

# GASIFICATION REACTIVITIES OF SOLID BIOMASS FUELS

Antero Moilanen, Esa Kurkela  
VTT Energy, P.O.Box 1601, FIN-02044 FINLAND

Keywords: Biomass, gasification, reactivity

## INTRODUCTION

The design and operation of the biomass based gasification processes require knowledge about the biomass feedstocks characteristics and their typical gasification behaviour in the process. In this study, the gasification reactivities of various biomasses were investigated in laboratory scale Pressurised Thermogravimetric apparatus (PTG) and in the PDU-scale (Process Development Unit) Pressurised Fluidised-Bed (PFB) gasification test facility of VTT (Figure 1).

## EXPERIMENTAL

In PTG, the effects of individual process parameters (relevant to pressurized fluidised bed gasification) on gasification rate were studied using following parameter ranges: gasification agent ( $\text{CO}_2$ ,  $\text{H}_2\text{O}$ ), temperature (700 - 1 000°C), pressure (1-30 bar). With some samples, also the effect of product gas on gasification rate was tested.

The characteristics of the samples are presented in Table 1. The selected samples are part of a biomass sample collection analysed in the EU-project (European Union) belonging JOULE II Program /1/.

The gasification rate measurements were carried out in the pressurised thermobalance (PTG), which is presented schematically in Figure 1. A more detailed description of its operation has been presented in /2/. The tests were carried out isothermally by lowering down the sample of about 50 mg in size to the reactor with the winch system equipped in the PTG. During this time, the sample was pyrolysed when it heated up to the reaction temperature at an estimated rate of above 10K/s. The weight change, which was recorded during this approximately 60 seconds period, was due to, mainly, the pyrolysis of the sample and the buoyancy phenomena. After this period, the weight change due to the gasification (and eventual postpyrolysis) was monitored.

In the fluidized-bed gasification tests, air and a small amount of steam were used as gasification agents. The feedstock and dolomite were fed into the lower part of the bed and part of the fines elutriated from the fluidized-bed were separated in the primary cyclone and recycled back to the bed. The fines separated by the secondary cyclone and the ceramic filter unit were collected, weighed and sampled. The main variable in the tests was the gasification temperature, which was controlled by changing the air-to-fuel ratio.

The carbon conversion data for three biomass fuels are presented together with data for two bituminous coals and Rhenish brown coal. The feedstock analyses are shown in Table 2. Examples of the operation conditions and process data for the different fuels are presented in Table 4.

## RESULTS

The gasification rates obtained from the PTG measurements are shown in Table 3 as a function of  $\text{CO}_2$  and  $\text{H}_2\text{O}$  pressure measured at 850°C. The gasification rate denoted as  $r''$  is indicated as an instantaneous gasification rate, i.e. mass change rate divided by residual ash-free mass (%/min). The conversion used indicates the burn-off of the whole fuel including the mass loss due moisture and pyrolysis release. In Figure 2, the conversion behaviour, i.e.  $r''$  vs. conversion, is given for the fuels which were gasified also in the PFB.

The PTG tests show that there are great differences in gasification rates between various fuels. The preliminary correlations between gasification rates and ash composition indicated that, especially,

the rates at higher fuel conversions seemed to decrease with increasing silica content in the fuel. This indicates that catalytically active ash components can lose their activity due to reactions with silica, or due to sintering behaviour. Also, adding a product gas component to the gasification gas decreased radically the gasification rate. For example, the gasification rate ( $r''$ ) of wheat straw decreased from 27 %/min to 10%/min when CO was added 10% to CO<sub>2</sub> at 30 bar pressure.

The carbon conversions of the PFB tests shown in Table 4 are calculated from the material balances. The great differences between the gasification behavior of the five feedstocks used in PFB measurements can be clearly seen by comparing the data shown in Figure 3. Only the two bituminous coals seemed to behave more or less similarly and a strong and clear correlation was found between carbon conversion and equivalence ratio (or temperature). With these fuels it took several hours to reach steady state char inventory in the bed and also in the freeboard and in the recycling loop.

