RELEVANCE OF BIOMASS COMMINUTION PHENOMENA IN GASIFICATION PROCESSES

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Introduction - I

- Gasification consists in the conversion of solid carbonaceous fuels, such as coal or biomass, into syngas via partial oxidation reactions.
- Biomass fuels provide an attractive primary energy source because of their renewable nature, neutrality with respect to greenhouse-compounds generation, and limited formation of pollutants.
- Gasification of solid biomass yields a high quality syngas with a more favorable H_2/CO ratio with respect to coal and with lower energy demand.
- Biomass, characterized by highly reactive chars, can also be suitably used in processes where the fuel gasification is carried out at relatively low temperature (chemical looping combustion and sorption enhanced gasification).

Introduction - II

✓ Biomass fuels, however, are characterized by a low energy specific content if compared with fossil fuels

Fuel pre-treatment (pelletization, torrefaction, compaction)

- increasing bulk density and specific energy content
- improving fuel properties (e.g. homogenizing , stabilizing, and strengthening the fuel particles)
- simplifying the design of handling and storage devices

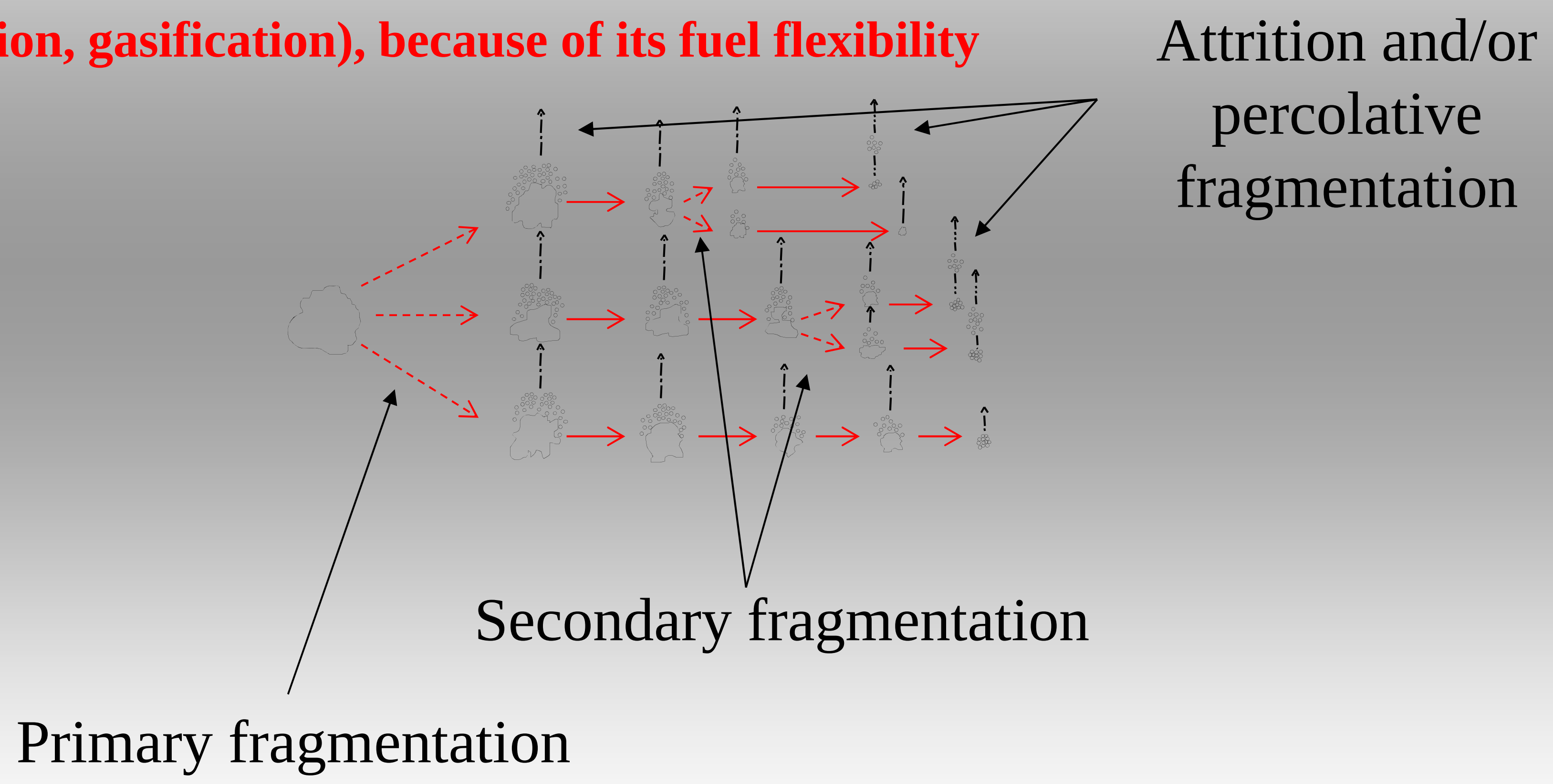
Biomass co-processing with coal, which has an almost double energetic density

