RESULTS OF CARDOON GASIFICATION IN FLUIDEZED BED

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FUEL ANALYSIS

Comparison of Various Cynara Samples

Moisture = 36.1% as received

Proximate Analysis	Arundo	Cardoon (Stem) Apariça	Cardoon (Whole) Apariça	Cardoon (Whole) Sesimbra	Cardoon WET (Whole) Apariça
Moisture (% w/w)	8.2	13.1	9.8	7.0	13.1

CHARACTERISTICS OF INSTALLATIONS

Gasification Bench Scale	
Gasifier Total Height (mm)	1 500
Bed Diameter (mm)	80
Bed Height (mm)	100
Distributor plate	12 injectors x 4 holes
Heating Method	Electric
Feeding Method	Calibrated Screw Feeder
Feeding Auxiliary Gas	Nitrogen

GASIFICATION BENCH SCALE

Fluid Bed Gasifier

Main Components

- Feeding system (water cooled)
- Gasification unit
- Cleaning and gas quenching unit
- Measure and gas analysis unit
- Steam generation system
- Temperature and pressure control

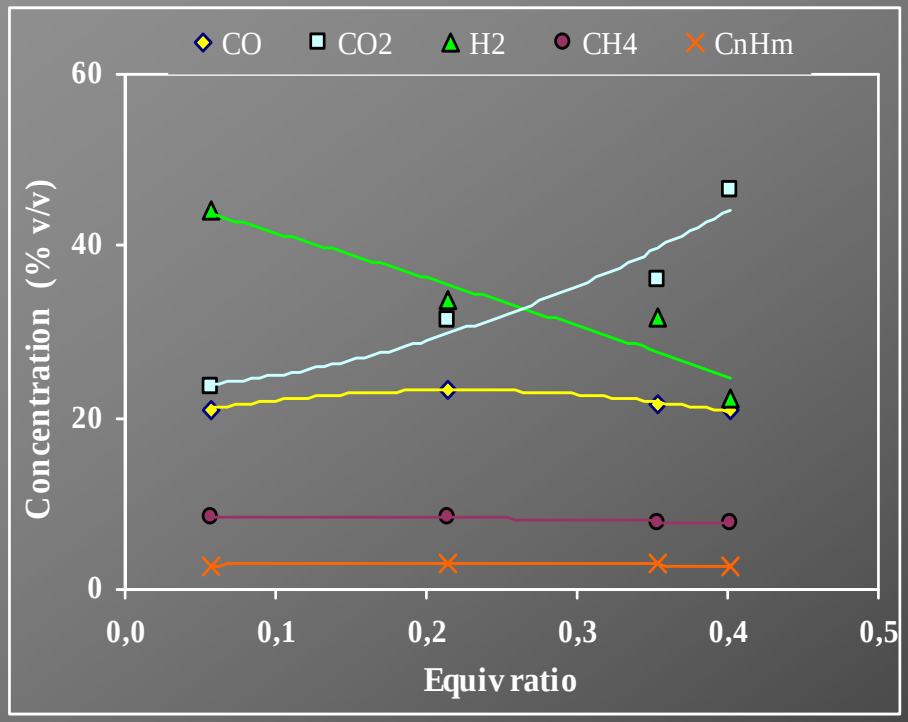
OPERATING CONDITIONS

Bench Scale

Reaction temperature (ºC)	850
Freeboard temperature (ºC)	850
Fuel mixture flow rate (g/min)	5.0
Particle size (µm)	Pellets
Pressure	Atmospheric
Steam flow rate (g/min)	1.2 – 5.8
Air flow rate (g/min)	1.35 – 10.70
Steam/fuel mixture ratio	0.25- 1.25
Equivalence ratio	0.06 – 0.40