The three different biomass fuels had also clearly different gasification behavior. In gasification of pine sawdust, very high carbon conversions could be achieved already at relatively low temperatures, while bark and straw were more difficult to be completely gasified. In the case of straw gasification high conversion efficiencies could be achieved at above 850°C, but unfortunately sintering of the straw ash caused severe operational problems. Pine bark did not have problematic ash sintering behavior, but has a clearly lower reactivity than wood or straw. Consequently high gasification temperatures and efficient recycling of elutriated fines are required with pine bark to reach high conversion efficiencies.

Rhenish brown coal is an excellent feedstock for fluidized-bed gasification and over 95 % carbon conversion could be reached already at about 900 °C temperature. This fuel has also a high reactivity measured in PTG /3/.

The results of this study shows that gasification reactivities of the biomasses can differ greatly from each other. The comparison of the results between PTG and PFB shows that the gasification rates measured in PTG have the same order as the reactivities in PFB based on achieved carbon conversion calculations.

#### REFERENCES

1. Wilén, C. et al. The feasibility of electricity production from biomass by gasification systems - Fuel analyses. EU-Joule II Program Contract No. JOU2-CT92-0226, ENEL, VTT, IVO, DMT, Final report. To be published 1995.
2. Saviharju, K, Moilanen, A., van Heiningen, A.R.P., New High Pressure Gasification Rate Data on Fast Pyrolysis of Black Liquor Char. Preprints 1995 International Chemical Recovery Conference TAPPI, April 24-27, 1995, Toronto, Canada, pp. A237-243.
3. Mühlen, H.-J., Sowa, F., van Heek, K.H., Comparison of the gasification behaviour of a West and East German brown coal. Fuel Proc. Tech., 36(1993), pp. 185-191.

Table 1a. The characteristics of the feedstock samples, wt%, dry basis

Sample	V.M. %	F.C. %	Ash, %	C, %	H, %	N, %	C <sub>fixed</sub> , %	S, %
Pine saw dust	83.1	16.8	0.1	51.0	6.0	0.1	42.8	nil
Pine bark	73.1	25.3	1.7	52.5	5.7	0.4	39.7	0.03
Forest residue (pine)	79.3	19.4	1.3	51.3	5.8	0.4	40.9	0.02
Salix	79.9	18.9	1.2	49.7	6.1	0.4	42.6	0.03
Wheat straw	77.7	17.6	4.7	47.5	5.9	0.6	41.5	0.07
Barley straw	76.1	18.0	5.9	46.2	5.7	0.6	41.5	0.08
Reed canary grass	73.5	17.6	8.9	45.0	5.7	1.4	38.9	0.14
Miscanthus	78.5	18.2	3.3	47.9	6.0	0.6	41.6	0.6
Sweet sorghum	77.2	18.1	4.7	47.3	5.8	0.4	41.7	0.1
Kenaf	79.4	17.0	3.6	46.6	5.8	1.0	42.8	0.1

V.M.: Volatile Matter Content, F.C.: Fixed Carbon

Table 1b. The ash compositions of the samples.

Sample	Ash composition, %									
	SiO <sub>2</sub>	Al <sub>2</sub> O <sub>3</sub>	Fe <sub>2</sub> O <sub>3</sub>	CaO	MgO	K <sub>2</sub> O	Na <sub>2</sub> O	TiO <sub>2</sub>	SO <sub>3</sub>	P <sub>2</sub> O <sub>5</sub>
Pine saw dust	8.3	4.0	3.7	41.8	11.8	24.6	0.5	0.12	1.9	10.5
Pine bark	1.3	10.6	0.6	40.6	4.5	15.2	1.0	0.12	2.0	9.6
Forest residue (pine)	38.5	9.4	7.4	15.4	4.0	16.6	0.7	0.5	1.6	6.4
Salix	0.4	0.6	0.4	30.8	5.1	53.0	0.5	0.02	3.0	22.9
Wheat straw	59.9	1.6	1.1	7.3	1.8	33.7	0.9	0.04	1.1	4.5
Barley straw	62.0	0.4	0.3	4.5	2.2	38.5	1.0	0.02	1.4	5.0
Reed canary grass	89.8	2.8	2.3	3.5	1.5	6.3	0.3	0.05	1.1	8.2
Miscanthus	42.8	1.0	0.8	7.6	4.8	50.6	1.3	0.03	2.1	10.5
Sweet sorghum	57.8	1.3	1.1	9.0	2.7	16.4	3.0	0.05	3.0	6.0
Kenaf	6.6	3.6	2.4	30.8	6.0	26.5	2.5	0.08	5.7	5.5

