PRESSURISED FLUIDISED BED GASIFICATION OF WOOD AND MISCANTHUS: HOT GAS CLEANING WITH CERAMIC CHANNEL FLOW FILTERS

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Abstract

Biomass gasification experiments were carried out using a 1 MW_{th} pressurised air blown bubbling fluidised bed gasifier including ceramic channel flow filters and gas turbine combustion chamber. The gasification tests were done by the section Thermal Power Engineering of the Delft University of Technology within the framework of the EU funded "TARGeT" project.

The installation was operated at 3.5 and 5 bar, bed temperatures of 750 to 900°C and with filter temperatures between 600 and 700°C. Four wood gasification tests without steam and three with steam were done. In the last two experiments miscanthus was gasified with two different additives, dolomite and minphyl.

Filter blinding and soot formation were observed in the wood gasification tests without steam. It was found that the soot formation and filter blocking could be suppressed by the use of steam. The blocking could even be reversed with the use of steam and operating near or just above the stoichiometric point. The minphyl additive had the strangest effect of reacting with the bed material thereby volatilising silicon, which could pass the ceramic filter. This silicon disturbed the operation of the combustor, causing high CO levels and intensifying the disturbance of the filter cleaning pulses.

1 Introduction

The road to new and clean technologies for energy conversion is neither always obvious nor easy. One of the concepts promising high efficiencies is that of the IGCC (Integrated Gasification Combined Cycle). This is especially the case when the traditional wet gas cleaning is replaced with dry hot gas cleaning as shown by Woudstra et al. (1995).

This hot gas cleaning is not always trivial. Cyclones are a proven technology for gas cleaning at higher temperatures. Unfortunately cyclones can only remove up to app. 99% and mostly only 90% of the ashes present in the gas. Several different types of filters are available nowadays for removing the remaining or all of the dust. Each type of filters seems to have its own type of problems. Candle filters for example are prone to breakage due to thermal stress or ash bridging, Sydkraft (2001). Wall flow monoliths can break from thermal stress/shock caused by oxidative regeneration. This oxidative regeneration can be either on purpose in dedicated soot filtration or occur accidentally, Andries et al. (2000).

This paper presents gasification and hot gas filtration tests with a 1 MW_{th} demonstration unit, situated in the laboratory of the section Thermal Power Engineering of Delft University of Technology.

2 Experimental setup and process parameters

The PFBG test rig can be operated at elevated pressures in the range of 3 to 8 bar and comprises a bubbling fluidised bed gasifier, a hot gas ceramic honeycomb filter and a modified gas turbine combustion chamber. It is depicted schematically in Figure 1. After a brief general process description, the filter unit will be discussed.

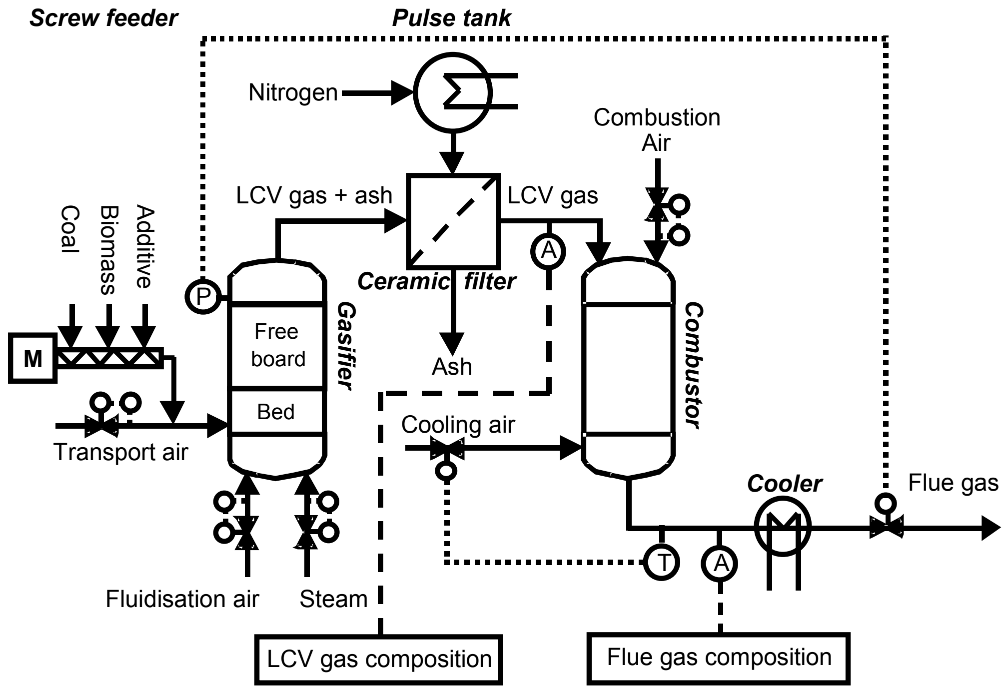

Figure 5: Simplified P&ID test rig.

