Fludized bed gasification and co-gasification of biomass and wastes

Giovanna Ruoppolo
Istituto di Ricerche sulla Combustione_CNR

Overview on our activity

- Gasification of biomass
- Tar abatement with in bed catalyst
- Reducing of segregation phenomena

- Co-gasification
- Co-gasification of biomass and coal
- Co-gasification of biomass and waste

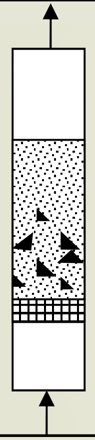
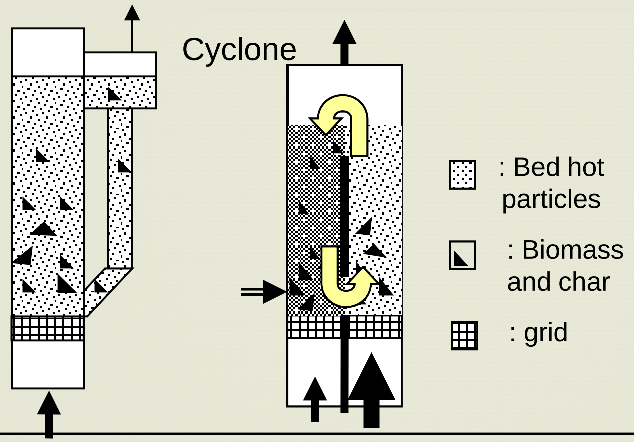
Gasification process

(Air, Steam, CO_2, and/or O_2) + FUEL → $CO, H_2, CO_2, H_2O, CH_4, C_2H_4$ + unconverted tars (all organic compound with mass > C_6H_6)

The main challenges of biomass gasification are:

- Good control of temperature in the reactor
  - High heating rate (hundreds of degrees per second) and high temperatures (around 800°C) are necessary to maximize the gas yield
- TARS conversion
  - TARs condense in the cold parts ⇒ plugging of tubes or agglomeration phenomena
  - TARS removal by filtration ⇒ lost of efficiency since they still contain energy

Fluidized Bed Gasifiers

Fluidized bed technology	
Bubbling fluidized bed	**Circulating fluidized bed**
	

Advantages:

uniform temperatures and high heating rates, greater tolerance to particle size range

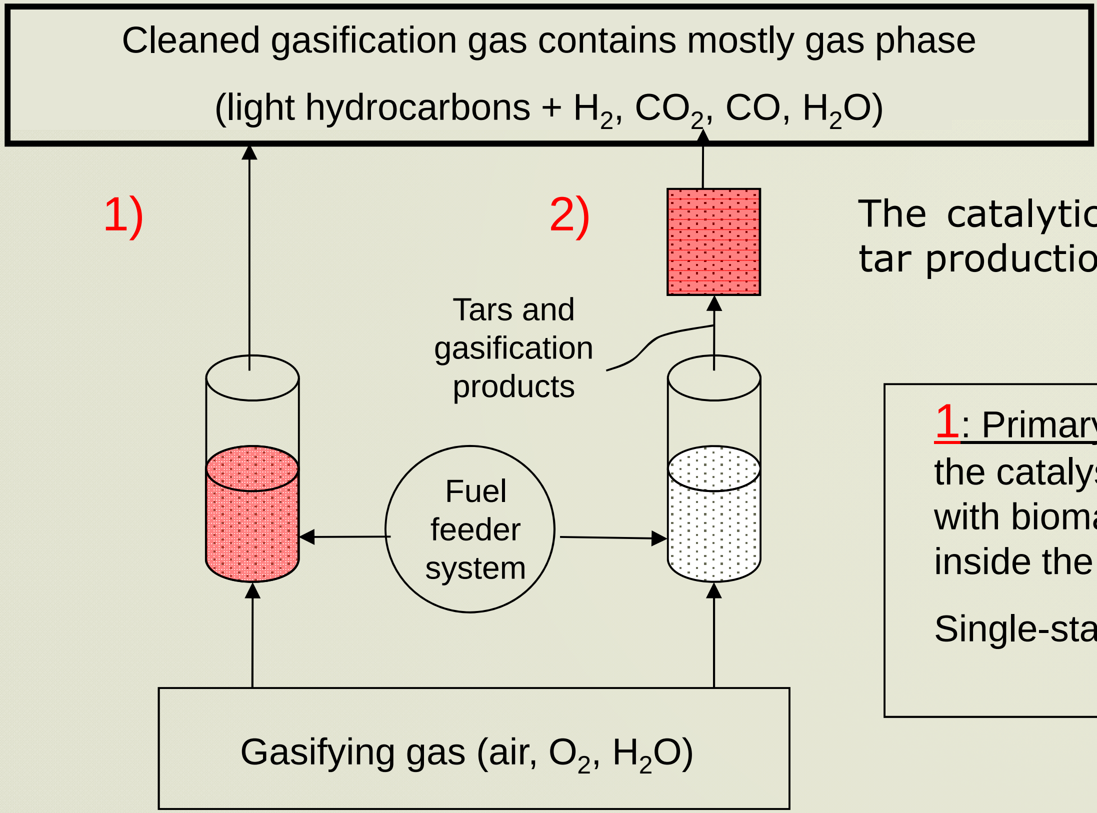
Drawbacks:

low density biomass fuel (with respect to the bed particles) segregates to the surface of the bed reducing the conversion rate.

Fine carbon particles produced in the reaction process elutriate (increasing the solid load to the cyclone and the filter).

Fused ash and tar condensation provokes defluidization.

Catalytic tar conversion



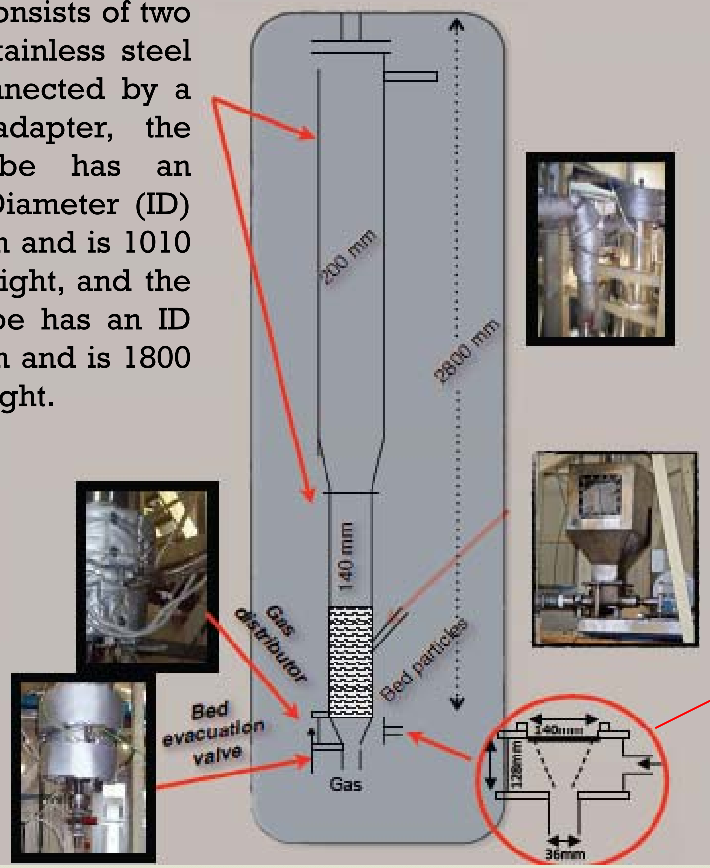
The catalytic tars conversion can both decrease tar production and modify gas composition.

