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Development of Recirculation System & Key Components in Oxy-fuel Combustion

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1. INTRODUCTION
Total Engineering of Power Plant

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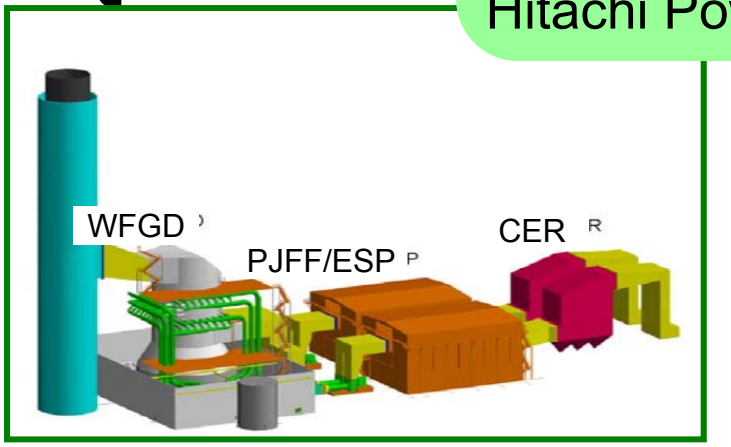
USC Power Plant

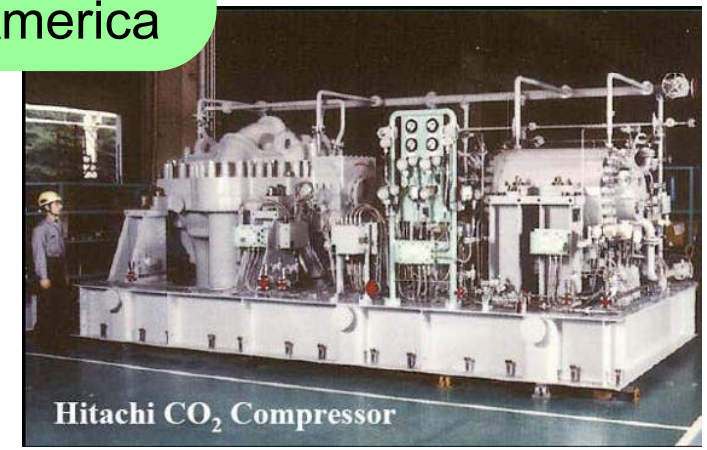
Turbine

Hitachi Ltd.
Hitachi Power Europe GmbH
Babcock-Hitachi K.K.
Hitachi Plant Technology
Hitachi Power Systems America

AQCS



Compressor



1.1 Overview of Hitachi Oxy-fuel Combustion Process

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1. Boiler design technology enhanced to oxy-fuel combustion
   - Design by analysis
     the latest simulation technology
     of fluid dynamics, combustion and heat transfer
   - Validation by data based on combustion testing

2. Design integration of ASU and CPU
   - mixing and firing system modifications
   - waste heat utilization

3. Total plant re-optimization in the context of CCS
   that involves air quality control system :
   Advanced technology of reducing SO3 and Mercury

1.2 Technology Development and Scalability (1)

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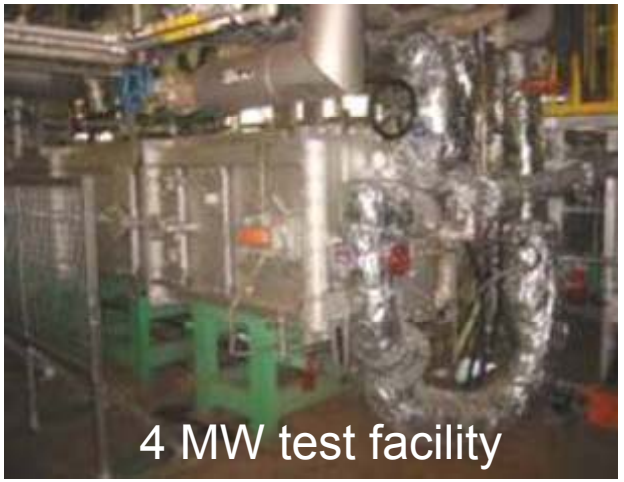
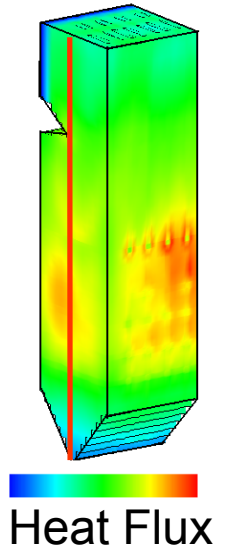
1. Design technology and data base developed since early 1970's
   - Low NOx burner & Furnace
   - Emission control (NOx, Sox, Hg)
2. Bench scale R&D
   - 4MW test facility of oxy-firing
   - Burners with high flame stability


4 MW test facility


Grid Computer
100CPU, 370GB

3. Cutting edge simulation technology
   - turbulence analysis by LES
     (Large Eddy Simulation)
   - multi-phase flow and combustion
   - full scale analysis of boiler


Heat Flux

1.2 Technology Development and Scalability (2)

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4. System testing (1.5 MWth)
   - Total flue gas system of coal-firing such as burner, furnace, tubing, DeNOx, EP and DeSOx,
   - Testing for various kinds of coal

5. Large pilot plant (30 MWth)
   - combustion testing with single and multi-type burners
   - firing coal and biomass

6. Commercial design
   - full size of 500 - 10000 MW
   - retrofits for existing plants and new plants


System test facility (1.5 MW)


Large pilot plant (30 MW)

1.2 Technology Development and Scalability (3)

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7. Joint Research in EU & US
   perticipation in COORETEC and DOE projects
   universities : Aachen, Stuttgart, Lehigh, North Dakota
   utilities : Eon, Electrabel, Vattenfall, Fortum, etc