Table 2. The analyses of the feedstock materials used in the fluidised bed tests.

	Polish coal	Colombian coal	Rhenish brown coal	Wheat straw	Pine sawdust	Pine bark
Moisture content, wt-%	3.6-6.7	7.6	11.5-12.2	6.1	6.1-16	5.6-6.7
<u>Proximate analysis, wt-% d.b.</u>						
Volatile matter	31.8	34.7	53.0	75.8	83.1	71.8
Fixed carbon	59.9	53.2	42.7	18.2	16.8	26.7
Ash	8.34	12.1	4.3	6.1	0.08	1.6
<u>Ultimate analysis, wt-% d.b.</u>						
C	75.5	71.9	63.8	46.1	51.0	53.9
H	4.7	4.9	4.6	5.6	6.0	5.8
N	1.3	1.5	0.8	0.52	0.08	0.35
S	0.7	1.0	0.3	0.08	< 0.01	0.03
O (diff.)	9.5	8.6	26.2	41.6	42.8	38.4
Ash	8.3	12.1	4.3	6.1	0.08	1.6

Table 3. The instantaneous gasification rates of the samples at the minimum and at the conversion value of 95% measured at 850°C.

Sample	1 bar CO <sub>2</sub>		30 bar CO <sub>2</sub>		1 bar H <sub>2</sub> O		30 bar H <sub>2</sub> O	
	r" min.	r" at X=95%	r" min.	r" at X=95%	r" min.	r" at X=95%	r" min.	r" at X=95%
Pine saw dust	27	39	22	43	25	25	50	71
Pine bark	9	16	7	13	7	13	44	71
Forest residue (pine)	18	20	na	na	na	na	na	na
Salix	29	42	23	50	30	130	60	225
Wheat straw	16	19	25	42	13	17	46	58
Barley straw	19	22	na	na	na	na	na	na
Reed canary g.	3	3	10	15	15	19	na	na
Miscanthus	18	25	26	59	24	45	na	na
Sweet sorgh.	20	23	26	51	29	62	na	na
Kenaf	50	83	55	103	67	83	na	na

Table 4. Operational data on typical set points with different fuels.

	Polish Coal	Colombian coal	Rhenish brown coal	Wheat straw	Pine sawdust	Pine bark
Equivalence ratio	0.47	0.49	0.44	0.3	0.39	0.34
Fuel feed rate, g/s	5.33	5.49	11.50	13.30	10.67	11.45
g/s-daf	4.70	4.50	9.70	11.70	9.00	10.40
Air feed rate, g/s	23.67	23.66	35.03	21.2	21.15	23.56
kg/kg-fuel(daf)	5.04	5.26	3.61	1.81	2.35	2.27
Steam feed rate, g/s	4.06	4.50	1.90	3.6	1.77	1.23
kg/kg-fuel(daf)	0.86	1.00	0.20	0.31	0.20	0.12
Purge N <sub>2</sub> feed rate, g/s	3.3	3.4	1.2	4.6	2.1	2.6
Dolomite feed, g/s	0.45	0.45	0	0	0.7	0.39
Pressure, MPa	0.5	0.5	0.5	0.5	0.5	0.5
Bed temperature, °C	1 001	980	824	772	831	871
Freeboard temperature, °C	1023	1014	910	848	968	978
Carbon conversion, wt%						
to gas (C1)	85.0	86.2	95.9	83.4	94.6	87.7
to gas+tars (C2)	85.3	86.7	96.2	93.9	100.3	90.0
incl.dolomite input (C3)	84.2	85.5	96.2	93.9	98.6	89.3
Carbon losses, wt-% of input, Bottom ash	0.5	0.2	0.1	0	0.1	0
Cyclone dust	2.3	3.4	2.4	2.1	0	2.5
Filter dust	13.0	11.1	1.1	2.5	0.8	8.3
Carbon balance closure output, wt % of input	100.0	100.2	99.8	98.5	99.5	100.1
Gas composition, vol%						
CO	8.7	6.9	16.4	9.0	8.8	12.0
CO <sub>2</sub>	10.6	10.8	10.0	11.5	13.8	12.8
H <sub>2</sub>	8.4	8.1	12.0	4.0	7.8	9.0
CH <sub>4</sub>	0.7	0.9	1.1	3.6	3.8	3.1
C <sub>2</sub> hydrocarbons	0.00	0.00	0.02	0.78	0.15	0.20
H <sub>2</sub> O	15.6	18.3	7.3	23.9	17.2	12.6
NH <sub>3</sub>	0.12	0.14	0.19	0.15	0.026	0.13
H <sub>2</sub> S	0.039	0.058	0.017	0.014	0.005	0.009
N <sub>2</sub> (+Ar)	55.8	54.8	53.0	47.1	48.4	50.2