CYNARA GASIFICATION RESULTS

- *Effect of air ratio*
  - *Gas Composition*



100% Cardoon ; T=850 ºC; steam/fuel =0.85

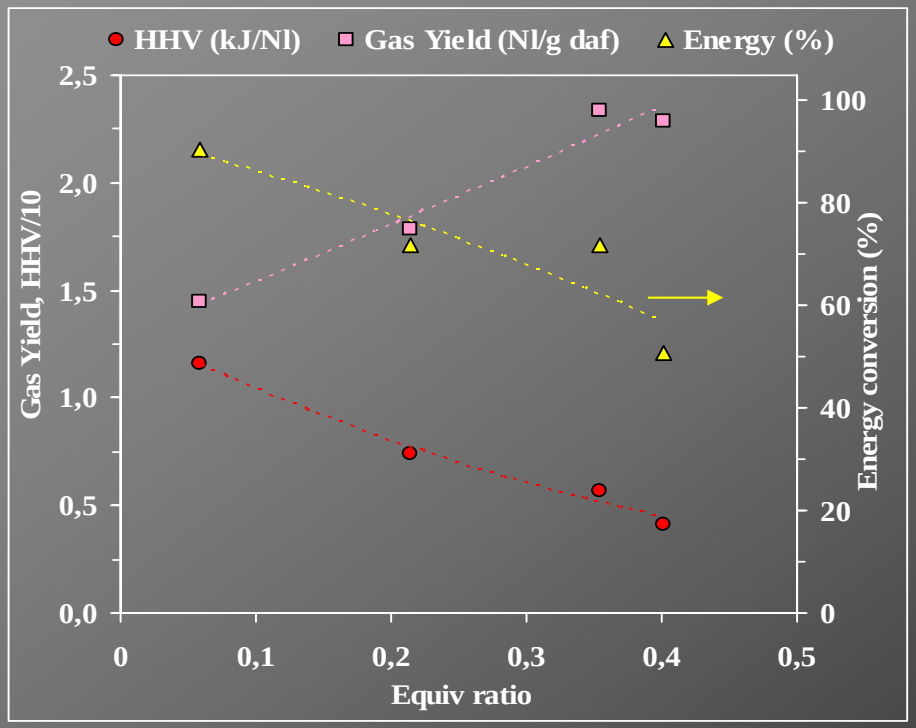
Comments

➢ The evolution of gas composition with the increase of air flow rate (higher ER) is typical of what is usual to obtain in biomass gasification.

➢ In fact, the rise of ER led to a decrease of H_2 and an increase of CO_2 as would be expected, due to the partial combustion reactions. However no noticeable changes were observed regarding CO and hydrocarbons contents.

CYNARA GASIFICATION RESULTS

- *Effect of air ratio*
  - *GY, HHV and EC*



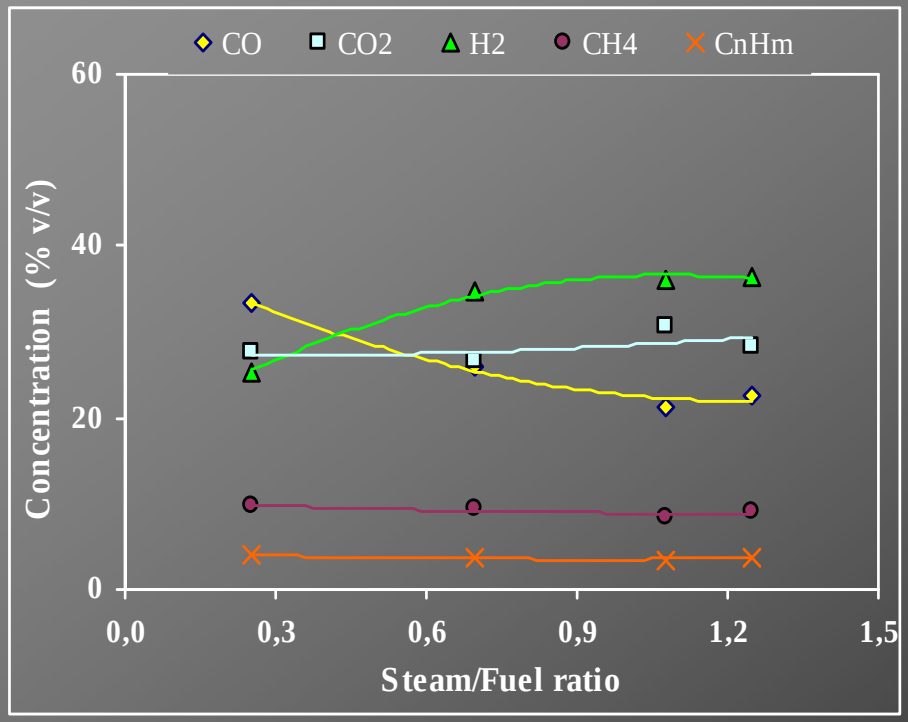
100% Cardoon ; T=850 ºC; steam/fuel =0.85

Comments

- The gas yield and HHV presented a very strong dependence on ER as expected. The rise of air flow rate produces a gas with a lower calorific value but the amount of gas produced is much higher, mainly due to the dilution effect of N_2 .
- As the increase in gas yield was not enough to compensate the decrease in heating value the energy conversion decreases as the ER increases.

