Polish research programme on Supercritical Coal Power Plants (2007-2010)

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Reasoning behind

Thesis 1

In the 20-30 (40) years perspective it is not expected that the revolutionary change will occur in the structure of fuels used for generating electricity and heat. For this reason, alongside the development of entirely new technologies (fuel cells, hydrogen energy), the fossil fuel technologies will be still used and improved

Thesis 2

Each technology has its development potential

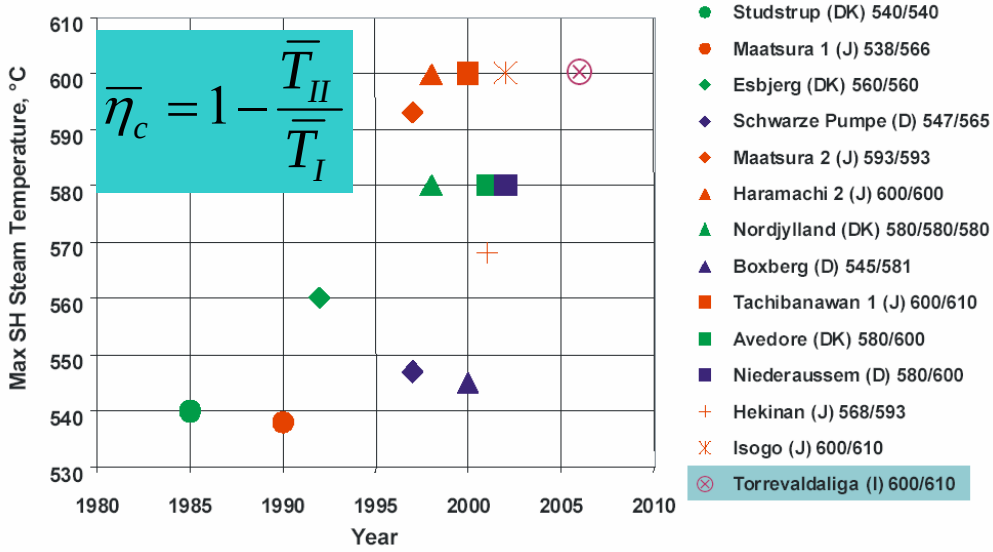
Thesis 3

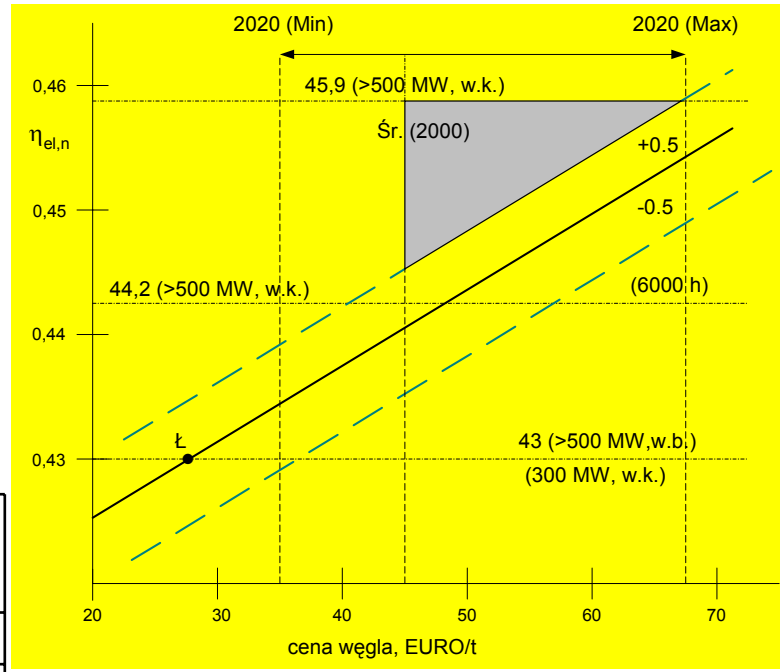
Fuel supply security is an important condition for the development and dissemination of energy technologies

Thesis 4

The electricity demand in the EU (25) will increase from 3000 TWh (2005) to 4400 TWh by 2020. Taking into account the age of the installations (required withdrawal) and phase-out of German nuclear power this would create a gap of around 2400 TWh.

Thermodynamics vs. Economy





Plant	Utility	Output MW	Steam paramenters	Commissioning
Neurath	RWE	2 x 1100	270/600/610	2009/2010
Boxberg R	Vattenfall	670	286/600/610	2010
Moorburg	Vattenfall	2 x 820	276/600/610	2010
Datteln	E.ON	1100	286/600/620	2011
Walsum	STEAG	790	274/603/621	2010
Karlsruhe	EnBW	820	250/600/620	2011
Hamm	RWE	800	286/600/620	2012

$$\eta_{el,op} = 0{,}055 \cdot e_p + 41{,}5$$

$20 < e_p < 70$ EURO/t.

THE REASONABLE CHOICE - SUPERCRITICAL COAL UNITS

Project objectives

- To obtain new information and develop instruments (models) for supporting the preparation and deployment of new Polish coal-fired power units that meet the highest standards of quality: technical, economic and environmental (including CO2 emissions)

- To develop new concepts in the field of combustion technology (including oxyfuel), flue gas decontamination technologies (including primary deNOx methods)

- To obtain high level of competence and specialization of research teams and an adequate level of computational and experimental facilities to initiate research under the 7th EU Framework Program, in which the problem of clean coal technologies is an important priority

PARTNERS AND BUDGET – 14 mln PLN (3.5mln EUR)

- **5 universities of technology:**

Silesian (coordinator) **Wroclaw** **Czestochowa** **Krakow** **Lodz**

- **1 institute of the Polish Academy of Sciences: Institute of Fluid-Flow Machinery in Gdańsk**

- **3 R&D institutes: Institute for Chemical Processing of Coal, Institute of Power Engineering and Elsamprojekt**

THEMATIC GROUPS

1. **Optimal structure of the supercritical coal units**, taking into account the development potential of the currently observed and projected coal technologies by 2010 and 2020
2. **New techniques of coal combustion**, including combustion in modified atmospheres with oxygen and other gases, leading to increased energy efficiency and enhanced environmental performance including potential for CO2 separation
3. Development and preparation for the **implementation of new designs, diagnostic and maintenance** procedures for machinery and power equipment
4. Development and validation of **active and passive methods for reduction of emissions**, especially nitrogen compounds and other substances (SO2 and Hg)
5. Development of a methodology and algorithms for determining the **safety of the supercritical coal-fired units** in the phases of their design, construction and operation
6. Modeling procedures and research on **interconnection between supercritical power unit and power grid**, in particular the analysis of the capacity of the power unit in the transition and emergency states (including blackout)

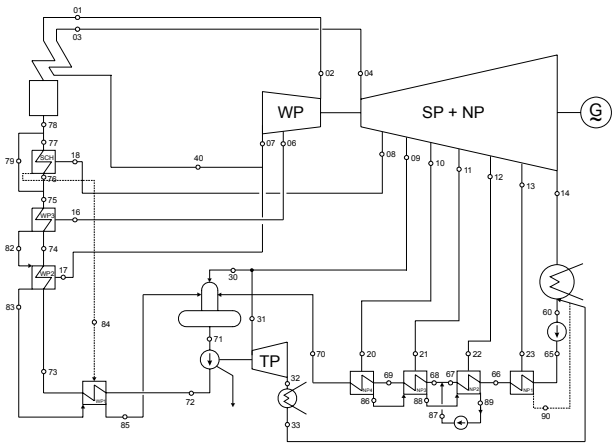
TG1: Optimal structure of supercritical coal units

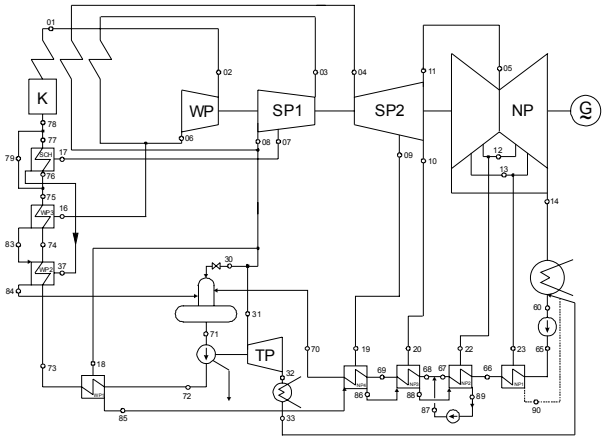
Objectives:

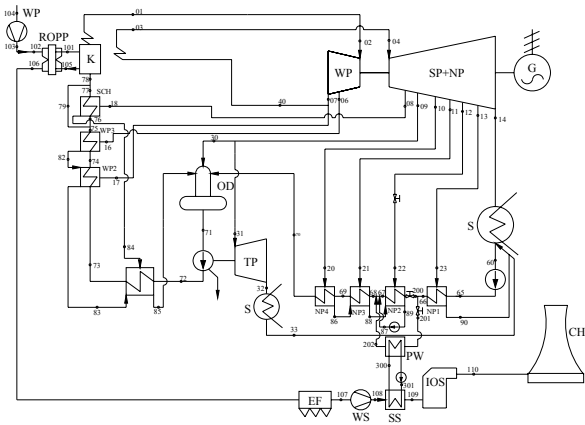
· Study on optimal thermal cycles of the supercitical power unit corresponding to the Polish energy policy objectives

· Improving methods of analysis and optimization of complex technology structures, including determination of the influence of different technologies reducing CO2 emissions

· Research on competitiveness of coal-fired units (with different technological structures) in comparison to other technologies using fossil fuel







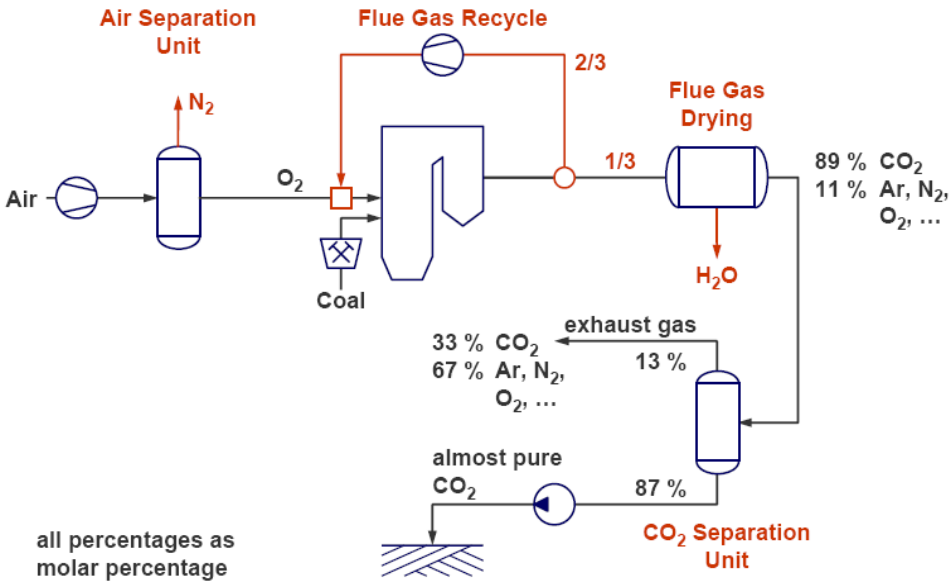
Reference cycle Eff=ca.49% (30/600/620) Double reheater Waste heat recovery

