IEA 2012 Workshop “Cofiring biomass with coal”
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ORAL SESSION: Emissions and Ash

Co-firing Tests of Bosnian Coal with Woody Biomass and Natural Gas in Laboratory and on 110 MWe Power Station

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Content of presentation

1. Background – Sustainability of the Project?
2. Question arisen
3. R&D: Experimental – Cofiring coal with woody biomass - Fuel test matrix, Laboratory set, Cofiring test trials and Results
4. Co-firing coal with woody biomass and natural gas – EXPERIMENTAL
5. Business Plan of introducing cofiring coal with woody biomass into Kakanj Thermal Power Plant (Kakanj TPP)
6. Trial run at Large utility: Kakanj TPP Unit 5 (110 MWe) – Program, Realization, Results
7. Conclusions

1. BACKGROUND

How to check and prove if Project is "sustainable"?

Project is "sustainable" if generates pozitive effects to the Economic, Environmental and Social aspect, measured through the strictly defined sustainable indicators, and which Total Sustainability Index agregated is to be better than in Base-line scenario, considering complete LifeTime of the Project.

The Work presents R&D activities and operation with cofiring in a Power plant, starting from the Project development, via Laboratory setting and the tests runs, till the Trial run in Large Utility, i.e. Introducing cofiring regimes into regulat Operation of a TPP, with the checking the results (on the base of settled indicators) by measurement in praxis.

2. QUESTIONS ARISEN

- Potential of woody biomass in case of Bosnia and Herzegovina ?
- Why Cofiring of Bosnian Coal with woody biomass in existing Coal-based power plants?
- Which are expected benefits of the cofiring?
- Which obstacles can be expected in practical aplication?

Potential of woody biomass in Case of Bosnia and Herzegovina ??

- Large potential (53% of area of Bosnia and Herzegovina is under forest).
- Wood industry well developed, there is a number of saw mills.
- Large amount of wooden residues and waste woody biomass.

Why Cofiring coal with woody biomass in existing Coal-based power stations?

- ✓ Existing coal-based power plants are surounded with large sources of wooden biomass - forest, saw-mills...
- ✓ Improving environmental issue of existing coal-based power plants and reduction of CO_2.
- ✓ Cheaper investment solution for use of woody biomass.
- ✓Saving coal reserves for future generation.
- ✓ Synergy effects at co-firing of low-rank coal with biomass.

Which are expected benefits?

- Improving **<u>Environmental Indicators</u>** of power production:
  - Reduction of CO_2
  - Reduction of SO_2
  - Use of wooden residues will also improve local environment

- Improving **<u>Resaurce Indicators</u>** due to reducing of coal consumption

- Improving **<u>Economic Indicators</u>** of power production due to **potential** lower price of the fuel (??) and **potential** certified CO_2 reduction (CER)

- Improving **<u>Social Indicator</u>**: New jobs on wood collecting

Which are possible obstacles in praxis?

I. Key point: Price of woody biomass in EUR/GJ or in EUR/t!

- Organization of wooden biomass collecting
- Insufficient auxilary infrastructure in forests (roads, depotes for auxilarry storage) and transport of woody biomass to the sites

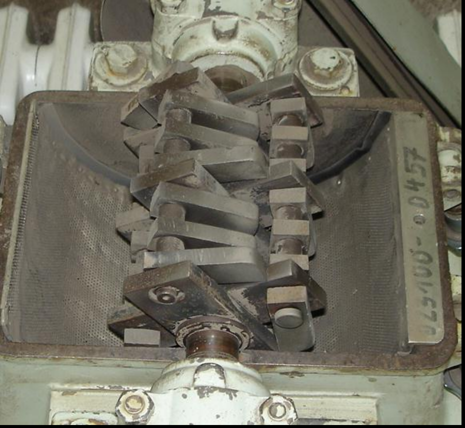
II. Key point: Investments on sites for co-firing regimes!

- Providing the depotes or boxes on sites for wooden biomass storage
- Adopting the boiler equipment for the woody biomass introducing

III. Key point: Possible increasing of O&M costs!

- Possible problems during combustion in co-firing regimes regarding combustion controll, slagging and fouling, corrosion...

3. R&D: Experimental - <u>Cofiring coal with woody biomass</u> Fuel test matrix, Laboratory set, Cofiring test trials and Results

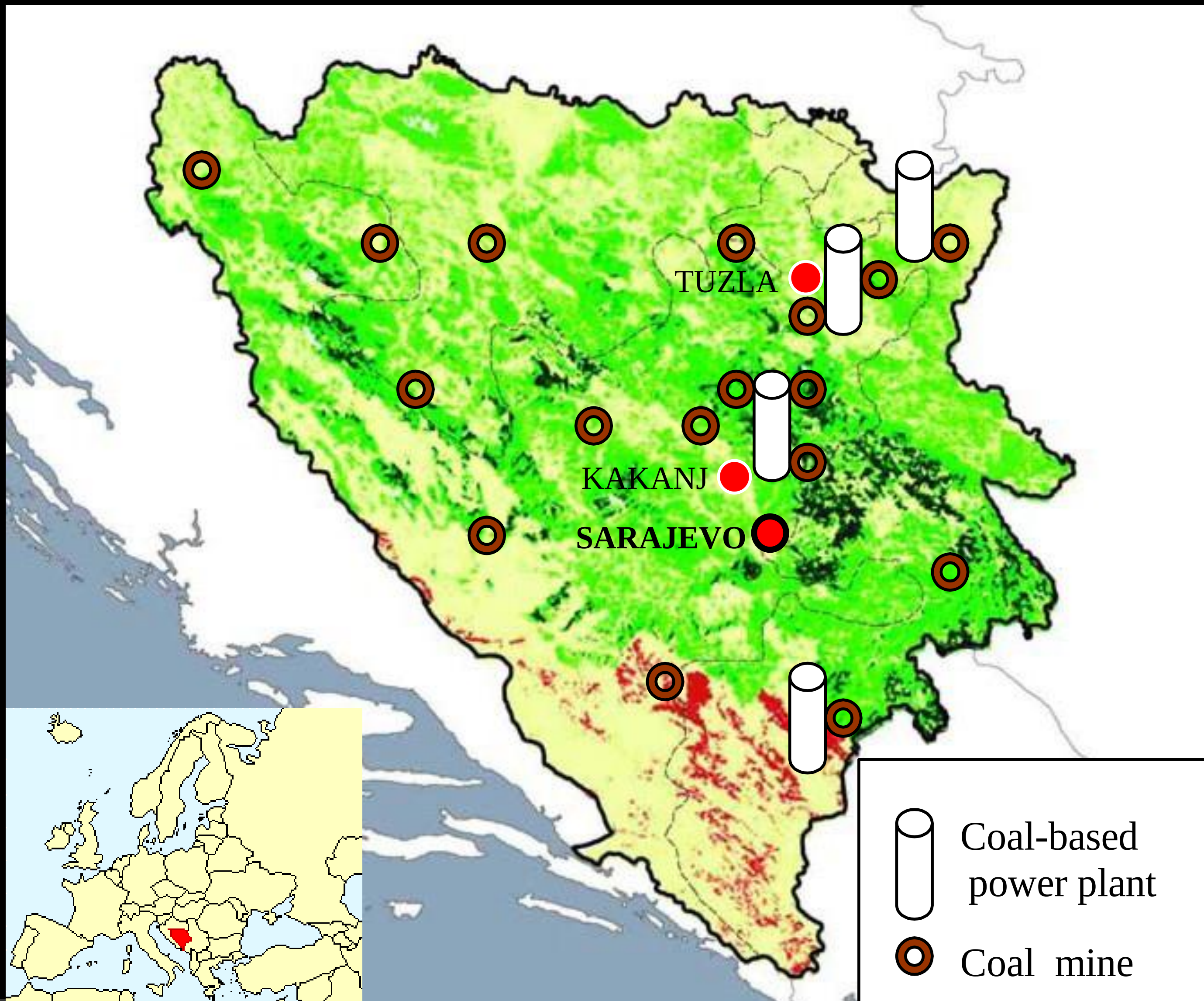


FUEL TEST MATRIX

Fuels Kakanj TPP	Symbol	% wt	% thermal
Kakanj brown coal	K	100	100
Spruce saw dust	S	100	100
Co-firing blend	K93S7	93/7	89/11
Co-firing blend	K80S20	80/20	72/28

Fuels Tuzla TPP	Symbol	% wt	% thermal
Dubrave/Šikulje lignite	L	D80:Š20	D81:Š19
Spruce saw dust	S	100	100
Co-firing blend	L93-S7	93/7	87/13
Co-firing blend	L80-S20	80/20	70/30

Bosnian coal types; lignite and brown coal



General coal characteristics

BOSNIAN LIGNITE

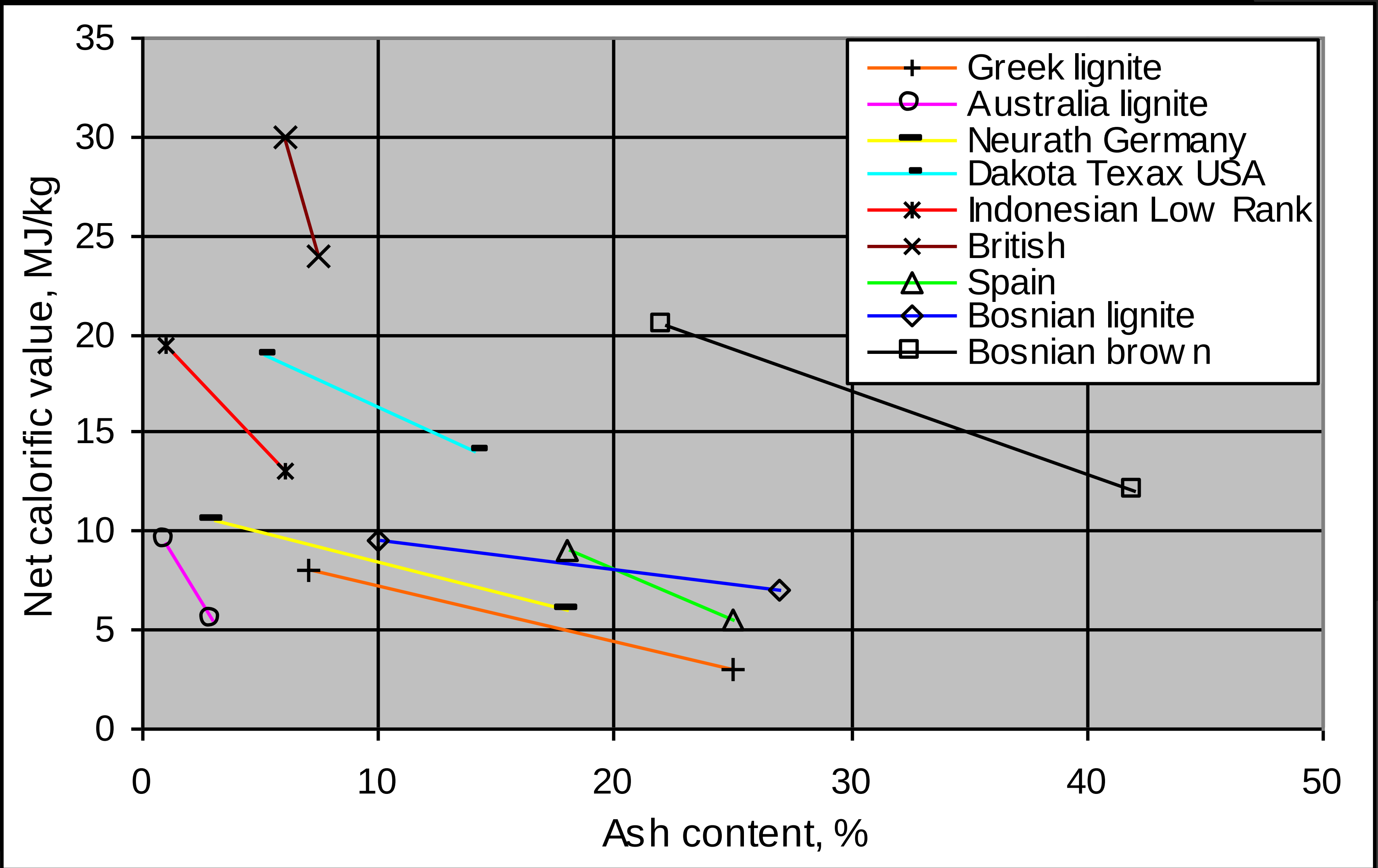
- Lower heating value:	**7 – 12 MJ/kg**
- Sulphur content:	**0.1 – 2.5 %**
- Ash content:	**10 - 30 %**
- CaO content in ash:	**4 – 35 %**

BOSNIAN BROWN COAL

- Lower heating value:	**12 – 21 MJ/kg**
- Sulphur content:	**2.0 – 5.0 %**
- Ash content:	**22 – 44 %**
- CaO content in ash:	**8 – 30 %**

Low rank coals!!

