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Tar removal from biomass producer gas by using biochar

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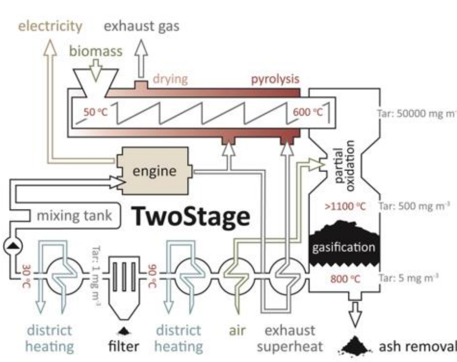
Which biochar?

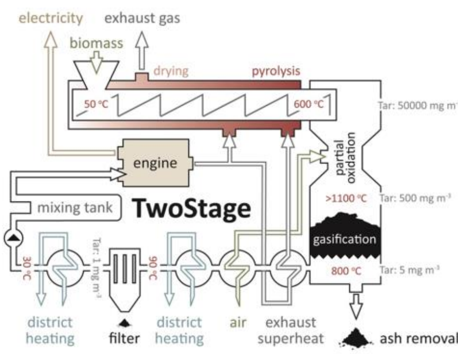
- Solid residue from most gasification processes is rich in carbon, and can be defined as "**biochar**"
- Is continuously produced in the gasification process, therefore is a **readily available** and **cheap material**
- If used as bed material for gas cleaning, spent biochar can be recycled within the system and gasified along with fresh feedstock

➢ Experience with the TwoStage process at DTU shows that a char bed can be very effective in removing tars from producer gas



Why biochar?

- The "Viking" gasifier at DTU, Risø is a TwoStage gasification plant (80 kW_{th}) which has been operated for more than 3000 hours
- This gasifier is able to generate a virtually tar-free gas (<1 mg/Nm^3)
- The "Viking" gasifier uses only a bag house filter for gas cleaning, maintaining a cold gas efficiency of 93%.
- Producer gas from the "Viking" gasifier has been applied successfully to both gas engine operation and fuel cell stacks

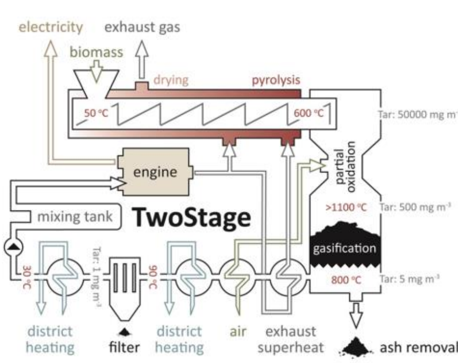


(Ahrenfeldt, J. et al., 2006)

(Gadsbøll, R.Ø. et al., 2017)

Research question

- Why the gas cleaning is so effective in the TwoStage process?
- What is the role of the fixed char bed in tar decomposition?
- Can this effect be replicated and applied to other gasification platforms?



Research question

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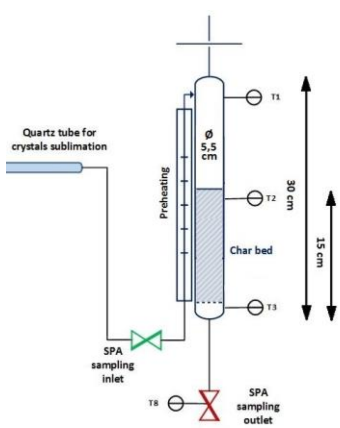
1. Dedicated **laboratory setup** to investigate the interaction between a **bed of residual biochar** and tar model compounds **(phenol, naphthalene)**

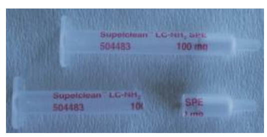
2. Physical and chemical **characterization** of the TwoStage residual char

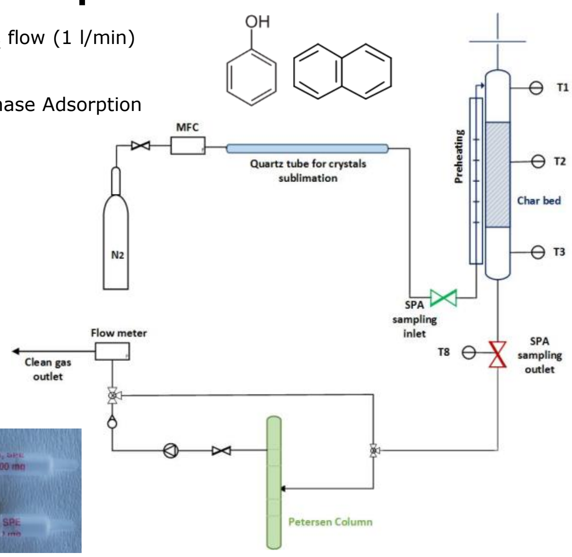
Char bed testing setup



Char bed testing set up

- Model compounds: sublimation in N_2 flow (1 l/min)
- Contact with hot biochar bed
- Inlet + outlet gas sampling: Solid Phase Adsorption (SPA) tubes and Petersen Column





