HIGH TEMPERATURE AIR/STEAM GASIFICATION OF STEAM EXPLODED BIOMASS

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Presentation schedule

- Introduction to biomass pretreatment
- Opening possibilities
- Background
- Objective of present work
- Methodology: The system and the fuel
- Gasification performance
- Insight into behaviour of tar
- Conclusions

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Biomass pretreatment

- Mechanical pretreatment
- Torrefaction
- HTC
- **Steam explosion**
  - heating biomass under high pressure steam
  - sudden release of pressure assuring explosive decompression
  - Typical conditions:
    - Pressure: 1.2-1.7 MPa
    - Temperature: 170-250°C
    - Time: 10sec-10min
  - limited energy consumption
  - low use of chemicals

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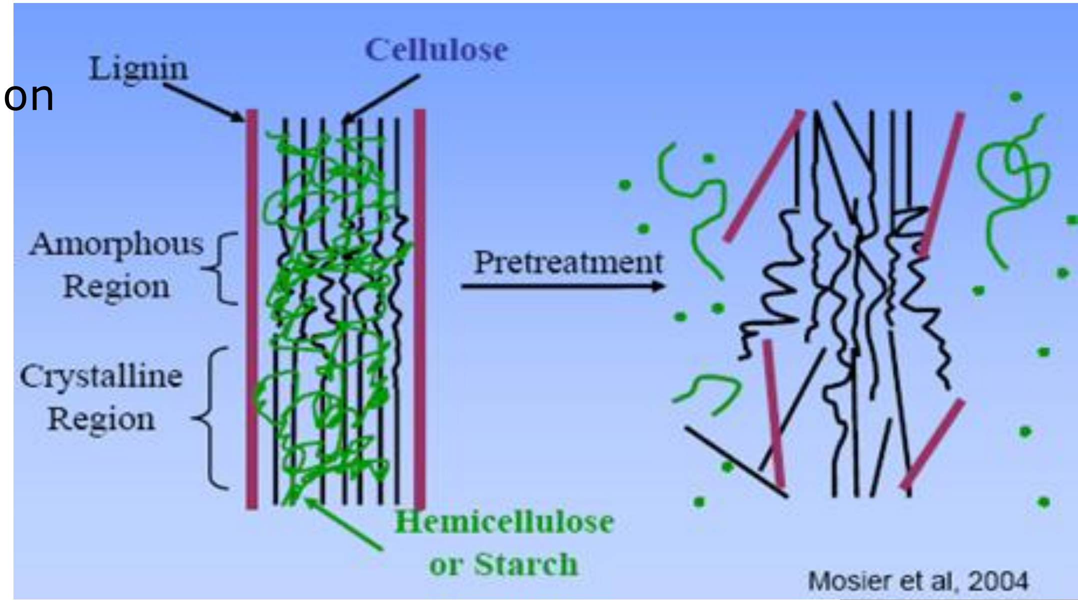

Opening possibilities

Structural change	Effect		Ultimate result			Opening possibilities
Hemicellulose & cellulose de-polymerization	Low thermal stability[1-5]		Early thermal degradation		+	Low temperature operations possible
Altered lignin structure						
Release of minerals	Low alkali metal content and low ash content		High ash fusion temperature		+	High temperature operations possible
Release of hemicellulose to solution	Low hemicellulose content	Reduced volatiles	Less reactive		-	Need longer bed (high H/D ratio)
		Less hydroxyl groups[3]	Hydrophobic		+	Transportation and storage easiness
		Less amorphous structures (High crystallinity)[6]	Heat diffusion limitations[7]		-	High temperature operation suitable
		Reduced O content	Low O/C and H/C (moving close to peat region)		+	Co-gasification possible
	High lignin content	High C content	High heating value	High energy density	+	Positive in transportation and storage
Disintegration of biomass	Fine particles	High pellet density	High bulk density		+	Compact reactor
		High impact and abrasive resistance[8]	Higher durability		+	Handling easiness