RWTH Aachen University, 125 kWth

IVD University of Stuttgart, 500kWth

Technical topics to be solved

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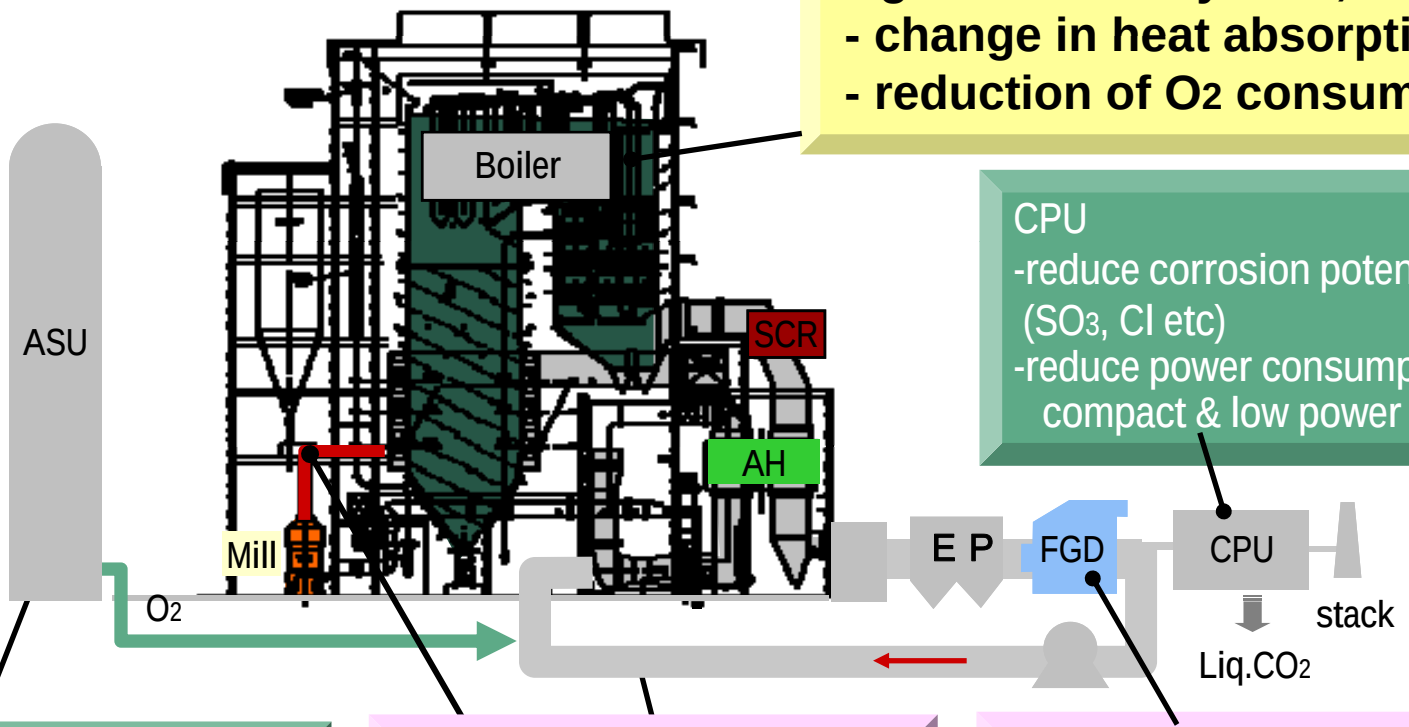
Burner & Boiler
High radiation by CO2,H2O
- change in heat absorption
- reduction of O2 consumption



CPU
-reduce corrosion potential
(SO3, Cl etc)
-reduce power consumption
compact & low power

ASU
-reduce initial cost
-reduce power consumption
compact & low power

Recirculation line
- corrosive gas: SO3

Mill outlet pipe
- temp. 70 - 90C

AQCS
- removal of SOx, Hg
- utilization of waste heat

2. Development of Recirculation System (1)

High reliability and lower energy loss

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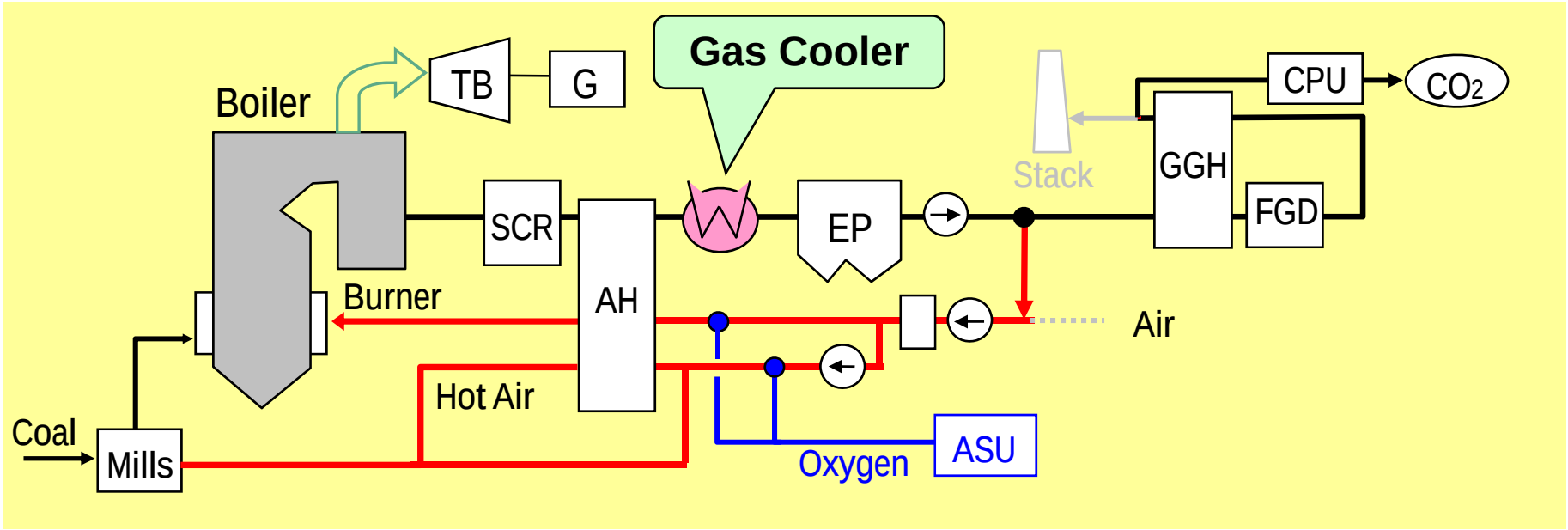
Hitachi's proprietary new system :
Installation of ultra low gas temp. type of gas cooler (upstream of EP)

(1) Sulfur tri-oxide (SO3) to be removed to prevent recirculation line from corrosion

(2) Residual heat of coolant to heat up boiler feed water to increase turbine output



2. Development of Recirculation System (2)

High reliability and lower energy loss

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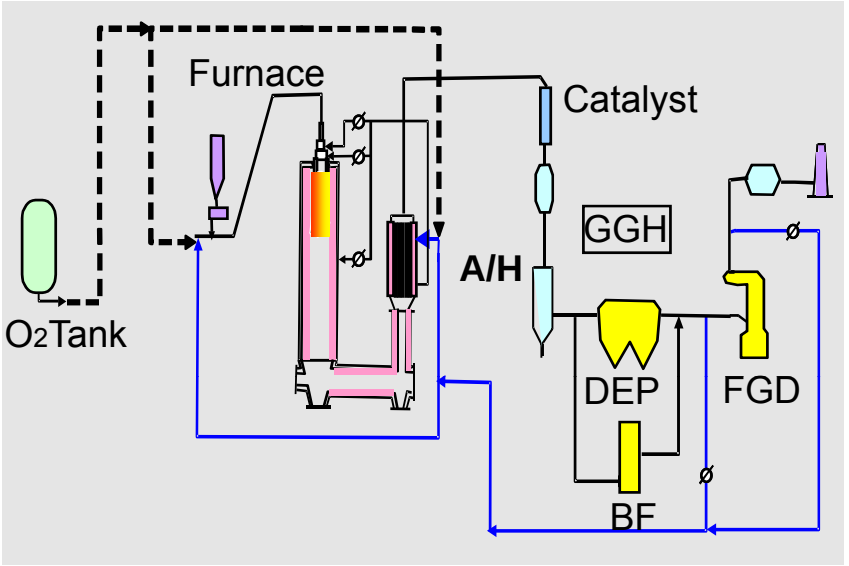
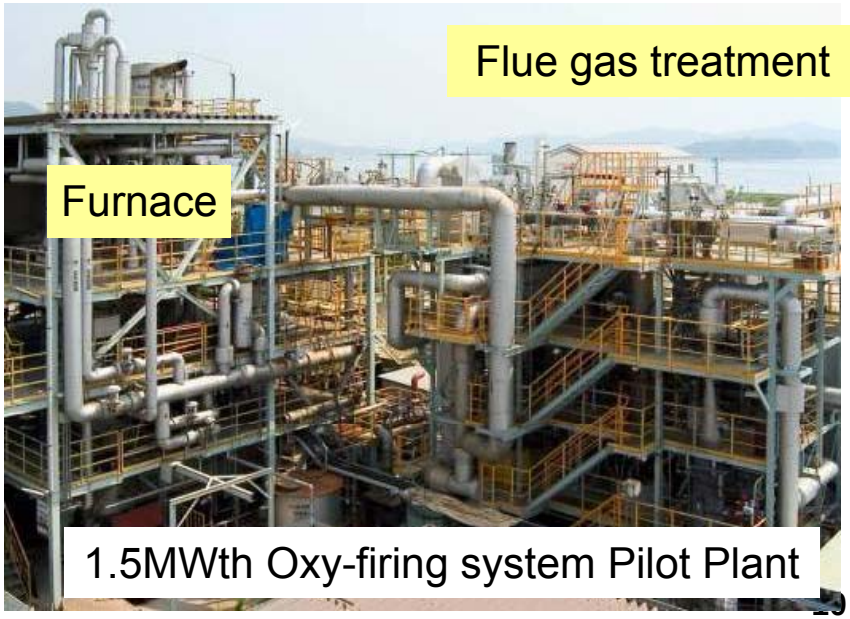
To evaluate removal of NOx, Sox and trace element (SO3, Hg) in both air- and oxy- firing



