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

Turbine Maintenance

Nobuchika KOIZUMI

J-POWER

Inspection Item at Periodical Maintenance

1. Main turbine
(1) Turbine rotor
- Cleaning by honing
- Detailed inspection and repair of the disk, the rotating blades and the rotor
- Measurement of run-out and centering of the shaft
- Inspection and repair of the coupling bolt

(2) Ejection Holes and Partitions
- Cleaning by honing
- Detail inspection and repair of the stationary blades and labyrinths

(3) Casing
- Measurement of the clearance of the inside and the outside of casing
- Detail inspection
- Measurement of the level of the horizontal flange
- Measurement of the alignment of the casing
- Maintenance of the bolts, hardness test

(4) Bearing
- Adjustment of the contact of the white metals
- Measurement of the bearing gaps

Inspection Item at Periodical Maintenance

2. Equipment attached to the turbine body
(1) Main Valves (MSV, CV, RSV, ICV)
- Maintenance and inspection of the inside and the outside of the valves, the valve rods, the valve seats, and the valve bodies
- Measurement of bend and the gaps of the valve rods
- Inspection of the bolts

(2) Speed Governor and Emergency Stopping Device
- Inspection of the speed governor mechanism and the piping for the control oil

(3) Turning Device
- Detailed and precision inspection of the gears and the bearings
- Inspection of the clutch mechanism

Inspection Item at Periodical Maintenance

3. Turbine lubricating oil device
(1) MOP, AOP, JOP and EOP
- Overhaul, repair and detailed and precision inspection

(2) Main Oil Tank and Oil Cooler
- Cleaning and oiliness test of the inside of the tank
- Cleaning of the oil cooler piping and the water chamber

(3) Oil filter, oil purifier
- Cleaning of the inside and replacement of the filter
- Overhaul and repair

Inspection Item of Condenser (1)

NO	ITEM	PURPOSE	METHOD
1	The inside of the cooling tubes	Clogging, corrosion, erosion	VI ET
2	The outer surface of the cooling tube	Erosion, damage	VI
3	The tube plate	To check marine creatures and dirty matter adhered To check the connecting part	VI
4	The inside of the water chamber	Swell, separation, damage, or a pin hole on the rubber lining Marine creatures and dirty matter adhered	VI PHT

VI: Visual Inspection
WT: Leak Test by Filling Water
DI: Dimensional Inspection
ET: Eddy Current Test
ST: Hardness Test
MT: Fluorescent Magnetic Test
PT: Liquid Penetrant Test
PHT: Pin Hole Test
DM : Thickness measurement

Inspection Item of Condenser (2)

NO	ITEM	PURPOSE	METHOD
5	The parts inside of the main body shell	Erosion, damage ,scale, dust	VI PT
6	Rubber expansion joint	Deterioration	VI ST
7	Nozzle for steam pipe	Crack	VI, PT

VI: Visual Inspection
Leak Test by Filling Water
DI: Dimensional Inspection
ET: Eddy Current Test
ST: Hardness Test
MT: Fluorescent Magnetic Test
PT: Liquid Penetrant Test WT:
PHT: Pin Hole Test
DM : Thickness measurement

Inspection Item of HP Feed Water Heater

NO	ITEM	PURPOSE	METHOD
1	Tube (steel)	Inlet attack	VI, DI
2	Tube (cu attribute)	Crack	ET
3	Water chamber	Crack	VI, PT, MT
4	Water chamber partition	Deformation	VI, DI
5	Shell	Erosion	VI, DM
6	Nozzle	Erosion	VI, DM

VI: Visual Inspection
Leak Test by Filling Water
DI: Dimensional Inspection

ET: Eddy Current Test
ST: Hardness Test
MT: Fluorescent Magnetic Test

PT: Liquid Penetrant Test WT:
PHT: Pin Hole Test
DM : Thickness measurement

Inspection Item of LP Feed Water Heater

NO	ITEM	PURPOSE	METHOD
1	Tube (steel)	Erosion	UT, ET
2	Tube (cu attribute)	Crack, ammonia attack	ET
3	Water chamber partition	Deformation	VI, DI
4	Shell	Erosion	VI, DM

VI: Visual Inspection
Leak Test by Filling Water
DI: Dimensional Inspection

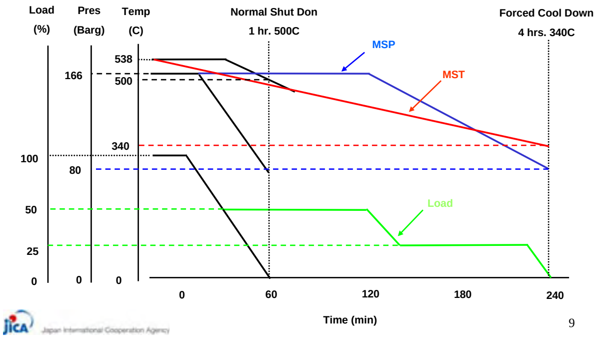
ET: Eddy Current Test
ST: Hardness Test
MT: Fluorescent Magnetic Test

PT: Liquid Penetrant Test WT:
PHT: Pin Hole Test
DM : Thickness measurement

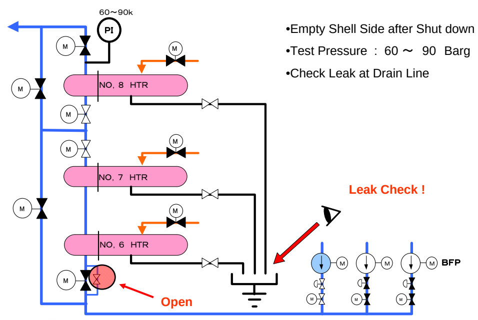
Turbine Shut Down and Preparation Works

1. **Turbine Forced Cooling**
2. **Heater Leak Check**
3. **Operation and Maintenance Coordination**

Turbine Forced Cool Down

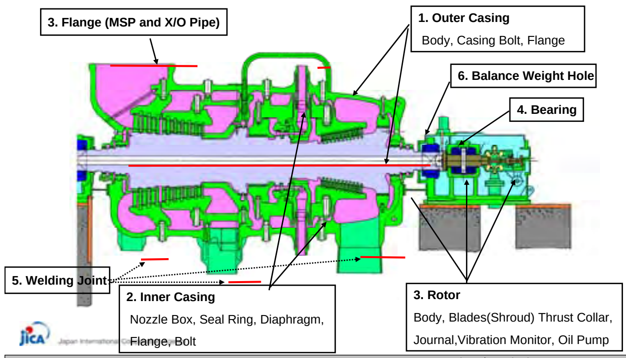


Heater Leak Check



- Empty Shell Side after Shut down
- Test Pressure : 60 ~ 90 Barg
- Check Leak at Drain Line

HP Turbine Inspection Points



HP Turbine Major Inspection - (1)

HP Turbine 1st Blade Erosion - Boiler Scale

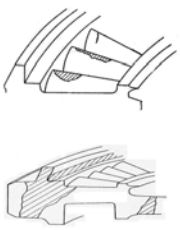
Example (Wear due to Scale)

HP Turbine Major Inspection - (2)

Example (Wear due to Scale) | Unit 2 (Foreign Material)

HP Turbine Major Inspection - (2)

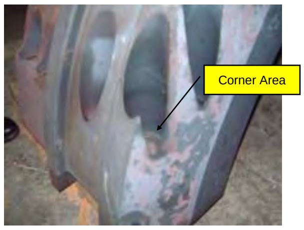
Typical Erosion | MSV Strainer



HP Turbine Major Inspection (3)

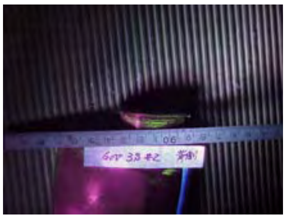
Example - Outer Casing (Stress Concentration)

Unit 2 HP Inner Casing



HP Turbine Major Inspection - (4)

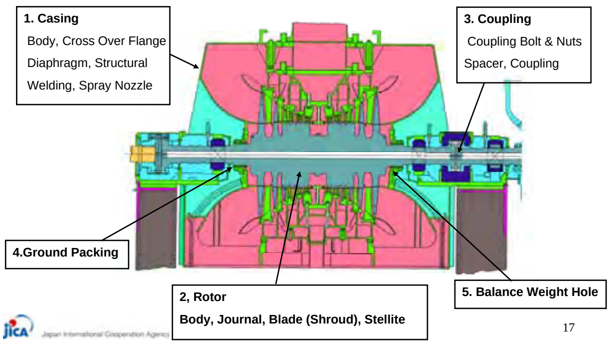
Creep - Shrouds and Roots



Damage Example - Shrouds

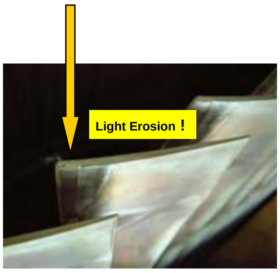
Typical Creep Damage Area

LP Turbine Inspection Points



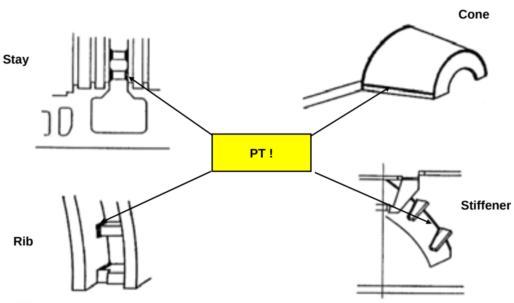
LP Turbine Major Inspection (1)

Unit 4 LP Last Blade - Stellite



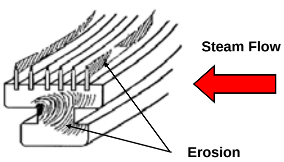
LP Turbine Major Inspection (2)

Casing Structure Welding



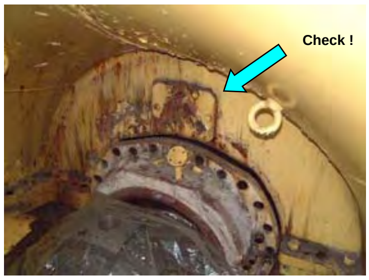
Turbine Major Inspection - Other Area (1)

Diaphragm Seal Ring Erosion
(Efficiency Loss)



Turbine Major Inspection - Other Area (2)

Balance Weight Flange

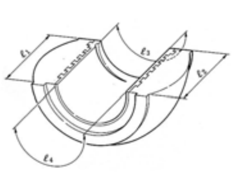


Turbine Major Inspection - Other Area (3)

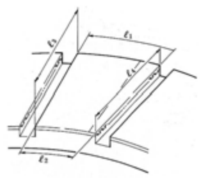
Cleaning
↓
Thread Inspection
↓
PT

Turbine Major Inspection - Other Area (4)

White Metal Bonding Condition

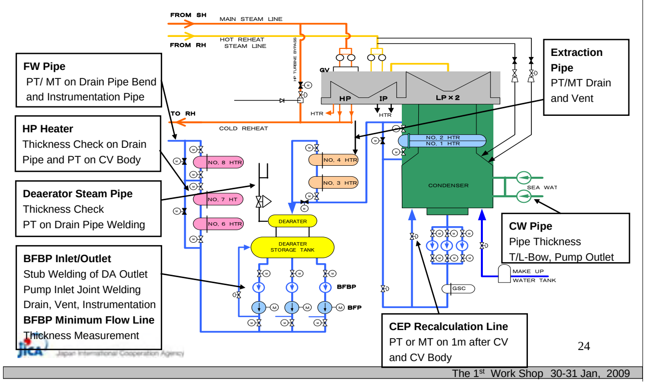


Radial Bearing

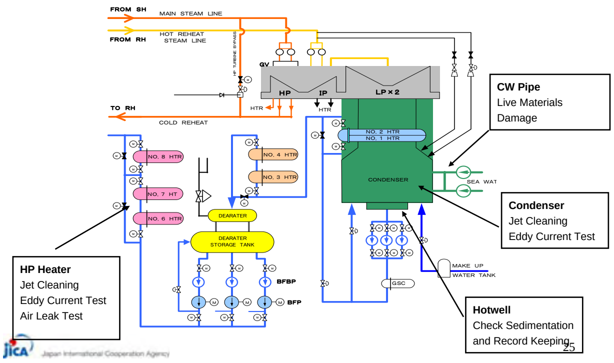


Thrust Bearing

Turbine Piping Inspection



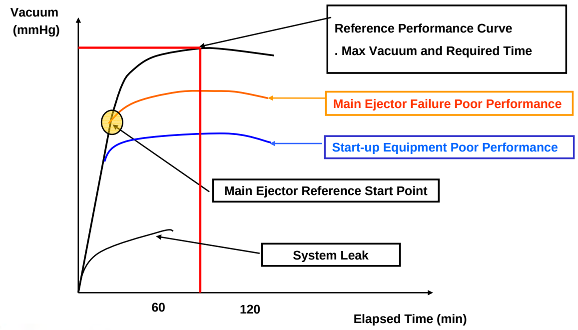
Turbine Auxiliary Inspection Point



Turbine Commissioning

1. Heater Leak Test
2. Condenser Tube Leak Test
3. Condenser Vacuum Test
4. Turbine Steam Admission & AOP/EOP Test
5. Turbine Overspeed Test
6. Unit Interlock Test (MFT, Unit Trip)

Turbine Commissioning - Vacuum Test



Turbine Overhaul Improvement - Acceleration Work

1. Overhaul Period (300MW Class)
   - J-Power P/S 45 days
2. Area of Consideration
   - Work Schedule Improvement
   - Equipment Improvement
   - Oil Flushing Improvement

Work Schedule Improvement

1. Turbine Cool Down Acceleration
2. Work Sequence Improvement

Disassembly Improvement

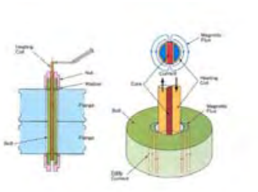
1. HP Turbine Casing Bolt Loose Before Turning Gear
2. Turbine Forced Cool Down Disassemble Flow Guide earlier and lift LP Casing
3. Lay down Area

Overhaul Schedule Optimization

Turbine Overhaul Improvement - Induction Heater (1)

Heating with Burner

New Type - Induction Heater



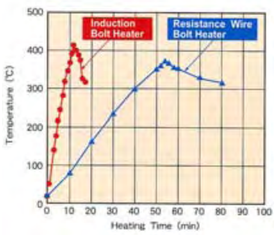
Thank You !

