4. Simulation Study
   ＊Steam Temperature difference
      Increased O_2% and Gas Recirculation
      Additional air port and OFA
      Division SH modification
   ＊SH and RH steam temperature
      Division SH modification

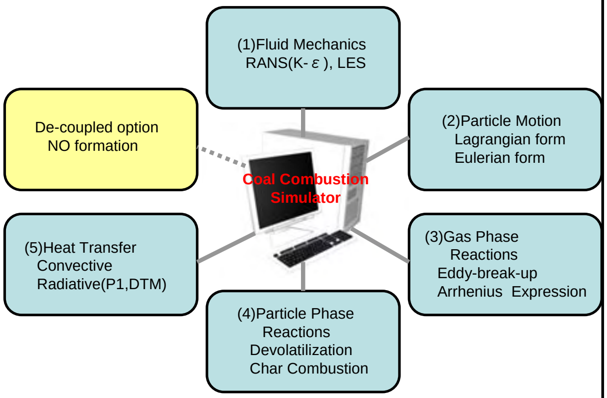


Figure 2.1 Sub models incorporated into Coal Combustion Simulator

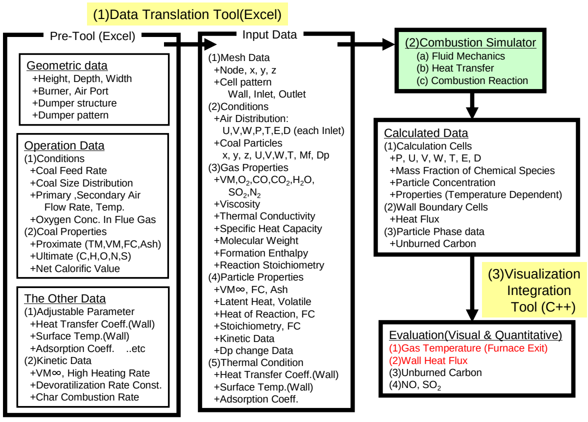


Figure 2. 2 Summary of the Input/Output Data in the combustion simulation

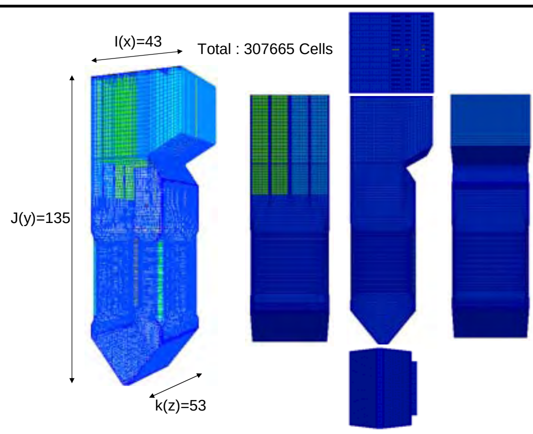
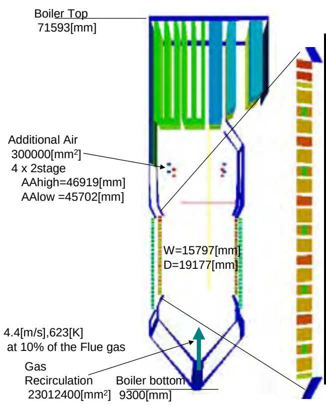


Figure 3.2 Unit 7&8 Mesh used for the base simulations

Table 3.1 Comparison of the Heating Areas etc.
between Vindyachal Unit7&8 and Simulation model

	Unit	Unit 7&8 ＊3) Effective Value	Simulation Model Total Value	note
Furnace Volume	[m^3]	16424	17813	＊1)
Surface Area				
Economiser	[m^2]	13105	Out of Domain	
Furnace (Water wall)	[m^2]	4837	4140	＊2)
Wall Super Heter	[m^2]	No Information	411	
LTSH(Stage #1)	[m^2]	6864	Out of Domain	
Divisional Panel(Stage #2)	[m^2]	1319	1644	
Platen(Stage #3)	[m^2]	1385	1428	
Reheaters	[m^2]	6018	1833	
Assembly				
Economiser	[-]	138	Out of Domain	
Wall Super Heter	[-]	4	4	
LTSH(Stage #1)	[-]	124	Out of Domain	
Divisional Panel(Stage #2)	[-]	48	24	
Platen(Stage #3)	[-]	25	14	
Reheaters	[-]	74	28	

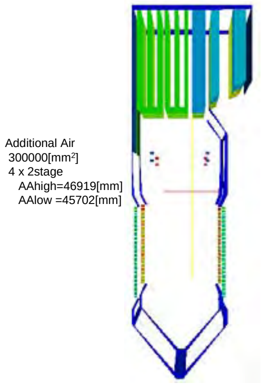
＊1) This value is the total volume of the simulation model.
The volume except Reheater zone is 16141[m3].
＊2) This value does not include the area of Wall Super Heater.
＊3) 15Boiler_Technical_details.pdf

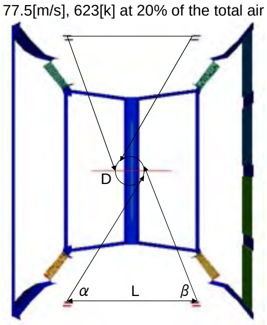


＊These values were obtained by measuring of the drawings

Port Name	Total Area [mm^2]	1st Area [mm^2]	2nd Area [mm^2]	Wind Box [mm^2]
OFA	320800	----	320800	579500
OFA	320800	----	320800	579500
TOP-EA	190400	----	190400	207400
COALK	512000	347593	164407	738100
OIL+AIR	243136	----	243136	555100
COALJ	512000	347593	164407	738100
INT-AIR	371200	----	371200	555100
COALH	512000	347593	164407	841800
OIL+AIR	243136	----	243136	591700
COALG	512000	347593	164407	841800
INT-AIR	371200	----	371200	591700
COALF	512000	347593	164407	841800
OIL+AIR	243136	----	243136	591700
COALE	512000	347593	164407	841800
INT-AIR	371200	----	371200	591700
COALD	512000	347593	164407	841800
OIL+AIR	243136	----	243136	591700
COALC	512000	347593	164407	841800
INT-AIR	371200	----	371200	591700
COALB	512000	347593	164407	841800
OIL+AIR	243136	----	243136	591700
COALA	512000	347593	164407	841800
BTM-EA	190400	----	190400	207400

Figure 3.1 Unit 7&8 structure used for the base simulations





D[mm]	1600
L[mm]	12197
α[deg]	53.5
β[deg]	61.6

Figure 3.3 Configuration of the Additional Air(AA) Ports

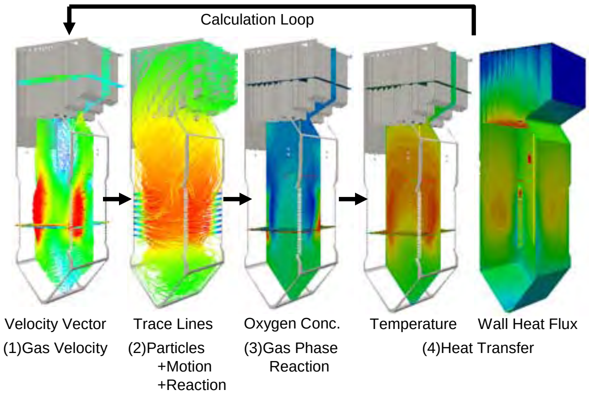


Figure 2. 5 Calculation procedure of the Coal Combustion Simulation

Table 3.2 Base condition for combustion simulation

Load	[MW]	500+α
Heat Input	[Kcal/hr]	1.20E+09
Coal Flow Rate	[ton/hr]	323
Coal Type	[--]	Typical
Proximate Analysis		
Total Moisture	[%]	17.8
Ash	[%]	31.0
Volatile Matter	[%]	22.4
Fixed Carbon	[%]	28.8
Gross calorific value(GCV)	[Kcal/kg]	3700.0
Ultimate Analysis		
C	[daf%]	76.4
H	[daf%]	5.1
N	[daf%]	1.6
O	[daf%]	16.6
S	[daf%]	0.3
Pulverized Coal Size -200#	[%]	83.5
Oxygen conc. in flue gas	[dry%]	3.0
Air Ratio	[--]	1.16
Stoichiometric Air	[kg/kgcoal]	5.03
Average Air/Coal for all mills	[ton/ton]	1.3
Total Air Flow Rate	[ton/hr]	1888.7
1st Air Flow Rate	[ton/hr]	420.0
1st Air Temperature	[degC]	75.0
2nd Air Flow Rate	[ton/hr]	1468.7
2nd Air Temperature	[degC]	350.0
Coal Flow Distribution	[--]	Uniform
2nd Air Flow Distribution	[--]	by dumper List
Mill Pattern (Top)	No service	AB
Mill Pattern (Middle)	No service	EF
Mill Pattern (Bottom)	No service	JK
Burner Tilt Angle	[deg]	-30,-10,0,+30
Additional Air(AA)	[%]	0.0
AA Temperature	[degC]	350.0
Gas Recirculation(GR)	[%]	0.0
GR Temperature	[degC]	350.0

Summary of the Simulation Cases

Burner pattern: Bottom、Middle、Top

Bottom	No Service Mill: JK
Middle	No Service Mill: EF
Top	No Service Mill: AB
Bottom2	No Service Mill: GH
Top2	No Service Mill: CD

Tilt angle: -30,-10,0,+30

Table 3.4 Case number of all simulations (102 cases)

Sheet 0: Base Cases 0

Original Boiler		Heater 0	Furnace Heat Transfer:Ash Free		
Heat Input	1.20E+09	[Kcal/hr]	1.39E+09 [W]		
O2=	3	[%]	OFA=	0	[%damper]
GR=	0	[%]	AA=	0	[%]
Pattern	Tilt	-30	-10	0	30
Bottom		011	012	013	014
Middle		021	022	023	024
Top		031	032	033	034

Sheet 1: Base Cases 1

1)Original Boiler		Heater 0	Furnace Heat Transfer:Realistic		
Heat Input	1.20E+09	[Kcal/hr]	1.39E+09 [W]		
O2=	3	[%]	OFA=	0	[%damper]
GR=	0	[%]	AA=	0	[%]
Pattern	Tilt	-30	-10	0	30
Bottom		111	112	113	114
Middle		121	122	123	124
Top		131	132	133	134

Sheet 2: Operation Study: Oxygen Concentration

2)Original Boiler		Heater 0	Furnace Heat Transfer:Realistic		
Heat Input	1.20E+09	[Kcal/hr]	1.39E+09 [W]		
O2=	5	[%]	OFA=	0	[%damper]
GR=	0	[%]	AA=	0	[%]
Pattern	Tilt	-30	-10	0	30
Bottom		211	212	213	214
Middle		221	222	223	224
Top		231	232	233	234

Sheet 3-1: Operation Study: Gas Recirculation 10%

3-1)Original Boiler		Heater 0	Furnace Heat Transfer:Realistic		
Heat Input	1.20E+09	[Kcal/hr]	1.39E+09 [W]		
O2=	0	[%]	OFA=	0	[%damper]
GR=	10	[%]	AA=	0	[%]
Pattern	Tilt	-30	-10	0	30
Bottom		311-1	312-1	313-1	314-1
Middle		321-1	322-1	323-1	324-1
Top		331-1	332-1	333-1	334-1

Sheet 3-2: Operation Study: Gas Recirculation 20%

3-2)Original Boiler		Heater 0	Furnace Heat Transfer:Realistic		
Heat Input	1.20E+09	[Kcal/hr]	1.39E+09 [W]		
O2=	0	[%]	OFA=	0	[%damper]
GR=	20	[%]	AA=	0	[%]
Pattern	Tilt	-30	-10	0	30
Bottom		311-2	312-2	313-2	314-2
Middle		321-2	322-2	323-2	324-2
Top		331-2	332-2	333-2	334-2

Sheet 4: Operation Study: Additional Air 20%

4)Original Boiler		Heater 0	Furnace Heat Transfer:Realistic		
Heat Input	1.20E+09	[Kcal/hr]	1.39E+09 [W]		
O2=	0	[%]	OFA=	0	[%damper]
GR=	0	[%]	AA=	20	[%]
Pattern	Tilt	-30	-10	0	30
Bottom		411	412	413	414
Middle		421	422	423	424
Top		431	432	433	434

Sheet 5: Operation Study: OFA Dumper Opening 5%

5)Original Boiler		Heater 0	Furnace Heat Transfer:Realistic		
Heat Input	1.20E+09	[Kcal/hr]	1.39E+09 [W]		
O2=	5	[%]	OFA=	50	[%damper]
GR=	0	[%]	AA=	0	[%]
Pattern	Tilt	-30	-10	0	30
Bottom		511	512	513	514
Middle		521	522	523	524
Top		531	532	533	534

Sheet 6: Division Panel Configuration, Heater 1

6)Modified Boiler		Heater 1	Furnace Heat Transfer:Realistic		
Heat Input	1.20E+09	[Kcal/hr]	1.39E+09 [W]		
O2=	5	[%]	OFA=	0	[%damper]
GR=	0	[%]	AA=	0	[%]
Pattern	Tilt	-30	-10	0	30
Bottom		611	612	613	614
Middle		621	622	623	624
Top		631	632	633	634

Sheet 7: Division Panel Configuration, Heater 2

7)Modified Boiler		Heater 2	Furnace Heat Transfer:Realistic		
Heat Input	1.20E+09	[Kcal/hr]	1.39E+09 [W]		
O2=	5	[%]	OFA=	0	[%damper]
GR=	0	[%]	AA=	0	[%]
Pattern	Tilt	-30	-10	0	30
Bottom			712		
Middle			722		
Top			732		

Sheet 8: Division Panel Configuration, Heater 3

8)Modified Boiler		Heater 3	Furnace Heat Transfer:Realistic		
Heat Input	1.20E+09	[Kcal/hr]	1.39E+09 [W]		
O2=	5	[%]	OFA=	0	[%damper]
GR=	0	[%]	AA=	0	[%]
Pattern	Tilt	-30	-10	0	30
Bottom			812		
Middle			822		
Top			832		

Table 3.5 Case number of additional simulations (16 cases)

Sheet No.	Title	Contents
9	Base Case1d	・Base Cases to have considered the effect of the ash layer ・External Heat Transfer BC for furnace wall h=200[W/m2/K], Text=623[K] ・External Heat Transfer BC for Super Heaters h=500[W/m2/K], Text=750[K] ・This condition is employed with all the following cases
10	Heater Configuration	・Studies to improve the steam temperature difference (3) ・Division panel configuration is changed into Heater 1

+Add cases Bottom2 & Top2 to confirm the effect of the Heater1

Sheet 9: Base Cases 1

1)Original Boiler		Heater 0	Furnace Heat Transfer:Realistic		
Heat Input	1.20E+09	[Kcal/hr]	1.39E+09 [W]		
O2=	3	[%]	OFA=	0	[%damper]
GR=	0	[%]	AA=	0	[%]
Pattern	Tilt	-30	-10	0	30
Bottom2		141	142	143	144
Top2		151	152	153	154

Sheet 10: Division Panel Configuration, Heater 1

6)Modified Boiler		Heater 1	Furnace Heat Transfer:Realistic		
Heat Input	1.20E+09	[Kcal/hr]	1.39E+09 [W]		
O2=	5	[%]	OFA=	0	[%damper]
GR=	0	[%]	AA=	0	[%]
Pattern	Tilt	-30	-10	0	30
Bottom2		641	642	643	644
Top2		651	652	653	654

1. Preliminary/Base Case Study

2. Simulation Study

Heat Input = 1.2E9[kcal/h]
Coal Flow = 323[ton/h]
Middle, Tilt = -10 deg
Super Heater :500[W/m²/K], 750[K]

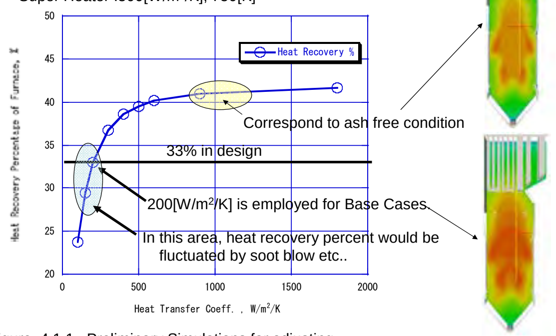


Figure 4.1.1 Preliminary Simulations for adjusting the heat recovery percentage of the furnace

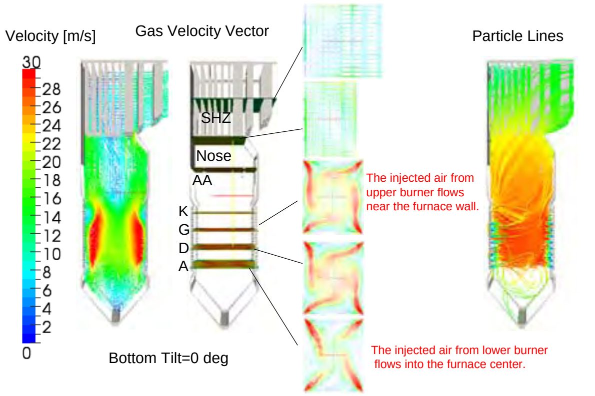


Figure 4.1.2 Typical Flow Pattern in tangential fired boiler(1)

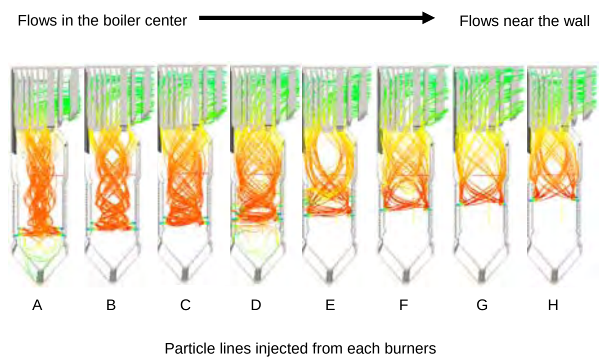


Figure 4.1.3 Typical Flow Pattern in tangential fired boiler(2)

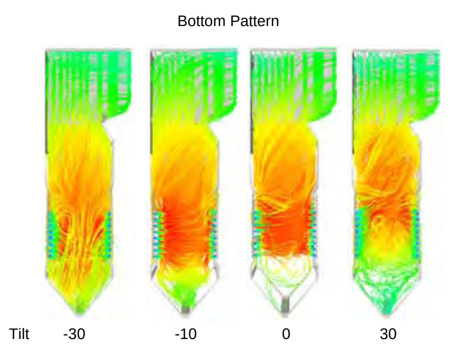


Figure 4.1.4 Typical Flow Pattern in tangential fired boiler(3)

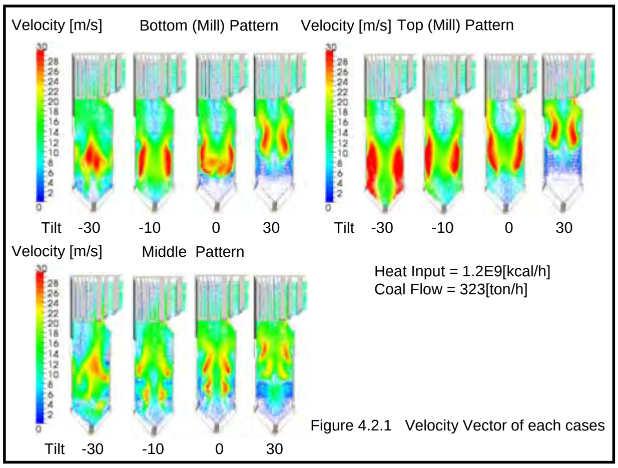


Figure 4.2.1 Velocity Vector of each cases

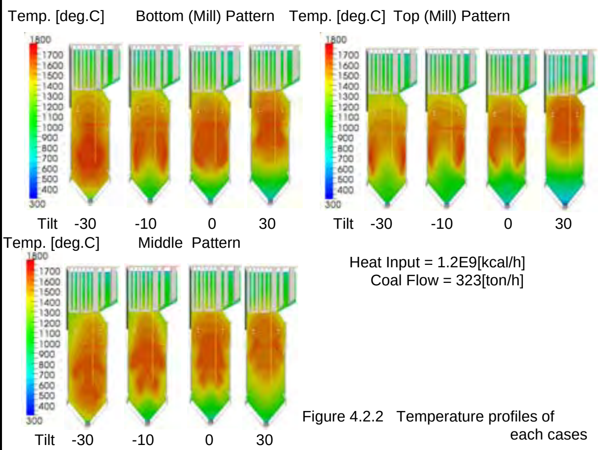


Figure 4.2.2 Temperature profiles of each cases

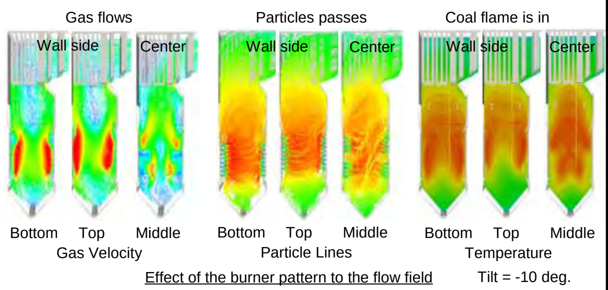


Figure 4.2.3 Typical Flow Pattern in tangential fired boiler(4)

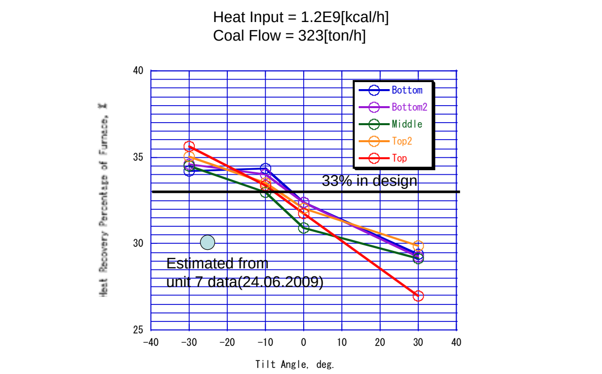


Figure 4.2.4 Predicted Heat Recovery Percentage of the Furnace

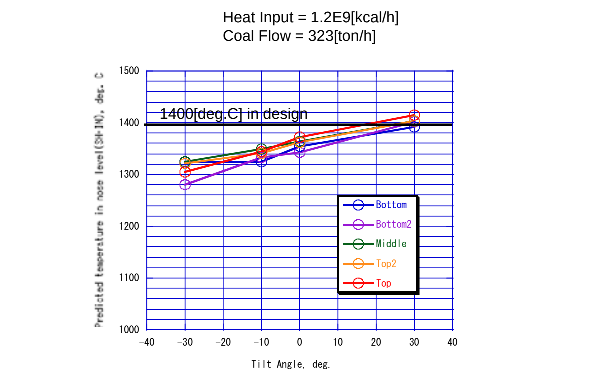


Figure 4.2.5 Predicted Temperature in nose level (SH-IN)

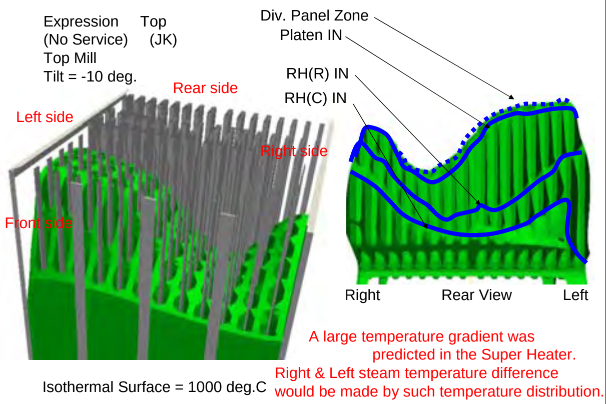


Figure 4.2.7 A cause of the Right & Left steam temperature difference(2)

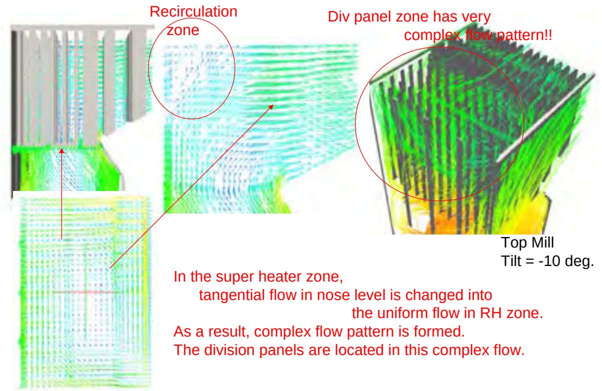
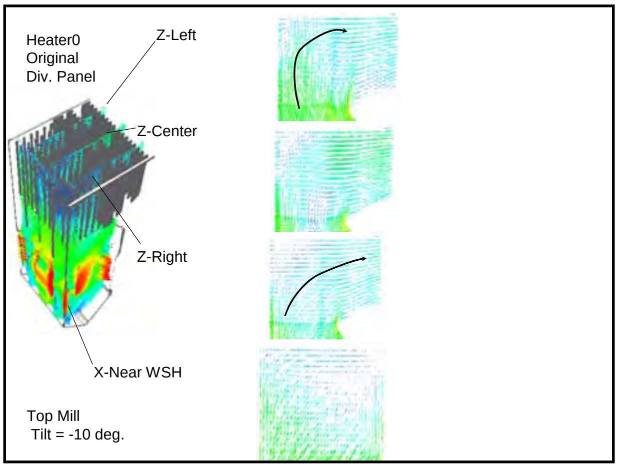


Figure 5.2.6 A cause of the Right & Left steam temperature difference(1)



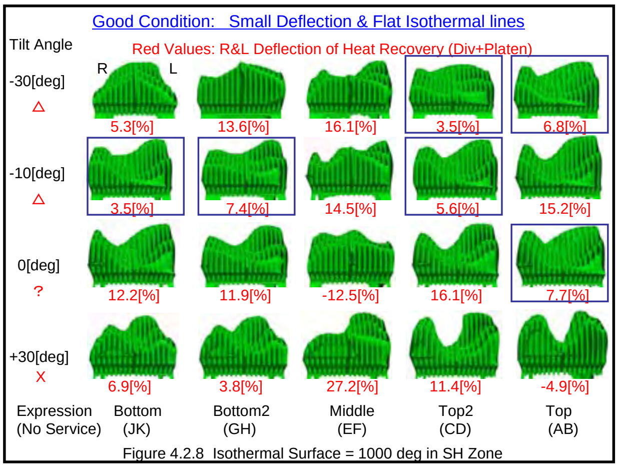


Figure 4.2.8 Isothermal Surface = 1000 deg in SH Zone

Evaluation Item		R&L Deflection of Heat Recovery %			
Pattern	Tilt	Base Div 1st	Base Div 2nd	Base Platen	Base Platen
Bottom (JK)	-30	6.64	6.51	3.48	5.32
	-10	1.81	7.84	1.41	3.48
	0	20.13	15.19	4.21	12.19
	30	11.53	8.39	2.40	6.81
Bottom2 (GH)	-30	6.53	18.15	12.84	13.56
	-10	7.05	8.76	6.56	7.37
	0	17.50	14.83	5.86	11.84
	30	6.47	6.32	0.06	3.79
Middle (EF)	-30	28.08	16.81	8.80	16.10
	-10	25.36	14.57	8.13	14.51
	0	-35.38	-13.59	2.02	-12.53
	30	38.88	32.37	17.33	27.20
Top2 (CD)	-30	-0.44	5.30	5.01	3.45
	-10	14.14	6.69	-1.78	5.57
	0	22.89	19.42	9.08	16.13
	30	16.17	15.25	5.36	11.36
Top (AB)	-30	10.87	8.35	2.45	6.78
	-10	18.67	17.74	10.53	15.16
	0	17.87	7.92	-0.62	7.66
	30	-35.67	1.15	4.01	-4.92
Average ABS(df%)		17.10	12.26	5.60	10.29
Max(ABS(df%))		38.88	32.37	17.33	27.20
MIN(ABS(df%))		0.44	1.15	0.06	3.45