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Background

- Mostly focus on ultimate use as fermentation to ethanol
- Several studies based on combustion of fermentation residue
- Some studies on thermochemical behaviour
- Thermal application is lacking

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Objective

- High Temperature Air/Steam Gasification (HTAG) of steam exploded biomass pellets compared to untreated biomass pellets in order to analyse qualitative and quantitative gasification performance

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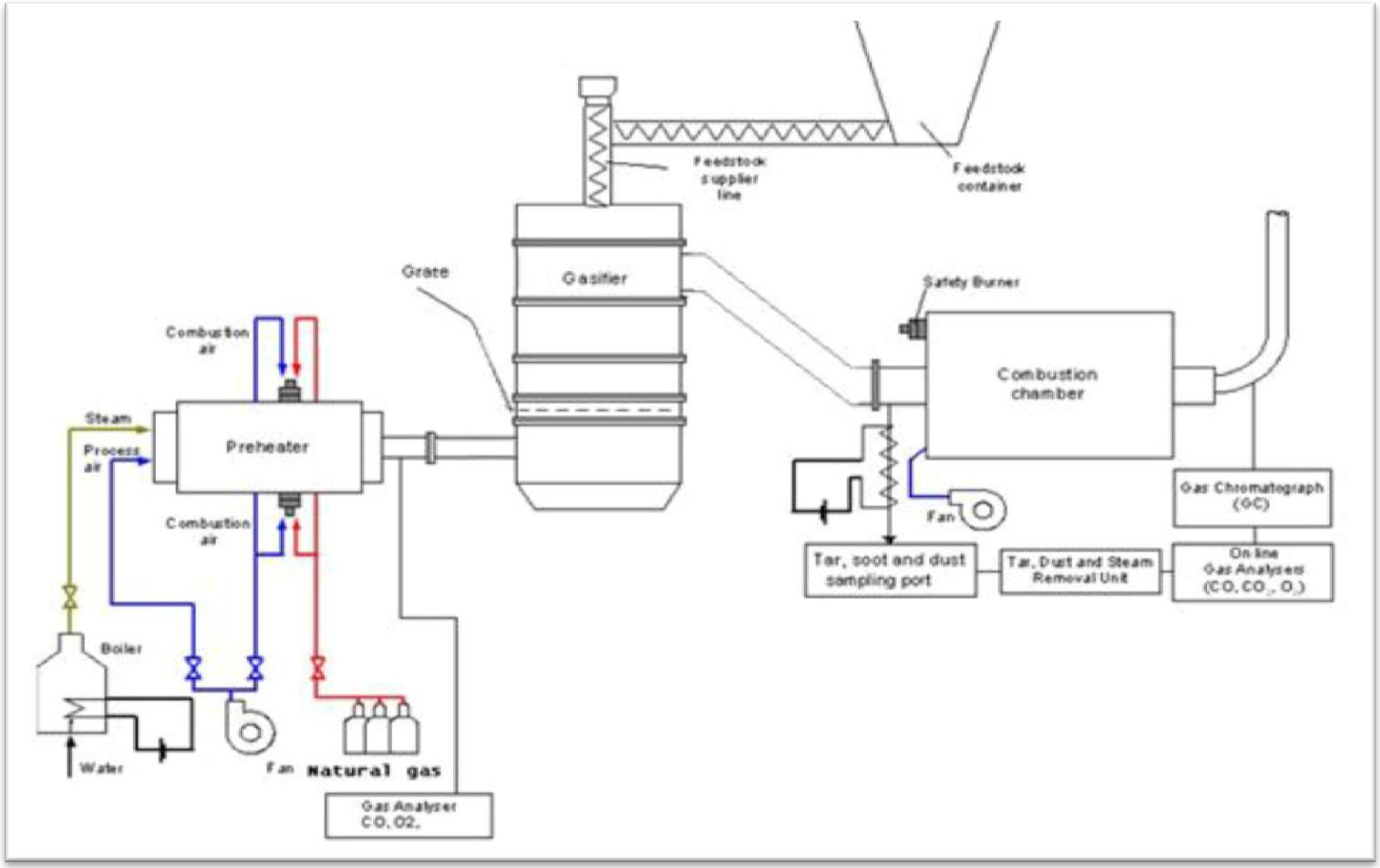
Gasifier system