GOALS

- **High Performance DeNOx/Hg oxidation catalyst at high conc. H_2O and SO_2**
- **High efficiency SO_2 removal by wet FGD (SO_2<5ppm for CO_2 compression)**
- **Trace pollutants (Hg, SO_3, HF etc.) removal**
- **Optimization of AQCS process**



3. Design by analysis (simulation tech.)

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1. Key technologies of engineering
   (1) burner design applicable to both air- & oxy- firing
   (2) retrofit modification of furnace and bank parts
   (3) compact design for new boiler

2. Hitachi's simulation tools
   (1) " NEXT FLAME " for Burner
      - Large Eddy Simulation (precise turbulent model)
      - Two-phase flow of coal particle

   (2) " CRAFT " for commercial boiler
      - combustion and chemical reaction in furnace
      - heat transfer in Bank parts

3.1 Simulation of burner combustion (1)

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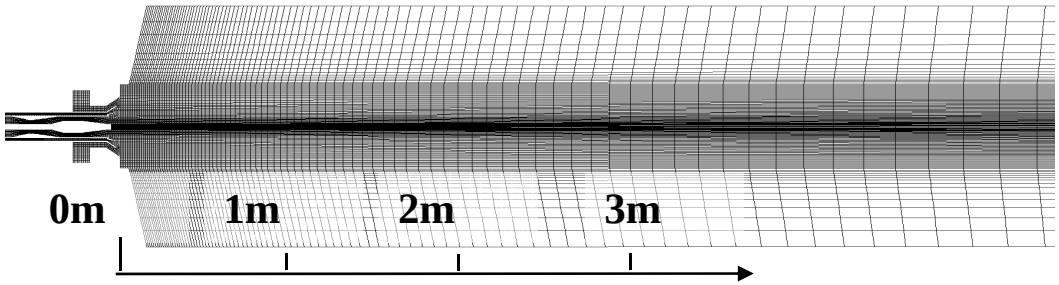
1. “Next Flame”,
   - Based on software “Open Frame”
   - Large Eddy Simulation
   - Combustion model

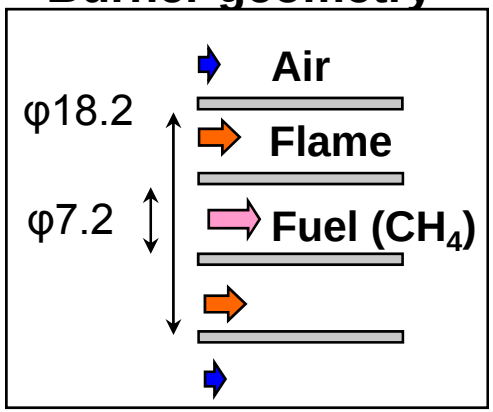
No. of meshes : 1 Million
Minimum length : 1 mm

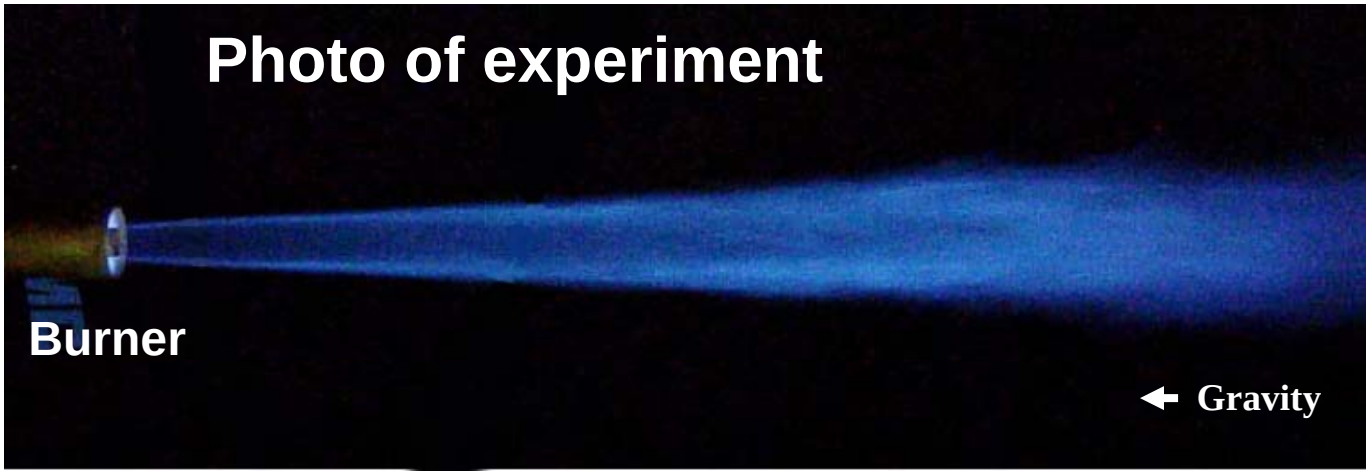
Analysis Meshes



2. Experiment (“Sandia Flame D”)

Burner geometry





※ 4th int. workshop on measurement and computation of turbulent non-premixed flames, Darmstadt (1999)