Turbine Overhaul Improvement - Induction Heater (2)

Resistance Wire

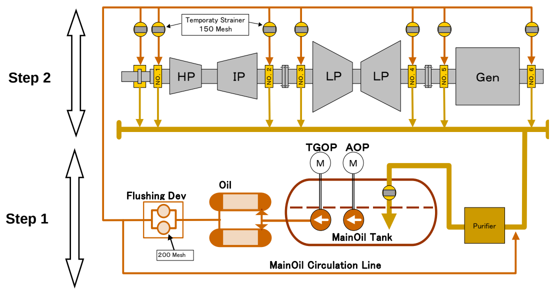
Saving Time

= 30min X 34 times = 1020 min (17 hrs)



Turbine Overhaul Improvement - Turbine Oil Flushing

Step 2 Oil Flushing after Bearing Assembly



Step 1 Oil Flushing before Bearing Assembly

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TURBINE RLA ASSESMENT

Nobuchika KOIZUMI

J-POWER

EXAMPLE OF ASSESMENT

Test Matrix for 200 MW LMZ Turbine — PRELIMINARY

Sr No.	Tests/ Components	VO	LP/DPT	MPI	UT	Replica	Hardness	Special Tests
1.0	HP+ IP Turbine Rotor							
1.1	Rotor	100%	Journal region	100% accessible regions by coil/yoke	through bore + externally accessible regions	8 locations	replicated locations	Bore UT, Videoscopy Stress analysis of Rotor Shaft
1.2	Blades	100%	NO	100% accessible regions by coil /yoke	NO	NO	NO	Deposit analysis Eddy Current test of moving blades
1.3	Shrouds	100%	NO	100% accessible regions by coil /yoke	NO	NO	NO	
1.4	Sealing Grooves(castellations)	100%	NO	100% accessible regions by coil /yoke	NO	NO	NO	
1.5	Coupling Bolts	100%	100%	NO	NO	NO	NO	
2.0	HP and IP Casing							
2.1	Casing Halves	100%	keys & keyways	only critical areas	NO	4 locations	replicated locations	Deposit analysis, Stress Analysis
2.2	Parting plane studs and Fasteners	100%		100% by yoke	NO	NO	high temperature studs	Destructive tests on one stud each from HP and IP regions
3.0	HP and IP Diaphragm and Liners							
3.1	Nozzle, Diaphragms, and Diaphragm carriers	100%	keys & keyways	100% by yoke	NO	8 locations	replicated locations	Deposit analysis
3.2	Parting plane Fasteners	100%	NO	10% by yoke	NO	NO	high temperature studs	

Legends:
VO=Visual Observations, LP/DPT=Dye Penetrant Test, MPI: Fluorescent Magnetic Inspection, UT: Ultrasonic Test, Replica In-situ Metallography,
Hardness: Portable rebound hardness

EXAMPLE OF ASSESMENT

Test Matrix for 200 MW LMZ Turbine — PRELIMINARY

Sr No.	Tests/ Components	VO	LP/DPT	MPI	UT	Replica	Hardness	Special Tests
4.0	Babbitted Bearings							
4.1	Babbit bonding and surface	100%	babbit s/c 100%	NO	babbit s/c 100%	NO	NO	
4.2	Bearing housing, pedestal	100%	NO	On parting plane	NO	NO	NO	
5.0	LP Turbine Rotor and Casing							
5.1	Rotor	100%	Journal region	100% accessible regions by coil /yoke	through bore + externally accessible regions	2 locations	2 locations	Bore UT, Videoscopy
5.2	Blades	100%	shields, damping wires	100% accessible regions by coil /yoke	NO	NO	NO	Eddy Current test of moving blades
5.3	Shrouds	100%	NO	100% accessible regions by coil /yoke	NO	NO	NO	
5.4	Sealing Grooves(castellations)	100%	NO	100% accessible regions by coil /yoke	NO	NO	NO	
5.5	Casing Halves	100%	NO	only critical areas	NO	NO	NO	
5.6	Coupling Bolts	100%	100%	NO	NO	NO	NO	

Legends:
VO=Visual Observations, LP/DPT=Dye Penetrant Test, MPI: Fluorescent Magnetic Inspection, UT: Ultrasonic Test, Replica In-situ Metallography,
Hardness: Portable rebound hardness

EXAMPLE OF ASSESMENT

Test Matrix for 200 MW LMZ Turbine — PRELIMINARY

Sr No.	Tests/ Components	VO	LP/DPT	MPI	UT	Replica	Hardness	Special Tests
6.0	Integral Steam Piping & Valves							
6.1	Integral Steam pipes - HP Casing	100%	NO	Critical Butt welds	Critical Butt welds	4 locations	replicated locations	Thickness Measurement at bends
6.2	Integral Steam pipes - IP Casing	100%	NO	Critical Butt welds	Critical Butt welds	4 locations	replicated locations	Thickness Measurement at bends
6.3	Main steam Piping critical weld and bend (Turbine main steam stop valve to HPT control valves)	100%	NO	Critical Butt welds	Critical Butt welds	6 locations	replicated locations	Thickness Measurement at bends, Stress Analysis
6.4	Hot Re-heat Piping critical weld and bend (IPT stop valve to IPT control valves)	100%	NO	Critical Butt welds	Critical Butt welds	6 locations	replicated locations	Thickness Measurement at bends, Stress Analysis
6.5	Cross over pipe	100%	NO	Weld joints	NO	NO	NO	
6.6	ESVs	100%	seat,cones, Chamber	spindle, strainers, Fastners	NO	4 locations	replicated locations	
6.7	IV	100%	seat,cones, Chamber	spindle, strainers Fastners	NO	4 locations	replicated locations	
6.8	HP Control Valves	100%	seat,cones, Chamber	spindle, strainers Fastners	NO	4 locations	replicated locations	
6.9	IP Control Valves	100%	seat,cones Chamber	spindle, strainers, Fastners	NO	4 locations	replicated locations	
6.10	HP/LP Bypass Main valves	100%	seat,cones Chamber	spindle, strainers, Fastners	NO	2 locations	replicated locations	

Legends:
VO=Visual Observations, LP/DPT=Dye Penetrant Test, MPI: Fluorescent Magnetic Inspection, UT: Ultrasonic Test, Replica In-situ Metallography,
Hardness: Portable rebound hardness

Thank You !

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ASSESEMENT OF PUMP

BOILER FEED WATER PUMP

CIRCULATING WATER PUMP

Japan International Cooperation Agency

Thank You !

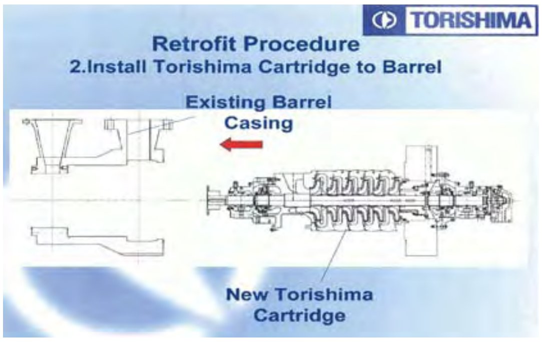
Japan International Cooperation Agency

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

RETROFIT OF 200 KHI BOILER FEED WATER PUMP

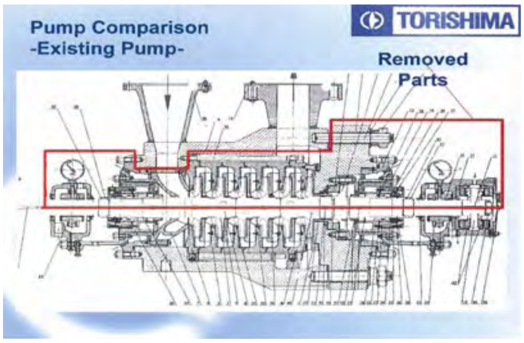
jica Japan International Cooperation Agency

jica



The 1st Work Shop 30-31 Jan, 2009

jica



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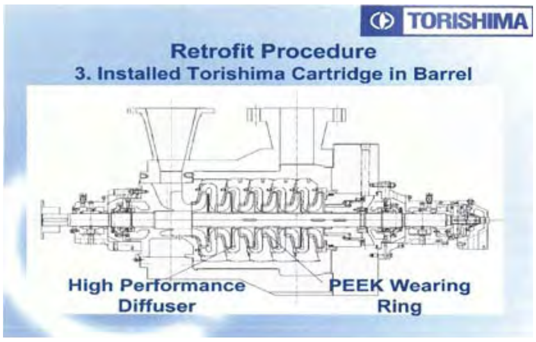

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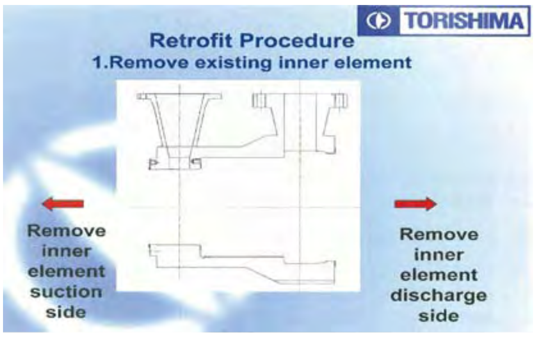


The 1st Work Shop 30-31 Jan, 2009

jica

The 1st Work Shop 30-31 Jan, 2009

TORISHIMA

5. Comparison of Performance: New/Existing

TORISHIMA

6. Expected Improvement & Effects

Energy saving

1) Efficiency : before and after improvement
Existing Sigma Pump E(ex)= 72%
Newly replaced by Torishima E(n) = 83%
* Improved EFF = 11%

2) Shaft power : before and after improvement
Existing Sigma Pump SP(ex)= 2500KW
* Expected Reducing SP = 2500KWx0.11= 275KW/hr

3) Yearly energy saving : after improvement
* Expected Yearly saving energy= 275KW/hrx8000hrs
= 2,200,000KW/year

Thank You !

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

LEAK BUSTER

(Detection technology of air leak into condenser)

LEAK BUSTER

Detection technology of air leak into condenser

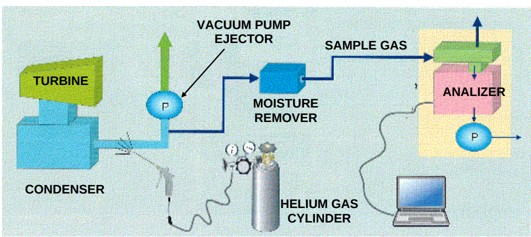
Features

1. Air leak points of the vacuum portion can be accurately detected during operation
2. **The applox. air leak volume can be measured.**
3. The measurement can be made without dismantling the heat insulation.
4. Measuring work is completed in a few days.
5. No major set up of equipment is required.

LEAK BUSTER

Detection technology of air leak into condenser

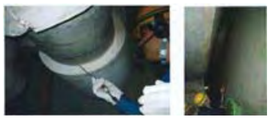
System configuration



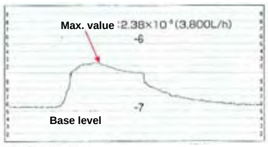
LEAK BUSTER

Detection technology of air leak into condenser

How to asses air leak volume?



