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10th International Conference on Circulating Fluidized Beds and Fluidization Technology - CFB-10

Refereed Proceedings

Spring 5-3-2011

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COAL AND BIOMASS CO-GASIFICATION IN A CIRCULATING FLUIDIZED BED REACTOR

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ABSTRACT

Co-gasification tests of subbituminous coal with biomass were performed. A rape straw blended with coal was used in a mass ratios of coal/biomass of 25%, 50% and 75%. The gasification process was conducted in a circulating fluid bed reactor at atmospheric pressure with air and steam addition was applied to the reaction. The addition of biomass to coal resulted in a higher conversion to gas and increased the gas calorific value due to higher content of carbon oxide.

INTRODUCTION

Co-gasification of biomass with coal can contribute to a reduction of CO_2 emissions and may reduce the dependence on fossil fuels [Valero and Uson (1), Kezhong et al (2)]. The high reactivity of biomass and its high volatile matter content suggests that some synergetic effects can be expected in a simultaneous thermo-chemical treatment of biomass and coal [Fermoso (3)].

Co-gasification of coal and biomass has been extensively studied in different scales, reactors and conditions [McKendry (4), Andre et al (5), Aznar et al (6), Pinto et al (7), Kurkela et al (8), de Jong et al (9), Brown et al (10), Chmielniak and Sciazko (11), Kumabe et al (12)]. Gasification of coal and biomass in a circulating fluid bed offers a number of advantages. However, the most important is stabilization of bed inventory due to lower reactivity of the coal char [Collot et al (13)]. As a result of decomposition three products are obtained: gas, coal tar and a solid product – char [Velez et al (14)]. The degree of decomposition of the fuels used and the efficiency of the process depend mainly on the temperature of gasification. Typically the process is carried out in the temperature range of 800 to 1000 °C. The main difference is manifested in the yield of products depending on the coal/biomass ratio.

TEST RIG DESCRIPTION

The testing facility used for the study of solid fuels gasification was aimed at obtaining two basic products: char and process gas. The main components of the plant were: a circulating fluidised bed reactor, a system for raw material preparation, char separation from a hot process gas, a process gas cooling and cleaning, and a combustion chamber for process gas utilization.

The gasification reactor consists of two sections: the lower, composed of two inverted cones connected by a cylindrical section of 0.38 m I.D., and the upper part – a riser of 0.14 m I.D. The total length of the riser was 4.41 m. The reactor operation depends on a gas phase velocity and on a solid phase concentration. The bottom section operates as a turbulent or a bubbling fluidised bed. These hydrodynamic conditions enable high values of heat/mass transfer coefficients and good mixing of blended fuels in the bed to be achieved.

A proper blends of coal and biomass after drying were delivered to the test facility in containers. The plant configuration and instrumentation enabled studying the gasification processes over a wide range of temperatures, using air and steam as gasification agents. The process diagram of the plant is shown in Figure 1.