- increasing specific energy content
- facing the temporary lacking of the primary fuel (i.e., the biomass)

✓ Of course, the process must be flexible toward the change of the fuel properties

Introduction - Comminution phenomena - I

Fluidized bed (FB) technology is considered as one of the most suitable choices for biomass conversion (combustion, gasification), because of its fuel flexibility



Introduction – Comminution phenomena - II

✓ Fuel attrition and fragmentation phenomena are well known to affect the reliability and efficiency of FB combustion and gasification processes

change of the particle size distribution

↓

influence on bed fluid-dynamics, heat and mass transfer coefficients and reaction rates

elutriation of fine material

↓

loss of unconverted carbon

Introduction – Comminution phenomena - III

- ✓ The relevance of attrition and fragmentation phenomena are emphasized when using high-volatile fuels (biomass, waste) instead of coals, since highly porous and friable or even incoherent chars are formed upon devolatilization.

- ✓ Several attrition studies are reported under FB combustion conditions (mostly focused on coal), but only limited activity is reported under gasification conditions.

IRC-CNR research activities

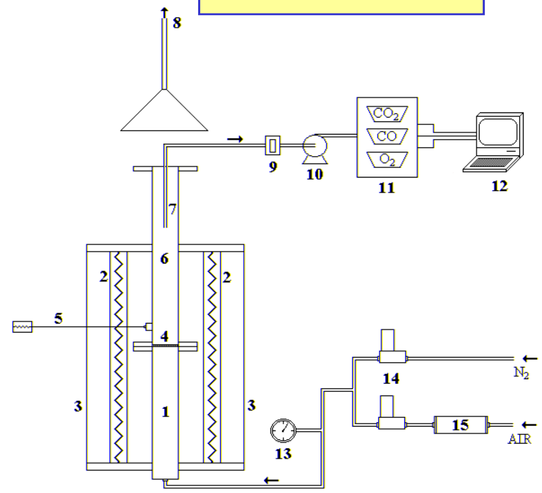
Relevance of comminution phenomena of wood-based fuels under gasification conditions in a laboratory bubbling fluidized bed

- ✓ effect of the pelletization process on wood biomass behaviour
- ✓ effect of co-processing wood biomass with coal

Additional activities under oxidizing and inert conditions to better understand the mechanism of wood biomass attrition and to underline the differences upon changing the reaction environment

Experimental - I

ID = 40 mm



1) gas preheating section; 2) electrical furnaces; 3) ceramic insulator; 4) gas distributor; 5) thermocouple; 6) fluidization column; 7) steel probe; 8) stack; 9) cellulose filter; 10) membrane pump; 11) gas analyzers; 12) personal computer; 13) manometer; 14) digital mass flowmeters; 15) air dehumidifier (silica gel).

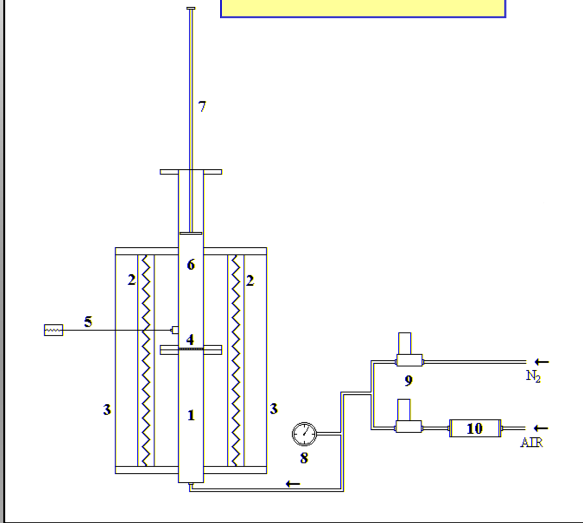
Configuration used for devolatilization experiments

Open-top FB

Operating conditions	
Sand size range (mm)	0.2-0.4 04-0.8
Temperature (°C)	800
Sand u_{mf} (m/s)	0.03
Sand bed (g)	180
Superficial gas velocity u (m/s)	0.3
Fluidizing gas	air
Fuel feeding	single particle

Experimental - II

ID = 40 mm



1) gas preheating section; 2) electrical furnaces; 3) ceramic insulator; 4) gas distributor; 5) thermocouple; 6) fluidization column; 7) steel basket; 8) manometer; 9) digital mass flowmeters; 10) air dehumidifier (silica gel).

