Centre for Research & Technology Hellas (CERTH)

Predictive method for low load off design operation of a lignite fired power plant

I. Avagianos, K. Atsonios, N. Nikolopoulos, P. Grammelis, N. Polonidis, Ch. Papapavlou, E. Kakaras

Contact: +30 211 1069 508, *Fax* : +30 211 1069 501,
e-mails: avagianos@certh.gr, atsonios@certh.gr,

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- Methodology
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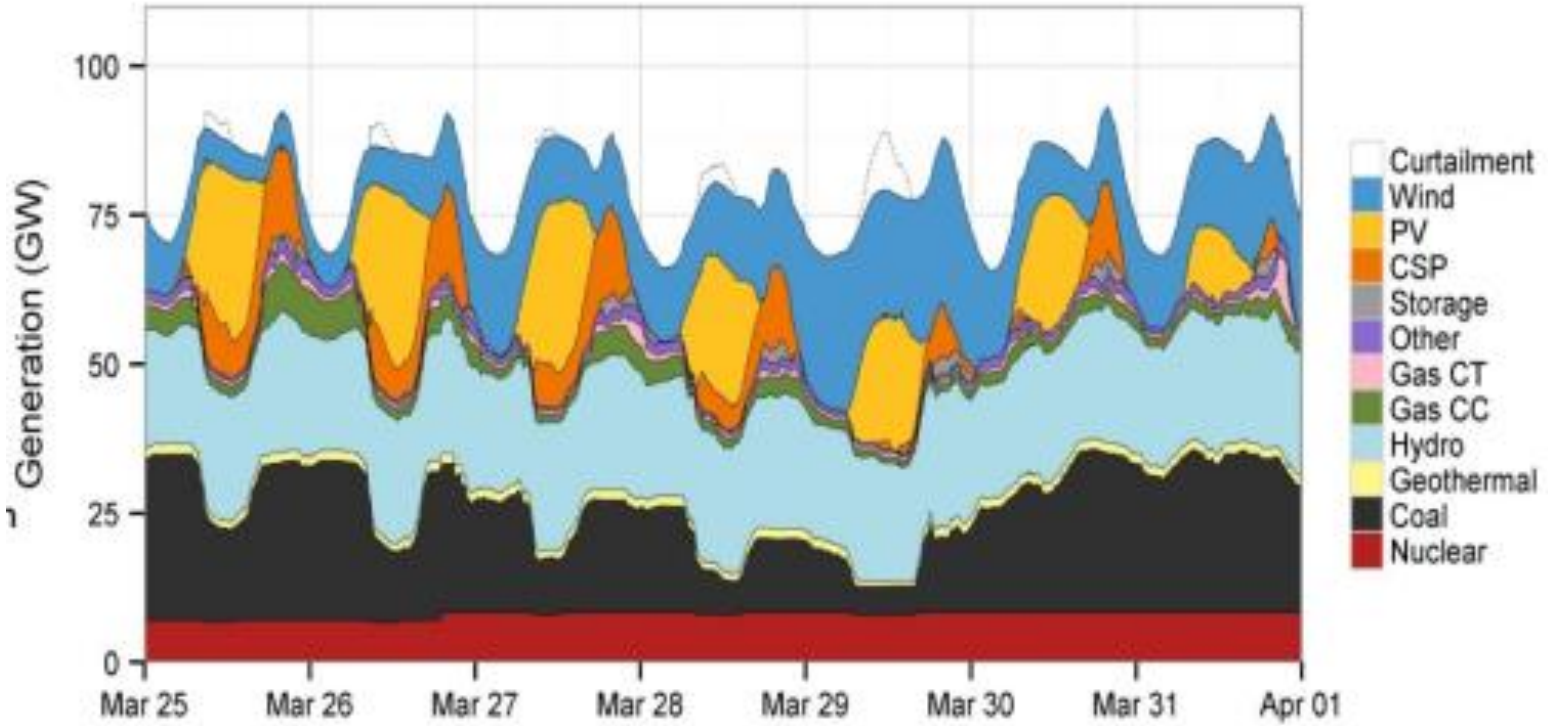
Scope

Motivation

- Lignite fired power plants cope with high RES penetration
- Increase flexibility for existing power plants
- Increase dispatch time for lignite power plants



Source: WWSIS Phase 1 (2010)

Scope

Objectives

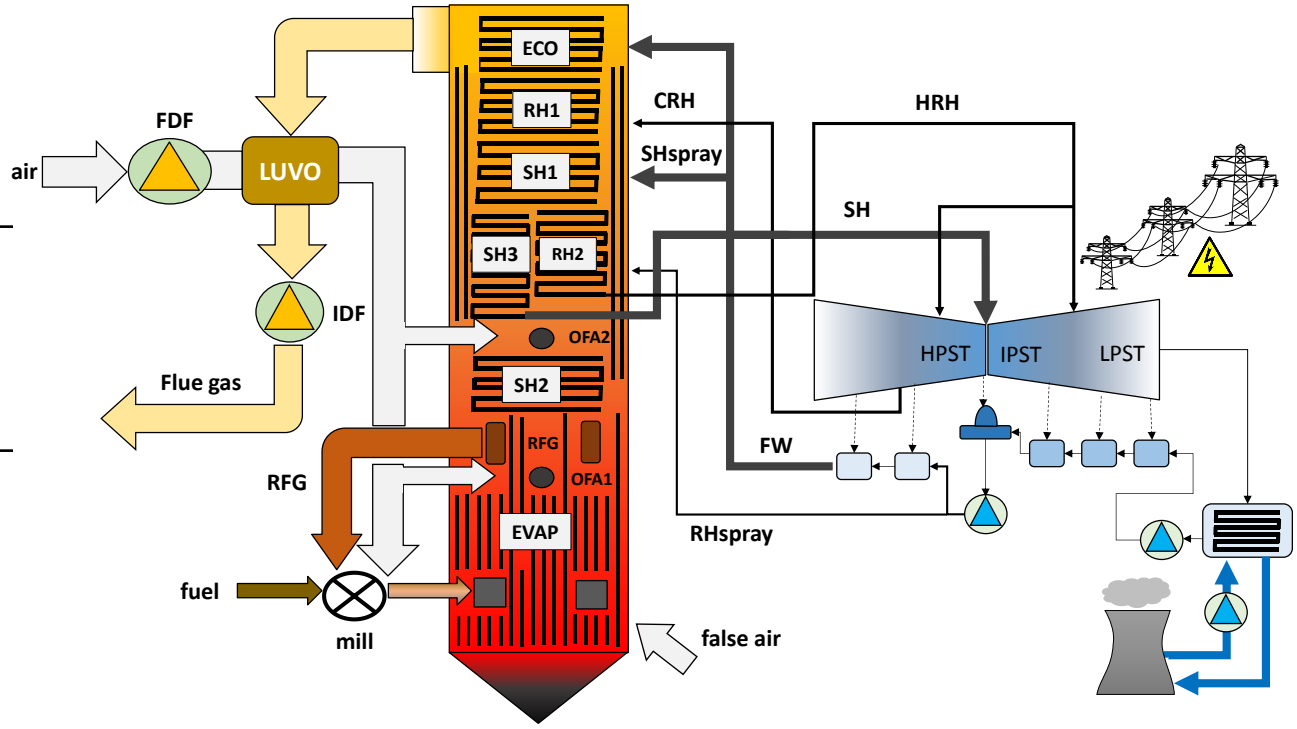
- Feasible 35% technical minimum load
- Pre-dried lignite co-firing
- Predictive method for boiler operation
- Synergy of thermodynamic and CFD tools
- Use of a wide range simulation tool