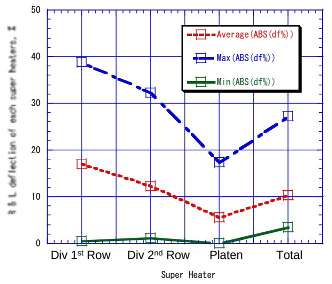


Figure 4.2.9 R & L deflection of each super heaters

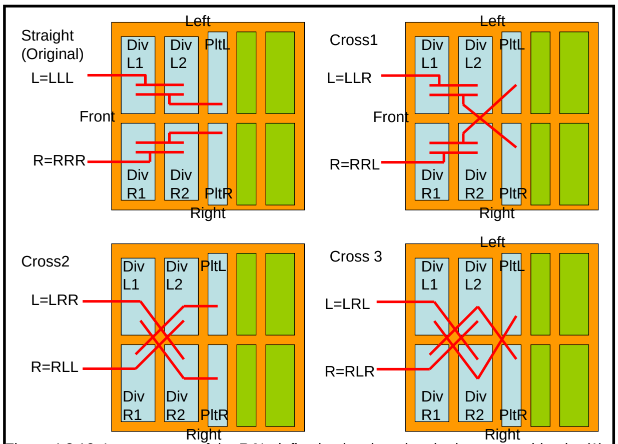


Figure 4.2.10 Improvement of the R&L deflection by changing the heater combination(1)

Evaluation Item		R&L Deflection of Heat Recovery (Division Panel + Platen)			
Pattern	Tilt	Base Straight	Base Cross1	Base Cross2	Base Cross3
Bottom (JK)	-30	5.32	2.50	-1.40	1.42
	-10	3.48	2.33	-2.43	-1.28
	0	12.19	8.78	-0.42	2.99
	30	6.81	4.83	-0.29	1.68
Bottom2 (GH)	-30	13.56	-0.73	-11.73	2.56
	-10	7.37	1.85	-3.56	1.96
	0	11.84	6.96	-2.18	2.70
	30	3.79	3.74	-0.10	-0.05
Middle (EF)	-30	16.10	8.25	-1.81	6.05
	-10	14.51	7.41	-1.55	5.56
	0	-12.53	-14.29	-6.10	-4.34
	30	27.20	11.73	-8.65	6.83
Top2 (CD)	-30	3.45	-0.53	-3.72	0.27
	-10	5.57	6.98	2.95	1.53
	0	16.13	8.64	-3.26	4.23
	30	11.36	6.87	-2.42	2.07
Top (AB)	-30	6.78	4.83	-0.14	1.81
	-10	15.16	6.81	-3.95	4.40
	0	7.66	8.14	3.45	2.96
	30	-4.92	-8.79	-9.52	-5.65
Average ABS(df%)		10.29	6.25	3.48	3.02
Max(ABS(df%))		27.20	14.29	11.73	6.83
MIN(ABS(df%))		3.45	0.53	0.10	0.05

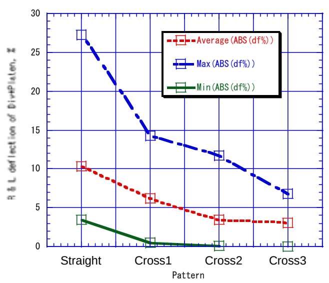


Figure 4.2.11 Improvement of the R&L deflection by changing the heater combination(2)

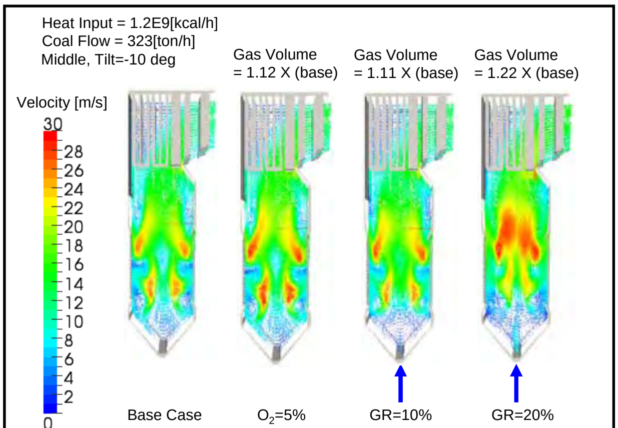


Figure 4.3.1 Velocity Vector of each cases

Heat Input = 1.2E9[kcal/h]
Coal Flow = 323[ton/h]
Middle, Tilt=-10 deg

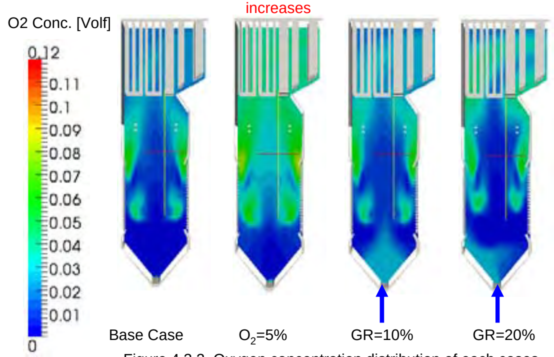


Figure 4.3.2 Oxygen concentration distribution of each cases

Heat Input = 1.2E9[kcal/h]
Coal Flow = 323[ton/h]
Middle, Tilt=-10 deg

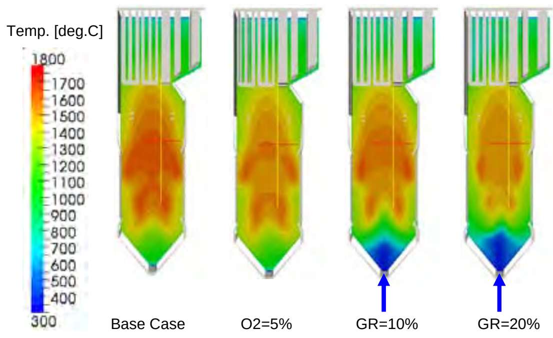


Figure 4.3.3 Temperature distribution of each cases

Heat Input = 1.2E9[kcal/h]
Coal Flow = 323[ton/h]
Middle, Tilt=-10 deg

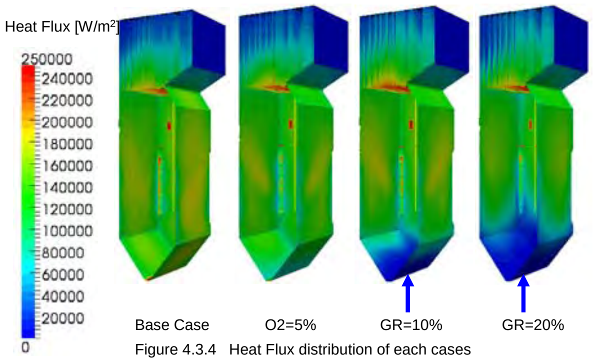


Figure 4.3.4 Heat Flux distribution of each cases

Table 4.3.1 Comparison of the Furnace Heat Recovery Percent

Evaluation Item		Heat Recovery % of Furnace(HRf) %				ΔHRf = HRf − HRf(Base) %		
Pattern	Tilt	Base	O2=5%	GR=10%	GR=20%	O2=5%	GR=10%	GR=20%
Bottom (JK)	−30	34.19	32.14	29.86	26.30	−2.05	−4.33	−7.88
	−10	34.36	32.43	28.15	23.39	−1.93	−6.21	−10.97
	0	32.40	30.34	27.77	23.58	−2.06	−4.63	−8.82
	30	29.35	27.36	25.12	21.90	−1.99	−4.24	−7.45
Middle (EF)	−30	34.48	32.38	30.49	26.61	−2.10	−4.00	−7.87
	−10	32.96	31.05	28.99	23.81	−1.91	−3.97	−9.15
	0	30.90	29.20	27.32	23.27	−1.70	−3.58	−7.62
	30	29.14	27.38	24.50	21.27	−1.77	−4.64	−7.87
Top (AB)	−30	35.62	33.32	32.40	28.00	−2.30	−3.22	−7.62
	−10	33.35	31.08	27.12	23.25	−2.27	−6.22	−10.10
	0	31.76	29.76	26.04	21.66	−2.00	−5.72	−10.10
	30	26.95	25.31	22.01	19.18	−1.64	−4.95	−7.77
Average Value		32.12	30.15	27.48	23.52	−1.98	−4.64	−8.60

O_2=5%:
2% of HRf is decreased.
GR=10%:
5% of HRf is decreased
GR=20%:
8.5% of HRf is decreased

Table 4.3.2 Comparison of the Furnace exit gas temperature (nose level)

Evaluation Item		Furnace Exit Gas Temperature deg C				ΔT = T − T(Base) deg C		
Pattern	Tilt	Base	O2=5%	GR=10%	GR=20%	O2=5%	GR=10%	GR=20%
Bottom (JK)	−30	1324.90	1268.30	1320.20	1299.00	−56.60	−4.70	−25.90
	−10	1325.10	1287.80	1345.50	1312.80	−37.30	20.40	−12.30
	0	1353.50	1310.80	1351.90	1319.20	−42.70	−1.60	−34.30
	30	1392.50	1358.30	1375.10	1339.00	−34.20	−17.40	−53.50
Middle (EF)	−30	1323.90	1289.70	1318.50	1294.70	−34.20	−5.40	−29.20
	−10	1348.70	1309.80	1340.70	1320.00	−38.90	−8.00	−28.70
	0	1363.90	1326.20	1358.60	1329.60	−37.70	−5.30	−34.30
	30	1402.90	1360.30	1382.90	1349.50	−42.60	−20.00	−53.40
Top (AB)	−30	1305.10	1271.40	1281.00	1293.60	−33.70	−24.10	−11.50
	−10	1344.70	1309.80	1348.20	1339.20	−34.90	3.50	−5.50
	0	1372.40	1330.60	1376.50	1350.40	−41.80	4.10	−22.00
	30	1414.20	1373.90	1378.30	1355.10	−40.30	−35.90	−59.10
Average Value		1355.98	1316.41	1348.12	1325.18	−39.58	−7.87	−30.81

O_2=5%:
40deg.C is decreased.
GR=10%:
5deg.C is decreased.
GR=20%:
30deg.C is decreased

Table 4.3.3 Comparison of the SH Heat Recovery Percent

Evaluation Item		Heat Recovery % of Super Heater(HRsh) WallSH+DivPanel+Platen %				ΔHRsh = HRsh − HRsh(Base) %		
Pattern	Tilt	Base	O2=5%	GR=10%	GR=20%	O2=5%	GR=10%	GR=20%
Bottom (JK)	−30	23.90	21.66	24.26	23.57	−2.24	0.36	−0.33
	−10	23.58	22.67	23.15	22.22	−0.91	−0.43	−1.36
	0	24.39	23.45	25.06	25.01	−0.94	0.67	0.62
	30	26.48	24.31	24.30	23.86	−2.17	−2.19	−2.62
Middle (EF)	−30	22.40	21.54	22.29	20.59	−0.86	−0.11	−1.82
	−10	23.42	22.47	23.97	21.73	−0.95	0.55	−1.69
	0	24.62	22.81	23.51	23.82	−1.81	−1.11	−0.80
	30	25.32	24.43	24.16	25.13	−0.89	−1.16	−0.19
Top (AB)	−30	23.03	22.33	22.61	23.11	−0.70	−0.43	0.07
	−10	24.43	23.65	24.53	23.23	−0.78	0.09	−1.20
	0	25.67	24.39	26.21	25.31	−1.28	0.54	−0.36
	30	25.56	24.87	26.06	26.33	−0.70	0.49	0.76
Average Value		24.40	23.22	24.18	23.66	−1.19	−0.23	−0.74

O_2=5%:
1% of HRsh is decreased.
GR=10%:
HRsh is almost equal.
GR=20%:
1% of HRsh is decreased

Table 4.3.4 Comparison of the RH IN gas temperature

Evaluation Item		Reheater in Gas Temperature deg C				ΔT = T − T(Base) deg C		
Pattern	Tilt	Base	O2=5%	GR=10%	GR=20%	O2=5%	GR=10%	GR=20%
Bottom (JK)	−30	971.30	964.63	990.16	1002.50	−6.67	18.86	31.20
	−10	975.57	965.51	1023.20	1045.30	−10.06	47.63	69.73
	0	980.93	984.60	1004.80	1003.50	3.67	23.87	22.57
	30	1013.60	1030.20	1058.50	1037.20	16.60	44.90	23.60
Middle (EF)	−30	990.22	987.37	1018.40	1041.40	−2.85	28.18	51.18
	−10	999.49	995.63	1008.60	1050.20	−3.86	9.11	50.71
	0	1016.10	1016.80	1018.70	1018.20	0.70	2.60	2.10
	30	1037.60	1028.50	1069.00	1034.80	−9.10	31.40	−2.80
Top (AB)	−30	955.35	952.30	963.15	992.94	−3.05	7.80	37.59
	−10	978.31	972.52	1004.60	1036.70	−5.79	26.29	58.39
	0	982.61	987.11	1016.00	1056.80	4.50	33.39	74.19
	30	1073.60	1054.30	1077.50	1046.00	−19.30	3.90	−27.60
Average Value		997.89	994.96	1021.05	1030.46	−2.93	23.16	32.57

O_2=5%:
Temp. is almost equal.
GR=10%:
20deg.C is increased.
GR=20%:
40deg.C is increased

Table 4.3.5 The effect of the oxygen conc. & gas recirculation to the heat recovery pattern

	Heat Recovery % (furnace)			Nose Temperature[degC]		
Operation	Base	Effect		Base	Effect	
O_2=5%	32.12	−1.98	↘	1355.98	−39.58	↘
GR=10%	32.12	−4.64	↘	1355.98	−7.87	↘
GR=20%	32.12	−8.60	↘	1355.98	−8.60	↘
	Heat Recovery % (SH)			RH_IN Temperature[degC]		
Operation	Base	Effect		Base	Effect	
O_2=5%	24.40	−1.19	↘	997.89	−2.93	→
GR=10%	24.40	−0.23	→	997.89	23.16	↗
GR=20%	24.40	−0.74	↘	997.89	32.57	↗
	Heat Recovery % (RH)					
Operation	Base	Effect				
O_2=5%	7.91	0.09	↗			
GR=10%	7.91	0.79	↗			
GR=20%	7.91	1.18	↗			

Note1:SH (Wall Heater + Div + Platen) Arrow: Red is good, Blue is bad.
Note2:RH data are reference value.

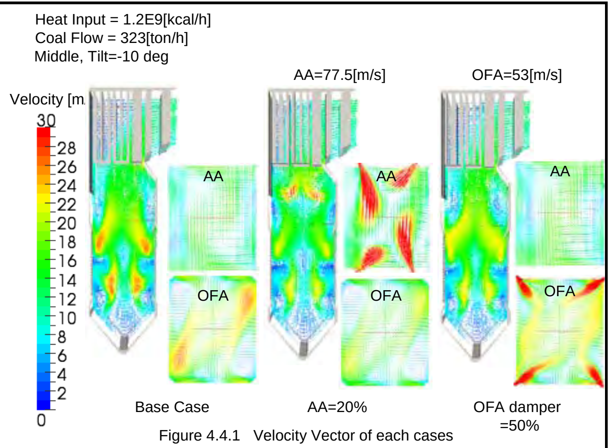


Figure 4.4.1 Velocity Vector of each cases

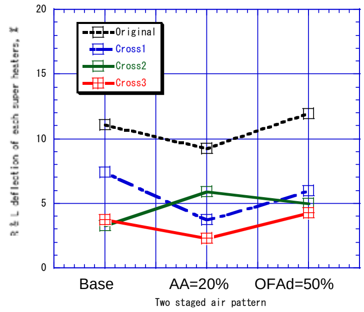
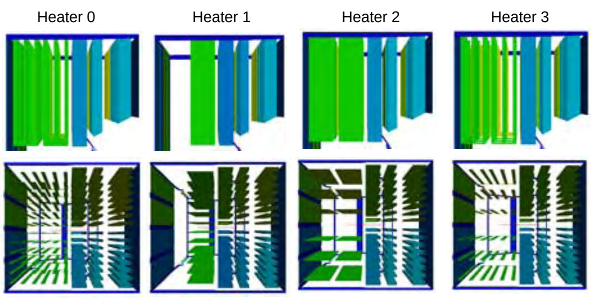


Figure 4.4.2 Average R&L Deflection of the Super Heaters



	Divisional Panel		Platen		Reheaters	
	Area	Assembly	Area	Assembly	Area	Assembly
	[mm^2]	[-]	[mm^2]	[-]	[mm^2]	[-]
Unit 7&8	1319	48	1385	25	6018	74
Heater0	1644	24	1428	14	1833	28
Heater1	1633	12	1428	14	1833	28
Heater2	1634	12	1428	14	1833	28
Heater3	822	12	1428	14	1833	28

Figure 3.4 Configuration changes in the division panels

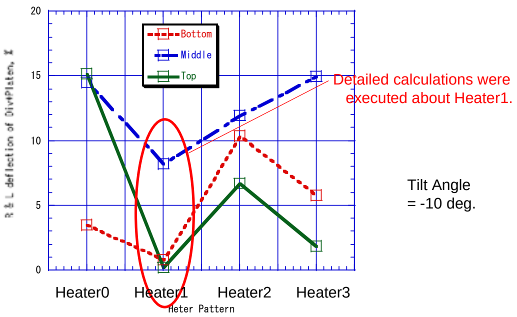


Figure 4.5.1 R & L deflection of heat recovery percent in each heater

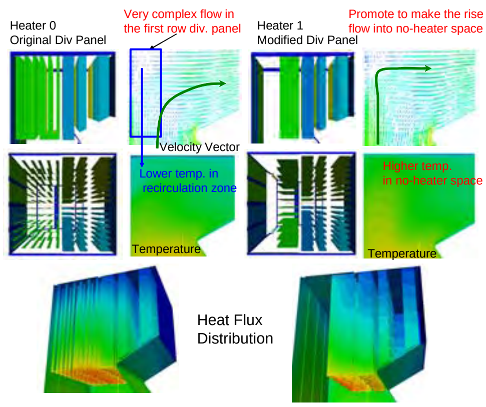


Figure 4.5.2 Concept of the Heater 1

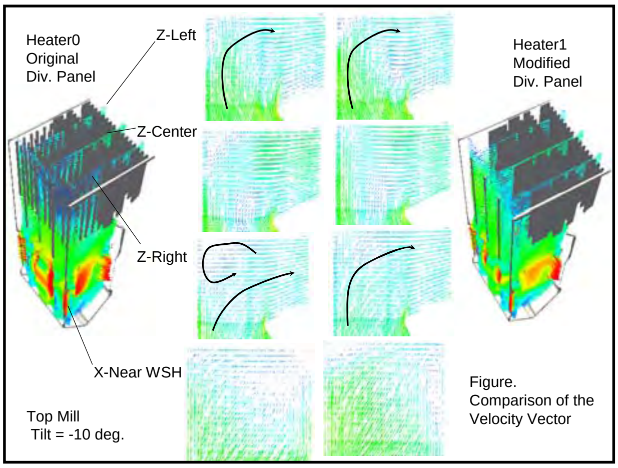


Figure.
Comparison of the
Velocity Vector

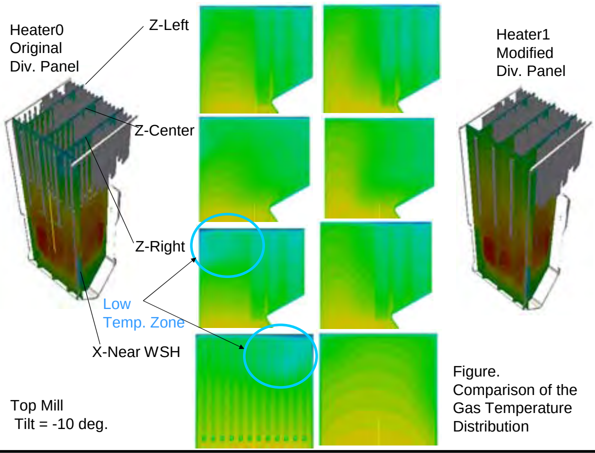


Figure.
Comparison of the
Gas Temperature
Distribution

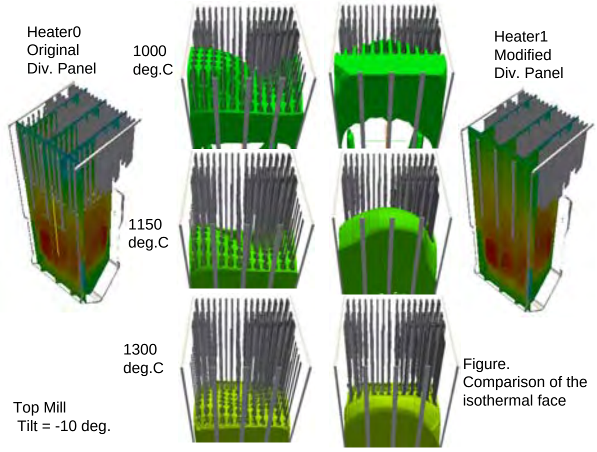


Figure.
Comparison of the
isothermal face

Good Condition: Small Deflection & Flat Isothermal lines

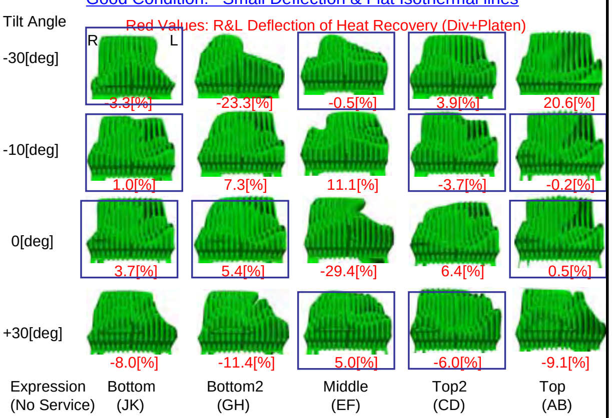


Figure 4.5.3 Isothermal Surface = 1000 deg in SH Zone

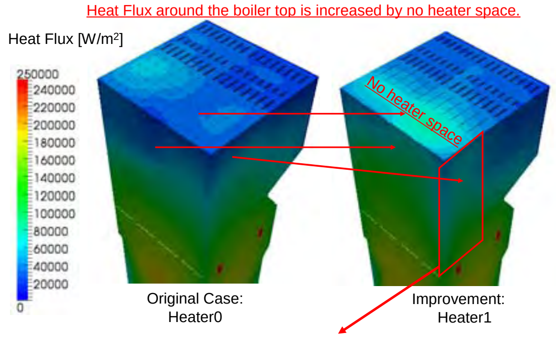
Table 4.5.1 Effect of the Heater1 to the Right & Left Deflection

Evaluation Item		R&L Deflection of Heat Recovery (Division Panel + Platen)			Heat Recovery % (Division Panel + Platen)			Heat Recovery % (Division Panel + Platen +WallSH)			R&L Deflection of Heat Recovery (Wall Super Heater)		
Pattern	Tilt	Base	Heater1	Δ%(*1)	Base	Heater1	Δ%(*1)	Base	Heater1	Δ%(*1)	Base	Heater1	Δ%(*1)
Bottom (JK)	-30	5.32	-2.50	-2.82	21.15	18.78	-2.38	23.90	21.89	-2.01	3.36	-7.92	4.56
	-10	3.48	0.80	-2.68	20.88	20.19	-0.69	23.58	23.43	-0.15	-5.01	-1.55	-3.46
	0	12.19	2.83	-9.36	21.62	21.14	-0.48	24.39	24.62	0.22	7.33	4.52	-2.81
	30	6.81	-5.85	-0.96	23.66	23.16	-0.50	26.48	26.47	-0.01	3.37	-11.64	8.26
Bottom2 (GH)	-30	13.56	-16.19	2.63	16.82	19.22	2.40	18.24	21.83	3.59	-4.34	5.30	0.96
	-10	7.37	5.61	-1.76	20.94	20.30	-0.64	23.47	23.57	0.09	5.71	0.56	-5.15
	0	11.84	4.13	-7.71	21.45	21.08	-0.37	24.04	24.39	0.35	7.88	5.50	-2.39
	30	3.79	-8.28	4.49	24.01	23.18	-0.83	26.90	26.42	-0.48	1.49	-9.51	8.02
Middle (EF)	-30	16.10	-0.37	-15.74	20.03	19.96	-0.08	22.40	22.63	0.22	14.17	-13.82	-0.35
	-10	14.51	8.21	-6.31	20.92	20.75	-0.16	23.42	23.89	0.46	12.29	9.47	-2.82
	0	-12.53	-20.65	8.12	21.96	20.83	-1.13	24.62	23.82	-0.80	-22.67	-34.35	11.68
	30	27.20	3.69	-23.52	22.88	23.44	0.56	25.32	26.72	1.40	12.51	-4.58	-7.94
Top2 (CD)	-30	3.45	2.91	-0.55	20.82	19.82	-0.99	23.64	23.03	-0.61	-13.46	-39.38	25.93
	-10	5.57	-2.85	-2.72	21.56	20.43	-1.13	24.38	23.76	-0.63	1.08	-1.19	0.11
	0	16.13	4.89	-11.24	21.96	21.19	-0.76	24.66	24.60	-0.06	4.46	2.91	-1.54
	30	11.36	-4.58	-6.78	23.40	23.12	-0.29	26.20	26.77	0.57	0.10	-16.22	16.12
Top (AB)	-30	6.78	-1.81	-4.96	20.26	21.61	1.35	23.03	24.43	1.40	3.01	4.95	1.94
	-10	15.16	-0.17	-14.99	21.61	21.18	-0.43	24.43	24.77	0.34	4.95	3.85	-1.10
	0	7.66	0.40	-7.26	22.60	21.58	-1.02	25.67	25.27	-0.40	8.41	2.38	-6.03
	30	-4.92	-6.44	1.52	23.38	24.16	0.78	25.56	27.32	1.76	-35.17	-27.05	-8.12
Average(ABS(Value))		10.29	5.16	-5.13	21.60	21.26	-0.34	24.22	24.48	0.26	8.54	10.33	1.79
Max(ABS(Value))		27.20	20.65	-6.55	24.01	24.16	0.15	26.90	27.32	0.42	35.17	39.38	4.21
Min(ABS(Value))		3.45	0.17	-3.28	16.82	18.78	1.96	18.24	21.83	3.59	0.10	0.56	0.46

Table 4.5.2 Effect of the Heater1 to the Heat Recovery Pattern

Evaluation Item		Heat Recovery % (Furnace)			Heat Recovery % (Wall Heater)			Temperature degC (SH Zone IN, Nose level)			Temperature degC (RH IN)		
Pattern	Tilt	Base	Heater1	Δ%(*1)	Base	Heater1	Δ%(*1)	Base	Heater1	Δ%(*1)	Base	Heater1	Δ%(*1)
Bottom (JK)	-30	34.19	34.82	0.63	2.74	3.11	0.37	1324.90	1299.90	-25.00	971.30	962.01	-9.29
	-10	34.36	35.12	0.76	2.70	3.24	0.54	1325.10	1330.30	5.20	975.57	972.35	-3.22
	0	32.40	32.58	0.18	2.77	3.48	0.70	1353.50	1360.20	6.70	980.93	979.77	-1.16
	30	29.35	29.41	0.05	2.82	3.31	0.49	1392.50	1405.80	13.30	1013.60	1016.50	2.90
Bottom2 (GH)	-30	34.57	35.09	0.52	1.42	2.62	1.19	1279.70	1306.60	26.90	1041.80	983.61	-58.19
	-10	34.00	34.32	0.32	2.54	3.27	0.73	1333.10	1337.10	4.00	988.41	966.02	-22.39
	0	32.39	32.93	0.54	2.59	3.31	0.73	1343.40	1355.80	12.40	990.71	978.66	-12.05
	30	29.25	29.60	0.35	2.89	3.24	0.35	1402.00	1407.00	5.00	1014.30	1019.00	4.70
Middle (EF)	-30	34.48	34.43	-0.06	2.37	2.67	0.30	1323.90	1322.40	-1.50	990.22	989.97	-0.25
	-10	32.96	33.38	0.42	2.51	3.13	0.63	1348.70	1352.80	4.10	999.49	986.19	-13.30
	0	30.90	31.37	0.48	2.66	2.99	0.32	1363.90	1351.30	-12.60	1016.10	1017.70	1.60
	30	29.14	29.52	0.38	2.44	3.27	0.83	1402.90	1410.40	7.50	1037.60	1011.50	-26.10
Top2 (CD)	-30	35.05	35.75	0.70	2.82	3.21	0.38	1321.40	1323.80	2.40	959.70	973.43	13.73
	-10	33.51	33.63	0.13	2.83	3.33	0.50	1341.60	1347.50	5.90	977.23	973.64	-3.59
	0	32.05	32.21	0.16	2.70	3.41	0.70	1363.10	1370.00	6.90	998.23	980.00	-18.23
	30	29.87	30.08	0.21	2.80	3.65	0.85	1403.90	1411.20	7.30	1019.90	1008.50	-11.40
Top (AB)	-30	35.62	33.35	-2.27	2.77	2.82	0.05	1305.10	1344.70	39.60	955.35	978.31	22.96
	-10	33.35	33.53	0.19	2.82	3.59	0.77	1344.70	1360.20	15.50	978.31	980.89	2.58
	0	31.76	31.99	0.24	3.07	3.69	0.63	1372.40	1377.40	5.00	982.61	987.62	5.01
	30	26.95	27.27	0.31	2.18	3.16	0.98	1414.20	1429.80	15.60	1073.60	1039.10	-34.50
Average(ABS(Value))		32.31	32.52	0.21	2.62	3.23	0.60	1353.00	1360.21	7.21	998.25	990.24	-8.01
Max(ABS(Value))		35.62	35.75	0.13	3.07	3.69	0.63	1414.20	1429.80	15.60	1073.60	1039.10	-34.50
Min(ABS(Value))		26.95	27.27	0.31	1.42	2.62	1.19	1279.70	1299.90	20.20	955.35	962.01	6.66

Heat Flux around the boiler top is increased by no heater space.