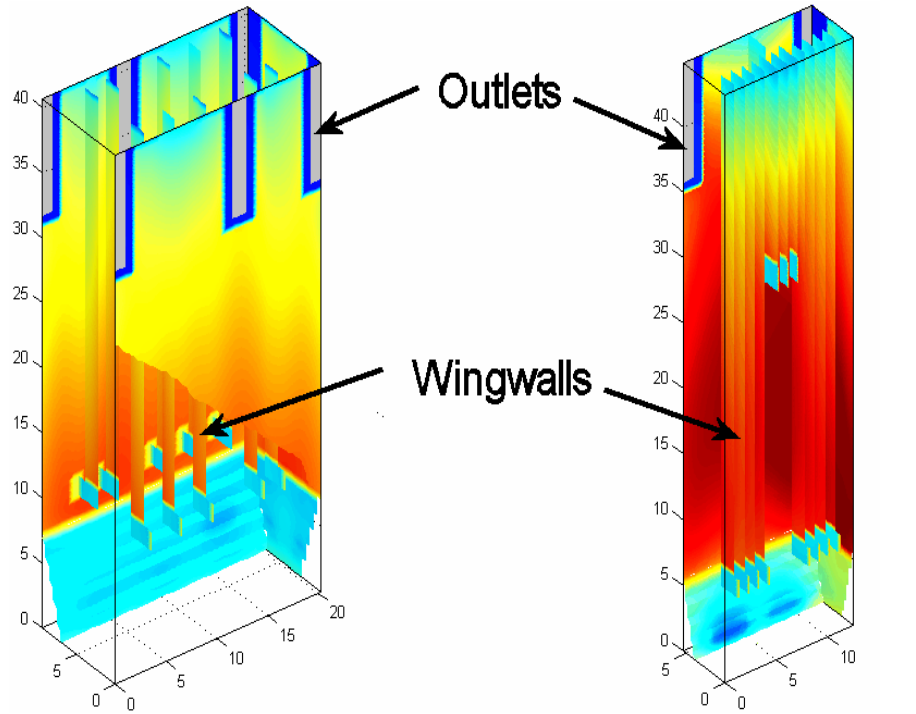
TG2: New techniques of coal combustion

Objectives: abatement of CO2 and NOx

- Analytical and numerical studies on combustion process in modified atmospheres (O2/CO2/inert)
- Study of combustion process in modified atmospheres for Circulating Fluidized Bed
- Combustion with preconditioning of fuel (drying)
- Studies on combustion of pulverized coal for increased O2 and CO2 concentration

TG2: Oxyfuel





40.8 m x 20.3 m x 9.4 m

45.0 m x 12.5 m x 5.3 m

21% O2 vs. 60% O2 -> 38% reduction in vol.

Retrofit potential

Down-sizing potential

TG2: Oxyfuel in Fluidized Bed Combustion

- Thermal output **0.1MW$_{th}$**
- Chamber height **5m**
- Chamber ID **0.1m**
- Hot cyclone diameter **0.25m**
- 4 electric furnaces
- Air/O2 mixing unit
- Carbon conversion factor

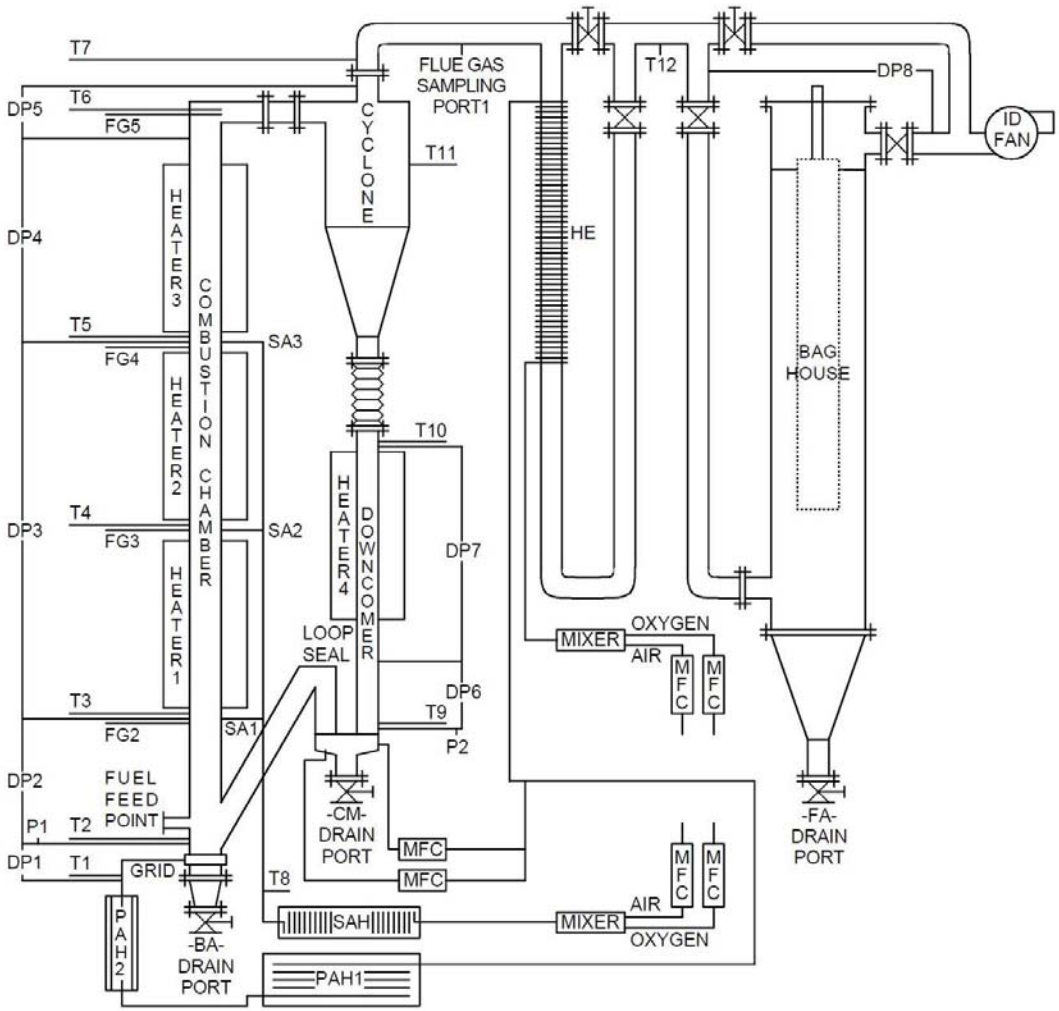
$$CR_{C->CO} = \frac{C_{fg}^{CO}}{C_{fg}^{CO2+CO}}$$

- Sulfur conversion factor

$$CR_{S->SO2} = \frac{\frac{S_{fg}^{SO2}}{C_{fg}^{CO2+CO}}}{\frac{S_{fuel}^{comb}}{C_{fuel}}} \left[\frac{\frac{\mathrm{kmol_S}}{\mathrm{kmol_C}}}{\frac{\mathrm{kmol_S}}{\mathrm{kmol_C}}} = - \right]$$

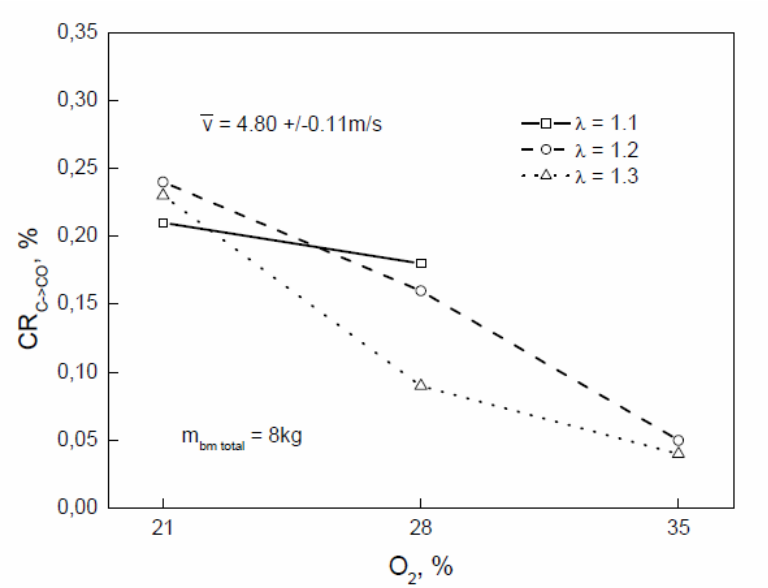
- Nitrogen conversion factor

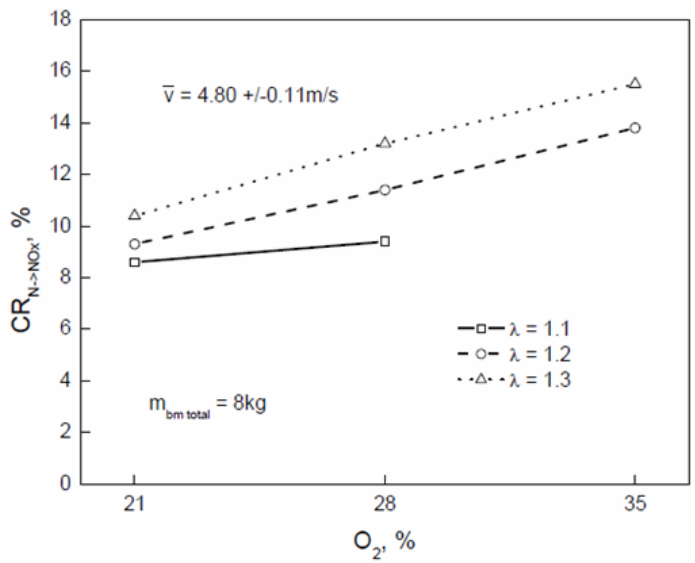
$$CR_{N->NOX} = \frac{\frac{N_{fg}^{NOX}}{C_{fg}^{CO2+CO}}}{\frac{N_{fuel}}{C_{fuel}}} \left[\frac{\frac{\mathrm{kmol_{N2}}}{\mathrm{kmol_C}}}{\frac{\mathrm{kmol_{N2}}}{\mathrm{kmol_C}}} = - \right]$$



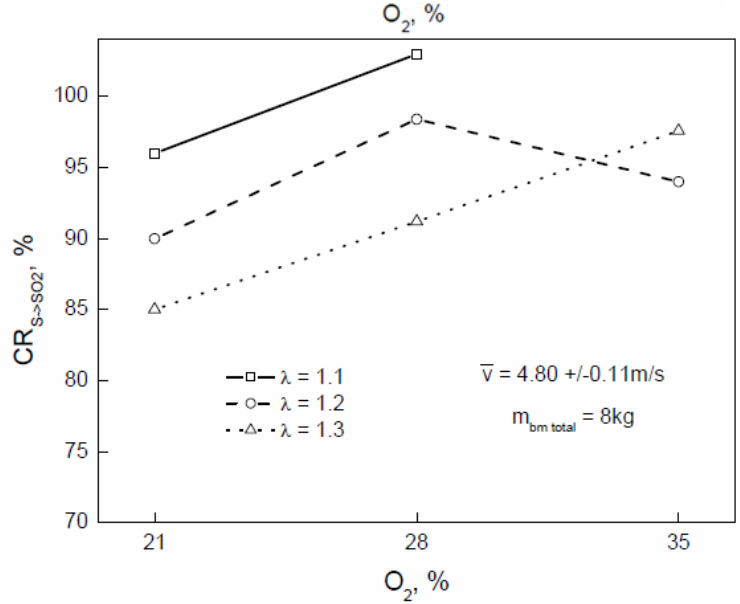
BA - bottom ash
CM - circulating material
DP - pressure drop measurement
FA - fly ash
FG - flue gas sampling
HE - heat exchanger
MFC - mass flow controller
P - absolute pressure measurement
PAH - primary air heater
SA - secondary air
SAH - secondary air heater
T - temperature measurement