Helium spraying



Air leak volume:
Equivalent to 5.0kg/h

LEAK BUSTER

Detection technology of air leak into condenser

LEAK BUSTER

Results	Result 1	Result 2	Result 3	Result 4	Result 5
Turbine maker	A Certain Company	A Certain Company	Fuji Electric Systems Co., Ltd	A Certain Company	Fuji Electric Systems Co., Ltd
Output (MW)	1000	1000	600	600	27
State before implementation	Operation of two vacuum pumps including the standby Vacuum deterioration 3.33kPa	Operation of two vacuum pumps including the standby No vacuum deterioration	Operation of two vacuum pumps including the standby No vacuum deterioration	Operation of two vacuum pumps including the standby No vacuum deterioration	Vacuum deterioration 1.33kPa
Design air amount	20kg/h	10kg/h	20kg/h	20kg/h	12kg/h
Air amount measurement	120kg/h or more (over range)	50kg/h	48kg/h	50kg/h	33kg/h
Increased air amount	100kg/h or more	40kg/h	28kg/h	30kg/h	21kg/h
Detecting air leak amount	131kg/h	39kg/h	29kg/h	29kg/h	10kg/h
Leak point	· LP turbine steam inlet pipe: 124kg/h · Condenser expansion joint: 4kg/h · Vacuum pump: 2kg/h · LP turbine gland: 1kg/h	· Drain piping around turbine bearing: 35kg/h · LP turbine: 4kg/h	· LP turbine: 13kg/h · Around condenser: 13kg/h · Around BFPT: 1.5kg/h · Vacuum pump: 0.8kg/h	· LP turbine: 9kg/h · Around condenser: 13kg/h · Around BFPT: 6kg/h · Vacuum pump: 5kg/h	· LP turbine: 4kg/h · Around condenser: 13kg/h · Around BFPT: 1kg/h · Vacuum pump: 1kg/h
Repair content	LP turbine inlet temporary repair	Piping replaced	LP turbine inlet temporary repair	BFPT, vacuum pump temporary repair	Condenser flange portion temporary repair
Air amount after temporary repair	Result: 60kg/h Prediction: unknown because outside the range		Result: 36kg/h Prediction: 33kg/h (=46−13)	Result: 40kg/h Prediction: 39kg/h (=50−11)	Result: checking when starting next time Prediction: 20kg/h (=33−13)
Air amount after permanent measures		10kg/h (Same level as at operation start)			
Main leak portions or repair situation	· LP turbine inlet steam bellows portion	· Drain piping through condenser (drain piping around turbine bearing)	· LP turbine gland portion taping done	· BFPT flange portion	· Condenser connecting flange portion
					

Thank You !

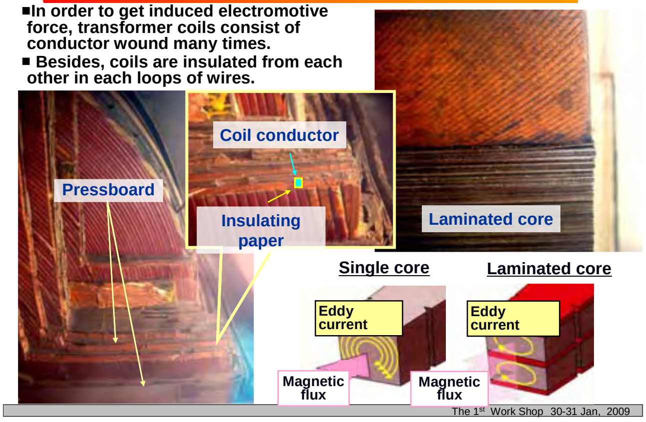
-Diagnosis of Transformer-

Jan. 2009

Japan International Cooperation Agency

Internal Structure of Transformer

- In order to get induced electromotive force, transformer coils consist of conductor wound many times.
- Besides, coils are insulated from each other in each loops of wires.



Contents

Inspection & Diagnosis of Transformer (in Japan)

Transformer inspection

Inspection	Frequency	Inspection contents
Patrol inspection	Once/day	Oil temp., oil level, Oil leak, abnormal sound, smell, rust, etc
Dissolved gas analysis (DGA)	Once/year	Dissolved Gas Analysis
PI (simple inspection)	Once/2 years	Megger testing, Visual inspection, etc.
PI (detail inspection)	Once/6 years	Protection relay performance test, etc.
PI (special inspection)	Depending on the results of DGA	

PI: Periodical inspection

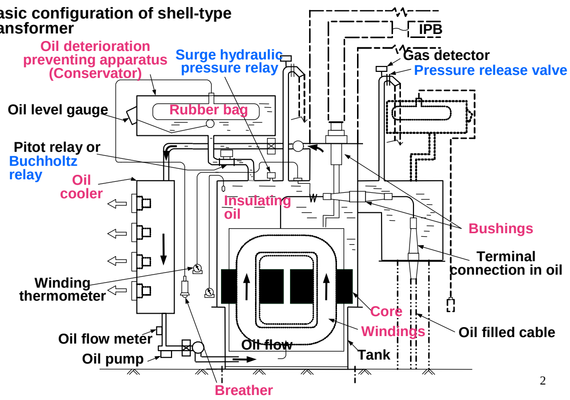
Transformer diagnosis

Diagnosis	Methods
Condition check diagnosis	Dissolved Gas Analysis
Deterioration diagnosis (Life-remaining diagnosis)	Furfural analysis(★) Carbon dioxide (CO_2 + CO) analysis

★ : adaptable for insulating paper made from kraft pulp

Main Components of Transformer

Basic configuration of shell-type transformer



Dissolved Gas Analysis (DGA) (1)

- Various gases are generated by heat decomposition of insulating paper and insulating oil, when abnormal condition such as electric discharge and over heating occurs in a transformer.
- Abnormal condition is estimated and analyzed from the gas components, the gas volume and the ratio of generated gas.

Abnormal condition	Main generated gas
Over heating insulating oil	H_2, CH_4, C_2H_6, C_2H_4, C_2H_2
Over heating at solid insulator	H_2, CH_4, C_2H_6, C_2H_4, C_2H_2, CO, CO_2
Electric discharge in insulating oil	H_2, CH_4, C_2H_4, C_2H_2
Electric discharge at solid insulator	H_2, CH_4, C_2H_4, C_2H_2, CO, CO_2

Dissolved Gas Analysis (DGA) (2)

Criteria of DGA (in Japan)

Unit : ppm

Gas	Caution I level	Caution Ⅱ level	Abnormal level
CO	≧ 300	(1) C_2H_2 : ≧ 0.5 or (2) Both C_2H_4 : ≧ 10 and TCG : ≧ 500	(1) C_2H_2 : ≧ 5 or (2) Both C_2H_4 ≧100 & TCG at least 700 or (3) Both C_2H_4 ≧ 100 & TCG increase ≧ 70 ppm/month
H_2	≧ 400		
CH_4	≧ 100		
C_2H_6	≧ 150		
C_2H_4	≧ 10		
C_2H_2	-		
TCG*	≧ 500		

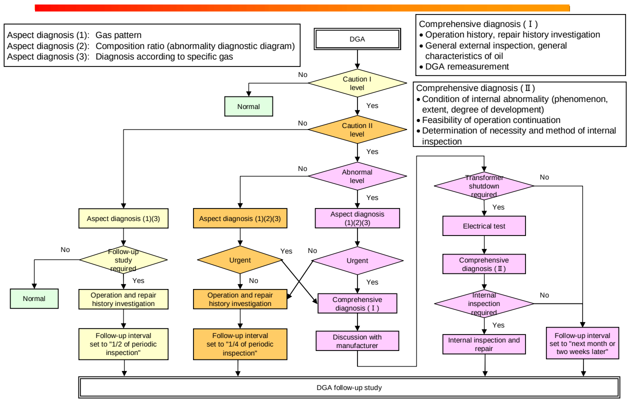
*TCG: Total Combustible Gas, the sum of CO to C2H2

Caution I level : The level that transformer is out of normal condition although it is not judged to be abnormal and dangerous condition

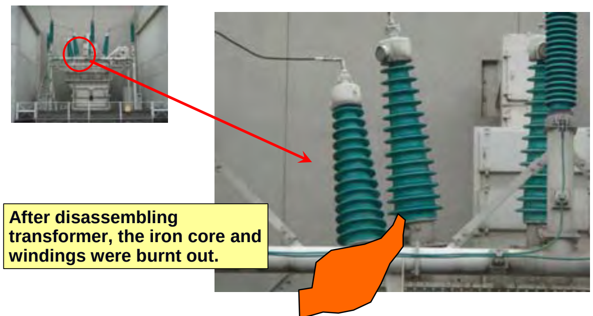
Caution II level : The level that transformer becomes abnormal condition gradually

Abnormal level : The level that transformer is clearly abnormal condition. (aggravating further from Caution Ⅱ level)

Diagnosis Flowchart with DGA



One Case of Transformer Troubles



After disassembling transformer, the iron core and windings were burnt out.

Burst-out of insulating oil

Analysis of the Transformer Trouble

Decline of insulating paper mechanical strength due to deterioration

↓

Damage to insulating paper due to damage factor

↓

Layer short

↓

Overheating/internal pressure up of insulating oil

↓

Burst-out of insulating oil

If any measures had been taken to comprehend internal condition of transformer, this trouble might have been avoided.

Important
Comprehending the condition
Implementing preventive maintenance

Long term plant outage & Large amount of repair cost is required

- **Operation loss because high efficiency plant has to stop.**
- **Energy loss because low efficiency plant has to operate.**
- **Insufficient power supply because of plant outrage**

Deteriorating Phenomenon of Transformer

- ■In transformers, deterioration of insulating materials are rather remarkable than that of metals
- ■In insulating materials, deterioration of mechanical function is proceeding faster than that of electrical.

Material type	Deteriorating phenomenon
Metal materials ●Conductor, silicon steel plate, etc.	●There are almost no mechanical/electrical deteriorating tendencies.
Insulating materials ●Insulating paper, Pressboard, etc. ●Insulating oil	●Deterioration of mechanical strength (tensile/ compressive) ●Decrease in breakdown voltage ●Generation of combustion gases, etc.

Insulating materials deteriorate faster than metal materials

Life of Transformer

■Among insulating materials, deteriorating severity of insulating oil is milder than others. Additionally, its function can be refreshed by degassing filtration treatment or exchanging to new one.

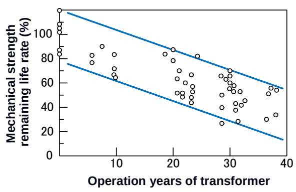
■Pressboard reaches its service limit slowly than insulating paper, because its temperature elevation is generally lower than insulating paper and its necessary function is compressive strength.

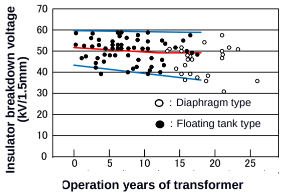
■When the insulating paper mechanical strength is decreased, there is an increased risk of breaking paused by electromagnetic force arising from surge current at the time of external short circuit fault and other accidents.

End of insulating paper life

■Basically, it is impossible to re-wind the insulating paper and to replace the transformer coils. Thus the insulating paper life means the transformer life.

Mechanical & Electrical Strength of Insulating Paper





Insulating strength:
Mechanical strength deteriorates faster than electrical strength

Organic constituents extracted from insulating paper aging

- Various organic constituents are produced by chemical changes of the cellulose.

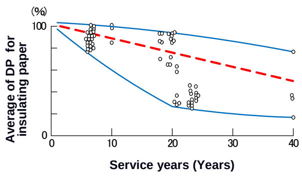
Inorganic	H_2O, CO, CO_2
Hydrocarbon	CH_4Methane, ethane, propane, propylene
Alcohol	Ethyl alcohol, furfuryl alcohol
Aldehyde/ Ketone	Acetaldehyde, furfural, 5-methylfurfural, 5-hydroxymethyl-2-furfural, acetone, methyl ethyl ketone
Acid	Formic acid, 2-furan carboxylic acid, acidum tartaricum, butyric acid
Others	Furan methyl carboxylic acid, acetic ether ($CH_3COOC_2H_5$), furan (C_4H_4O), 2-acetyl furan

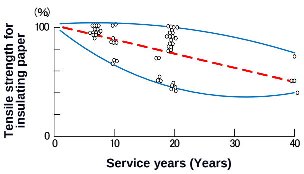
The quantity of organic constituents marked by this symbol has close relevance with mechanical strength of insulating paper.

CO,CO2 and Furfural are closely related with insulating paper strength
Remaining life diagnosis is conducted with the relation.

Insulation Paper Strength and Degree of Polymerization

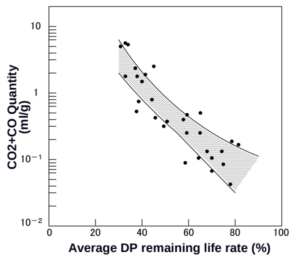
- Measuring the strength of insulating paper in a fully inspection costs a lot and is difficult to do accurate because of the insulation paper core set.
- The degree of polymerization (DP) is the fiber density of insulating paper and is closely related with the mechanical strength of insulating paper.

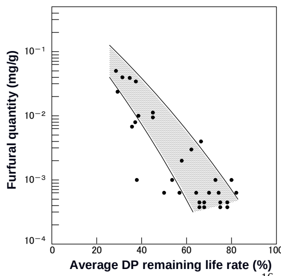




Average DP survival rate and deterioration indicator substances

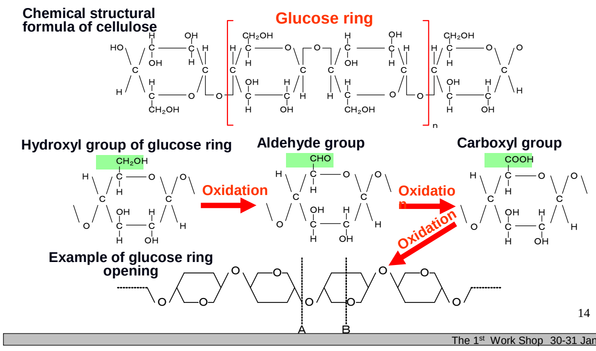
- The qty. of (CO+CO2) and the qty. of furfural are closely related with the average DP remaining life rate of insulating paper. They can be therefore treated as deterioration indicators (the components which deterioration level can be measured).
- One of the main reasons for the data spread is difference in the load factor of transformers.