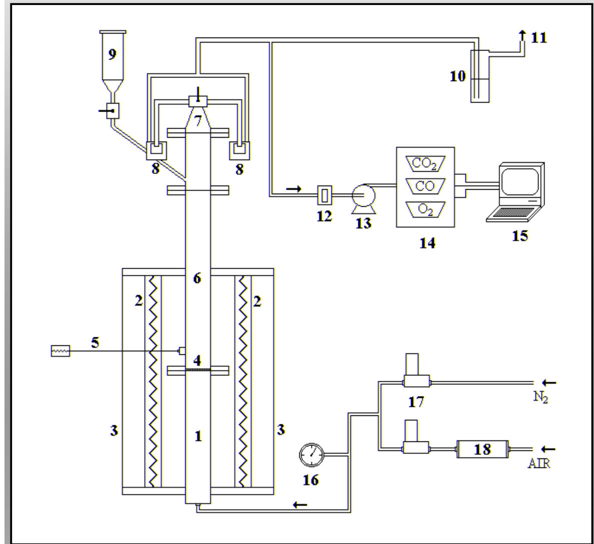
Configuration used for fragmentation experiments

Basket equipped FB

	Primary fragmentation	Secondary fragmentation
Sand size range (mm)	0.2-0.4	
Temperature (°C)	800	
Sand u_{mf} (m/s)	0.03 0.13	0.03
Sand bed (g)	180	
Superficial gas velocity u (m/s)	0.3	0.3
Fluidizing gas	N_2	60% CO_2 in N_2
Fuel feeding	single particle	3-4 pre-devolatized char particles

Experimental - III

ID = 40 mm



1) gas preheating section; 2) electrical furnaces; 3) ceramic insulator; 4) gas distributor; 5) thermocouple; 6) fluidization column; 7) head with three-way valve; 8) sintered brass filters; 9) hoppper; 10) scrubber; 11) stack; 12) cellulose filter; 13) membrane pump; 14) gas analyzers; 15) personal computer; 16) manometer; 17) digital mass flowmeters; 18) air dehumidifier (silica gel).

Configuration used for attrition experiments

Two-exit head FB

Operating conditions	
Sand size range (mm)	0.2-0.4
Temperature (°C)	800
Sand u_{mf} (m/s)	0.03
Sand bed (g)	180
Superficial gas velocity u (m/s)	0.8
Fluidizing gas	60% CO_2 in N_2 N_2 4.5% O_2 in N_2
Fuel feeding	2g of pre-devolatized char

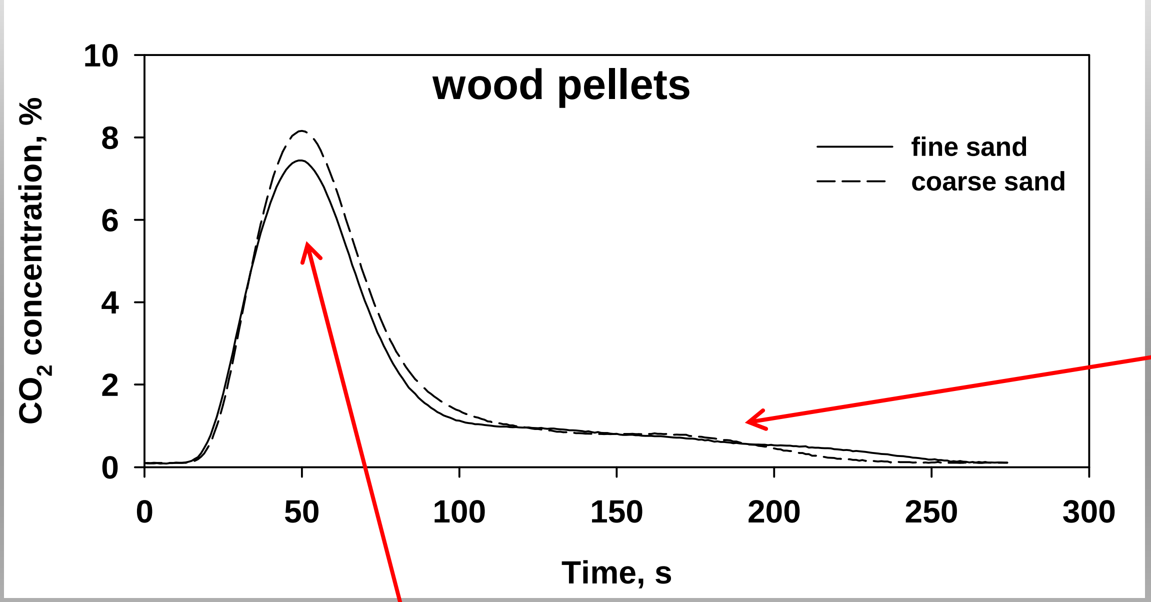
Effect of pelletization - Fuel materials