TG2: Oxyfuel in Fluidized Bed Combustion





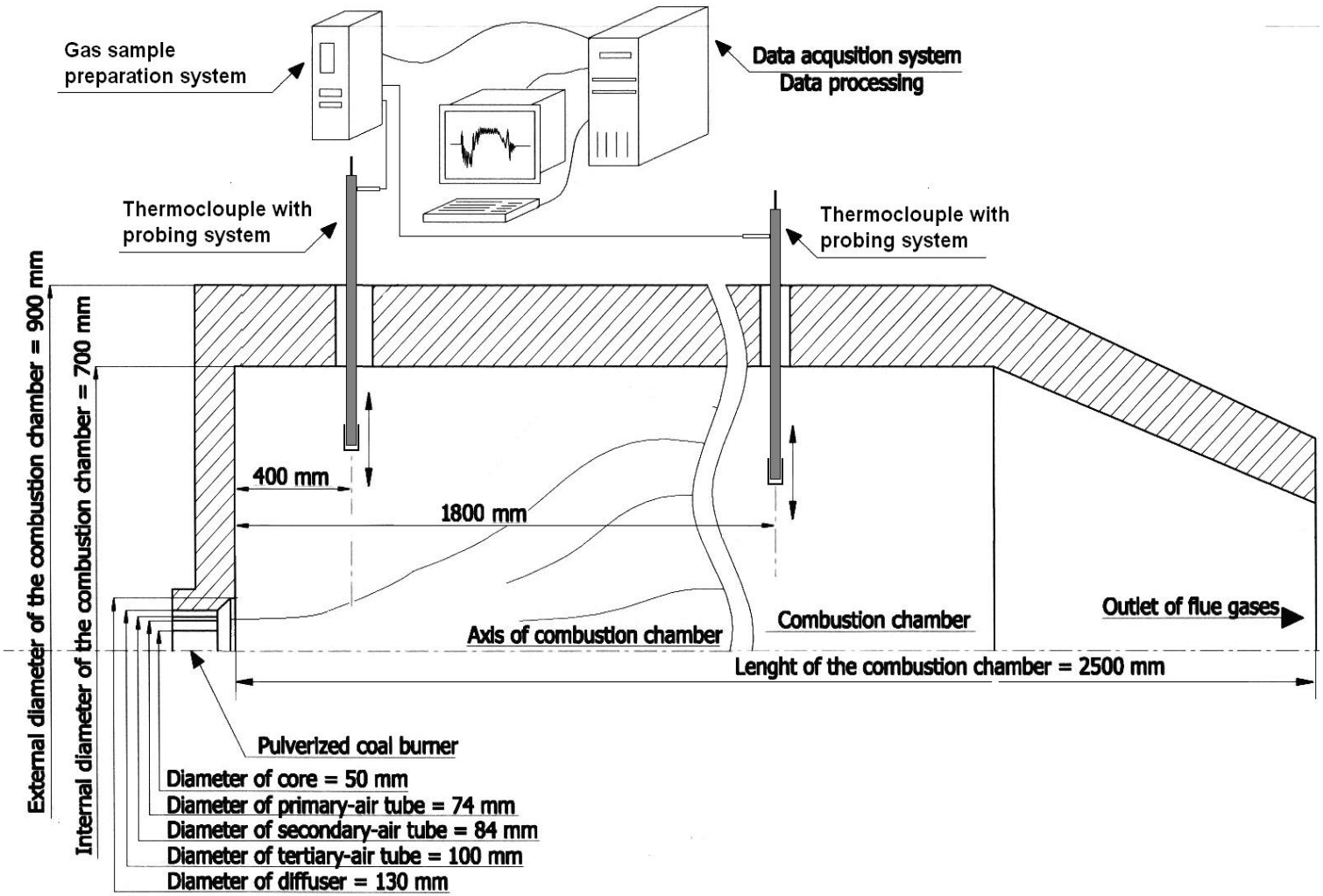
Clear influence of process stoichiometry;
Less pronounced influence of temperature



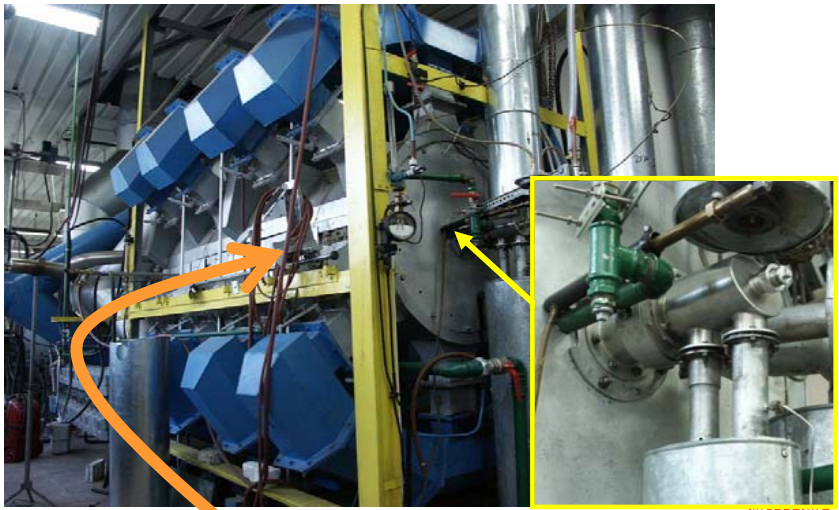
TG2: Oxyfuel in Pulverized Coal Burner - assumptions

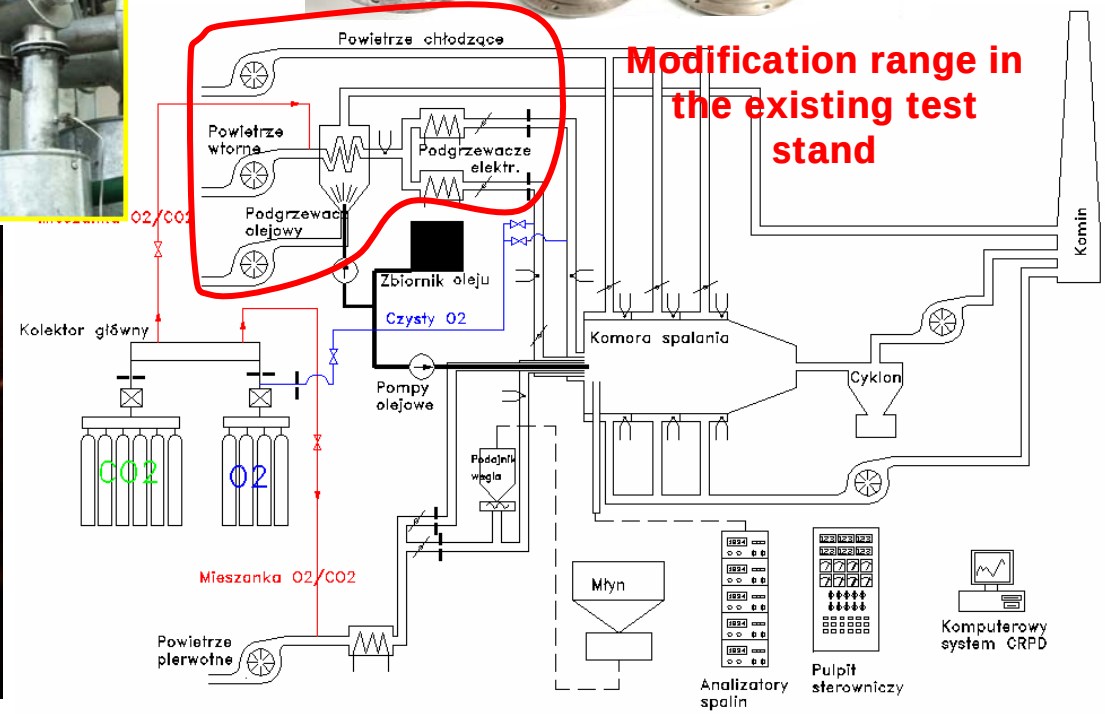
1. Burner operates with pure air as well as in O2/CO2 atmosphere
2. Burner operates in a stable regime for a wide range of flue gas recirculation ratio
3. Comparable maximum temperatures
4. O2 content in gas-coal mixture in the range of 21% - 29% vol.

TG2: Oxyfuel in Pulverized Coal Burner – location of probes



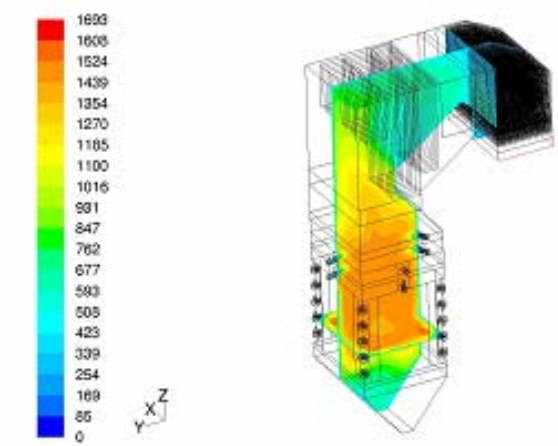
TG2: Oxyfuel in Pulverized Coal Burner – neccesary modifications



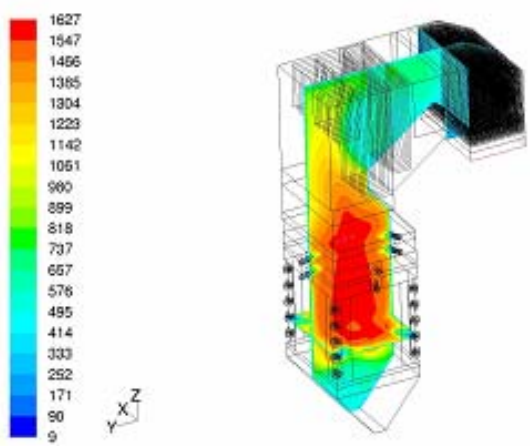


Modification range in the existing test stand

TG2: Oxyfuel in Pulverized Coal Boiler – modeling results

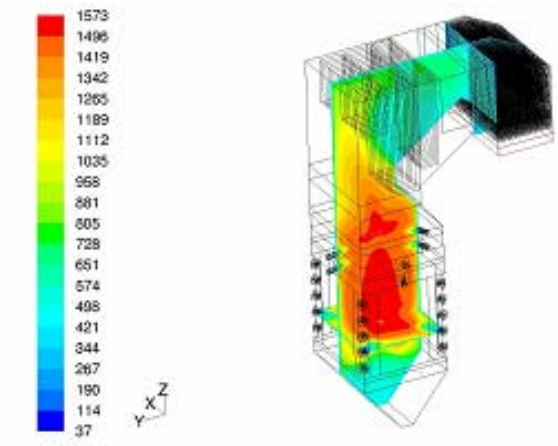


(a) reference (air)