CYNARA GASIFICATION RESULTS

- *Effect of steam ratio*
  - *Gas Composition*



100% Cardoon ; T=850 ºC

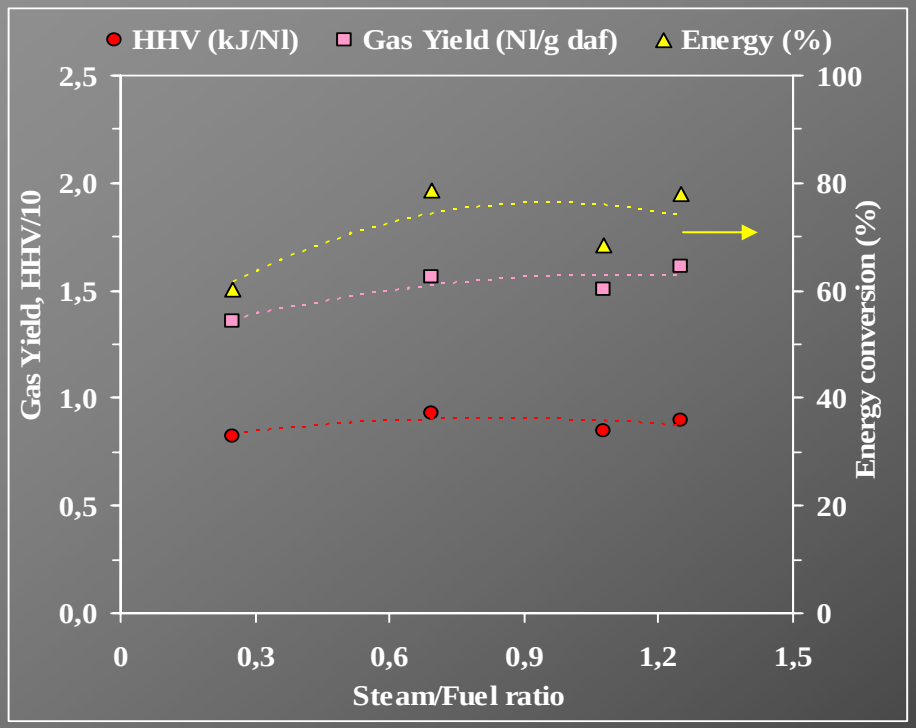
Comments

➢ The variation of gas composition as a function of steam flow rate, also follows the tendencies observed in the gasification of biomass or coal.

➢ When more steam is used the gasification reactions of carbon with steam and the water gas shift reaction are more effective producing more H_2 and CO_2 and less CO. Also a decrease in hydrocarbons should be obtained due to the steam reforming reactions, which were not observed.

CYNARA GASIFICATION RESULTS

- *Effect of steam ratio*
  - *GY, HHV and EC*



100% Cardoon ; T=850 ºC; ER = 0.15

Comments

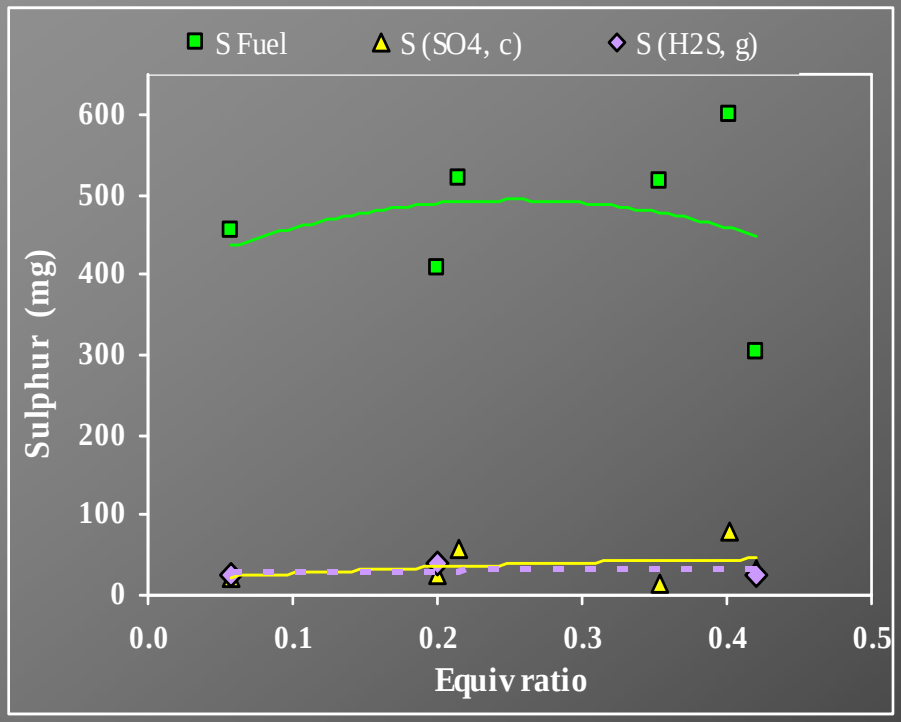
- The gas yield and HHV presented a much lower dependence on steam/fuel ratio as expected. The increase of steam flow rate till a certain value produces a greater amount of gas with a higher calorific value in the gasification process.