3.1 Simulation of burner combustion (2)

Large Eddy Simulation of the gas flow

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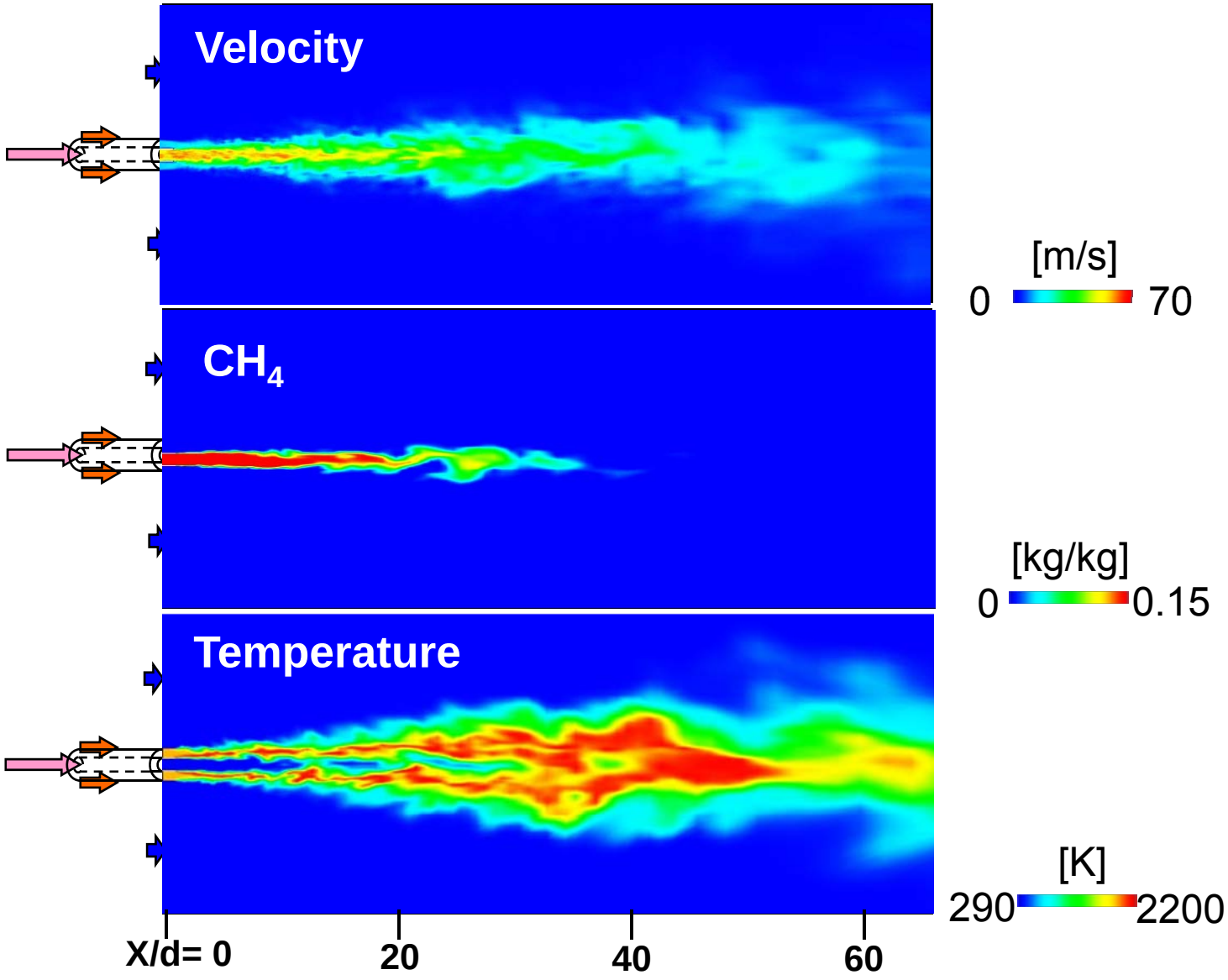

3.1 Simulation of burner combustion (3)
validation of the simulation

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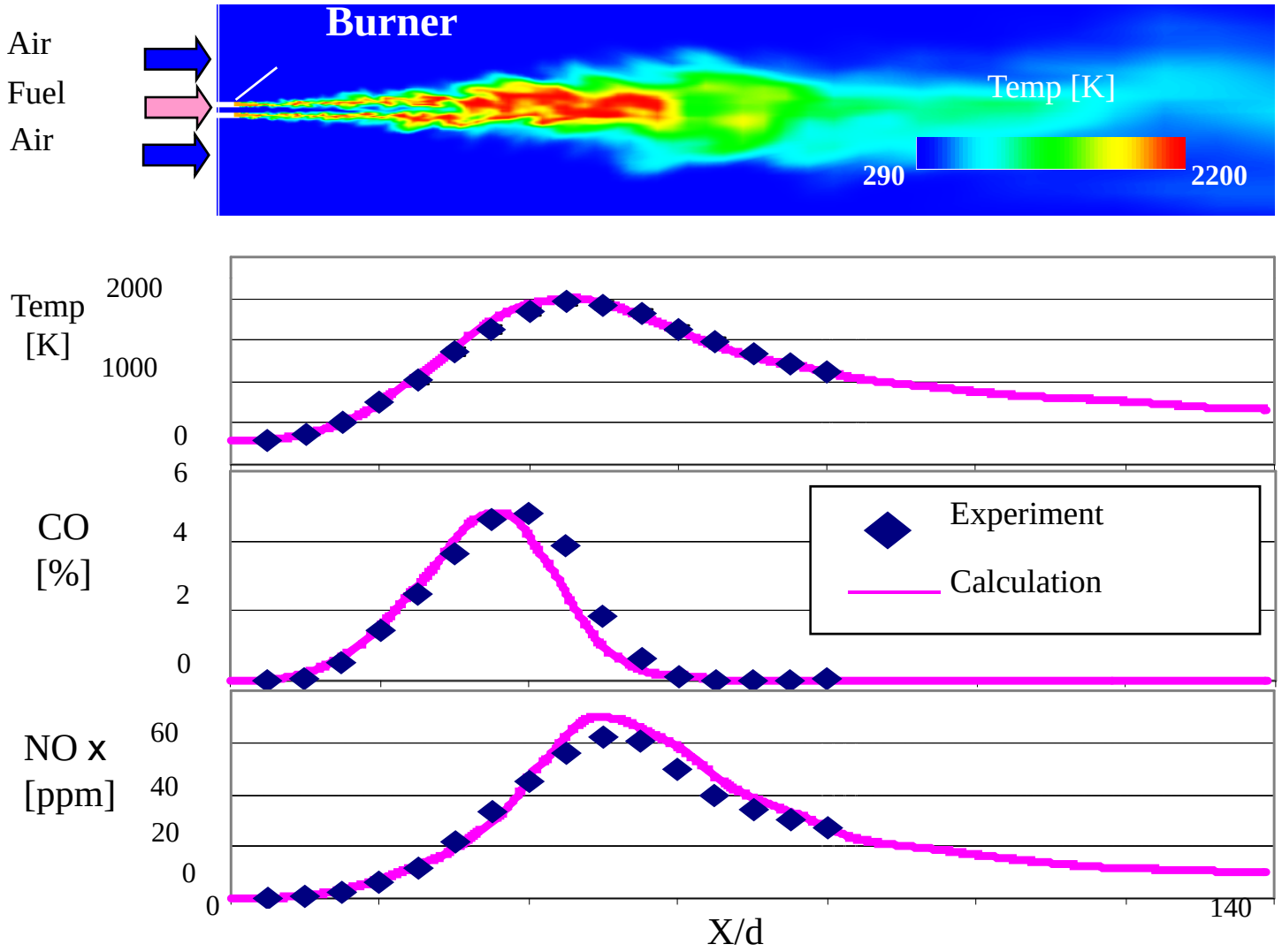

3.1 Simulation of burner combustion (4)
Large Eddy Simulation of coal combustion

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Basic experimental apparatus of coal combustion