Weakening process of insulation paper strength (Generation of organic constituents)

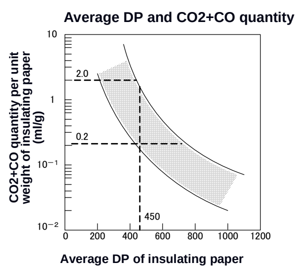
- The decrease of insulating paper mechanical strength is caused by chemical changes (glucose bond breaking and ring opening) of the cellulose.

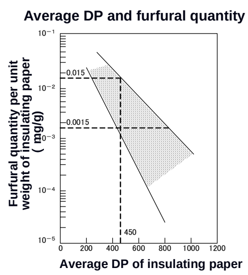


Judgment Criteria for Remaining Life Diagnosis (Deterioration Diagnosis) (Japanese case)

- Reference values for the remaining life of insulating paper is set to Average DP 450
- Based on this, the judgment criteria of deterioration indicators is developed.

	Level of caution	Level of danger
CO2+CO qt.	0.2 (ml/g)	2.0 (ml/g)
Furfural qt.	0.0015 (mg/g)	0.015 (mg/g)





Applicability of Gas Analysis

Applicability of CO and CO2

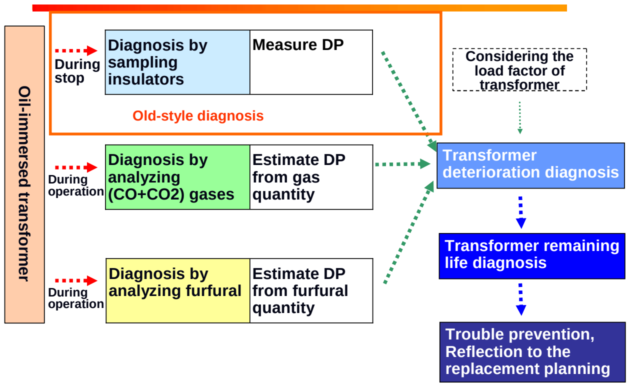
■This method cannot be applied to open type transformers, because CO and CO2 in the transformer is released to the atmosphere.

Applicability of furfural method

■Furfural is a liquid of 161℃ in boiling point and dissolves to insulating oil.
Therefore, it can be detected even in an open type transformer.

■When adsorbing materials exist in a transformer, this method cannot be applied to because furfural is adsorbed to it.

Flowchart of Transformer Preventive Maintenance



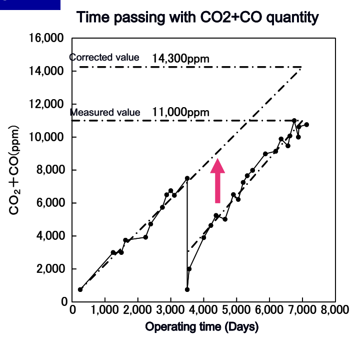
Degassing correction method

Why need degassing correction?

■Gas quantity is decreasing at the time of insulating oil exchange, degasification, etc. Therefore, degassing correction is needed.

How to correct?

■Make clear the quantitative changes of deterioration indicator substances along with time in the event of insulating oil exchange, degasification, etc. Then, make corrections by linking balanced properties after degasification to those before degasification.



Thank You !

Quoted from
Maintenance Management for Oil-immersed Transformer Vol. 54 No. 1 (Part 1)
Published by Electric Technology Research Association（Japan)

Japan International Cooperation Agency

Remaining Life Diagnosis of Transformer

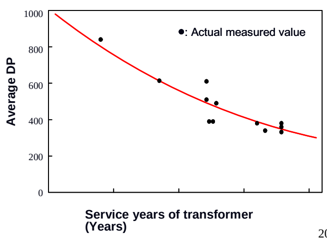
Remaining life diagnosis method by average DP

■The average DP is estimated by sampling approach, CO/CO2 method or furfural method, and the remaining life of transformer is calculated by Acker's regression formula.
■Remaining life diagnosis of transformer enable trouble prevention, reflection to replacement planning and so on.

Acker's regression formula

$$L_R = L_0 (1 - r)^n$$

L_R : DP
L_0 : Initial DP
r : coefficient estimated the results of diagnoses
n : Operating years



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

Instrumentation and Control Systems

Japan International Cooperation Agency

Contents

Instruments used in Japanese Power Stations

Main Instruments used in Japanese Power Stations

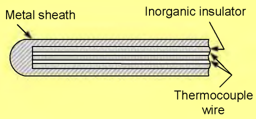
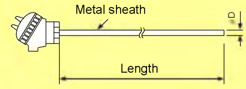
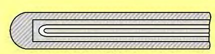
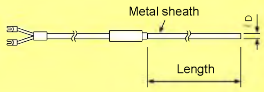
Item	Outline
• **Thermometer**	**Thermocouple measurement features and applicable areas** **Resistance temperature detector measurement features and applicable areas**
• **Flow meter**	**Various flow meter measurement methods, features and applicable areas**
• **Waste gas analyzer**	**Various gas analyzer measurement methods and applicable areas**

Methods and features of temperature measurement at power station

	Measurement methods	Temp. range	Applications at power plant	Features
1	Thermocouple	-200 ~ 1700°C	Feedwater temp. Steam temp. Different metal temp. * For general use	Different types according to different materials. Large thermo electromotive force and small variation in properties. Excellent in resisting heat and corrosion. Limitations on types due to measurement atmosphere. Reference junction temperature compensation required.
2	Resistance temperature detector	-200 ~ 650°C	Condense Water intake temperature * For precise measurement	Higher accuracy and stability than thermocouple. Slower responsiveness than thermocouple. Sensitive to mechanical shock and vibration.
	• Two-wire			Susceptible to the influence of change in outside air temperature.
	• Three-wire			Not susceptible to the influence of change in outside air temperature.
	• Four-wire			Not affected to the influence of change in outside air temperature.

Types of thermoelectric pyrometer

- Sheath thermocouple

Structure of measuring junction	Configuration of sheath thermocouple
Grounding system 	With terminal plate 
Non-grounding system 	Without terminal plate 

Methods and features of flow measurement at power station

	Measurement methods	Target fluids: Liquid	Gas	Steam	Application at power plant	Features
1	Differential pressure	○	○	○	Main steam flow rate Main feedwater flow rate	Wide measuring range, low cost, and big error in low flow rate region.
2	Area	○	○	○	Auxiliary equipment cooling water flow rate	Simple structure & low cost. Subject to error in gas measurement
3	Positive Displacement	○	○	×	Incoming fuel flow rate Makeup water flow rate	High accuracy & for high viscosity but weak against dirt. In the bearing, there is longevity.
5	Electromagnetic	○	×	×	Desulfurization slurry Waste water treatment	Superb in resisting corrosion and wear. Electric conductivity required.
6	Vortex	○	○	○	Gas turbine fuel flow rate	Wide measuring range, high accuracy, but unsuitable for small flow.
7	Ultrasonic	○	○	△	Desulfurization slurry Waste water treatment	Superb in resisting corrosion and wear. Susceptible to influence of air bubbles.

Methods, Types and Areas of Waste Gas Analysis in Power Stations

	Measurement Item	Measurement Method	Area of Use
1	NOx, SO2	Infrared method	Denitrification inlet, denitrification outlet, desulfurization inlet, desulfurization outlet, stack inlet
		Chemi-luminescent method	
2	O2	Zirconia method	ECO outlet (For optimum combustion control)
		Magnetic wind method	Denitrification inlet, denitrification outlet
		Magnetic pressure method	
3	Dust concentration	Transmission method	EP outlet
		Scattered light method	

Control technology for multi coal fired boiler

1. Coal-fired boiler constraints
2. Necessity of control technology for multi coal fired boiler
3. Basic concept of control technology for multi coal fired boiler
4. Division of multi coal fired boiler operational logic and boiler control logic
5. Adjustment of boiler control logic parameters

Reference: Optimum combustion control

Control technology for multi coal fired boiler

1. Coal-fired boiler constraints

Boiler heat capacity

With variable-pressure boiler, pressure (saturation temperature) changes with load. ⇨

Consider:
Heat quantity corresponding to evaporation when load changes
+
Heat quantity corresponding to change in heat capacity of retained water and steel of boiler tube header, etc.

Change in characteristics with coal brand

- **Change in fuel consumption due to difference in heating value**
- **Change in heat absorption characteristics due to difference in combustibility**
- **Change in mill capacity and coal supply characteristics due to difference in grindability**

Change in boiler characteristics over time

Boilers tend to get dirty and their characteristics change greatly over time.

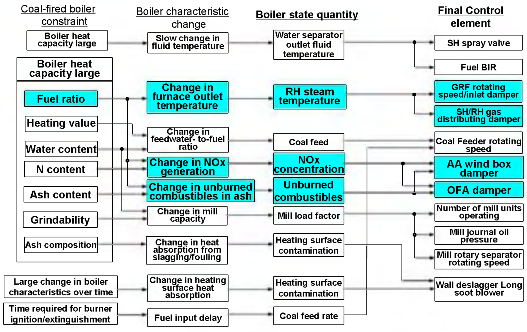
Burner ignition/extinguishment time

- **Since coal burner ignition takes time, the control designing should take into account the ignition/extinguishment time.**
- **A mill motor is a large auxiliary machine; thus, it is unsuitable for repeated starts and stops. Therefore, it is difficult in practice to change loads with continuously changing the number of mills in operation.**

Control technology for multi coal fired boiler

2.Necessity of control technology multi coal fired boiler

Table 1 Relationship between control operating element and change in boiler characteristics with respect to coal-fired boiler constraints



Control technology for multi coal fired boiler

2.Necessity of control technology for multi coal fired boiler

Coal-fired boiler constraints

⇩

Boiler heat characteristics, exhaust gas property characteristics, and mill characteristics undergo large changes statically/dynamically according to the type of coal.

⇩

Necessity of control function that supplements boiler control corresponding to this change

- Control that adjusts boiler characteristic changes
- Control that adjusts mill capacity changes
- Control of soot blower

Control technology for multi coal fired boiler

2.Necessity of control technology for multi coal fired boiler

Key points of control

1. Proper grasp of heat transfer characteristics from combustion state of boiler, regardless of coal type data
2. Grasp of coal property changes in mill from mill's operating state

⇨ Optimum correction of related parameters

To be more precise

1. **Grasp of distribution of furnace/superheater/reheater's heat absorption from estimation of heating surface's heat absorption state**
2. **Grasp of coal heating value from estimation of boiler's total heating value**
3. **Grasp of change in coal properties in mill from mill heat balance, mill current value, and other operating state quantities**

Proper control parameter correction ⇨ Achievement of optimum boiler operation regardless of change in coal properties and contamination over time

Control technology for multi coal fired boiler

3. Basic concept of control technology for multi coal fired boiler

Influencing factors and quantities involved in control of technology for multi coal fired boiler

Factor that Affects Control	Effect	Quantification of Influencing Factor	Correcting Control Item
Fuel ratio	Deviation in furnace heat absorption Deviation in degree of superheat	Heat absorption index	BIR for fuel, feedwater, air, etc. Steam temperature control Gas distributing damper control, other
Contamination	Deviation in furnace heat absorption Deviation in degree of superheat		
Heating value	Deviation in fuel feed rate Deviation in BIR	Total heating value	Heating value correction
Ash content	Deviation in feed rate		
Water content	Delay in coal exhaustion	Change in mill state quantity	Mill outlet temperature control Mill pressurization equipment hydraulic control Mill rotary classifier control Mill primary air flow control
Grindability	Change in mill's actual capacity Delay in coal exhaustion		

Control technology for multi coal fired boiler

3. Basic concept of Control technology for multi coal fired boiler

Quantified influencing factors

① Heat absorption index (HAI):
Value that shows distribution of heat absorption of furnace and superheater/reheater. Represents change in combustion due to change in burner position, contamination distribution, flammability (equivalent to fuel ratio) associated with coal properties, etc.

② Total heating value:
Represents change in fuel input due to change in water content, caloric value of fuel, etc.

③ Change in mill state quantity:
Utilizes changes in state quantities of mill roll lift, mill current value, and water content ratio estimated from the mill heat balance to represent the change in mill coal exhaustion capability caused by a change in coal properties.

Correction

Adjusted control parameters based on standard coal ⇨ **Enables optimum control that suppresses changes in characteristics of multi-coal-type coal-fired boiler.**

Control technology for multi coal fired boiler

4. Division of multi coal fired boiler operational logic and boiler control logic

Multi coal fired boiler operational logic
- Heating surface state estimation (fuzzy technique) → Heat absorption index (HAI) → BIR of fuel, feedwater, air, etc. / Steam temperature control / Gas distributing damper control
- Heating surface state estimation (fuzzy technique) → Total heating value → Heating value correction
- Mill heat balance calculation → Total water content of mill → Mill outlet temperature control (Mill pressurization equipment hydraulic control) (Mill rotary classifier control) (Mill primary air flow control)

Boiler control logic

Control technology for multi coal fired boiler

5.Adjustment of boiler control logic parameters

Basic concept

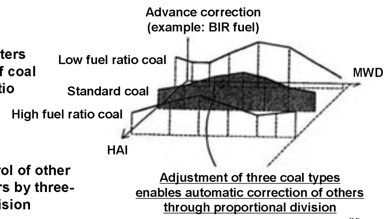
Adjustment of parameters based on combustion of standard coal

⇩

Adjustment of parameters based on combustion of coal with different fuel ratio

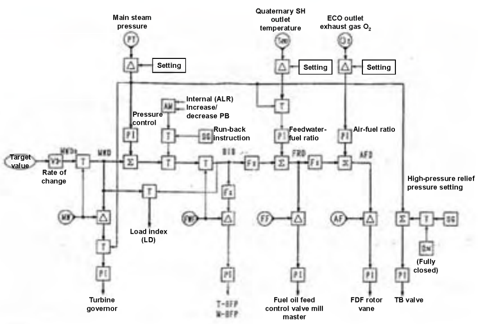
⇩

Automatic setting and control of other fuel ratio property parameters by three-point proportional division



Reference: Optimum combustion control

To improve the controllability of the ECO outlet gas O_2 deviation, multi point analyzers with zirconia type are used because of their fast response. As a result, optimum combustion is achieved.