- It was observed that the gas yield, energy conversion and calorific value increases with steam/biomass ratio till values around 0.6, while for values above 0.6 no noticeable changes were observed in gasification parameters.

CYNARA GASIFICATION RESULTS

- *Effect of air ratio*

- *SO_4 in Raw and H_2S in Clean Gas*



100% Cardoon ; T=850 ºC; steam/fuel =0.85

Comments

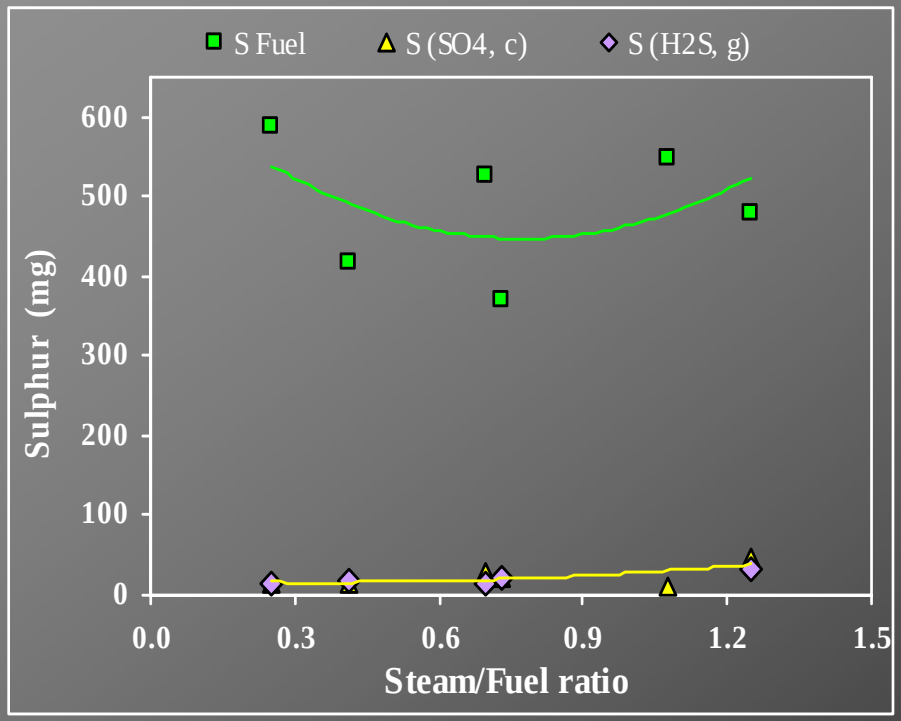
- No clear effect of ER over sulphur condensation was observed in the runs carried out.

- The balance on sulphur showed that the quantity of S condensed in the quenching system is very low. The maximum value obtained was around 15%.

- The values of H_2S obtained at different ER are very low varying between 25-40 mg.