Net calorific value and ash content for some world low rank coal types



Characteristics of tested Fuels

Kakanj brown coal (K)

Hd = 12 657 kJ/kg , W = 11.3%, A = 42%, S = 2.2%

CaO = 12%, SiO_2 = 44%

Dubrave/Sikulje lignite (L)

Hd = 8 588 kJ/kg , W = 34%, A = 24%, S = 0.7%

CaO = 4.4%, SiO_2 = 50%

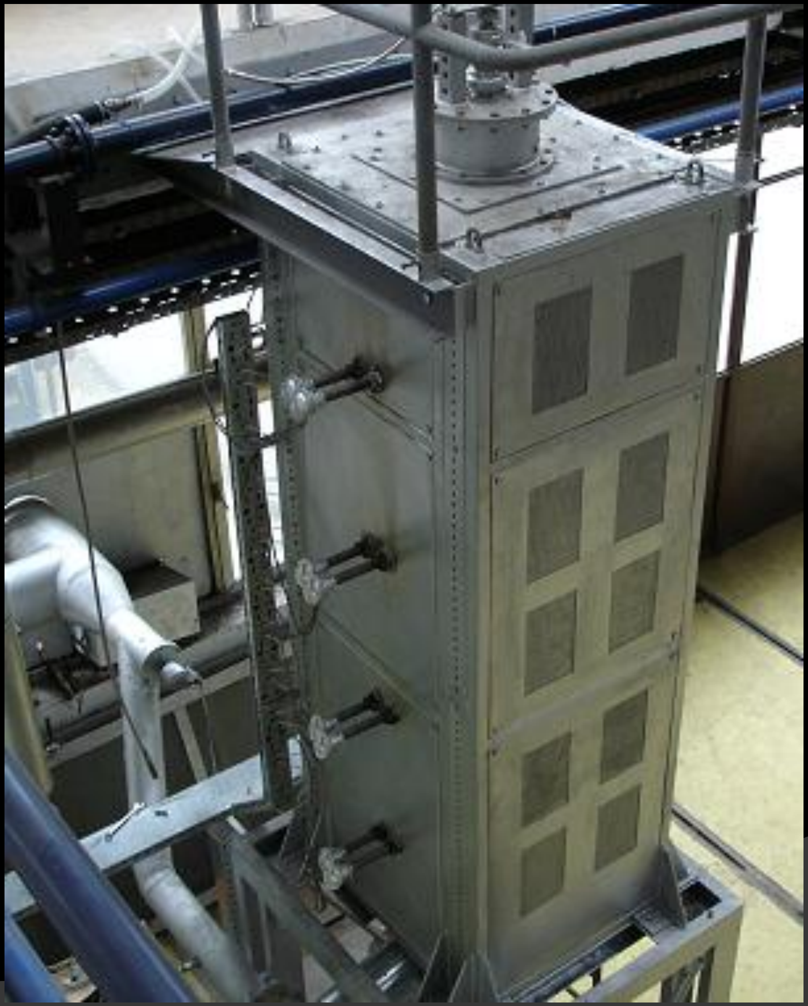
Wooden biomass Spruce (S)

Hd = 15 612 kJ/kg, W = 11.2%, A = 0.26%,

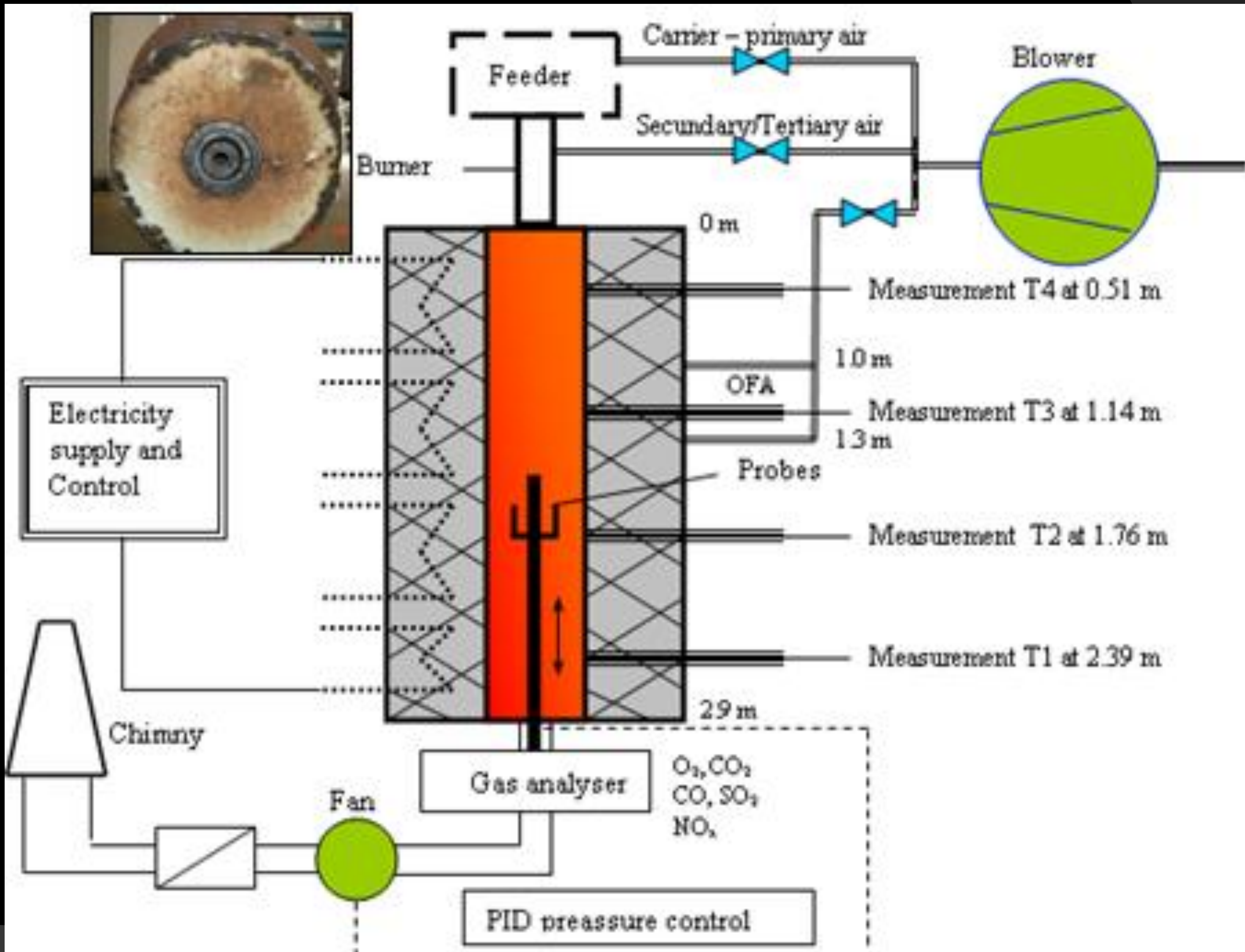
CaO = 14.6%, SiO_2 = 21.3%

Laboratory for combustion of coal and biomass at Faculty of Mechanical Engineering of Sarajevo University

20-kW PF entrained flow reactor

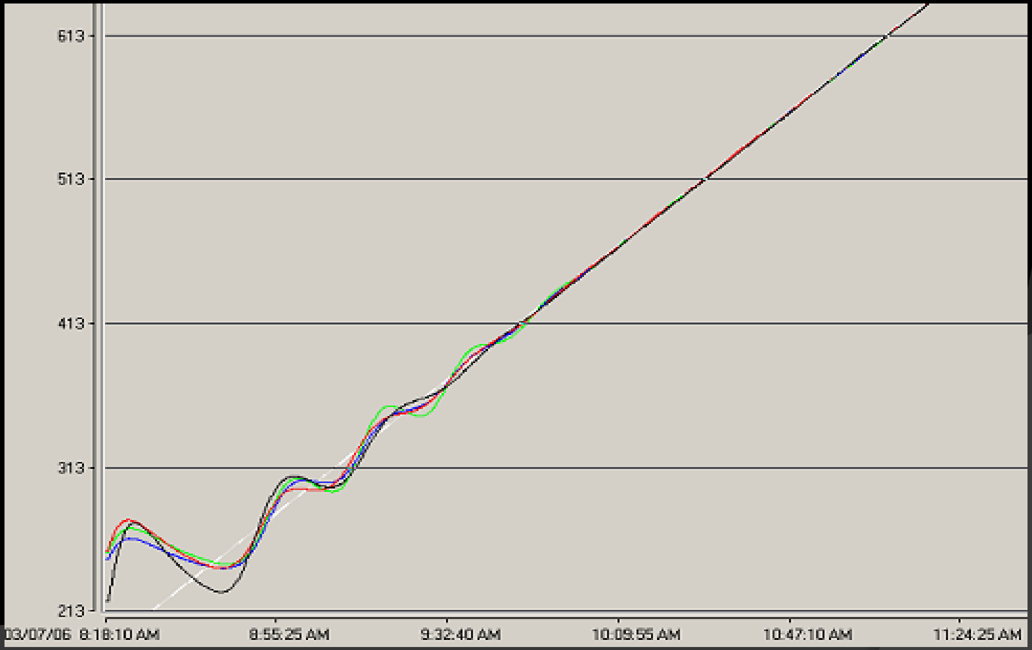


Scheme of the reactor



Electrical and control equipment

Temperature can be varied at desire from ambient till 1550 °C



70 kW electrical

Systems for air and fuel supply

Fuel mass flow 0.25 – 5.0 kg/h

20 kW thermal

Controlled air distribution, including adjusting primar / secundar and primar+secundar / OFA

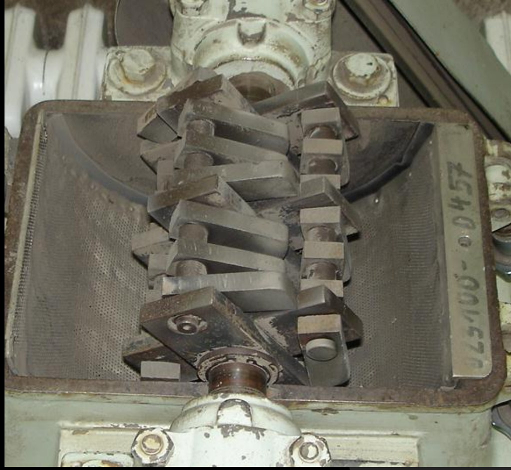
Air staging, Fuel staging

Ash Depozit and flue gas sampling

Collecting ash depozits
on ceramic probes
and water cooled lance

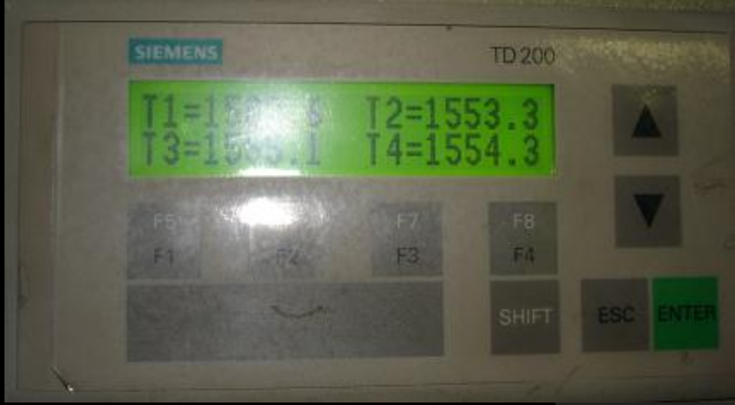
Emissions
measurement

Particle size distribution



	Rest	Total %	200 µm	100 µm	90 µm	80 µm	71 µm	63 µm	45 µm	Passed
1	K	100	18,2	28,0	-	17,4	-	-	-	36,4
2	**Spruce**	**100**	**67,5**	**-**	**-**	**26,7**	**2,0**	**1,0**	**1,2**	**1,6**
3	K93S7	100	21,1	-	-	34,2	4,7	22,3	3,0	14,7
4	K80S20	100	29,6	-	-	31,3	5,7	16,9	4,0	12,5
5	L93S7	100	49,5	-	-	25,5	3,7	12,5	2,0	6,8
6	L80S20	100	49,0	-	-	27,9	3,1	8,6	2,9	8,5

Co-firing test program



Variation of process temeprature, ℃

K	-		**1140 / 1250 / 1400 / 1550**
K93S7	-	**960**	**1140 / 1250 / 1400**
K80S20	-	**960**	**1140 / 1250 / 1400 / 1550**
DŠ	-	**880 / 960 / 1050 /**	**1140 / 1250**
DŠ93S7	-	**960**	**1140 / 1250**
DŠ80S20	-	**960**	**1140 / 1250**

Variation of excess air ratio

λ = 0.9 / 1.0 / 1.1 / 1.2 / 1.3 / 1.4

Combustion behaviours investigated

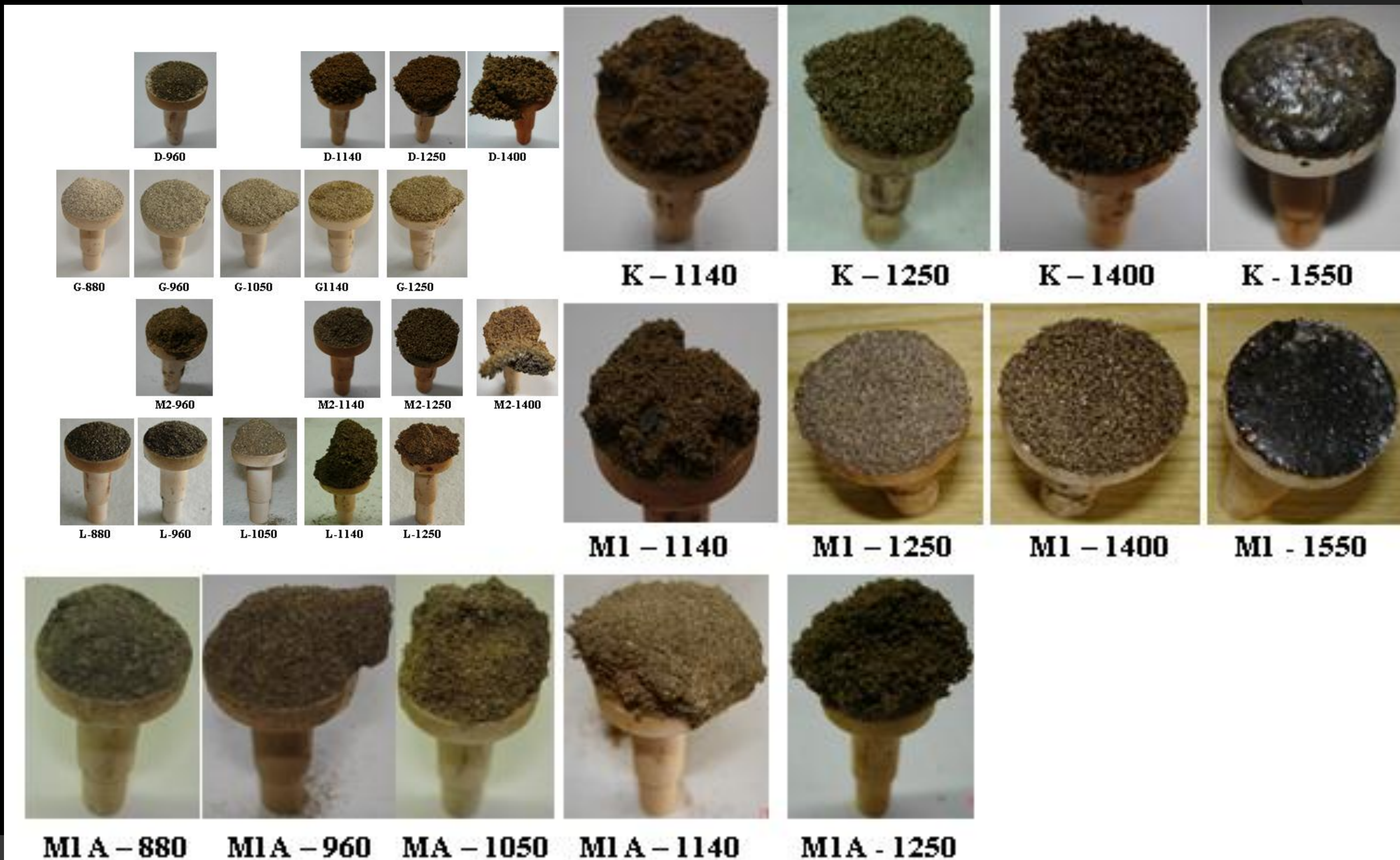
- Slagging and fouling
- Emissions
- Combustion efficiency