HTAG



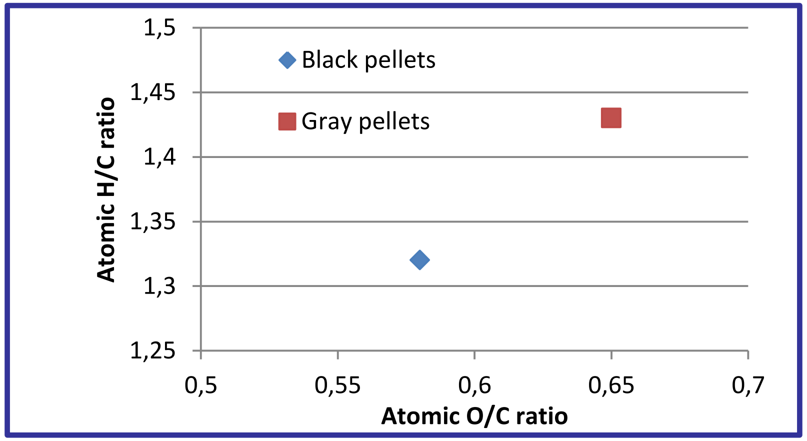
HTAG system including preheater, feeding system and after burner

Fuel

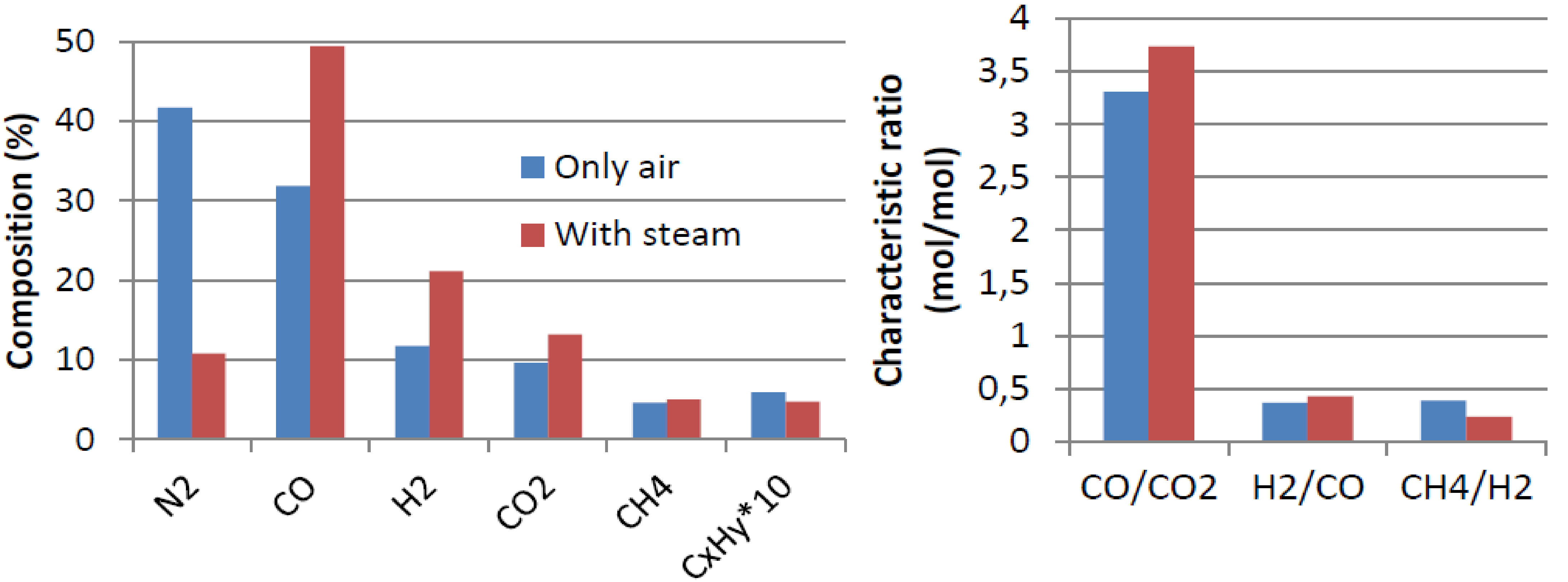
	Black pellets	Gray pellets
Proximate analysis		
Moisture content at 105°C	4,2%	9,8 %
Ash cont. at 550°C	, % (dry)	1,9 % (dry)
LHV (as received)	,3 MJ/kg	16,6 MJ/kg
Volatile matter	76, % (dry)	81,2 % (dry)
Bulk density	740 kg/m^3	603 kg/m^3
Ultimate analysis		
Carbon C	52,6% (dry)	49,4 % (dry)
Hydrogen H	5,8% (dry)	5,9 % (dry)
Nitrogen N	<0,1 % (dry)	0,17 % (dry)
Oxygen O	40,6% (dry)	42,6 % (dry)
Ash fusion temperatures (oxidizing conditions)		
Shrinking temperature, ST	1050 °C	1050 °C
Deformation temperature, DT	1480 °C	1190 °C
Hemisphere temperature, HT	1490 °C	1210 °C
Flow temperature, FT	1500 °C	1230 °C