When the part of the furnace side wall is also replaced to wall SH,
the heat recovery fraction of SH will be able to be increased a little more.

Figure 4.5.4 Effect of the Heater1 to the Right & Left Deflection

Evaluation Item		R&L Deflection of Heat Recovery (Division Panel + Platen)			
Pattern	Tilt	Base Straight	Heater1 Straight	Heater1 Cross	
Bottom (JK)	-30	5.32	2.50	-1.40	
	-10	3.48	2.33	-2.43	
	0	12.19	8.78	-0.42	
	30	6.81	4.83	-0.29	
Bottom2 (GH)	-30	13.56	-0.73	-11.73	
	-10	7.37	1.85	-3.56	
	0	11.84	6.96	-2.18	
	30	3.79	3.74	-0.10	
Middle (EF)	-30	16.10	8.25	-1.81	
	-10	14.51	7.41	-1.55	
	0	-12.53	-14.29	-6.10	
	30	27.20	11.73	-8.65	
Top2 (CD)	-30	3.45	-0.53	-3.72	
	-10	5.57	6.98	2.95	
	0	16.13	8.64	-3.26	
	30	11.36	6.87	-2.42	
Top (AB)	-30	6.78	4.83	-0.14	
	-10	15.16	6.81	-3.95	
	0	7.66	8.14	3.45	
	30	-4.92	-8.79	-9.52	
Average ABS(df%)		10.29	6.25	3.48	
Max(ABS(df%))		27.20	14.29	11.73	
MIN(ABS(df%))		3.45	0.53	0.10	

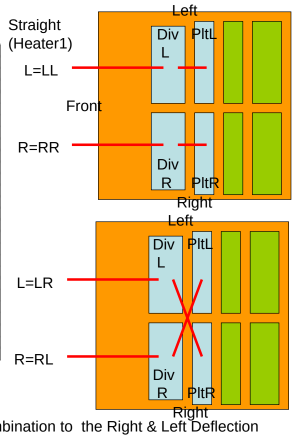


Figure 4.5.5 Effect of the Heater combination to the Right & Left Deflection

Ref. 1 Effect of each operations to the heat recovery percent of the re-heaters

Evaluation Item		Heat Recovery percent (Rad RH + Conv RH))						
Pattern	Tilt	Base [%]	O2=5% [%]	GR=10% [%]	GR=20% [%]	AA=20% [%]	OFAd=50% [%]	Heater1 [%]
Bottom (JK)	-30	7.50	7.54	8.09	8.51	7.50	7.70	7.24
	-10	7.22	7.24	8.66	9.33	7.22	7.42	7.14
	0	7.48	7.58	8.17	8.50	7.48	8.61	7.33
	30	8.37	8.87	9.61	9.40	8.37	8.44	8.39
Bottom2 (GH)	-30	9.00	--	--	--	--	--	7.77
	-10	7.54	--	--	--	--	--	7.06
	0	7.57	--	--	--	--	--	7.34
	30	8.39	--	--	--	--	--	8.42
Middle (EF)	-30	7.92	8.01	8.64	9.33	6.86	8.80	7.78
	-10	7.97	8.05	8.32	9.56	7.29	7.68	7.59
	0	8.39	8.51	8.69	8.73	7.49	8.21	8.48
	30	8.89	8.79	9.83	9.24	9.83	8.76	8.17
Top2 (CD)	-30	7.10	--	--	--	--	--	7.29
	-10	7.33	--	--	--	--	--	7.20
	0	7.78	--	--	--	--	--	7.29
	30	8.35	--	--	--	--	--	7.97
Top (AB)	-30	6.86	6.93	7.24	8.14	7.67	6.65	7.29
	-10	7.29	7.31	8.45	9.15	8.93	7.60	7.25
	0	7.49	7.65	8.42	9.53	8.67	7.90	7.40
	30	9.83	9.52	10.36	9.74	7.92	10.05	9.06
Average		7.91	8.00	8.71	9.10	7.94	8.15	7.67
Max		9.83	9.52	10.36	9.74	9.83	10.05	9.06
MIN		6.86	6.93	7.24	8.14	6.86	6.65	7.06

Note:
The prediction of the convection heaters is not so accurate in this simulation.
These data is submitted as a reference value.

Recommendation

1. L & R deflection

- The Bottom pattern and the Tilt -10 degree operation for L & R deflection

  Carry out trial operation by applying the best parameters written above to the current boiler. For further mitigation of temperature imbalance,

- Modify the boiler by applying the cross-connecting pipes between Division SH and Platen SH.

2. SH and RH steam temperature

- To increase SH and RH steam temperature, remove front Division SH, and add the same heating surface to rear Division SH by modification of rear Division SH.
  In addition, apply wall SH at left and right sides of furnace where Division SH is located.

  Removal of front Division SH is also effective for mitigation of temperature imbalance.

Boiler Combustion Simulation

Simulation of Air and Fuel Bias

●Additional Request to improve the R&L deflection
(1)Right & Left 2nd Air Bias
by changing the wind box draft.
(2)Right & Left Fuel Bias (1st Air)
(3)Right & Left Fuel Bias (1st Air) + 2nd Air Bias

Note: Simulation Conditions same as previous study report.

Simulation of Air and Fuel Bias

Sheet No *1)	Title	Contents
0	Base Case1	- Base Cases to have considered the effect of the ash layer - External Heat Transfer BC for furnace wall h=200[W/m2/K], Text=623[K] - External Heat Transfer BC for Super Heaters h=500[W/m2/K], Text=750[K] - This condition is employed with all the following cases
1	2nd Air Bias	Bias% -20% (Left = -10%, Right = +10%)
2		Bias% -10% (Left = -5%, Right = +5%)
3		Bias% +10% (Left = +5%, Right = -5%)
4		Bias% +20% (Left = +10%, Right = -10%)
5	1st Air Fuel Bias	Bias% -20% (Left = -10%, Right = +10%)
6		Bias% -10% (Left = -5%, Right = +5%)
7		Bias% +10% (Left = +5%, Right = -5%)
8		Bias% +20% (Left = +10%, Right = -10%)
9	1st/2nd Air Fuel Bias	Bias% -20% (Left = -10%, Right = +10%)
A		Bias% -10% (Left = -5%, Right = +5%)
B		Bias% +10% (Left = +5%, Right = -5%)
C		Bias% +20% (Left = +10%, Right = -10%)

*1) Simulation Condition are discribein each sheet in next table

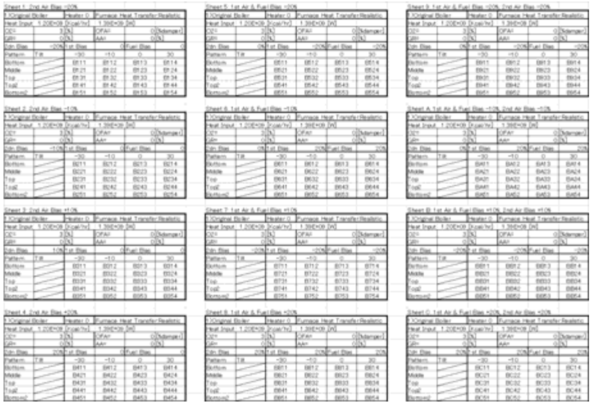
Boiler Combustion Simulation

Case number of all simulations (20 base cases)

Sheet 0: Base Cases 1							
1)Original Boiler		Heater 0		Furnace Heat Transfer:Realistic			
Heat Input	1.20E+09	[Kcal/hr]	1.39E+09	[W]			
O2=	3	[%]	OFA=	0	[%damper]		
GR=	0	[%]	AA=	0	[%]		
2dn Bias	0	1st Bias	0	Fuel Bias	0		
Pattern	Tilt	-30	-10	0	30		
Bottom		111	112	113	114		
Middle		121	122	123	124		
Top		131	132	133	134		
Top2		141	142	143	144		
Bottom2		151	152	153	154		

Bottom	No Service Mill: JK
Bottom2	No Service Mill: GH
Middle	No Service Mill: EF
Top2	No Service Mill: CD
Top	No Service Mill: AB

Case number of all simulations (240 Bias cases)



Boiler Combustion Simulation

Cases are considered SH cross connection patterns

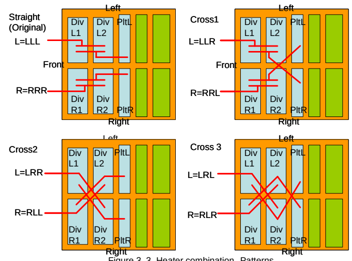
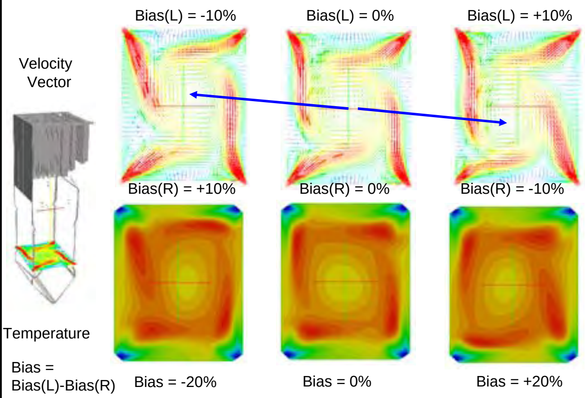


Figure 3. 3 Heater combination Patterns

Improve the R&L deflection

(1)Right & Left 2nd Air Bias

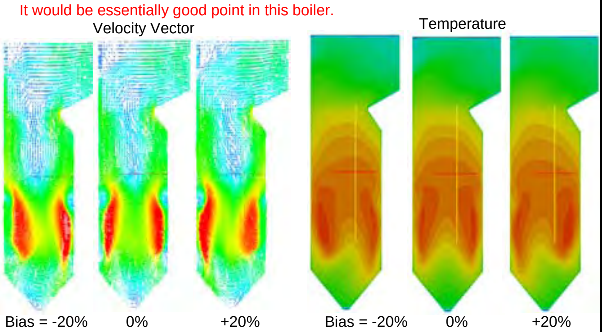
by changing the wind box draft.



Bottom Mill pattern , Tilt= -10[deg], Burner A

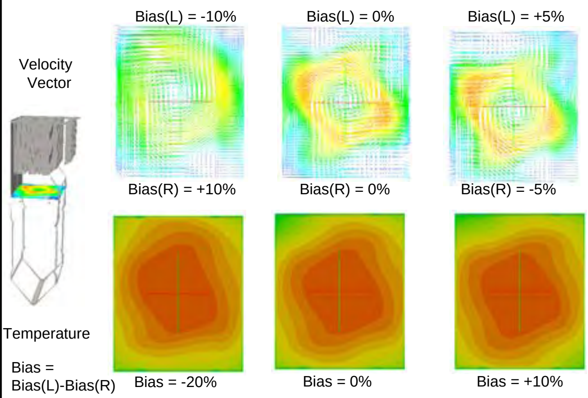
Figure 4.2.1 Effect of the Right & Left 2nd Air bias(1-1)

The difference in lower burner region was found.
But, the results in nose level were almost same.
The reason is that the swirl pattern in the furnace does not change basically.
It is understood the this boiler is stable against the fluctuation.
It would be essentially good point in this boiler.



Bottom Mill pattern , Tilt= -10[deg], Burner A

Figure 4.2.2 Effect of the Right & Left 2nd Air bias(1-2)



Top Mill pattern , Tilt= 30[deg], AA Level

Figure 4.2.3 Effect of the Right & Left 2nd Air bias(2-1)

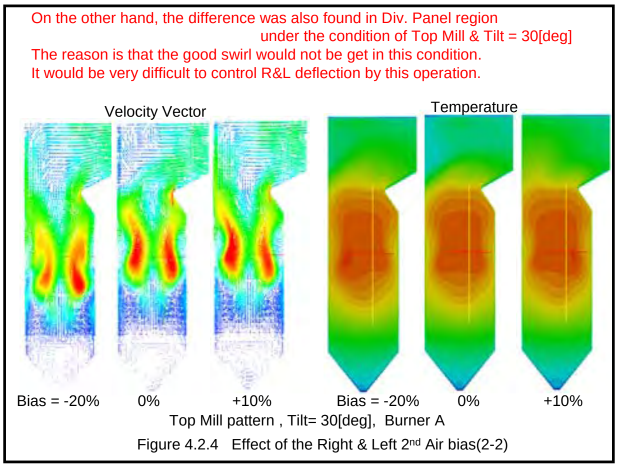


Figure 4.2.4 Effect of the Right & Left 2nd Air bias(2-2)

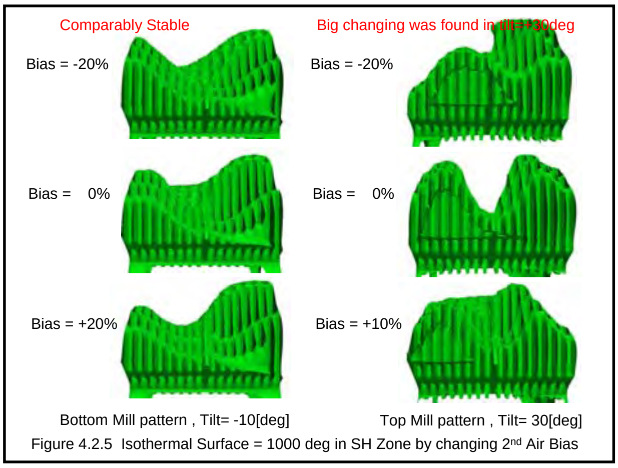


Figure 4.2.5 Isothermal Surface = 1000 deg in SH Zone by changing 2nd Air Bias

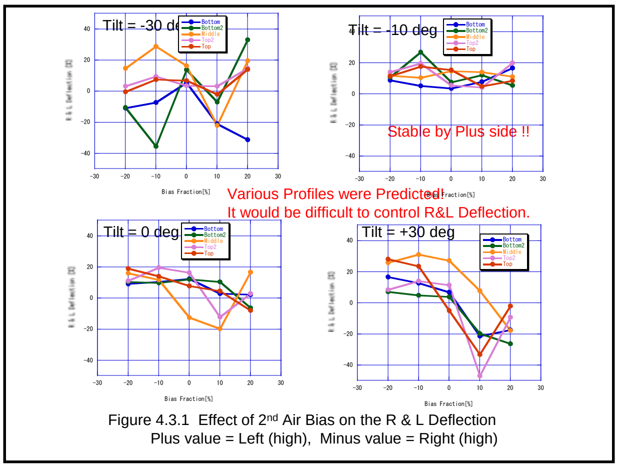
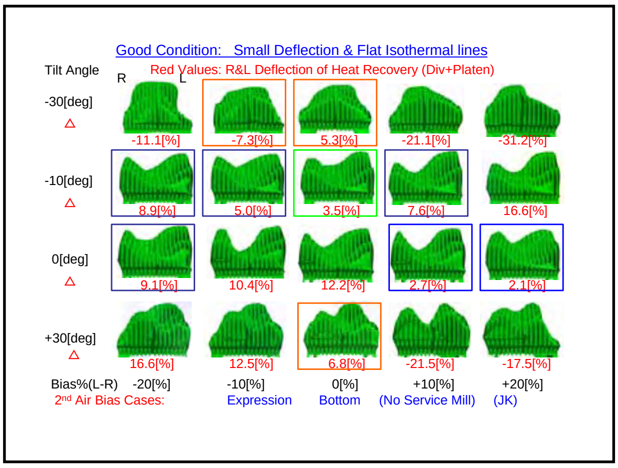


Figure 4.3.1 Effect of 2nd Air Bias on the R & L Deflection
Plus value = Left (high), Minus value = Right (high)



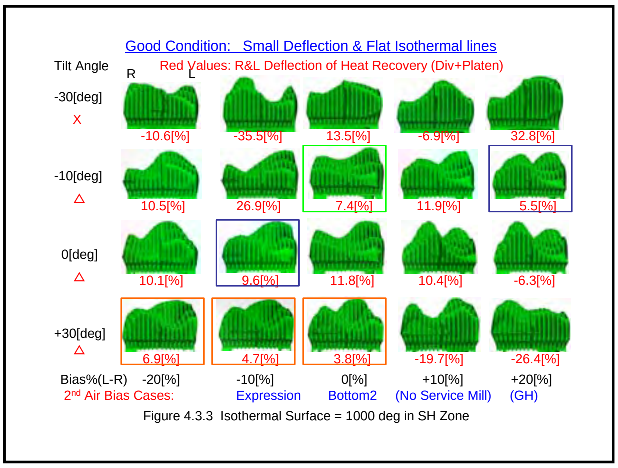


Figure 4.3.3 Isothermal Surface = 1000 deg in SH Zone

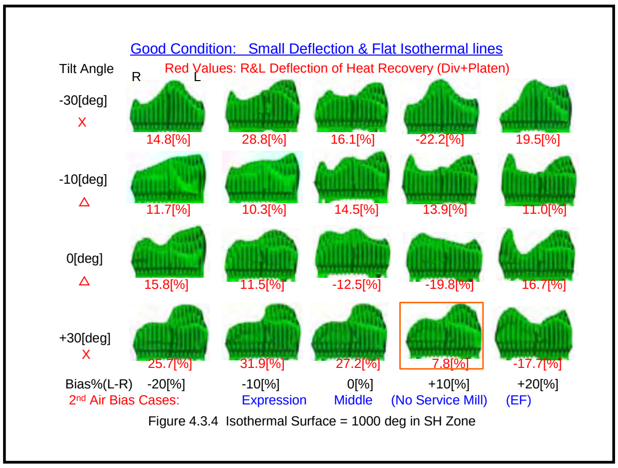


Figure 4.3.4 Isothermal Surface = 1000 deg in SH Zone

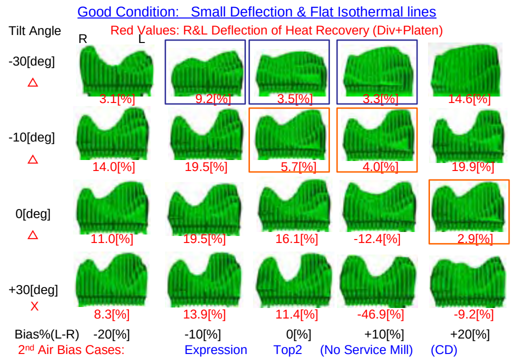


Figure 4.3.5 Isothermal Surface = 1000 deg in SH Zone

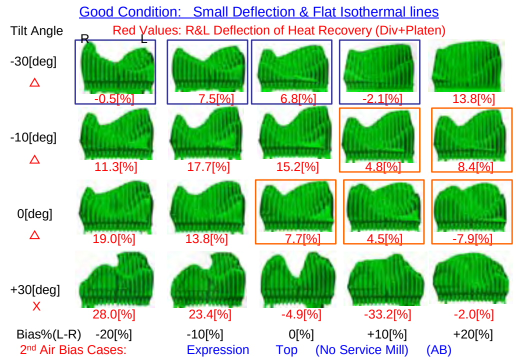


Figure 4.3.6 Isothermal Surface = 1000 deg in SH Zone

Table 4.3.1 Effect of 2nd Air Bias on the R & L Deflection
Plus value = Left (high), Minus value = Right (high)

Evaluation Item		R&L Deflection of Heat Recovery (Division Panel + Platen)				
Pattern	Tilt	Straight −20	Straight −10	Straight 0	Straight 10	Straight 20
Bottom (JK)	−30	−11.09	−7.26	5.32	−21.13	−31.15
	−10	8.86	5.04	3.48	7.58	16.57
	0	9.12	10.44	12.19	2.73	2.12
	30	16.60	12.54	6.81	−21.47	−17.45
Bottom2 (GH)	−30	−10.56	−35.46	13.56	−6.97	32.81
	−10	10.51	26.68	7.37	11.90	5.54
	0	10.19	9.57	11.84	10.41	−6.33
	30	6.92	4.69	3.79	−19.69	−26.42
Middle (EF)	−30	14.77	28.75	16.10	−22.15	19.48
	−10	11.68	10.28	14.51	13.93	11.04
	0	15.81	11.52	−12.53	−19.81	16.65
	30	25.65	31.01	27.20	7.83	−17.76
Top2 (CD)	−30	3.11	9.21	3.45	3.29	14.61
	−10	14.00	19.51	5.57	3.98	19.86
	0	11.01	19.53	16.13	−12.36	2.90
	30	8.34	13.91	11.36	−46.92	−9.20
Top (AB)	−30	−0.50	7.53	6.78	−2.13	13.82
	−10	11.28	17.70	15.16	4.79	8.44
	0	18.98	13.82	7.66	4.53	−7.87
	30	28.00	23.44	−4.92	−33.22	−2.01
AverageABS(df%)		12.35	15.90	10.29	13.84	14.10
Max(ABS(df%))		28.00	35.46	27.20	46.92	32.81
MIN(ABS(df%))		0.50	4.69	3.45	2.13	2.01

- ●R & L deflection seems to be minimum in non-bias condition (Bias Fraction=0%).
- ●Effect of the Cross Combination 2 and 3:
  - + Cross combination 2 and 3 is very effective to minimize the deflection under a lot of operating conditions.
  - +Cross combination 1 is also effective, but a big deflection is sometimes found in bias condition.
- ●It would be better to take non-bias condition with the cross combination.

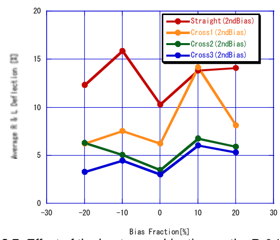


Figure 4.3.7 Effect of the heater combination on the R & L Deflection under the bias condition

Table 4. 3.2 Effect of 2nd Air Bias with Cross 1 on the R & L Deflection
Plus value = Left (high), Minus value = Right (high)

Evaluation Item		R&L Deflection of Heat Recovery (Division Panel + Platen)				
Pattern	Tilt	Cross1 −20	Cross1 −10	Cross1 0	Cross1 10	Cross1 20
Bottom (JK)	−30	−3.44	−7.45	2.50	−17.17	−16.76
	−10	8.10	7.62	2.33	21.34	9.04
	0	1.81	7.70	8.78	16.14	7.57
	30	6.18	5.73	4.83	−5.18	−8.53
Bottom2 (GH)	−30	3.13	−13.02	−0.73	20.91	1.13
	−10	−2.89	8.89	1.85	17.37	9.38
	0	−2.05	4.78	6.96	3.04	6.22
	30	4.72	3.01	3.74	4.06	−19.46
Middle (EF)	−30	0.91	8.55	8.25	−9.68	6.25
	−10	4.34	4.28	7.41	20.79	7.94
	0	9.31	0.36	−14.29	−21.76	7.03
	30	9.76	11.95	11.73	25.57	−11.12
Top2 (CD)	−30	14.77	6.32	−0.53	7.69	4.72
	−10	4.13	11.27	6.98	17.78	9.50
	0	6.49	8.59	8.64	−1.04	7.64
	30	6.43	8.86	6.87	−29.61	−9.14
Top (AB)	−30	10.58	10.43	4.83	6.83	3.80
	−10	7.24	6.88	6.81	14.48	7.36
	0	6.40	4.16	8.14	0.73	5.95
	30	12.13	10.54	−8.79	−22.01	3.70
AverageABS(df%)		6.24	7.52	6.25	14.16	8.11
Max(ABS(df%))		14.77	13.02	14.29	29.61	19.46
MIN(ABS(df%))		0.91	0.36	0.53	0.73	1.13

ABS(Orange Frame)
<±10%

Table 4.3.3 Effect of 2nd Air Bias with Cross 2 on the R & L Deflection
Plus value = Left (high), Minus value = Right (high)

Evaluation Item		R&L Deflection of Heat Recovery (Division Panel + Platen)				
Pattern	Tilt	Cross2 −20	Cross2 −10	Cross2 0	Cross2 10	Cross2 20
Bottom (JK)	−30	4.74	−2.46	−1.40	2.12	2.90
	−10	1.45	3.39	−2.43	10.10	−2.68
	0	−6.80	−0.24	−0.42	6.28	6.59
	30	−4.43	−2.65	−0.29	5.46	−0.51
Bottom2 (GH)	−30	8.60	9.64	−11.73	22.28	−21.41
	−10	−12.08	−10.51	−3.56	0.22	6.10
	0	−9.58	−3.44	−2.18	−8.63	11.74
	30	0.40	−1.11	−0.10	9.42	−4.60
Middle (EF)	−30	−10.36	−11.94	−1.81	−0.36	−6.97
	−10	−4.44	−2.74	−1.55	6.25	1.39
	0	−1.31	−8.19	−6.10	−6.28	−5.14
	30	−8.63	−10.92	−8.65	11.57	−2.11
Top2 (CD)	−30	13.31	0.25	−3.72	6.43	−4.59
	−10	−7.54	−2.82	2.95	7.22	−5.55
	0	−2.97	−5.36	−3.26	0.99	4.83
	30	0.85	−1.24	−2.42	0.35	−8.42
Top (AB)	−30	11.25	5.31	−0.14	8.93	−5.10
	−10	−1.35	−5.95	−3.95	5.78	1.58
	0	−8.14	−6.32	3.45	−13.66	11.96
	30	−7.95	−7.15	−9.52	−3.00	3.48
AverageABS(df%)		6.31	5.08	3.48	6.77	5.88
Max(ABS(df%))		13.31	11.94	11.73	22.28	21.41
MIN(ABS(df%))		0.40	0.24	0.10	0.22	0.51

ABS(Orange Frame)
<±10%

Table 4.3.4 Effect of 2nd Air Bias with Cross 3 on the R & L Deflection
Plus value = Left (high), Minus value = Right (high)

Evaluation Item		R&L Deflection of Heat Recovery (Division Panel + Platen)				
Pattern	Tilt	Cross3 −20	Cross3 −10	Cross3 0	Cross3 10	Cross3 20
Bottom (JK)	−30	−2.92	−2.28	1.42	5.12	−11.49
	−10	2.21	0.81	−1.28	1.82	4.85
	0	0.50	2.51	2.99	−2.55	1.13
	30	5.99	4.16	1.68	−1.41	−9.43
Bottom2 (GH)	−30	−5.09	−12.80	2.56	15.32	10.27
	−10	1.32	7.28	1.96	−14.58	2.26
	0	2.65	1.35	2.70	−17.52	−0.81
	30	2.59	0.58	−0.05	0.20	−11.56
Middle (EF)	−30	3.50	8.27	6.05	−2.95	6.26
	−10	2.90	3.26	5.56	1.72	4.49
	0	5.18	2.98	−4.34	−8.72	4.48
	30	7.26	8.14	6.83	−0.71	−8.74
Top2 (CD)	−30	1.65	3.14	0.27	4.30	5.31
	−10	2.33	5.42	1.53	−0.02	4.80
	0	1.55	5.58	4.23	−4.63	0.09
	30	2.76	3.81	2.07	−6.06	−8.48
Top (AB)	−30	0.18	2.41	1.81	5.14	4.91
	−10	2.70	4.86	4.40	−1.22	2.66
	0	4.44	3.34	2.96	−20.40	−1.86
	30	7.92	5.75	−5.65	−6.67	−2.22
AverageABS(df%)		3.28	4.44	3.02	6.05	5.31
Max(ABS(df%))		7.92	12.80	6.83	20.40	11.56
MIN(ABS(df%))		0.18	0.58	0.05	0.02	0.09

ABS(Orange Frame)
<±10%

Improve the R&L deflection
(2)Right & Left Fuel Bias (1st Air).