Slagging/fouling analysis

Criteria used for evaluation of ash depozit:

Criteria No	Description
1	SHAPE OF DEPOZIT
2	MELTING STATE OF DEPOZIT
3	STRUCTURE OF DEPOZIT
4	ADHESION OF DEPOZIT
5	COHESION OF DEPOZIT
6	DEPOZITION INTENSITY
+	ASH DEPOZIT CHEMICAL COMPOZITION

CRITERIA 1. Shape of depozit, CRITERIA 2. Melting state of depozit, by Visual observation, photograficaly



CRITERIA 3. Structure of depozit, by Optical observation of ash deposits

“5 multiply” enlargement

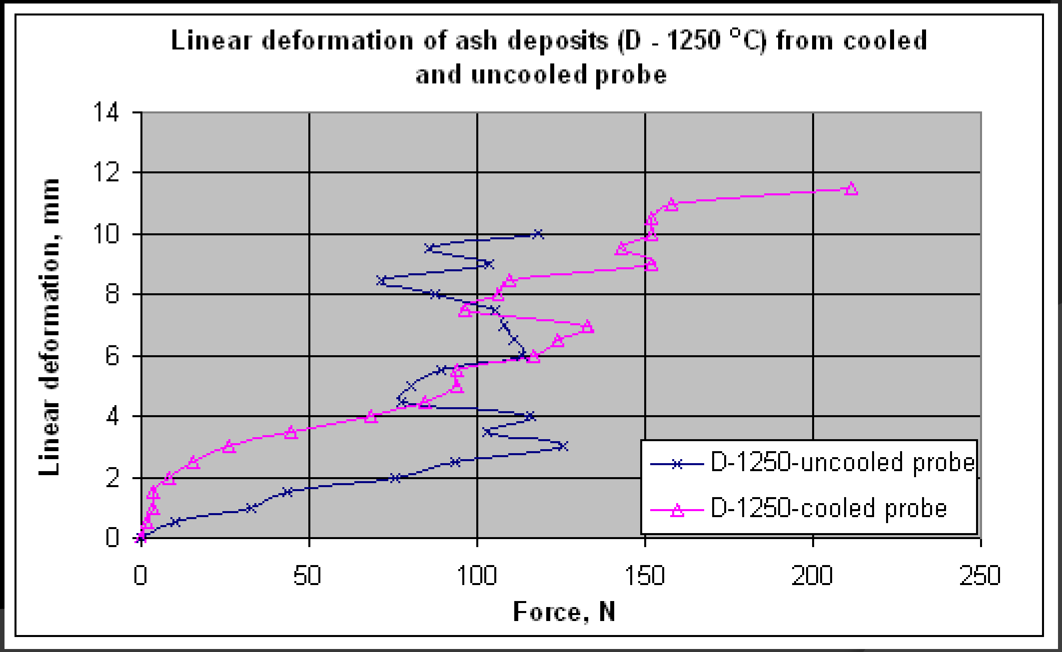
M1A – 1250 ºC - slag sample

“100 multiply” enlargement

M1A – 1250 ºC - ash deposit sample

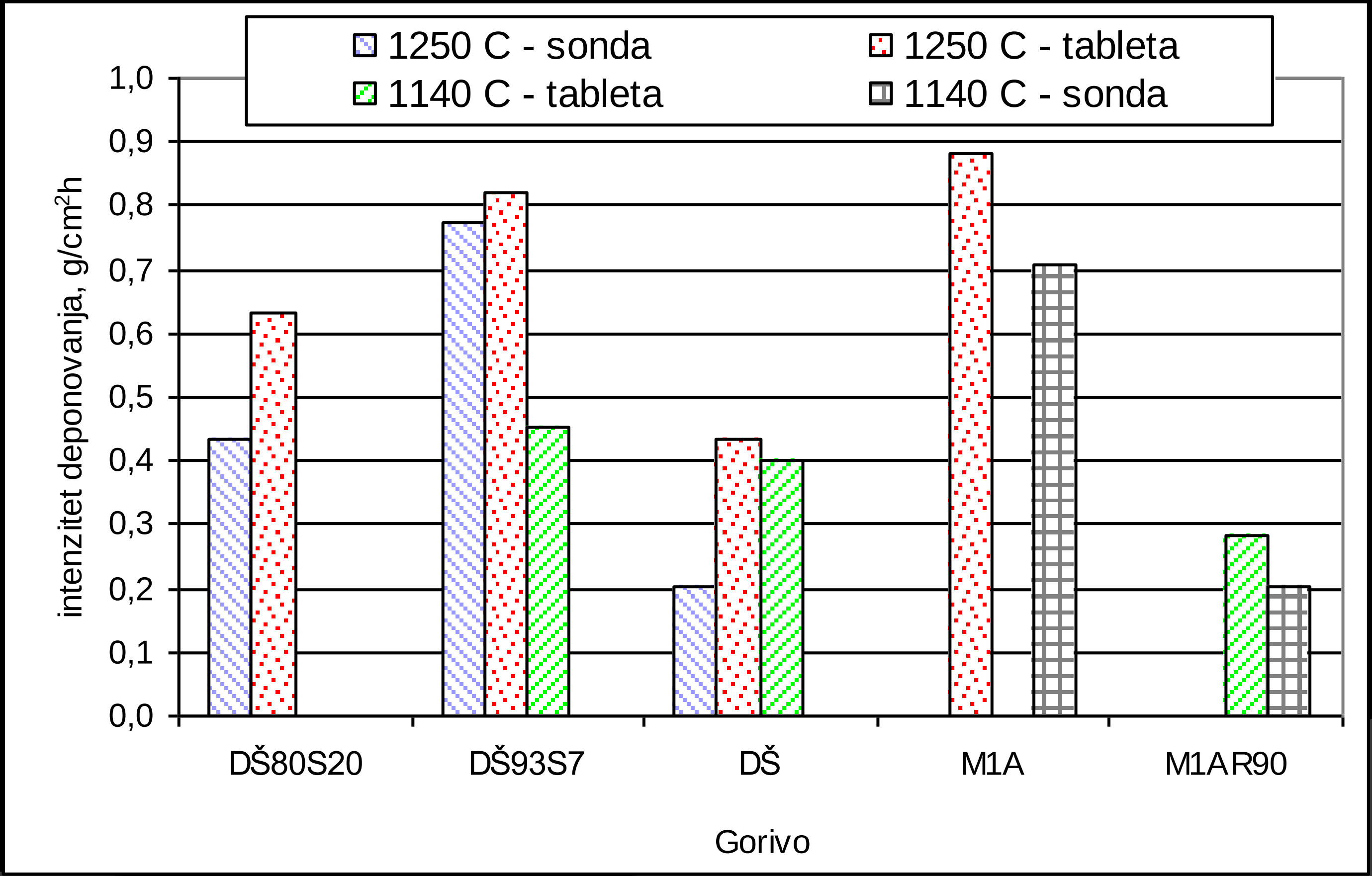
CRITERIA 4. Test of adhesion

CRITERIA 5. Test of cohezion



CRITERIA 6. Depozition Rate [Id]

$$Ir = [g / (cm^2 \times h)]$$

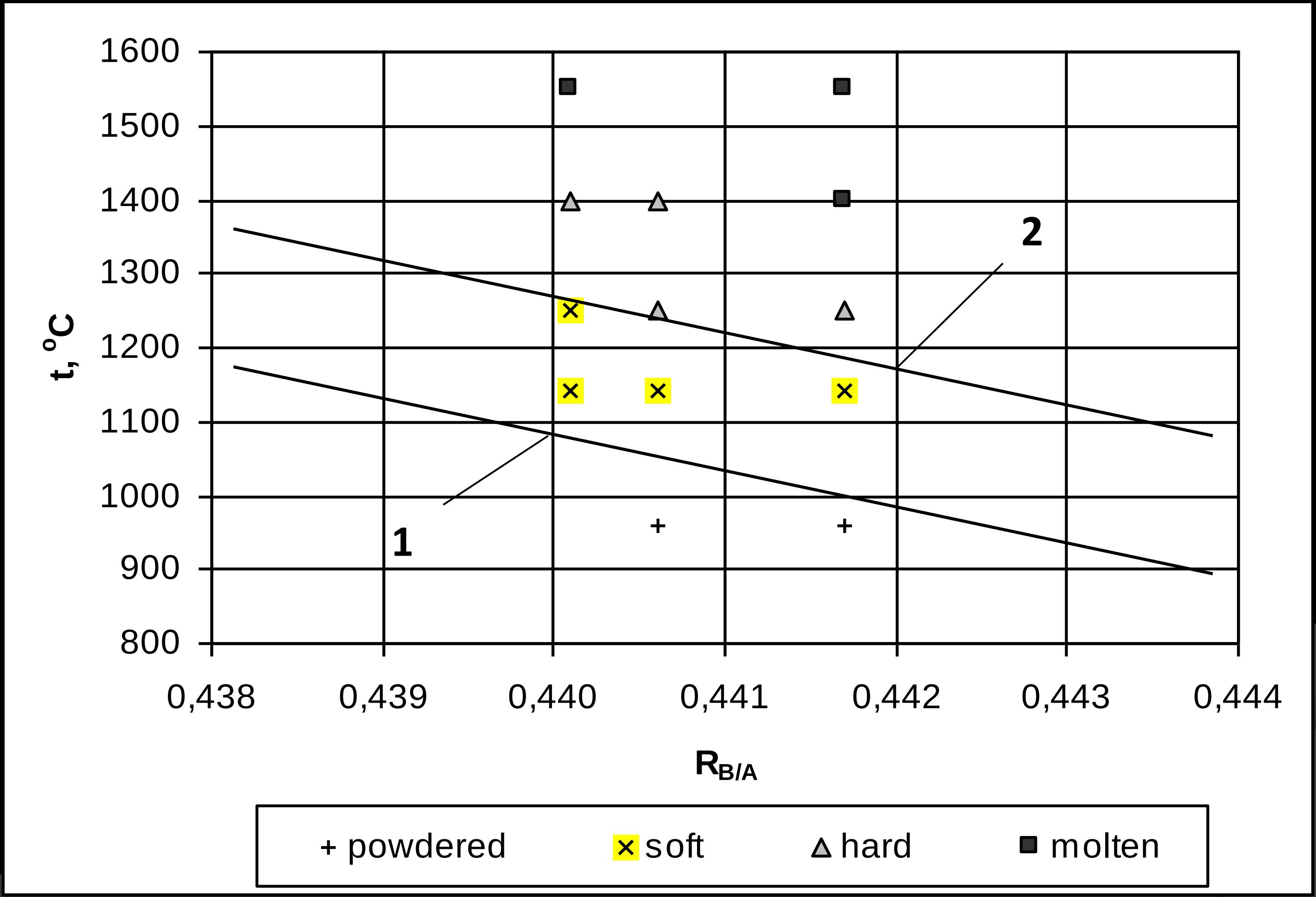


Principle of aggregation of single criteria evaluations

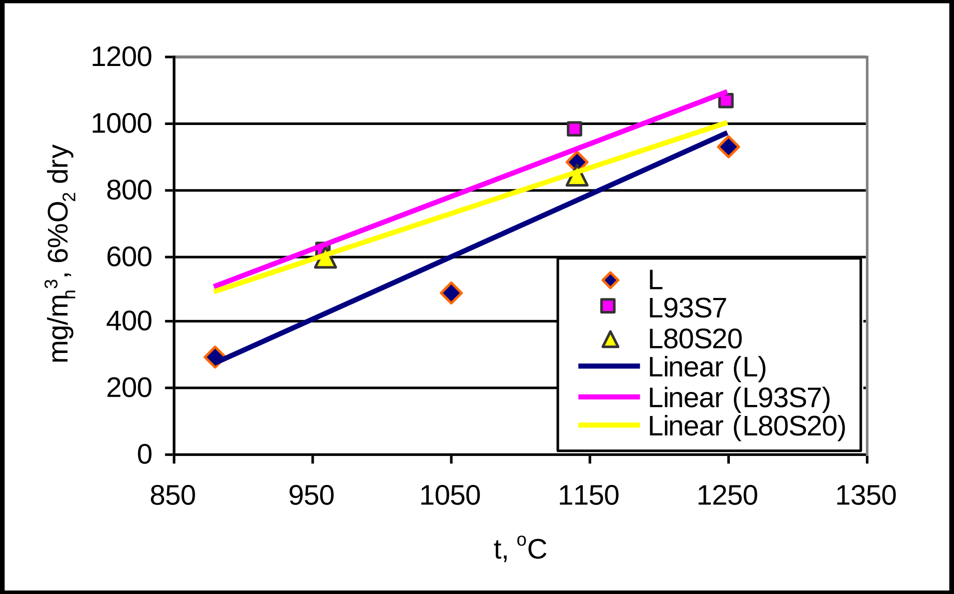
Final evaluation	*LOW*	*MODERATE*	*STRONG*	*VERY STRONG*
Zone	*A*	*B*	*C*	*C*
Prevailing gradation	i	ii	iii	iv, v
Criteria 1 *Shape*	Pyramid (i) Cone (ii)	Cone (ii) Truncated cone (iii)	Truncated cone (iii) Flat (iv)	Flat (iv)
Criteria 2 *Melting state*	Dry (i)	Start of melting (ii)	Melted (iii)	Molten (iv)
Criteria 3 *Structure*	Powder (i)	Particles (ii)	Particles (ii) Fibres (iii)	-
Criteria 4 *Adhesion*	Low (i)	Moderate (ii)	Moderate (ii) Strong (iii)	Very strong (iv)
Criteria 5 *Cohesion*	Low (i)	Moderate (ii)	Moderate (ii) Strong (iii)	Very strong (iv)
Criteria 6 *Deposition intensity*	Low (i)	Moderate (ii)	Moderate (ii) High (iii)	High (iii) Very high (iv)