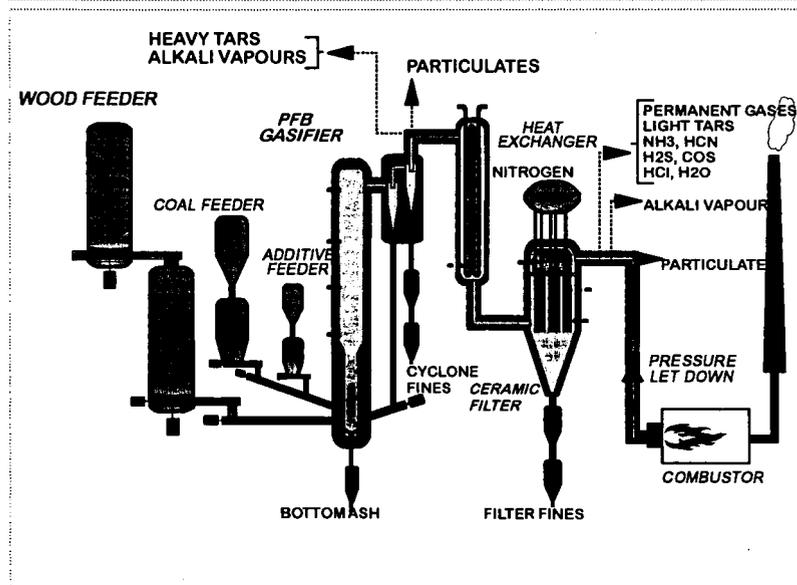
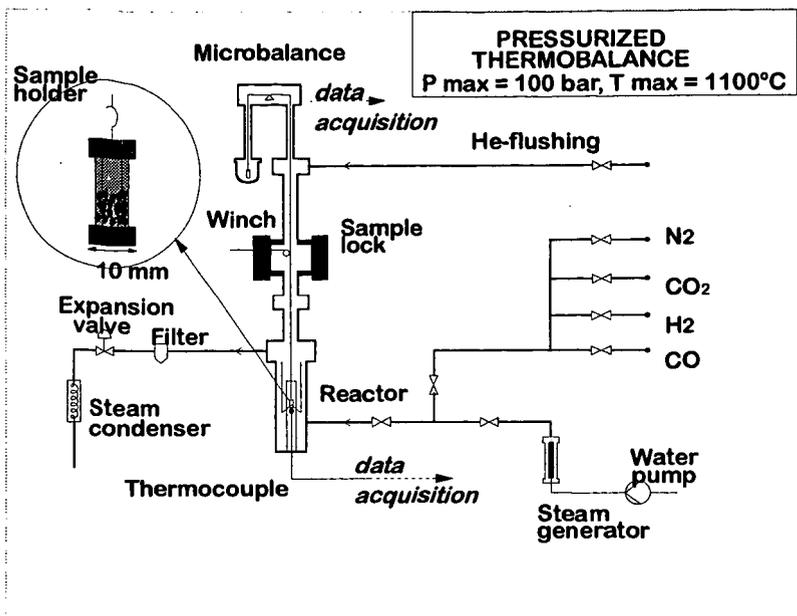


Figure 1. The pressurized thermogravimetric apparatus and pressurized fluidized-bed gasification test facility used in the study.