Assessment of control system

1. Objectives
2. Investigation Items
3. Investigation Method
4. Assessment Contents (Summary)

Assessment of control system

1. Objectives
The objectives is to confirm the state of key facilities at a power station and to investigate the feasibility of improving the reliability, operating performance and functionality of the power station through renovating or modifying its instrumentation and control systems.

2. Investigation Items
- Control performance of control systems
- Installed condition of control systems and field measuring instruments
- Weak regions of control systems

3. Investigation Method
- Acquired data analysis
- Observation of operating conditions
- Visual inspection of field equipment
- Interviews with personnel involved

Assessment of control system

4. Assessment contents (Summary)
a. Grasp of control performance (operating data, observation, interviews)
(1) Records of operating trends
(2) Confirmation of the control mode
(3) Conditions and causes of manual intervention by operators

b. Appropriateness of the installed state of equipment
(control systems, field measuring instruments) (visual check)
(1) Installed environment and state
(2) Equipment maintenance conditions
(3) Detection pipes

c. Gauging of control system weak regions (maintenance records)
(1) Records of unit trip caused by the control system
(2) Adjustment accuracy and inspection frequency of measuring instruments
(3) Soot blower system operating history and conditions

Site investigation period
Around 3 days/1 unit

⇩

d. Identification of parts of instrumentation and control systems that can be improved

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8.2.2 Other work shop and seminar

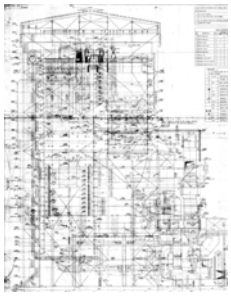
Diagnosis Boiler Problem

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）**

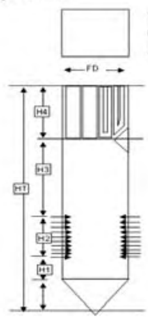
Step II

- **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

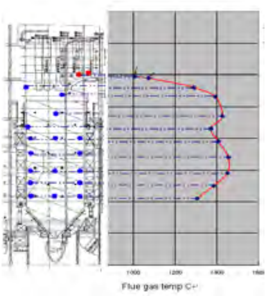
No	Item	Unit	Same type of Boiler in Japan	Vindhyachal Unit 7
1	Rated Output	MW	500	500
2	Boiler High (HT)	m	56	63
3	Bottom of SH Panel to roof (H4)	m	14	16
4	Top Burner level to Bottom of SH Panel (H3)	m	17	18
5	Burner Zone (H2) Burner	m	10 (6 stages)	13 (10 stages)
6	Hopper Bent to bottom of burner (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

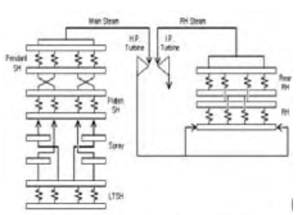


Fig. 6.1-2 Outline of Steam Flow Diagram (Same type of Boiler in Japan)

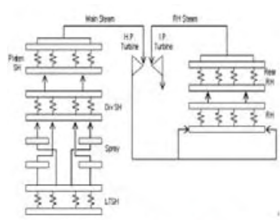


Fig. 6.1-3 Out line of Steam Flow Diagram (Vindhyachal Unit 7)

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.

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

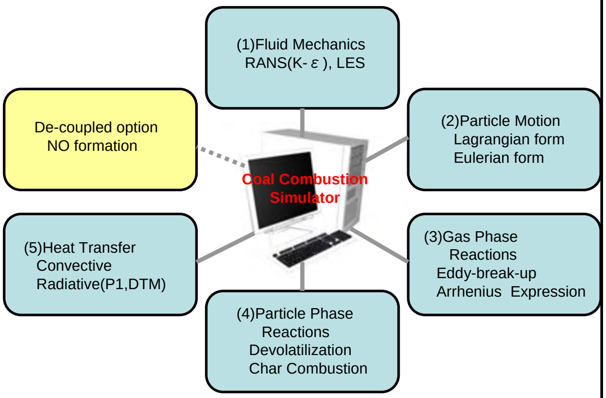


Figure 2.1 Sub models incorporated into Coal Combustion Simulator

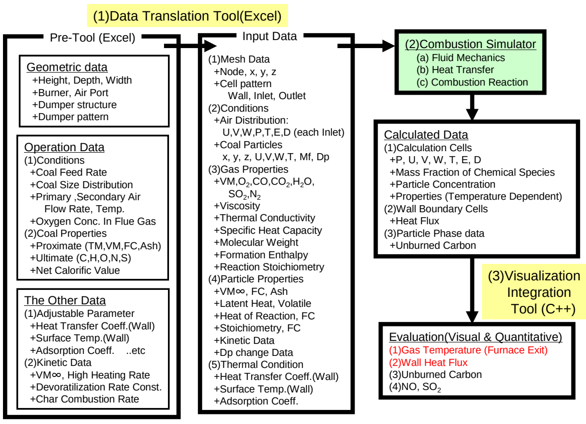


Figure 2. 2 Summary of the Input/Output Data in the combustion simulation

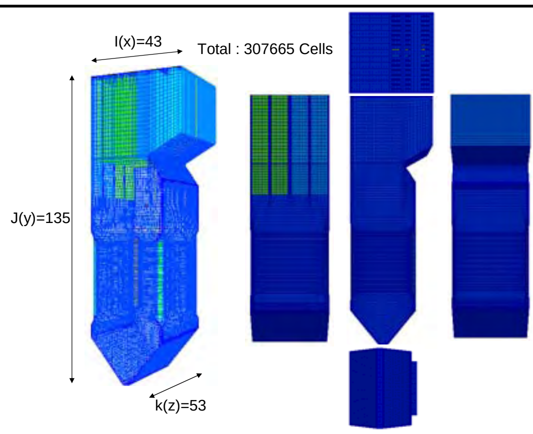
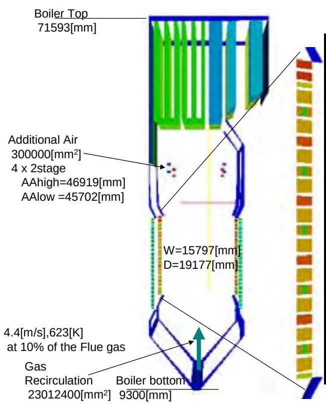


Figure 3.2 Unit 7&8 Mesh used for the base simulations

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	

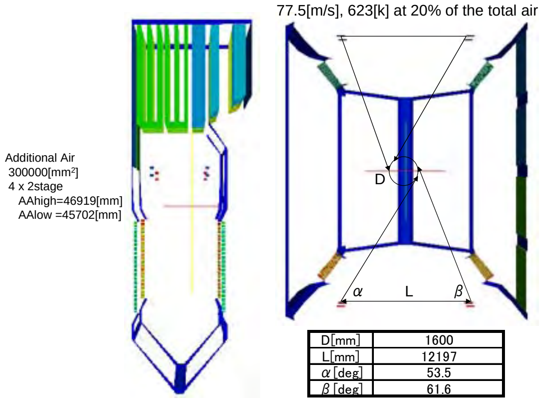
*1) This value is the total volume of the simulation model.
The volume except Reheater zone is 16141[m3].
*2) This value does not include the area of Wall Super Heater.
*3) 15Boiler_Technical_details.pdf



*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

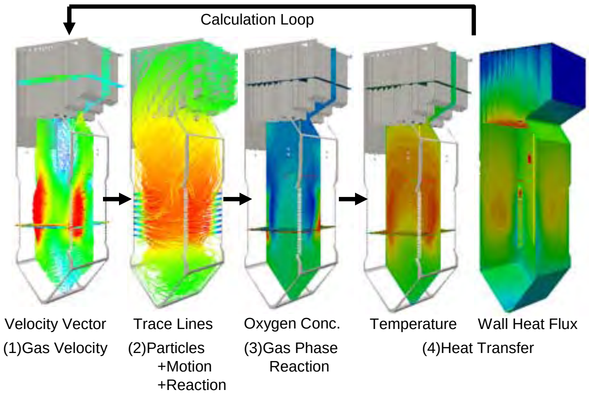


Figure 2. 5 Calculation procedure of the Coal Combustion Simulation

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]

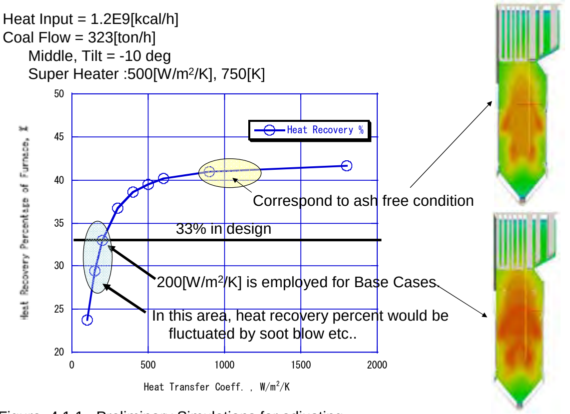


Figure 4.1.1 Preliminary Simulations for adjusting the heat recovery percentage of the furnace

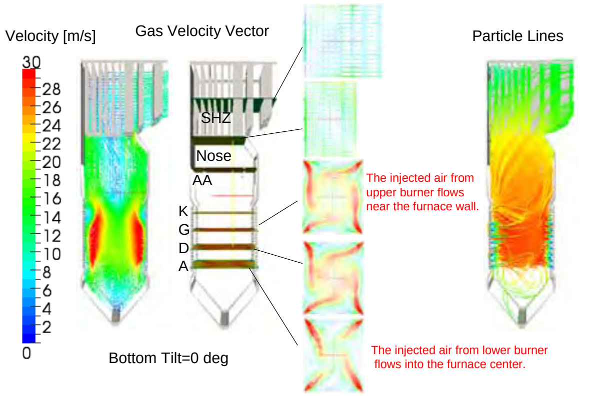


Figure 4.1.2 Typical Flow Pattern in tangential fired boiler(1)

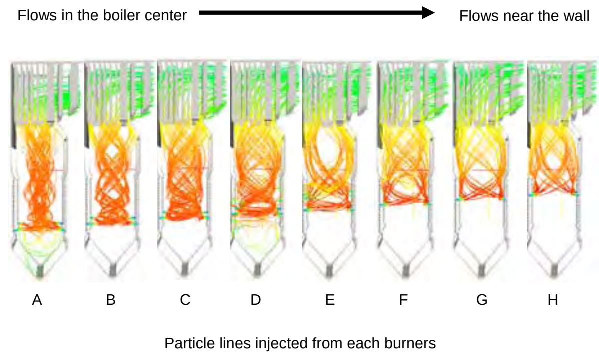


Figure 4.1.3 Typical Flow Pattern in tangential fired boiler(2)

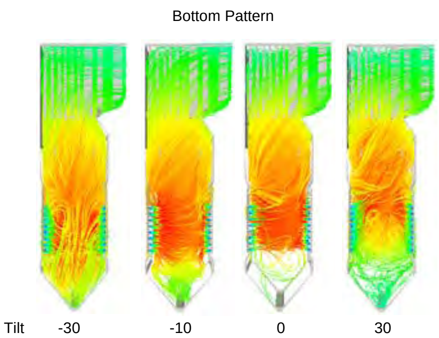


Figure 4.1.4 Typical Flow Pattern in tangential fired boiler(3)

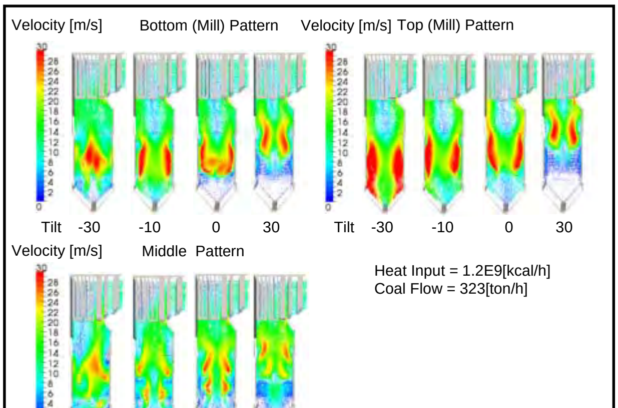


Figure 4.2.1 Velocity Vector of each cases

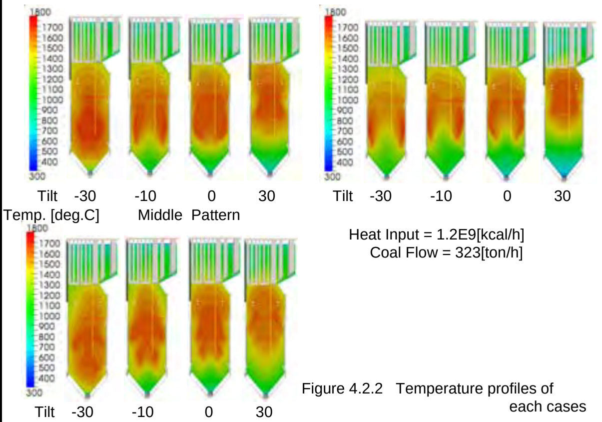


Figure 4.2.2 Temperature profiles of each cases

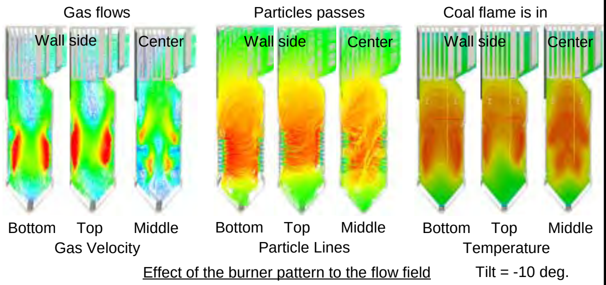


Figure 4.2.3 Typical Flow Pattern in tangential fired boiler(4)