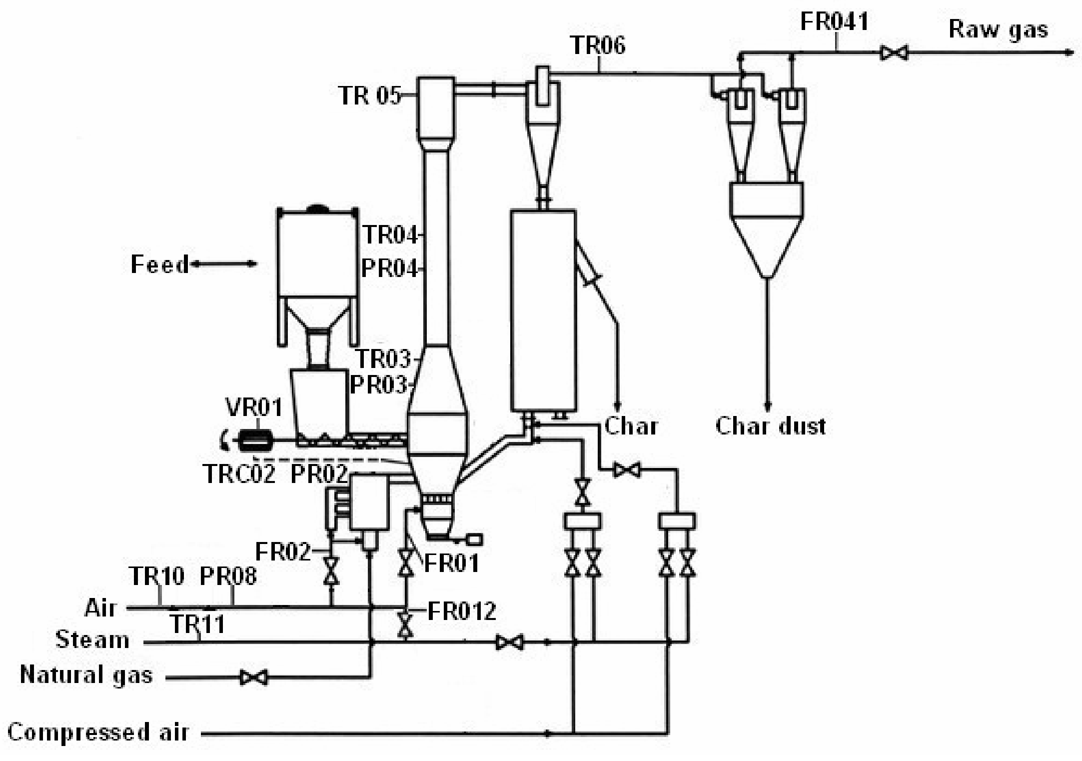

Figure 1. Test rig for coal - biomass co-gasification

The temperature and pressure distributions were measured throughout the system and air, steam and process gas flow rates were recorded for a mass balance evaluation. Coal, biomass and char mass flow rates were determined by averaging measured mass of the solids fed or received over the testing time.

TESTING METHODOLOGY

Six tests were performed to gasify coal (Run 1), biomass (Runs 5 and 6) and coal – biomass mixtures (Runs 2 - 4). A hammer mill and a drum dryer-mixer were used to prepare homogenous raw materials and their mixtures. Tests were started once the plant had been checked and the raw material prepared. The reaction system was heated to the desired temperature by burning a butane - propane mixture. The feeding of coal was started when the temperature in the gasification zone reached about 650°C. Having initiated the process of gasification, the burner of the start-up combustion chamber was shut off. Once a stable temperature in the gasification zone was achieved at the level of about 800°C the start-up material was replaced with the proper fuel and the assumed process parameters were achieved. The test was started after stabilisation of process conditions. On average, one test run was carried out over 4 h.

PROPERTIES OF FUELS USED

The composition of the raw materials gasified is given in Table 1.

Table 1. Raw material composition in the gasification tests

Test No.	Raw material composition, w/w %	
	Wieczorek coal	Rape straw
Run 1	100	0
Run 2	75	25
Run 3	50	50
Run 4	25	75
Run 5	0	100
Run 6	0	100

Properties of Wieczorek coal and rape straw are given in Table 2.

Table 2. Physicochemical properties of Wieczorek coal and of rape straw*)

Property	Wieczorek coal	Rape straw
Proximate analysis, w/w %		
Moisture content	3.9	6.1
Ash content	9.9	4.3
Volatile content	30.6	73.8
Ultimate analysis, w/w %		
Total sulphur content	0.6	0.1
Total carbon content	72.4	45.1
Hydrogen content	4.2	5.2
Nitrogen content	1.1	0.4
Chlorine content	0.28	0.31
Fluorine content	<0.01	<0.01
Net calorific value, MJ/kg	28.4	15.4

*) air dry basis

The characteristic temperatures of Wieczorek coal and rape straw ash fusibility are given in Table 3.

Table 3. Characteristic temperatures of Wieczorek coal and rape straw ash under oxidative conditions

Characteristic temperature, °C	Wieczorek coal	Rape straw
Sintering point	1100	900
Softening point	1200	1380
Melting point	1220	1530
Flow point	1280	1540

The partice size analysis of the Wieczorek coal and of rape straw are given in Table 4.

Table 4. Particle size analysis of Wieczorek coal and of rape straw

Particle size, mm	Content, %	
	Wieczorek coal	Rape straw
>3.15	6.8	3.8
3.15-2.0	14.3	11.0
2.0-1.0	22.9	32.5
1.0-0.5	17.4	29.9
0.5-0.2	15.5	16.7
<0.2	23.1	6.1
Total	100.0	100.0

PROCESS DATA

Basic process parameters of gasification tests are presented in Table 5.