Plant Description

Agios Dimitrios V

Power plant characteristics

Gross power output	374.2 MWe
Net power output	330.0 MWe
HP steam production	912.5 t/h
HP steam characteristics	538 °C/194 bar
HRH steam characteristics	538 °C/33 bar



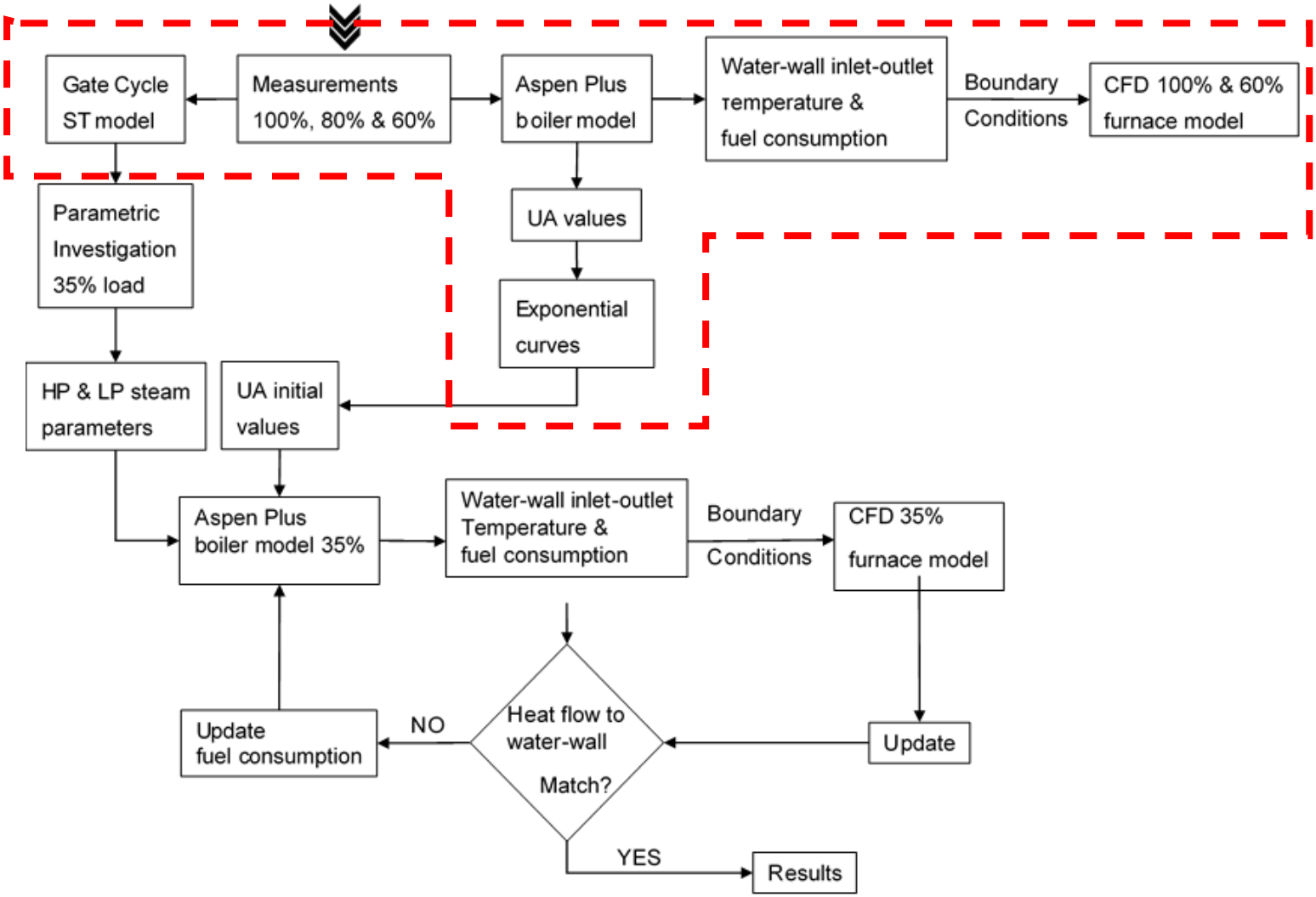
Fuel characteristics

	Water	Ash	Volatiles	Fixed carbon	LHV (d.b.) (kJ/kg)
Raw lignite	49.7	18.47	22.32	9.51	12698.3

Methodology (1/3)