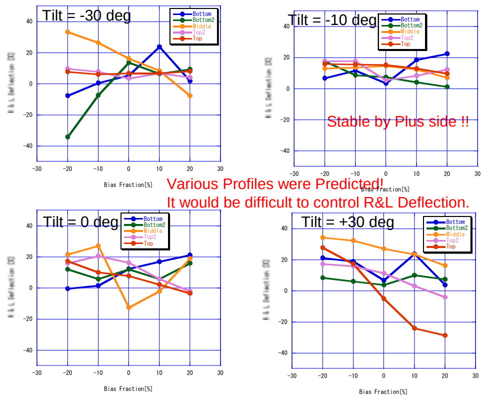


Figure 4.4.1 Effect of Fuel & 1st Air Bias on the R & L Deflection
Plus value = Left (high), Minus value = Right (high)

Good Condition: Small Deflection & Flat Isothermal lines

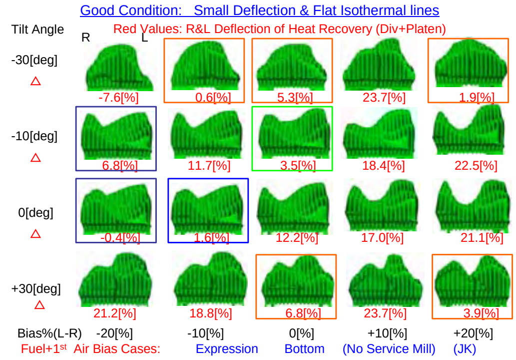
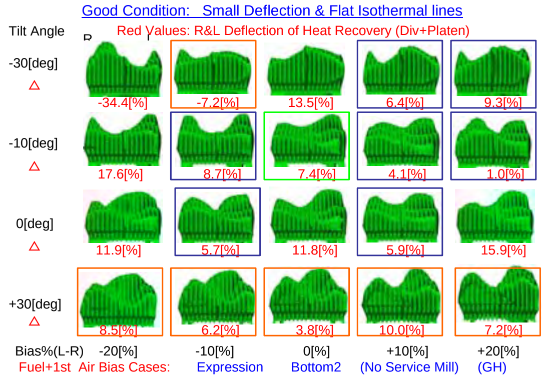


Figure 4.4.2 Isothermal Surface = 1000 deg in SH Zone

Good Condition: Small Deflection & Flat Isothermal lines



Good Condition: Small Deflection & Flat Isothermal lines

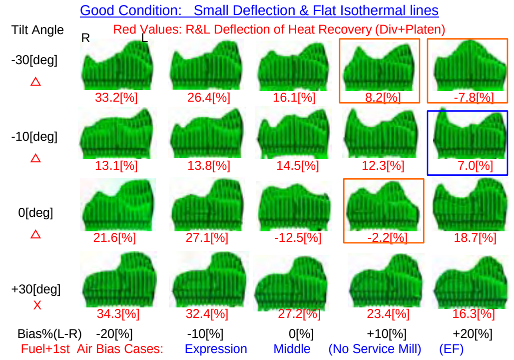


Figure 4.4.4 Isothermal Surface = 1000 deg in SH Zone

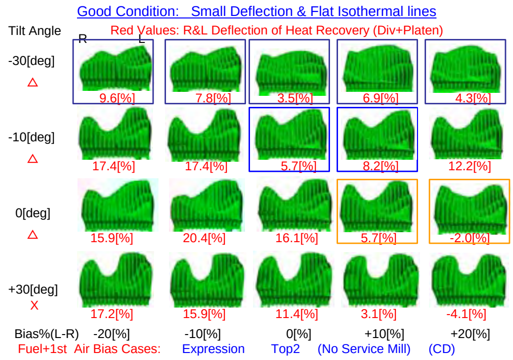


Figure 4.4.5 Isothermal Surface = 1000 deg in SH Zone

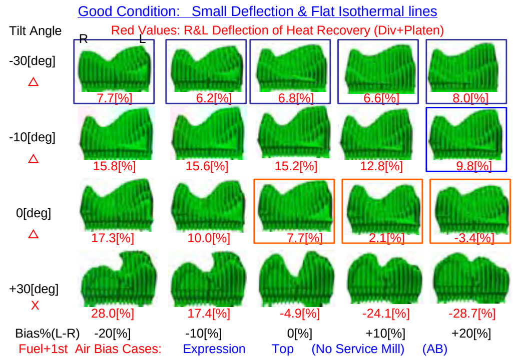


Figure 4.4.6 Isothermal Surface = 1000 deg in SH Zone

Table 4.4.1 Effect of Fuel & 1st Air Bias on the R & L Deflection
Plus value = Left (high), Minus value = Right (high)

Evaluation Item		R&L Deflection of Heat Recovery (Division Panel + Platen)				
Pattern	Tilt	Straight −20	Straight −10	Straight 0	Straight 10	Straight 20
Bottom (JK)	−30	−7.60	0.61	5.32	23.72	1.88
	−10	6.79	11.74	3.48	18.42	22.54
	0	−0.35	1.62	12.19	16.98	21.08
	30	21.23	18.75	6.81	23.72	3.92
Bottom2 (GH)	−30	−34.36	−7.21	13.56	6.36	9.33
	−10	17.64	8.71	7.37	4.12	1.04
	0	11.89	5.74	11.84	5.90	15.89
	30	8.45	6.21	3.79	10.01	7.24
Middle (EF)	−30	33.18	26.38	16.10	8.23	−7.82
	−10	13.13	13.76	14.51	12.27	7.02
	0	21.62	27.11	−12.53	−2.19	18.71
	30	34.26	32.36	27.20	23.36	16.25
Top2 (CD)	−30	9.60	7.78	3.45	6.87	4.25
	−10	17.40	17.43	5.57	8.23	12.23
	0	15.94	20.37	16.13	5.70	−1.96
	30	17.17	15.86	11.36	3.09	−4.06
Top (AB)	−30	7.71	6.23	6.78	6.62	7.99
	−10	15.79	15.59	15.16	12.82	9.78
	0	17.30	9.95	7.66	2.07	−3.37
	30	27.88	17.39	−4.92	−24.07	−28.69
AverageABS(df%)		16.96	13.54	10.29	11.24	10.25
Max(ABS(df%))		34.36	32.36	27.20	24.07	28.69
MIN(ABS(df%))		0.35	0.61	3.45	2.07	1.04

- R & L deflection seems to be minimum in non-bias condition (Bias Fraction=0%).
- Effect of the Cross Combination 2 and 3:
  + Cross combination 2 and 3 is very effective to minimize the deflection under a lot of operating conditions.
  +Cross combination 1 is also effective, but a big deflection is sometimes found in bias condition.
- It would be better to take non-bias condition with the cross combination.

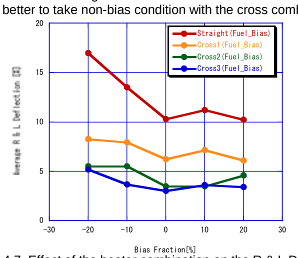


Figure 4.4.7 Effect of the heater combination on the R & L Deflection under the Fuel + 1st Air bias condition

Table 4.4.2 Effect of Fuel & 1st Air Bias with Cross 1 on the R & L Deflection
Plus value = Left (high), Minus value = Right (high)

Evaluation Item		R&L Deflection of Heat Recovery (Division Panel + Platen)				
Pattern	Tilt	Cross1 −20	Cross1 −10	Cross1 0	Cross1 10	Cross1 20
Bottom (JK)	−30	5.62	−9.78	2.50	14.02	−3.04
	−10	7.57	9.39	2.33	7.87	12.74
	0	5.76	8.44	8.78	7.37	11.35
	30	7.71	7.55	4.83	14.02	0.99
Bottom2 (GH)	−30	−11.93	−10.98	−0.73	−9.66	−7.89
	−10	8.58	6.01	1.85	4.93	6.55
	0	6.91	10.47	6.96	5.75	10.13
	30	5.07	4.43	3.74	4.64	0.58
Middle (EF)	−30	11.05	9.55	8.25	6.64	−2.75
	−10	4.07	6.43	7.41	7.51	6.49
	0	11.60	11.84	−14.29	1.00	4.84
	30	12.11	12.67	11.73	11.07	9.26
Top2 (CD)	−30	6.82	5.78	−0.53	1.35	0.20
	−10	8.11	5.56	6.98	7.95	8.26
	0	7.96	7.47	8.64	4.12	−1.99
	30	9.41	8.62	6.87	3.29	0.61
Top (AB)	−30	10.01	7.77	4.83	1.92	1.18
	−10	6.98	6.51	6.81	6.28	6.86
	0	7.73	5.75	8.14	5.50	6.38
	30	10.39	3.65	−8.79	−18.17	−19.37
AverageABS(df%)		8.27	7.93	6.25	7.15	6.07
Max(ABS(df%))		12.11	12.67	14.29	18.17	19.37
MIN(ABS(df%))		4.07	3.65	0.53	1.00	0.20

ABS(Orange Frame) <±10%

Table 4.4.3 Effect of Fuel & 1st Air Bias with Cross 2 on the R & L Deflection
Plus value = Left (high), Minus value = Right (high)

Evaluation Item		R&L Deflection of Heat Recovery (Division Panel + Platen)				
Pattern	Tilt	Cross2 −20	Cross2 −10	Cross2 0	Cross2 10	Cross2 20
Bottom (JK)	−30	10.26	−10.31	−1.40	−1.17	−3.46
	−10	3.16	1.38	−2.43	−5.13	−3.19
	0	6.10	7.11	−0.42	−4.77	−3.73
	30	−7.04	−6.16	−0.29	−1.17	−4.56
Bottom2 (GH)	−30	9.20	−6.20	−11.73	−14.52	−14.42
	−10	−3.69	0.26	−3.56	2.42	6.98
	0	−2.58	6.86	−2.18	1.41	−2.24
	30	−1.03	−0.72	−0.10	−4.71	−7.65
Middle (EF)	−30	−11.26	−7.99	−1.81	2.14	0.65
	−10	−4.37	−2.37	−1.55	−0.23	2.46
	0	−3.36	−8.13	−6.10	0.89	−11.84
	30	−12.86	−11.27	−8.65	−6.84	−4.00
Top2 (CD)	−30	0.83	0.58	−3.72	−3.40	−2.70
	−10	−5.23	−8.55	2.95	1.85	−1.19
	0	−3.39	−7.44	−3.26	−1.74	−3.55
	30	−2.29	−3.02	−2.42	−1.35	−0.10
Top (AB)	−30	4.68	3.42	−0.14	−3.60	−5.45
	−10	−4.05	−4.37	−3.95	−2.81	0.05
	0	−4.28	−1.92	3.45	3.68	8.89
	30	−11.14	−12.18	−9.52	−6.19	−4.39
AverageABS(df%)		5.54	5.51	3.48	3.50	4.58
Max(ABS(df%))		12.86	12.18	11.73	14.52	14.42
MIN(ABS(df%))		0.83	0.26	0.10	0.23	0.05

ABS(Orange Frame) <±10%

Table 4.4.4 Effect of Fuel & 1st Air Bias with Cross 3 on the R & L Deflection
Plus value = Left (high), Minus value = Right (high)

Evaluation Item		R&L Deflection of Heat Recovery (Division Panel + Platen)				
Pattern	Tilt	Cross3 −20	Cross3 −10	Cross3 0	Cross3 10	Cross3 20
Bottom (JK)	−30	−2.96	0.07	1.42	8.53	1.45
	−10	2.38	3.73	−1.28	5.42	6.62
	0	0.00	0.29	2.99	4.84	6.00
	30	6.48	5.04	1.68	8.53	−1.63
Bottom2 (GH)	−30	−13.22	−2.42	2.56	1.51	2.80
	−10	5.37	2.96	1.96	1.61	1.48
	0	2.40	2.13	2.70	1.55	3.52
	30	2.35	1.06	−0.05	0.66	−0.99
Middle (EF)	−30	10.87	8.84	6.05	3.73	−4.42
	−10	4.69	4.96	5.56	4.53	3.00
	0	6.66	7.14	−4.34	−2.31	2.04
	30	9.28	8.42	6.83	5.46	2.99
Top2 (CD)	−30	3.61	2.57	0.27	2.12	1.35
	−10	4.05	3.32	1.53	2.13	2.78
	0	4.59	5.45	4.23	−0.16	−3.52
	30	5.47	4.21	2.07	−1.56	−4.76
Top (AB)	−30	2.39	1.88	1.81	1.11	1.35
	−10	4.76	4.72	4.40	3.74	2.97
	0	5.29	2.28	2.96	0.24	−0.85
	30	6.35	1.56	−5.65	−12.09	−13.71
AverageABS(df%)		5.16	3.65	3.02	3.59	3.41
Max(ABS(df%))		13.22	8.84	6.83	12.09	13.71
MIN(ABS(df%))		0.00	0.07	0.05	0.16	0.85

ABS(Orange Frame) <±10%

Improve the R&L deflection

(3)Right & Left Fuel Bias (1st Air) + 2nd Air Bias.

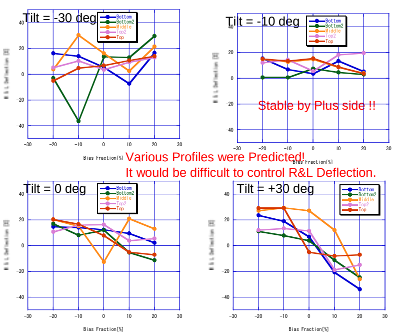


Figure 4.5.1 Effect of Fuel & 1st Air (+2nd Air) Bias on the R & L Deflection
Plus value = Left (high), Minus value = Right (high)

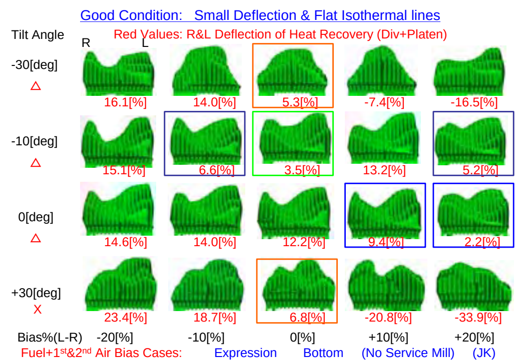


Figure 4.5.2 Isothermal Surface = 1000 deg in SH Zone

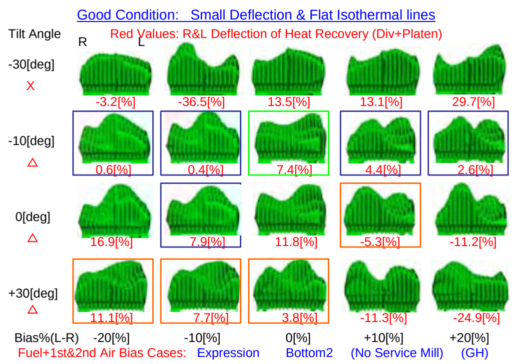


Figure 4.5.3 Isothermal Surface = 1000 deg in SH Zone

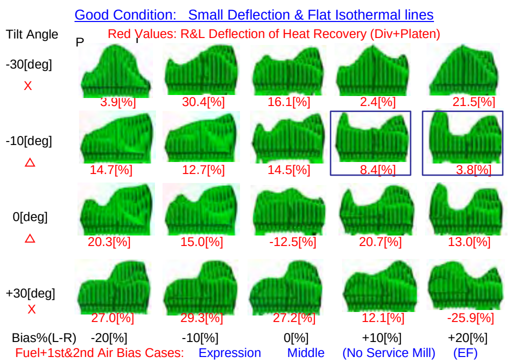


Figure 4.5.4 Isothermal Surface = 1000 deg in SH Zone

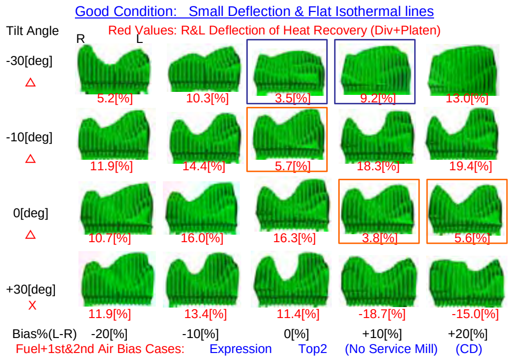


Figure 4.5.5 Isothermal Surface = 1000 deg in SH Zone

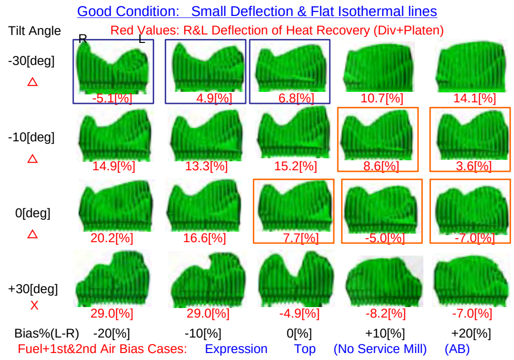


Figure 4.5.6 Isothermal Surface = 1000 deg in SH Zone

Table 4.5.1 Effect of Fuel & 1st Air (+2nd Air) Bias on the R & L Deflection
Plus value = Left (high), Minus value = Right (high)

Evaluation Item		R&L Deflection of Heat Recovery (Division Panel + Platen)				
Pattern	Tilt	Straight −20	Straight −10	Straight 0	Straight 10	Straight 20
Bottom (JK)	−30	16.08	14.01	5.32	−7.36	16.51
	−10	15.14	6.58	3.48	13.27	5.23
	0	14.58	14.01	12.19	9.40	2.18
	30	23.41	18.72	6.81	−20.80	−33.94
Bottom2 (GH)	−30	−3.16	−36.46	13.56	13.09	29.66
	−10	0.64	0.42	7.37	4.37	2.64
	0	16.85	7.89	11.84	−5.29	−11.23
	30	11.07	7.71	3.79	−11.31	−24.88
Middle (EF)	−30	3.89	30.43	16.10	2.35	21.46
	−10	14.66	12.66	14.51	8.35	3.79
	0	20.29	14.96	−12.53	20.70	12.99
	30	26.99	29.27	27.20	12.09	−25.90
Top2 (CD)	−30	5.22	10.31	3.45	9.22	13.03
	−10	11.92	14.41	5.57	18.31	19.42
	0	10.72	16.00	16.13	3.80	5.55
	30	11.92	13.38	11.36	−18.71	−15.02
Top (AB)	−30	−5.11	4.91	6.78	10.71	14.08
	−10	14.92	13.32	15.16	8.62	3.60
	0	20.21	16.58	7.66	−4.97	−6.98
	30	29.00	29.00	−4.92	−8.16	−7.00
AverageABS(df%)		13.79	15.55	10.29	10.54	13.75
Max(ABS(df%))		29.00	36.46	27.20	20.80	33.94
MIN(ABS(df%))		0.64	0.42	3.45	2.35	2.18

- ●R & L deflection seems to be minimum in non-bias condition (Bias Fraction=0%).
- ●Effect of the Cross Combination 2 and 3:
  - + Cross combination 2 and 3 is very effective to minimize the deflection under a lot of operating conditions.
  - +Cross combination 1 is also effective, but a big deflection is sometimes found in bias condition.
- ●It would be better to take non-bias condition with the cross combination.

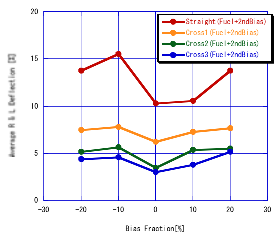


Figure 4.5.7 Effect of the heater combination on the R & L Deflection under the Fuel + 1st & 2nd Air bias condition

Table 4.5.2 Effect of Fuel & 1st Air (+2nd Air) Bias with Cross 1 on the R & L Deflection
Plus value = Left (high), Minus value = Right (high)

Evaluation Item		R&L Deflection of Heat Recovery (Division Panel + Platen)				
Pattern	Tilt	Cross1 −20	Cross1 −10	Cross1 0	Cross1 10	Cross1 20
Bottom (JK)	−30	13.37	6.92	2.50	−6.32	7.45
	−10	8.47	7.94	2.33	6.07	7.16
	0	5.56	6.92	8.78	7.76	7.83
	30	8.17	7.44	4.83	−14.91	−19.53
Bottom2 (GH)	−30	2.32	−12.51	−0.73	−5.15	7.62
	−10	−3.07	−5.59	1.85	6.53	8.03
	0	−1.68	−3.68	6.96	9.07	5.80
	30	5.99	4.94	3.74	−11.31	−13.80
Middle (EF)	−30	0.56	6.35	8.25	−3.53	5.59
	−10	4.65	4.09	7.41	7.19	5.27
	0	9.58	10.20	−14.29	9.91	8.99
	30	10.37	10.43	11.73	6.22	−9.41
Top2 (CD)	−30	14.49	9.66	−0.53	2.90	4.47
	−10	7.70	8.17	6.98	7.51	6.43
	0	7.27	7.86	8.64	7.09	7.60
	30	8.02	8.55	6.87	−16.41	−8.15
Top (AB)	−30	9.62	11.11	4.83	3.14	3.65
	−10	7.71	6.67	6.81	7.06	6.81
	0	8.44	5.30	8.14	6.16	5.99
	30	12.35	12.33	−8.79	−1.82	3.75
AverageABS(df%)		7.47	7.83	6.25	7.30	7.67
Max(ABS(df%))		14.49	12.51	14.29	16.41	19.53
MIN(ABS(df%))		0.56	3.68	0.53	1.82	3.65

ABS(Orange Frame) <±10%

Table 4.5.3 Effect of Fuel & 1st Air (+2nd Air) Bias with Cross 2 on the R & L Deflection
Plus value = Left (high), Minus value = Right (high)

Evaluation Item		R&L Deflection of Heat Recovery (Division Panel + Platen)				
Pattern	Tilt	Cross2 −20	Cross2 −10	Cross2 0	Cross2 10	Cross2 20
Bottom (JK)	−30	2.63	−3.72	−1.40	−3.41	−3.48
	−10	−2.81	3.47	−2.43	−4.06	2.98
	0	−5.59	−3.72	−0.42	0.60	6.69
	30	−6.59	−5.18	−0.29	−4.59	−0.79
Bottom2 (GH)	−30	3.94	11.24	−11.73	−13.27	−10.58
	−10	−4.25	−6.85	−3.56	3.53	6.66
	0	−13.63	−10.57	−2.18	14.02	14.36
	30	−0.15	−0.39	−0.10	−6.59	0.44
Middle (EF)	−30	−1.85	−15.65	−1.81	−6.27	−7.86
	−10	−5.94	−4.81	−1.55	2.59	2.89
	0	−4.42	0.01	−6.10	−5.77	−1.92
	30	−7.97	−10.79	−8.65	−4.31	5.04
Top2 (CD)	−30	11.54	3.24	−3.72	−3.05	−3.83
	−10	−0.23	−2.20	2.95	−7.10	−8.86
	0	−0.38	−3.83	−3.26	3.26	3.15
	30	1.19	−0.17	−2.42	−9.42	−3.15
Top (AB)	−30	13.30	8.19	−0.14	−4.02	−5.39
	−10	−3.33	−3.19	−3.95	1.04	4.24
	0	−6.75	−6.83	3.45	9.56	10.94
	30	−7.33	−8.75	−9.52	1.00	6.76
AverageABS(df%)		5.19	5.64	3.48	5.37	5.50
Max(ABS(df%))		13.63	15.65	11.73	14.02	14.36
MIN(ABS(df%))		0.15	0.01	0.10	0.60	0.44

ABS(Orange Frame) <±10%

Table 4.5.4 Effect of Fuel & 1st Air (+2nd Air) Bias with Cross 3 on the R & L Deflection
Plus value = Left (high), Minus value = Right (high)

Evaluation Item		R&L Deflection of Heat Recovery (Division Panel + Platen)				
Pattern	Tilt	Cross3	Cross3	Cross3	Cross3	Cross3
		−20	−10	0	10	20
Bottom (JK)	−30	5.35	3.37	1.42	−4.45	5.58
	−10	3.86	2.11	−1.28	3.14	1.04
	0	3.43	3.37	2.99	2.25	1.04
	30	8.64	6.10	1.68	−10.48	−15.20
Bottom2 (GH)	−30	−1.55	−12.71	2.56	4.97	11.46
	−10	−0.54	−0.84	1.96	1.37	1.27
	0	4.90	1.00	2.70	−0.34	−2.67
	30	4.93	2.38	−0.05	−6.59	−10.65
Middle (EF)	−30	1.48	8.44	6.05	−0.39	8.01
	−10	4.08	3.76	5.56	3.74	1.40
	0	6.29	4.77	−4.34	5.02	2.08
	30	8.64	8.05	6.83	1.56	−11.46
Top2 (CD)	−30	2.27	3.89	0.27	3.27	4.72
	−10	4.00	4.04	1.53	3.70	4.13
	0	3.07	4.31	4.23	−0.03	1.10
	30	5.08	4.66	2.07	−11.72	−10.01
Top (AB)	−30	−1.43	1.99	1.81	3.54	5.03
	−10	3.89	3.46	4.40	2.60	1.03
	0	5.02	4.45	2.96	−1.57	−2.03
	30	9.32	7.93	−5.65	−5.34	−3.99
AverageABS(df%)		4.39	4.58	3.02	3.80	5.20
Max(ABS(df%))		9.32	12.71	6.83	11.72	15.20
MIN(ABS(df%))		0.54	0.84	0.05	0.03	1.03

ABS(Orange Frame)
<±10%

The result of Simulation
Air and Fuel Bias

●R & L deflection dose not have a consistent tendency to the bias fraction.
Tilt=-10deg:R & L deflection is stable by plus value.
(Strong swirl flow in the furnace)
Tilt=+30deg:The big changing by bias was predicted.
(Weak swirl flow in the furnace)

●It would be very difficult to control R&L deflection by this bias operation.