1: <u>Primary method</u>: the catalyst is mixed with biomass directly inside the gasifier. Single-stage process	2: <u>Secondary method</u>: the catalyst is placed down stream the gasifier. Dual-stage process

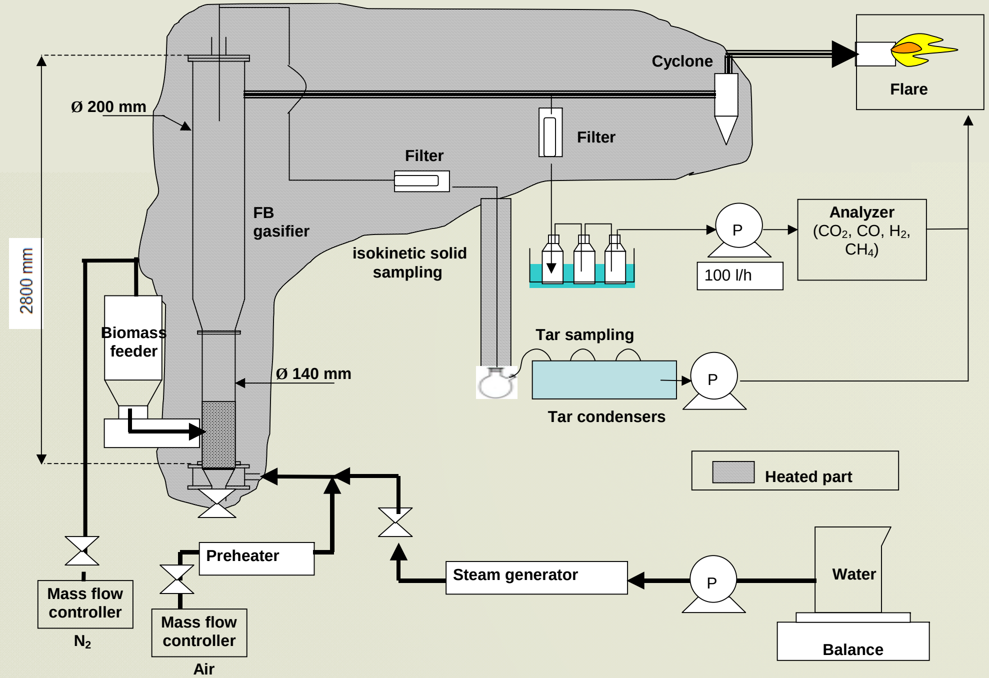
Using a fluidized bed reactor it is possible to realize a single stage process using the catalyst directly inside the reactor and coupling good control of temperature and high heating rate of the biomass fuel.

Fludized bed reactor

The fluidized bed gasifier consists of two vertical stainless steel tubes connected by a conical adapter, the lower tube has an Internal Diameter (ID) of 140 mm and is 1010 mm in height, and the upper tube has an ID of 200 mm and is 1800 mm in height.



Experimental rig

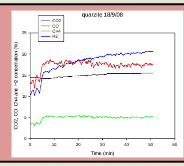


Analysis → **Gas**, **Solid**, **Tar**

Gas →

Online analysis for CO, H_2, CO_2 CH_4

Offline micro GC analysis for lighter hydrocarbon (nC2-nC7)

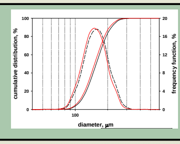


Solid →

Gravimetric analysis

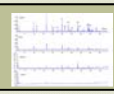
Granulometric analis

LECO CHN analysis



Tar →

Gravimetric analysis for condensed species (20°C and -10°C)



Gasification of biomass

Tar abatement with in bed catalyst

Materials

Biomass characteristics: commercial pellet

Moisture (%wt)	Volatiles (wt%)	Fixed carbon (wt%)	Ash (wt%)	C (%wt)	H (%wt)	O (%wt)	LHV (wet fuel)
8.5	74	17.1	0.3	49.2	5.89	44.5	18.5 $MJ \cdot kg^{-1}$

Bed material characteristics:

Haider and Levenspiel, Powder Techn., (1989) 58, p.63, Eq. 21

Geldart "Gas Fluidizat. Techn.", 1986 J. Wiley & Son - eq 2.27 (dp>100 mm)

Material	Density (kg/m^3)	Amount loaded (kg)	Size (μm)	u_{mf} (m/s)	u_t (m/s)
quarzite	2500	5.0	250	$2.0 \cdot 10^{-2}$	1.7
olivine	3200	6.4	250	$2.8 \cdot 10^{-2}$	2.0
calcined dolomite	1600	3.4	170	$0.6 \cdot 10^{-2}$	0.5
catalyst	1800	3.5	150	$0.5 \cdot 10^{-2}$	0.4

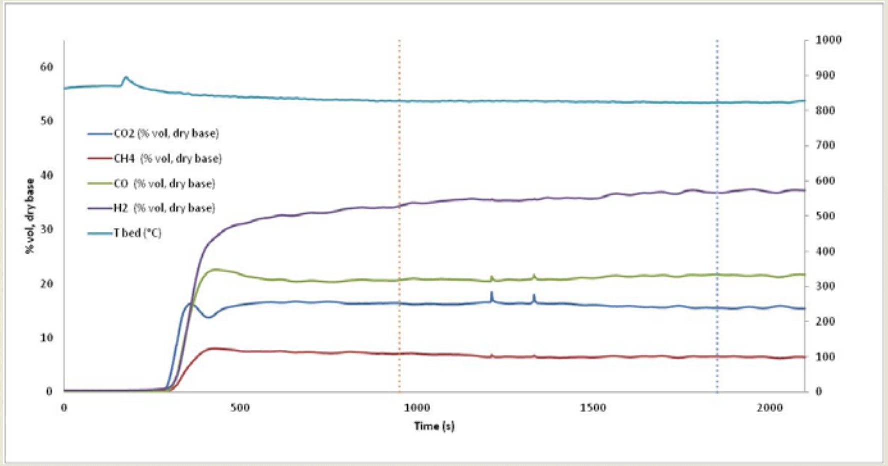
5.5 (wt%)Ni on γ-Al_2O_3 (Sasol) with high mechanical resistence (Ka=0,1) prepared by wet impregnation starting from nickel nitrate and calcined at 850°C. Surface area =156m^2/g. Active phase nickel aluminate