	Wood chips	Wood pellets
LHV, kJ/kg	11700	18500
Proximate analysis (as received), $\%_w$		
moisture	34.9	8.4
volatiles	51.6	74.2
fixed carbon	13.3	17.1
ash	0.2	0.3
Ultimate analysis (dafb), $\%_w$		
carbon	47.5	49.4
hydrogen	6.1	5.9
nitrogen	0.2	< 0.1
oxygen (diff)	46.2	44.6

Pellet size = 6x20mm

Chip size = 6.35-9mm

Effect of pelletization - Preliminary devolatilization tests



T= 800 °C
U= 0.3 m/s
Gas = air

char combustion stage

devolatilization stage

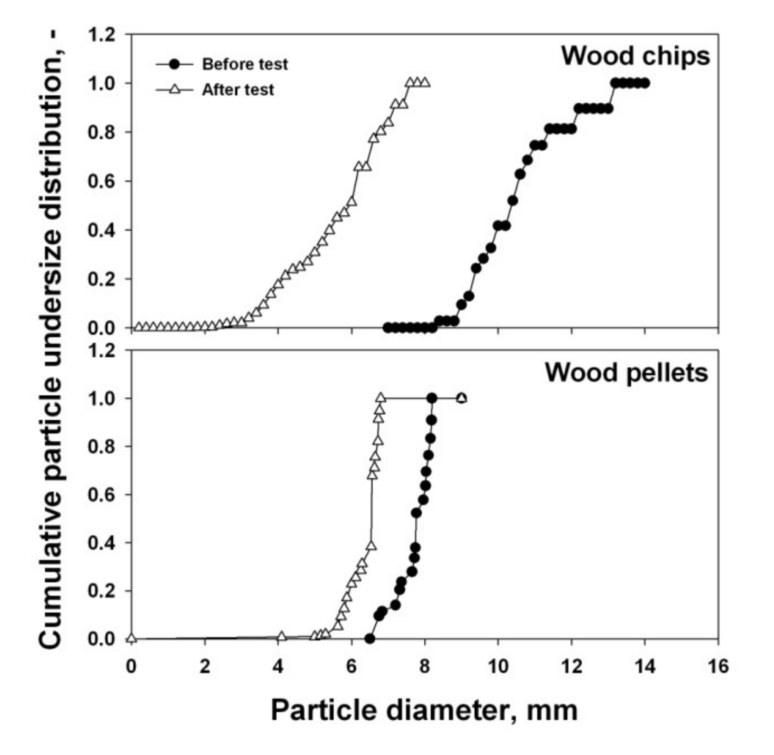
Wood pellet devolatilization time = 100s

Wood chip devolatilization time=10s*

*Solimene et al., 2012 AIChE J. (58) 622-645

The external heat transfer has a low influence on the devolatilization rate, which is likely to be dominated by the internal heat transfer.

Effect of pelletization - Primary fragmentation tests results



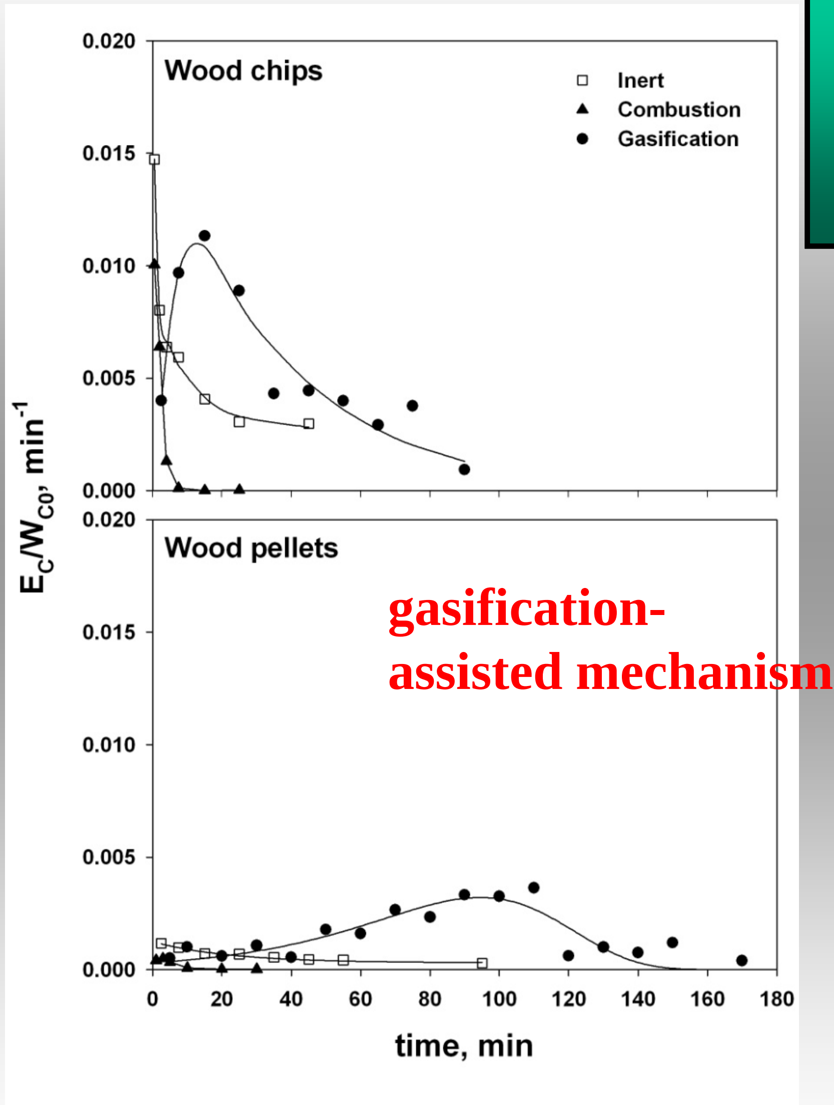
particle shrinkage!