●Effect of the Cross Combination 2 and 3:
+ Cross combination 2 and 3 is very effective to minimize the deflection under a lot of operating conditions.
+However, a big deflection is sometimes found in bias condition.

●It would be better to take non-bias condition with the cross combination.

JICA Study Team for Enhancing Efficiency of Operating Thermal Power Plant in NTPC-India

Boiler RLA

JICA Study Team
Boiler RLA

Target units

- ➢ **Singrauli Unit 6 (500MW Drum Boiler)**
  Cumulative operation hours: 172,000 hours
  (27th October to 1st November, 2009)

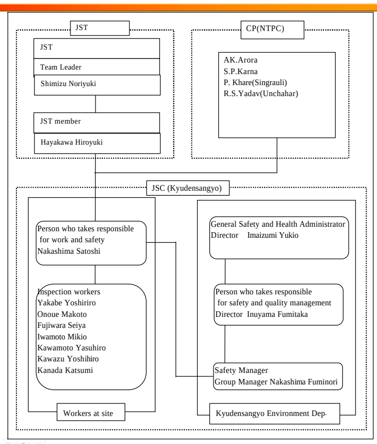
- ➢ **Unchahar Unit 2 (200MW Drum Boiler)**
  Cumulative operation hours: 139,098 hours
  (4th November to 9th November, 2009)

Schedule for Boiler RLA demo

Schedule for Boiler RLA

	Month	October								November											～January
	Day	24	25	26	27	28	29	30	31	1	2	3	4	5	6	7	8	9	10	11	
	Day of the week	Sa	Su	Mo	Tue	We	Th	Fr	Sa	Su	Mo	Tue	We	Th	Fr	Sa	Su	Mo	Tue	We	
Singrauli UNIT6	Boiler Inspection				10/27−11/1																
Unchahar UNIT2	Meeting											■									
	Boiler Inspection												11/4−11/9								
	◇Examination in Japan																				■

Work organization



Safety working

Following the instruction of power station, keeping Japanese safety management.

- ✓ Falling
  In danger of falling, working at 2m or more high altitude.
- ✓ Lack of oxygen
  In danger of lack of oxygen, working in the boiler furnace.
- ✓ Dropping
  In danger of equipments dropping at hanging in and out
  Maximum weight 50 kg.
  In danger of manual tools and small parts dropping.

*Check the portion that **asbestos** used.
If asbestos treating work begins, Interrupt working.

*Information sharing to avoid working during upper portion working, γ-ray inspection, etc.

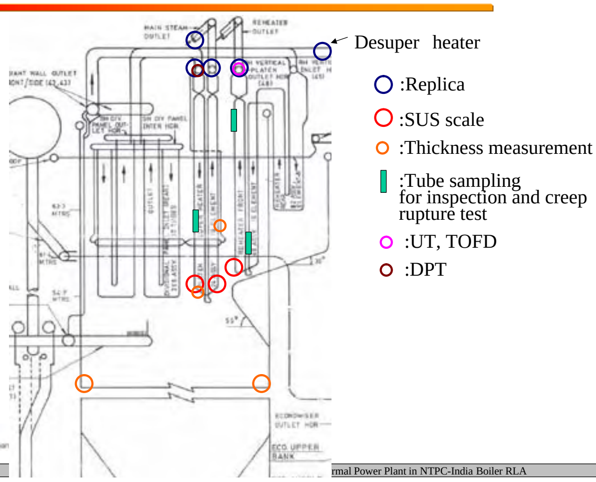
Scope of work (1)

NO.	Parts	INSPECTION	Singrauli #6	Unchahar #2
1	WATER WALL	VT	･Mainly at burner level ･Errosion part	
2		THICKNESS MEASUREMENT	･20 points(5points each from 4corners)	
3	SUPER HEATER	VT	･Mainly Platen super heater	
4		THICKNESS MEASUREMENT	･50 points around soot blower	
5		SAMPLE TUBE INSPECTION *	1 tube with 1m length for Platen SH including weld joint portion	2 tubes with 1m length from Final SH, 1 tubes with 1m length from Platen SH including weld joint portion that is selected by steam oxide scale measurement result.
6		CREEP RUPTURE TEST*	･3 specimens from base metal, 3 specimens from weld joint from the tube identical to above.	･3 specimens from base metal, 3 specimens from weld joint from the tube identical to above.
7		SUS SCALE DEPOSITION INSPECTION	･50 points of bottom bend portion of austenitic steel tubes	･29 ×3 points of bottom bend portion of austenitic steel tubes
8	REHEATER	VT	･Mainly around soot blower.	
9		SAMPLE TUBE INSPECTION *	2 tubes with 1m length for Final RH (one each from furnace inside and penthouse) including weld joint portion.	
10		CREEP RUPTURE TEST*	･3 specimens from base metal, 3 specimens from weld joint from the tube identical to the one of the above sample tubes.	
11		SUS SCALE DEPOSITION INSPECTION	･50 points of bottom bend portion of austenitic steel tubes	

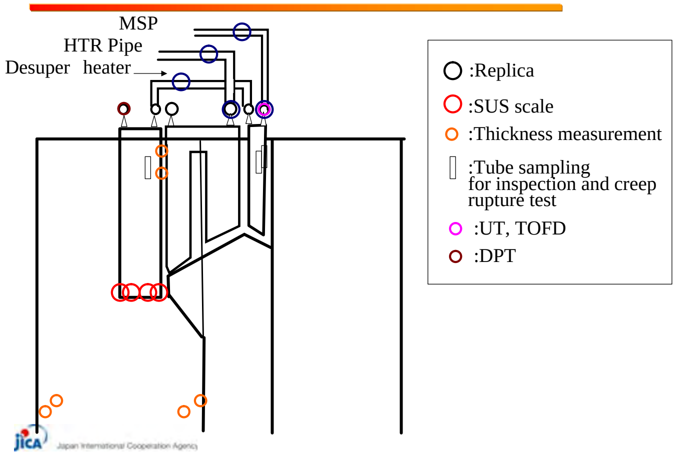
Scope of work (2)

NO.	Parts	INSPECTION	Singrauli #6	Unchahar #2
12	SUPER HEATER HEADER	VT	・Visual inspection in penthouse	
13		PT(DPT)	・4 portions at stub weld of Inlet header .	・4 portions at stub weld of Platten inlet header right side.
14		UT		・1ring of circumferential weld of Final outlet header right side with UT and TOFD identical to the replica portion
15		REPLICA INSPECTION	・1 point on 1ring of circumferential weld of left outlet header. ・1 point on base metal of left outlet header.	・1 point of circumferential weld potion of right side of Final outlet header.
16	DE SUPER HEATER PIPE	REPLICA INSPECTION	・2 points (one each from 1ring of circumferential weld right and left).	
17	REHEATER HEADER	VT	・Visual inspection in penthouse	
18		UT	・1ring of circumferential weld of outlet header with UT and TOFD identical to the replica portion	
19		REPLICA INSPECTION	・2 points (one each from circumferential weld of left and right of out let header.	・3 points of circumferential weld potion of right and left side outlet header.
20	MAIN STEAM PIPE (near the stop valve weld joint)	REPLICA INSPECTION	・2 points on a circumferential weld of left main steam pipe	・2 points on two circumferential welds of right main steam pipe
21	HOT RHEAT PIPE	REPLICA INSPECTION		・1 point on a circumferential weld of right High temperature reheat pipe.

Inspection points (Singrauli #6)



Inspection points (Unchahar #2)



Findings (1) (Singrauli #6)

Components	Inspection method	Findings
Water wall tube	Visual check	・Erosion of a number of tubes around short soot blower were found. ・No erosion at any other portions. ・No erosion and decease in thickness around burners.
	Thickness measurement of tubes	Thickness was measured at erosion regions around soot blowerrs near each 4 corner. Min. thickness was 3.7mm(2nd blower in forntwal first from right. f 51* 5.6mm, SA210 Gr.C
Platten SH	Visual check	・Attrition of binding tube #4 and #5 was found.(Min.2.8mm) ・Attrition of cooling spacer tubevwith front tube of #14 panel (Min.5.0mm) ・Disorder of arrangement at lower part of panel with distortion to adjacent panel. ・A number of disjointed slide spac
	Thickness measurement of tubes	・1:Outer tube of rear side portion at sootblower level(24points)⇒Min.6.3mm ϕ63.5* 6.3mm SA213 TP347H ・2:Outer bottom tube (24points)⇒Min.9.8mm ϕ54.0* 9.5mm SA213 TP347H ・3:Attrition of coolin
	SUS scale deposition inspection	Nos. exceeding 10% fullness : 7 /50 (magnetized effect of material)
	Tube sampling for sample tube inspection (inspected in Japan).	#12-3(from leftside) f 47.63*8.6-f 47.63*10, SA213 T22
	Creep rupture test (inspected in Japan)	

Findings (2) (Singrauli #6)

Components	Inspection method	Findings
Reheater	Visual check	・Disorder of arrangement at lower part of panel with distortion to adjacent panel.
	SUS scale deposition inspection	No exceeding 10% fullness
	Tube sampling for sample tube inspection (inspected in Japan).	#3-1(from leftside in penthouse) 1m including weld f 54*5.6, SA213 T22 #14-5(from rear side in furnace) (SA213T22 f 54*4.5-SA213T11 f 54*4.0)
	Creep rupture test (inspected in Japan) for 1 tube with 1m length.	
Super heater header	Visual check	・No appearance abnormarity in stubs and other weld portion.
	DPT	#2(1,4,7,12) Indication was found in #2-12 stub at tube side. Indication disaappeared after grindng off the tube in 1mm depth .
	Replica inspection	・No crack in Base metal, HAZ(Heat Affected Zone) and weldmetal. ・More detail microstructural observation is required in labo.
De superheater pipe	Replica inspection	・No crack in Base metal, HAZ(Heat Affected Zone) and weldmetal. ・More detail microstructural observation is required in labo.
Reheater header	Visual check	・No appearance abnormarity in stubs and other weld portion.
	Replica inspection	・No crack in Base metal, HAZ(Heat Affected Zone) and weldmetal. ・More detail microstructural observation is required in labo.
	UT	・No detection of flaw beyond H-detection line. ・4 detected flaw under H-detection line.
	TOFD	・A number of flaw considered as satle blow holes and slag inclusions were detected. ・No considerable crack detected.
Main steam pipe (near the stop valve weld joint)	Replica inspection	・No crack in Base metal, HAZ(Heat Affected Zone) and weldmetal. ・More detail microstructural observation is required in labo.

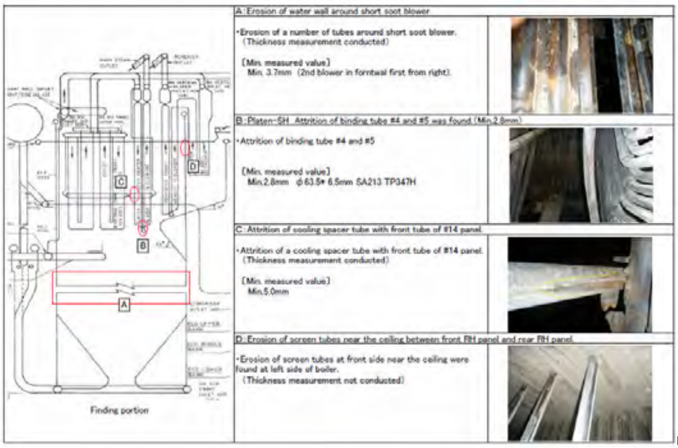
Findings (3) (Unchahar #2)

Components	INSPECTION	Unchahar #2 Brief comment
WATER WALL	VT	Erosion of a number of tubes around short soot blower were found. Erosion of corner tubes at soot blower level.(Thickness measurement 28points (Min.4.2mm)
	THICKNESS MEASUREMENT	Eroded tubes around short soot blower were meareured .(69points measured) Min 5.3mm (2nd short blower rear wall #1 form left)
SUPER HEATER	VT	Disorder of arrangement at lower part of panel with disjointed slide spacers. Slight erosion of rear tubes at the highest level of short soot blower.
	THICKNESS MEASUREMENT	Rear tubes at the highest level of short soot blower.(29points, Min.9.8mm) 2nd tubes from rear tubes at the highest level of short soot blower.(3points, Min.10.0mm) Rear tubes at the second highest level of short soot blower.(29points, Min.9.8mm)
	SAMPLE TUBE INSPECTION *	1 sample tube from Platen-SH in furnace (#3panel- 8th tube from rear) 2 sample tubes from Final-SH in furnace (#1-3rd tube from rear, #119-3rd tube from rear)
	CREEP RUPTURE TEST*	1 sample tube from Platen-SH in furnace (#3panel- 8th tube from rear), 1 sample tubes from Final-SH in furnace (#119-3rd tube from rear)
	SUS SCALE DEPOSITION INSPECTION	3 tubes with 15% fullness and 2 tubes with 10% fullness at front bend portion. 1 tube with 15% fullness and the others with less than 10%.
REHEATER	VT	No abnormality with panel ar r angement Slight erosion of tubes at the highest level of short soot blower.

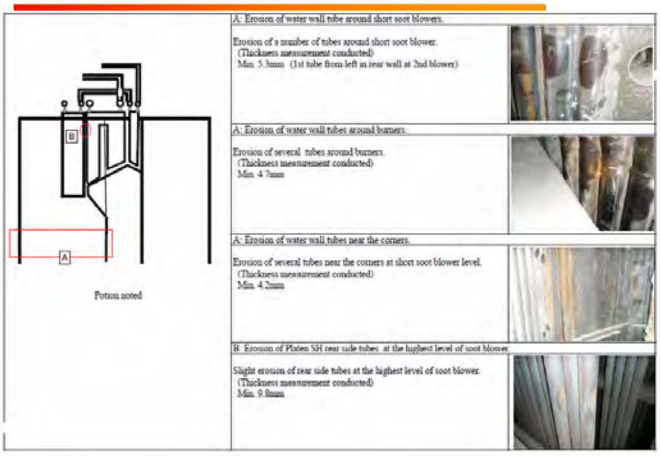
Findings (4) (Unchahar #2)

Components	INSPECTION	Unchahar #2 Brief comment
SUPER HEATER HEADER	VT	No appearance abnormality in stubs and other weld portion.
	PT(DPT)	3 small circular indication patterns by ark strike at 4th tube from front.
	UT	No detection of flaw which echo exceeds L-line by UT. Continuous indication with fine flaws detected at 80mm depth from surface by TOFD.
	REPLICA INSPECTION	No crack in Base metal, HAZ(Heat Affected Zone) and weld metal. More detail microstructural observation is required in labo.
DE SUPER HEATER PIPE	REPLICA INSPECTION	No crack in Base metal, HAZ(Heat Affected Zone) and weld metal. More detail microstructural observation is required in labo.
REHEATER HEADER	VT	No appearance abnormality in stubs and other weld portion.
	REPLICA INSPECTION	No crack in Base metal, HAZ (Heat Affected Zone) and weld metal. Abnormal microstructure observed in base metal region of right-hand weld of header, which is considered to be the effect of ark during welding. More detail microstructural observation.
MAIN STEAM PIPE (near the stop valve weld joint)	REPLICA INSPECTION	No crack in Base metal, HAZ(Heat Affected Zone) and weld metal. More detail microstructural observation is required in labo.
HOT RHEAT PIPE	REPLICA INSPECTION	No crack in Base metal, HAZ(Heat Affected Zone) and weld metal. More detail microstructural observation is required in labo. Some deposit metal by welding attached to base metal near the weld ring.

Visual inspection (Singrauli #6)



Visual inspection (Unchahar #2)



Thickness measurement

Thickness measurement (1)

【Equipment】

Ultrasonic thickness meter including a probe with a digital display and waveform indicator.

【Couplant】

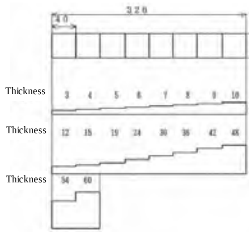
Glycerin paste or glycerin solution with the 75% concentration or more

Thickness measurement (2)

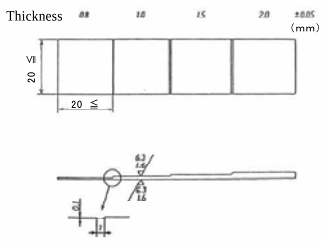
【Reference block】

- Reference block: RB-T and RB-E (for regular interval checking and daily checking)

RB-E



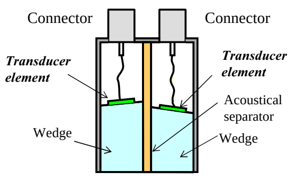
RB-T



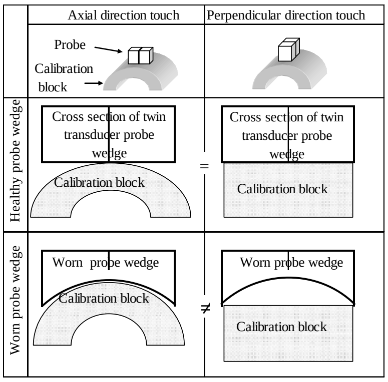
Thickness measurement (3)

【 Original reference block 】

- **Carbon steel**
- **Austenitic steel**



Double transducer normal probe



Thickness measurement (4)

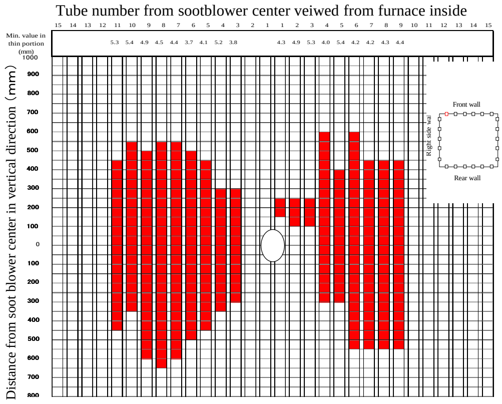
【 Acceptance Criteria 】

Measurement result is judged by the calculated value (tsr: thickness required) based on "Technical standards for thermal power generation facilities" and JIS B 8201 : 2005.

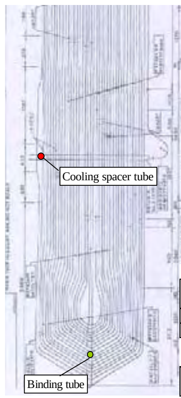
$$tsr = (Pd/2\sigma_a + P) + 0.005d \qquad \text{(JISB8201)}$$

- tsr : Minimum required thickness of tube (mm)
- P : Maximum operating pressure(MPa)
- d : Outside diameter of tube (mm)
- σ_a: Allowable tensile stress of the material (N/mm²)

Thickness measurement results of WW (Singrauli #6)



Thickness measurement results of Platen SH (Singrauli #6)



Binding tube

Panel No. (From left)	Thin point	Normal point
4R	2.8	6.5
5L	3.3	6.6

(unit : mm)

Cooling spacer tube

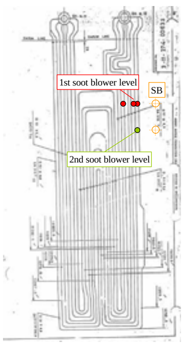
Attrition point with front tube of #14 panel	5.0

(unit : mm)

Thining portion of cooling spacer tube

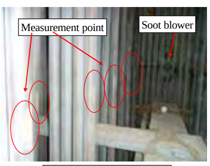
Thining portion of binding tube

Thickness measurement results of Platen SH (Unchahar #2)

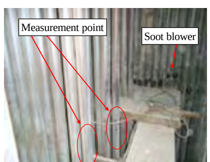


Tube specification: SA213T22 f 51.0×t9.6(tsr9.4mm)

Panel No. (From left)	Soot blower level: 1st soot blower level ● 1st tube from rear	1st soot blower level ● 2nd tube from rear	1st soot blower level ● 5th tube from rear	2nd soot blower level● 1st tube from rear
1	9.8	-	-	10.0
2	9.9	-	-	10.0
3	10.0	-	-	10.2
4	10.2	-	-	10.4
5	9.9	-	-	10.2
6	10.3	-	-	10.3
7	10.1	-	-	10.2
8	10.1	-	-	10.1
9	9.9	10.1	-	10.1
10	10.1	-	-	10.3
11	10.1	10.0	-	10.2
12	10.1	-	-	10.2
13	10.0	-	-	10.1
14	9.9	-	-	10.0
15	10.1	-	10.2	10.3
16	10.1	-	-	10.3
17	9.9	-	-	9.9
18	10.2	-	-	10.2
19	10.2	-	-	10.1
20	10.1	-	-	10.2
21	10.0	-	-	10.1
22	10.3	-	-	10.3
23	10.3	-	-	10.2
24	10.3	-	-	10.2
25	10.0	-	-	10.1
26	10.2	-	-	10.2
27	10.2	-	-	10.2
28	10.2	-	-	10.3
29	10.2	-	-	10.3



Around 1st soot blower level



Around 2nd soot blower level

Thickness measurement results

Thickness measurement of tubes (Singrauli #6)

Tube	Material	Designed OD (mm)	Designed t (mm)	Designed Pressure P (kg/cm2)	Designed Temp. (℃)	Allowable Stress S (MPa)	tsr (mm)	Measured (Min) (mm)	Note
Water wall	SA210 Gr.C	51.0	5.6	197.3	416	90.1	5.2	3.7	Erosion around short soot blower
PLATEN SH ST-Ⅱ	SA213 TP347H	54.00	9.50	178	540*	92	> 4.9	9.8	
	SA213 TP347H	63.50	6.30	178	540*	92	> 5.8	2.8	Attrition with bind tubes
	SA213 TP347H	63.50	6.30	178	540*	92	> 5.8	6.3	Soot blower level (#1 from rear side)
	SA213 TP347H	54.00	6.00	178	540*	92	> 4.9	6.3	Soot blower level (#2 from rear side)

*Designed value of header

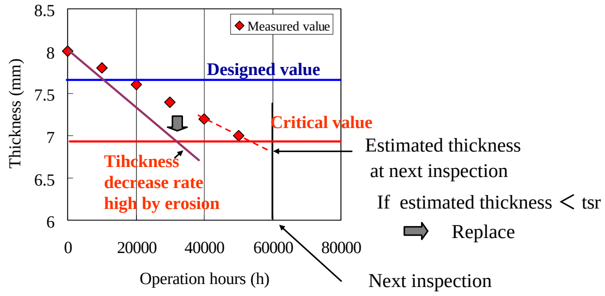
Thickness measurement of tubes (Unchahar #2)

Tube	Material	Designed OD (mm)	Designed t (mm)	Designed Pressure P (kg/cm2)	Designed Temp. (℃)	Allowable Stress S (MPa)	tsr (mm)	Measured (Min) (mm)	Note
Water wall	SA-210, GR.A1	63.5	6.3	175.8	404	86.8	6.1	4.2	Erosion around short soot blower
PLATEN SH (ELE 1)	SA 213 T 22	51	9.6	175.8	566	39.7	9.4	9.8	Highest soot blower level
PLATEN SH (ELE 1)	SA 213 T 22	51	9.6	175.8	566	39.7	9.4	9.8	Second highest soot blower level
PLATEN SH (ELE 2)	SA 213 T 22	51	9.6	175.8	566	39.7	9.4	10.0	Highest soot blower level

t:Thickness

tsr = PD/(2S+P)+0.005D

Thickness management



【 Critical thickness value 】

Japan : tsr (thiciness shell required) by "Technical standards for thermal power generation facilities"

NTPC : Thckness reduction ratio to designed thickness

Thickness management

How to determine design thickness in Japan ?

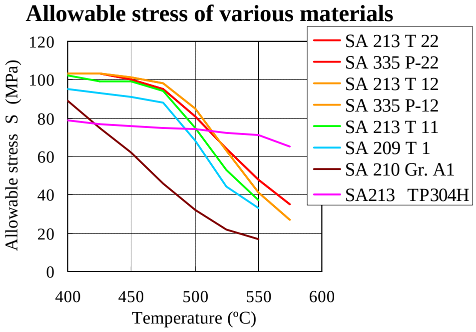
Design temperature T, Material ⇨ Allowable stress S

Allowable stress S + Design pressure P, Design OD D ⇨ tsr ⇨ Designed thickness

Thickness management

How to determine design thickness in Japan ?

Allowable stress of various materials



by Technical standards for thermal power generation facilities

Thickness management

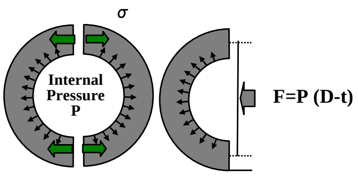
How to determine design thickness in Japan ?

Design temperature T, Material ⇨ Allowable stress S

Allowable stress S + Design pressure P, Design OD D ⇨ tsr ⇨ Designed thickness

Thickness management

How to determine design thickness in Japan ?



F=P (D-t)

$2t\ \sigma = F$

$\sigma = P\,(D - t) / 2t$

σ : Hoop stress

t : thickness

$\sigma = P\,(D-t)/2t \leqq$ Allowable stress S

$tsr = PD / (2S+P) + 0.005D$

Designed thickness $\geqq$ tsr

Thickness management

How to determine design thickness in Japan ?

Design temperature T, Material ⇨ Allowable stress S

Allowable stress S + Design pressure P, Design OD D ⇨ tsr ⇨ Designed thickness

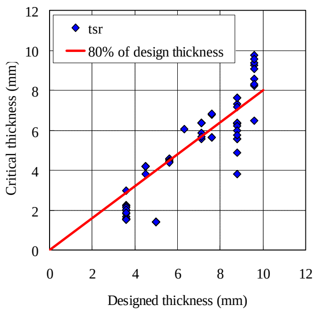
How much mergin to be taken from tsr by OEM ?

Designed thickness = tsr + mergin

If the mergin is small, 80% of designed thickness is not secure.

If the mergin is large, 80% of designed thickness is conservative.

Thickness management criteria



What is to be taken as criteria ?

Where is the origin of designed thickness ?

Integrity calculation documents by OEM is essential.