Table 5. Process parameters of gasification tests

Test No.		Run 1	Run 2	Run 3	Run 4	Run 5	Run 6
Temperatures							
TR02, °C	Gasification zone	940	981	910	966	899	812
TR03, °C	Outlet from the reactor	957	937	990	1094	1021	944
TR04, °C	Riser	921	865	925	897	912	836
TR05, °C	Expander	866	825	805	743	793	795
TR06, °C	Downstream the cyclone	742	705	658	560	655	720
TR10, °C	Air to the reactor	80	63	56	58	60	61
TR11, °C	Steam	137	152	100	101	149	154
Flow rates							
FR01, m^3/h	Air to the reactor	115.2	117.5	90.4	85.6	94.7	92.1
FR02, m^3/h	Air to the combustion chamber	20.5	24.2	20.02	18.9	19.3	18.9
FR12, kg/h	Steam to the reactor	11.0	0.3	0.3	0.8	2.8	0.0

Table 5 (continued)

Test No.		Run 1	Run 2	Run 3	Run 4	Run 5	Run 6
FR041, m^3/h	Process gas downstream the cyclones battery	167.0	159.0	133.0	125.0	157.0	163.0
Pressures							
PR02, kPa	Gasification zone	6.1	6.3	6.6	9.3	8.7	9.4
PR03, kPa	Outlet from the reactor	1.8	2.3	1.9	2.1	4.0	5.0
PR04, kPa	Riser	2.0	2.4	2.0	2.2	4.1	5.7
Output of the screw-conveyor feeder							
VR01, %	Feeder revolutions	26.3	42.9	35.6	44.3	61.7	80,6
Coal/biomass flow rate, kg/h		112,0	83.5	82.7	70.8	97.0	116.0

ANALYSIS OF RESULTS

Mass balances for the gasification tests were made and were found to agree within a relative error not higher than ±3%. The fuel conversion efficiency in a particular test is presented in Fig. 2. It was calculated as feedstock quantity converted to gas divided by the total solid fuels fed to the reactor expressed in w/w %.

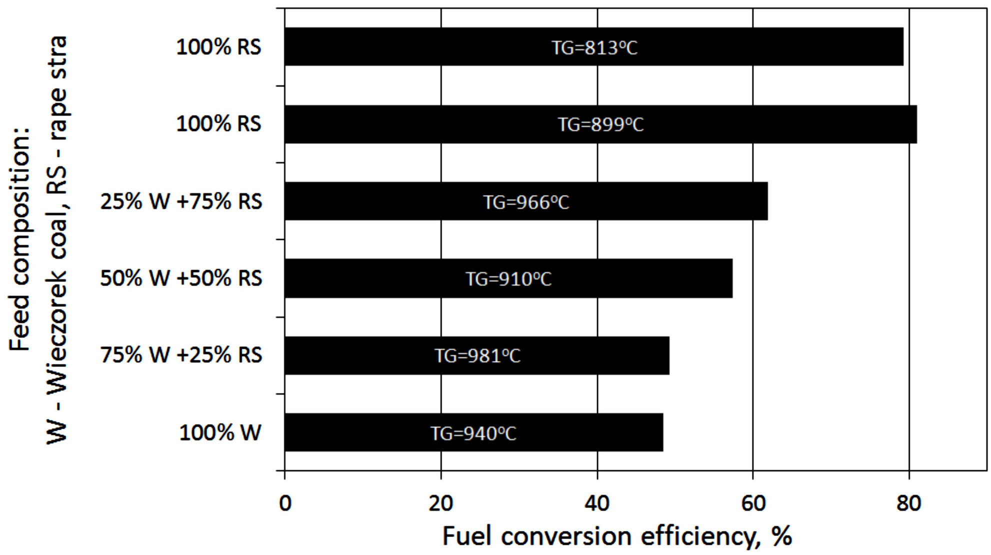

Figure 2. Fuel conversion efficiency versus feed composition (TG - gasification temperature)

The fuel conversion efficiency increased with increasing rape straw content in the gasified mixture (which ranged from 48% for coal to 81% for rape straw). The highest increase in the fuel conversion efficiency was observed at rape straw contents in the mixture of 75% to 100%. A decrease of straw gasification temperature by around 90°C resulted in the decrease of its conversion efficiency by about 2%. The output data for process gas and char are shown in Fig. 3. The highest yield of gas (2.4 kg/kg) was obtained for the mixture containing 75% coal and 25% rape straw. The lowest yield (1.71 kg/kg) was for pure rape straw gasified at 812°C. The char yield systematically decreased with increasing rape straw content in the mixture. A decrease in straw gasification temperature by around 90°C resulted in a slight (by 0.2 kg/kg) increase in char yield.