Loads within operating range

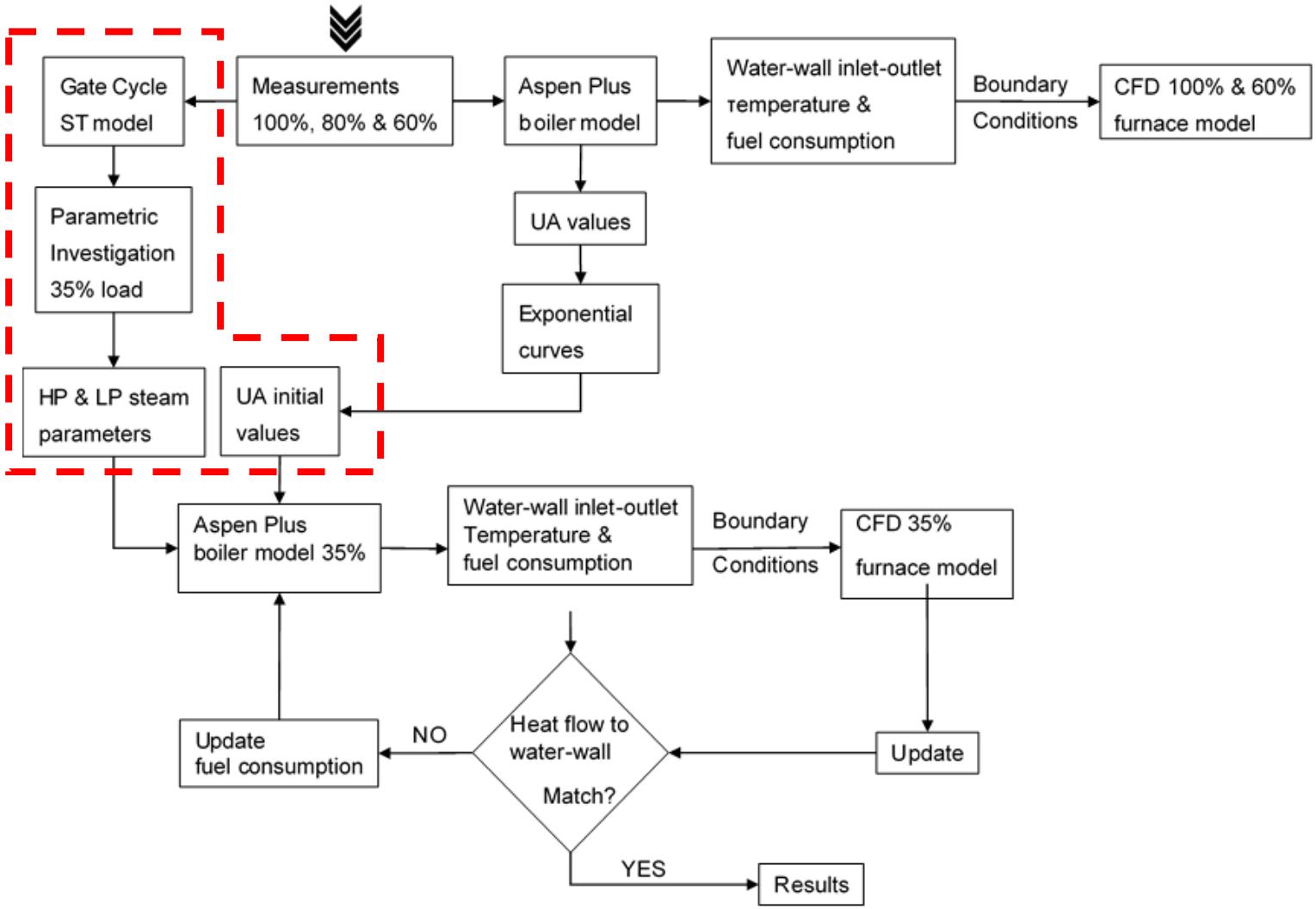
- Measurements for three loads
- Steam turbine with Gate Cycle
- Boiler with Aspen Plus & CFD
- Two loads feed boundary conditions to CFD
- Three loads for UA values & exponential curves



Methodology (2/3)

- Initial UA value for 35% load for all cross-flow heat exchangers
- steam turbine: in Gate Cycle based Stodola law
- steam temperature & RH spraywater mass flow from parametric investigation
- Definition of steam mass flow and temperature for HP & LP turbine

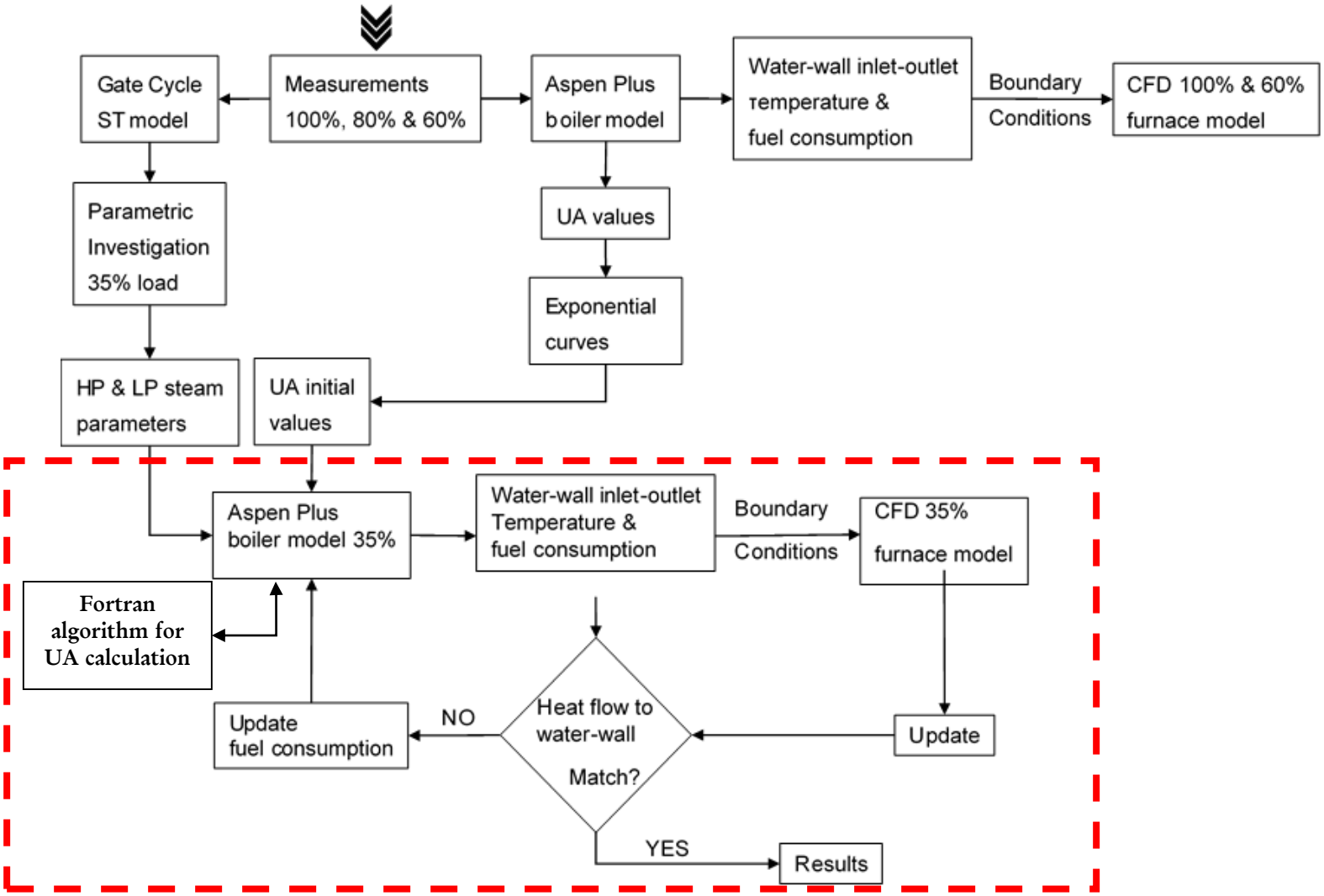
35% load: process configuration initialization