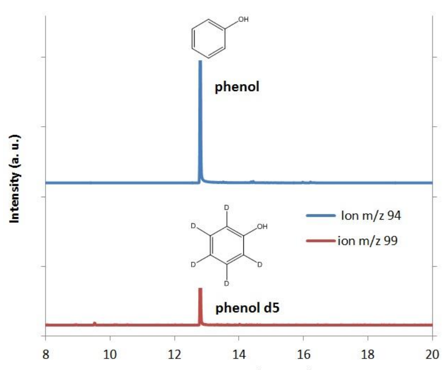
Stable isotope dilution analysis

Petersen
Sample dissolved in acetone

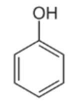
SPA
Cartridge desorbed in acetone

- Labelling with deuterated compounds (d5, d8)
- GC-MS analysis

Compound concentration in the gas [mg/m^3]



Results – Phenol

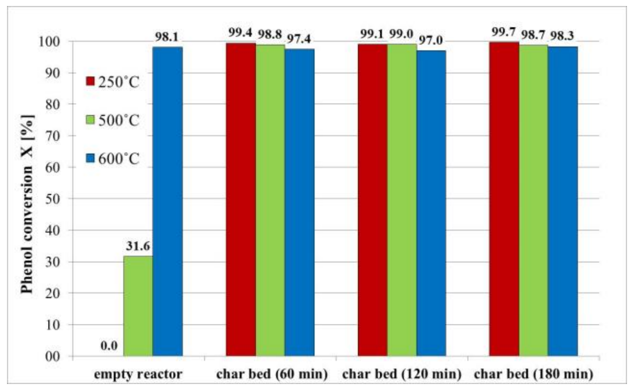


Experiments conditions:

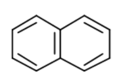
- Tested char bed temperatures: 250˚C, 500˚C and 600˚C
- Phenol concentration measured at inlet: C_{in} = 572 ±110 mg/Nm^3
- Reactor conditions: Empty reactor, char bed (30g)
- Residence time: 10.4s (250˚C), 7s (500˚C) and 6.2s (600˚C)

- Degree of conversion (X) calculated with SPA values

$$X = \frac{C_{in} - C_{out}}{C_{in}}$$



Results – Naphthalene

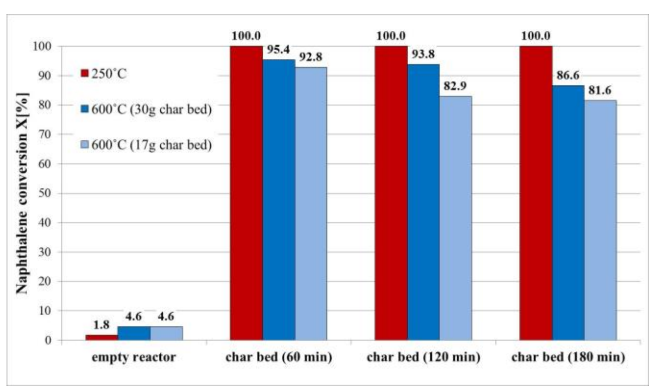


Experiments conditions:

- Tested char bed temperatures: 250˚C, 600˚C
- Naphthalene concentration measured at inlet: C_{in} = 234 ±37 mg/Nm^3
- Reactor conditions: Empty reactor, char bed (30g and 17g)
- Residence time: 10.4s (250˚C), and 6.2s (600˚C) and 2.7s (600˚C, 17g char bed)

- Degree of conversion (X) calculated with SPA values

$$X = \frac{C_{in} - C_{out}}{C_{in}}$$



Char characterization

- Proximate composition
- Elemental composition (C,H,N,S)
- Brunauer-Emmett-Teller (BET) specific surface area, total pore volume
- Scanning Electron Microscopy coupled with Energy Dispersive Spectroscopy (SEM-EDS)
- Particle size evaluation

Composition

Proximate composition		Method
Volatiles (db%)	6.8	CEN/TS 15148
Fixed carbon (db%)	79.6	
Ashes (db%)	13.6	DIN EN 14775
Elemental composition		
C (wt%)	78.0	VarioEl, Elementar Analysensysteme GmbH, Germany
H (wt%)	0.07	
N (wt%)	0.82	
S (wt%)	0.15	
Σ PAH (mg/Kg^{-1})	0.69	(Hansen et al, 2015)