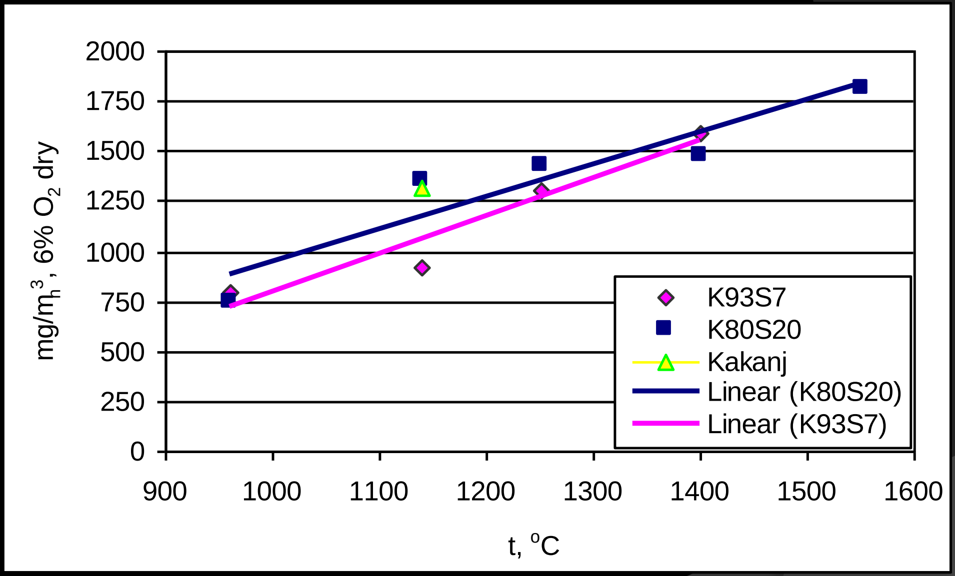
Correlation between base-acid ratio and gas temperature for the Kakanj coal-spruce sawdust co-firing

below line 1: low slagging/fouling, above line 2: strong slagging/fouling, between line 1 and line 2: moderate slagging/fouling



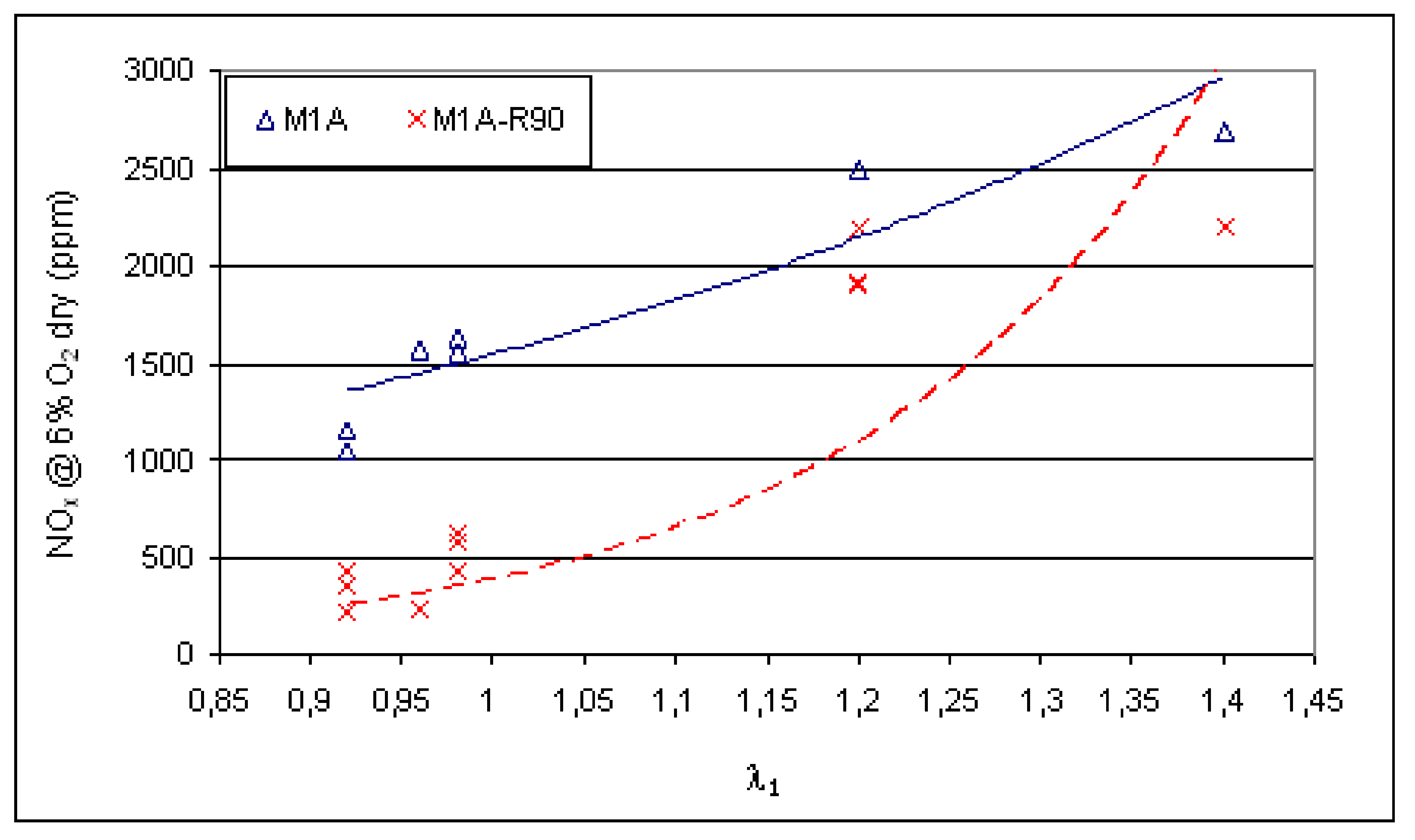
NO_x emissions in co-firing tests



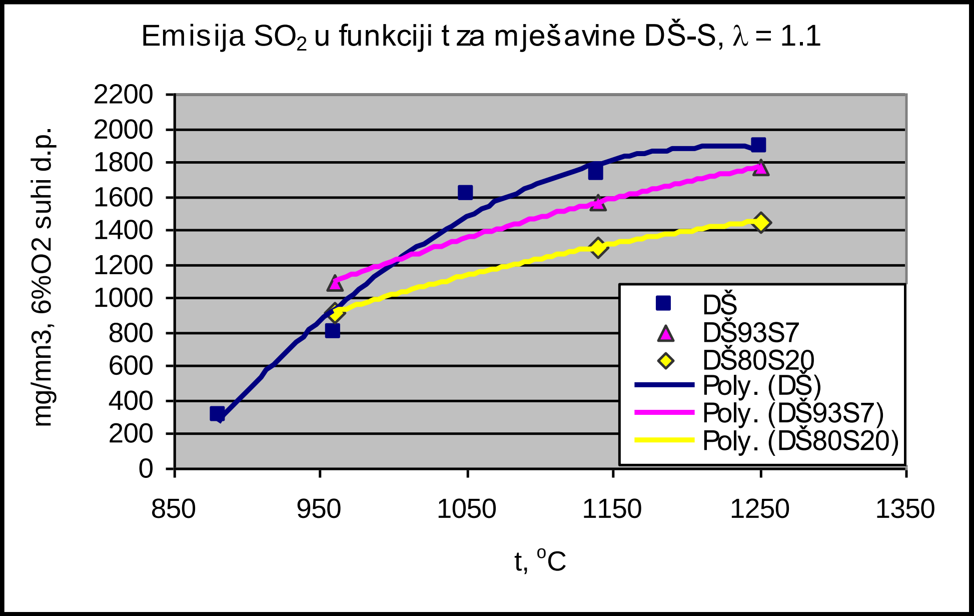


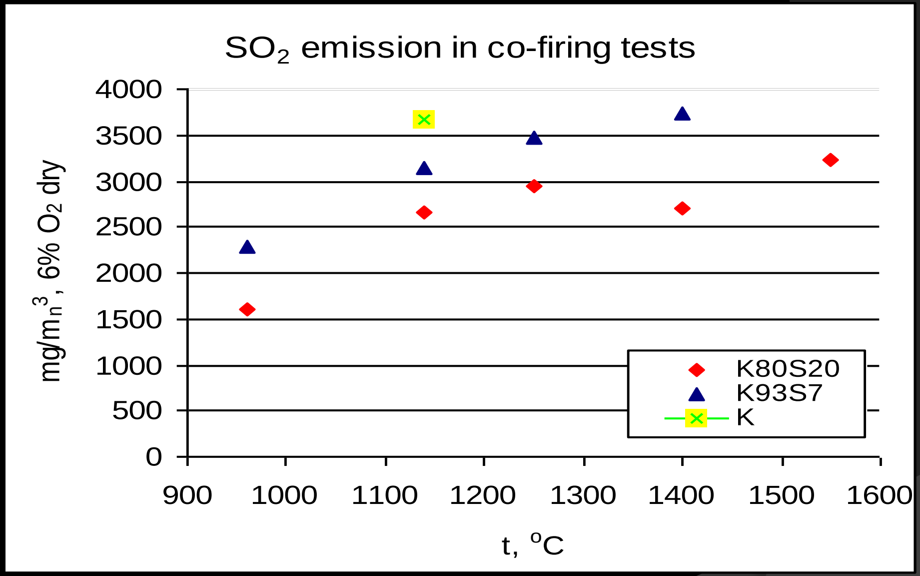
There was no clear relation noteced between the share of woody biomass in the fuel mixture and NOx emissions!!

Investigation of NO_x emissions in air staging combustion



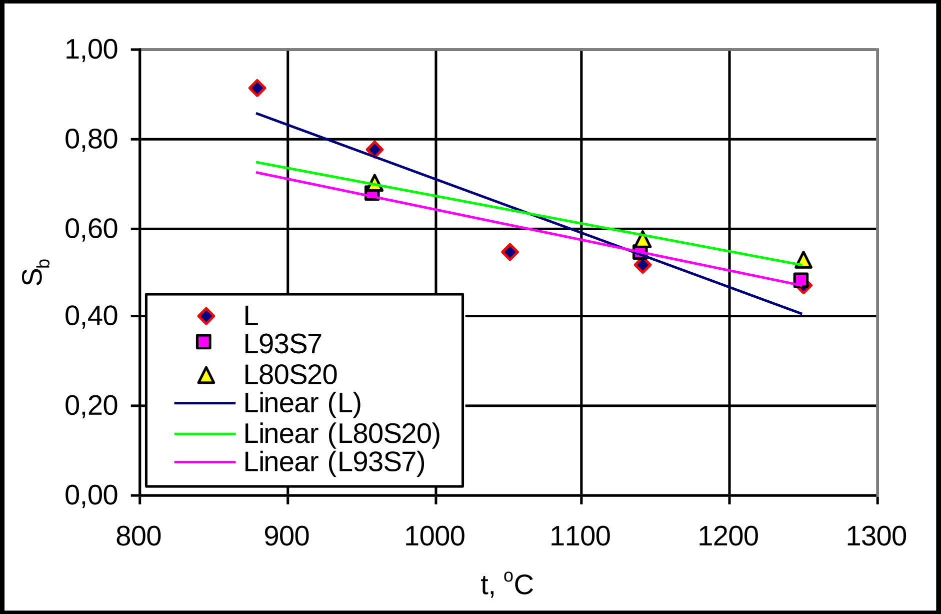
SO_2 emissions in co-firing tests

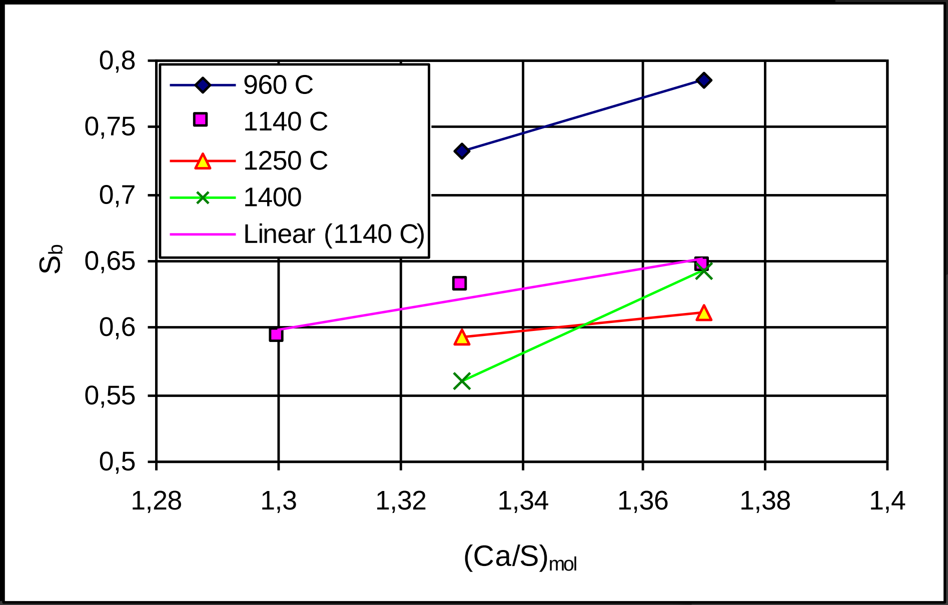




Reduction of SO2 emissions (even till 25% for the fuel mixture with 20%wt of wooden biomass) was recorded in all cofiring tests compared with the tests with coal aloen!

Sulphur capture rate





Recomendation from Experimental

- Blend of the coal with 7% of woody biomass could be used in Large Boiler of existing TPP Kakanj and TPP Tuzla with no any unusual operational problem related to regular operation of the main or auxilary equipment, slagging/fouling problem, or stability of combustion proscess, i.e. with no reasonable risk to regular operation.