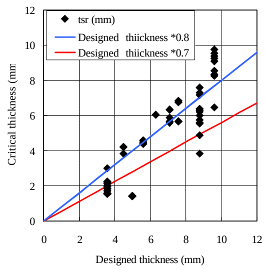
Thickness criterion (Unchahar #2)

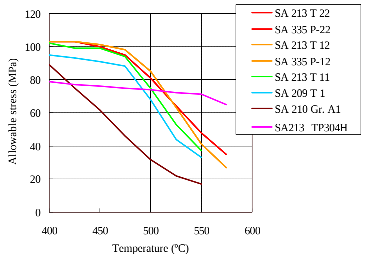
Thickness measurement of tubes

Tube	Material	Designed O.D. D(mm)	Designed t (mm)	Designed Pressure P (kg/cm2)	Designed Temperature (ºC)	Allowable Stress S (MPa)	tsr (mm)	Measured (Min) (mm)	Note
Water wall	SA-210, GR.A1	63.5	6.3	175.8	404	86.8	6.1	4.2	Erosion around short soot blower
Platten SH (ELE 1)	SA 213 T 22	51	9.6	175.8	566	39.7	9.4	9.8	Highest soot blower level
Platten SH (ELE 1)	SA 213 T 22	51	9.6	175.8	566	39.7	9.4	9.8	Second highest soot blower level
Platten SH (ELE 2)	SA 213 T 22	51	9.6	175.8	566	39.7	9.4	10.0	Highest soot blower level

O.D.:Outer Diameter
t:Thickness

tsr = PD/(2S+P)+0.005D





Caluculated designed creep life (Unchahar #2)

Creep life calculation of header and pipe based on disigned condition

Header and Pipe	Material	Designed O.D. D(mm)	Designed t (mm)	Designed Pressure P (kg/cm2)	Designed Temperature (ºC)	Allowable Stress S (MPa)	tsr (mm)	Hoop stress (MPa)	Estimated Life(h) calculated by creep rupture data
Platen SH outlet header	SA 335 P-22	323.9	56	163.8	534	58.2	37.5	35.3	8.58E+06
Re-Heater outlet header	SA 335 P-22	558.8	45	44.1	555	45.4	25.0	23.8	9.19E+06
LTSH outlet header	SA 335 P12	323.9	40	167.6	450	101.0	24.7	60.0	4.81E+08
Links to DESH	SA 335 P12	406.4	45	167.6	450	101.0	31.0	67.6	2.57E+08
DESH	SA 335 P12	406.4	45	167.6	450	101.0	31.0	67.6	2.57E+08
Links from DESH	SA 335 P12	406.4	45	167.6	427	102.8	30.5	67.6	2.25E+09
Platen SH inlet header	SA 335 P12	323.9	40	167.6	427	102.8	24.3	60.0	4.30E+09
Platen SH outlet header	SA 335 P-22	323.9	56	163.8	534	58.2	37.5	35.3	8.58E+06
Links to Final SH	SA 335 P-22	406.4	70	163.4	534	58.2	47.0	35.4	8.49E+06
SH Finish inlet header	SA 335 P-22	406.4	65	163.4	534	58.2	47.0	39.0	5.54E+06
SH Finish outlet header	SA 335 P-22	457.2	100	160.6	555	45.4	63.8	25.0	7.76E+06
Main Steam Pipe	SA 335 P-22	355.6	50.3	160.5	540	54.4	42.8	44.6	1.98E+06
Hot Reheat Pipe	SA 335 P-22	508	28	37.6	540	54.4	16.4	30.9	9.91E+06

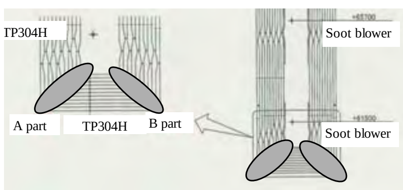
tsr = PD /(2S?+2kP)+a (?=1, a=0)

k	Temperature(ºC) ≦350	480	510	535	565	590	620
Feritic steel	0.4	0.4	0.5	0.7	0.7	0.7	0.7

Detection technique for scale deposition of SUS (Austenite Steel) boiler tube

Detection technique for scale deposition of SUS (Austenitic Steel) boiler tube (1)

(Backgraoud)
Steam oxide scale of austenitic stainless steel (SUS steel) tubes such as TP304, TP321 used for SH and RH, exfoliates and deposits at the bottom inside during long term operation and blocks tube-coolant flow leading to over heat of the tube at down stream side.



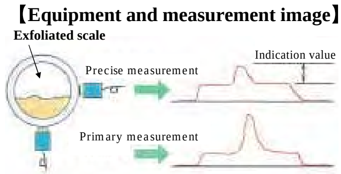
Conventionally γ-ray transmission test method is applied.

From the view point of efficiency and safety

Using the induction principle, the magnetic scale inside of nonmagnetic tube was detected.

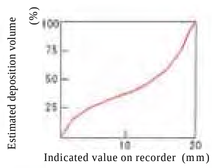
Detection technique for scale deposition of SUS (Austenitic Steel) boiler tube (2)

【Equipment and measurement image】



Measurement technique

Measurement equipment

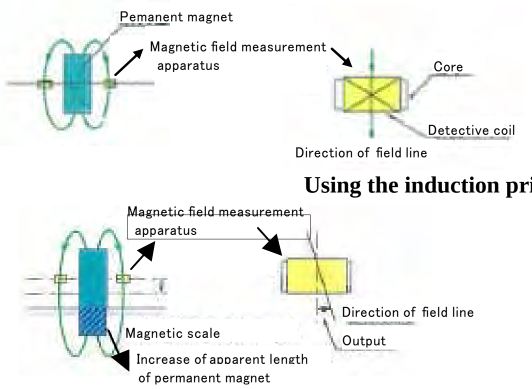


Example of standard curve

Measurement image

Detection technique for scale deposition of SUS (Austenite Steel) boiler tube (3)

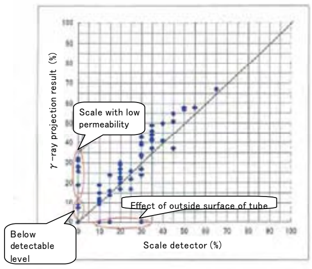
【Detection principle 】



Using the induction principle

Detection technique for scale deposition of SUS (Austenite Steel) boiler tube (4)

【Comparison between γ-ray projection and scale detector results】



【Detectable level】

Detectable level ≧ 10%.

【Effect of outside surface of tube】

The effect of magnetic scale on the tube outside and local magnetization of the tube by long term heat. Suspected signals require to be confirmed by γ-ray detection.

【Scale with low permeability】

The deposit scale with lower permeability than one of reference scale is not detected, such as austenitic stainless steel tips by cutting and limescale etc.

Detection technique for scale deposition of SUS (Austenite Steel) boiler tube (5)

【 Confirmation of scale deposition 】

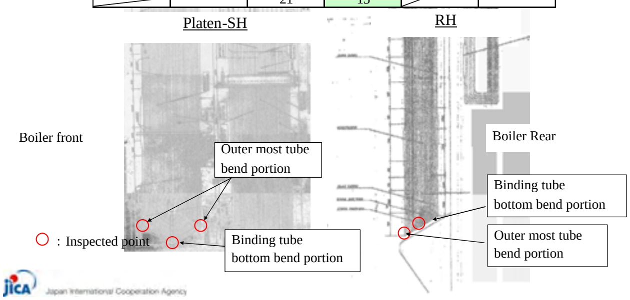
It is preferable to apply γ-ray detection besides scale detector, in order to recognize the effect of the outside surface of tube and the existence of the scale with low permeability.

Sampling inspection by γ-ray detection will improve the accuracy of scale deposition estimation.

SUS scale deposition inspection results (Singrauli #6)

Platen SH (outermost tube)				RH (outermost tube)	
Front		Rear		Front	
Panel No.	Fullness (%)	Panel No.	Fullness (%)	Panel No.	Fullness (%)
14	15	6	15	3	15
20	10	13	10		
21	15	18	10		
		21	15		

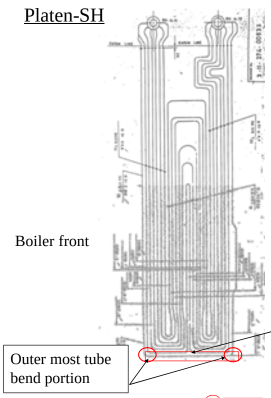
Platen-SH RH



○ : Inspected point

SUS scale deposition inspection results (Unchahar #2)

Platen-SH



Platen Super Heater (Outermost tube bend portion)			
Front		Rear	
Panel No.	Fullness (%)	Panel No.	Fullness (%)
17	10	27	15
18	15		
19	10		
20	15		
22	15		

〔Remarks〕

- Standard curve with φ54.0×t9.5 was used for evaluation of fullness.
- The signal by magnetization of tube material with heat was recognized at front bend, rear bend and horizontal portion.

: Inspected point

DPT (Liquid Panetrant Testing)

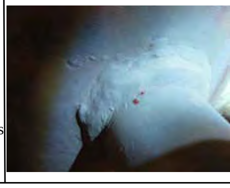
DPT procedure (Platen SH inlet header 4 stub weld portion)

Process			Content
Pretreatment			Remove oil and dirt on the surface using cleaning agents with the defect opnening, then dry thoroughly.
Osmosis treatment			Penetrant is painted on the surface. Keep for 5 to 60 minutes, so that penetrant penetrates enough into the defect.
Removal / cleaning process			Penetrant on the surface is removed with dry waste cloth. Then wiped up with moisturized cloth.
Development process			Developing powder is coated on the surface with a thin and uniform coating, after stirring developing powder spray sufficiently. Development time is usually 10 to 30 minutes.
Observation			Observe the surface of test material in a bright place. Crack (flaw) appears as red indication on a white background.

More careful surface treatment with wire blush

More carefully

DPT results (Platen SH inlet header 4 stub weld portion)

	After DPT	After grinding off
【Singrauli #6 】 ✓One linear indication in tube side. ✓Disappeared after grinding off 1mm depth from surface.		
【Uncahar #2】 ✓ Two circular indication pattern were detected. ✓ After grinding off, a new circular indication pattern appeared, that was not judged as crack.		

DPT (Liquid Panetrant Testing) (1)

【Classification of penetrant indication 】

Based on JIS Z 2343-1:2005 「Non-destructive testing－Penetrant testing－Part 1 : General principles－Method for liquid penetrant testing and classification of the penetrant indication」

＊Classification of the penetrant indication

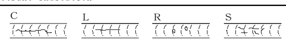
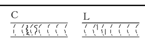
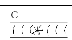
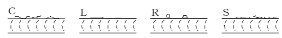
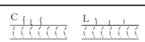
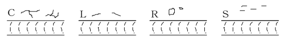
Classification of the penetrant indication		Mark	Definition
Isolated penetrant indication	Indication by cracking	C	Indication by cracking
	Indication with linear pattern	L	Indication in length more than 3 times as width except for cracking
	Indication with circular pattern	R	Non linear indication except for cracking
Continuous penetrant indication		F	A number of indication exisisting on a line
Dispersed penetrant indication		S	A number of indication exisisting in a constant area

DPT (Liquid Panetrant Testing) (2)

【Classification by the position and direction in weld 】

Based on JIS Z 2343-1:2005 「Non-destructive testing－Penetrant testing－Part 1 : General principles －Method for liquid penetrant testing and classification of the penetrant indication」

＊Classification by the position and the direction in weld

Position and direction of penetrant indication	Mark	illustration (C,L,R ,S in figures show classification of the penetrant indication
Longitudinal direction along weld line	A	
Horizontal direction perpendicular to weld line	B	
In weld metal	X	
Longitudinal direction along HAZ line	C	
Horizontal direction perpendicular to HAZ line	D	
In Base metal	E	

8x2F : More than 2 indications with 8mm in length on a line
(0. 5) : 0.5mm depth of flaw

DPT (Liquid Panetrant Testing) (3)

【Criteria for indication by “Technical standards for thermal power generation facilities” 】

Based on JIS Z 2343-1:2005 「Non-destructive testing－Penetrant testing－Part 1 : General principles －Method for liquid penetrant testing and classification of the penetrant indication」

- No penetrant indication by crack
- No linear penetrant indication and indication by linear flaw with longer than 1mm in length.
- No circular penetrant indication and indication by circular flaw with longer than 4mm in length.
- In case of 4 or more circular penetrant indications or circular indications by circular flaw located in a line, the spacing between adjacent indications needs to be longer than 1.5mm.
- No more than 10 or more circular penetrant indications or circular indications by circular flaw are included within the rectangular area of 3750mm^2(short side length is longer than 25mm)

Ultrasonic testing
TOFD (Time of Flight Diffraction)

Ultrasonic testing (1)

Radiographic testing and ultrasonic testing are the typical nondestructive testing that inspects the inside of weld of tubes and pipes. In general, when setting Radiographic film is difficult, the ultrasonic testing is applied.

【Detecting equipment】

- **DSM35 Krautkramer Universal UltrasonicFlaw Detector**

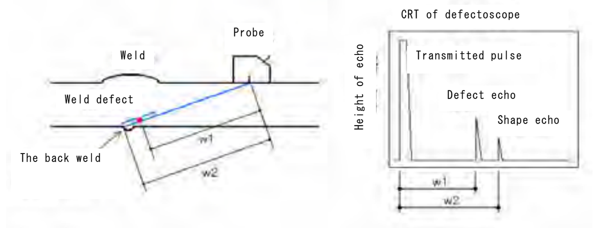
【Couplant】

- **Glycerin paste or glycerin solution with the 75% concentration or more.**

Ultrasonic testing (2)

【Principle of ultrasonic testing (UT) 】

As for the butt-weld joint, "angle beam method" is usually applied because of weld reinforcement.



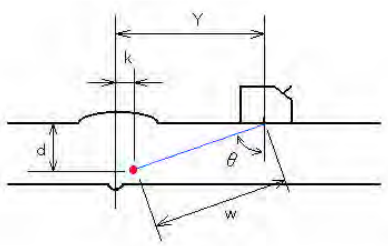
Ultrasonic testing (3)

【Calculation of defect position】

Y can be measured with the scale and W can be read from CRT.
The position of the defect can be calculated by the following formula.

$d = W \times \cos\theta$
$k = Y - W \times \sin\theta$

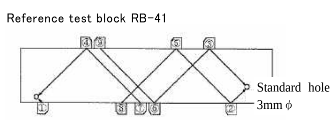
θ (angle of refraction) is measured beforehand, usually using nominal value 40,45,60,65,70.



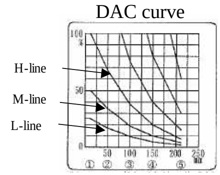
Ultrasonic testing (4)

【Distinction of defect and measurement of echo height】

The echo that appears on CRT is judged whether a defect or not (shape echo) from the reflection source and the echo height. The reflection source is calculated from d and k in equations. If it is located in the weld, the echo is judged to come from a weld defect. The H-line is defined by linking the heights of the echo on CRT that reflects at the drilled hole with 3mm in the diameter of reference test block RB41. M -line is a half of H-line (-6db), L -line is a quarter of the height of H-line (-12db). These lines are called as "Dividing curves of echo height "That is made before flaw detection. The echo that exceeds L line in this echo height area during scanning the probe for flaw detection is judged to be a defect based on L line .



DAC curve



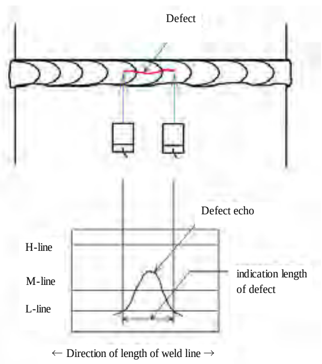
(JIS Z3060：2002)

Ultrasonic testing (5)

【Measurement of length of defect】

The range that exceeds L line during scanning the probe along the direction of the weld line is defined as "the indication length of defect".

(JIS Z3060：2002)



Ultrasonic testing (6)

【Classification of flaw 】

Echo height area and classification of flaw by indication length of flaw						
Area	Ⅲ in case of level M detection Ⅱ and Ⅲ in case of level L detection			Ⅳ		
thickness (t) / Classification	18 ≦ t	18 ＜ t ≦ 60	60 ＜ t	18 ≦ t	18 ＜ t ≦ 60	60 ＜ t
The first class	≦ 6	≦ t/3	≦ 20	≦ 4	≦ t/4	≦ 15
The second class	≦ 9	≦ t/2	≦ 30	≦ 6	≦ t/3	≦ 20
The third class	≦ 18	≦ t	≦ 60	≦ 9	≦ t/2	≦ 30
The fourth class	The one exceeding the third class					
JIS Z3060:2002 from appendix 7 of examining ultrasonic wave of welded steel joint						

Ultrasonic testing (7)

【Acceptance Criteria】

To satisfy either of the following (1) or (2).

(1) Height of the reflected wave from the flaw in the weld on CRT must be below the height of reflected wave from the reference hole corrected by the probe to flaw distance.

(2) The length of the flaw from which the height of the reflected wave on CRT beyond the height of reflected wave from the reference hole corrected by probe to flaw distance, must be the value or less as shown below.

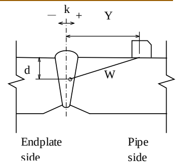
Division of thickness of weld(mm)	Length(mm)
t ≦ 18	6
18 < t ≦ 57	1/3 of thickness of weld
57 < t	19

*Technical standards for thermal power generation facilities

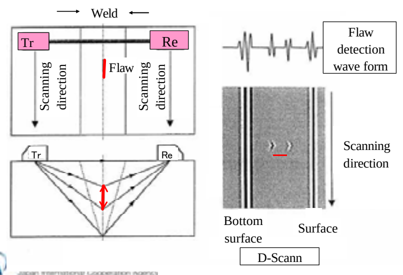
TOFD (Time of Flight Diffraction) method (1)

【UT inspection 】

- ✓ **Angle beam probe detection**
- ✓ **Angle of refraction 70 °**



【TOFD inspection 】



- ✓ **High inspection efficiency**
- ✓ **Flaw sizing in depth direction**
- ✓ **High sensitivity**

TOFD (Time of Flight Diffraction) method (2)

Time of Flight Diffraction (TOFD) method of Ultrasonic inspection is a very sensitive and accurate method for nondestructive testing of welds for defects.

【Detecting equipment】

- ➢ **μ -Tomoscan(R/D Tech)**
  Amplitude linearity : within ±3% based on JIS Z 2352 4.1.
  Time base linearity : within ±1% of full scale based on JIS Z 2352 4.2.

【Probes and Wedges】

- ➢ **Probes for transmission and receiver are the longitudinal wave angle beam probe with the same performance.**
  Wave frequency: 2～10MHz
  Resonator dimensions: 0.25in～0.5in
  Wedges: the longitudinal wave angle 45° or 60°

【Couplant】

Glycerin paste or glycerin solution with the 75% concentration or more.

TOFD (Time of Flight Diffraction) method (3)

【Test sample】

➢Test sample with same dimension as inspected part is preferable .

【An example of selection of transducers and transducers spacing 】

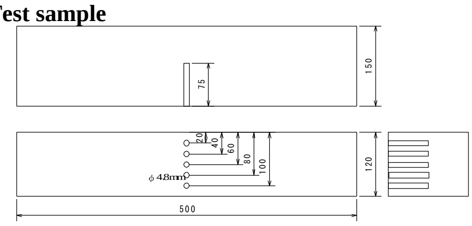
Thickness of sample (mm)	Number of pair of transducers	Center wave frequency (MHz)	Dimension of transducers (mm)	Nominal refractive angle (°)	Transducers spacing (mm)
25	1 pair	5～10	2～6	60	58
90	2 pairs	5～10	2～6	60	69
		2～5	6～12	45	140

TOFD (Time of Flight Diffraction) method (4)

【Sensitivity of detection】

➢The sensitivity of detector is adjusted at the 80% of echo height from the horizontal cave that is the lowest echo. Also the noise level is kept at lower than 5 to 10%.

Test sample

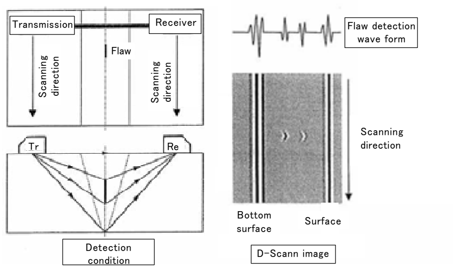


TOFD (Time of Flight Diffraction) method (5)

【Flaw detection 】

➢The pair of probes across the weld line is manually scanned in the direction parallel to the weld.

➢The range of flaw to detect is within the extent to 1 inch (25.4mm) away from weld potion.

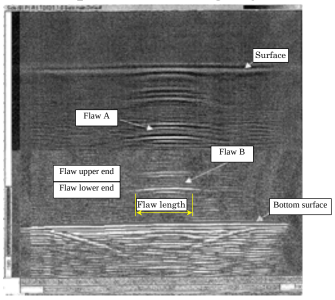


TOFD (Time of Flight Diffraction) method (6)

【Evaluation】

➢**Flaw (depth, length and height) is evaluated by D-scan image.**

An example of flaw image by D-scan

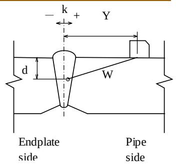


UT& TOFD inspection

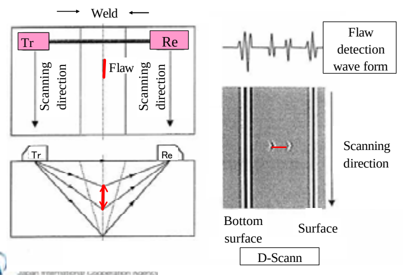
【UT inspection 】

✓ **Angle beam probe detection**

✓ **Angle of refraction 70 °**



【TOFD inspection 】



✓ **High inspection efficiency**

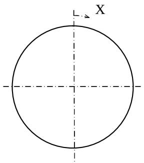
✓ **Flaw sizing in depth direction**

✓ **High sensitivity**

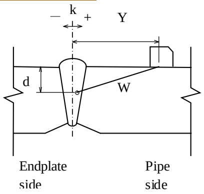
UT inspection results （Singrauli #6)

UT ・ TOFD inspection location

(RH outlet header)



View from end plate



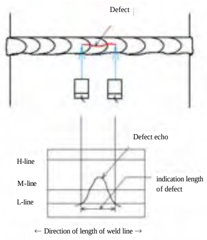
UT detection results

Flaw ?	X	Y	W	d	k	Region of echo height	l	Remarks
1	582	93	104.6	37.5	-4.7	Ⅱ	10	Out of scope of TOFD inspection
2	820	122	129.2	46.3	1.4	Ⅲ	34	
3	940	51	26.8	9.6	26	Ⅱ	6	
4	1110	101	101.3	36.3	6.4	Ⅱ	8	

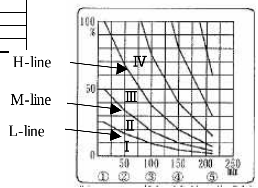
UT inspection results （Singrauli #6)

UT detection results

Flaw ?	X	Y	W	d	k	Region of echo height	l	Remarks
1	582	93	104.6	37.5	-4.7	Ⅱ	10	Out of scope of TOFD inspection
2	820	122	129.2	46.3	1.4	Ⅲ	34	
3	940	51	26.8	9.6	26	Ⅱ	6	
4	1110	101	101.3	36.3	6.4	Ⅱ	8	



Dividing curves of echo height



【Acceptance Criteria】

Region of echo height Ⅳ

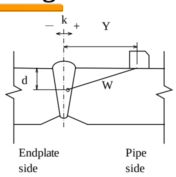
Division of thickness of weld (mm)	Length (mm)
t≦18	6
18＜t ≦ 57	1/3 of thickness of weld
57＜ t	19

*Technical standards for thermal power generation facilities

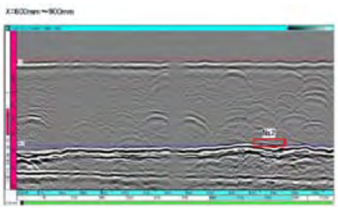
Correspondence between UT and TOFD inspection result (Singrauli 6 unit)

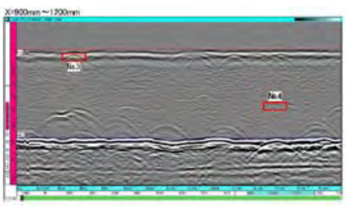
UT detection results

Flaw ?	X	Y	W	d	k	Region of echo height	l	Remarks
1	582	93	104.6	37.5	-4.7	Ⅱ	10	Out of scope of TOFD inspection
2	820	122	129.2	46.3	1.4	Ⅲ	34	
3	940	51	26.8	9.6	26	Ⅱ	6	
4	1110	101	101.3	36.3	6.4	Ⅱ	8	



【 TOFD inspection result 】





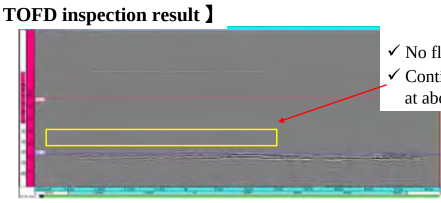
UT inspection results （Unchahar #2)

UT ・ TOFD inspectio n location

(Final SH outlet header)

✓ No flaw echo exceeding the criteria was detected by UT.

【 TOFD inspection result 】



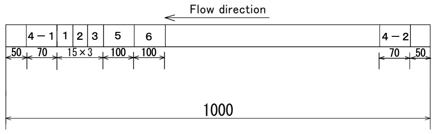
✓ No flaw echo judged as a crack.

✓ Continuous subtle flaw echoes at about 80mm in depth from surface.