T= 800 °C
U= 0.3 m/s
Gas = N_2

	d_0, mm	S_f	n_1	d_1, mm
Wood chips	10.4	0.95	4.5	5.3
Wood pellets	6.0	0.29	1.4	4.9

d_0 initial Sauter diameter
S_f primary fragmentation probability
n_1 primary fragmentation multiplication factor
d_1 final Sauter diameter

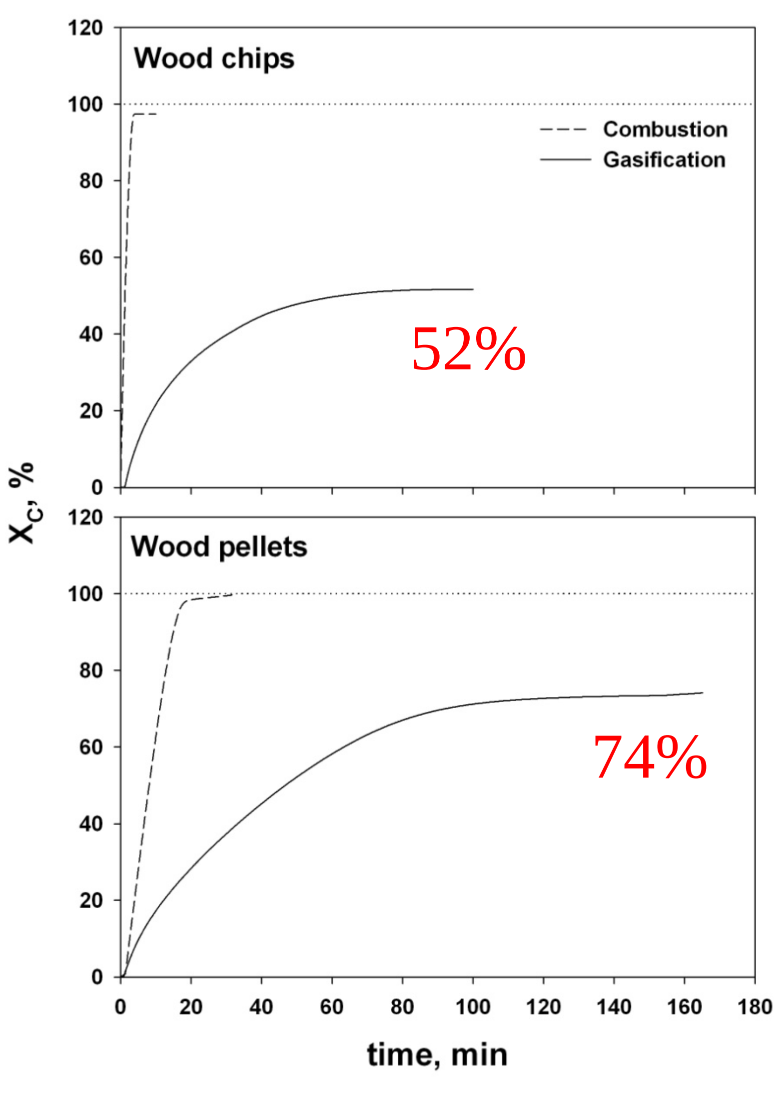
Effect of pelletization - Char attrition tests results – attrition rate



T= **800 °C**
U= **0.8 m/s**
W_{batch} = 2 g
Gas = N_2 (inert)
= N_2 + O_2 (4.5%) (combustion)
= N_2 + CO_2 (60%) (gasification)

Percentage of the initial carbon cumulatively elutriated

	inert	combustion	gasification
Wood chips	23	2.65	48
Wood pellets	4	0.35	26



Effect of pelletization - Char attrition tests results – carbon conversion

T= 800 °C
U= 0.8 m/s
W_{batch} = 2 g
Gas = $N_2 + O_2$ (4.5%) (combustion)
= $N_2 + CO_2$ (60%) (gasification)

Pelletized biomass showed a higher carbon conversion!