Biomass gasification test: effect of bed material

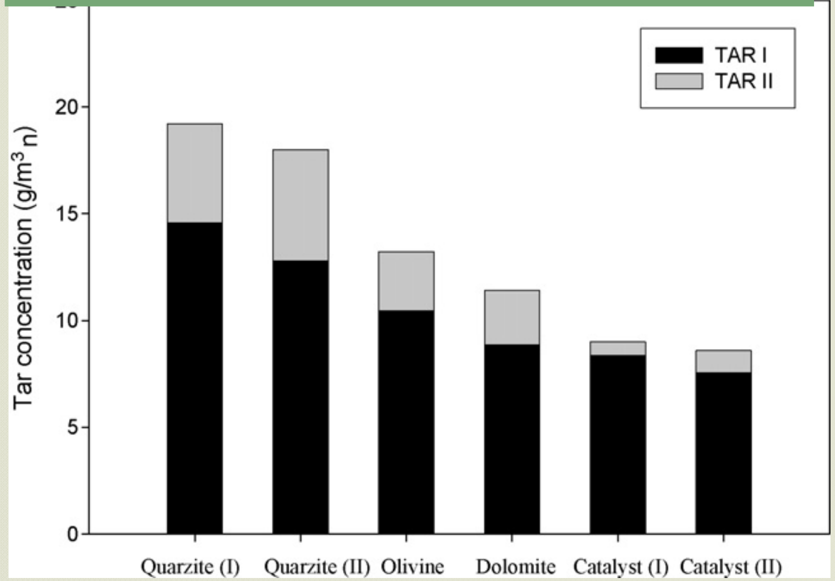
Experimental conditions

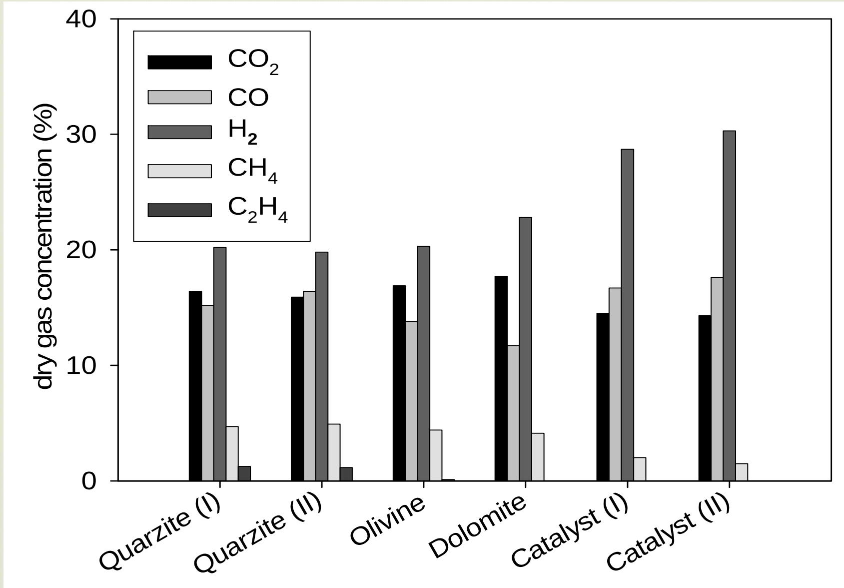
Q_{air}= 2.25 Nm^3
Q_{N2}= 0.6 Nm^3
Q_{fuel}=2.9 kg/h (dry)
Q_{H2O}=1.6 kg/h

T= 780°C
ϕ=0.17
S/B=0.65
u =0.30 m/s
H/D=1.5-2

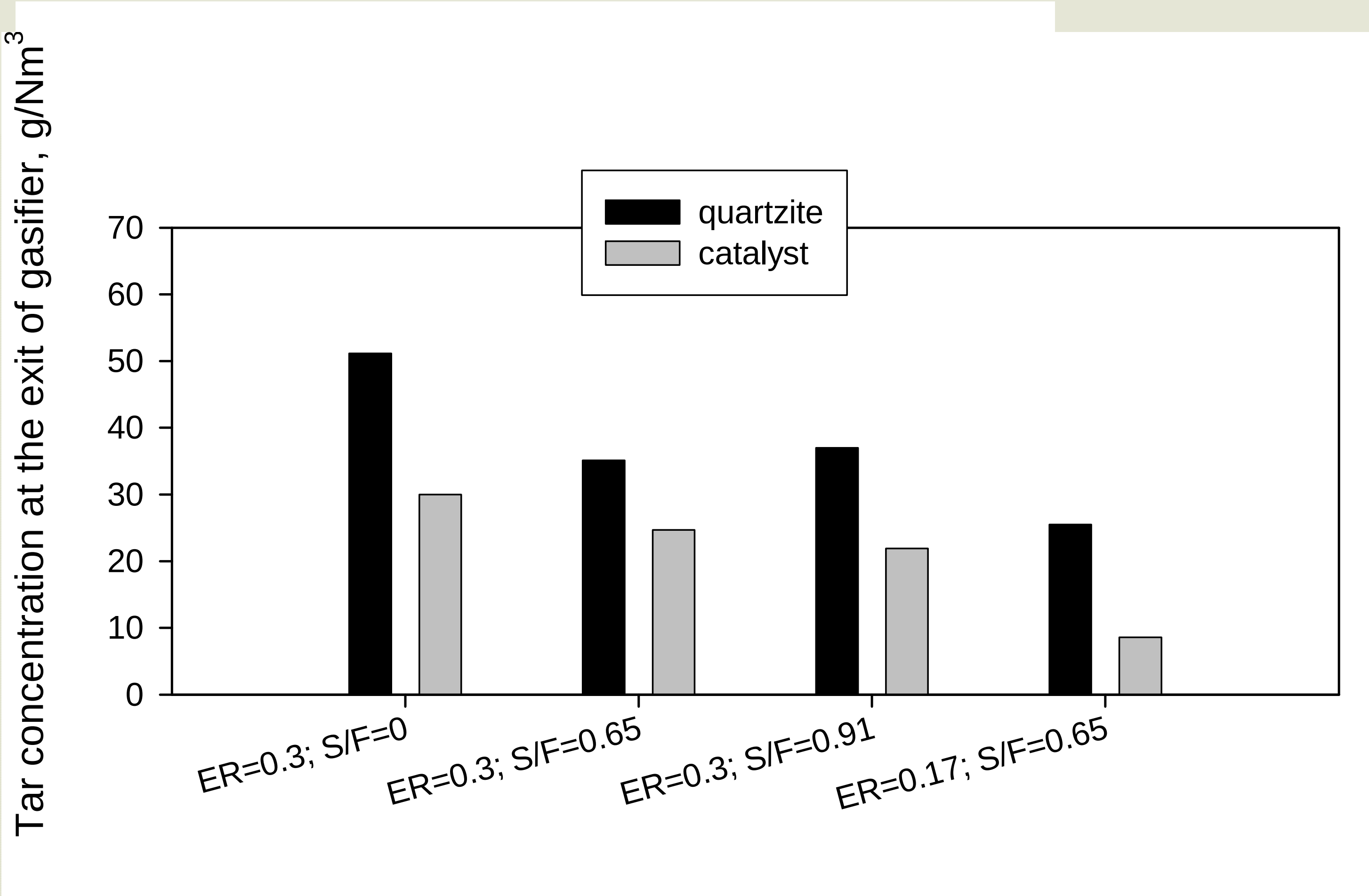


The gas concentration rapidly reached a stable value and no significant deviations were observed for the entire duration of the test.