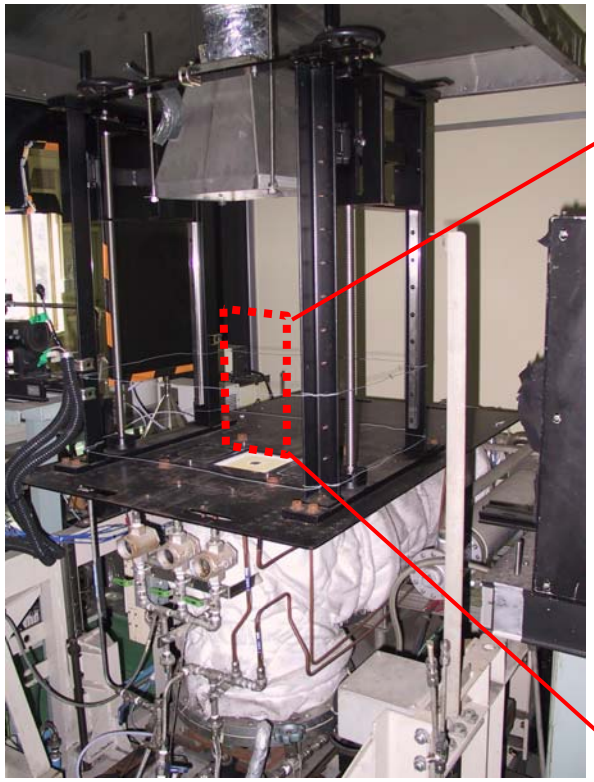
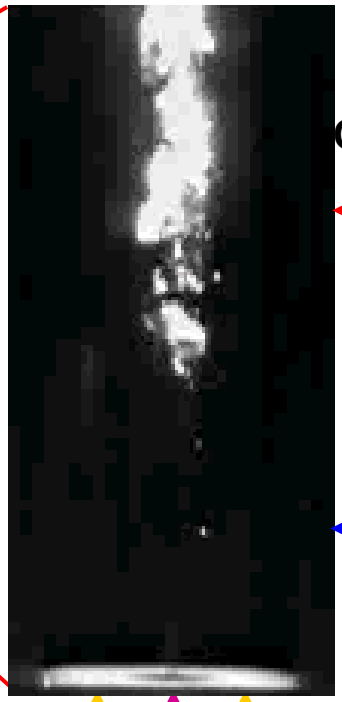


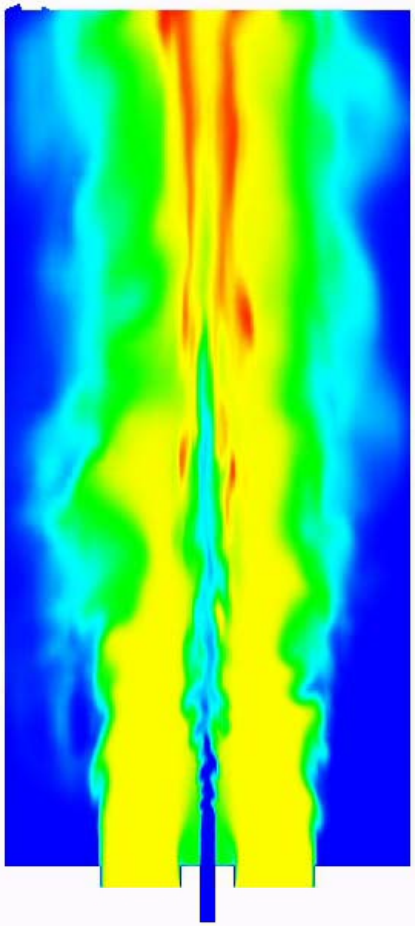
Image of high speed camera



Continuous flame

Ignition point

Calculation Result



Temperature[K]
27 1627

Air + Coal : 27℃, 10m/s

High Temperature gas : 1237℃, 4.8 m/s

3.1 Simulation of burner combustion (5) calculation example of burner

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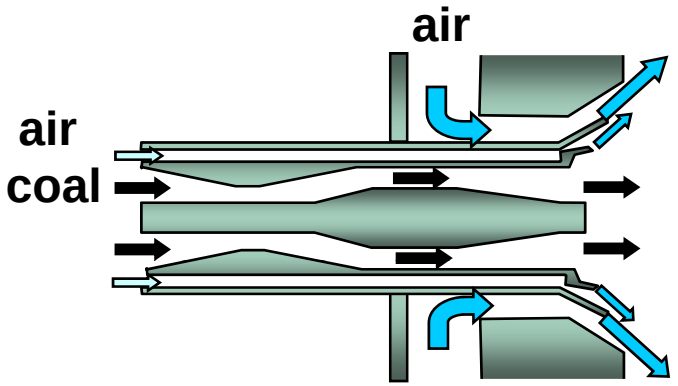
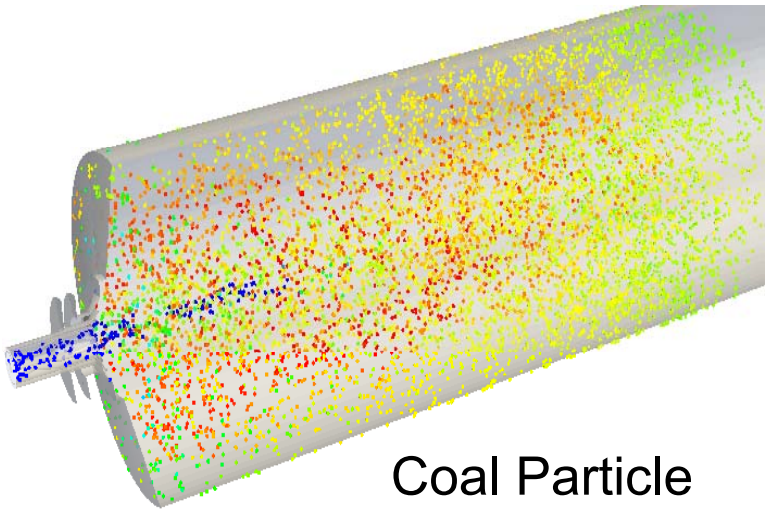
1. Application of " Next Flame "
   - screening of burner structures
   - flame stability
   - low emission of chemicals
   - Optimization
     of coal and oxygen mixture

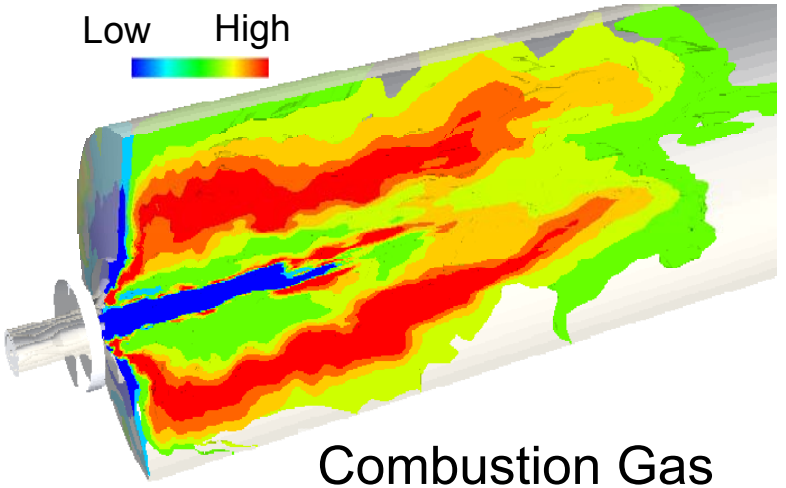
Burner Structure





Coal Particle

Temperature



Combustion Gas

3.1 Simulation of burner combustion (6) burner design and validation

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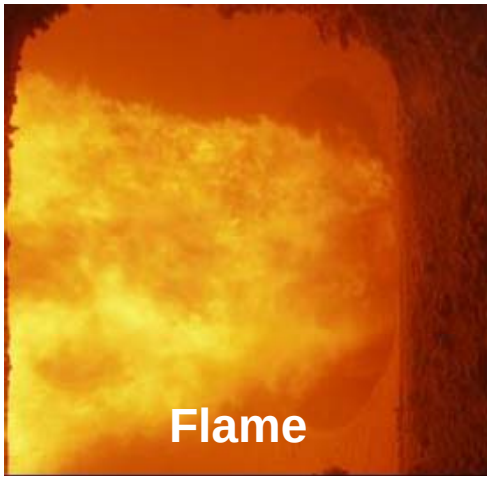
Pilot Testing (30 MW)