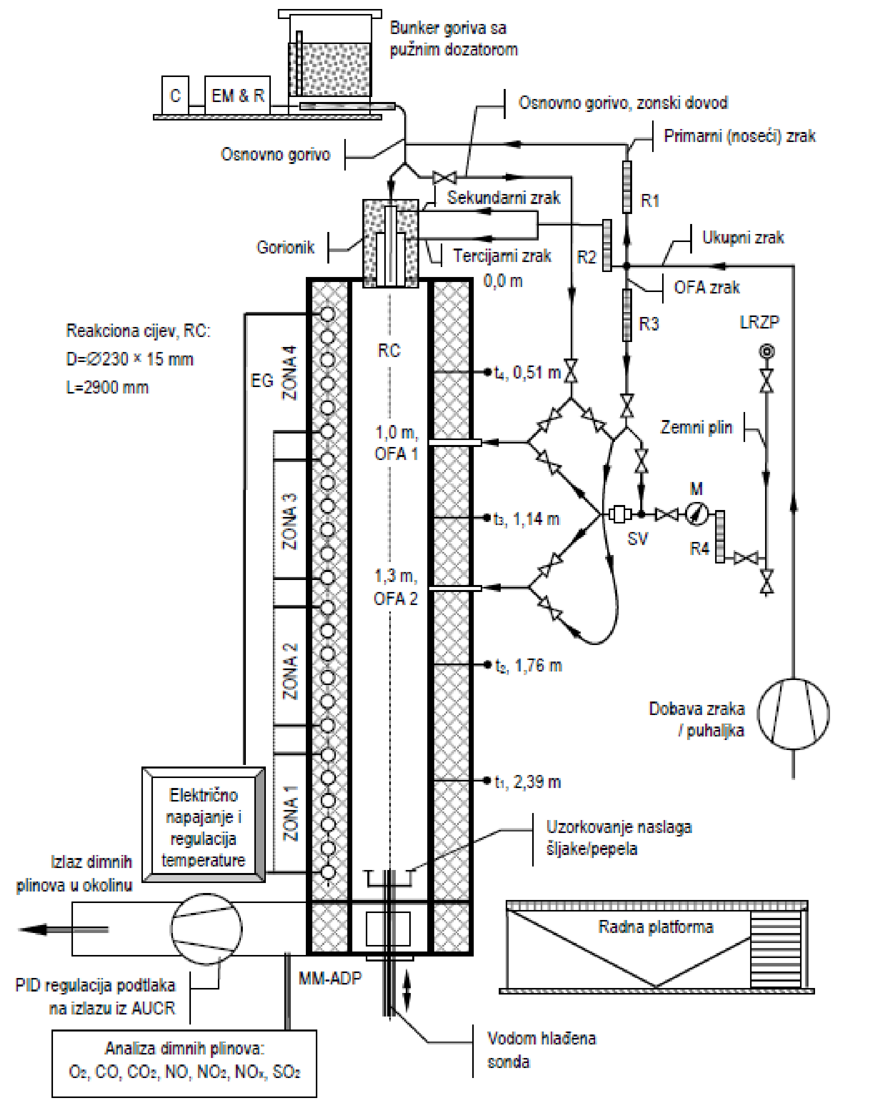
- However, this must be checked and finally proven in praxis in a trial run on a real large utility of Kakanj TPP and Tuzla TPP.

4. CO-FIRING TESTS OF COAL WITH WOODY BIOMASS AND NATURAL GAS - EXPERIMENTAL

COAL (U)-WOODY BIOMASS (B)-NATURAL GAS (P) --- COFIRING TEST MATRIX

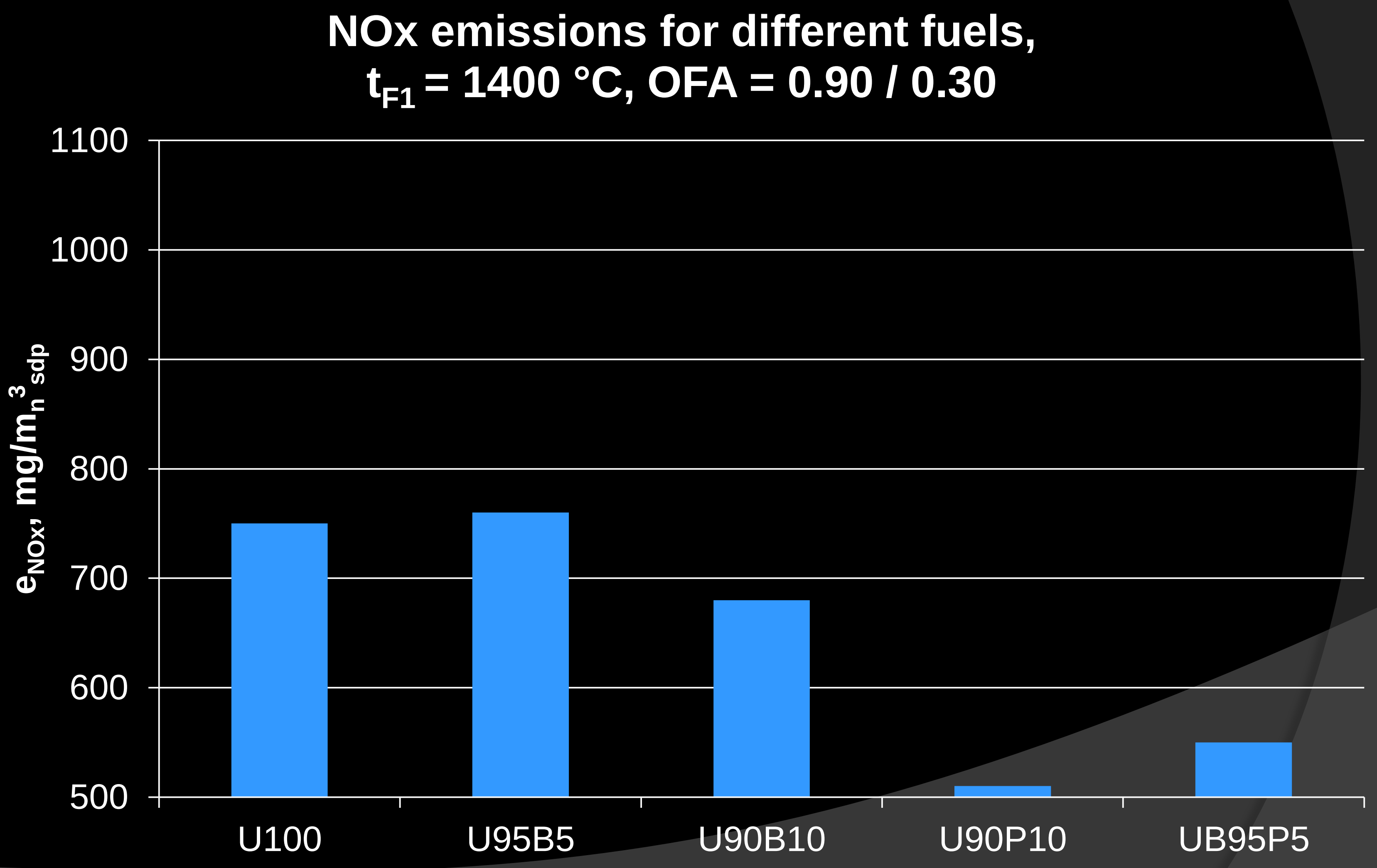
	Fuel	Fuel type	Symbol	% Weight	% Thermal
1	Coal with Natural gas (Reburning!)	Co-fuel	U95P5		95:5
2	Coal with Natural gas (Reburning!)	Co-fuel	U90P10		90:10
3	Coal with Biomass and Natural gas (Reburning!)	Co-fuel	UB95P5		95:5
4	Coal with Biomass and Natural gas (Reburning)	Co-fuel	UB90P10		90:10

Scheme of the reactor with gas supply system



Slika 1. Principijelna šema eksperimentalnog postrojenja AUCR; Oznake: C – kontroler opterećenja dozatora goriva, EM & R – elektromotor i reduktor broja obrtaja, RC – reakciona cijev, R_i – rotametri za mjerenje protoka pojedinačnih struja zraka i zemnog plina, EG – SiC električni grijači poredani u četiri zone/nivoa, LRZP – laboratorijski razvod zemnog plina, SV – sigurnosni ventil sa ugrađenim hvatačem plamena, M – manometar, MM-ADP – mjerno mjesto / analiza dimnih plinova.

NOx emissions during cofiring of coal and woody biomass with natural gas



Conclusions on Emissions of NO_x in cofiring campaignes with natural gas

- Slight increase of NOx emissions recorded with increase of process temperature from1350 till 1450 °C.
- Slight decrease of NOx emissions with an increase of share of bioamss – but not in all campaignes!
- Use of OFA have reduced NOx emissions in all campaignes.
- Lower NOx emissions when upper OFA is used (OFA 1 - closer to the burner zone of the reactor).
- With use both OFA, NOx emissions equel to the NOx emissions when only OFA 2 is used.
- Significant reduction of NOx emissions recorded in cofiring campaignes “reburning with natural gas” (till 35% lower NOx emissions compared to the case coal alone).

5. Business Plan

Introducing of cofiring coal with woody biomass into regular operation of Kakanj TPP Unit 5 (110 MWe)

Switching 7%w of brown coal by woody biomass, based on optimization in laboratory and recommandation of limitation to 7%w to maintain net efficiency of the unit, avoid slagging and fouling problems and avoid woody biomass transportation problems.

ENVIRONMENTAL INDICATORS

Expected reduction of Emissions

tones/a	CO_2	NO_X	SO_2
Existing emissions (Coal only)	**689 500**	**2 011**	**20 478**
Emissions for Cofiring (7%w)	**646 796**	**1 910**	**18 430**
Total emissions reduction	**42 704**	**101**	**2 048**

Transport woody biomass into Boiler

Option 1: Preparing of woody biomass and blending with coal on the coal depot, combustion of PF coal-biomass blend on coal burners.
- Investment estimation for a 110 MWe unit: **250 000 EUR**

Otion 2: Introducing of biomass in the boiler through the biomass transport ducts – combustion of biomass on the rost.
- Investment estimation for a 110 MWe unit: **1.450.000 EUR**

Option 3: Gasification of biomass into gassifyer – combustion of biogas in boiler furnace above OFA pozition – *Fuel Staging*
-Investment estimation for a 110 MWe unit: above **2.000.000 EUR**, and is strongly depended on gassifyer thermal power

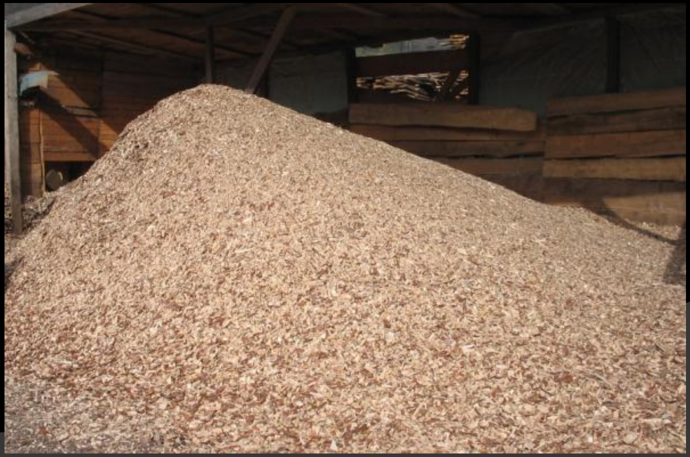
-Option 1 was choosen!

TOTAL PROJECT COSTS FOR OPTION 1

Activity	Total	
Design and Planning	170 000	€
Project Management	70 000	€
Process measurements (incl. meas. equipm)	160 000	€
Civil works on the site (arrangement of the depot and storing area, base, fencing…)	250.000	€
Mechanical equipment of cut machines (vibration plate, metal detector, cutter,…)	300.000	€
Electrical equipment of cut machines, protections and I&C	200.000	€
Installation	190 000	€
Contingencies	120 000	€
Total investment	**1 460 000**	€

Prices in 2008 (2011)

- Coal = 31 (35) €/ton
- Woody biomass = 16 (2x > ?) €/ton
- Electricity = 40 (42) €/MWh
- CER = 15 (<10) €/t CO_2



ECONOMIC INDICATORS
Expected annual net savings

Saving elements	Present situation		After new measure		Savings	
Prices 2008!	Amount	€/year	Amount	€/year	Amount	€/year
Fuel - *coal, t*	518 991	16 213 461	486 847	15 209 265	32 144	1 004 196
Fuel - *wooden biomass, t*	0	0	36 644	586 436	- 36 644	- 586 436
CER (CDM)						640 560
Own electricity consumption of cut machines, kWh)	0	0	1 661 000	66 447	- 1 661 000	- 66 447
Operation/Maintenance		1 100 000		1 177 553		- 77 553
Other	-	-	-	-	-	-
Total annual net savings						273 760

6. Trial run in Large utility: Kakanj TPP Unit 5 (110 MWe)

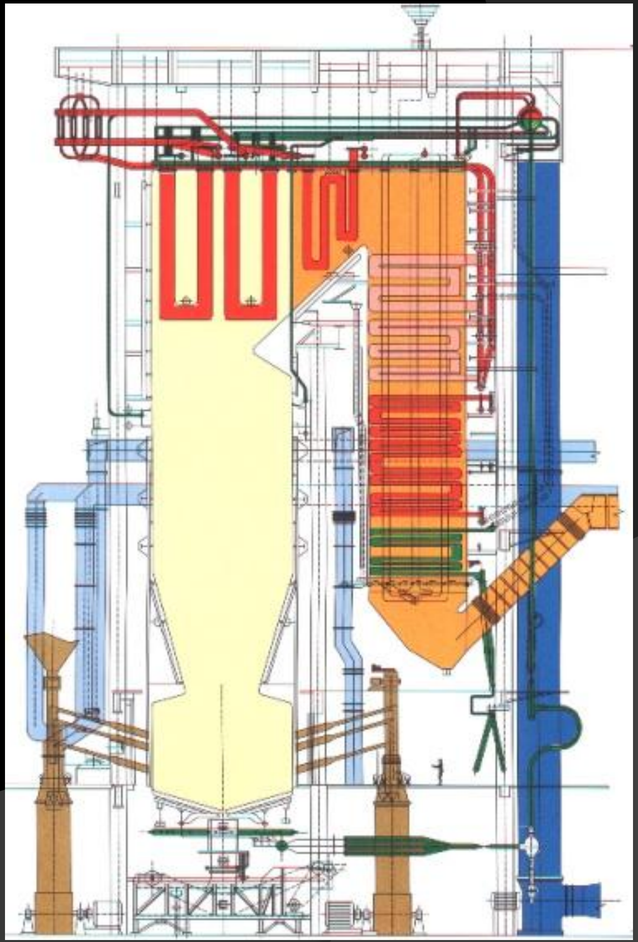
Program, realization, results

TPP Kakanj unit 5 (110 MWe)

- Cogeneration unit (electricity + heat for district heating)
- PF Boiler with slag tap furnace
- 12 Low NOx swirl coal burners

placed in two rows

- 6 Hammer mils
- OFA system (placed in two rows)
- Hybrid dust filter (<10 mg/mn3)
- 91% Boiler efficiency
- 34% net efficiency of the unit



Programme of the Trial Run

FUEL CAMPAIGN:

- 1. Campaign (6 days): Coal 100%w (U100) - Referent case (Baseline scenario)
- 2. Campaign (3 days): Coal 93%w / Biomass 7%w (U93-B7)
- 3. Campaign (3 days): Coal 95%w / Biomass 5%w (U95-B5)