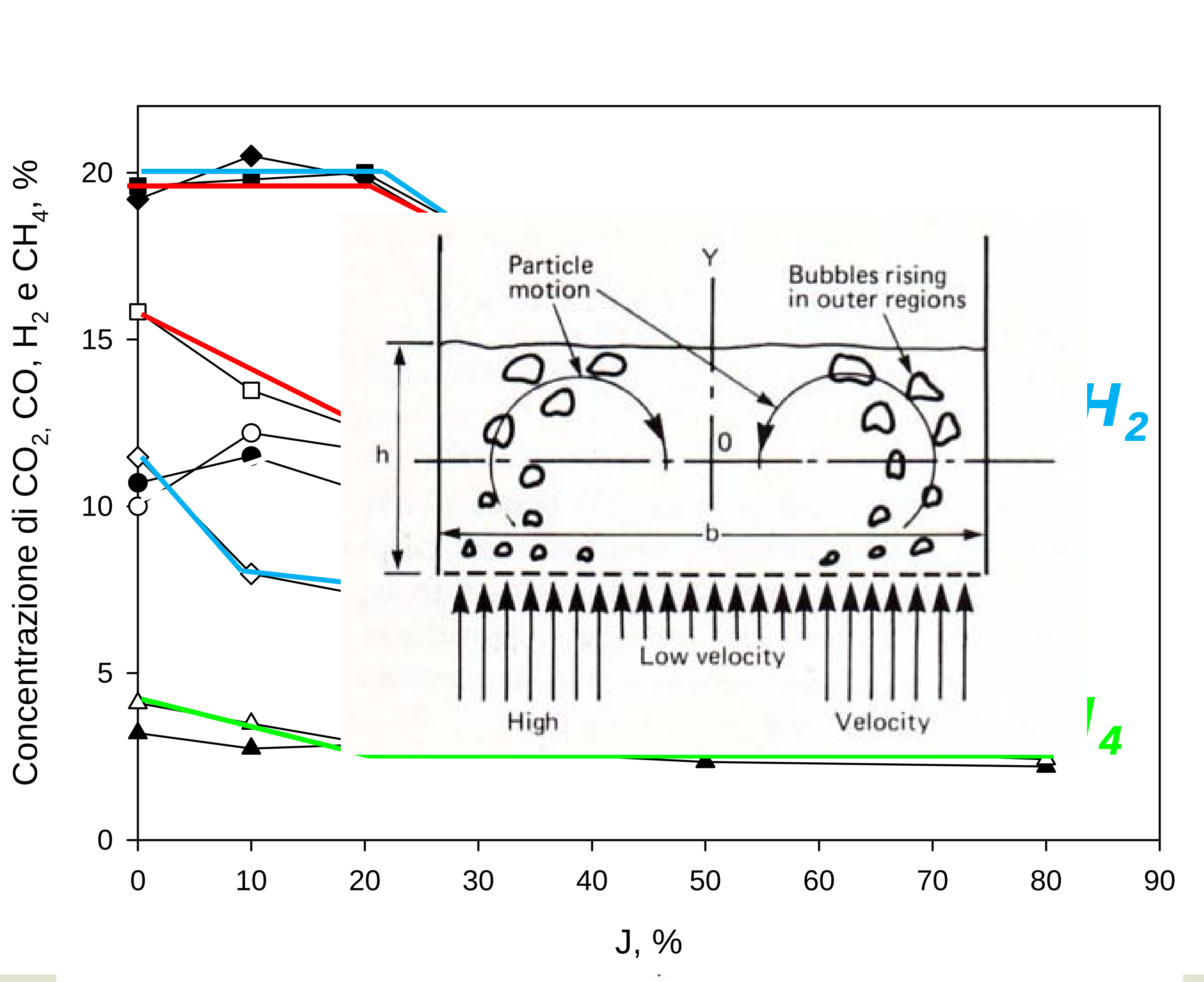


Biomass gasification test: effect of ϕ and S/F ratio

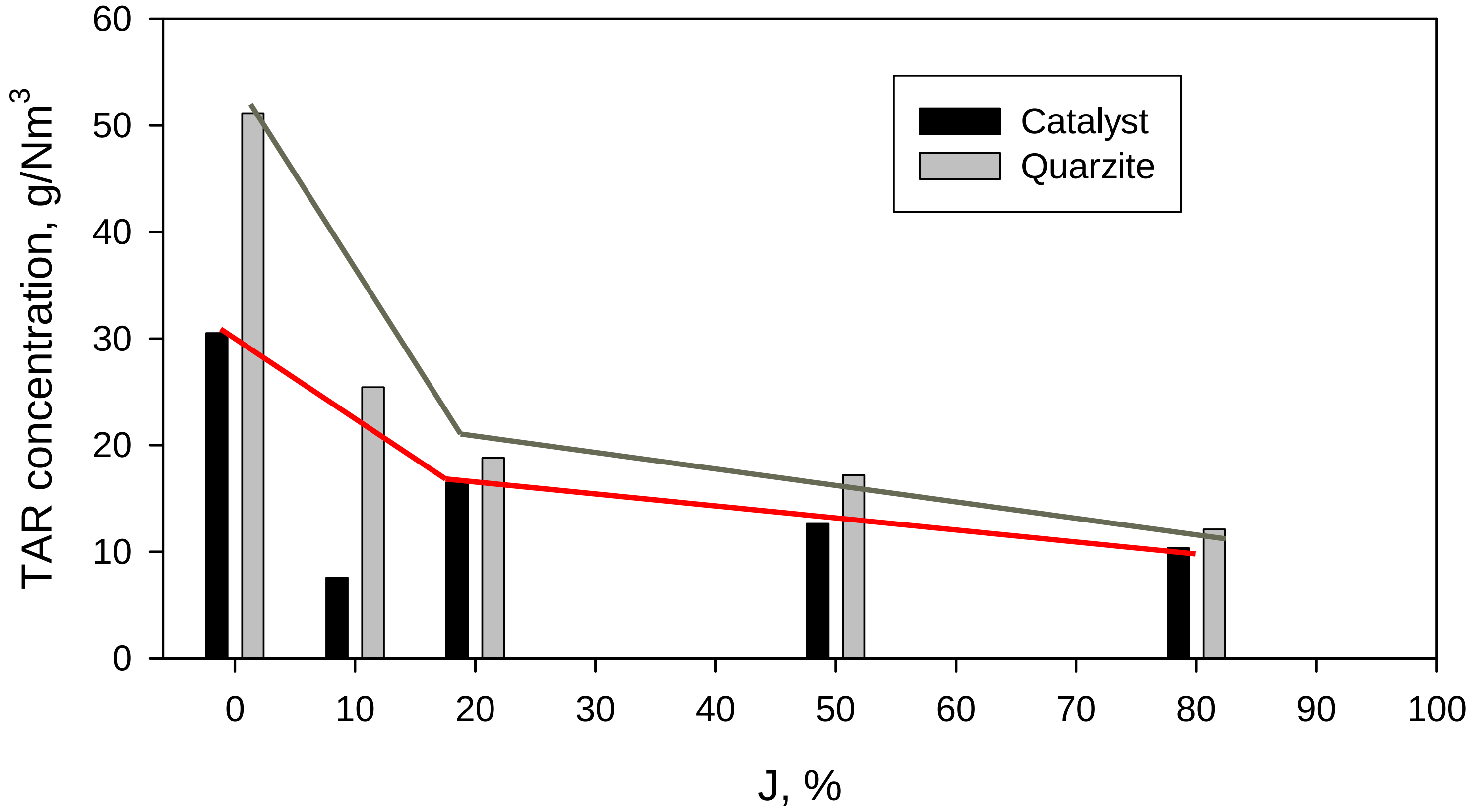


Gasification of biomass
Reducing of segregation phenomena

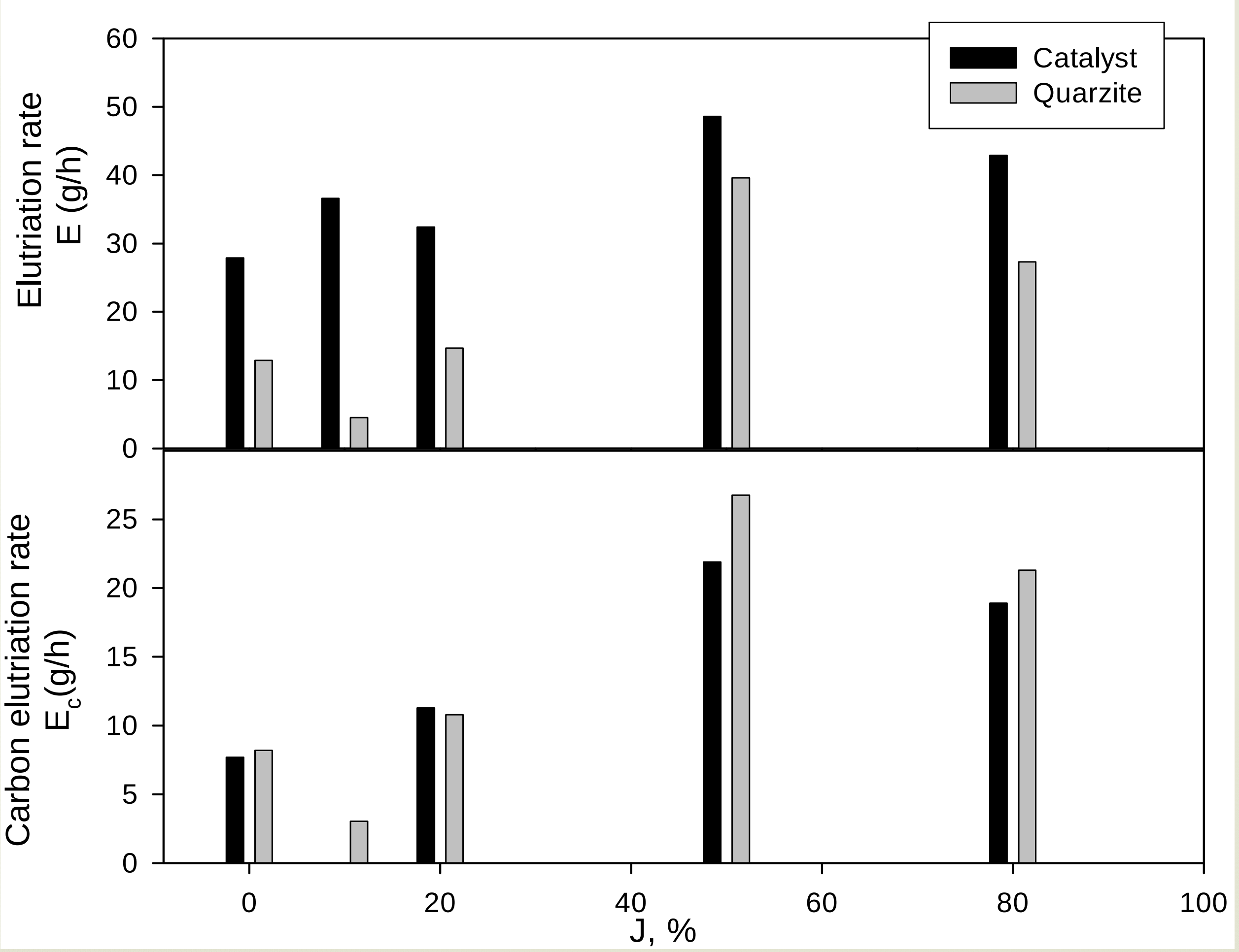
Decreasing of segregation phenomena: adding of a central spout



Effect of j on tar concentration



Effect of j on elutriation rate



Co-gasification