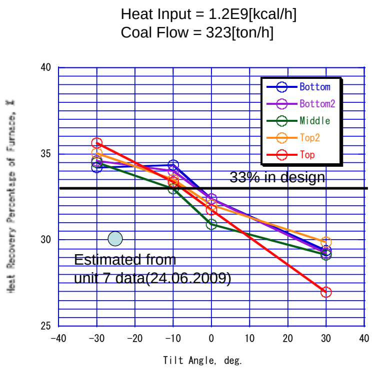


Figure 4.2.4 Predicted Heat Recovery Percentage of the Furnace

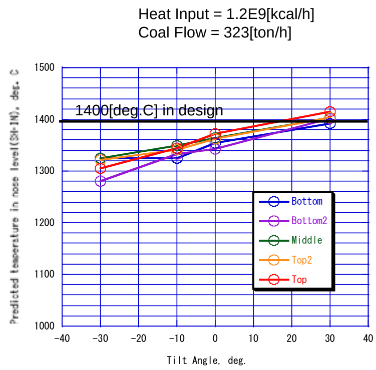


Figure 4.2.5 Predicted Temperature in nose level (SH-IN)

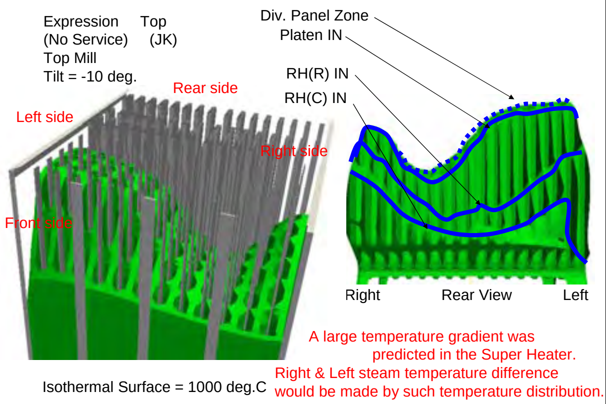


Figure 4.2.7 A cause of the Right & Left steam temperature difference(2)

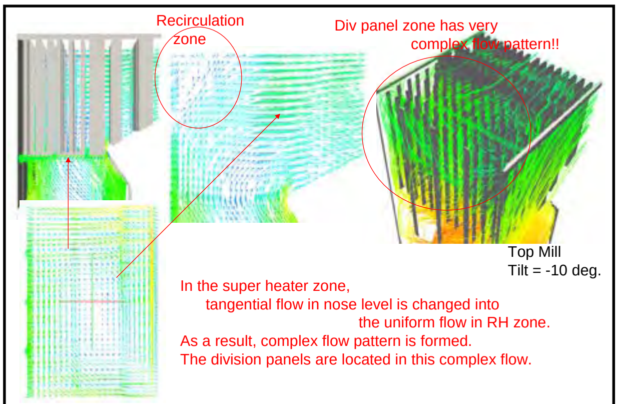
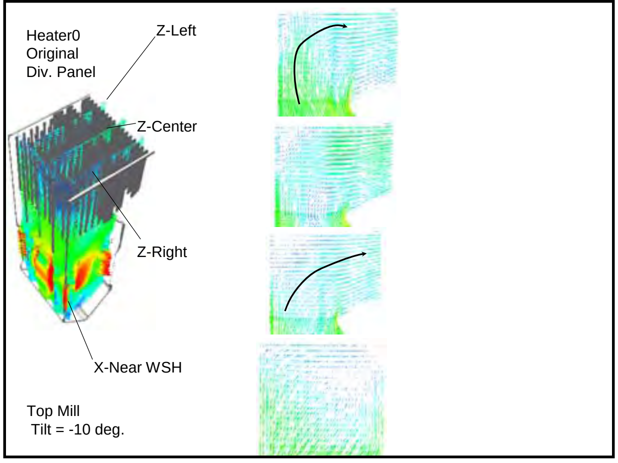


Figure 5.2.6 A cause of the Right & Left steam temperature difference(1)



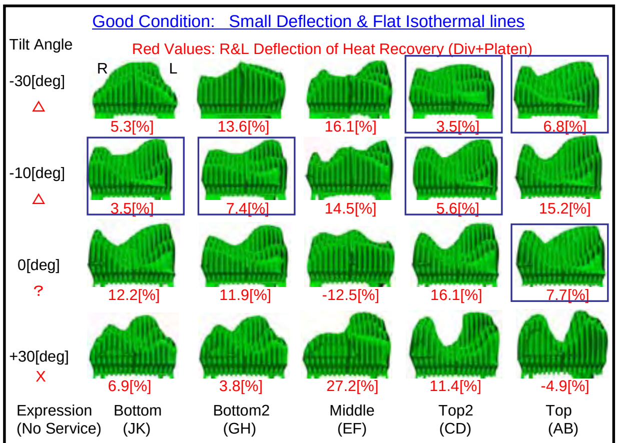


Figure 4.2.8 Isothermal Surface = 1000 deg in SH Zone

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

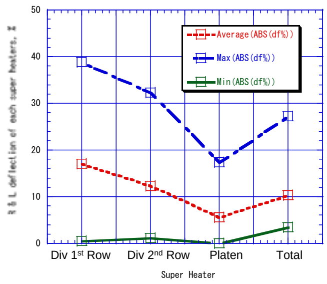


Figure 4.2.9 R & L deflection of each super heaters

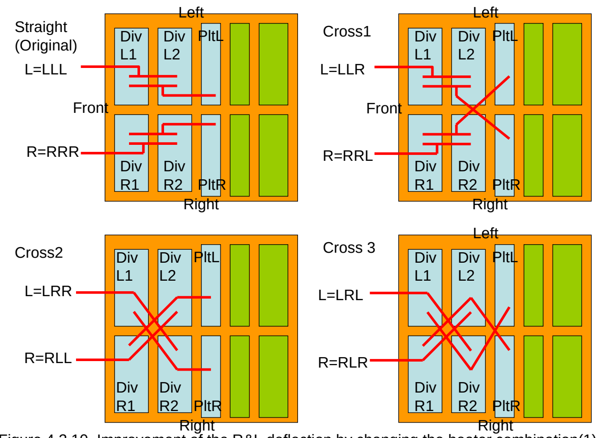


Figure 4.2.10 Improvement of the R&L deflection by changing the heater combination(1)

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

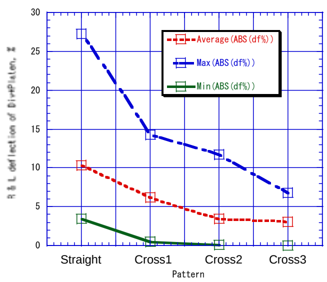


Figure 4.2.11 Improvement of the R&L deflection by changing the heater combination(2)

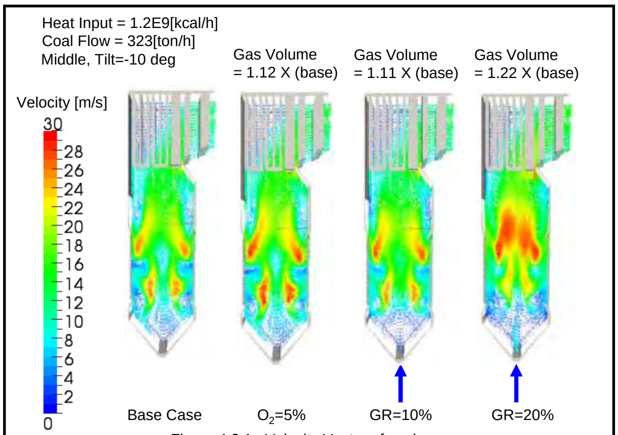


Figure 4.3.1 Velocity Vector of each cases

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

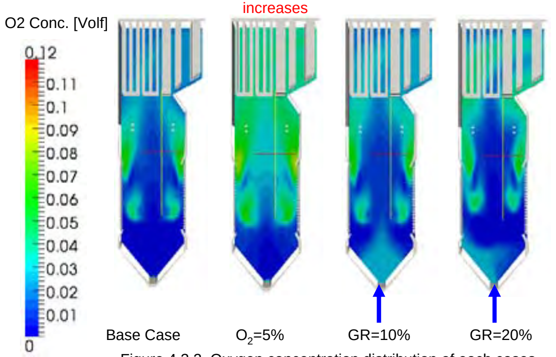


Figure 4.3.2 Oxygen concentration distribution of each cases

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

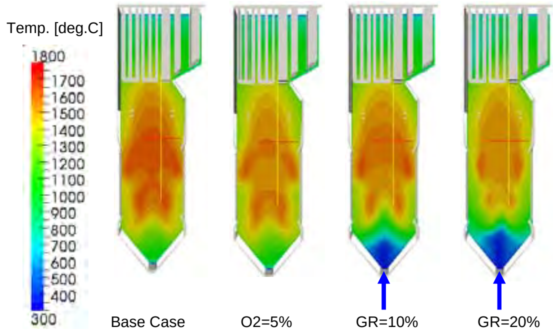


Figure 4.3.3 Temperature distribution of each cases

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

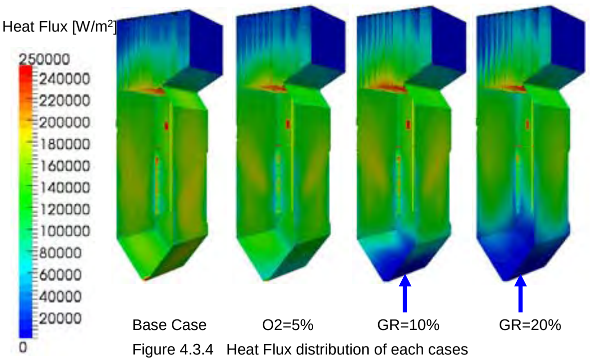


Figure 4.3.4 Heat Flux distribution of each cases

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.

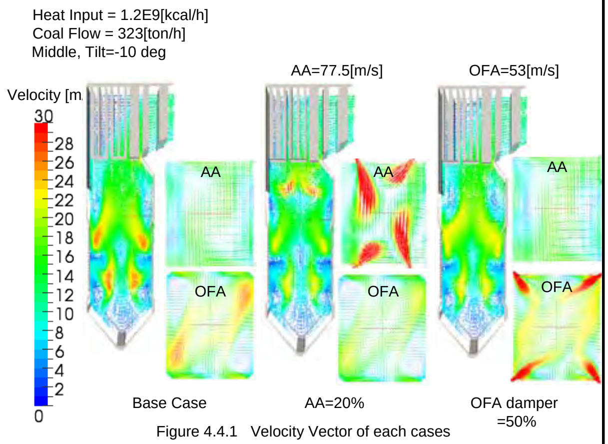


Figure 4.4.1 Velocity Vector of each cases

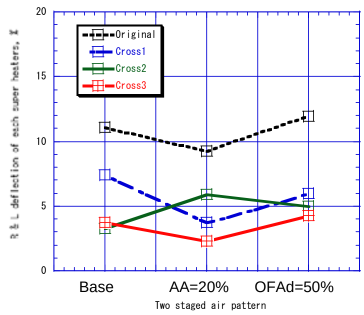
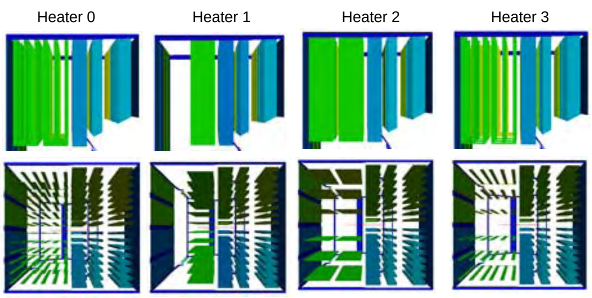