Methodology (3/3)

35% load: iteration method before final case

- boiler model initial simulation
- ε-NTU code iterative method for UA values
- Boundary conditions to CFD
- Iterative loop with fuel mass flow update



Modelling & simulation (1/3)

Aspen Plus

- Databanks
  - ✓ PURE32
  - ✓ AGUEOUS
  - ✓ SOLIDS
  - ✓ INORGANIC
  - ✓ NIST-TRC
- Property methods
  - ✓ Water/steam IAPWS-95
  - ✓ Flue gas SRK (Redlich-Kwong-Soave)

Aspen Plus

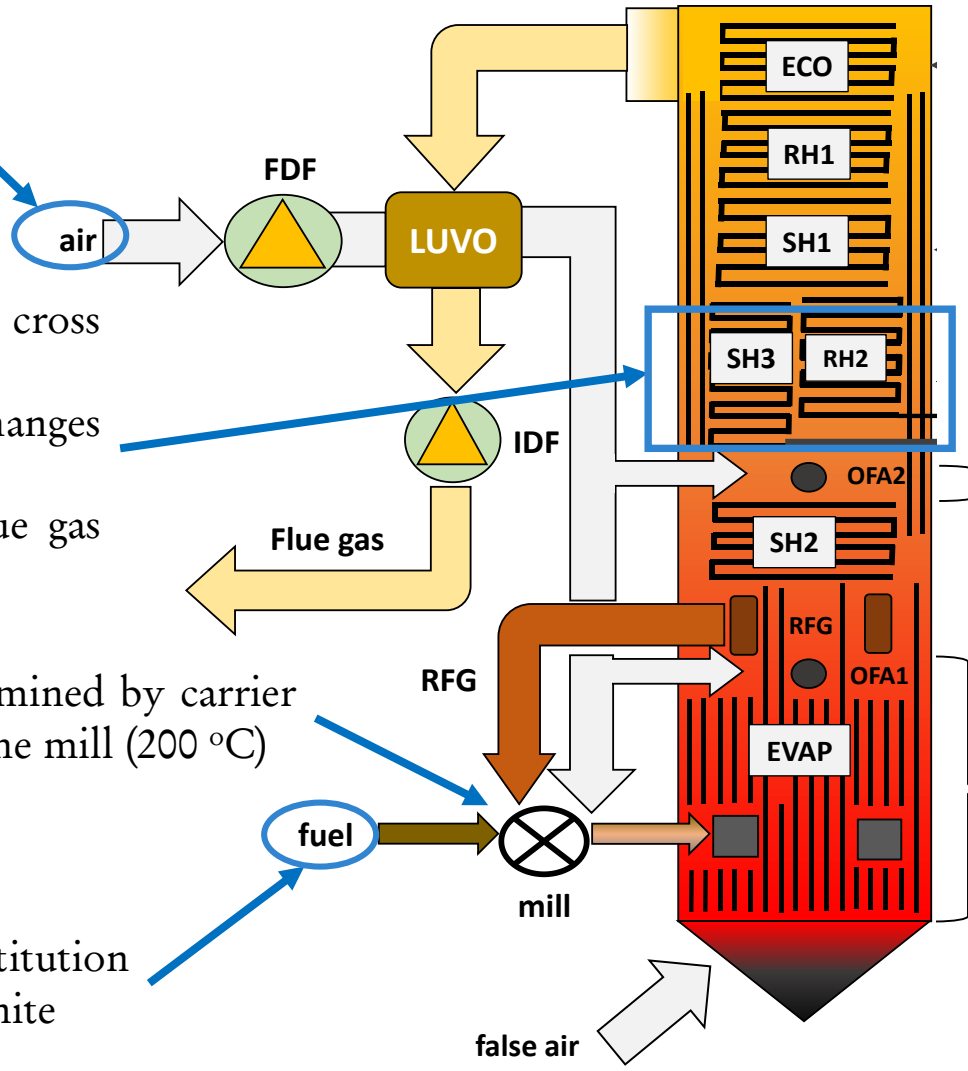
- Cross-flow heat exchanger
  - ➢ HeatX block
- Water-wall
  - ➢ Heater block
- Combustion
  - ➢ Chemical equilibrium with modifications from CFD for CO and char production

Data obtained from CFD simulation and used at the thermodynamic model		
load	100%	60%
char combustion efficiency at lower lever	92.5	96.24
total char combustion efficiency	99.9	99.9
CO concentration (% w/w)	0.213	0.210

Modelling & simulation (2/3)

combustion air/false air distribution taken into account

- SH3 and RH2 covering each half cross section of the furnace
- Assumed half flue gas mass exchanges heat with SH3 and half with RH2
- Assumed full mix of the two flue gas halves heating the SH1



upper level: combustion of unburnt char from lower level

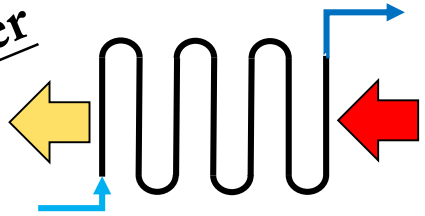
Recirculated FG determined by carrier gas temperature after the mill (200 °C)

lower level: primary combustion

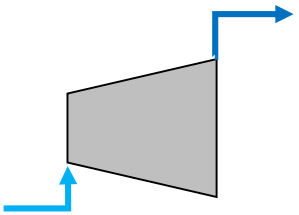
25% thermal substitution with pre-dried lignite

Modelling & simulation (3/3)

heat exchanger



steam turbine



ε-NTU method

- Cross-flow heat exchangers
- UA product from three loads for all cross-flow heat exchangers
- Initial value from exponential curve fitting for 35% load
- Iterations for final value for each heat exchanger

$$q = \varepsilon \cdot C_{min} \cdot (T_{h,i} - T_{c,i}) = \varepsilon \cdot C_{min} \cdot \Delta T_{max}$$
$$\varepsilon = q/q_{max}$$
$$NTU = U \cdot A/C_{min}$$
$$C^* = C_{min}/C_{max}$$
$$\varepsilon = 1 - exp\left\{\frac{-[1 - exp(-NTU \cdot C^*)]}{C^*}\right\}$$
$$NTU = -\frac{1}{C^*} \cdot ln[1 + C^* \cdot ln(1 - \varepsilon)]$$

35% load steam turbine

- Stodola's law for steam turbine operation
- Parametric investigation
  - ✓ Super heated steam temperature
  - ✓ Reheated steam spray water mass flow

