SOLID OXIDE FUEL CELL COMBUSTIBLE BY PLASMA SPOUTED BED GASIFICATION OF GRANULATED BIOMASS

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Introduction

In the search for both the most suitable and efficient methods of biomass gasification, the plasma spouted bed reactor, already tested[1,2] in this application exhibits, among other benefits, high transformation rates for solids to gases and the absence of tarry by products. This short report is a statement on our continuing research program and describes the most recent results where the research effort has been concentrated on process efficiency issues, including determining mass and energy balances.

Experimental

Raw Materials. The properties of the canola used as the raw material, were as follows: average grain size ≈ 1.5 mm, the moisture content of ≈8 %, ultimate analysis: mass composition of 56.43 ! 1 % carbon, 8.76 ! 0.2 % hydrogen, 23.43 ! 0.5 % oxygen, 7.34 ! 0.15 % nitrogen, 3.75 ! 0.1 % ash and traces of sulphur < 0.3 % and chlorine < 0.1 %. The heating value using the Dulong formula amounts to 28.23 MJ/kg.

Apparatus. The pyrolitic gasification tests were performed in an atmospheric-pressure bench scale plasma spouted bed apparatus (Fig.1).

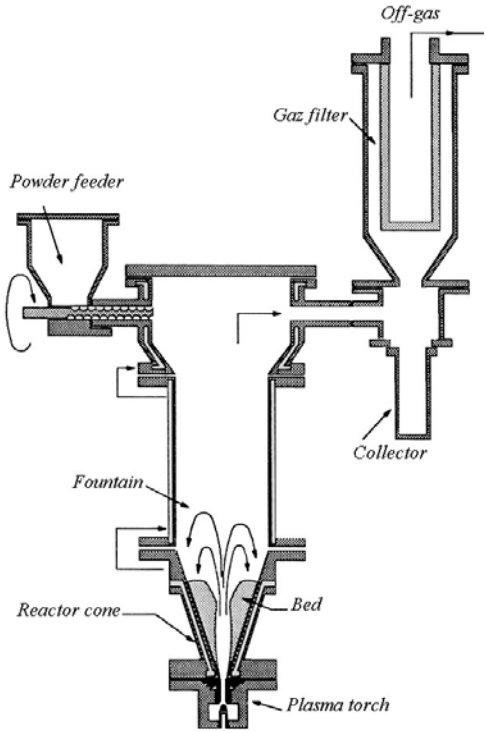

Figure 1. The schematic of the plasma spouted bed apparatus used in this study.

The stainless steel reactor, comprised a 150 mm cylindrical chamber part fitted to a conical (40°) base, protected with a thermal barrier ZrO_2 coating on the inside, and coupled with a standard DC plasma torch. The carbon dioxide was injected through three orifices at the periphery of the 4 mm torch nozzle. The seeds material was screw fed into the reactor from the sealed top.

Results and Discussion

Series of tests were performed to determine the effect of plasma power and injected carbon dioxide flow rate on product gas yield, its composition and overall energetic efficiency of the process.

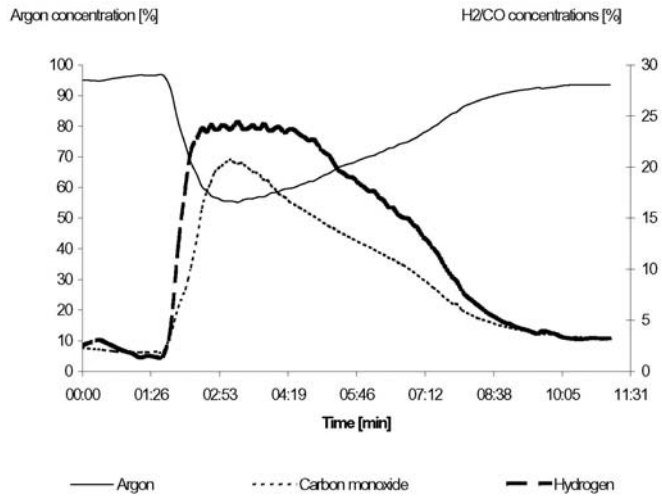

Figure 2. The variation of the off-gas composition during experiment for non-reactive plasma (without carbon dioxide).

Table 1. The Distribution of Solids (By Size Fraction) Remaining After the Run for Injected Power of 4,69 kW (% of Initial Load).