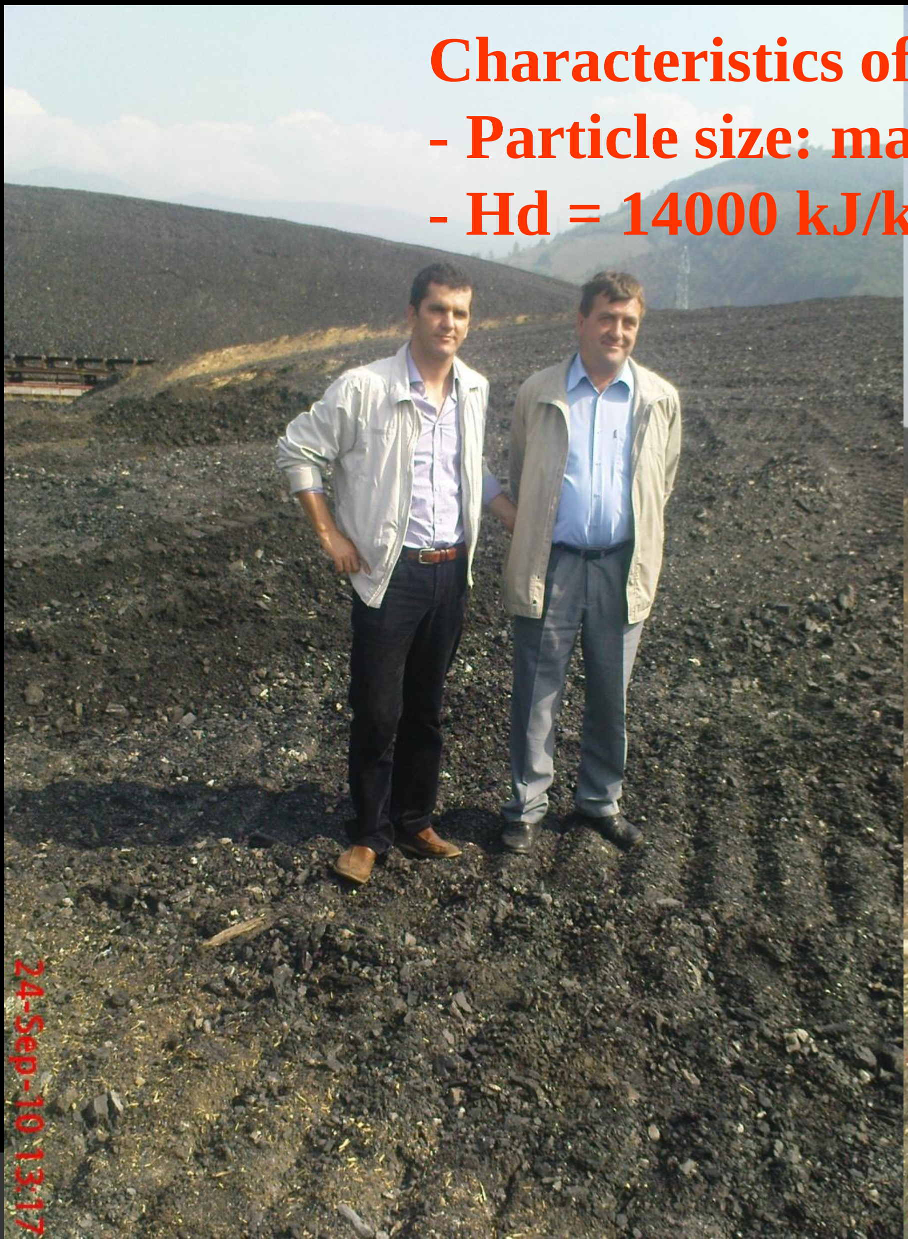
OPERATION, MEASUREMENTS AND ANALYSES:

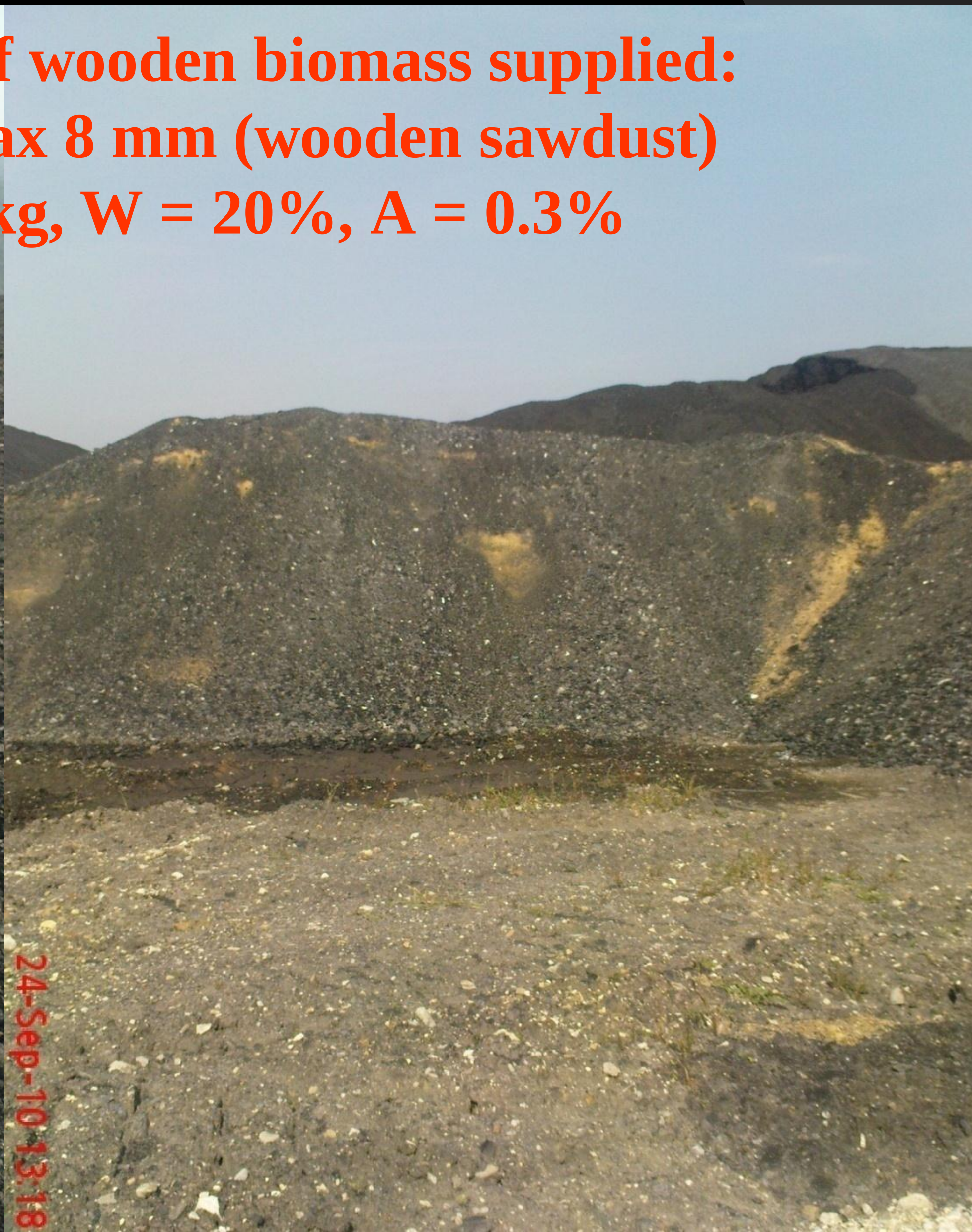
- Varying thermal load (Power) of the Unit: 100% (110 MW), 80% (85 MW) and 60% (70 MW) during the Trial run Operation.
- Measurements all important parameters on the unit during Operation, checking and monitoring the boiler equipment.
- 4 stopage of the unit: before, between and after the campagnes, to complete all necessary visual inspections, sampling, analyses and mneasurements.
- Chemical analyses of the fuels, slag and ash samples

Coal and woody biomass mixed and homogenized on coal depot: 11807 t of coal + 890 t (4340 m^3) of wooden sawdust

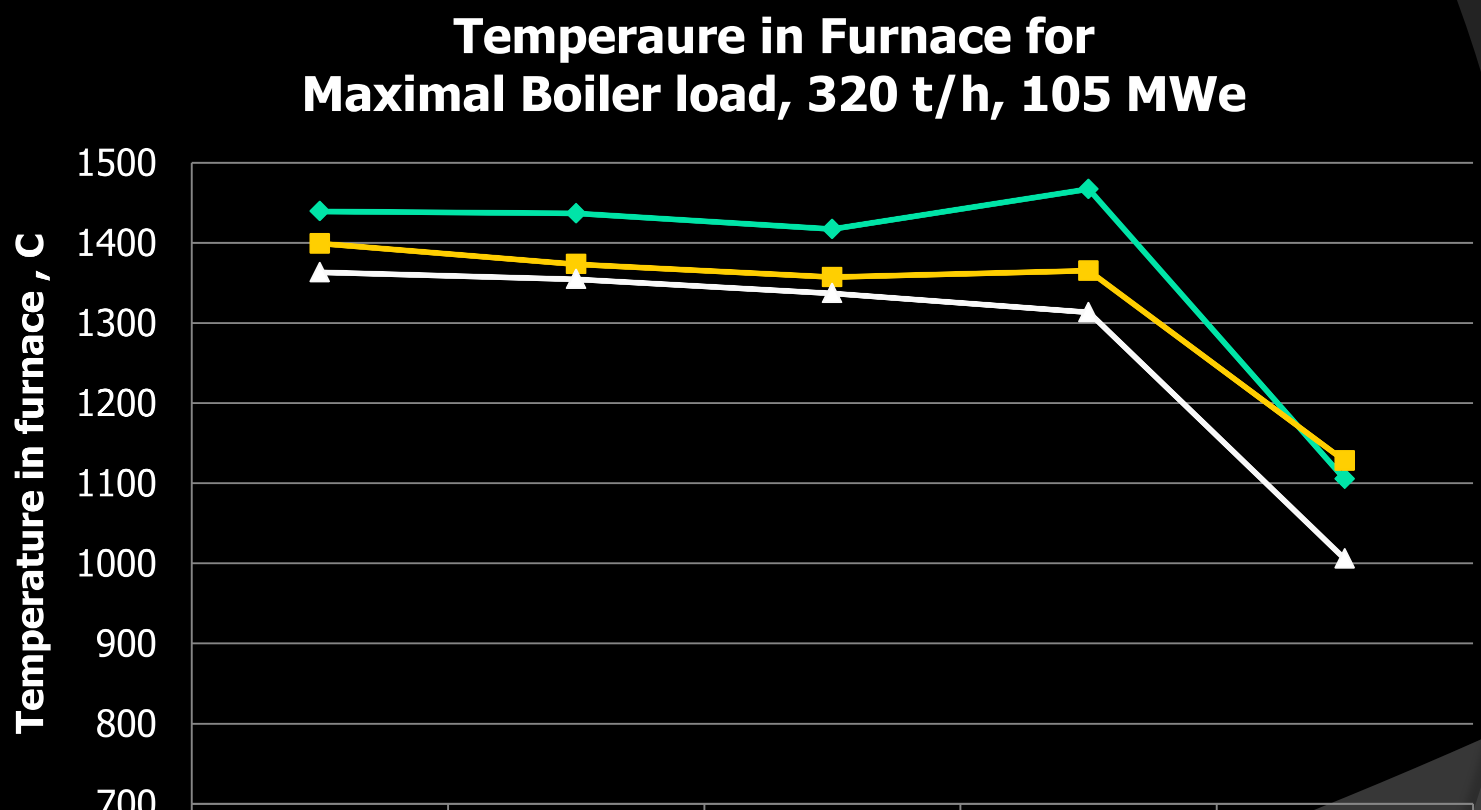
Characteristics of wooden biomass supplied:

- Particle size: max 8 mm (wooden sawdust)
- Hd = 14000 kJ/kg, W = 20%, A = 0.3%



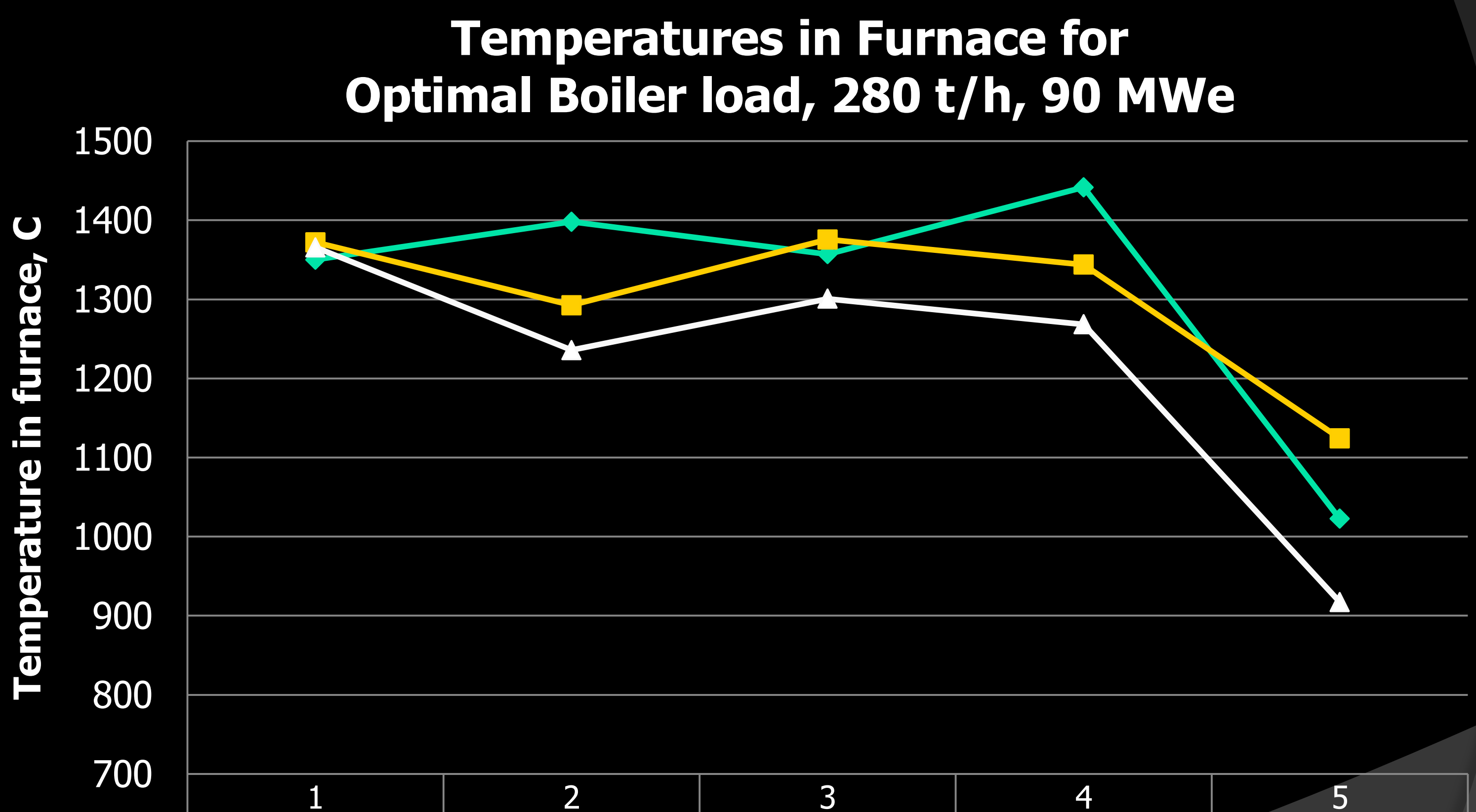


Furnace temperatures for Max. load



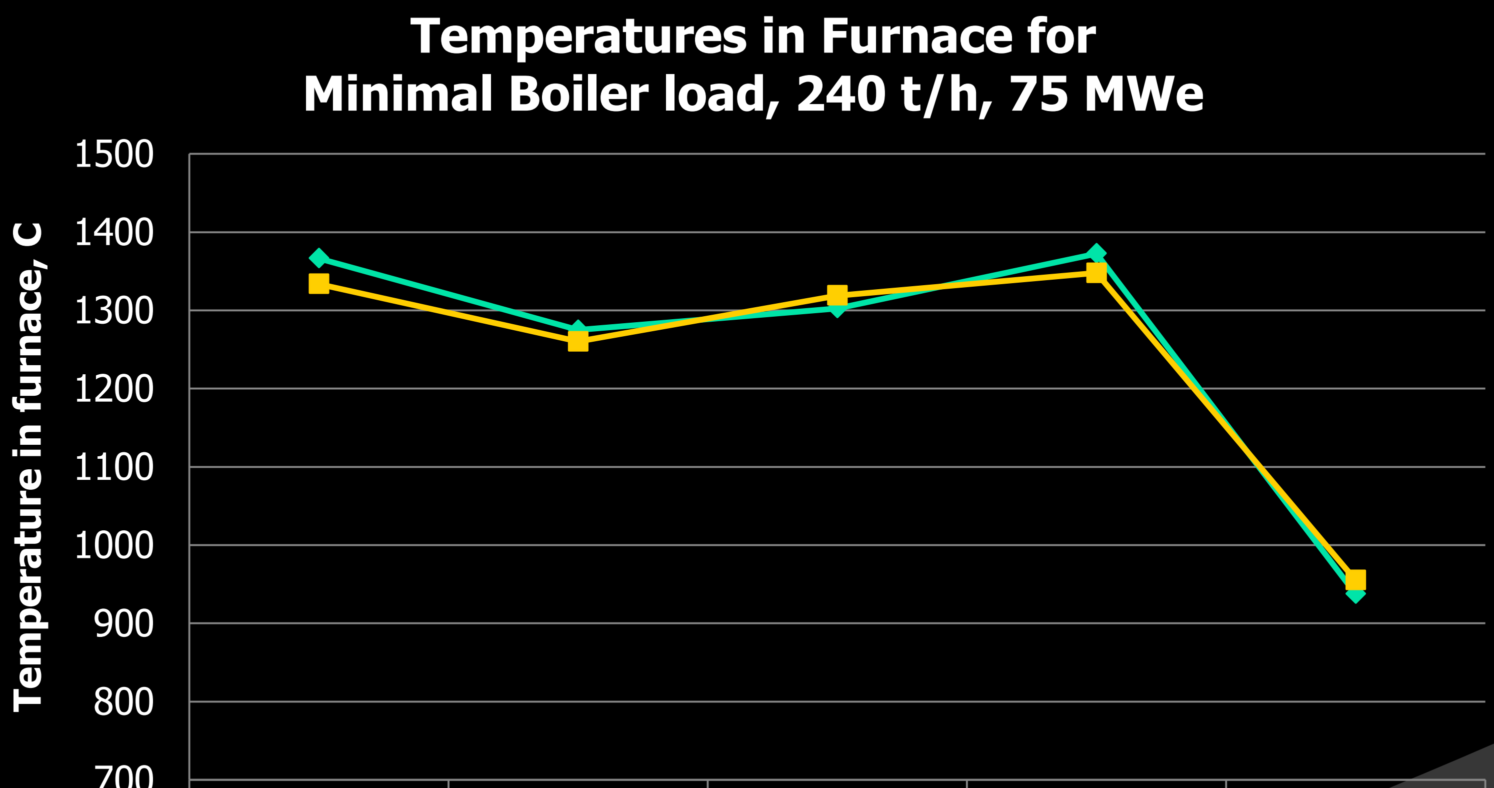
	1	2	3	4	5
U 100	1439	1437	1417	1467	1105
U93 B7	1399	1373	1357	1365	1128
U95 B5	1363	1355	1337	1313	1006

Furnace temperatures for Opt. load



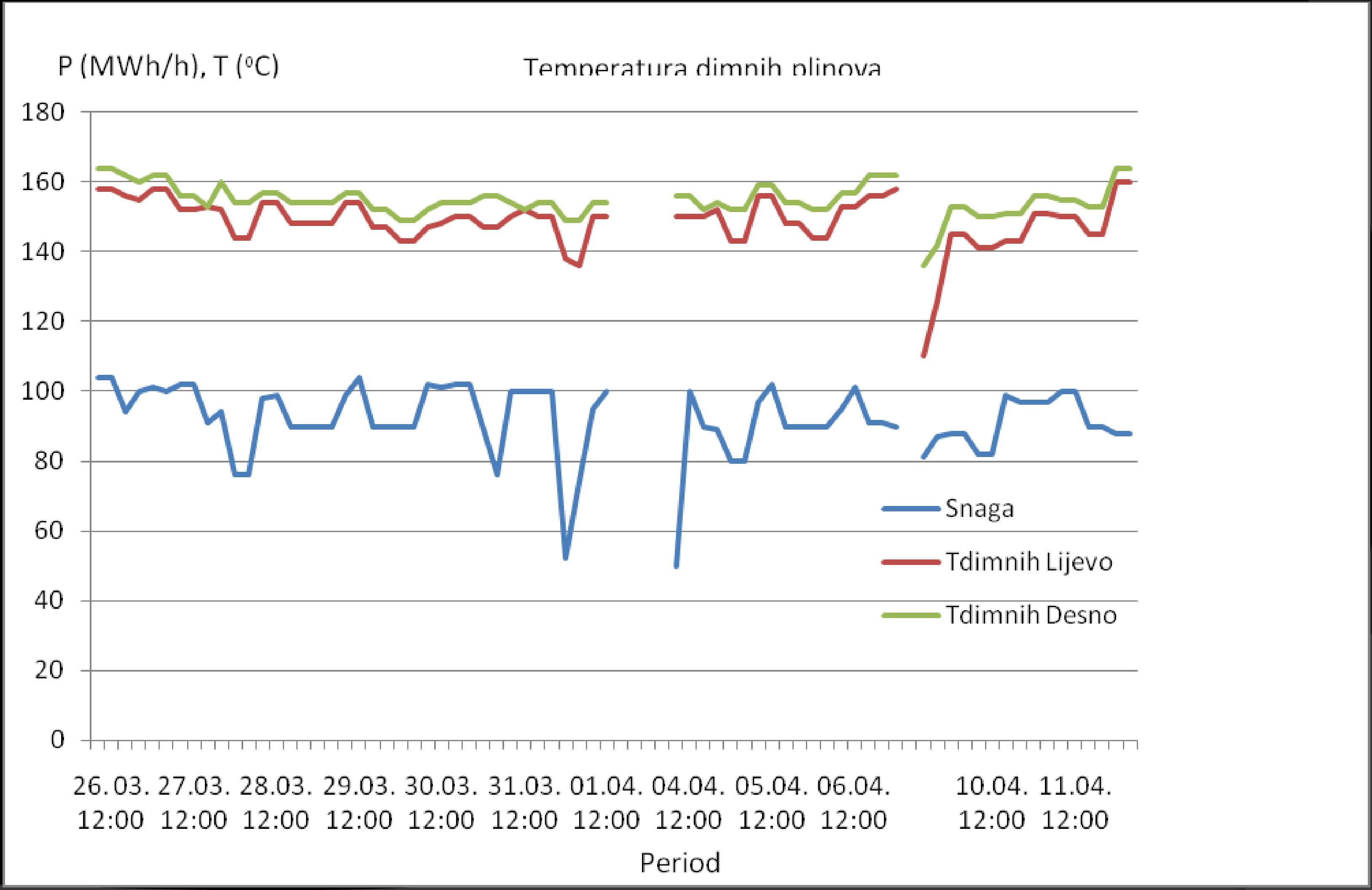
	1	2	3	4	5
U100	1350	1398	1357	1442	1023
U93 B7	1372	1292	1376	1344	1124
U95 B5	1366	1236	1301	1268	917

Furnace temperatures for Min. load



	1	2	3	4	5
U100	1366	1275	1303	1372	937
U93 B7	1334	1260	1319	1348	955
U95 B5	0	0	0	0	0

Boiler outlet Flue gas temperature during Trial run



Taking the ash depozits from Furnace outlet heating surfaces after campaign “Coal alone”

Furnace outlet after campaign “Coal 93% - woody biomas 7%w” – clean heating surfaces!

Comparison of ash depozits for three fuel campaigns: depozit taken from SH2A superheater placed at furnace outlet

U100

U95-B5

U93-B7

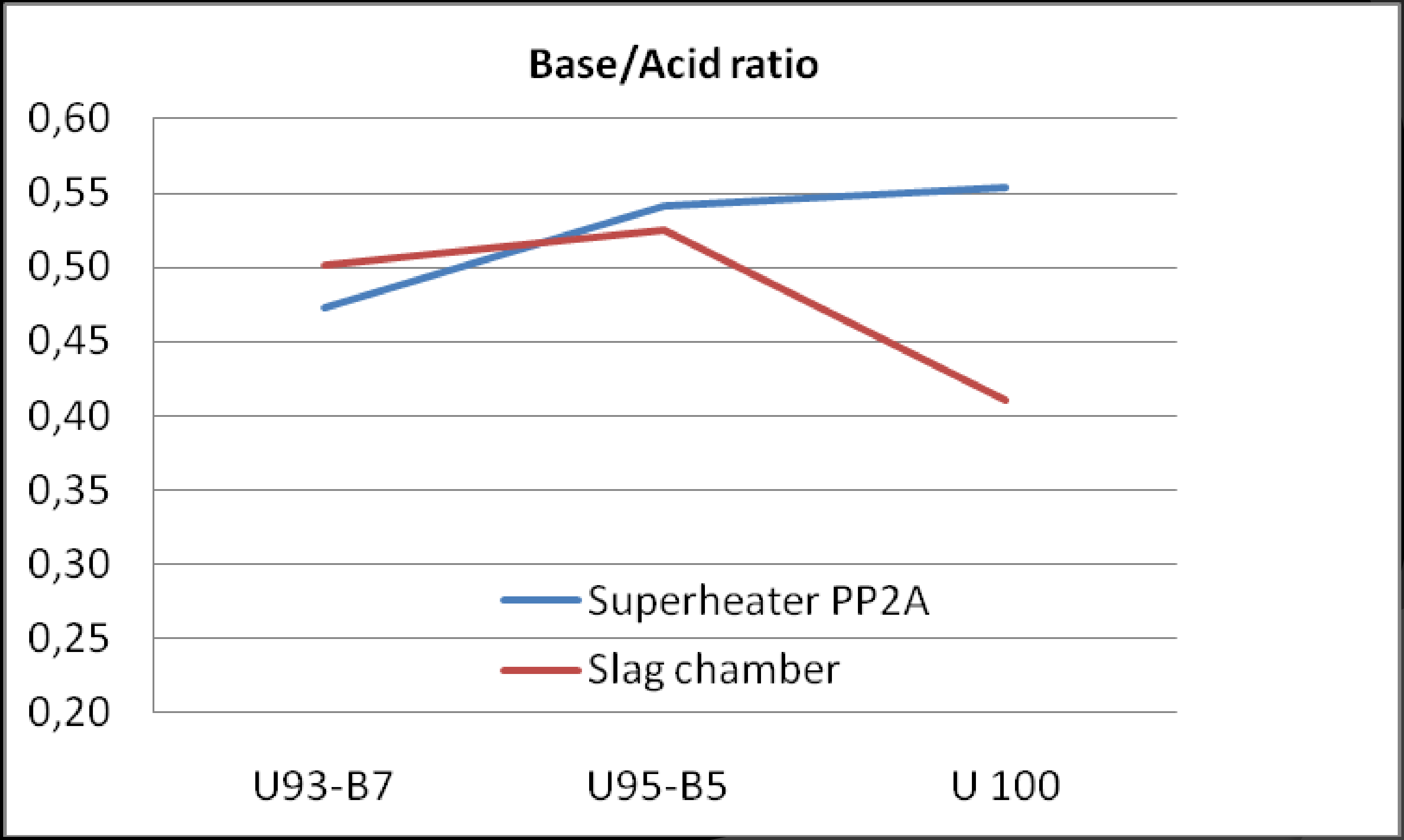
Comparison of ash depozits for three fuel campaigns: depozit taken from cartain SH2 superheater placed in boiler cross draft