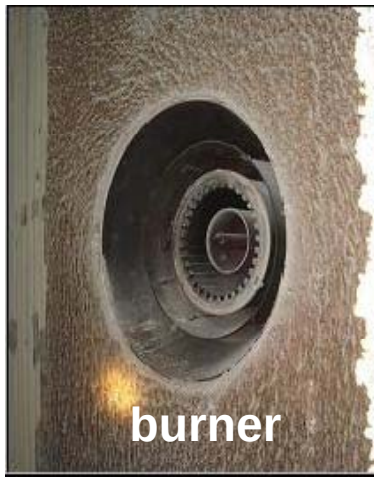
(1) different fuels and mixtures

(2) Emissions and burn out

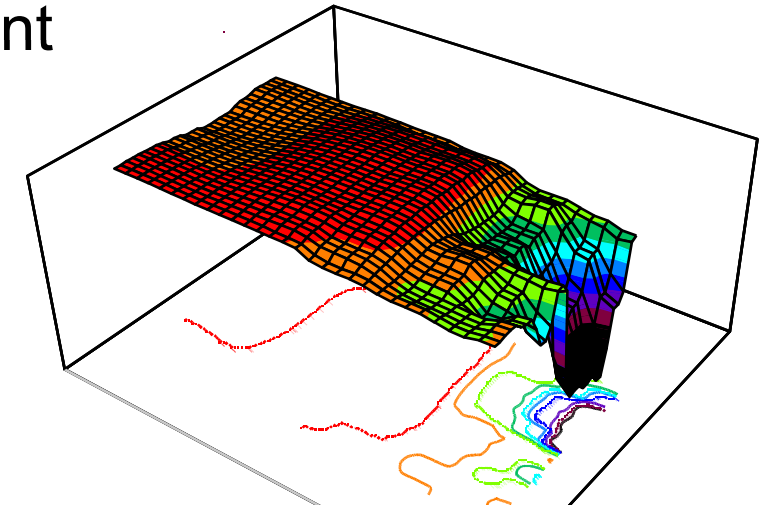
(3) Temperature distribution

(4) CFD validation and improvement





Final testing and design check
at Schwarze Pumpe plant in 2010



Temperature Distribution at Burner Axis (Top View)

3.2 Simulation of Furnace (1) total simulation of boiler

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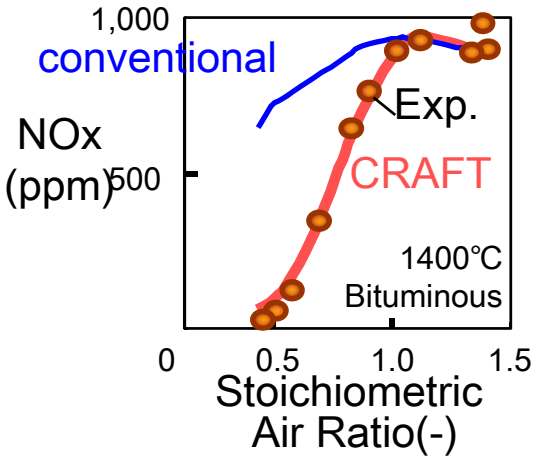
Hitachi's in-house software of Boiler simulation "CRAFT"

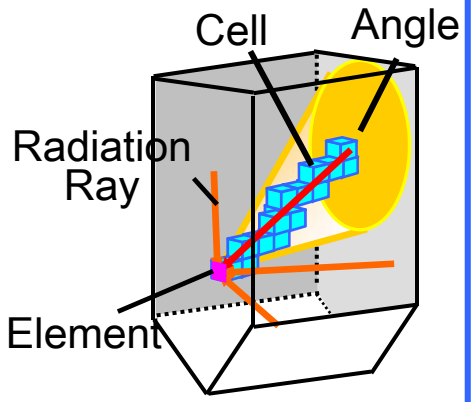
Key phenomena and modeling	
Combustion	Data-base & reaction model of Coalcombustion
Radiation	Ray Tracing Method
Ash Deposition	Formulation of Deposition Rate

Key phenomena and modeling	
Fluid dynamics	Density with Heat Absorption Two Phased Flow model
Heat Absorption	Built-in Conventional Equations for Banks

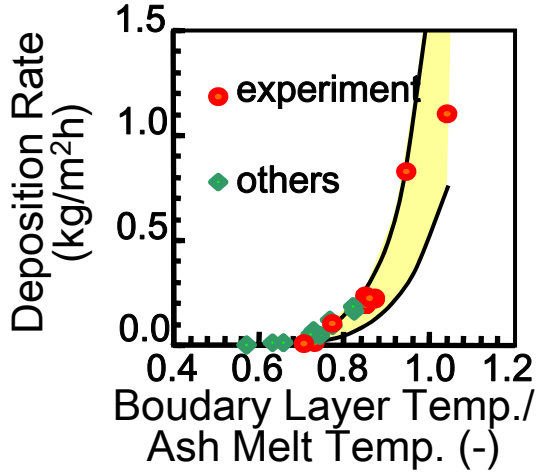
Combustion DB



Ray Traycing



Ash Deposition



3.2 Simulation of Furnace (2) Validation

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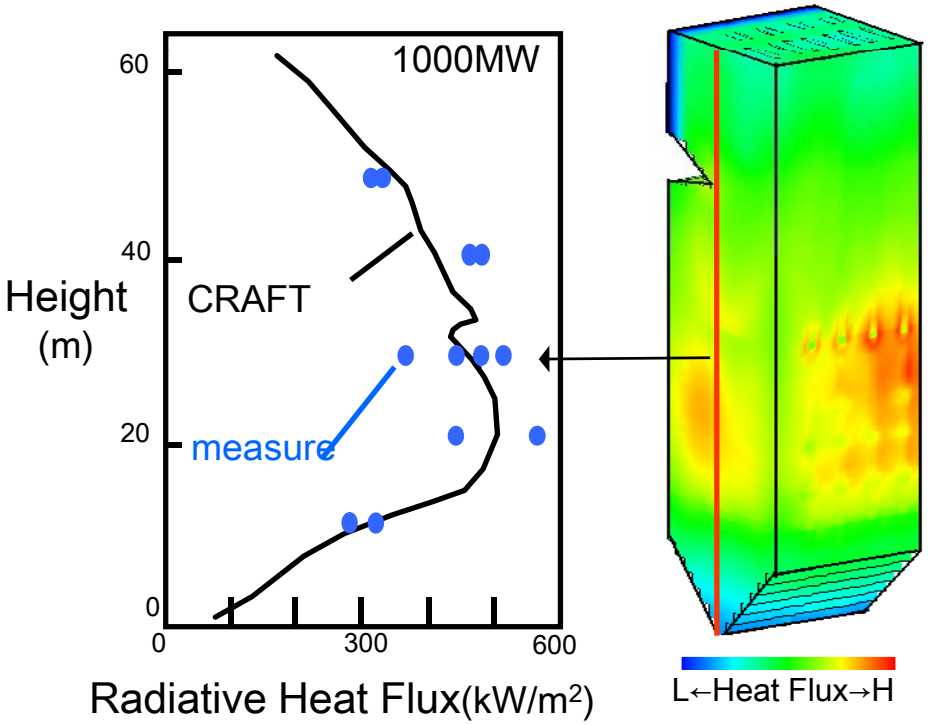
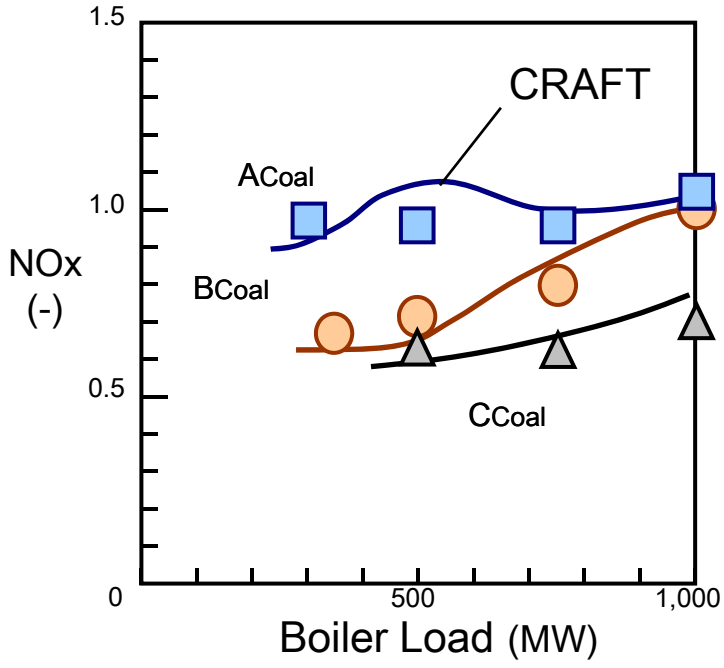
CRAFT shows good agreement with data obtained in existing boilers.