Biomass and coal

option for overcoming the limitation of the low energetic density of biomasses since coal has almost double energetic density and the temporarily lacking of biomass availability due to its seasonality

+

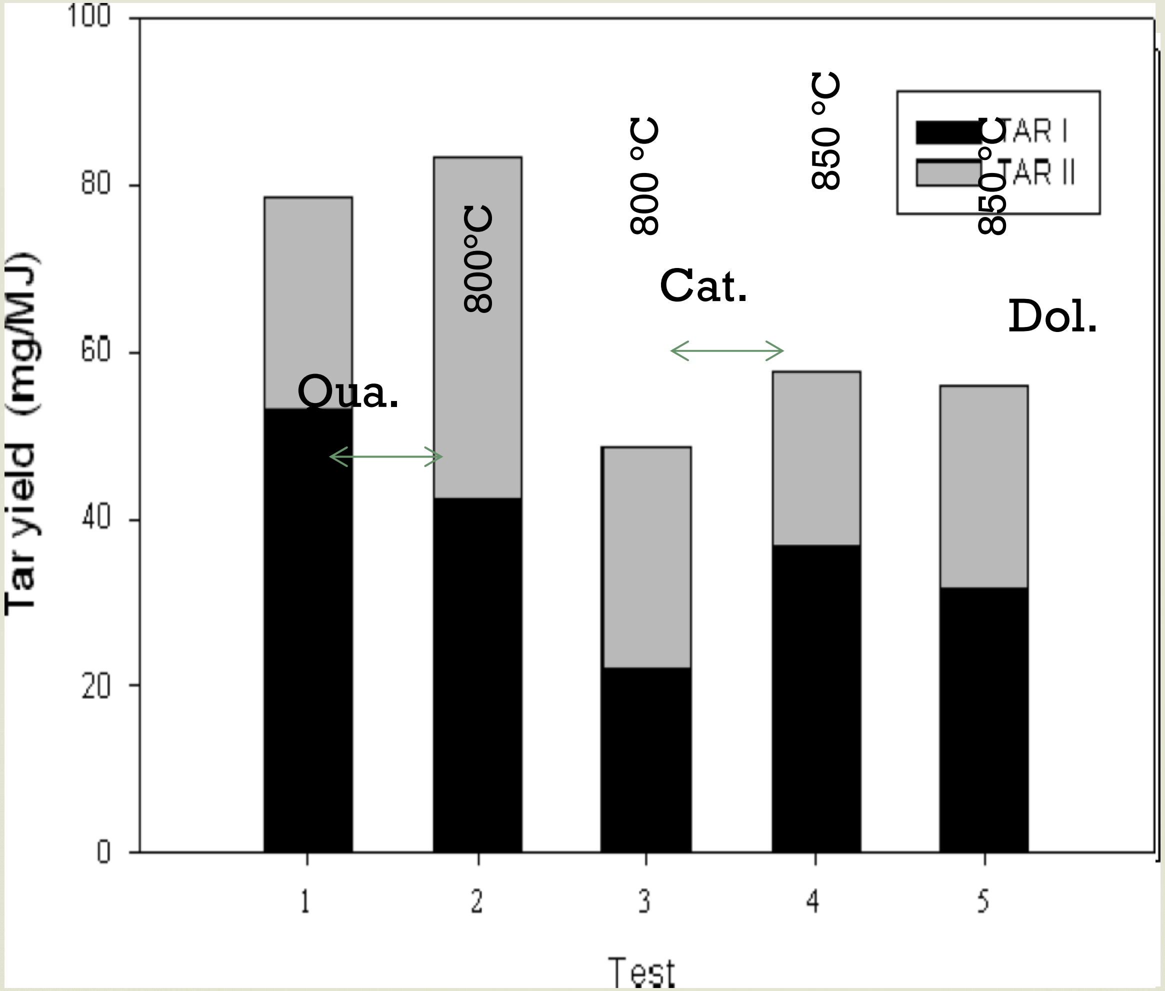
materials

Pelletization of the raw material has shown positive effects in terms of homogenization of the original material