Size fraction	Reactor		Collector	Filter	Total
③m	Bottom	Walls			
$d_p > 425$	4,59	1,51	1,00	0,87	7,97
$425 > d_p > 212$	0,79	1,21	1,70	2,94	6,64
$212 > d_p > 150$	0,23	0,70	0,39	1,64	2,97
$150 > d_p > 125$	0,14	0,71	0,21	1,84	2,89
$125 > d_p > 90$	0,12	1,28	0,25	0,82	2,47
$90 > d_p > 45$	0,09	2,11	0,25	0,37	2,82
$45 > d_p$	0,00	1,50	0,08	0,00	1,59
Total	5,96	9,03	3,88	8,49	27,35

Due to the appreciable variation in off-gas composition for various applied plasma powers related to the different rate of pyrolysis for the input volatile matter (Fig.2), the total volume of gases produced for each pyrolytic gasification run was chosen as the mean for making comparison between the different runs (Table 2a,b,c). Time period of each experiment: 450 seconds.

Table 2a. Total Volume of Gas Produced per Gram of Canola Consumed During Complete Run for Injected Power of 3,58 kW.

Gas	Volume of gas produced per gram of canola consumed (L/g)			
	Spouting gas composition			
	Ar (plasma gas)	CO_2 Flowrate (Lpm)		
	30 Lpm	2,5	5	10
H_2	0.33	0.28	0.24	0.19
CO	0.16	0.26	0.37	0.46
CH_4	0.02	0.15	0.017	0.016
CO_2	0.03	-	-	-
C_2H_4	0.03	0.03	0.03	0.03
C_2H_2	0.13	0.08	0.08	0.06
Total	0.7	0.8	0.74	0.76

Table 2b. Total Volume of Gas Produced per Gram of Canola Consumed During Complete Run for Injected Power of 4,69 kW.

Gas	Volume of gas produced per gram of canola consumed (L/g)			
	Spouting gas composition			
	Ar (plasma gas)	CO_2 Flowrate (Lpm)		
	30 Lpm	2,5	5	10
H_2	0.33	0.39	0.38	0.31
CO	0.16	0.20	0.36	0.48
CH_4	0.02	0.02	0.02	0.02
CO_2	0.03	0.04	-	-
C_2H_4	0.03	0.03	0.03	0.03
C_2H_2	0.13	0.14	0.17	0.09
Total	0.7	0.82	0.96	0.93

Table 2c. Total Volume of Gas Produced per Gram of Canola Consumed During Complete Run for Injected Power of 5,88 kW.

Gas	Volume of gas produced per gram of canola consumed (L/g)			
	Spouting gas composition			
	Ar (plasma gas)	CO_2 Flowrate (Lpm)		
	30 Lpm	2,5	5	10
H_2	0.33	0.42	0.38	0.34
CO	0.16	0.21	0.33	0.43
CH_4	0.02	0.02	0.02	0.02
CO_2	0.03	0.04	-	-
C_2H_4	0.03	0.03	0.03	0.03
C_2H_2	0.13	0.13	0.11	0.09
Total	0.7	0.85	0.87	0.91

As seen from table 1a,b,c the increase in the plasma power and the introduction of carbon dioxide corresponds to the increased volume of gases produced during the same time period. The input seeds are exposed to higher temperatures resulting in liberation of more volatile matter and its increased decomposition rate, in addition to increased formation of carbon monoxide trough char oxidation by carbon dioxide.

Analysis of the overall energy efficiency values, which can reach 60% for the medium value plasma power of 9.4 kW and decrease for the highest plasma power value employed, indicates the necessity for further process optimization especially in respect of the reactor design (its volume versus the plasma jet length).

Table 2. Overall Energy Efficiency of the Process

Plasma power		CO_2 Flow rates			
Electric	Effective injected	0 lpm	2.5 lpm	5 lpm	10 lpm
[kW]	[kW]	[%]	[%]	[%]	[%]
6.5	3.58	58	53	59	56
9.4	4.69	54	59	57	60
12	5.88	48	51	50	52

Conclusions

The plasma spouted bed gasification of canola seeds is characterized by following advantages:

- Process is very fast – comparable with flash pyrolysis;
- Absence of tarry by products – at least at the process scale investigated;
- Very high overall energy efficiencies – up to 60 %, it is expected, that for continuous operation of such reactor the efficiency will increase further;
- High hydrogen and carbon monoxide contents in the gas product accompanied only by light hydrocarbons: methane, ethylene and acetylene with absence of sulphur;
- The possibility of employing medium temperature SOFC off-gas recycling into a plasma spouted bed gasifier is a very interesting option to consider for achieving future balanced energy needs.

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References

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(2) Lemoine, A., Jurewicz J.W., *Proc. of International Symposium on Plasma Chemistry ISPC-15*, **2001**, pp. 2873-8.