Effect of co-processing - Fuel materials

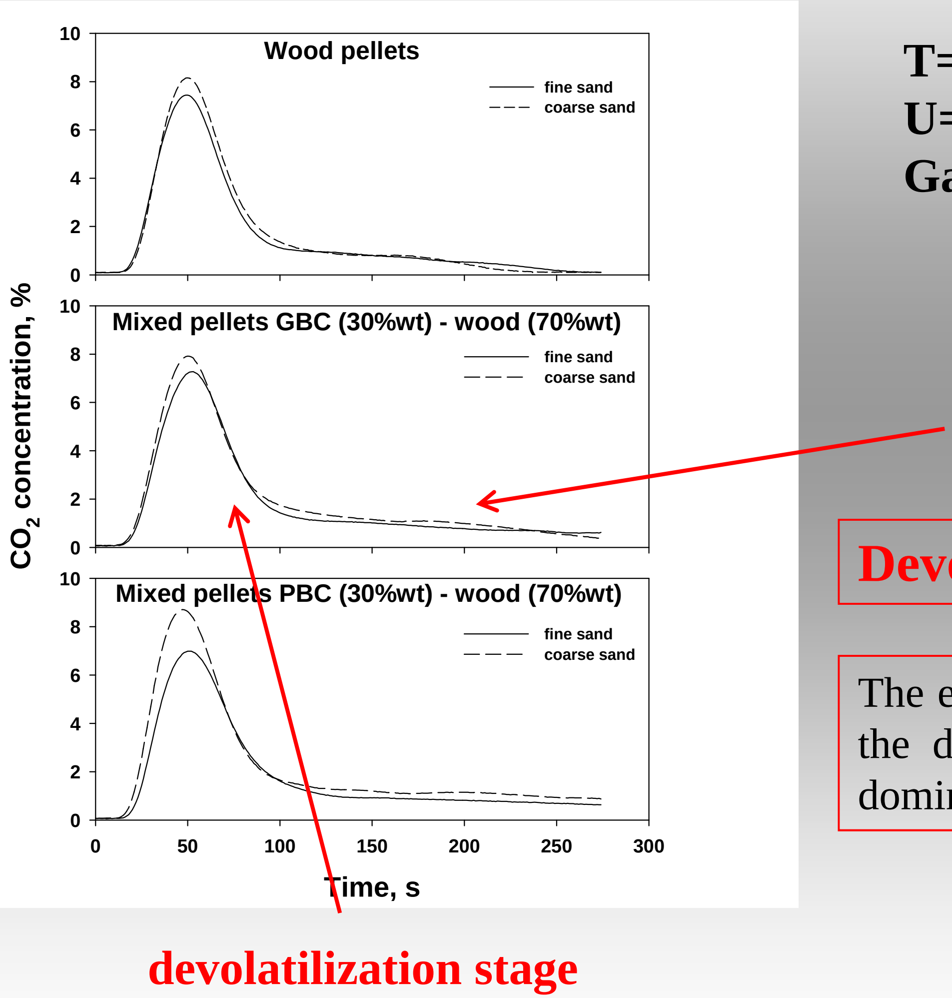
	Wood pellets	70% wood - 30% German coal pellets	70% wood - 30% Polish coal pellets
Proximate analysis (as received)			
Moisture, %wt.	8.4	9.3	8.2
Volatiles, %wt.	74.2	66.8	61.4
Fixed carbon, %wt.	17.1	22.8	27.6
Ash, %wt.	0.3	1.1	2.8
Ultimate analysis (dafb)			
Carbon, %wt.	49.4	55.1	58.7
Hydrogen, %wt.	5.9	5.7	5.8
Nitrogen, %wt.	<0.1	0.1	0.4
Oxygen, %wt.	44.6	39.1	35.1
Lower heating value, MJ/kg	18.5	21.7	23.4