Untreated (Gray pellets)

Steam exploded (Black pellets)

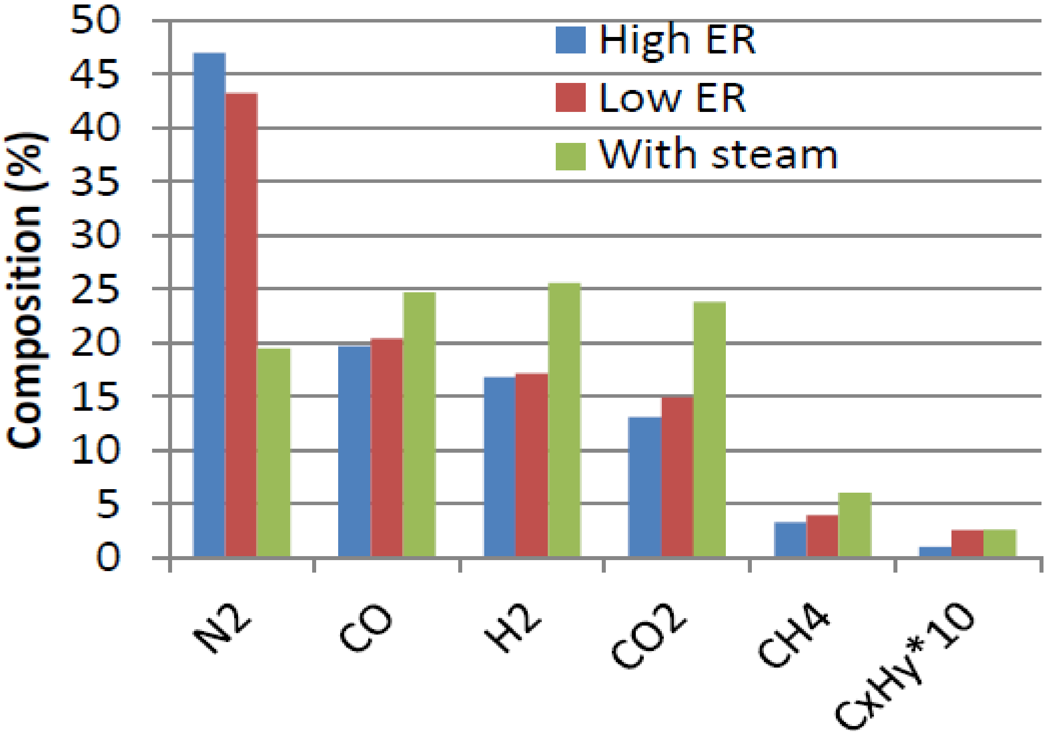


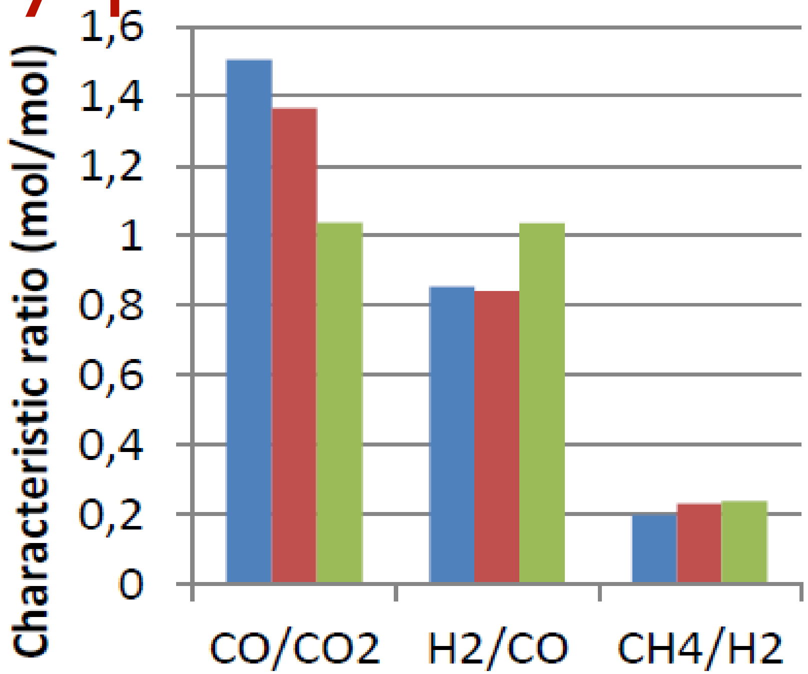
Gas composition - Black pellets



Possible reactions with steam	Observed consequences
Steam reforming of carbon and hydrocarbon	High H_2 and CO content, low CH_4/H_2
Boudouard reaction	High CO/CO_2
Water gas shift reaction not played much role	Only slight increment of H_2/CO and high CO/CO_2

Gas composition - Gray pellets





Possible reactions with steam	Observed consequences
Water gas shift reaction	High H_2/CO
Steam reforming and Boudouard reaction not played much role	High CH_4 and C_xH_y content, high CH_4/H_2 and low CO/CO_2
Possible reactions with high ER	**Observed consequences**
Boudouard reaction	High CO/CO_2
Hydrocarbon cracking	High H_2/CO and low CH_4/H_2

Heating value, gas yield and efficiency

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Run	Biomass type	ER	LHV of biomass MJ/kg	LHV of gas MJ/Nm	Gas yield Nm^3/kg	Gasification efficiency %
1	Black pellets	0,180	,3	7,3	2,0	75,6
2	Black pellets with steam	0,032		10,6	1,4	76,9
3	Gray pellets	0,223	,	6,0	2,1	75,9
4	Gray pellets high ER	0,267		5,5	2,4	79,5
5	Gray pellets with steam	0,071		8,2	1,5	74,1

- Steam addition: High LHV, low gas yield
- High ER: Low LHV, high gas yield
- Maximum efficiency seen with high ER case
- ER should be optimized with more trials

Gas purity

	Black pellets	Black pellets with steam	Gray pellets low ER	Gray pellets high ER
Total tar (g/m^3)	15,4	11,4	13,4	4,4
Tar yield (g/kg)	30,8	16,0	28,1	10,6
Gas exit temperature (°C)	658	631	828	837

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- Steam addition: Low tar due to steam reforming
- High ER: Low tar due to cracking