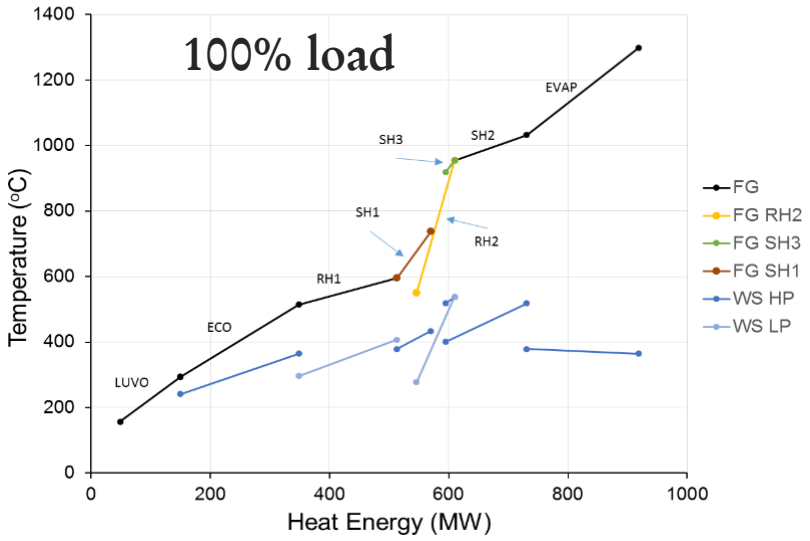
Results (1/8)

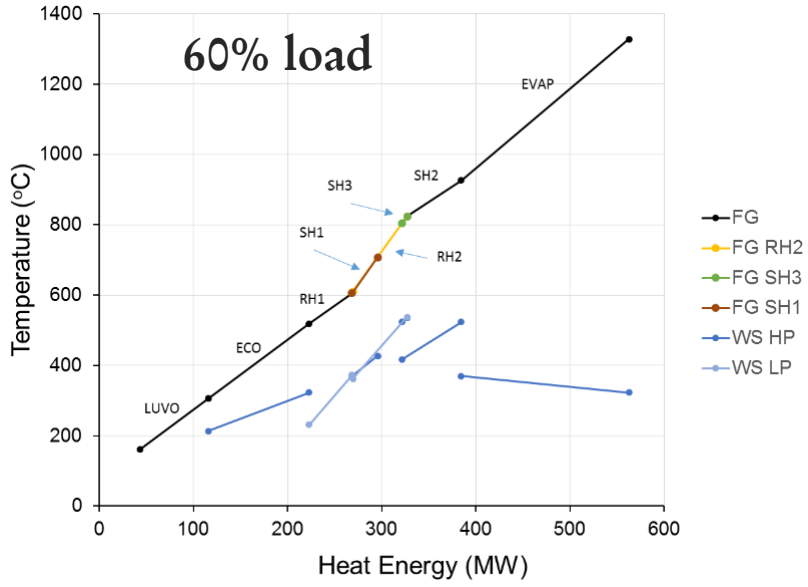
Aspen Plus boiler simulation results within operating range

Load	100%	80%	60%
Gross power output, MW_e	366.9	296.6	216.7
Air to fuel equivalence ratio	1.15	1.31	1.31
Fuel consumption, t/h	639.9	524.3	391.7
Total electric consumptions, MW_e	26.4	21.5	16.1
HP steam production, t/h	936.0	770.0	585.0
RH steam production, t/h	994.5	760.5	534.6
SH steam characteristics, ^oC/bar	538/194	538/192	535/191
RH steam characteristics, ^oC/bar	538/33.4	538/24.1	538/19.0
Flue gas temperature outlet, ^oC	157.0	162.4	160.2
Gross efficiency, %	37.4	36.9	36.1
Boiler efficiency, %	84.9	84.4	84.2
Net efficiency, %	34.7	34.3	32.4

- Stable parameters for steam characteristics, flue gas outlet temperature, boiler efficiency

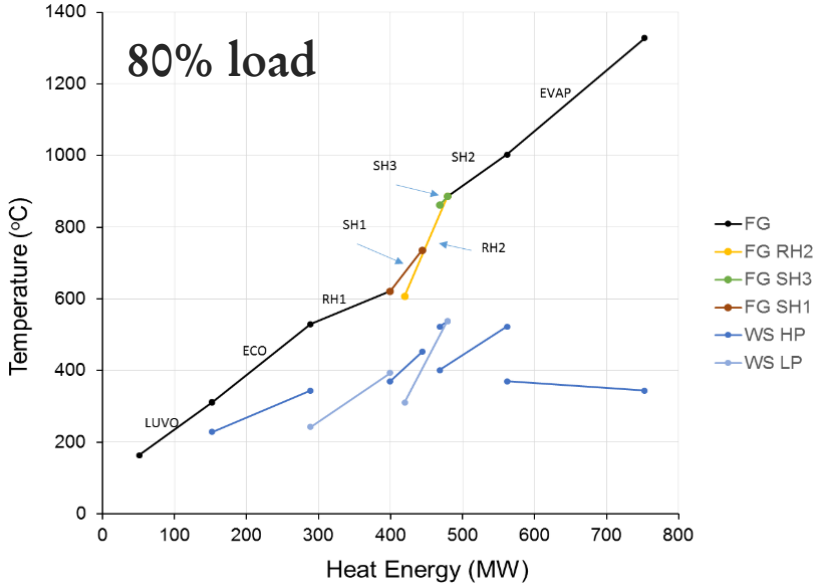
Results (2/8)





Q-T diagrams

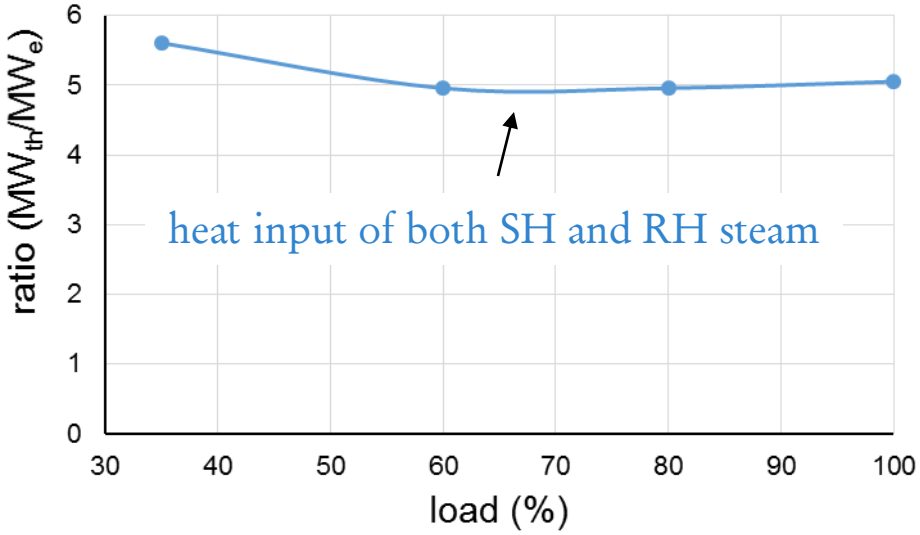
- Constant flue gas temperature outlet
- Small flue gas-water temperature difference at ECO outlet