CYNARA GASIFICATION RESULTS

- *Effect of steam ratio*
  - *SO_4 in Raw and H_2S in Clean Gas*



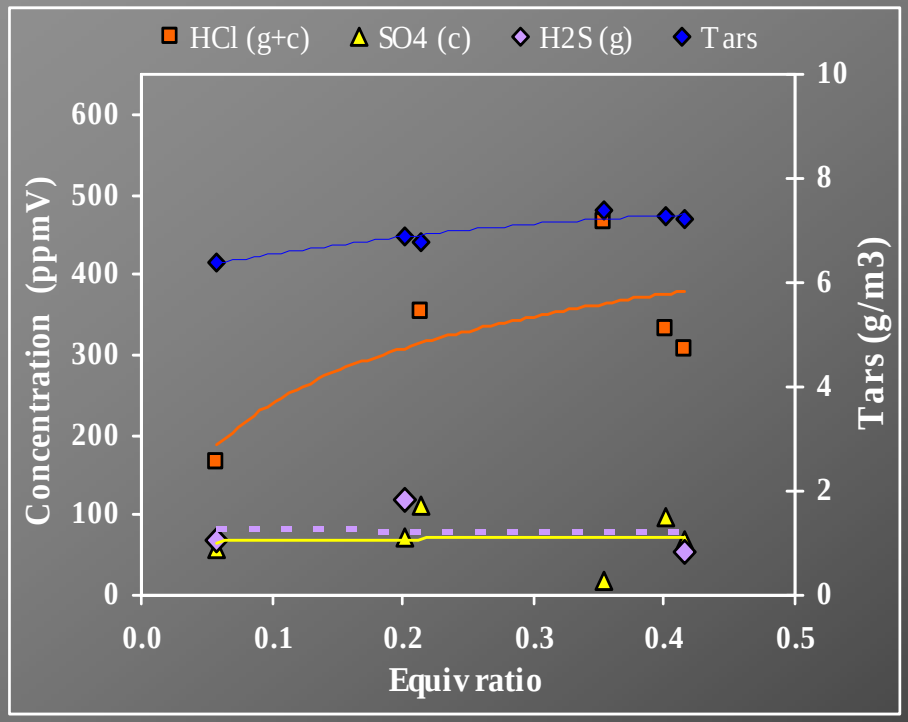
100% Cardoon ; T=850 ºC; ER = 0.15

Comments

- As can been seen the increase in steam flow rate does not have significant influence in the sulphur retained in the quenching system, besides a small increase tendency.
- The values of H_2S obtained for different steam/cardoon ratio are still low, besides a small increase tendency.
- The balance on sulphur showed that the quantity of S condensed in the quenching system is very low. The maximum value obtained was around 10%.

CYNARA GASIFICATION RESULTS

- *Effect of air ratio*
  - *Cl, S and H_2S in Gas*



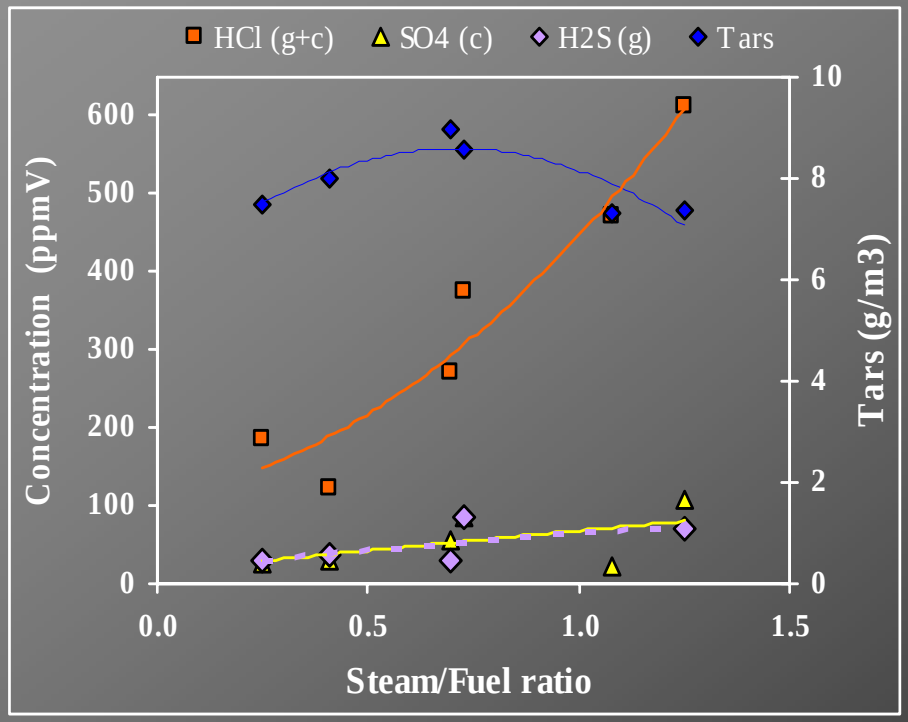
100% Cardoon ; T=850 ºC; steam/fuel =0.85