Pellet size = 6x20mm

Pellet size = 6x20mm

Pellet size = 6x20mm

Effect of co-processing - Preliminary devolatilization tests

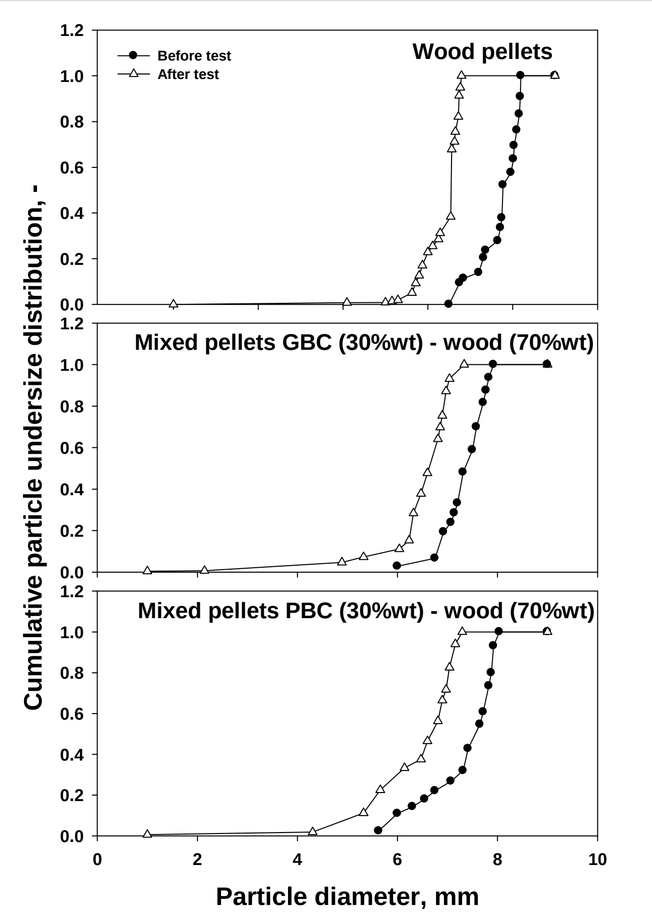


T= 800 °C
U= 0.3 m/s
Gas = air

Devolatilization time = 90-100s

The external heat transfer has a low influence on the devolatilization rate, which is likely to be dominated by the internal heat transfer.

Effect of co-processing - Primary fragmentation tests results



particle shrinkage!

T= 800 °C
U= 0.3 m/s
Gas = N_2
Time = 5 min

Fuel	**d_0, mm**	**S_f**	**n_1**	**d_1, mm**
Wood pellets	6.00	0.29	1.38	4.92
70% wood - 30% GBC pellets	7.35	0.21	2.47	6.37
70% wood - 30% PBC pellets	7.30	0.30	3.30	6.24

d_0 initial Sauter diameter
S_f primary fragmentation probability
n_1 primary fragmentation multiplication factor
d_1 final Sauter diameter

Effect of co-processing - Secondary fragmentation tests results

Char of wood pellets

t=0
X_C=0%

t=10 min
X_C=17%

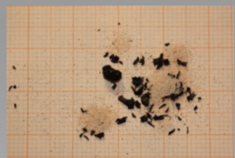
t=30 min
X_C=47%

t=60 min
X_C=77%

Char of mixed pellets GBC (30%wt) - wood (70%wt)

t=0
X_C=0%

t=20 min
X_C=44%

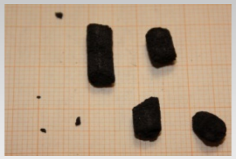


t=40 min
X_C=76%

T= 800 °C
U= 0.3 m/s
Gas = 60% CO_2 in N_2

Char of mixed pellets PBC (30%wt) - wood (70%wt)