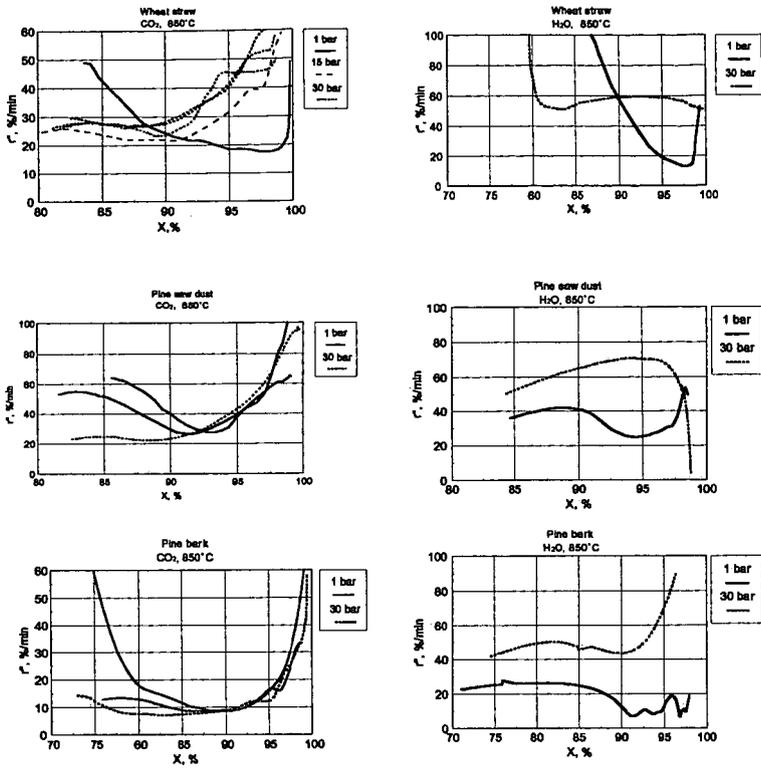


Figure 2. The gasification rate  $r''$  vs. fuel conversion  $X$  of  $\text{CO}_2$  and  $\text{H}_2\text{O}$  gasification in 1 and 30 bar pressures and at  $850^\circ\text{C}$ .

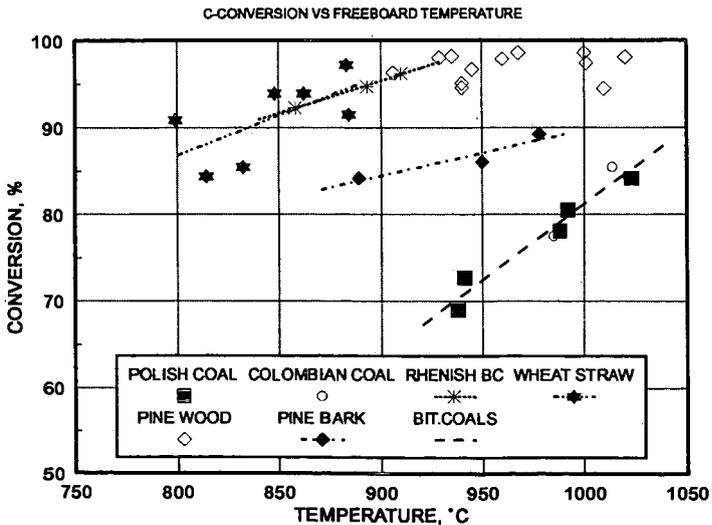


Figure 3. The achieved carbon conversions as a function of freeboard temperature in the PFB.