Pelletization can improve the raw fuel mechanical properties and, in turn, the carbon conversion efficiency during fluidized bed conversion

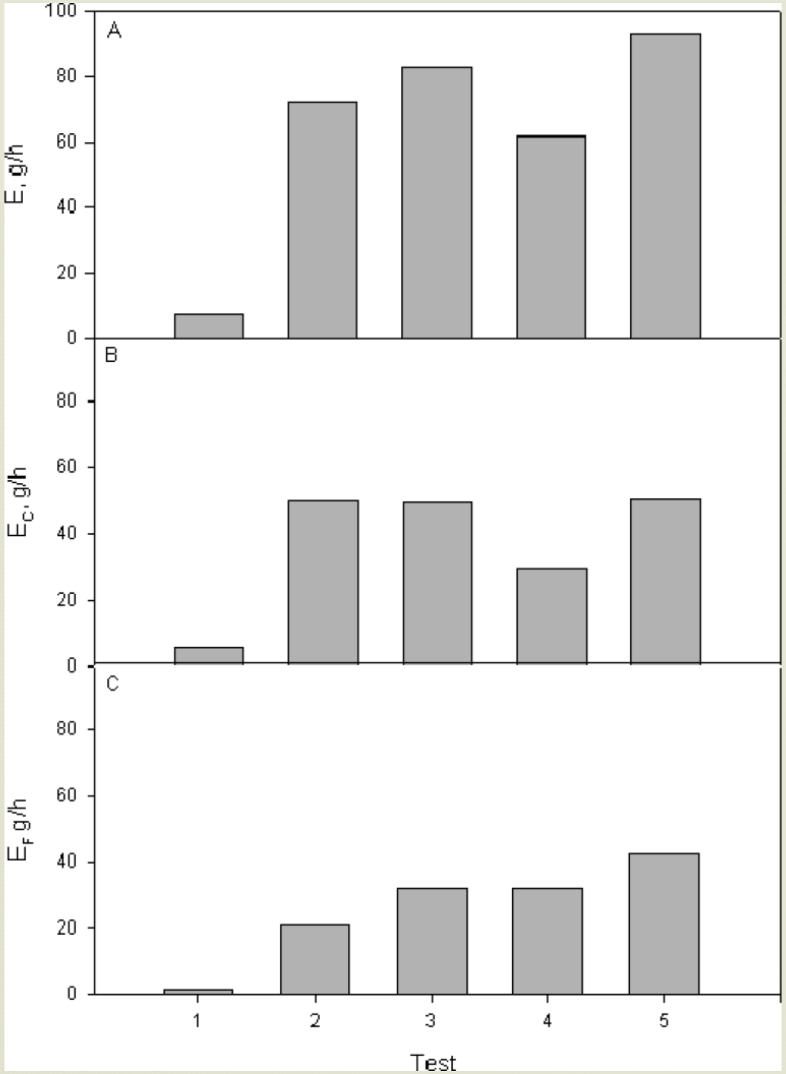
Fuel	Wood pellet	GBC /wood pellet (30% w/w)
Dim. pellet (D x L), mm	6x20	6x20
Umidità, % w/w	8,5	9,4
Volatili, % w/w	74,1	66,7
C Fisso, % w/w	17,1	22,8
Ceneri, % w/w	0,3	1,1
C, % w/w dry basis	49,3	55,1
H, % w/w dry basis	5,9	5,7
N, % w/w dry basis	<0.1	0,1
O, % w/w dry basis	44,4	38
LHV, MJ/kg	18,5	21,7

biomass and coal co-gasification



U = 0.35 m/s, $\Phi = 0.17$, $\Psi = 0.64$.

Fine elutriated



The gasification of wood/coal pellets gives rise to a substantially higher elutriation rate of fine particles with respect to wood pellets, as a consequence of the larger ash and fixed carbon content in the wood/coal pellets as well as the lower char reactivity

Co-gasification
Biomass and waste

The possibility of producing a syngas from residual materials prone for conversion into methanol was analyzed

Materials

Fuel:

Biomass (75wt%): Dry olive husk produced in substantial amounts in the Campania *region (75wt%)*

Waste (25wt%): Polyethylene Terephthalate (PET) from packaging of drink bottles and Tyre granules, obtained by proper demolition of automobile.

Bed material:

γ-Alumina prevents the agglomeration phenomena associated with the use of olive husk

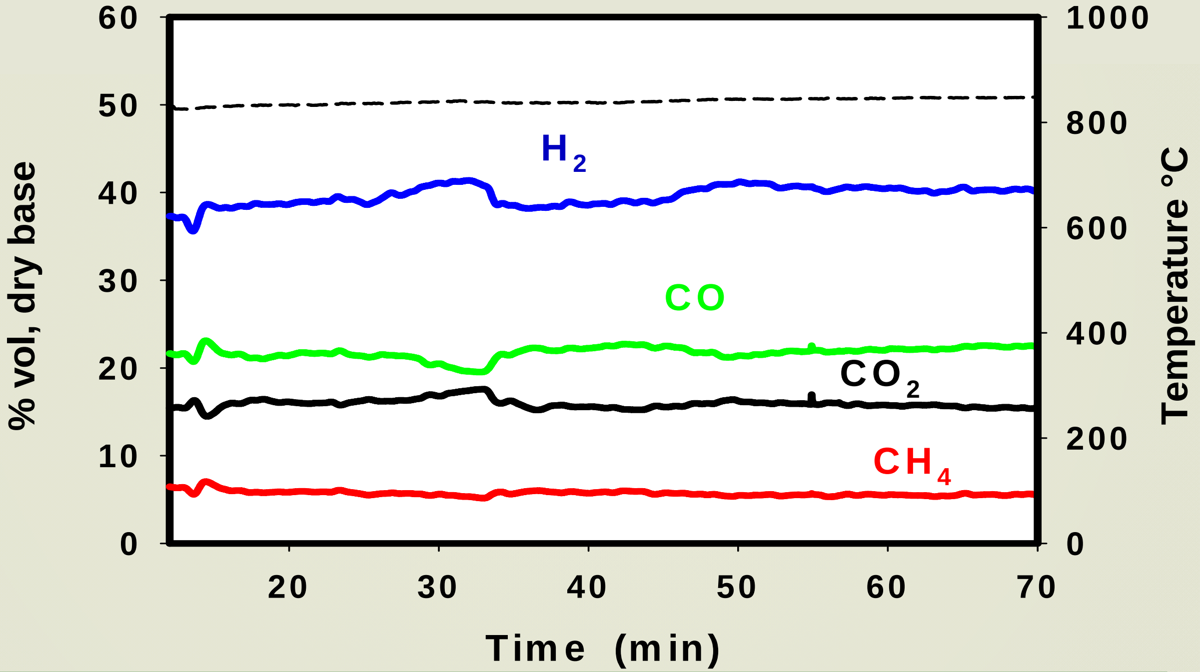
Mixed Al and Ni/γ-Al2O3 (60%wt).
Non different performances with the 100%wt catalyst