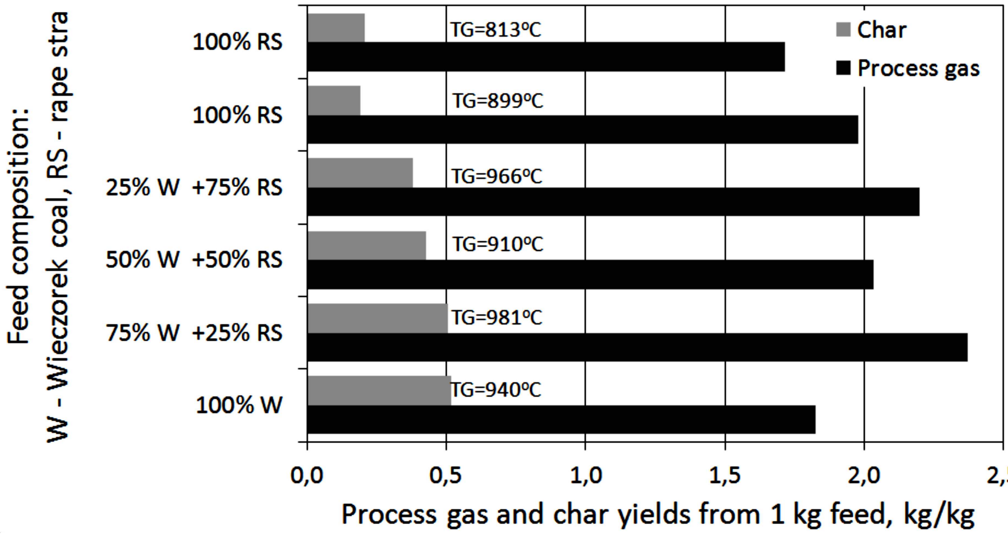

Figure 3. Process gas and char yields

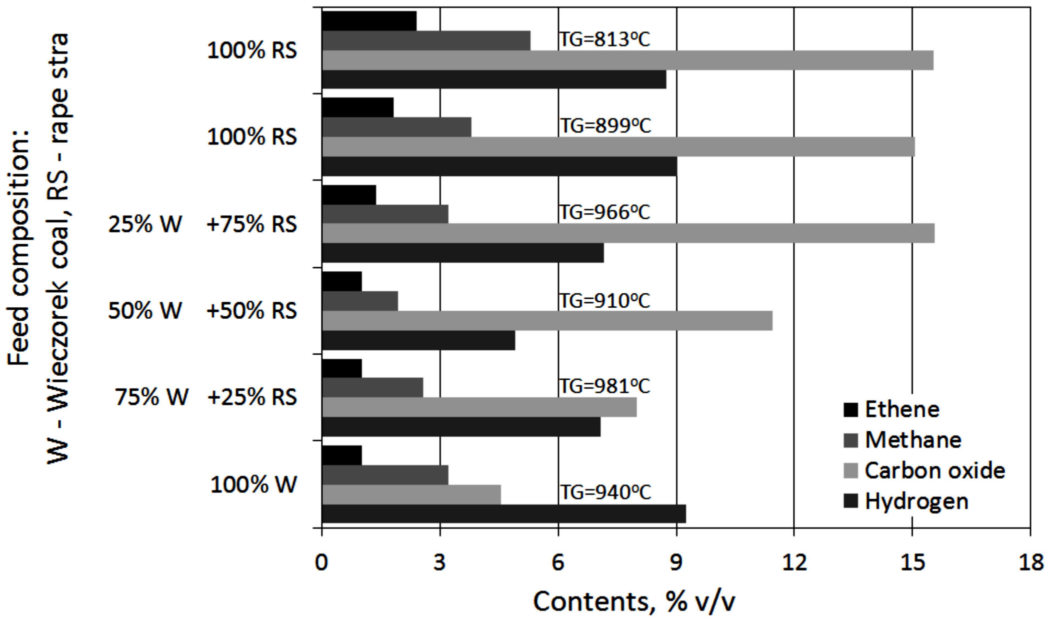

Figure 4. Main combustible component content in the process gas

Hydrogen, carbon oxide, methane and ethane contents in the process gases obtained from the tests are presented in Fig. 4. The content of carbon oxide, methane and ethane show an increasing trend with an increase in the rape straw content in the gasified mixtures. The hydrogen content reached a minimum (4.90%) for the mixture containing 50% of Wieczorek coal and rape straw.

The content of the condensable organic matter (tar) in the process gases (presented in Fig. 5) increased with increasing content of the rape straw in the mixtures and ranged from 6 g/Nm^3 for pure Wieczorek coal to 12.6 g/Nm^3 for pure rape straw. Depending on process parameters the HHV of process gas ranged from 4 to 7 MJ/m^3 (Fig. 6).