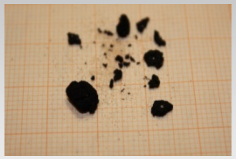
t=0
X_C=0%



t=20 min
X_C=13%

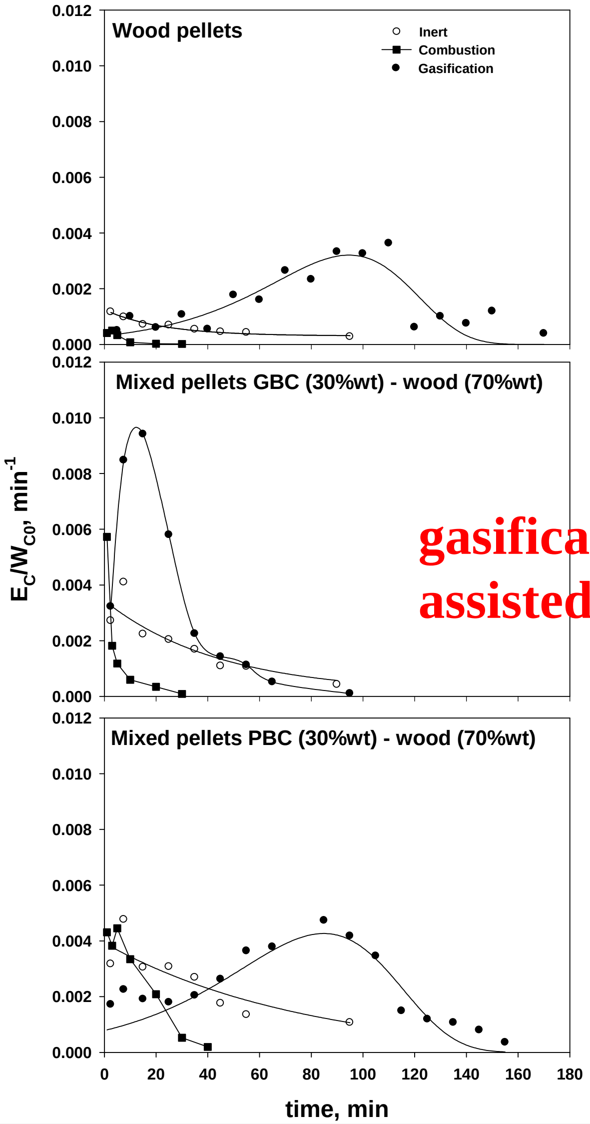
t=40 min
X_C=29%

t=70 min
X_C=46%



t=90 min
X_C=58%

Effect of co-processing - Char attrition tests results – attrition rate



gasification-assisted mechanism

T= 800 °C

U= 0.8 m/s

W_{batch} = 2 g

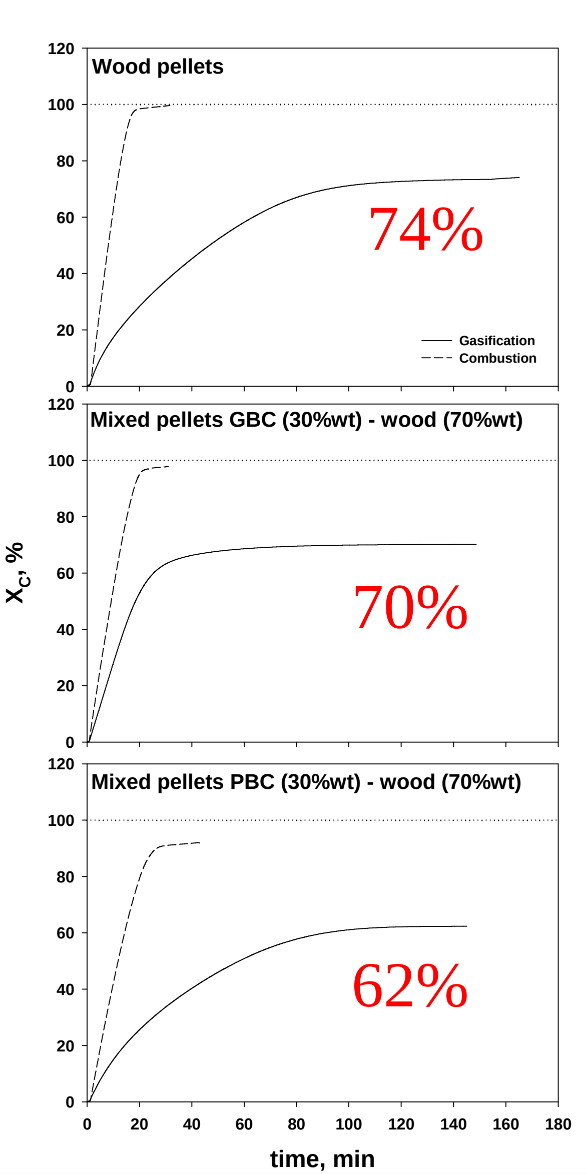
Gas = N_2 (inert)

= $N_2 + O_2$ (4.5%) (combustion)

= $N_2 + CO_2$ (60%) (gasification)

Percentage of the initial carbon cumulatively elutriated

Attrition conditions	Wood pellets	Mixed pellets GBC (30%wt) - wood (70%wt)	Mixed pellets PBC (30%wt) - wood (70%wt)
Inert	7	21	12
Gasification	26	29	38
Combustion	0.35	2.19	7.97



Effect of pelletization - Char attrition tests results – carbon conversion

T= 800 °C

U= 0.8 m/s

W_{batch} = 2 g

Gas = $N_2 + O_2$ (4.5%) (combustion)

= $N_2 + CO_2$ (60%) (gasification)

Conclusions

Relevance of comminution phenomena of wood-based fuels under gasification conditions in a laboratory bubbling fluidized bed

- ✓ effect of the pelletization process on wood biomass behaviour
- ✓ effect of co-processing wood biomass with coal

- ✓ Particle breakage by primary fragmentation was limited for wood pellets, indicating that pelletization procedure was able to give mechanical strength to the particles.
- ✓ Pelletization was also able to decrease the extent of fines generation by attrition.
- ✓ A *gasification-assisted attrition* mechanism is proposed to explain the experimental results. The low reactivity of the generated fines under gasification conditions makes the loss of carbon by fines elutriation much more significant than that found under combustion conditions.
- ✓ On the whole, the carbon loss by elutriation is certainly one of the critical factors during the gasification process, especially at low gasification rates.

Thank you for your attention