Figure 4.4.2 Average R&L Deflection of the Super Heaters



	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

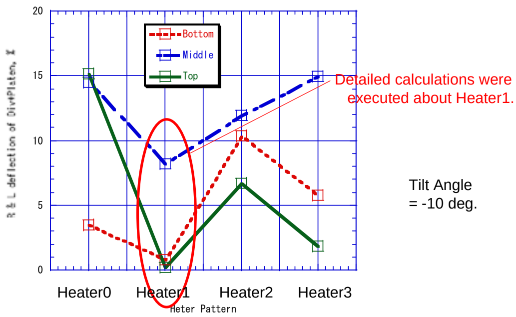


Figure 4.5.1 R & L deflection of heat recovery percent in each heater

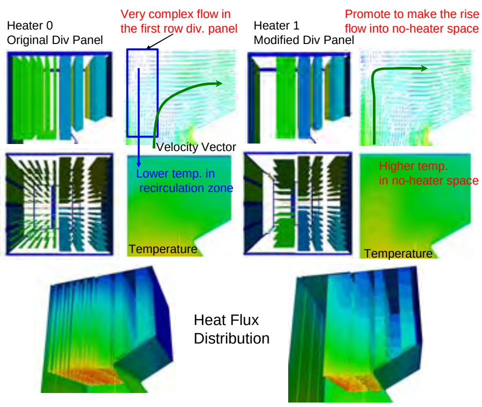


Figure 4.5.2 Concept of the Heater 1

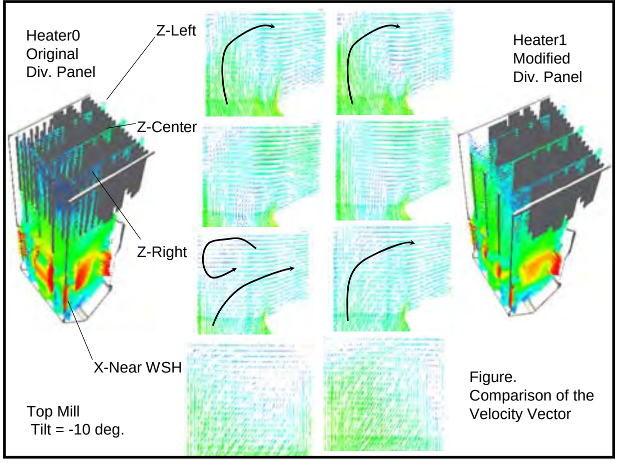


Figure.
Comparison of the
Velocity Vector

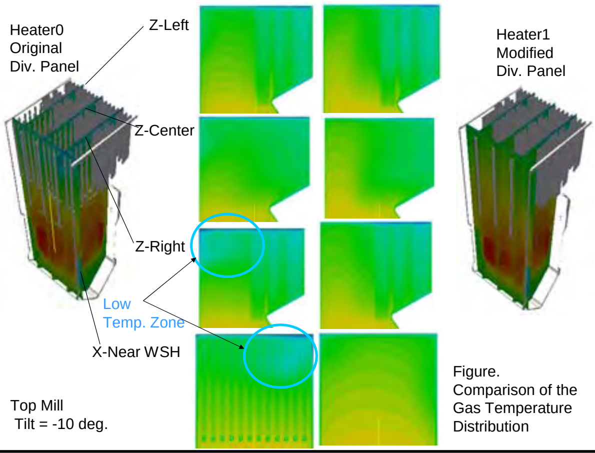


Figure. Comparison of the Gas Temperature Distribution

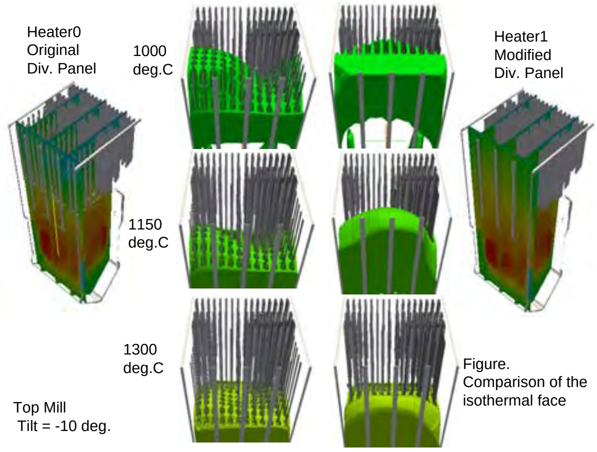


Figure. Comparison of the isothermal face

Good Condition: Small Deflection & Flat Isothermal lines

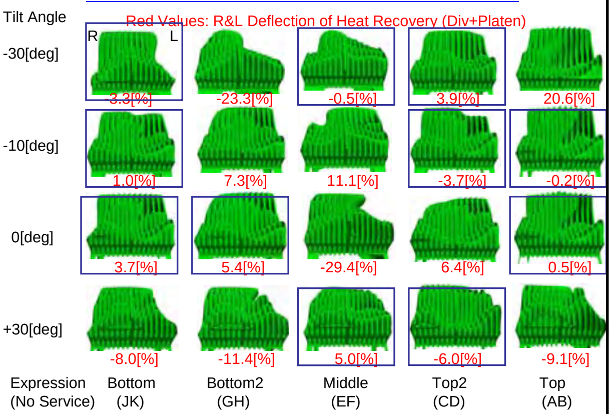


Figure 4.5.3 Isothermal Surface = 1000 deg in SH Zone

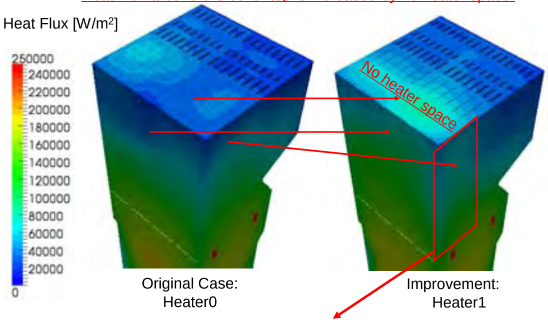
Table 4.5.1 Effect of the Heater1 to the Right & Left Deflection

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	-0.95	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	
AverageABS(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	

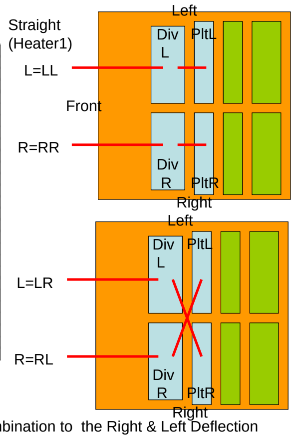


Figure 4.5.5 Effect of the Heater combination to the Right & Left Deflection

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

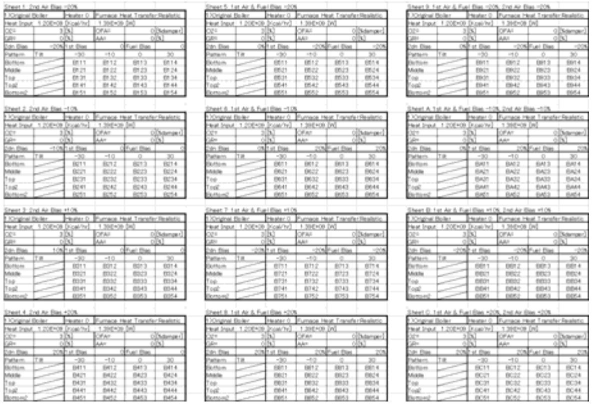
Boiler Combustion Simulation

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

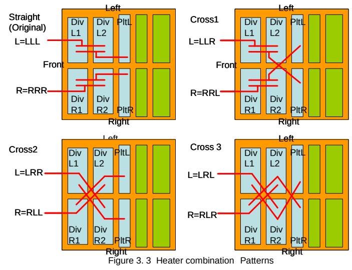
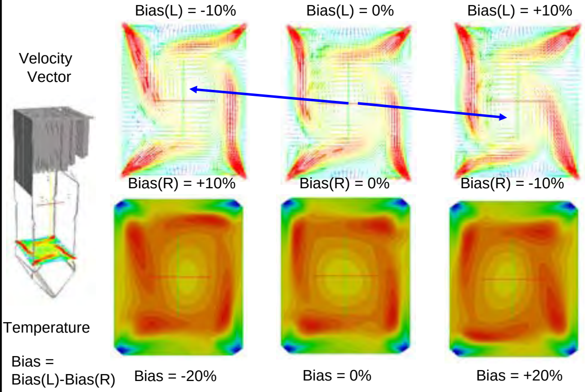


Figure 3. 3 Heater combination Patterns

Improve the R&L deflection

(1)Right & Left 2nd Air Bias

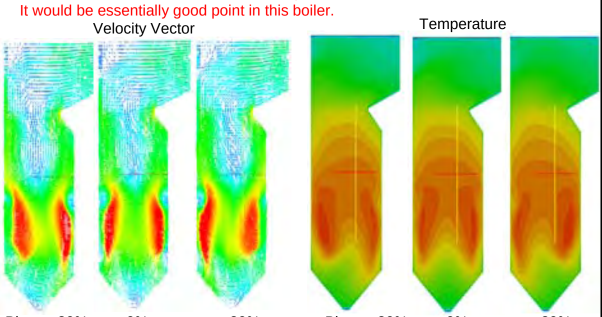
by changing the wind box draft.



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

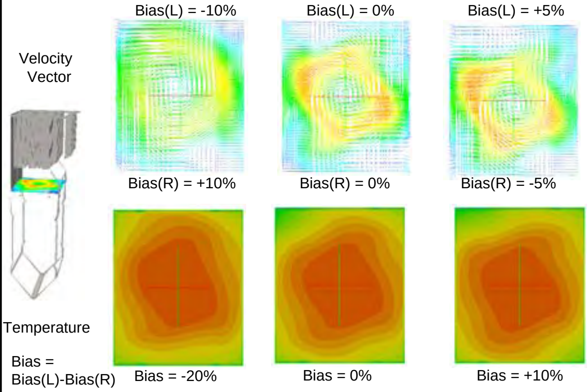
Figure 4.2.1 Effect of the Right & Left 2nd Air bias(1-1)

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

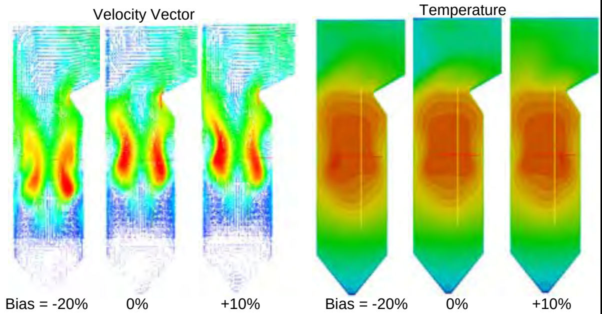
Figure 4.2.2 Effect of the Right & Left 2nd Air bias(1-2)



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

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

On the other hand, the difference was also found in Div. Panel region
under the condition of Top Mill & Tilt = 30[deg]
The reason is that the good swirl would not be get in this condition.
It would be very difficult to control R&L deflection by this operation.



Top Mill pattern , Tilt= 30[deg], Burner A

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

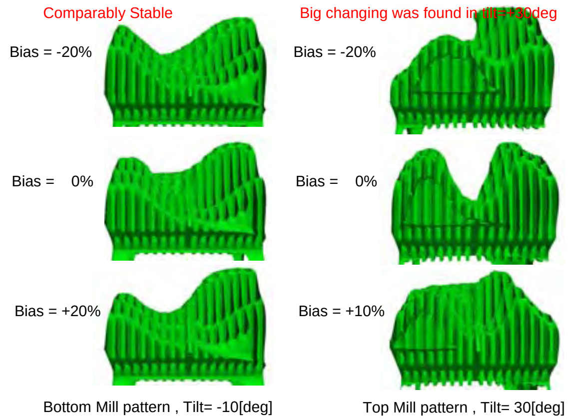


Figure 4.2.5 Isothermal Surface = 1000 deg in SH Zone by changing 2nd Air Bias

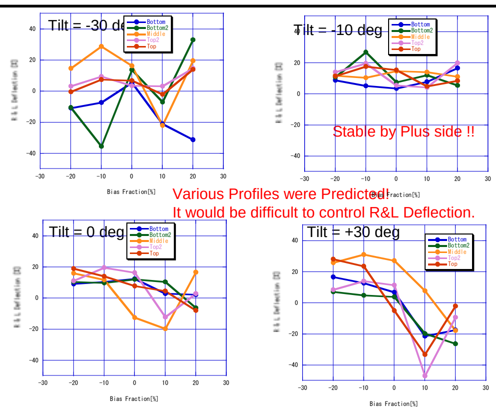
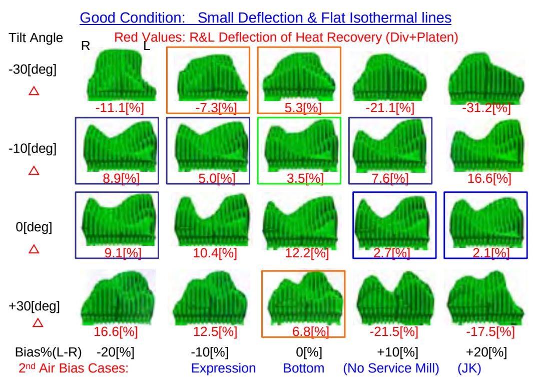


Figure 4.3.1 Effect of 2nd Air Bias on the R & L Deflection
Plus value = Left (high), Minus value = Right (high)