Comments

- Analysis carried out over "clean" gas (after condenser) shows that the Cl and SO_4 content are nearly zero, which means that practically almost chlorine (as HCl) and sulphur (as SO_4) are condensed in the quenching system.
- The chlorine content in gas seems to increase with ER for the lower values of this parameter.
- The tars content (around 7 g/m^3) in "raw" gas is similar to those obtained with other kind of biomasses and lower than values of coal or plastics.
- The values of H_2S (in gas) and SO_4 (condensates) do not show significant variations with equivalence ratio.

CYNARA GASIFICATION RESULTS

- *Effect of steam ratio*
  - *Cl, S and H_2S in Gas*



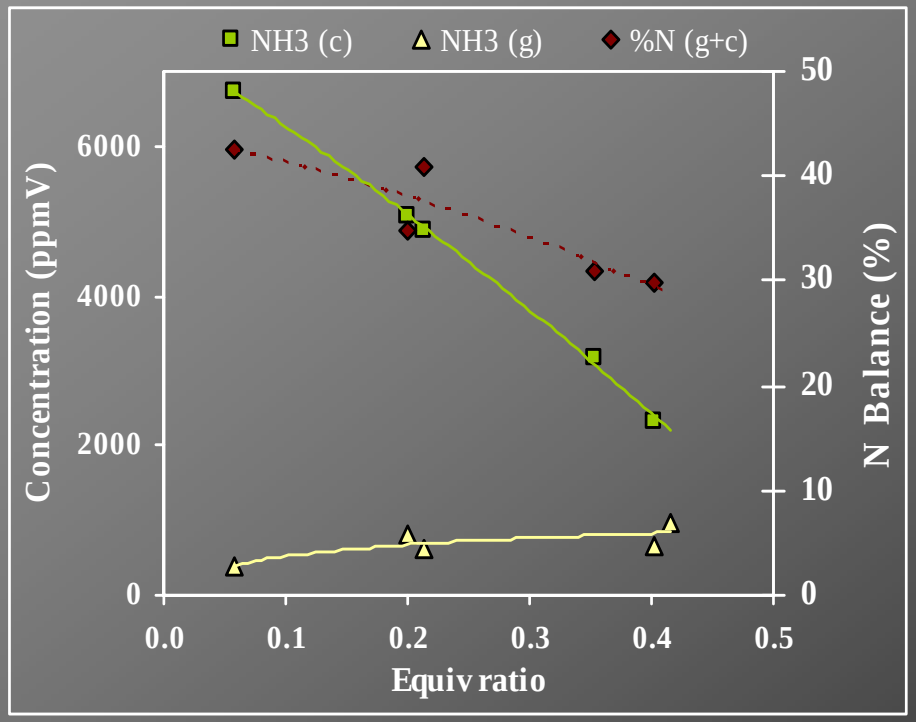
100% Cardoon ; T=850 ºC; ER = 0.15

Comments

- It can been seen that there is a strong influence of steam in chlorine condensation. In fact, HCl content found in condenser increases sharply with the increase of steam flow rate.
- Analysis carried out over "clean" gas shows that the Cl and SO_4 content are nearly zero.
- The tars content (around 7.5 g/m^3) in "raw" gas seems to not be affected by the increase of steam flow rate.