Sample tube inspection

Sample tube inspection (1)

【Examination items 】



1： Scale thickness on inner surface of tube・Microstructure
2： Hardness
3： Tube Dimension
4－1： Scale volume on inner surface of tube (upper side) Observation of scale surface
4－2： Scale volume on inner surface of tube (under side)
5： Scale composition・Appearance of tube
6： Preservation

Sample tube inspection (2)

【 Tube appearance observation 】

Cutting the tube → Acid cleaning → Observation

100 mm in length

Dissolute in the acid solution
H_2O………77.6 ml
HCl………22.2 ml（8%）
Inhibitor……0.2 ml（2%）
at 60±5℃ for 1～2Hr

or

Dissolute in the ammonia solution
H_2O……58.8 ml
HCl………40 ml（10%）
H_2O_2 …1.2 ml（1.2%）
40 ~ 50 ℃ for 60 to 90 minutes
（until Cu is removed.）

Appearance of fireside of tube outside

As received

After acid cleaning

Appearance of fireside of tube inside

As received

After acid cleaning

Sample tube inspection (3)

【 Tube Dimension 】

Cutting the tube → Acid cleaning → Grinding → Measurement

12～18mm in thickness

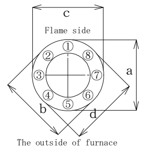
hydrochloric acid ammonia solution
HCL(35%) …29ml
Inhibitor………1ml （60±5℃）

or

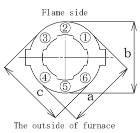
Ammonia（28%）…16ml
Bromine acid soda…… 1 g
Bicarbonate of ammonium 1.2g
（room temperature）

80 → # 600 waterproof SiC paper

- Comparison with designed dimension
- Local thinning (High temperature corrosion, local corrosion
- Deformation （Bulging）



a～d：Outside diameter
①～⑧：Thickness



a～c：Outside diameter
①～⑥：Thickness

Sample tube inspection (4)

【 Hardness measurement 】

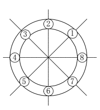
Cutting the tube → Grinding → Measurement

12～18mm in thickness

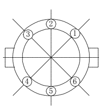
80 → # 600 water proof SiC paper

Vickers hardness test
or
Rockwell hardness test

- Comparison with virgin material data



No fin tube



Fin tube

Average of 3 times measurement for each points

Sample tube inspection (5)

【 Scale composition analysis 】

Cutting the tube → Dissolution of scale on inside surface → Evaporation to dryness → Dissolution in the acid solution for chemical analysis → Atomic Absorption Spectrometry analysis

100 mm in length

Dissolute in the acid solution
H_2O………77.6 ml
HCl………22.2 ml（8%）
Inhibitor……0.2 ml（2%）
at 60±5℃ for 1～2Hr

or

Dissolute in the ammonia solution
H_2O……58.8 ml
HCl………40 ml（10%）
H_2O_2 …1.2 ml（1.2%）
40 ~ 50 ℃ for 60 to 90 minutes
（until Cu is removed.）

Dissolute in the acid solution HCl 10cc， before HNO_3 10cc

for Atomic Absorption Spectrometry analysis

Analysis elements
Fe, Cu, Ni, Mn, Zn, Al
Fe_3O_4 : Fe＝1.38 : 1 ∴ Fe_3O_4＝Fe×1.38
CuO＝Cu×1.25, NiO＝Ni×1.27, MnO＝Mn×1.29,
ZnO=Zn×1.24, Al_2O_3＝Al×1.89

Sample tube inspection (6)

【 Scale adhesion volume】

- Cutting the tube — 70 mm in length
- ↓ Removal of slag on outside surface with grinder
- ↓ Cutting the tube into furnace inside and outside
- ↓ Weight measurement with electronic balance
- ↓ Removal of scale with electrical polishing
- ↓ Measurement of weight loss with electronic balance

Electrolyte composition（10%sulfate）
Sulfate(H_2SO_4（98%） 85 ml
Inhibitor……8 ml（2%）
Thiourea (CSN2H4) 30g
Distilled water
Total 1500ml

Scale weight of unit area mg/cm2

Sample tube inspection (7)

【 Scale observation】

- Cutting the tube — 12～18mm in thickness
- ↓ Mounting — Cold mounting with epoxy resins or acrylic resins
- ↓ Grinding — # 80 → # 1500 water proof SiC paper
- ↓ Polishing — Polishing is achieved with steps of successively finer abrasive particles with diamond particle or oxide particle 3 μ m→0.1 μ m.
- ↓ Scale observation


Scale on water wall tube inside

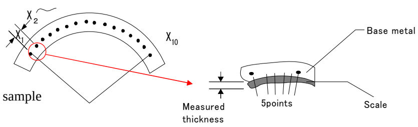

Scale on SH tube inside

The area at which the scale thickness is measured at fire side is observed with optical microscope ×100～×200 in magnification

Sample tube inspection (8)

【 Scale thickness measurement】

- Cutting the tube — 12～18mm in thickness
- ↓ Mounting — Cold mounting with epoxy resins or acrylic resins
- ↓ Grinding — # 80 → # 1500 water proof SiC paper
- ↓ Polishing — Polishing is achieved with steps of successively finer abrasive particles with diamond particle or oxide particle 3 μ m→0.1 μ m.
- ↓ Scale thickness measurement



・ Average thickness in 90°（180°）of sample area
・ Maximum thickness of scale
・ Scale conversion rate（Combined with the results of scale volume）

Scale conversion rate＝μ m／mg・cm²

Sample tube inspection (9)

【 Microstructural observation】

- Cutting the tube — 12～18mm in thickness
- ↓ Mounting — Cold mounting with epoxy resins or acrylic resins
- ↓ Grinding — # 80 → # 1500 water proof SiC paper
- ↓ Polishing — Polishing is achieved with steps of successively finer abrasive particles with diamond particle or oxide particle 3 μ m→0.1 μ m.
- ↓ Scale observation

The area at fire side is observed with optical microscope ×100,×400 in magnification

Sample tube inspection （Sample tube specification Singrauli #6 ）

Sample	Material	Designed OD×t(mm)	Designed Temperature(℃)	Designed Pressure (MPa)
Platen-SH #12-3	SA213T11※	ϕ 47.63×t8.6	Not availabl	17.46
	SA213T11	ϕ 47.63×t10.0	Not available	
RH #3-1 (in penthouse)	SA213T22※	ϕ 54.0×t5.6	540	5.27
	SA213T22	ϕ 54.0×t5.6	540	
RH #14-5 (in furnace)	SA213T22	ϕ 54.0×t4.5	Not available	5.27
	SA213T11※	ϕ 54.0×t4.0	Not available	

Chemical composition analysis results by spark discharge optical emission analysis (wt%)

Sample tube	C	Si	Mn	P	S	Cr	Mo
Platen-SH#12-3	0.10	0.53	0.38	0.026	0.012	1.14	0.46
RH #3-1 (in penthouse)	0.10	0.28	0.45	0.013	0.008	2.20	0.95
RH #14-5 (in furnace)	0.10	0.67	0.41	0.006	0.008	1.30	0.58
SA213T11 (JIS-STBA23)	≦0.15	0.50～1.00	0.30～0.60	≦0.030	≦0.030	1.00～1.50	0.45～0.65
SA213T22 (JIS-STBA24)	≦0.15	≦0.50	0.30～0.60	≦0.030	≦0.030	1.90～2.60	0.87～1.13

Sample tube inspection （Sample tube specification Unchahar #2 ）

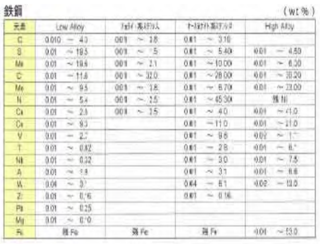
Sample	Material	Designed OD×t(mm)	Designed Temperature (℃)	Designed Pressure (MPa)
Platen-SH #3-8	SA213T22	ϕ51.0×t9.6	553	17.24
	SA213T11※	ϕ51.0×t7.1	503	
Final-SH #1	SA213T22	ϕ51.0×t9.6	554	17.24
	SA213T22※	ϕ51.0×t8.8	545	
Final-SH #119	SA213T22	ϕ51.0×t9.6	545	17.24
	SA213T22※	ϕ51.0×t8.8	534	

Chemical composition analysis results by spark discharge optical emission analysis (wt%)

Sample tube	C	Si	Mn	P	S	Cr	Mo
Platen-SH #3-8	0.09	0.58	0.44	0.032	0.010	1.12	0.49
Final-SH #1	0.10	0.24	0.42	0.030	0.012	2.20	0.95
Final-SH #119	0.10	0.24	0.42	0.030	0.013	2.22	0.96
SA213T11 (JIS-STBA23)	≦0.15	0.50～1.00	0.30～0.60	≦0.030	≦0.030	1.00～1.50	0.45～0.65
SA213T22 (JIS-STBA24)	≦0.15	≦0.50	0.30～0.60	≦0.030	≦0.030	1.90～2.60	0.87～1.13

Portable chemical analysis equipment (for information)

Portable chemical composition analysis by spark exititation



鉄鋼 (wt %)

元素	Low Alloy	フェライト系ステンレス	オーステナイト系ステンレス	High Alloy
C	0.010 ~ 4.0	0.01 ~ 1.8	0.01 ~ 3.10	
Si	0.01 ~ 18.5	0.01 ~ 1.5	0.01 ~ 5.40	0.01 ~ 4.50
Mn	0.01 ~ 19.6	0.01 ~ 2.1	0.01 ~ 10.00	0.01 ~ 6.30
Cr	0.01 ~ 11.6	0.01 ~ 32.0	0.01 ~ 28.00	0.01 ~ 30.20
Mo	0.01 ~ 9.5	0.01 ~ 1.8	0.01 ~ 8.70	0.01 ~ 23.00
Ni	0.01 ~ 5.4	0.01 ~ 2.5	0.01 ~ 45.30	残 Ni
Cu	0.01 ~ 2.5	0.01 ~ 1.5	0.01 ~ 4.0	0.01 ~ [illegible]
Co	0.01 ~ 9.3		0.01 ~ 11.0	0.01 ~ 21.0
V	0.01 ~ [illegible]		0.01 ~ 9.6	0.02 ~ [illegible]
Ti	0.01 ~ 0.82		0.01 ~ 2.8	0.01 ~ [illegible]
Nb	0.01 ~ 0.32		0.01 ~ 3.0	0.01 ~ 7.5
Al	0.01 ~ [illegible]		0.01 ~ 3.1	0.01 ~ 6.6
W	0.04 ~ [illegible]		0.04 ~ 8.1	0.02 ~ 13.0
Zr	0.01 ~ 0.16		0.01 ~ 0.16	
Pb	0.01 ~ 0.25			
Mg	0.01 ~ 0.10			
Fe	残 Fe	残 Fe	残 Fe	0.01 ~ 53.0

Sample tube inspection items

Singrauli #6 Sample tube	Inspection item						
	1	2	3	4	5	6	7
	Outer surface appearance	Internal surface appearance	Tube dimension・Hardness	Metallography	Scale analysis	RLA by microstructure degradation	Creep rupture test
Platen-SH #12-3	○	○	○	○	○	○	○
RH #3-1 (in penthouse)	○	○	○	○	○	○	–
RH #14-5 (in furnace)	○	○	○	○	○	○	○

Unchahar #2 Sample tube	Inspection item						
	1	2	3	4	5	6	7
	Outer surface appearance	Internal surface appearance	Tube dimension・Hardness	Metallography	Scale analysis	RLA by microstructure degradation	Creep rupture test
Platen-SH	○	○	○	○	○	○	○
Fainal-SH#1	○	○	○	○	○	○	–
Fainal-SH#119	○	○	○	○	○	○	○

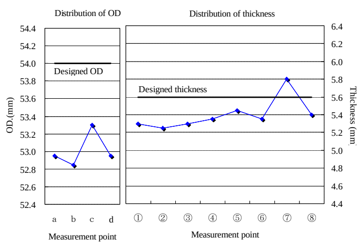
Sample tube inspection (Outer surface appearance)

- ✓ Trace of corrosion at outside surface
- ✓ Slightly rough condition at inside surface

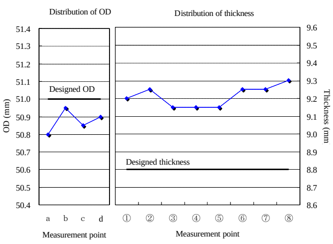
Dissolute in the acid solution
H_2O………77.6 ml
HCl………22.2 ml （8%）
Inhibitor……0.2 ml （2%）
at 60±5℃ for 1～2Hr

Sample tube inspection (Tube dimension)

RH(in penthouse) Singrauli #6



Final-SH #1 Unchahar #2

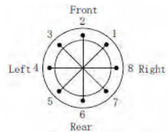


Singrauli #6

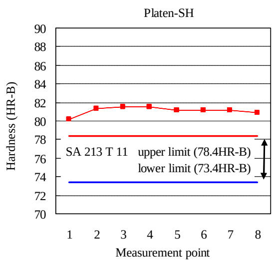
- ✓ OD of RH tubes in penthouse and in furnace was less than designed value.
- ✓ Thickness of RH tubes in penthouse was less than designed value.

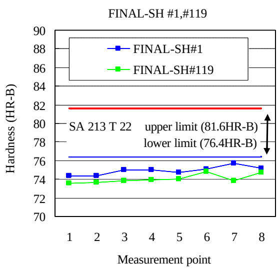
Unchahar #2

- ✓ OD of each tube was less than designed value.
- ✓ Thickness of each tube was larger than the designed value.

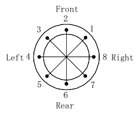


Sample tube inspection (Hardness)

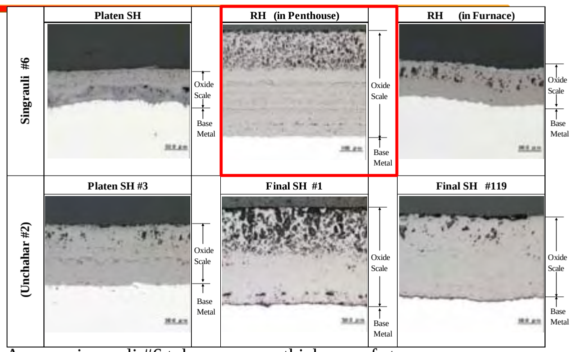




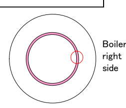
- ✓ Hardness values were stable in circumferential direction.
- ✓ Measured values in SA213T11 were higher than the normal value of virgin material by Japanese steel manufacturer.
- ✓ Measured values in SA213T22 were lower than the normal value of virgin material by Japanese steel manufacturer.



Sample tube inspection (Steam oxide scale adhering condition)

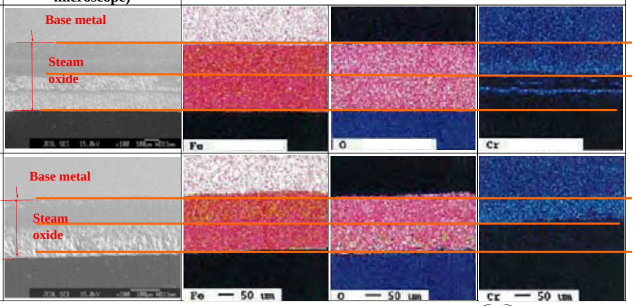


- ✓ Among singrauli #6 tubes, average thickness of steam oxide scale was remarkably large in RH tube(in penthouse) 500 μ m.

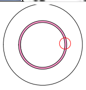


Sample tube inspection (Steam oxide scale composition analysis)

	SEM Image (Scanning electron microscope)	Element Mapping Image by EPMA (Electron probe micro analyzer)
Singrauli #6		
(Unchahar #2)		



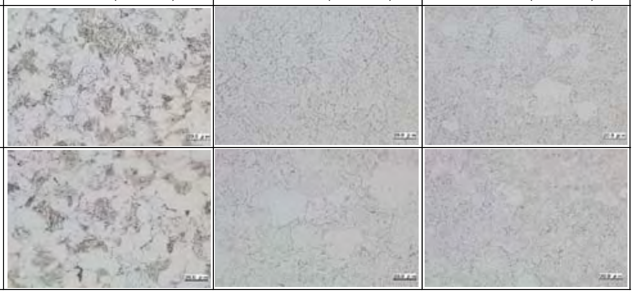
✓ Dual layer comosed of inner layer (Fe, O, Cr) and outer layer (Fe, O).



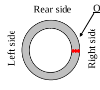
Sample tube inspection (Metallogrphy)

Singrauli #6

	Platen-SH (SA213T11)	RH-Penthouse (SA213T22)	RH-Furnace (SA213T22)
Outside surface side			
Inside surface side			



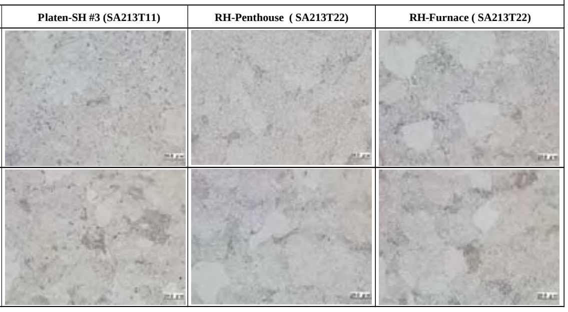
✓ Slight degradation observed in RH-Penthouse (SA213T22).



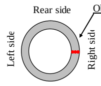
Sample tube inspection (Metallogrphy)

Unchahar #2

	Platen-SH #3 (SA213T11)	RH-Penthouse (SA213T22)	RH-Furnace (SA213T22)
Outside surface side			
Inside surface side			



✓ No remarkable degradation for each tube

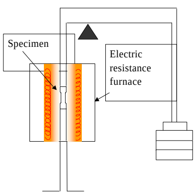


Creep rupture test

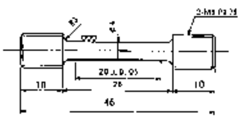
Creep rupture test (1)

Creep rupture test is the most reliable method to evaluate the remaining creep life.

(Test machine)



(Example of specimen for creep rupture test)



➢ **The larger size of specimen is better because of oxidation during the test.**

(Test condition)

➢**Test condition is determined based on the hoop stress under operational condition.**

➢**In order to shorten the test time, test stress or temperature are set at higher than operational condition.**

Creep rupture test (Parameter method) (2)

(Example of test condition and result by parameter method)

➢ **The lowest stress is almost same stress as operational stress .**
The temperature is set so that the estimated creep rupture time is within about 3000hrs .

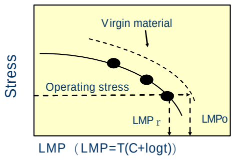
➢ **With the test temperature and rupture time, LMP (Larson-Miller parameter) is obtained.**

Sample	Material	Test condition		Estimated rupture time (h)	Rupture time t (h)	Rupture LMP C=15.8
		Temperature T (℃)	Stress (MPa)			
2nd SH tube	A213 T22	670	30	2,500	1,200	17,806
		670	40	1,500	600	17,522
		670	50	800	400	17,356
		670	60	400	100	16,788

LMP = (273.15+T) (C+log t)

Creep rupture test (Parameter method) (3)

- **If the reliable virgin material data is available, the equivalent temperature can be estimated and residual life is evaluated with the equivalent temperature instead of designed temperature.**



LMPr by test data at operating stress
LMPo by virgin material data base at operating stress

Assumption :

Initial creep rupture strength = Virgin material data

Residual life "tr" at a temperature T : $tr = 10^{(LMPr/T - C)}$

The whole life " t " of the virgin material at a temperature T : $t = 10^{(LMPo/T - C)}$

To hold the assumption that " $t = tr + to$ (to: operating hour)" ,

appropriate T_E can be determined.

The residual life tr is calculated at temperature T_E

$tr = 10^{(LMPo/(273.15+T_E) - C)}$

Creep rupture test (Isostress method) (4)

(Example of test condition and result)

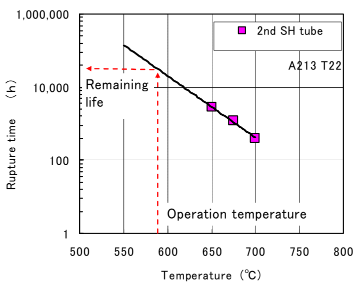
- **The stress is set same as operational stress .**
- **The lowest temperature is set so that the estimated creep rupture time is within about 3000hrs .**

Sample	Material	Test condition		Estimated rupture time	Rupture time
		Temperature T (℃)	Stress (MPa)		t (h)
2nd SH tube	A213 T22	650	30	2,500	2,400
		675	30	1,000	1,200
		700	30	200	400

Creep rupture test (Isostress method) (5)

(Evaluation of test result by Isostress method)

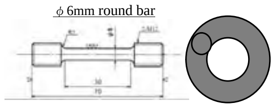
- **The rupture time is extrapolated to operation temperature.**



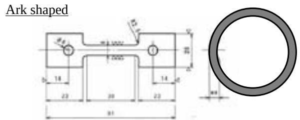
Creep rupture test (condition and test specimens) Singrauli #6

Sample tube	Portion	Material	Test condition		Shape of specimen
			Tem. (℃)	Stress (MPa)	
Platen-SH	Base Metal	SA213T11	665	49.0	f 6mm round bar
			665	63.7	
			700	38.3	
	Weld Metal	SA213T11	665	49.0	
			665	63.7	
			700	38.3	
RH(in furnace)	Base Metal	SA213T11	665	44.1	Arc shaped
			665	58.8	
			700	27.9	
	Weld Metal	SA213T11	665	44.1	
			665	58.8	
			700	27.9	

φ 6mm round bar



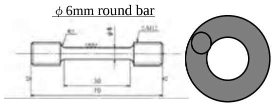
Ark shaped



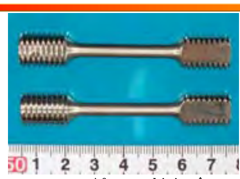
Creep rupture test (condition and test specimens) Unchahar #2

Sample tube	Portion	Material	Test condition		Shape of specimen
			Tem. (℃)	Stress (MPa)	
Platen-SH	Base Metal	SA213T11	635	68.6	φ 6
			635	83.4	
			665	45.9	
	Weld Metal	SA213T11	665	68.6	
			665	83.4	
			700	45.9	
Final-SH #119	Base Metal	SA213T22	665	63.7	φ 6
			665	78.5	
			700	38.3	
	Weld Metal	SA213T22	665	63.7	
			665	78.5	
			700	38.3	

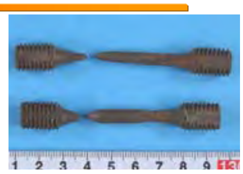
φ 6mm round bar



Creep rupture test specimens before and after testing

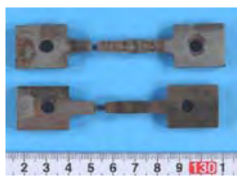


After machining ↑



After creep rupture test ↑

After machining ↑



After creep rupture test ↑

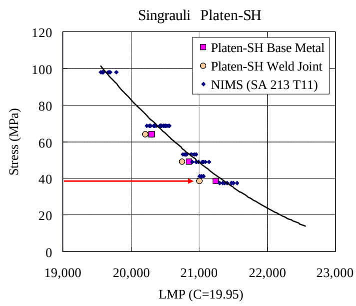
Creep rupture test results Singrauli #6

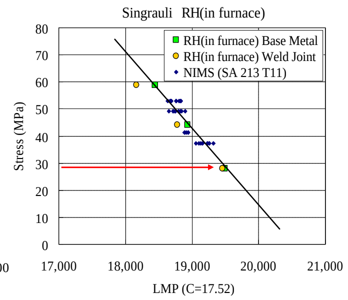
Component		Material	Test condition Temp. T(℃)	Test condition Stress (MPa)	Rupture time t (h)	LMP* C=19.95	Fracture elongation (%)	Reduction of area (%)
Platen-SH	Base Metal	SA 213 T11	665	49.0	187.7	20,852	102	97
			665	63.7	48.7	20,302	87	94
			700	38.3	76.1	21,248	88	94
	Weld Metal	SA 213 T11	665	49.0	149.0	20,758	36	92
			665	63.7	39.0	20,212	44	92
			700	38.3	43.5	21,012	35	95

Component		Material	Test condition Temp. T(℃)	Test condition Stress (MPa)	Rupture time t (h)	LMP* C=17.52	Fracture elongation (%)	Reduction of area ** (%)
RH(in furnace)	Base Metal	SA 213 T11	665	44.1	457.0	18,933	53	57
			665	58.8	139.2	18,448	62	63
			700	27.9	319.4	19,488	39	55
	Weld Metal	SA 213 T11	665	44.1	310.9	18,776	20	52
			665	58.8	69.3	18,164	13	53
			700	27.9	296.8	19,457	16	56

- LMP=(273.15+T) (C+log t)
- Facture elongation: (L-Lo)/Lo, Lo: Initial gauge length, L: Gauge length after rupture
- Reduction of area : (Ao-A)/Ao, Ao: Initial cross sectional area, A: cross sectional area after rupture

Creep rupture test results Singrauli #6





NIMS : Natinal Institute of Materials Science

✓Creep rupture strength of base metal in Platen-SH is lower than NIMS data.

✓ Creep rupture strength of base metal in RH (in furnace) is almost same as NIMS data.

* LMP=(273.15+T) (C+log t)

Residual life evaluation by creep rupture test Singrauli #6

Parameter method (evaluated at designed temp.)								
Component		Material	Hoop Stress σ (MPa)	LMP obtained by creep rupture test C=19.95 (SH) C=17.52 (RH)	Designed temp.T (℃)	Residual life tr (h)	Creep life consumption ratio φc to/(to+tr)	Evaluated residual life tr/2 (h)
Platen-SH	Base Metal	SA 213 T11	38.3	21,248	540(※1)	1,505,000	0.10	750,000
	Weld Joint	SA 213 T11	38.3	21,012	540(※1)	770,000	0.18	380,000
RH(in furnace)	Base Metal	SA 213 T11	27.9	19,488	540(※2)	2,783,000	0.06	1,300,000
	Weld Joint	SA 213 T11	27.9	19,457	540(※2)	2,549,000	0.06	1,200,000

※1; Designed temp. at Platen-SH Outlet Header
※2; Designed temp. at RH Outlet Header
Operation hours to: 172000 h

✓ Hoop stress σ = P (D-t) / 2t

where P : Designed pressure
D : Measured OD of sample tube
t : Measured thickness of sample tube

✓ $tr = 10^{(LMP/(273+T)-C)}$

Residual life evaluation by creep rupture test Singrauli #6

Parameter method (evaluated at equivalent temp.)									
Component		Material	Hoop Stress σ (MPa)	LMP obtained by creep rupture test C=19.95 (SH) C=17.52 (RH)	LMPo by NIMS virgin material	Equivalent temperature T_E (℃)	Residual life tr (h)	Creep life consumption ratio φc to/(to+tr)	Evaluated residual life tr/2 (h)
Platen-SH	Base Metal	SA 213 T11	38.3	21,248	21,339	553	598,000	0.22	290,000
	Weld Joint	SA 213 T11	38.3	21,012	21,339	553(※3)	309,000	0.36	150,000
RH(in furnace)	Base Metal	SA 213 T11	27.9	19,488	19,531	551	1,347,000	0.11	670,000
	Weld Joint	SA 213 T11	27.9	19,457	19,531	551(※3)	1,235,000	0.12	610,000

※3; Same equivalent temperature used as base metal
Operation hours to: 172000 h

<u>Assumption : Initial creep rupture strength = NIMS data</u>

$$LMPo = (273.15+T_E) (C+\log (to+tr))$$

$$tr = 10^{(LMP/(273.15+T_E) - C)}$$

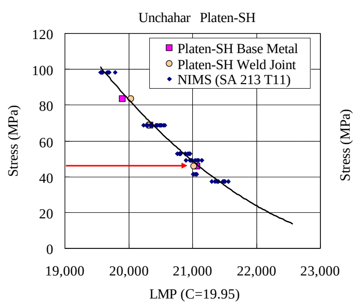
Creep rupture test results Unchahar #2

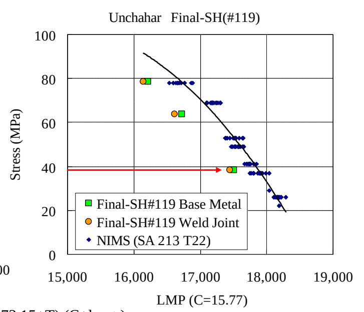
Component		Material	Test condition Temp. T(℃)	Test condition Stress (MPa)	Rupture time t (h)	LMP C=19.95	Fracture elongation (%)	Reduction of area (%)	Remark
Platen-SH	Base Metal	SA 213 T11	635	68.6	278.7	20,341	62	94	Ruptured
			635	83.4	90.8	19,899	57	91	Ruptured
			665	45.9	322.4	21,072	86	94	Ruptured
	Weld Metal	SA 213 T11	635	68.6	264.3	20,320	16	81	Ruptured
			635	83.4	127.5	20,033	18	82	Ruptured
			665	45.9	287.5	21,026	13	80	Ruptured

Component		Material	Test condition Temp. T(℃)	Test condition Stress (MPa)	Rupture time t (h)	LMP C=15.77	Fracture elongation (%)	Reduction of area (%)	Remark
Final-SH#119	Base Metal	SA 213 T22	665	63.7	113.1	16,725	69	91	Ruptured
			665	78.5	32.1	16,212	55	92	Ruptured
			700	38.3	162.6	17,503	67	94	Ruptured
	Weld Metal	SA 213 T22	665	63.7	86.0	16,614	30	84	Ruptured
			665	78.5	27.3	16,146	31	83	Ruptured
			700	38.3	143.7	17,451	22	81	Ruptured

LMP=(273.15+T) (C+log t)

Creep rupture test results Unchahar #2





* LMP=(273.15+T) (C+log t)

✓Creep rupture strength of SA 213 T22 is lower than NIMS data.

✓ Creep rupture strength of SA213 T11 is almost same as NIMS data.