FUELS	*OH* 	*OHPET* 	*OHTYRE* 
Pellets dimensions (diameter x length), mm	6 x 20 	6 x 20 	6 x 20 
Moisture, wt.%	8,9	6.2	14. 8
Volatiles, wt.%	68,2	74. 5	63.2
Fixed carbon, wt.%	19,7	16.6	17.9
Ash, wt.%	3,2	2.7	4.1
Carbon, wt.% on dry basis	55,2	59.3	53.3
Hydrogen, wt.% on dry basis	5,9	7.2	6.1
Nitrogen, wt.% on dry basis	1.0	0.4	0.5
Oxygen, wt.% on dry basis	37,9	33.1	40.1
Low heating value, MJ/kg	19,3	22.8	22.3

Results: gas profiles

Temperature range:750-850°C
S/F range: 0.6-1
ER=0.1
Unexpanded Bed height: 0.18m

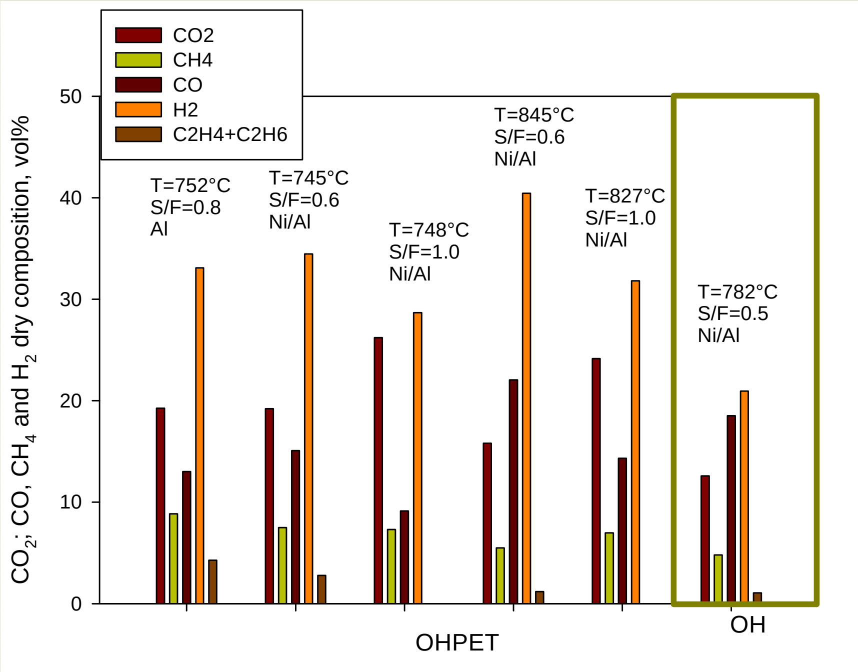
OHPET and the Ni base catalyst at 827°C ER=0.1 and S/F=1.0

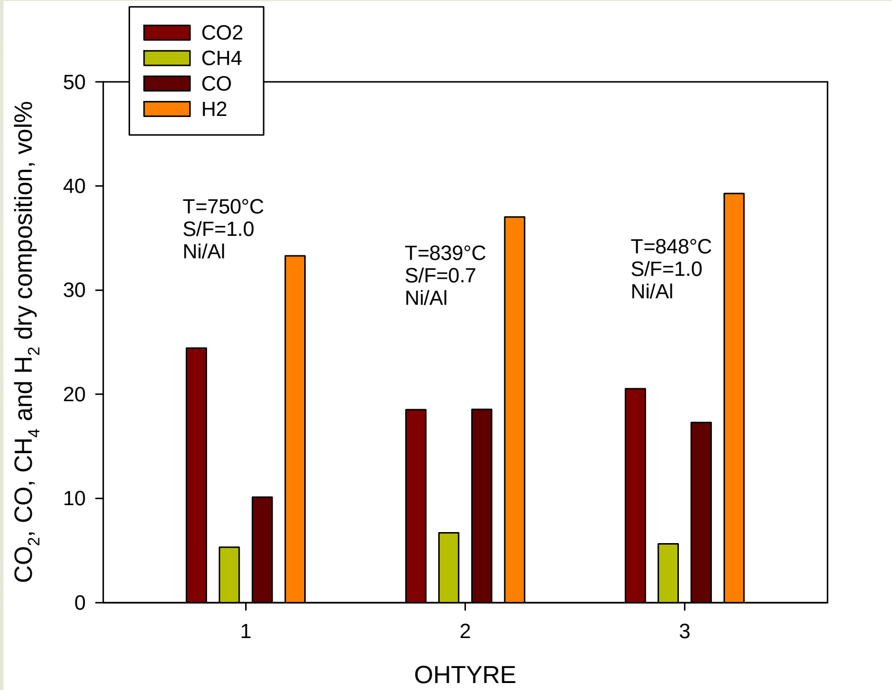


A stable state observed for the all time suggests that whatever are the adopted experimental conditions:

- No problems in the fuel feedstock handling and metering devices.
- agglomeration problems do not occur
- catalyst deactivation does not occur