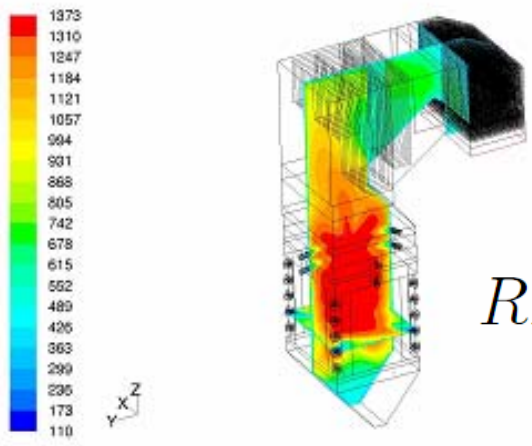


(b) oxycombustion, $RR = 74\%$

- Similarity to air combustion achieved for RR=65-70%
- Lower furnace part less active - shift of heat transfer
- Lower NOx emission for oxycombustion



(c) oxycombustion, $RR = 78\%$



(d) oxycombustion, $RR = 84\%$

$$RR = \frac{Q_{mas,s}}{Q_{mas,s} + Q_{mas,p}}$$

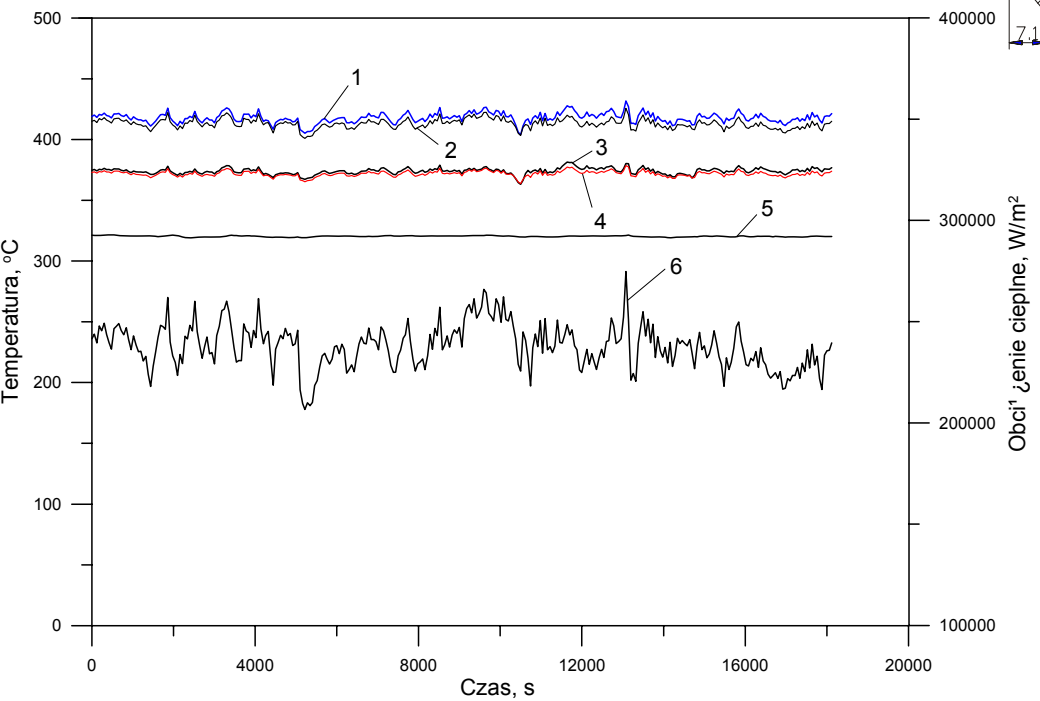
TG3: Implementation of new designs, diagnostic and maintenance procedures

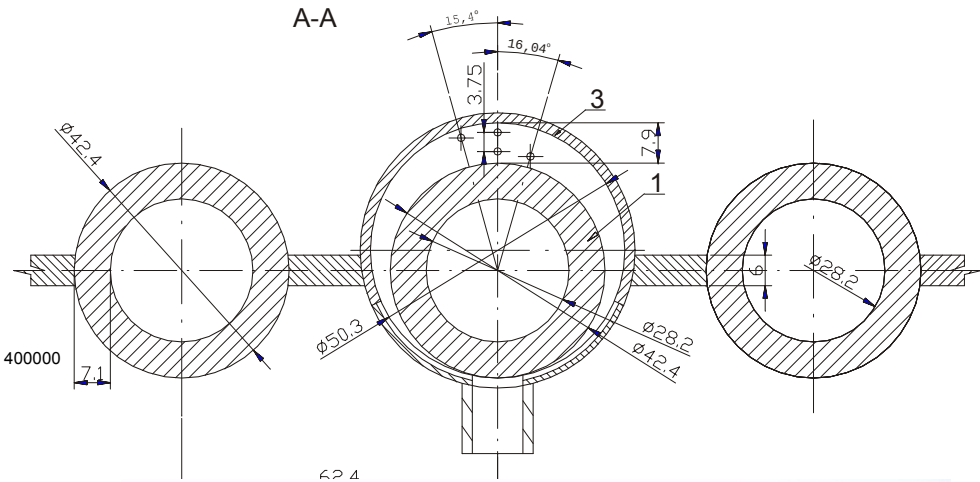
Objectives:

- Creation of databases supporting design and operation of power units for the ultra - supercritical steam parameters that meet the highest standards of quality: technical, economic and ecological
- Selection procedures for boilers and turbines for supercritical coal-fired units. Significant feature of the developed methodology is to integrate design and optimization of the thermal system and to obtain consistency with new standards of flexibility, availability and sustainability
- Methodology and procedures of advanced operation techniques for power units: optimum operating conditions in various modes (start-up, steady-state and non-steady state operation, shut off)
- Optimizing the diagnostic monitoring of the unit, taking into account the major technological modules - boiler and turbine

TG3: Water wall heat flux probe

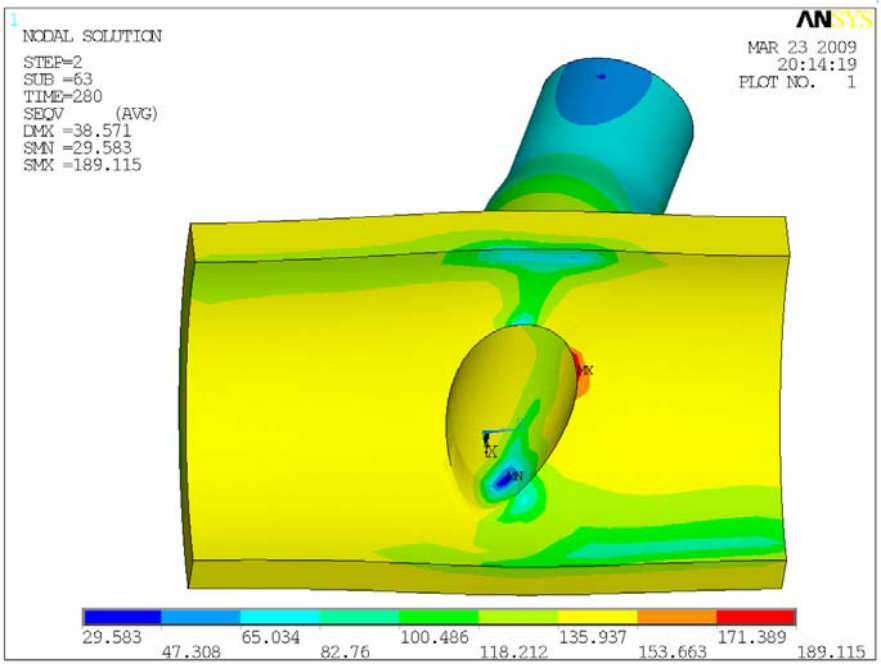
Temperature and heat flux recorded at the water wall insert:
1, 2 – T close to outer surface (fireside)
3, 4 – T close to inner surface (fireside)
5 – T at outer surface
6 – heat flux

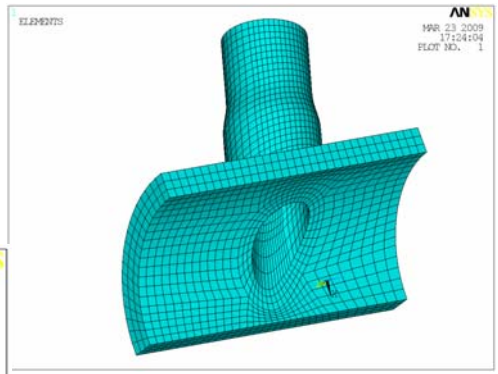


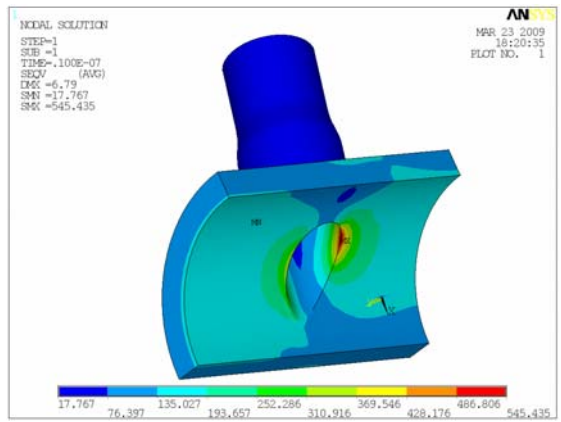


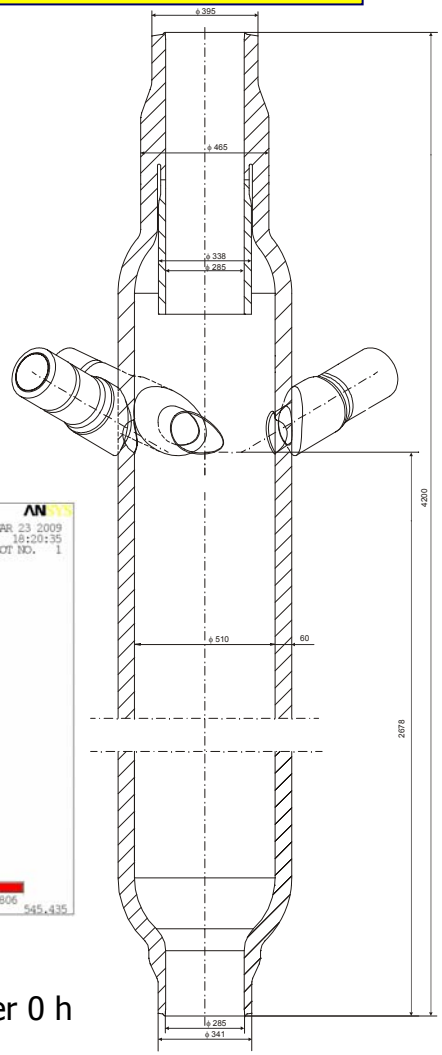
TG3: Stress analysis of steam-water separator

Reduced stress @ 625 C, 29.7 MPa after 280 h









Reduced stress @ 625 C, 29.7 MPa after 0 h

TG4: Active and passive methods for reduction of emissions

Objectives:

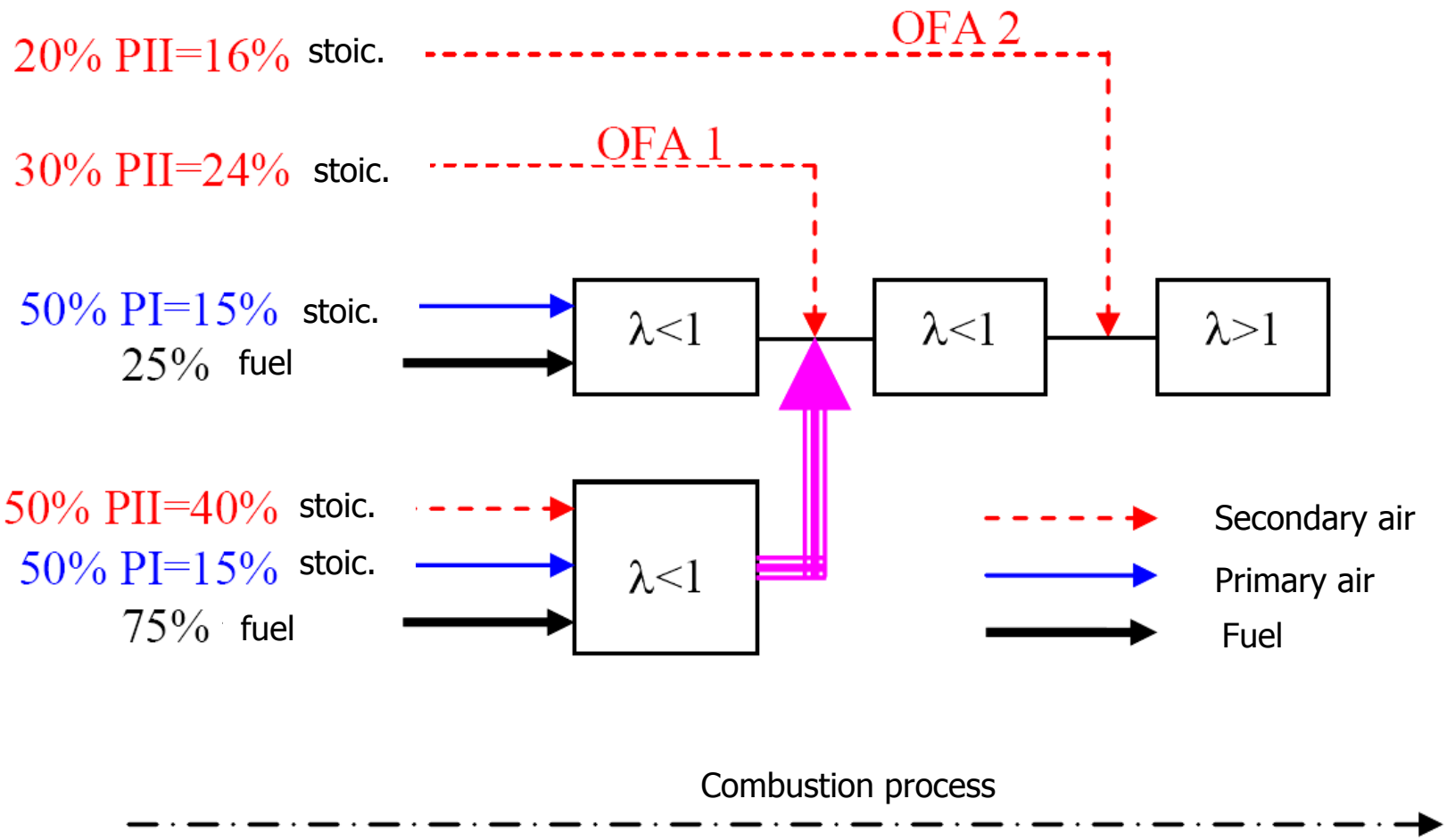
- Experimental and analytical research on the application of innovative low-emission technologies in coal-fired power boilers. These are the primary methods for reducing NOx emissions supplemented by secondary catalytic DeNOx and reduction of NOx by oxidation of NO to NO2 and subsequent leaching of NO2 from the flue gas in FGD
- Reduce mercury emissions from boiler installations by means of low-temperature pyrolysis of coal – fuel pretreatment
- Laboratory investigations and numerical modeling of new designs of low-emission pulverized-coal burners
- In-furnace optimisation of low-emission combustion – staged combustion and mitigation of its negative influence on furnace waterwalls and heating surfaces
- Optimisation of coal mills – grinding quality

TG4: Legal regulations - NOx

NO_x (NO2) emission standards in mg/ m3n @ 6 % O_2 - hard coal combustion

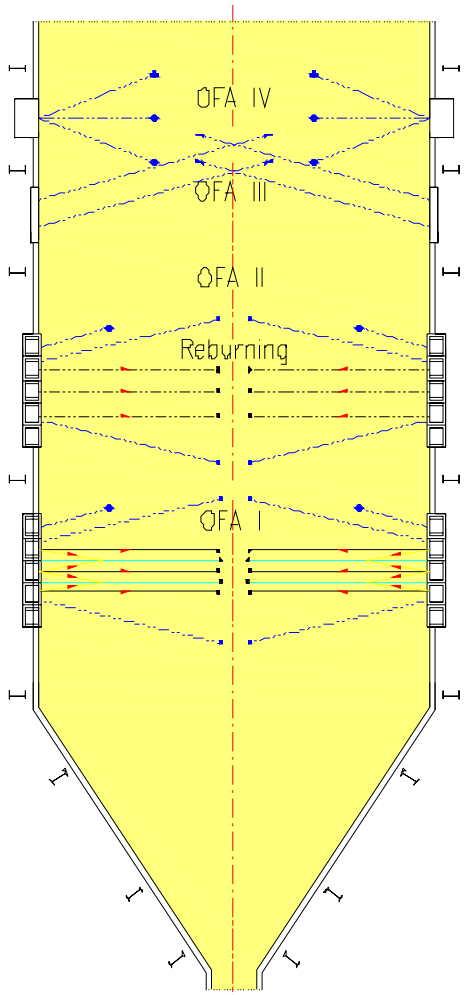
Nominal thermal output	Installations operational before 29.03.1990r.			Installations operational after 28.03.1990	
	up to 31.12.2007	from 01.01.2008 to 31.12.2015	from 01.01.2016	up to 31.12.2015	from 01.01.2016
> 50 ≤ 500	600	600	600	500	500
> 500	540	500	200	500	200

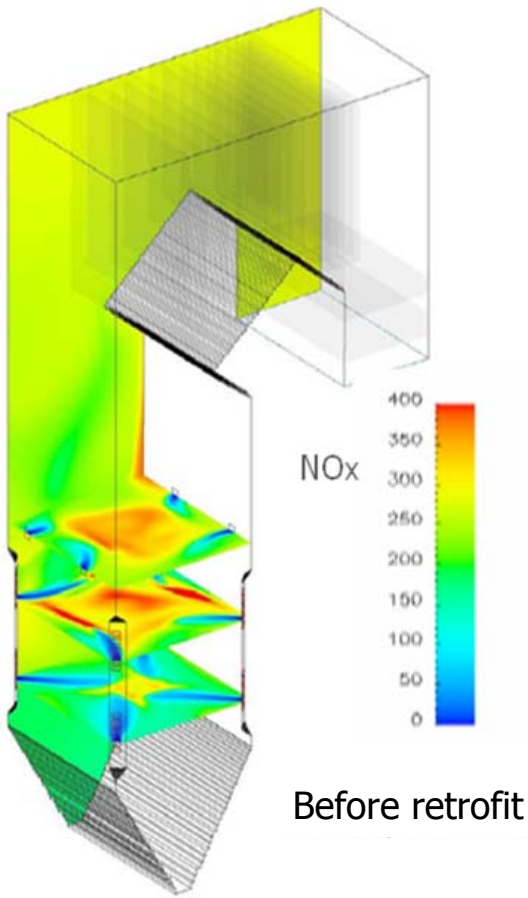
TG4: Innovative staged combustion (dense and diluted mixtures)



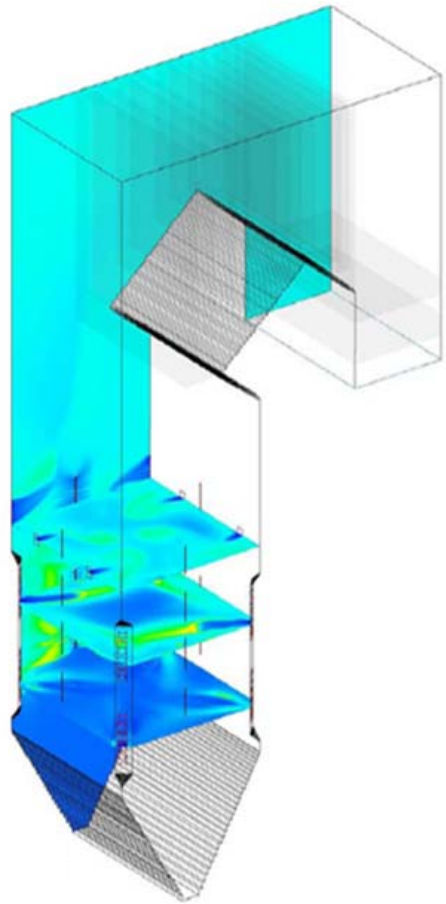
TG4: Low-NOx retrofit in Polaniec power plant - Electrabel (boiler EP 650)

NOx 200 standard achieved for the very first time in Poland





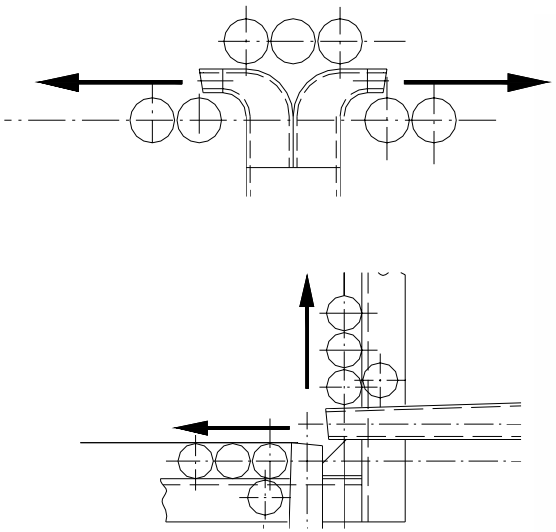
Before retrofit



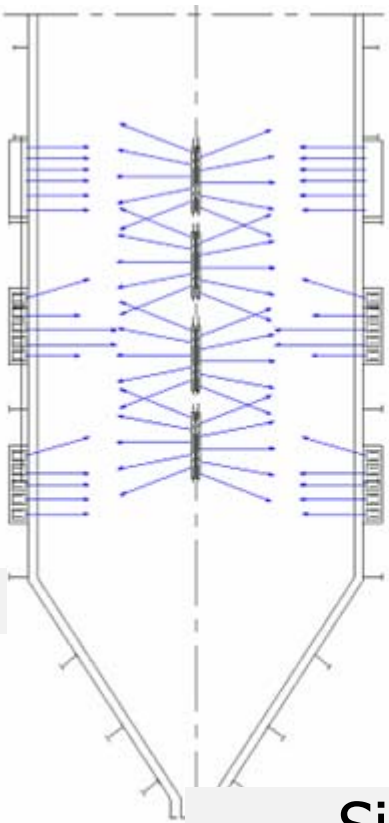
After retrofit

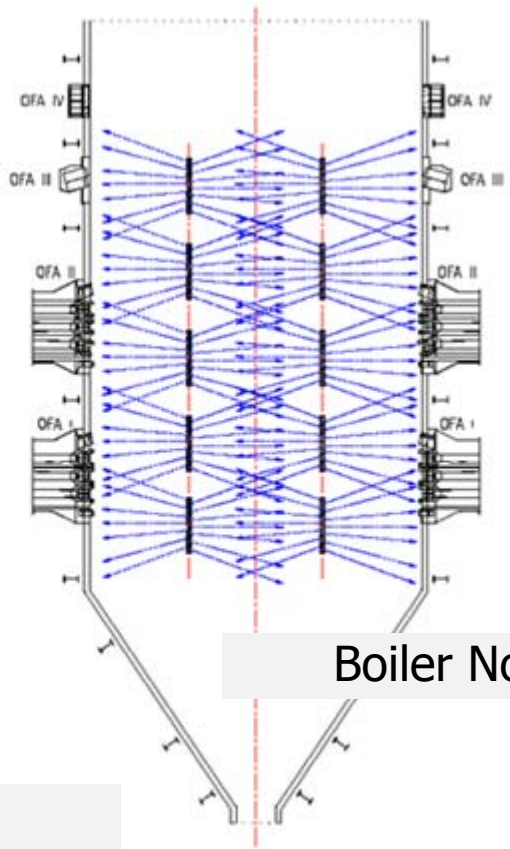
TG4: Low-NOx retrofit in Polaniec power plant - Electrabel (boiler EP 650)