CYNARA GASIFICATION RESULTS

- *Effect of air ratio*
  - *NH_3 in Gas*



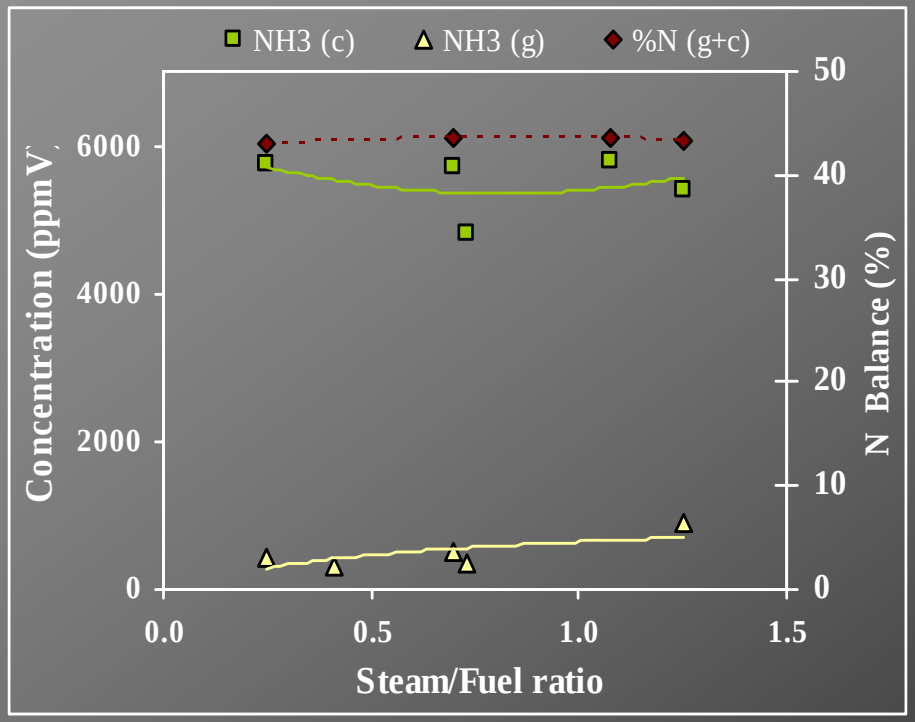
100% Cardoon ; T=850 ºC; steam/fuel =0.85

Comments

- It is clear a noticeable decrease of ammonia content with the increase of ER. This fact could be attributed to oxidizing conditions inside gasifier (larger amount of air) which promotes other nitrogen products instead of ammonia production
- As expected, almost all of the NH_3 formed reacts with water in the condenser and only a small part of it (380–970 ppmv) goes along with the gas. The percentage of ammonia reduction was 80 to 98%
- Between 30 - 42% of the N in cardoon was converted to NH_3 and the rest was retained in solid phase (cyclone + bed)

CYNARA GASIFICATION RESULTS

- *Effect of steam ratio*
  - *NH_3 in Gas*



100% Cardoon ; T=850 ºC; ER = 0.15

Comments

- The results shows that steam has a very small effect over ammonia release.
- Between 85 and 99% of the NH_3 formed was retained in the condensate of the quenching system, as could be expected, and only a minor quantity of it stays in the gas (300 – 900 ppmv)
- In these runs about 43% of the N in cardoon was converted to NH_3 and the rest was retained in solid phase (cyclone + bed)

CONCLUSIONS

- The utilization of cardoon as feedstock, in pelletized form, has not been found to give rise to any problems related with the feeding system. However some bed agglomeration was observed in the gasification runs.

- Gasification gas composition obtained from cardoon is influenced by air and steam as would be expected.

- The rise of air flow rate produces a gas with a lower calorific value but the amount of gas produced is much higher, mainly due to the dilution effect of N_2 with a decrease in energy conversion.

- The rise of ER led to a decrease of H_2 and an increase of CO_2 as would be expected, due to the partial combustion reactions.

- The increase of steam flow rate promotes the gasification char-water reactions as well as the water gas shift reaction becomes more effective producing more H_2 and CO_2 at expenses of CO. Also a decrease in hydrocarbons should be obtained due to the steam reforming reactions, which were not observed.

CONCLUSIONS

☛It was observed that the gas yield, energy conversion and calorific value increases with steam/biomass ratio till values around 0.6

☛ In the gasification of cardoon, very small amounts of char were found in bed, which means that almost all cardoon was gasified.

☛ It was observed some bed agglomeration tendencies that could be due to the high alkali metals of cardoon.

☛ The percentage of NH_3 reduction in the condenser was 80 to 99%. Between 30 - 42% of the N in cardoon was converted to NH_3 and the rest was retained in solid phase (cyclone + bed).

☛ Analysis carried out over “clean” gas shows that the Cl and SO_4 content are nearly zero.

CONCLUSIONS

☛No clear effect of ER or steam amount over sulphur condensation was observed in the runs carried out.

☛ Steam has a strong influence in chlorine condensation. In fact, HCl content found in condenser increases sharply with the increase of steam flow rate.

☛ The tars content (around 7 g/m3) in “raw” gas is similar to those obtained with other kind of biomasses and lower than values of coal or plastics.

☛ The cool down of the gas using a water scrubber system could be an valuable option for removal of NH_3 and HCl from gaseous stream

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