- **radiative heat flux on water wall**
- **NOx concentration at furnace exit**



Heat Absorption of Furnace Wall



NOx Concentration at Furnace Exit

3.3 Design Study (1) oxy-fuel combustion retrofit modification – gas temperature –

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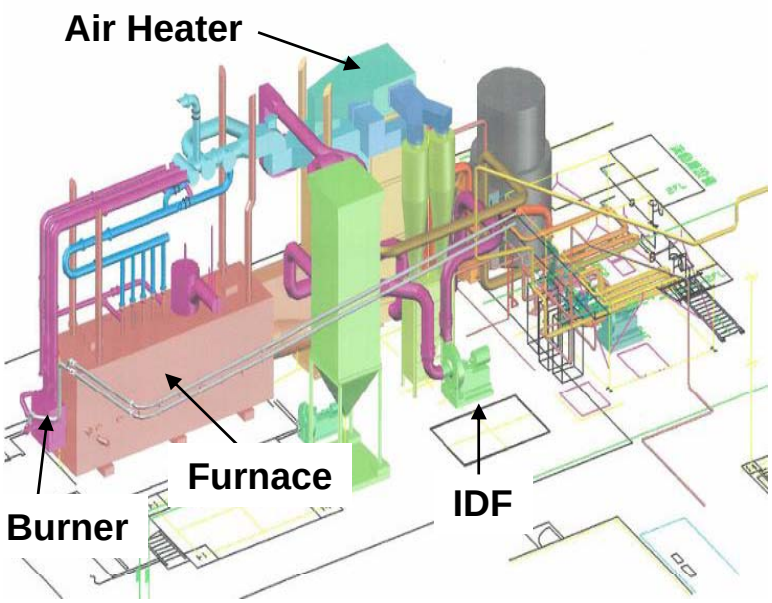
Data acquisition of oxy-firing
- **Radiation rate**
- **Heat transfer**
- **Ash deposition**

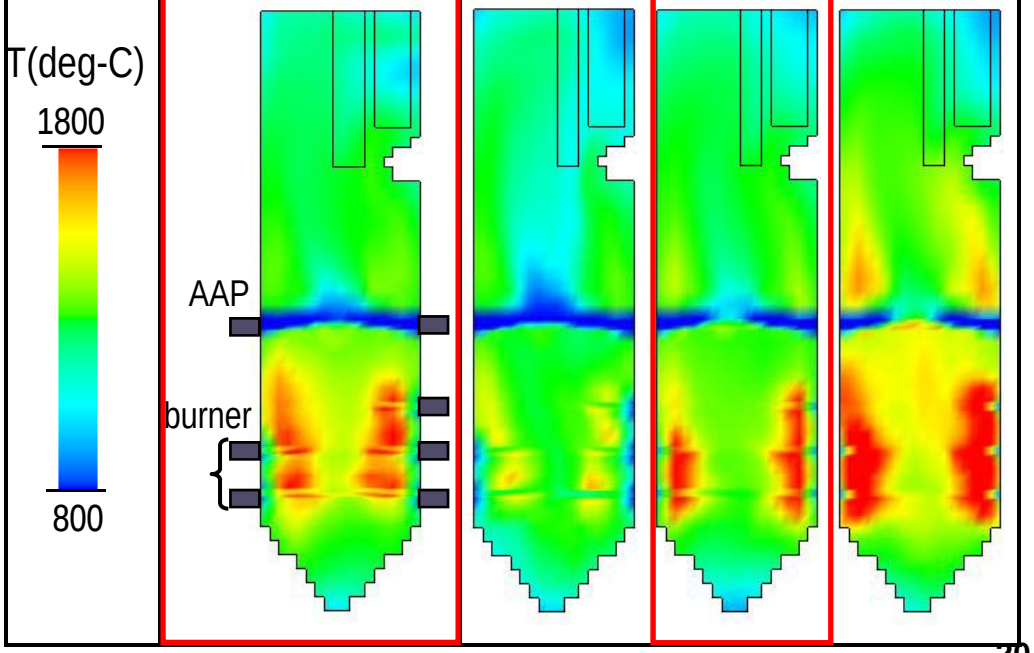


4MWth Test facility

CASE STUDY (500 MW)