Results (3/8)

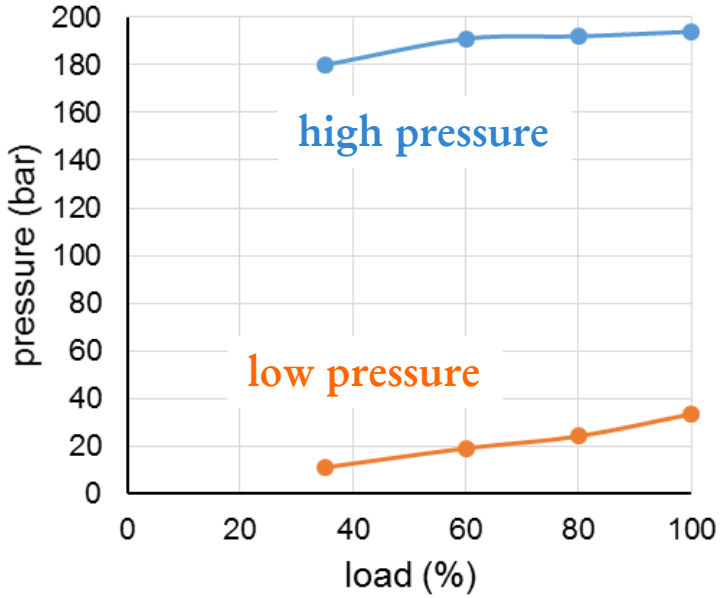
Thermal load to electric load ratio against load

- Expected trend for curve
- Typical for 100%, 80% and 60%
- Increase for new technical minimum



High and low steam pressure against load

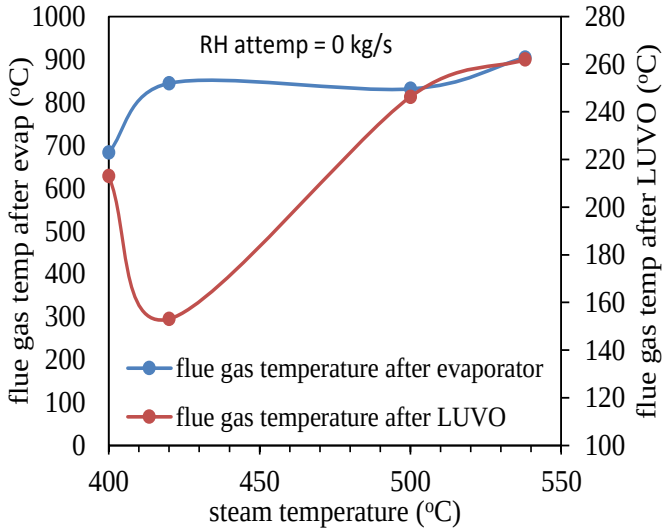
- Pressure projection for 35% defined by steam turbine model with Stodola law

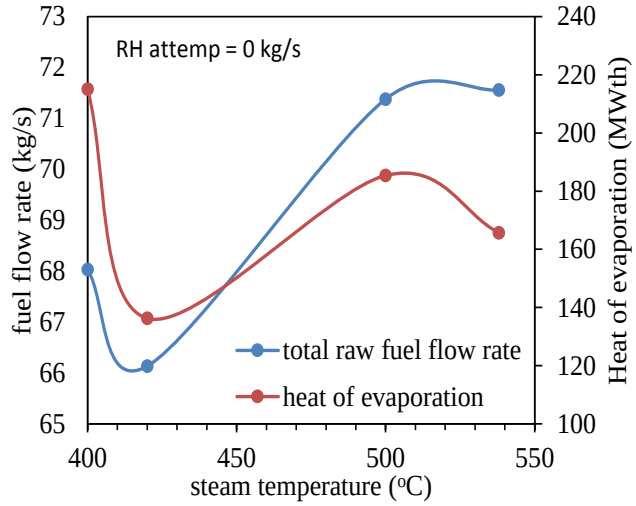


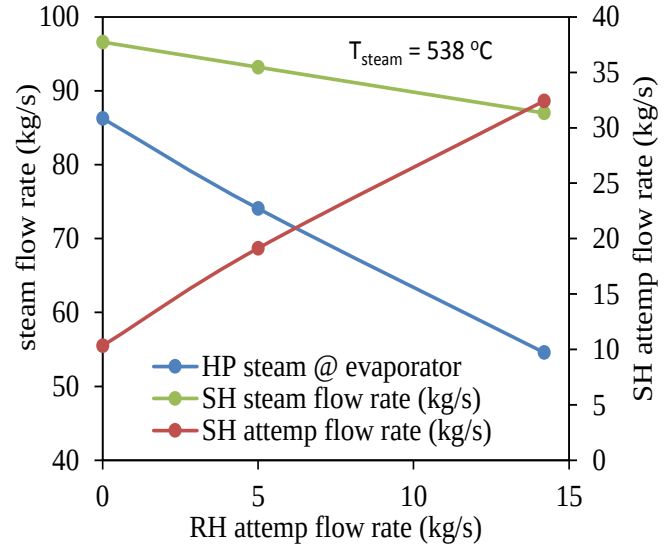
Results (4/8)

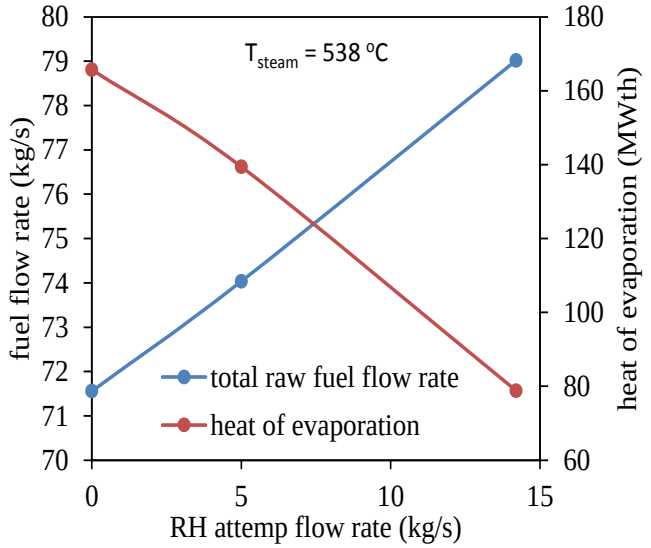
Gate Cycle
steam turbine parametric investigation results for 35% load