Creep rupture test results Unchahar #2

Parameter method (evaluated at designed temp.)									
Component		Material	Hoop Stress (MPa)	LMP obtained by creep rupture test C=19.95 (T11) C=15.77 (T22)	Designed temp.T (℃)	Residual life tr (h)	Creep life consumption ratio ϕc to/(to+tr)	Evaluated residual life tr/2 (h)
Platen-SH	Base Metal	SA 213 T11	45.9	21,072	503	15,726,180	0.01	7,800,000
	Weld Joint	SA 213 T11	45.9	21,026	503	13,692,433	0.01	6,800,000
Final-SH#119	Base Metal	SA 213 T22	38.3	17,503	534	812,994	0.15	400,000
	Weld Joint	SA 213 T22	38.3	17,451	534	700,466	0.17	350,000

Operation hours to: 139098 h

Parameter method (evaluated at equivalent temp.)									
Component		Material	Hoop Stress (MPa)	LMP obtained by creep rupture test	LMPo by NIMS virgin material	Equivalent temperature T_E (℃)	Residual life tr (h)	Creep life consumption ratio ϕc to/(to+tr)	Evaluated residual life tr/2 (h)
				C=19.95 (T11) C=15.77 (T22)					
Platen-SH	Base Metal	SA 213 T11	45.9	21,072	21,072	Non evaluation(※1)			
	Weld Joint	SA 213 T11	45.9	21,026	21,072				
Final-SH#119	Base Metal	SA 213 T22	38.3	17,503	17,865	573	82,798	0.63	41,000
	Weld Joint	SA 213 T22	38.3	17,451	17,865	573(※2)	71,826	0.66	35,000

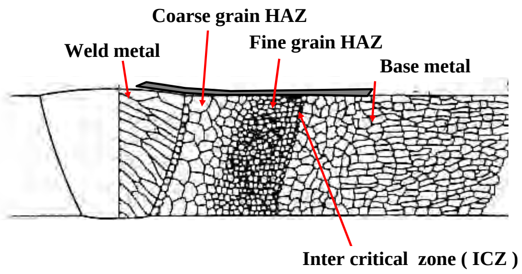
※1; Equivalent temperature could not be evaluated since the test results for base metal in Platen-SH tube indicate higher creep rupture strength than NIMS data.

※2; Same equivalent temperature used as base metal

Sampling of replica and extracted replica

Sampling of replica and extracted replica (1)

Microstructure of weld portion cross section

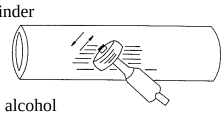


Residual life assessment by microstructural comparison method

Sampling of replica and extracted replica (2)

Grinding

Grinding with handy flexible grinder wheel until #120 roughness



Fine grinding

Grinding with PVA（polyvinyl alcohol (PVA)-based porous elastic grinding wheel until #60 ～#1000 roughness

Polishing

Polishing with 3μm ～0.25μm diamond particles.

Chemical etching

Etchant

For carbon steel,low alloy steel :

Nital (Ethanol 100ml ＋ 2～5ml HNO_3)

For Austenitic alloy steel :

Villella's solution (Ethanol 94ml+ HCl 5ml + picric acid 1g)

Sampling of replica and extracted replica (3)

Drying

Wash out the etchant with ethanol and dry with air spray.

Replica sampling

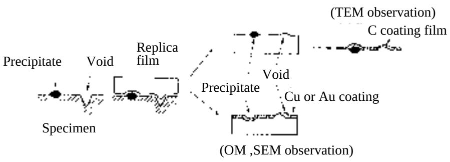
Stick a replica film on dropping the methyl acetate.
Take off the replica film after drying out, paste it on a slide glass.

OM, SEM observation

Polishing

Polishing again with 1μm diamond particles.

Chemical etching



Extracted Replica sampling

TEM observation

Boiler remaining life assessment

Japanese Boiler RLA Guidline (1)

To extend periodical inspection interval 2 year to 4year after 100,000 hours operation.

(1) Degradation factor to be evaluated

- Creep rupture remaining life
  (Designed temperature beyond 450℃)

(2) Components to be evaluated

- Furnace evaporation header
- Super heater header or Main steam pipe
- Reheater header or High temperature reheat pipe

Representative points among high heat loaded and high stressed portion in these components

Japanese Boiler RLA Guideline (2)

(3) Method to assess the remaining life

- More than one method used as shown in table below

Method	Guideline		This study	
	Base metal	Weld (HAZ)	Base metal	Weld (HAZ)
Hardness measuring	—	○		
Electrical resisitance	—	○		
Chemical composition of carbide	○	○		
Creep cavity evaluation	—	○		
Microstructural comparison	○	○	○	○
Urtra sonic scattering noise	—	○		
Interparticle spacing	○	—		
Crystal grain deformation	○	—		
Destructive test	○	○		
Analytical method	○	○		

○ : applicable, − : not applicable

(4) Effective (countable) remaining life

- 1/ 2 of remaining life evaluated by above methods

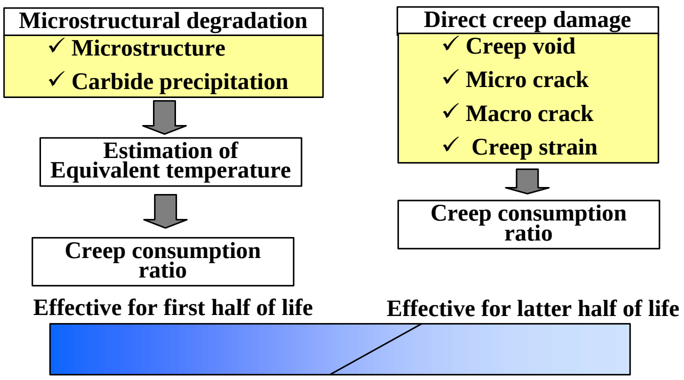
Microstructural comparison method outline

Remaining life synthetically evaluated by three types of damage related to the creep damage ratio as shown below.

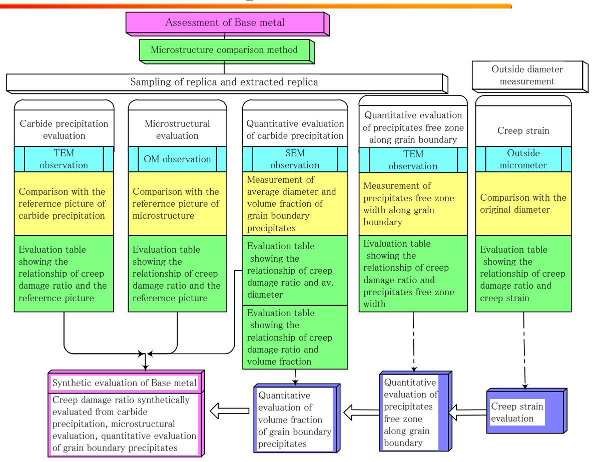
【Base metal】
・Evaluation of average diameter of grain boundary precipitates
・Comparison with the reference picture of microstructure
・Comparison with the reference picture of carbide precipitation

【Weld metal】
・Comparison with the reference picture of creep void and micro crack
・Comparison with the reference picture of microstructure
・Comparison with the reference picture of carbide precipitation

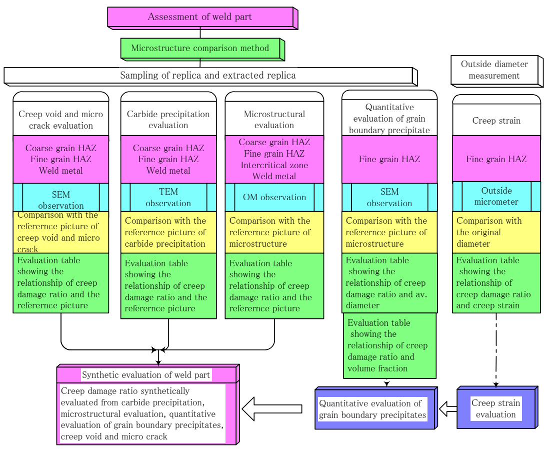
Microstructural comparison method



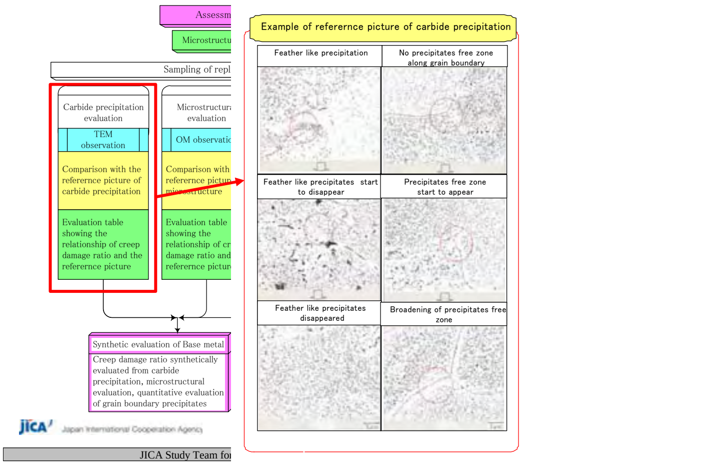
Microstructural comparison method (Base metal)



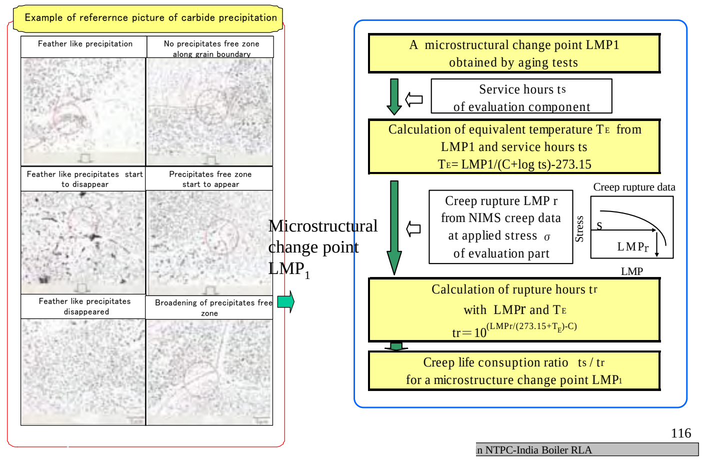
Microstructural comparison method (Weld portion)



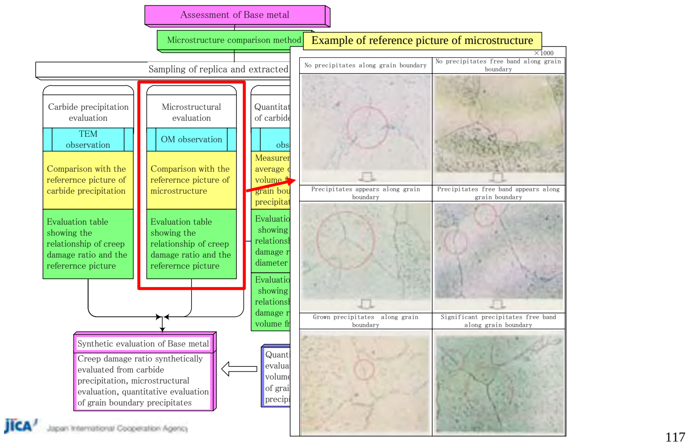
Microstructural comparison method in this study (Base metal)



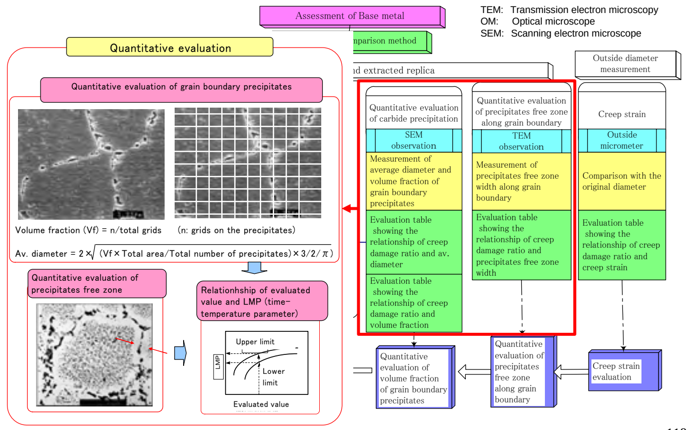
Microstructural comparison method in this study (Base metal)



Microstructural comparison method in this study (Base metal)



Microstructural comparison method in this study (Base metal)

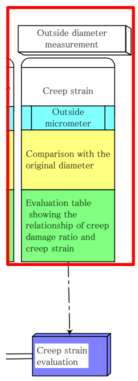


Microstructural comparison method in this study (Base metal)

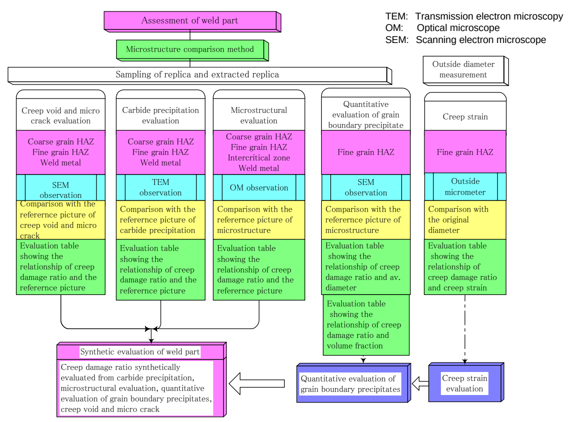
Creep strain evaluation

【Example of the relationship between creep damage ratio and creep strain e】

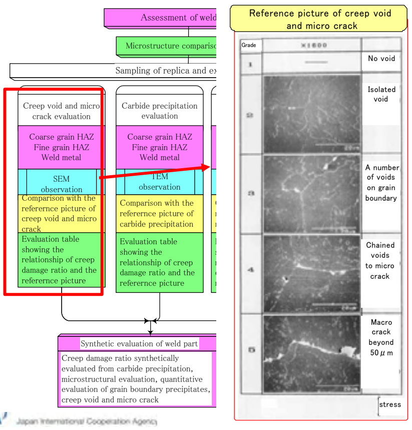
Creep strain	e＜1.0%	: 0～70%
Creep strain	1.0%≦ e ≦2.0%	: 50～80%
Creep strain	e ≧2.0%	: 70～100%



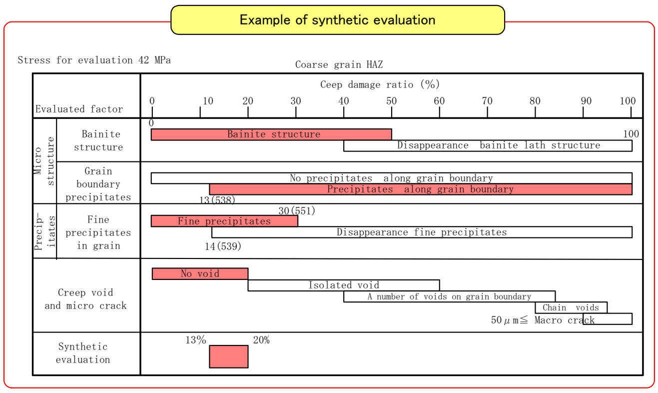
Microstructural comparison method in this study (Weld)



Microstructural comparison method in this study (Weld)



Synthetic evaluation by microstructural comparison method in this study



Replica inspection (Singrauli #6)

Component		Material	Designed OD (mm)	Designed t (mm)	Designed Temp. (℃)	Designed Pressure (MPa)	Hoop Stress (MPa)
Platen SH Outlet Header	Left	SA335P12	508.0	80.0	540	17.46	46.69
De-SH	Left		508.0	70.0	406	18.51	57.89
	Right						
RH Outlet Header	Left	SA335P22	558.8	50.0	540	4.26	21.68
	Right						
Main Steam Pipe	Left		520.0	85.0	540	17.46	44.67

Replica inspection (Unchahar #2)

Component		Material	Designed OD (mm)	Designed t (mm)	Designed Temp. (℃)	Designed Pressure (MPa)	Hoop Stress (MPa)
Final SH Outlet Header		SA335P22	457.2	100.0	555	15.75	28.1
De-SH	Left	SA335P12	406.4	45.0	450	16.44	66.0
	Right						
RH Outlet Header		SA335P22	558.8	45.0	555	4.32	24.7
Main Steam Pipe	Right		355.6	50.3	540	15.74	47.8
Hot Reheat Pipe	Right		508.0	28.0	540	3.69	31.6

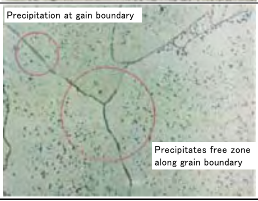
Observation of replica

Observation item		Microstructure	Carbide precipitation	Precipitates free band width along grain boundary	Creep void grade	Average diameter of grain boundary precipitates	Average volume fraction of grain boundary precipitates
Observation method		Optical microscope	TEM (Transmission Electron Microscope)		SEM (Scanning Electron Microscope)		
Observed target		Micro crack and microstructural degradation	Morphology and distribution of precipitates	Quantitative evaluation of precipitates free band width	Micro crack and creep void	Quantitative evaluation of grain boundary precipitates	Quantitative evaluation of grain boundary precipitates
Observed magnification		×500 ×1000	×2000 ×10000	×2000	×500 ×2000	×3000 (Base metal) ×4000 (Fine grain HAZ)	
Observed area	Base metal	○	○	○		○	○
	Intercritical zone	○					
	Fine grain HAZ	○	○			○	○
	Coarse grain HAZ	○	○		○		
	Weld metal	○	○				

Microstructure observation results (Singrauli #6)

Components	Location		Observed region	Optical microscope observation – Microstructural features: Precipitation at gain boundary	Precipitates free zone along grain boundary
Reheater outlet header (SA 335 P22)	Left	Circumferential weld	Base metal	Appeared	Not appeared
			Intercritical zone	Appeared	Not appeared
			Fine grain HAZ	Appeared	
			Coarse grain HAZ	Not appeared	
			Weld metal		
Main steam pipe (SA 335 P22)	Left	Circumferential weld (near the stop valve) intrados side	Base metal	Appeared	Appeared
			Intercritical zone	Appeared	Appeared
			Fine grain HAZ	Appeared	
			Coarse grain HAZ	Not appeared	
			Weld metal		

Microstructure observation results (Singrauli #6)

Components	Region	Replica microstructure	Reference Picture
RH outlet header left (SA 335 P22)	Base metal		
Main steam pipe left (SA 335 P22)	Base metal		

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Microstructure observation results (Unchahar #2)

Components	Location		Observed region	OM (Optical microscope observation) Microstructural features: Precipitation at gain boundary	Precipitates free zone along grain boundary
Final SH outlet header (SA 335 P22)	Rightside of header	Circumferential weld	Base metal	Appeared	Not appeared
			Intercritical zone	Not appeared	Not appeared
			Fine grain HAZ	Appeared	
			Coarse grain HAZ	Appeared	
			Weld metal		
Main steam pipe (SA 335 P22)	Right	Circumferential weld (near the stop valve)	Base metal	Appeared	Not appeared
			Intercritical zone	Appeared	Not appeared
			Fine grain HAZ	Appeared	
			Coarse grain HAZ	Not appeared	
			Weld metal		

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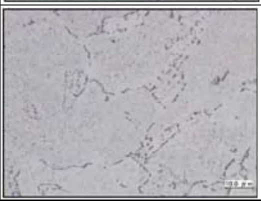
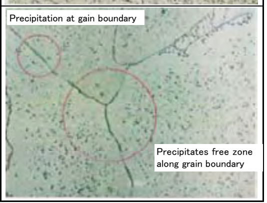
Microstructure observation results (Unchahar #2)

Components	Region	Replica microstructure	Reference Picture
Final SH outlet header (SA 335 P22)	Base metal		
Main steam pipe right (SA 335 P22)	Base metal		

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Observation of replica

Observation item		Microstructure	Carbide precipitation	Precipitates free band width along grain boundary	Creep void grade	Average diameter of grain boundary precipitates	Average volume fraction of grain boundary precipitates
Observation method		Optical microscope	TEM (Transmission Electron Microscope)		SEM (Scanning Electron Microscope)		
Observed target		Micro crack and microstructural degradation	Morphology and distribution of precipitates	Quantitative evaluation of precipitates free band width	Micro crack and creep void	Quantitative evaluation of grain boundary precipitates	Quantitative evaluation of grain boundary precipitates
Observed magnification		×500 ×1000	×2000 ×10000	×2000	×500 ×2000	×3000 (Base metal) ×4000 (Fine grain HAZ)	
Observed area	Base metal	○	○	○		○	○
	Intercritical zone	○					
	Fine grain HAZ	○	○			○	○
	Coarse grain HAZ	○	○		○		
	Weld metal	○	○				

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Precipitates distribution observation results (Singrauli #6)

Components	Location		Observed region	TEM (Transmission Electron Microscope observation) Carbide precipitates features: Precipitates free zone along grain boundary	Featherlike precipitates	Fine needlelike and granular precipitates	Needlelike precipitates	Fine needlelike and granular precipitates in bainite grain
Reheater outlet header (SA 335 P22)	Right	Circumferential weld	Base metal	Not appeared	Remained		No decrease in ferrite grain	Remaining
			Fine grain HAZ				Remaining	
			Coarse grain HAZ			Remaining		
			Weld metal			Remaining		
Main steam pipe (SA 335 P22)	Left	Circumferential weld (near the stop valve) intrados side	Base metal	Appeared	Disappeared		No decrease in ferrite grain	Partially disappeared
			Fine grain HAZ				Disappeared	
			Coarse grain HAZ			Disappeared		
			Weld metal			Disappeared		

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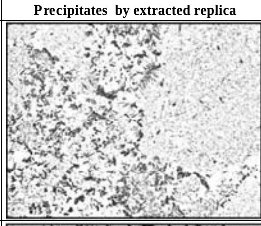
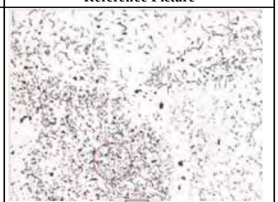
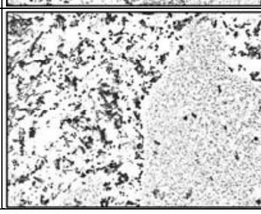
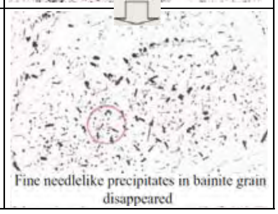
Precipitates distribution observation results Singrauli #6

Components	Region	Precipitates by extracted replica	Reference Picture
RH outlet header left (SA 335 P22)	Base metal		
Main steam pipe left (SA 335 P22)	Base metal		

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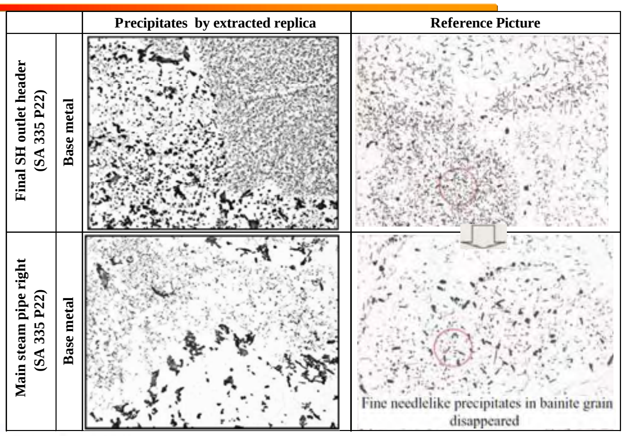
Precipitates distribution observation results （Unchahar #2)

Components	Location		Observed region	TEM (Transmission Electron Microscope observation) Precipitates features: Precipitates free zone along grain boundary	Featherlike precipitates	Fine needlelike and granular precipitates	Needlelike precipitates	Fine needlelike and granular precipitates in bainite grain
Final SH outlet header (SA 335 P22)	Left outlet header	Circumferential weld	Base metal	Appeared	Disappeared		No decrease in ferrite grain	Partially disappeared
			Fine grain HAZ				Remaining	
			Coarse grain HAZ			Remaining		
			Weld metal			Remaining		
Main steam pipe (SA 335 P22)	Right	Circumferential weld (near the stop valve)	Base metal	Appeared	Disappeared		No decrease in ferrite grain	Disappeared
			Fine grain HAZ				Spherodized	
			Coarse grain HAZ			Remaining		
			Weld metal			Remaining		

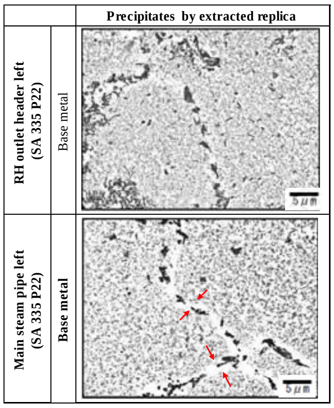
Precipitates distribution observation results Unchahar #2



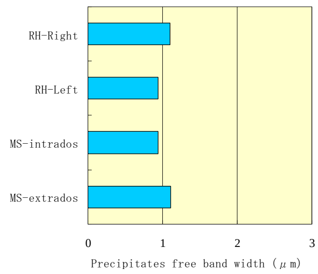
Quantitative evaluation of precipitates free band width

Observation item		Microstructure	Carbide precipitation	Precipitates free band width along grain boundary	Creep void grade	Average diameter of grain boundary precipitates	Average volume fraction of grain boundary precipitates
Observation method		Optical microscope	TEM (Transmission Electron Microscope)		SEM (Scanning Electron Microscope)		
Observed target		Micro crack and microstructural degradation	Morphology and distribution of precipitates	Quantitative evaluation of precipitates free band width	Micro crack and creep void	Quantitative evaluation of grain boundary precipitates	Quantitative evaluation of grain boundary precipitates
Observed magnification		×500 ×1000	×2000 ×10000	×2000	×500 ×2000	×3000 (Base metal) ×4000 (Fine grain HAZ)	
Observed area	Base metal	○	○	○		○	○
	Intercritical zone	○					
	Fine grain HAZ	○	○			○	○
	Coarse grain HAZ	○	○		○		
	Weld metal	○	○				

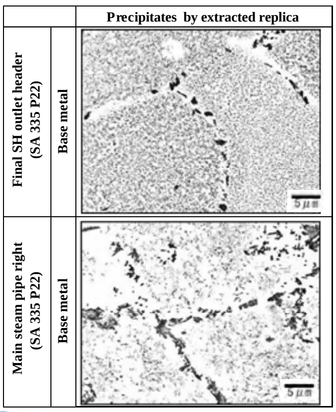
Quantitative evaluation of precipitates free band width



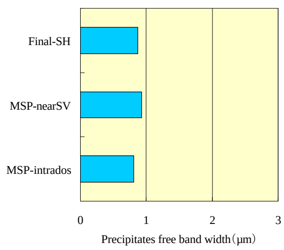
Singrauli #6



Quantitative evaluation of precipitates free band width



Unchahar #2



Observation of replica

Observation item		Microstructure	Carbide precipitation	Precipitates free band width along grain boundary	Creep void grade	Average diameter of grain boundary precipitates	Average volume fraction of grain boundary precipitates
Observation method		Optical microscope	TEM (Transmission Electron Microscope)		SEM (Scanning Electron Microscope)		
Observed target		Micro crack and microstructural degradation	Morphology and distribution of precipitates	Quantitative evaluation of precipitates free band width	Micro crack and creep void	Quantitative evaluation of grain boundary precipitates	Quantitative evaluation of grain boundary precipitates
Observed magnification		×500 ×1000	×2000 ×10000	×2000	×500 ×2000	×3000 (Base metal) ×4000 (Fine grain HAZ)	
Observed area	Base metal	○	○	○		○	○
	Intercritical zone	○					
	Fine grain HAZ	○	○			○	○
	Coarse grain HAZ	○	○		○		
	Weld metal	○	○				