Optimization to be the same FEGT as air-firing : 27 % of oxygen

	Air	Oxy-fuel (wet GR)		
O2(%)	21	21	27	35
FEGT (deg-C)	1163	1104	1163	1202



3.3 Design Study (2)
retrofit modification – Heat absorption –

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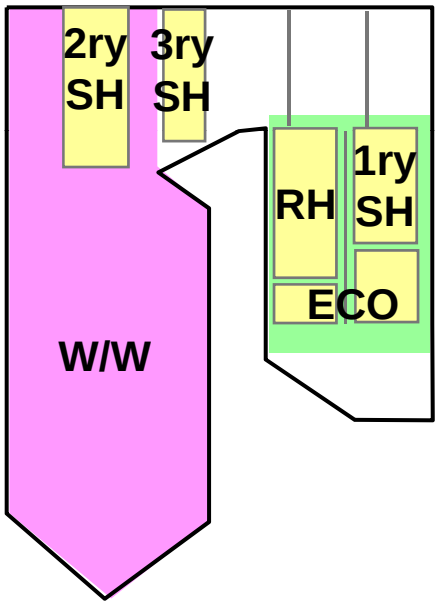
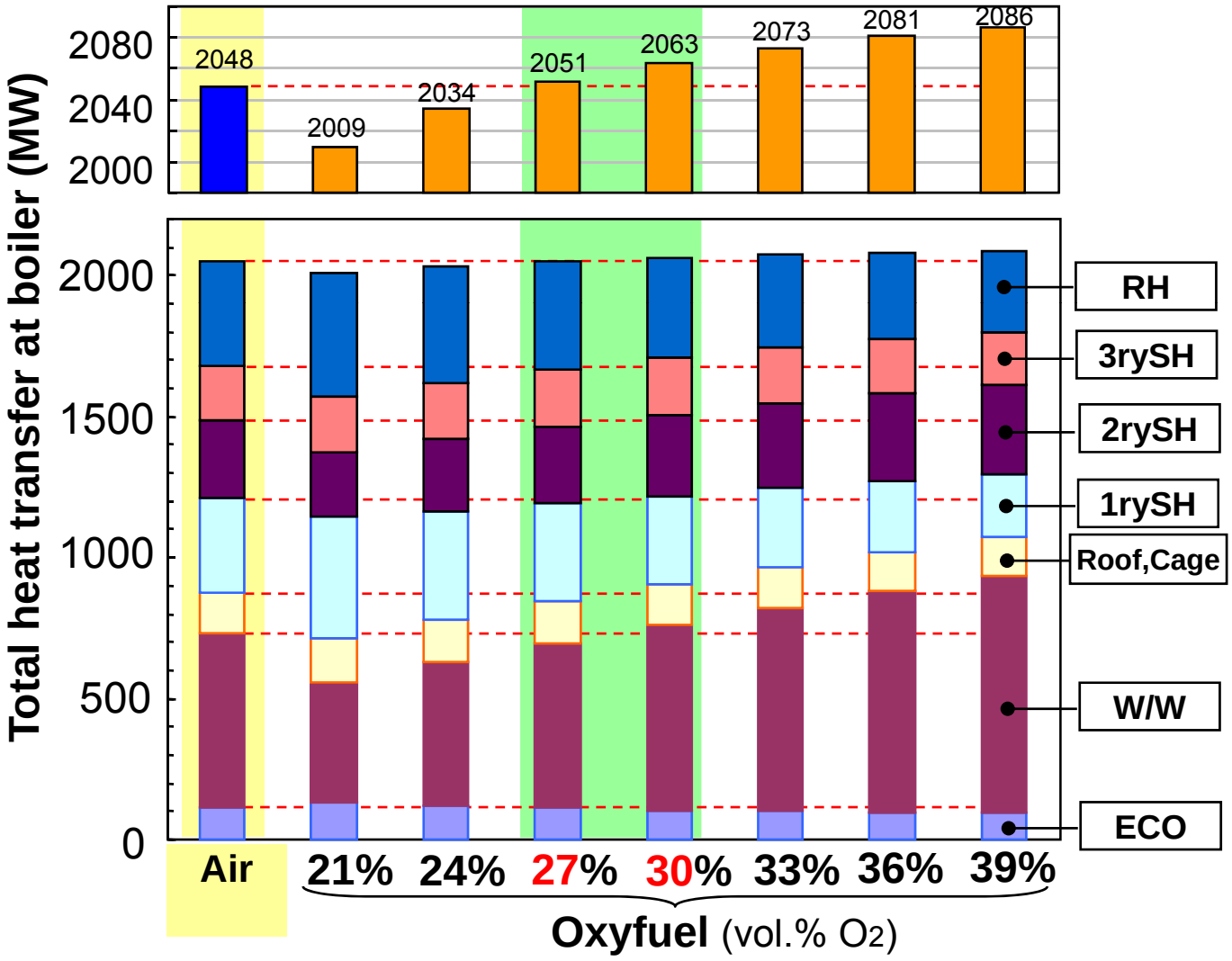
Optimization :
- 27 % of oxygen



W/W : water wall
SH : super heater
RH : re-heater
ECO : economizer

Tube Arrangement



Total heat transfer and distribution in parts

3.3 Design Study (3)
retrofit modification – area arrangement –

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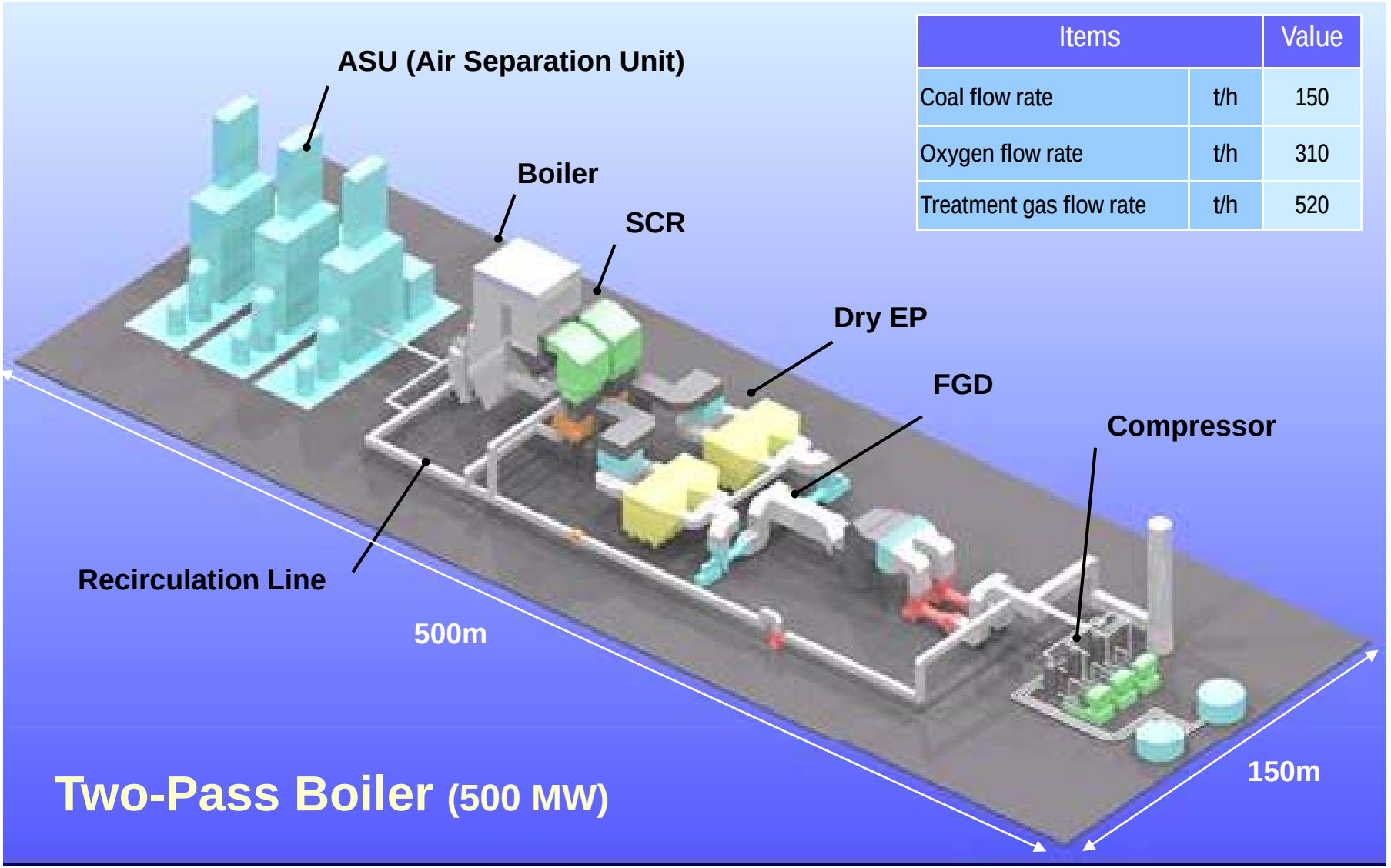
Items		Value
Coal flow rate	t/h	150
Oxygen flow rate	t/h	310
Treatment gas flow rate	t/h	520



4. Conclusions

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1. Hitachi recirculation system
   - Highly reliable and with lower energy loss
   - Ultra low gas temp. type of gas cooler,
     achieving removal of SO_3 and Hg, utilizing waste heat

2. Design by analysis
   (1) Burner development
      - combustion simulation with the LES turbulent model
      - to achieve flame stability and low consumption of O_2
   (2) Commercial boiler retrofitting
      - Hitachi's in-house total simulation tool, " CRAFT "
      - performance appropriate to both air- & oxy- firing
        : oxygen, gas temp., heat absorption, ash deposition