Mitigation of negative effects – protection air system against waterwall corrosion

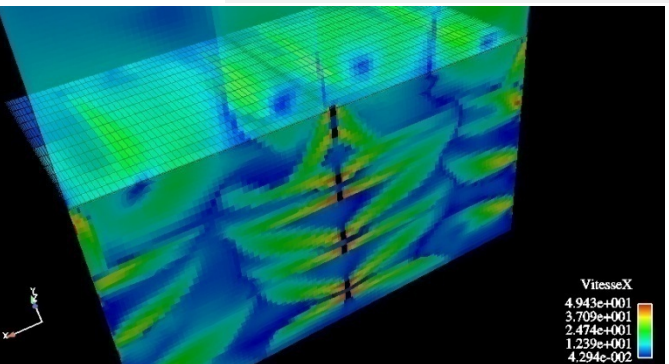


Boiler No.4



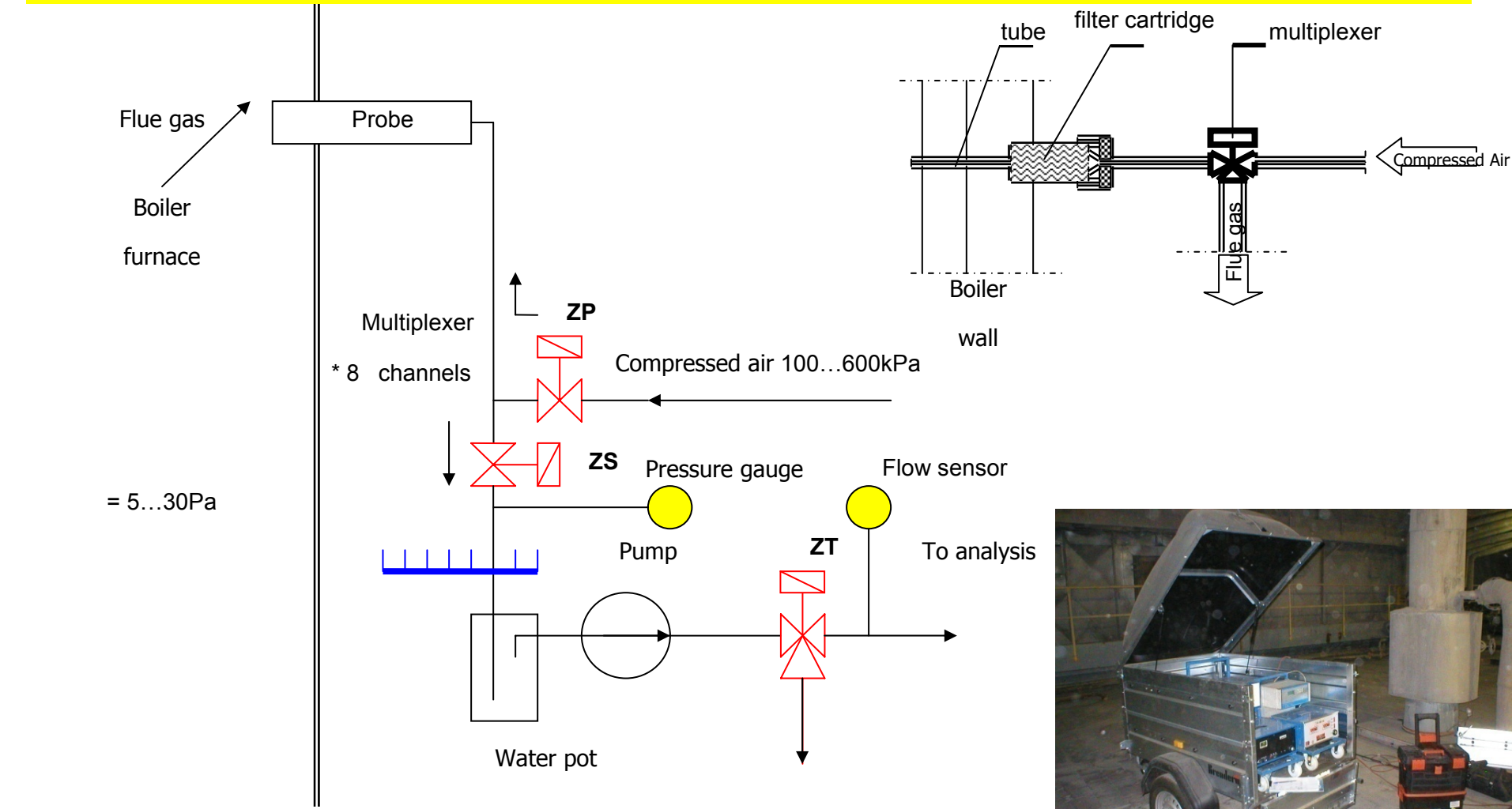


Boiler No.5



Side walls protection

TG4: Low-NOx retrofit in Polaniec power plant - Electrabel (boiler EP 650)



Mitigation of negative effects – Continuous CO and O2 monitoring at furnace walls

TG4: Simplified method for estimation of high-temperature corrosion rate [nm/h] in supercritical power boilers

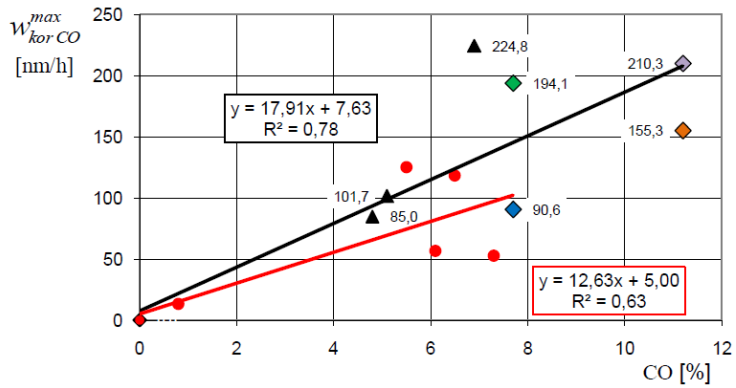
$$w_{kor} = X_{kor}\, w^{max}_{kor\,CO}\, X_{tsc}\, X_{Cl}$$

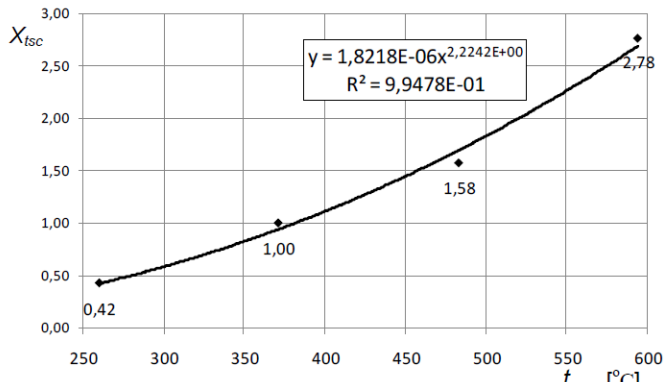
$$w_{korCO} = \frac{\Delta g}{\Delta \tau} = 17{,}91[CO] + 7{,}63$$

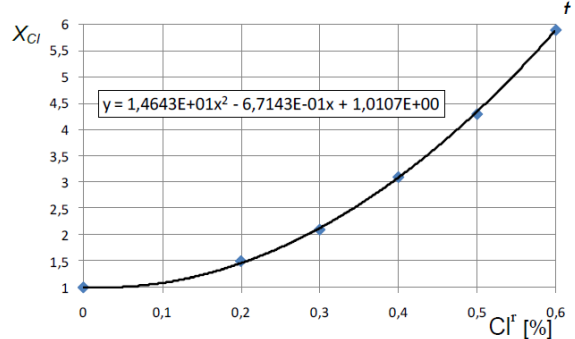
$$X_{tsc} = 1{,}8218\, t^{2{,}2242}_{sc\,z}$$

$$X_{Cl} = 14{,}643[Cl^r]^2 - 0{,}6714[Cl^r] + 1{,}0107$$

$$X_{kor} = w_{kor\,CO} / w^{max}_{kor\,CO}$$





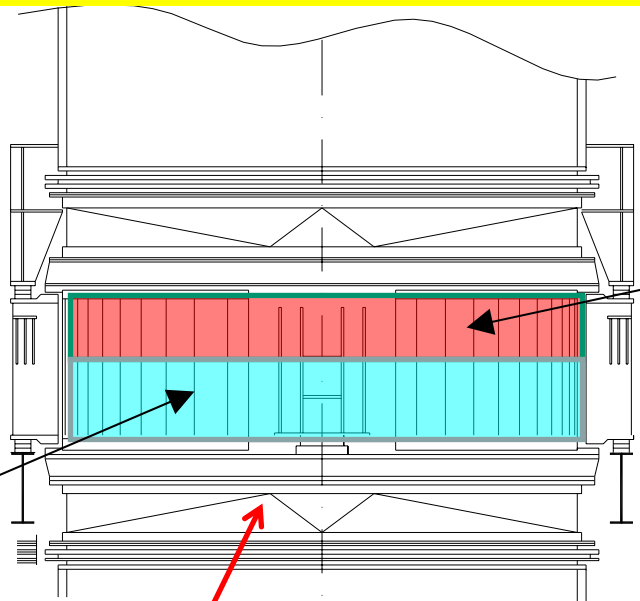


[CO] - CO fraction in the water wall boundary layer, vol.%
Dg/ Dt – max. tube thickeness loss rate, nm/h
$t_{sc\,z}$ – tube surface temperature, ° C
[Cl^r] – Cl content in the fuel, as received

TG4: Investigations of SCR at Rotary Air Heater (RAH)