- RH attemperator mass flow rate and steam temperature
- Minimum flue gas temperature for 420°C steam temperature
- Minimum fuel consumption for zero RH steam mass flow rate









Results (5/8)

35% load

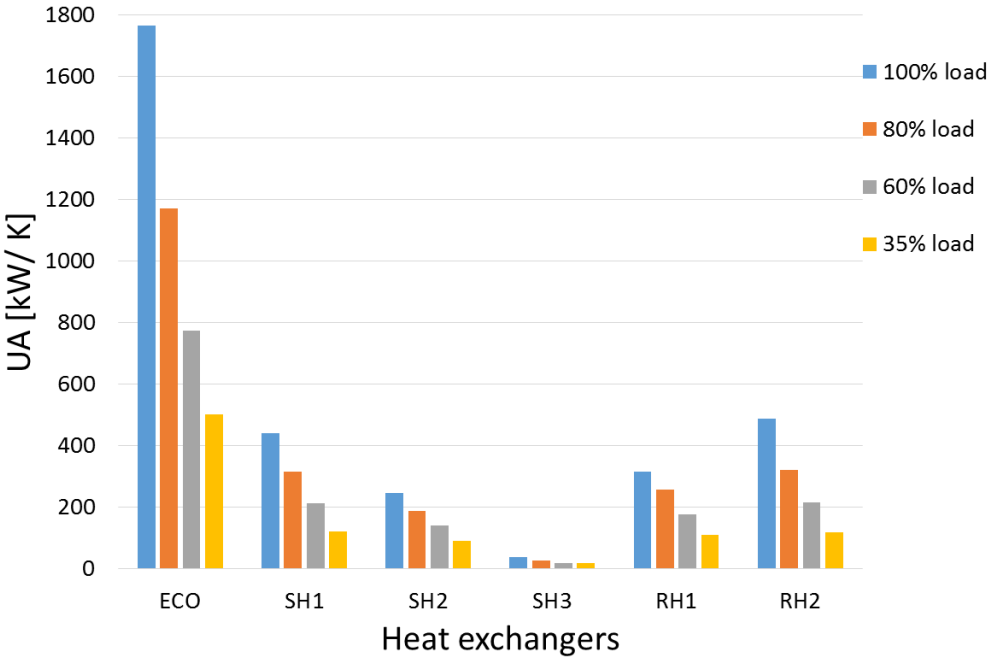
- Pre-dried lignite use beneficiary for boiler efficiency
- Retain gross efficiency
- Improved net efficiency

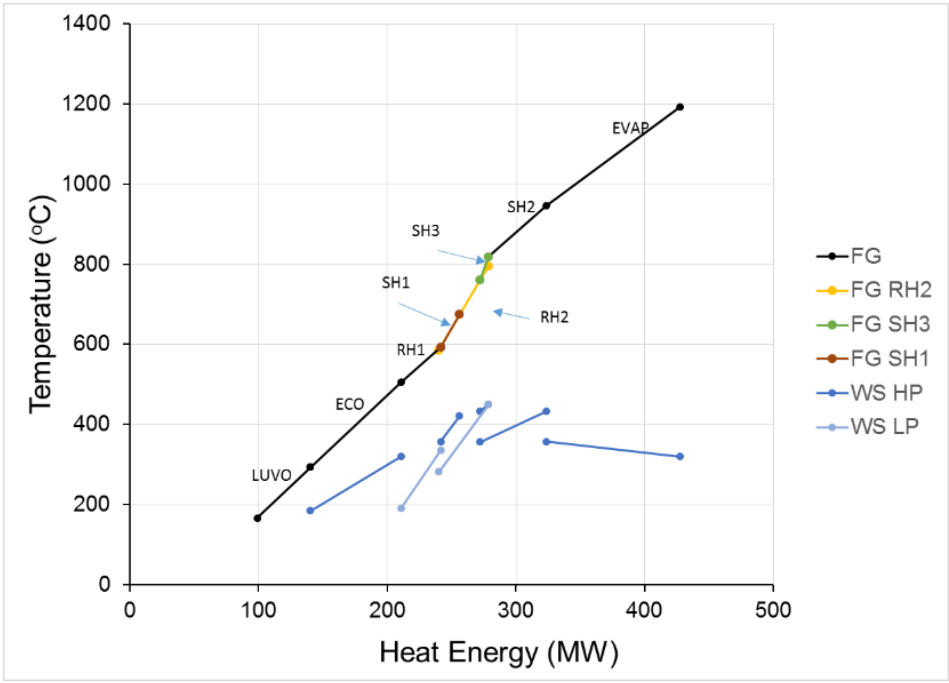
Load	100%	80%	60%	35%
Gross power output, MW_e	366.9	296.6	216.7	128.4
Air to fuel equivalence ratio	1.15	1.31	1.31	1.41
Fuel consumption (raw), t/h	639.9	524.3	391.7	238.1
Fuel consumption (pre-dried), t/h	-	-	-	21.8
Total electric consumptions, MW_e	26.4	21.5	16.1	10.8
HP steam production, t/h	936.0	770.0	585.0	419.8
RH steam production, t/h	994.5	760.5	534.6	405.0
SH steam characteristics, ^oC/bar	538/194	538/192	535/191	420/180
RH steam characteristics, ^oC/bar	538/33.4	538/24.1	538/19.0	420/11.0
Flue gas temperature outlet, ^oC	157.0	162.4	160.2	153.1
Gross efficiency, %	37.4	36.9	36.1	36.4
Boiler efficiency, %	84.9	84.4	84.2	88.9
Net efficiency, %	34.7	34.3	32.4	33.3

Results (6/8)

35% load

- Load dependent heat transfer UA value
- Exponential decrease





- Slightly lower flue gas temperature favors boiler efficiency

Results (7/8)

Comparison of results

- Deviations with measurements around retrofit area
- Deviations with the CFD results for total heat transfer under 5%