- High weight percentage of carbon
- Low PAH (*Acenaphthene, Fluorene, Phenanthrene, Fluoranthene, Pyrene, Benzo(bjk)fluoranthene, Benzo(a)pyrene, Indeno(1,2,3-cd)pyrene and Benzo(ghi)perylene*) contamination due to the high temperature separation of the solid residue from the producer gas

BET surface area, total pore volume

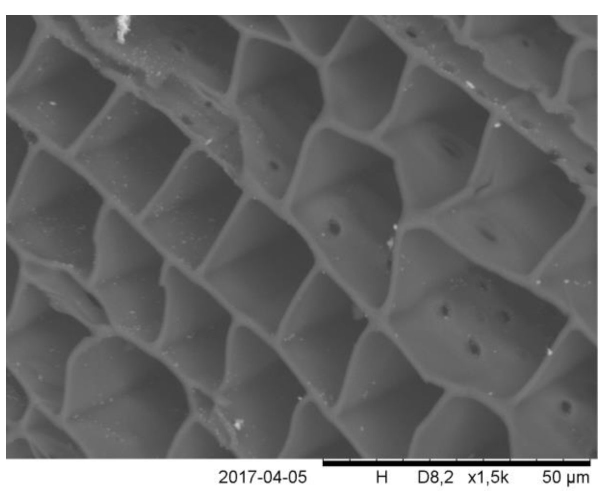
The specific surface area of the char was determined by the Brunauer-Emmett-Teller (BET) method by nitrogen gas sorption at 77 K

	Particles > 1mm	Particles < 0.5 mm	Non-sieved sample
Weight fraction of total sample (%)	62	28	100
BET specific surface area (m^2/g)	1126	495	1030
Total pore volume (cm^3/g)	0.78	0.61	0.75

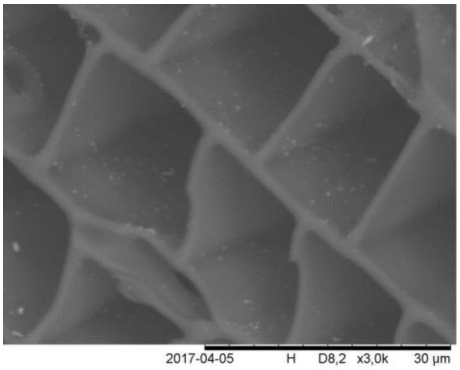
	Feedstock	Technology	Gasifying agent	Nominal power	T (°C)	S_{BET} (m^2/g)
A	wood chips	downdraft	air	45 kWel 120 kWth	~650	352.41
B	pellets	rising co-current	air	180-190 kWel 220-240 kWth	~700	127.67
C	wood chips	downdraft	air	100-150 kWel 200-250 kWth	~650	77.90
D	wood chips	downdraft	air	300 kWel 600 kWth	~800	281.23
E	wood chips	dual stage gasifier	air	50 kWel 80 kWth	~900	586.72

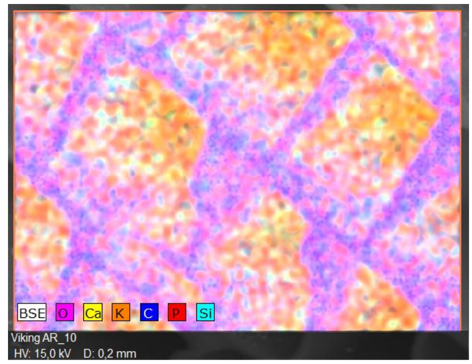
(Benedetti, V., Patuzzi, F. & Baratieri, M., 2016)

Scanning Electron Microscopy - SEM



SEM -Energy Dispersive Spectroscopy (EDS)





- Inorganics detected: Calcium, Potassium, Silicon

Conclusions

- Residual char has a significant effect on removing tar model compounds (phenol and naphthalene) at all tested temperatures.
- The nature of the interaction between char and model tars is probably limited to physical adsorption at these temperatures. This is confirmed by the diminished effect on naphthalene at 600°C.
- The bed temperature is expected to influence the irreversibility of the tar-char interaction. Further experiments up to 800°C will be performed with the objectives of
  1. optimizing tar removal
  2. maximizing conversion into stable gases (CO, CO_2,H_2)
- Residual char from the "Viking" TwoStage gasification plant has characteristics comparable to activated carbons, in terms of BET surface area and pore volume

→ Further experimental work will be performed contacting the residual biochar with real producer gas with a high tar load.

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Thank you for your attention

Questions?

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