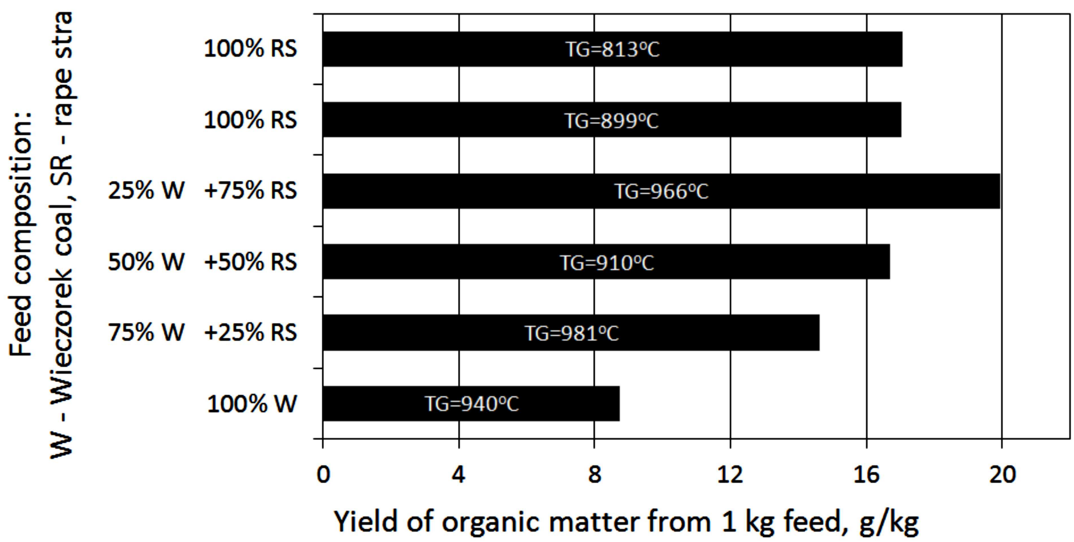

Figure 5. Yield of condensable organic matter

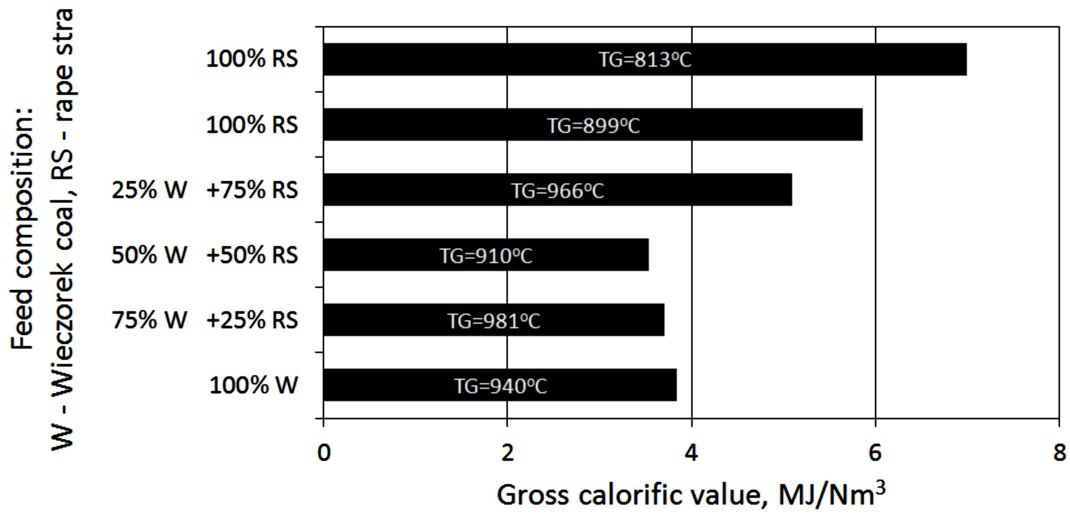

Figure 6. Process gas high heating value

CONCLUSIONS

The mass balances for the gasification tests had relative error smaller than 3%. The fuel conversion efficiency (feedstock quantity converted to gas divided by the total solid fuels fed to the reactor) increased as long as the rape straw content increased in the gasified blend. A drop in gasification temperature with rape straw by 90^oC caused the drop in its conversion efficiency by 2%. The addition of biomass to coal resulted in a higher conversion to gas and increased the gas calorific value due to higher content of carbon oxide.

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