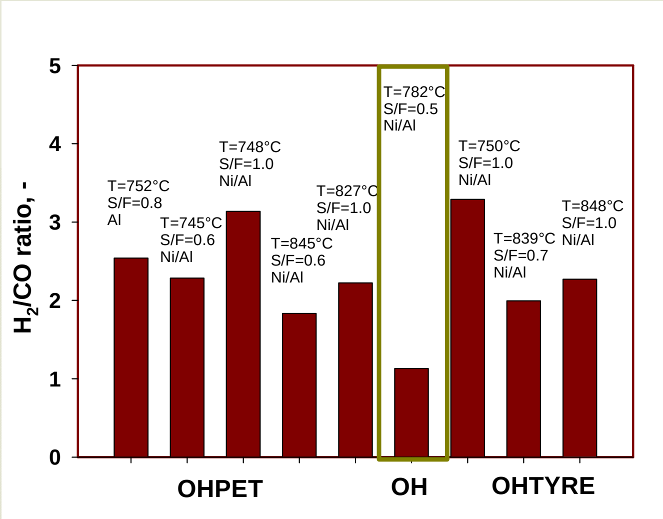
Results: average gas composition

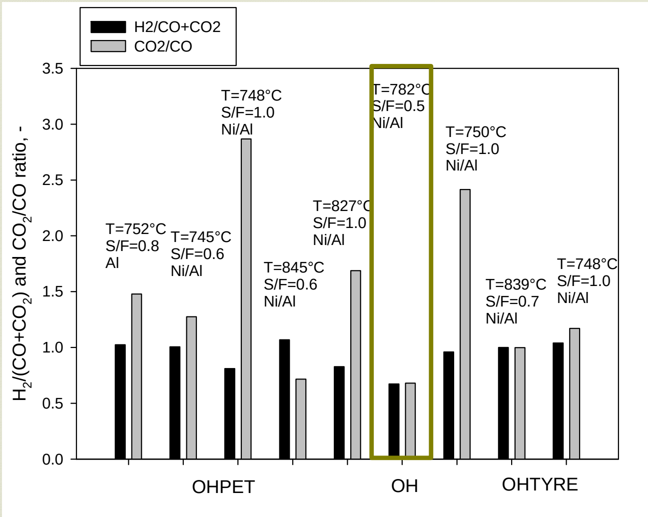




The presence of PET and TYRE strongly enhances the H_2 production

Results: quality of syngas



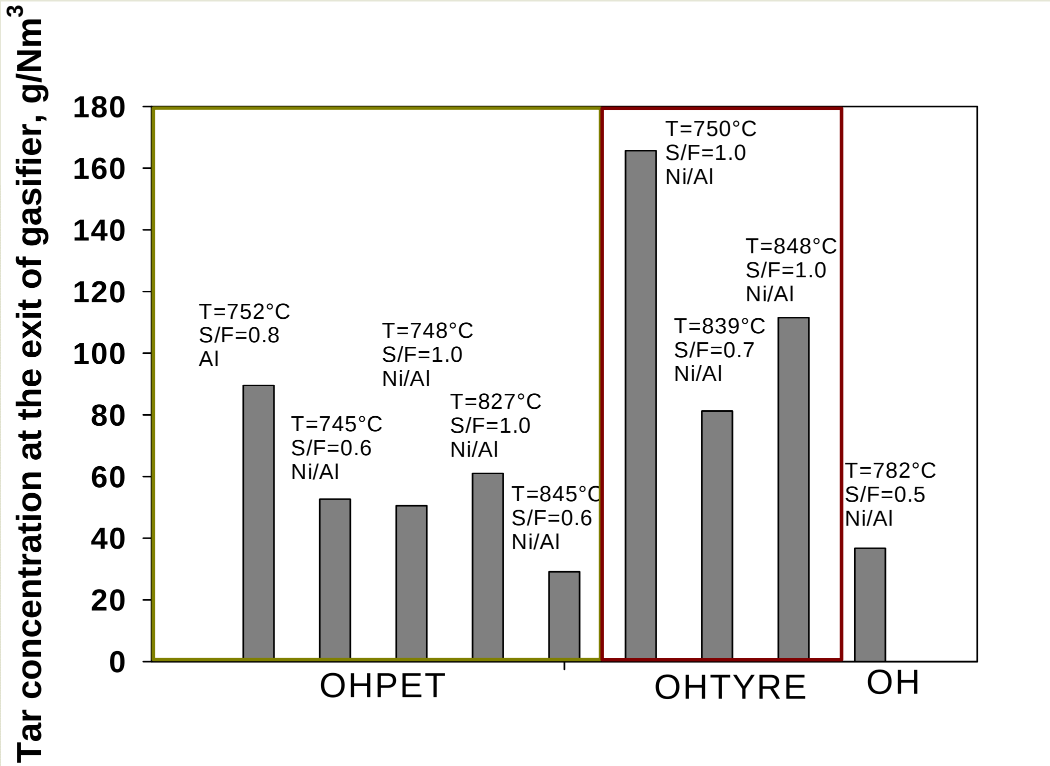


- The H_2/CO ratio is always higher than that obtained with the olive husk pellet confirming that the co-gasification is a suitable strategy to produce a syngas with the H_2/CO required for the methanol synthesis

- The yield of methanol is sensitive to the $H_2/(CO + CO_2)$ ratio, while the selectivity to the CO_2/CO ratio

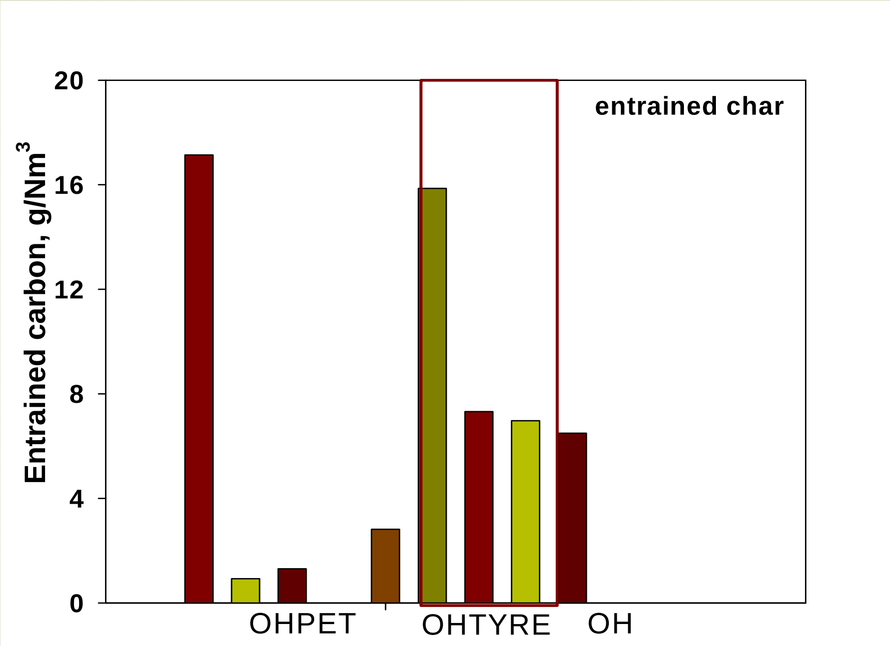
When the CO_2/CO ratio is >1, the selectivity of methanol decreases sharply
With a partial removal of CO_2 can be changed greatly the CO_2/CO in the feed gas

Results: tar analysis



- The level of tar decreases as the temperature increases.
- The presence of catalyst reduces the amount of tar.
- The tar decrease is reflected in an higher formation of light hydrocarbons C_2H_6 and C_2H_4.

Entrained char



- The temperature increase reduces the carbon elutriated
- The OHPET pellets show a lower carbon elutriation rate probably due to the higher reactivity of the fuel component

Conclusions

- The presence of a catalytic bed, especially in the case when an "ad hoc" reactor configuration is used: adoption of a central jet in addition to the conical distributor, increases hydrogen rich syngas yield and decreases tar production. However some expected negative effects of such configuration on attrition phenomena has been highlighted.
- The effect of equivalent ratio and the presence of steam affect the performance of gasifier less than the presence of catalyst provided that the segregation phenomena are negligible.
- The use of pellets results into beneficial effects on solid particles emissions but when mixed pellets are used there is an important role played by properties of the parent fuels
- Among the mixed pellet tested, the biomass/plastic pellets exhibited promising results in terms of the hydrogen yield even if they suffered from a higher production of TAR

Thank you for the attentions

References

Paola Brachi, Riccardo Chirone, Francesco Miccio, Michele Miccio, Antonio Picarelli, Giovanna Ruoppolo (2014) Fluidized bed co-gasification of biomass and polymeric wastes for a flexible end-use of the syngas: Focus on bio-methanol in Fuel

Giovanna Ruoppolo, Francesco Miccio, Paola Brachi, Antonio Picarelli, Riccardo Chirone (2013) Fluidized Bed Gasification of Biomass and Biomass/Coal Pellets in Oxygen and Steam Atmosphere in Chemical Engineering transactions

G. Ruoppolo, P. Ammendola, R. Chirone, F. Miccio (2012) H2-rich syngas production by fluidized bed gasification of biomass and plastic fuel in Waste management

Ruoppolo, G; Miccio, F; Chirone, R (2010) Fluidized Bed Cogasification of Wood and Coal Adopting Primary Catalytic Method for Tar Abatement in Energy & fuels