U100

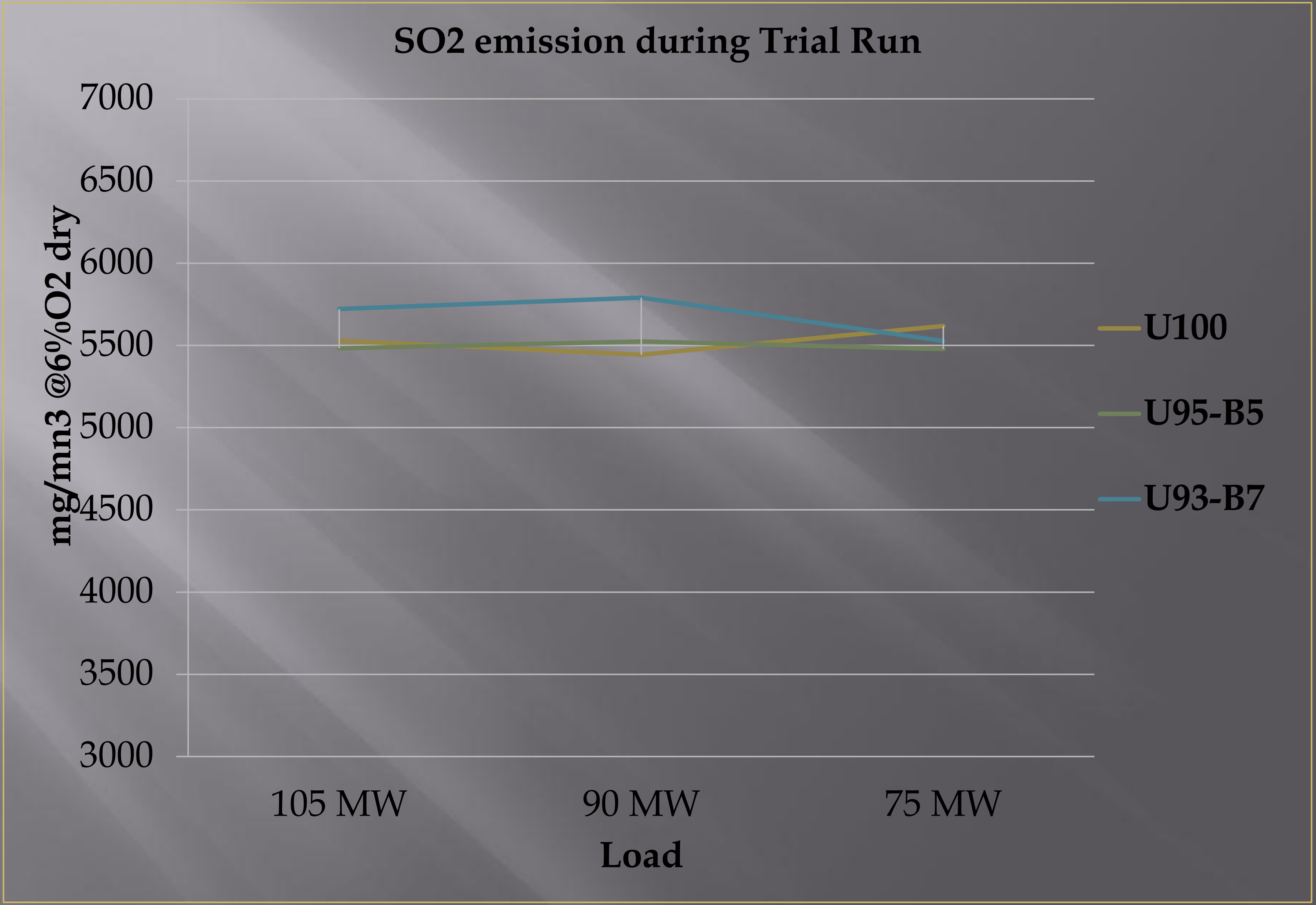
U95-B5

U93-B7

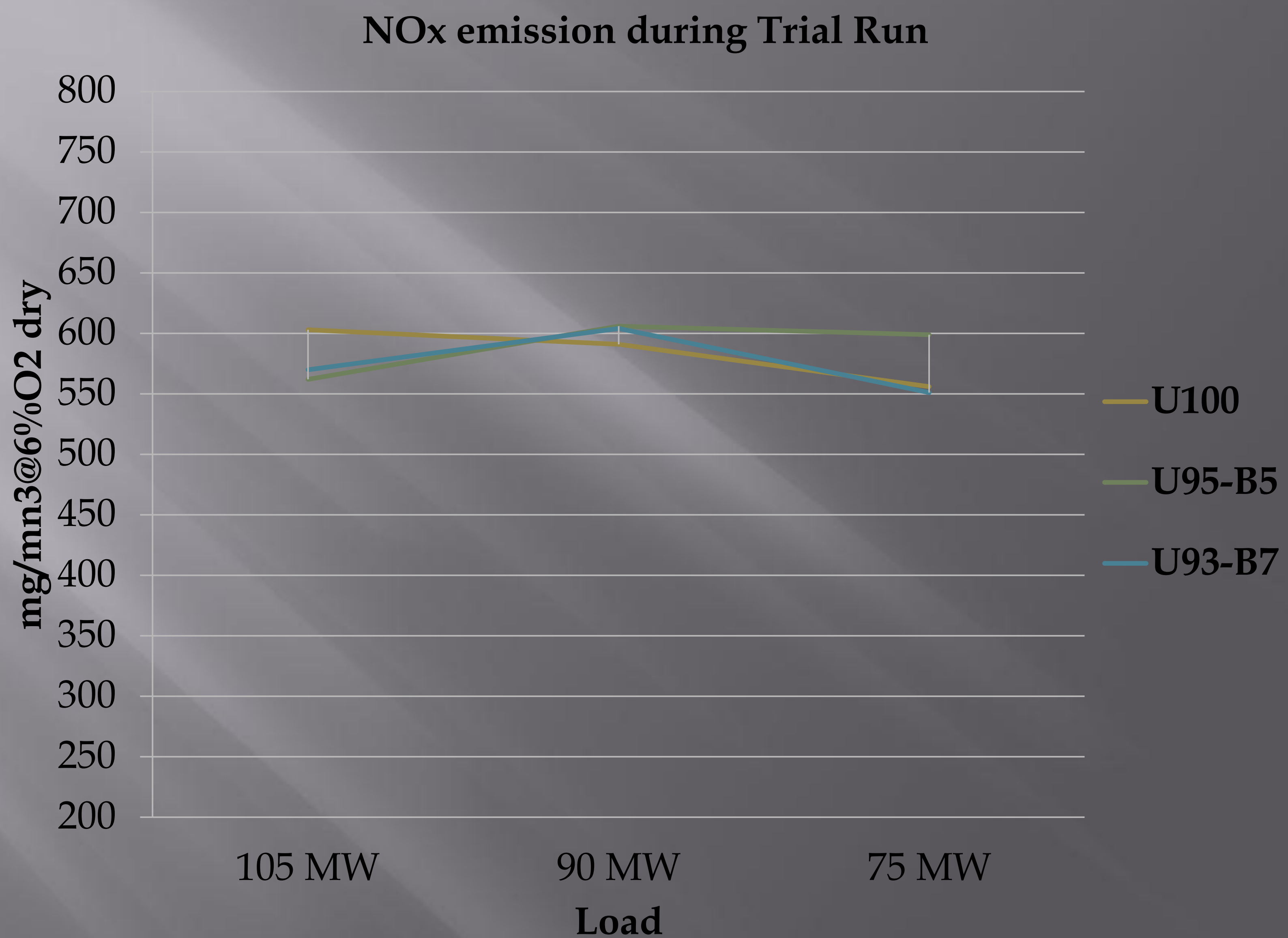
Base/acid ratio for the ash deposits generated in Trial Run



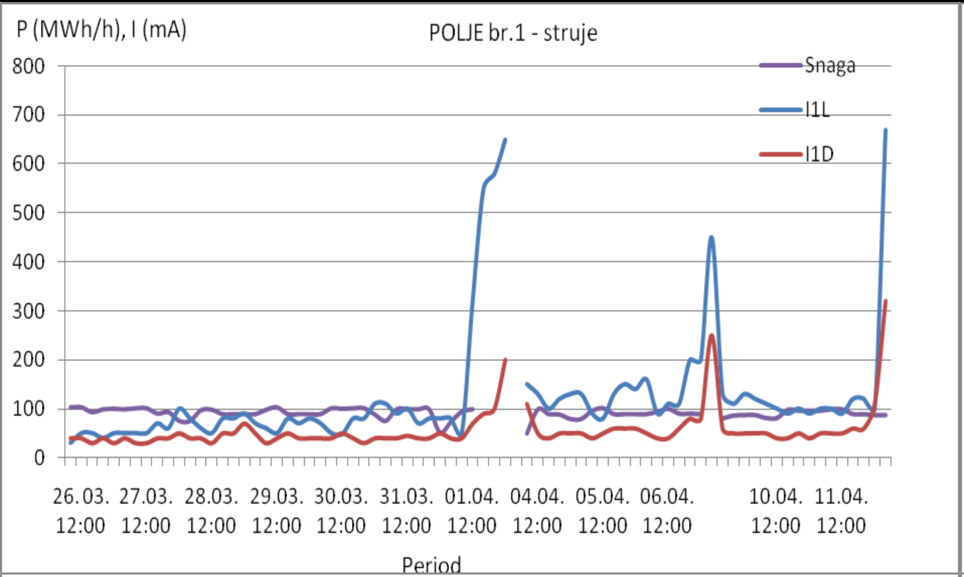
Emissions of SO2

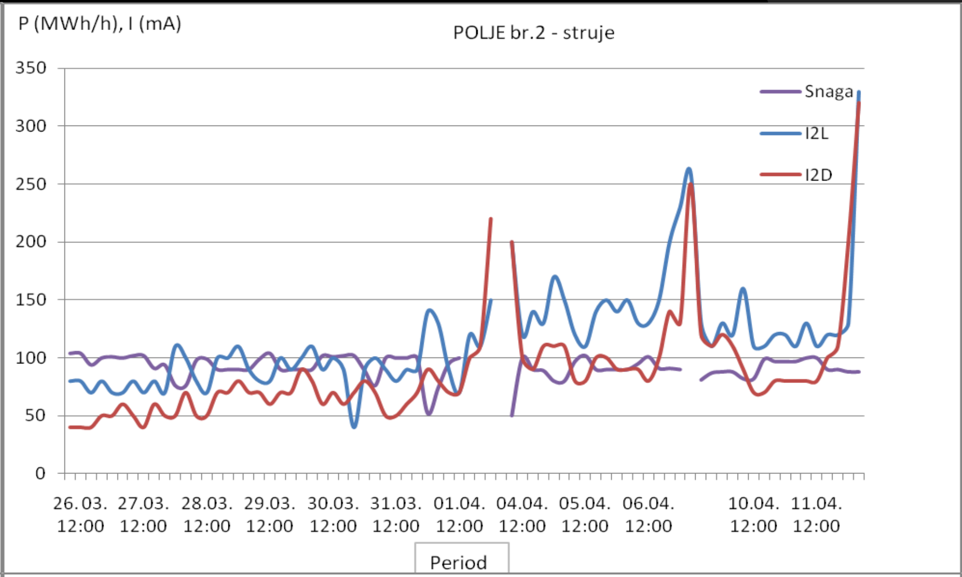


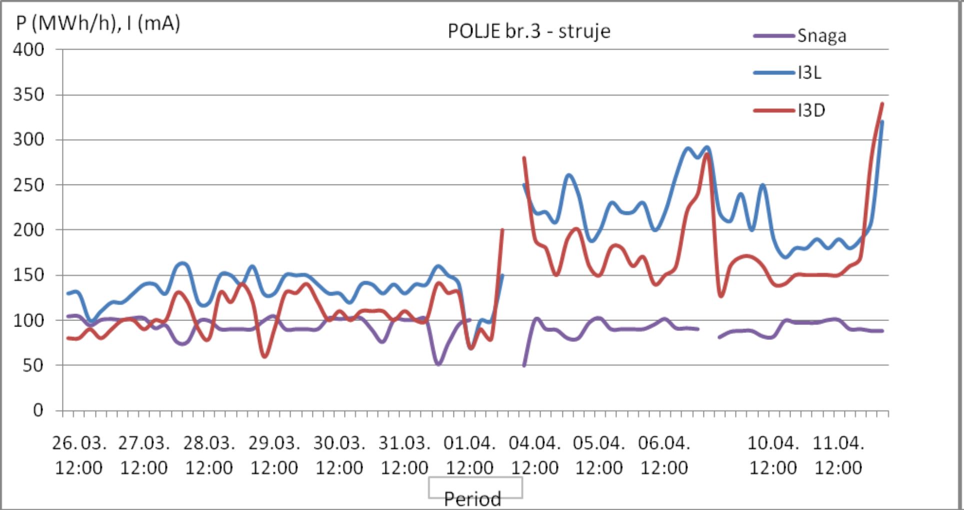
Emissions of NOx

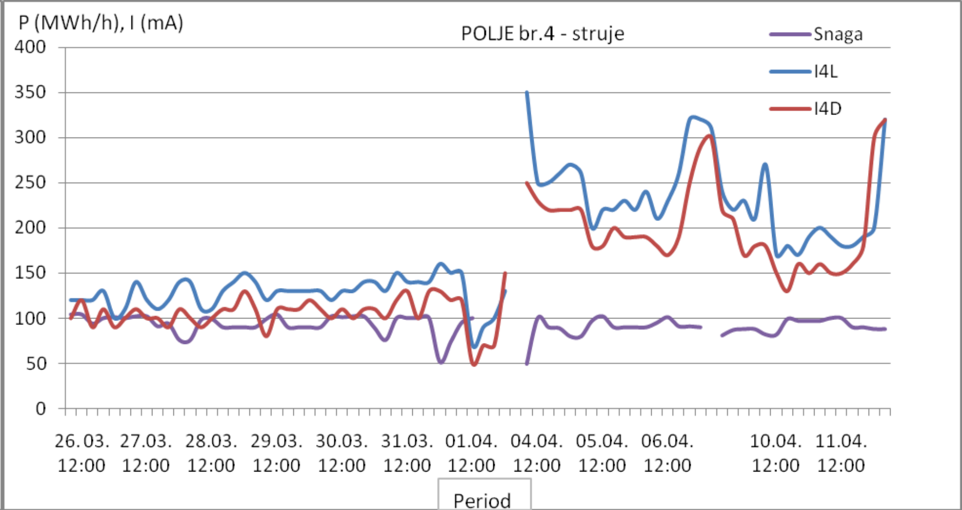


Pozitive effect to the operation of Electrostatic precipitator – lower electricity consumption in cofiring regimes!









7. Conclusions

From experimental

1. Optimization of coal-biomass blend (share of biomass in the coal/biomass mixture) is performed by an experimental PF entrained flow reactor:

-Recomended to use till 7%w of wooden biomass with coal in large Bosnian power plants to avoid any risk in operation of Large utility

2. Specific results on emissions in Laboratory research of cofiring coal with woody biomass:

-Reduction CO_2, Reduction SO_2, no clear relation to NOx!

3. Specific results on emissions in Laboratory research of cofiring coal with woody biomass:

Significant reduction of NOx emissions recorded in cofiring campaignes “reburning with natural gas” (with 10%th of natural gas used fuel, NOx emissions reduction is till 40% compared to the NOx emissions when coal only is used).

Conclusions from Trial run in Large utility (Kakanj TPP)

1. Results of Trial Run of cofiring coal with 5%w and 7%w of woody biomass on TPP Kakanj unit 5 (110 MWe):

- No significant operational problems!!
- Lower ash depozition!
- No significant influence to SO_2 and NOx,
- Pozitive effect to operation of EP, Lower electricitx consumption and dust emission slightly reduced!

2. Economic benefits do not come any more from lower fuel price than could come from certified CO_2 reduction (CER)! CDM?