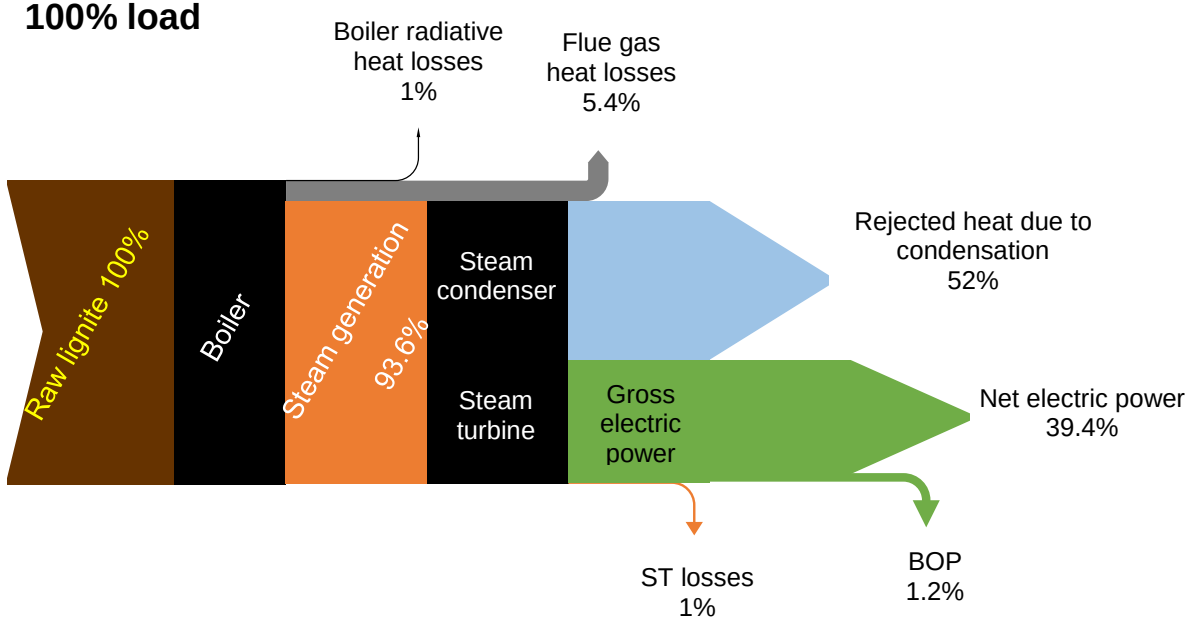
		Temp. @ the main furnace outlet	Temp. before RH2-SH3	Temp. before ECO	Temp. @ the convective section outlet surface	Total heat transfer
		(K)	(K)	(K)	(K)	(MW)
100% load	Thermodynamic results	1303.58	1226.89	787.2	563.15	832
	CFD results	1306.0	1100.37	729.29	543	805
	Measurements	-	1039.47	692	562	836
	Difference with CFD results	-0.19%	10.31%	7.36%	3.58%	3.25%
	Difference with measurements	-	15.28%	12.09%	0.20%	-0.48%
60% load	Thermodynamic results	1213.21	1096.81	791.62	579.37	507
	CFD results	1179.59	1012.45	726.65	553.63	486
	Measurements	-	972.75	667.65	546.75	548
	Difference with CFD results	-2.85%	-8.33%	-8.94%	-4.65%	-4.32%
	Difference with measurements	-	3.92%	8.12%	1.24%	-12.76%
35% load	Thermodynamic results	1121.77	985.6	726.54	543.15	314
	CFD results	1071.14	895.4	652.15	539.7	300
	Difference with CFD results	-4.73%	-10.07%	-11.41%	-0.64%	-4.67%

Results (8/8)

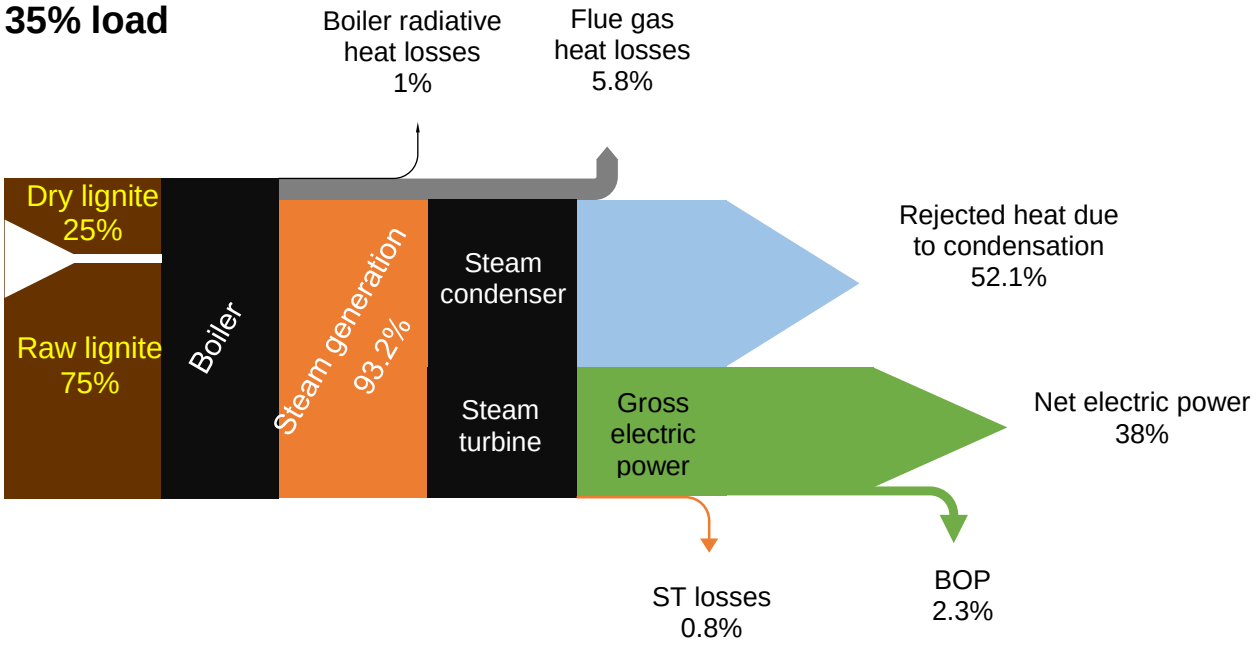
Comparison of results

- Similar maximum and minimum load
- Similar flue gas heat losses
- Efficient heat use from the boiler

100% load



35% load



Conclusions and further remarks

Conclusions

- Effective synergy of different thermodynamic and CFD simulation tools
  - Good agreement with CFD results for total heat transfer calculations (<5%)
  - Fair agreement with CFD results for FG temperature calculations (<12%)
- Feasibility of new technical minimum load operation, 35% load with 0.9 percentage points higher net efficiency than current technical minimum load (60%)
- 25% thermal share of pre-dried and raw lignite co-firing improves boiler efficiency by 4 percentage points
- Pre-dried lignite use for reaching off-design technical minimum load

Further remarks

- Include elaborated water-wall and steam turbine modeling in Aspen Plus
- Integration with lignite drying unit
- Integrate flue gas treatment unit and carbon capture unit
- Comparison with measurements after the retrofit when available

Thank you for your attention!

Questions?

Acknowledgements
This study has been carried out in the framework of the European Commission – **Research Fund for Coal and Steel** Contract no. RFCR-CT-2014-00009 (**DRYLIG**).