Black pellets vs Gray pellets

Observed with Black pellets	Possible reason
High CO content	Low H/C ratio in feedstock
Low H_2 content	
Low H_2/CO	
High CO/CO_2	Dominance of Boudouard reaction
High C_xH_y	Low gas exit temperature
High LHV	High energy feedstock, High C_xH_y Content in gas
Small increment of tar content	Low gas exit temperature
Dominates secondary tar	

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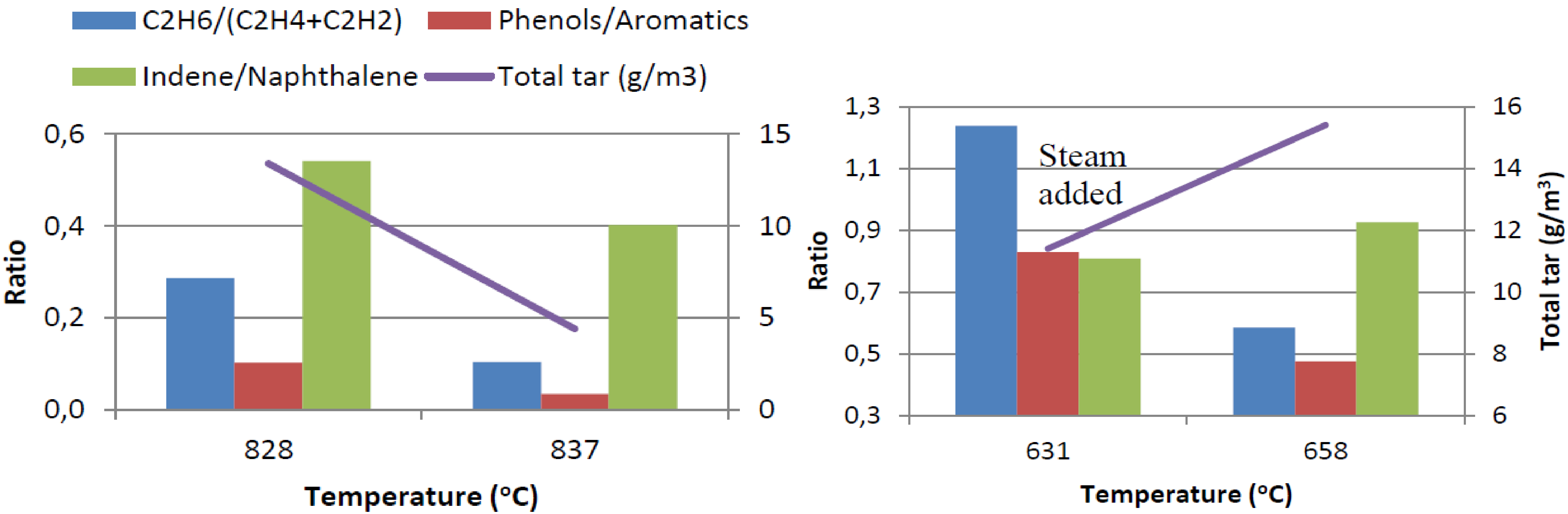
Tar - characteristic ratios



- Strong dependency of $C_2H_6/(C_2H_4+C_2H_2)$ ratio and Phenols/Aromatics ratio on temperature
- Weak dependency of Indene/Naphthalene ratio
- Indene/Naphthalene shows same trend as total tar even when steam is present

Conclusions

- Steam exploded pellets shows some promising features
  - Transportation and storage easiness
  - Co-gasification possible
  - Handling easiness
  - Compact reactor
  - Syngas with high heating value
- Limitations
  - Heat transfer limitations (High temperature operation suitable)
  - Low reactivity (Longer bed is required)
  - Less H_2 content in syngas (Not much suitable for H_2 synthesis)
  - Slightly higher tar content (May be downdraft gasification is better)

- Indene/Naphthalene shows valid prediction of tar content even when steam is present (possible application of online measurement such as PID[1])

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[1] Use of PID (Photo Ionization Detector) technique for on-line tar measurement has been proposed by Ahmadi et al.,2011

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