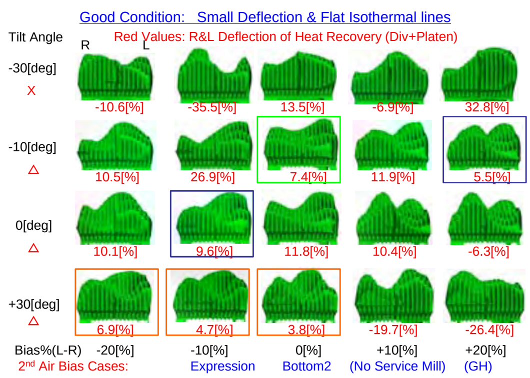


Figure 4.3.3 Isothermal Surface = 1000 deg in SH Zone

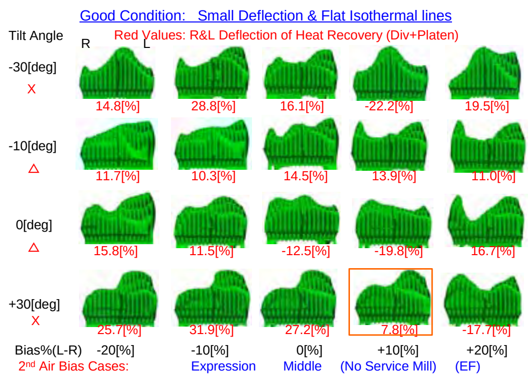


Figure 4.3.4 Isothermal Surface = 1000 deg in SH Zone

Good Condition: Small Deflection & Flat Isothermal lines

Red Values: R&L Deflection of Heat Recovery (Div+Platen)

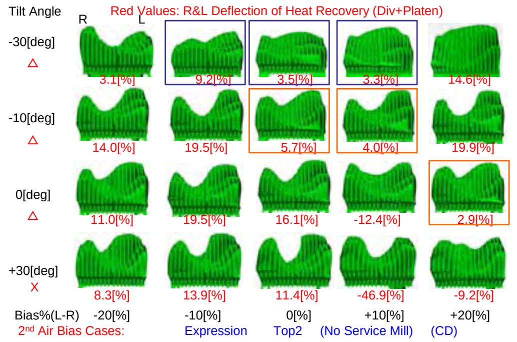


Figure 4.3.5 Isothermal Surface = 1000 deg in SH Zone

Good Condition: Small Deflection & Flat Isothermal lines

Red Values: R&L Deflection of Heat Recovery (Div+Platen)

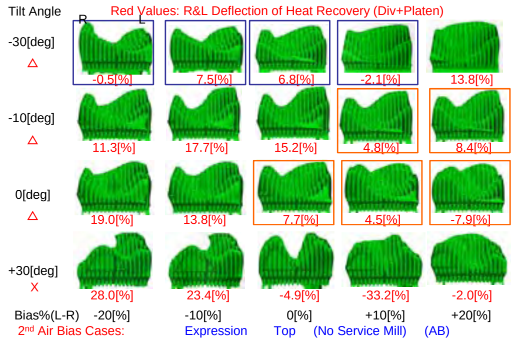


Figure 4.3.6 Isothermal Surface = 1000 deg in SH Zone

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.

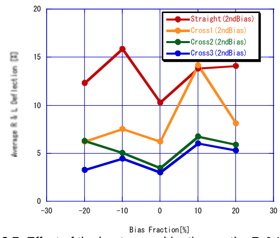


Figure 4.3.7 Effect of the heater combination on the R & L Deflection under the bias condition

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).

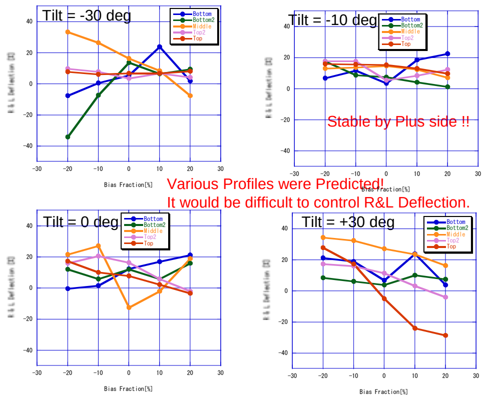
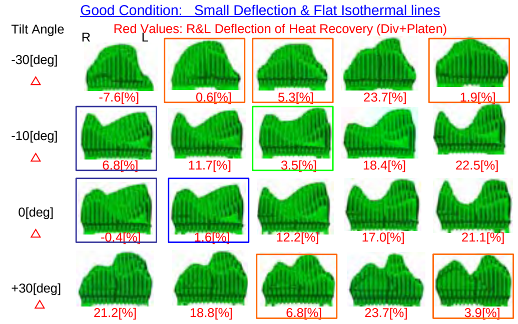


Figure 4.4.1 Effect of Fuel & 1st Air Bias on the R & L Deflection
Plus value = Left (high), Minus value = Right (high)

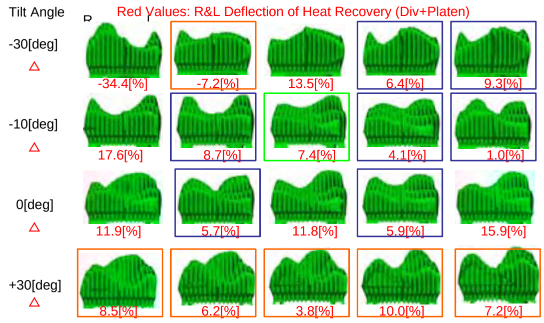
Good Condition: Small Deflection & Flat Isothermal lines
Red Values: R&L Deflection of Heat Recovery (Div+Platen)



Bias%(L-R) -20[%] -10[%] 0[%] +10[%] +20[%]
Fuel+1st Air Bias Cases: Expression Bottom (No Service Mill) (JK)

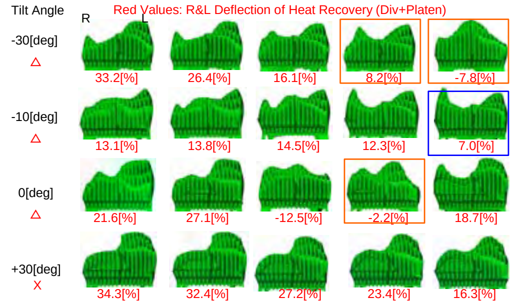
Figure 4.4.2 Isothermal Surface = 1000 deg in SH Zone

Good Condition: Small Deflection & Flat Isothermal lines
Red Values: R&L Deflection of Heat Recovery (Div+Platen)



Bias%(L-R) -20[%] -10[%] 0[%] +10[%] +20[%]
Fuel+1st Air Bias Cases: Expression Bottom2 (No Service Mill) (GH)

Good Condition: Small Deflection & Flat Isothermal lines
Red Values: R&L Deflection of Heat Recovery (Div+Platen)



Bias%(L-R) -20[%] -10[%] 0[%] +10[%] +20[%]
Fuel+1st Air Bias Cases: Expression Middle (No Service Mill) (EF)

Figure 4.4.4 Isothermal Surface = 1000 deg in SH Zone

Good Condition: Small Deflection & Flat Isothermal lines

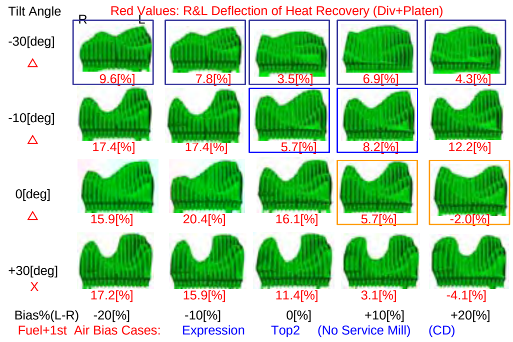


Figure 4.4.5 Isothermal Surface = 1000 deg in SH Zone

Good Condition: Small Deflection & Flat Isothermal lines

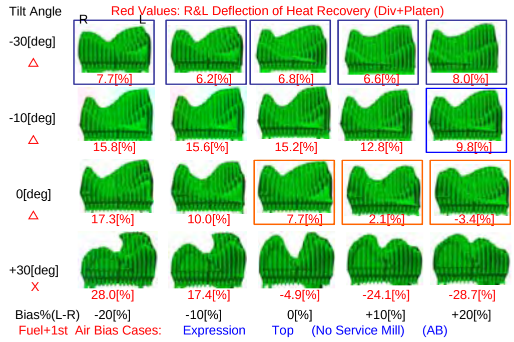


Figure 4.4.6 Isothermal Surface = 1000 deg in SH Zone

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.

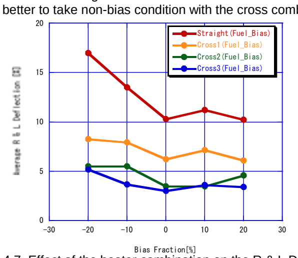


Figure 4.4.7 Effect of the heater combination on the R & L Deflection under the Fuel + 1st Air bias condition

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.

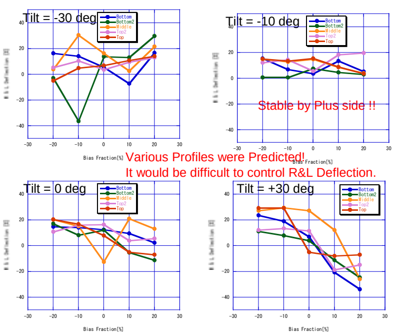


Figure 4.5.1 Effect of Fuel & 1st Air (+2nd Air) Bias on the R & L Deflection
Plus value = Left (high), Minus value = Right (high)

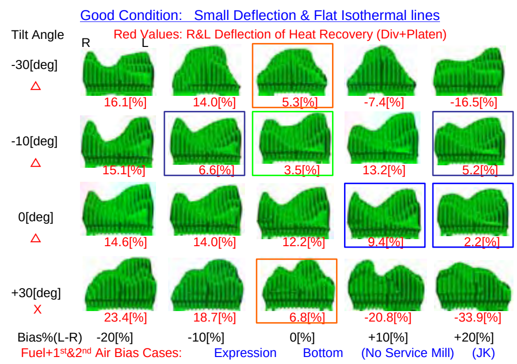


Figure 4.5.2 Isothermal Surface = 1000 deg in SH Zone

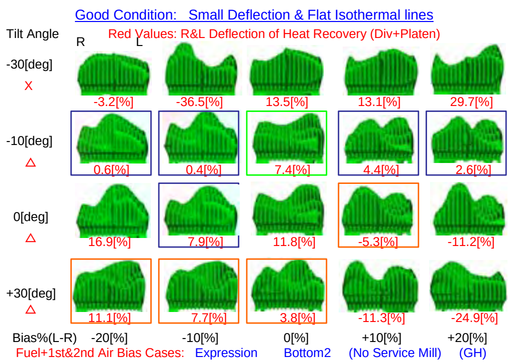


Figure 4.5.3 Isothermal Surface = 1000 deg in SH Zone

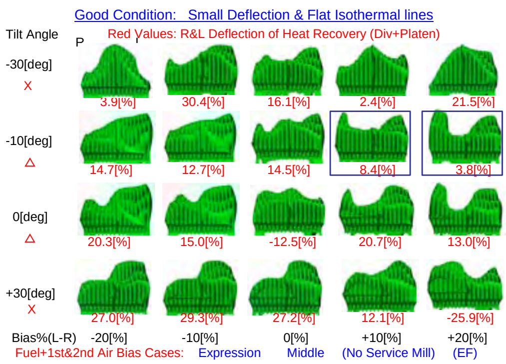


Figure 4.5.4 Isothermal Surface = 1000 deg in SH Zone

Good Condition: Small Deflection & Flat Isothermal lines

Red Values: R&L Deflection of Heat Recovery (Div+Platen)

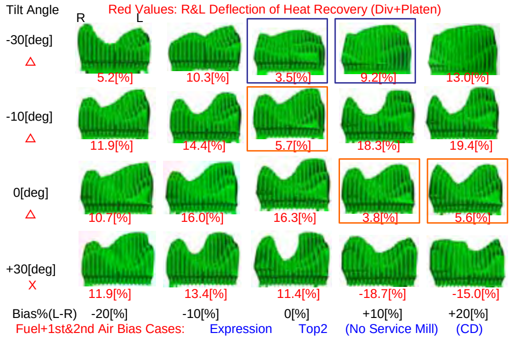


Figure 4.5.5 Isothermal Surface = 1000 deg in SH Zone

Good Condition: Small Deflection & Flat Isothermal lines

Red Values: R&L Deflection of Heat Recovery (Div+Platen)

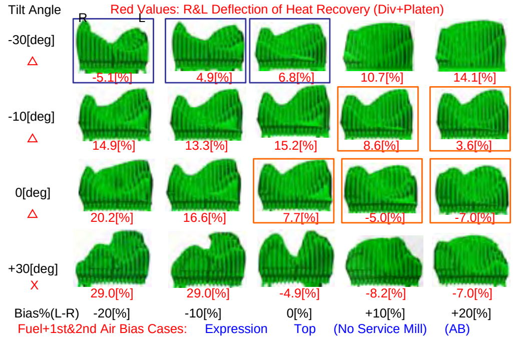


Figure 4.5.6 Isothermal Surface = 1000 deg in SH Zone

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.

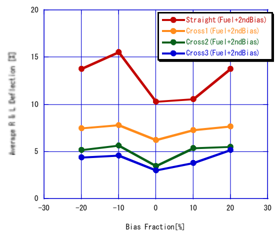


Figure 4.5.7 Effect of the heater combination on the R & L Deflection
under the Fuel + 1st & 2nd Air bias condition

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 −20	Cross3 −10	Cross3 0	Cross3 10	Cross3 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.

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