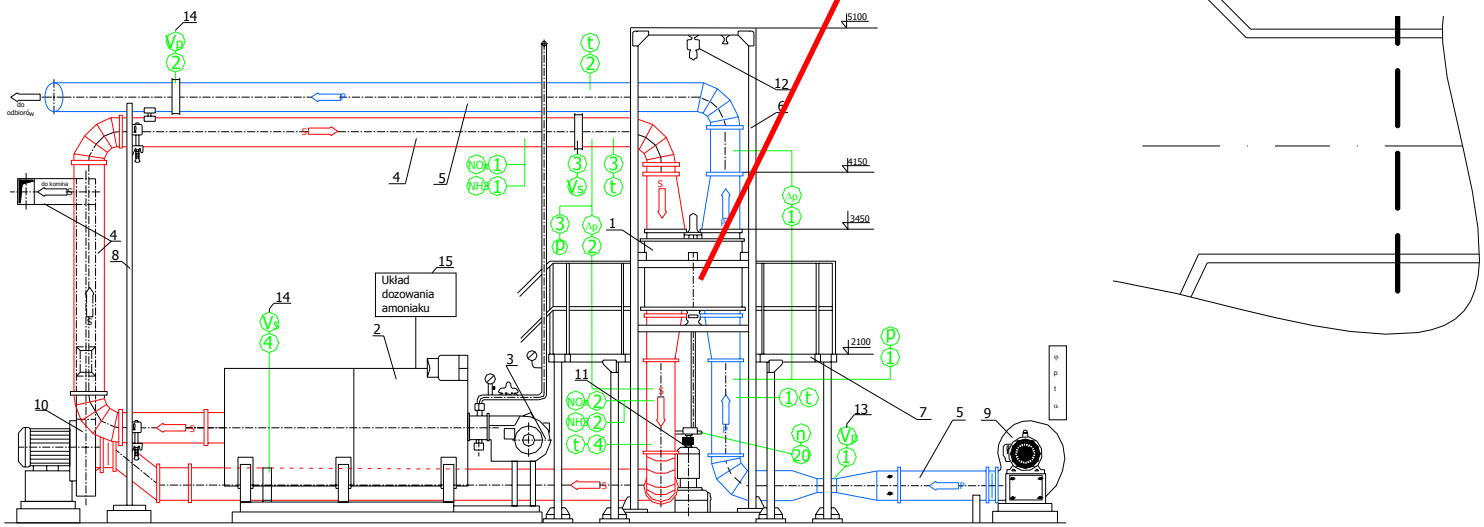
Cu-Mn catalyst on aluminosilicate

ca.30% reduction

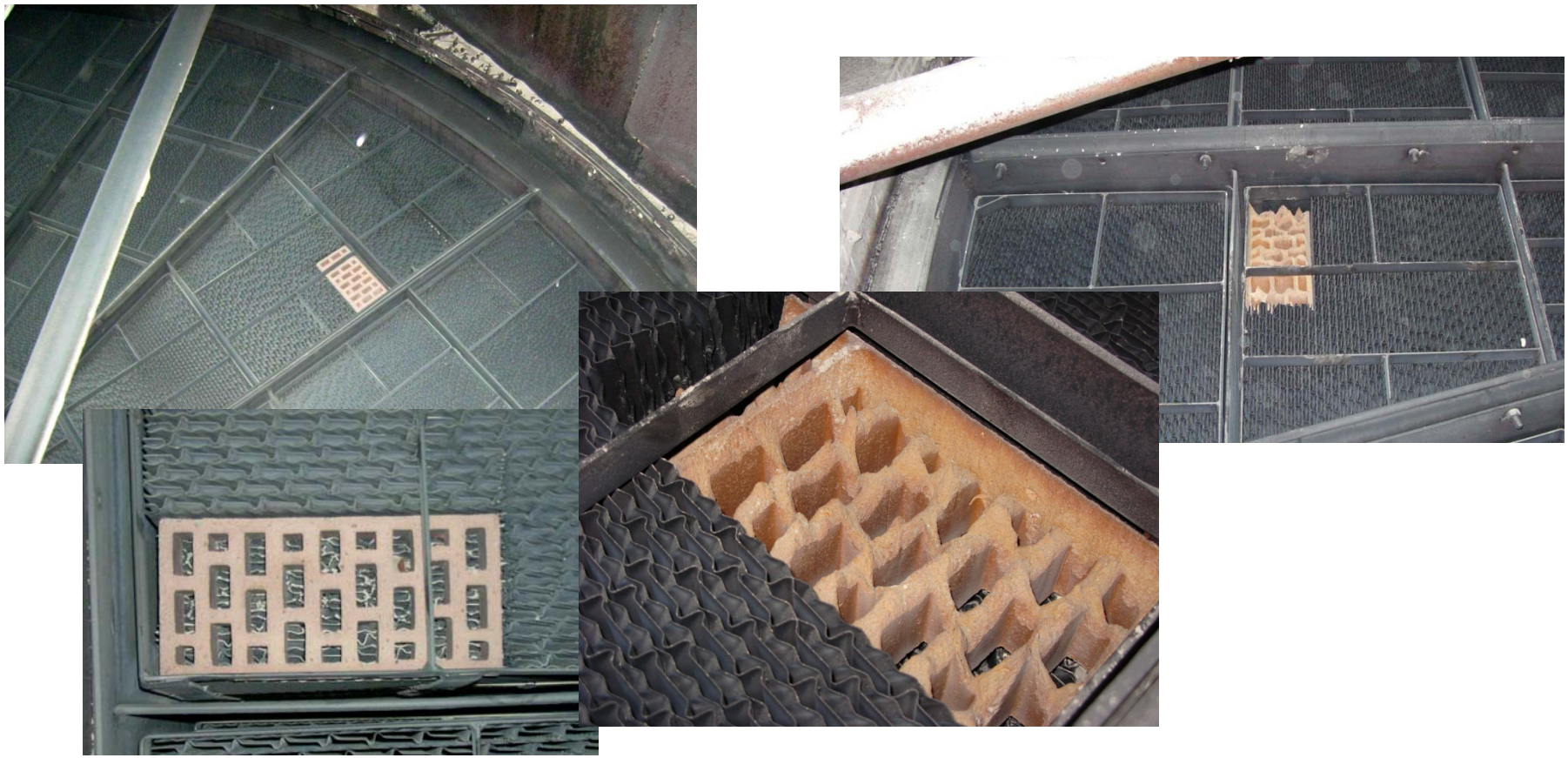


Catalytic cartridges at hot-end of rotary air heater

Cold-end of rotary air heater

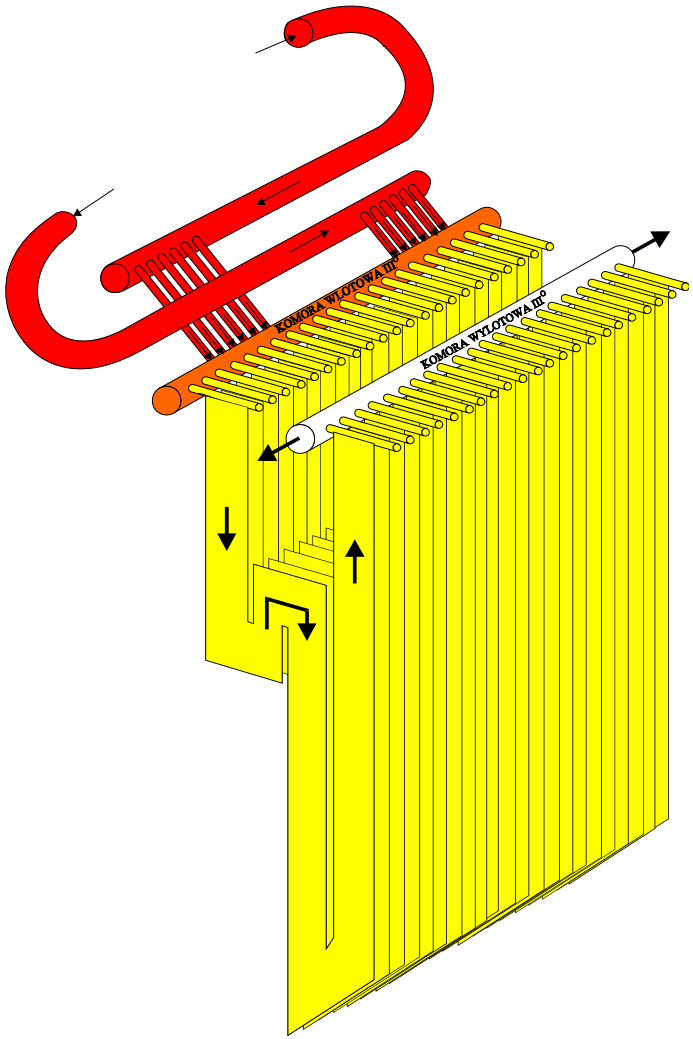


TG4: Investigations of SCR at Rotary Air Heater (RAH) – Rybnik power plant

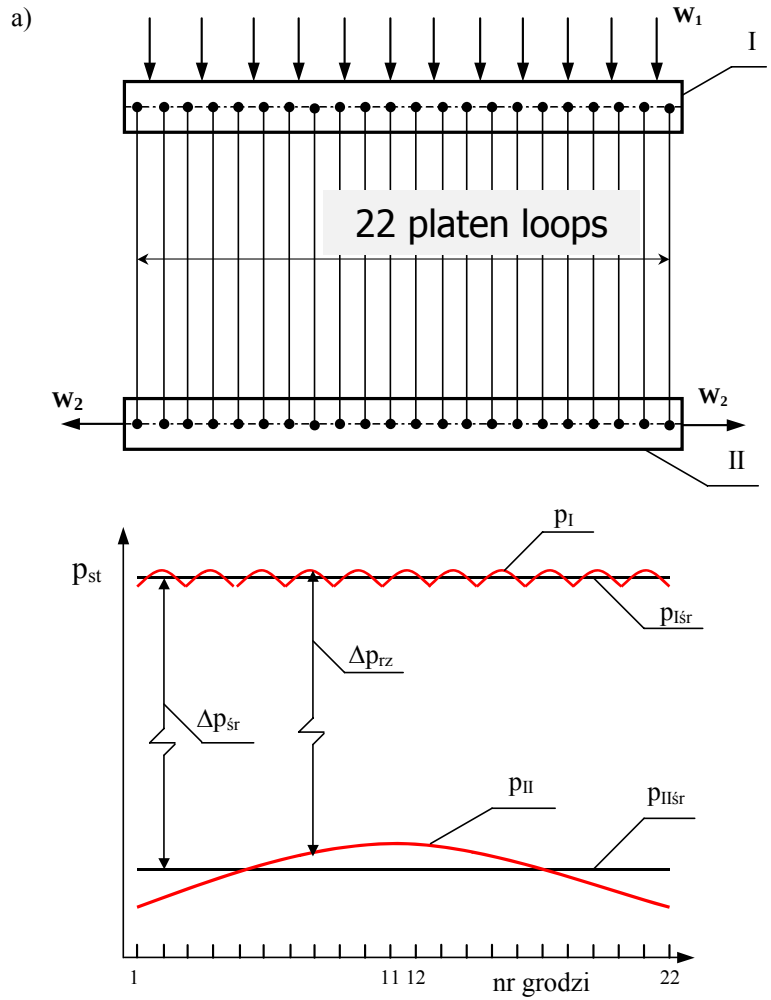


After 1.5 years of exposure to erosion and temperature cycles only minor wear has been discovered

TG4: Durability of superheaters under low-emission firing



3rd superheater at OP650



Distribution of static pressure
Most endangered tubes should have T sensor applied

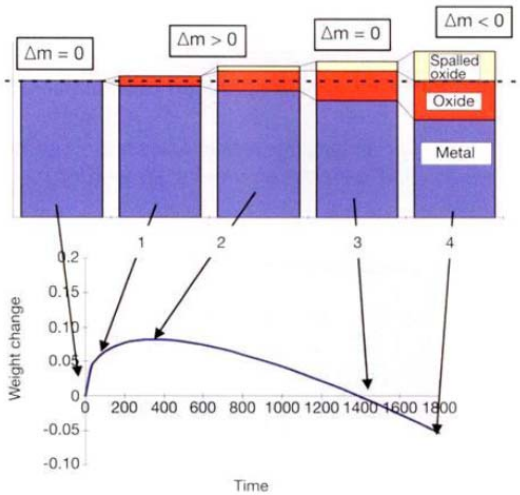
TG5: Safety of the supercritical coal-fired units

Objectives:

- Reliability of supercritical coal-fired units
- Deterministic and probabilistic of wear in boiler and turbine elements
- Risk assessment of power unit
- Elaboration of database for high-temperature creepresisting steels
- Recommendations for weldability, welding conditions and on technologies of welding homogeneous joints with cobalt and tungsten additives
- Endurance of welded joints for cyclic thermo-mechanical loads
- High temperature corrosion resistance in aggressive environment for up to 700°C - basic materials and welds

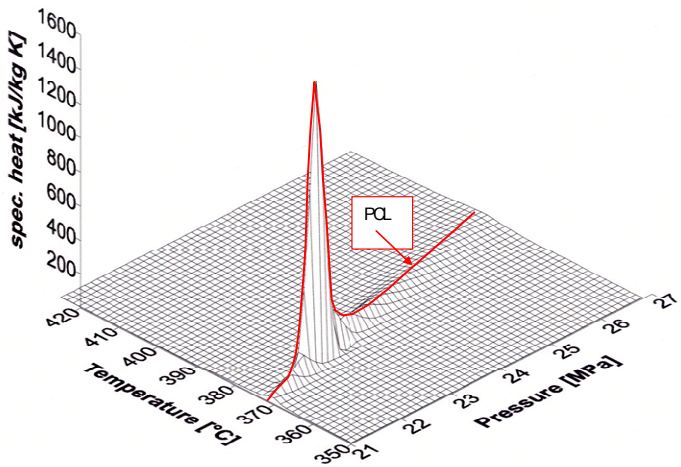
TG5: Exfoliation phenomena at supercritical conditions

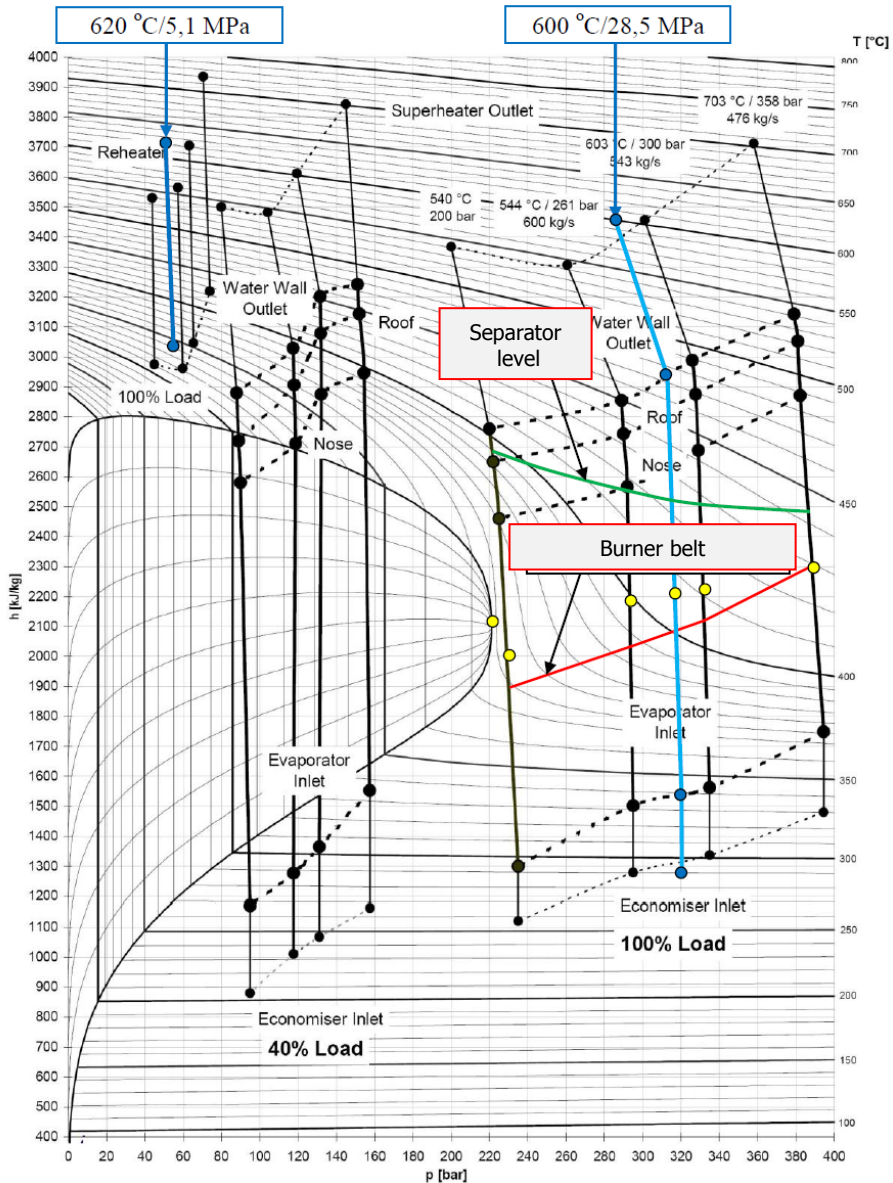
Reference boiler — PCL ○



Possible model for oxidation and spallation:
Weight change of specimens vs. time:

1. parabolic oxide growth (red)
2. oxide growth and spallation (yellow)
3. because of strong spallation, weight change is zero.
4. entire outer oxide scale is spalling, causing weight change to become negative





TG6: Interconnection between supercritical unit and power grid; transient states

- Optimization and minimisation of the internal load needs
- Analysis of the reliability of electricity generation in supercritical unit
- Analysis of conditions for interconnection with a power grid
- Control requirements for supercritical unit and its voltage-frequency profile
- Modeling of transient and emergency states of supercritical unit

Follow-up

Results of the research programme on Supercritical Coal Power Plants (2007-2010) will be used and further investigated (hopefully) in the following future projects:

1. Strategic research programme (national) on Advanced Methods of Power Generation (budget of about 60 mln PLN – 15 mln Eur) – already applied
2. Membership in the Knowledge and Innovation Community – KIC ‘InnoEnergy’ under leadership of TU Karlsruhe – already applied
3. FP7 projects: Industry and Academia Partnership and Pathways, project ‘REDEM’ (SUT, TU Clausthal, TU Wroclaw, EDF R&D and ESKOM South Africa) - already applied
4. …other to come

BACK TO THE FUTURE

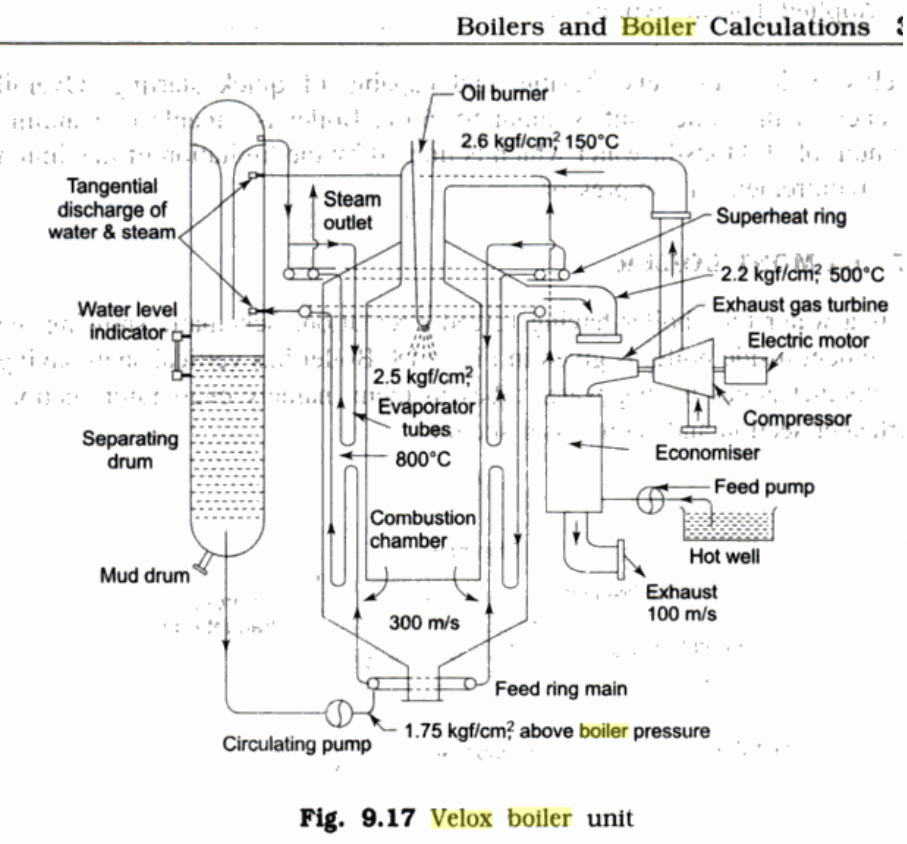
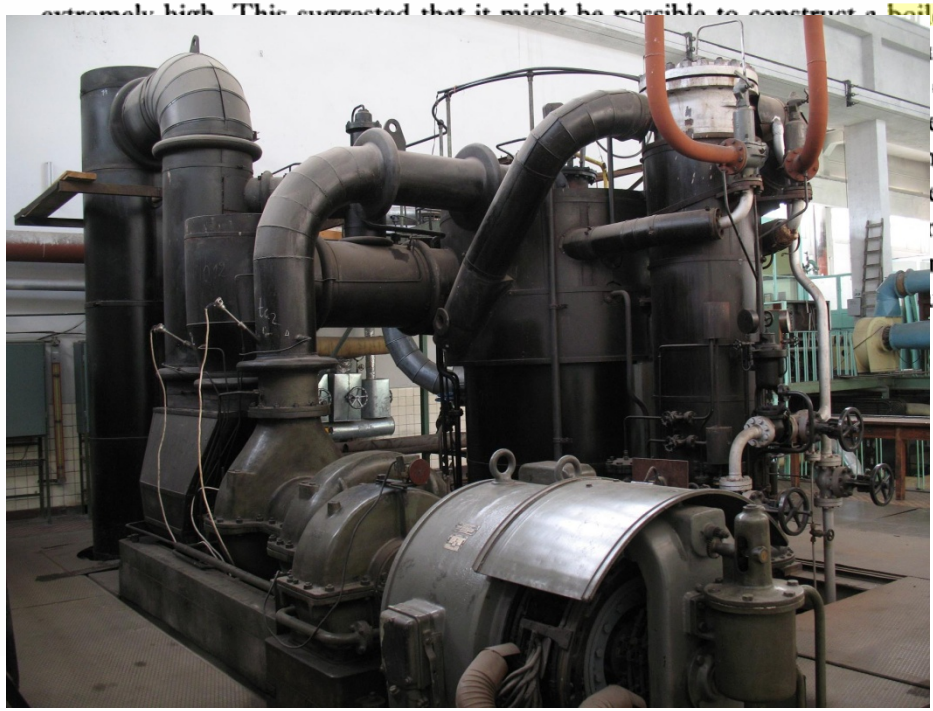


Fig. 9.17 Velox boiler unit

1933–1946: beginnings of the modern gas turbine

There was a substantial hiatus in gas turbine activity following the early attempts to construct the machines described above, while efforts were made to develop high efficiency compressors with an adequate compression ratio (at least 4:1). In addition, during this period, as a consequence of their work with Holzwarth's Hamborn gas turbine, the Brown Boveri Company took an important step toward the development of a practical gas turbine based on the constant pressure heat addition cycle. It was noted that in the Hamborn machine, because of the high velocity and pressure of the combustion gases, the heat transfer rates in the combustion chambers and turbine inlet nozzles were



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An encyclopaedia of the history of technology – Ian McNeil, Routledge, 1990