General process description

The installation consists of a solid fuel lock-hopper feeding system, a bubbling fluidised bed gasifier, a high temperature ceramic filter and a gas turbine combustion chamber. The fuel is fed into the gasifier with optionally an additive. In the gasifier the fuel is gasified with air and steam at approximately 800°C. The dust laden LCV (Low Calorific Value) gas generated in the gasifier is subsequently cleaned from solids by a high temperature ceramic channel filter and combusted in the gas turbine combustion chamber. The filter is cleaned by back pulsing it with preheated nitrogen of 200°C. The main design specifications are given in

Table 8.

Table 8: Main design parameters.

Bed diameter	(m)	0.4
Freeboard diameter	(m)	0.5
Maximum bed height	(m)	2.0
Minimum freeboard height	(m)	4.5
Fluidisation velocity	($m \cdot s^{-1}$)	0.5 – 1.0
Operating pressure	(bar)	3.0 – 8.0
Bed temperature	(°C)	750 – 950
Fuels		biomass, brown coal, coal

Maximum thermal power	(MW)	1.5 (coal combustion)

Table 9: Filter data

Filter temperature	(°C)	600 – 800
Filter material β-cordierite		$(Mg_2Al_3(AlSi_5)O_{18})$
Dimensions, (D x L)	(mm)	301 x 300
Filtration area	(m^2)	6.8
Filtration area/volume ratio	(m^2/m^3)	244
Average wall pore size	(µm)	4-50
Average membrane pore size	(µm)	≈0.3

Filters

Inside the filter vessel there are 3 ceramic channel flow filters or wall flow monoliths. This filter type offers high filtration efficiency combined with a high surface to volume ratio.

Each filter element is periodically cleaned with a back pulse of preheated nitrogen of 200°C. The pulse nitrogen is preheated to reduce the thermo-shock to the ceramic filters and to prevent condensation. The ash is collected at the bottom of the filter vessel and periodically removed through a lock hopper system. The collected ash is weighed continuously.

3 Experimental results

All in all, 14 successful gasification experiments have carried during the measurement campaign from October 2001 to May 2002. The tested fuels were wood, browncoal and miscanthus. As a comparison miscanthus was gasified with both dolomite and minphyl additive. Browncoal proved to be the least troublesome fuel with respect to filter operation these experiments will not be discussed further here. The proximate compositions and higher heating values of the fuels are given in Table 10.

Table 10: Fuels compositions**.**

Fuel		***Wood***	***miscanthus***
Moisture	(wt.%)	8.4	8.5
Volatiles	(wt.%)	74.9	73.5
Fixed-C	(wt.%)	16.5	15.5
Ash	(wt.%)	0.2	2.5
HHV	(MJ/kg)	18.6	17.7

Due to limitations of space not all the results can be shown here. The relevant experiments and results are shown in Table 11 below.

Most interesting with regard to filter operation were the wood gasification tests where soot formation and filter blocking occurred. It was found that the formation of soot could be suppressed by adding steam. The effect of dolomite was not significant on tar and soot formation in the wood tests. Adding minphyl to the miscanthus instead of dolomite yielded very interesting and unpredicted results. One result was the increase of the HCN concentrations in the freeboard. Another effect was a fine spray of silicon droplets escaping the filter causing operational problems with the combustor.

Filter regeneration and blocking

Unexpected was the occurrence of filter blinding with the gasification of wood. In the previous campaigns this was never observed, de Jong et al. (2001). It must be noted however that there the used fuels were miscanthus or coal miscanthus mixtures and not wood. In the previous campaigns also almost always steam was added. The effect of steam will be underlined further in the next paragraph. In Figure 6 the filter pressure drop and temperature are shown for the test day of 05 February 2002 (experiment 4).

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Table 11: Overview experimental results**.**

Experiment			*1* *27.11*	*3* *29.01*	*4* *05.02*	*5* *12.02*	*11* *29.04*	*12* *13.05*
Pressure	p	(bar)	3.5	5.0	5.0	5.0	3.5	3.5
Bed temperature	T_b	(°C)	858	941	933	894	811	830
Fuel mass flow		(kg/h)	112	126	128	109	127	130
Additive to fuel		(kg/kg)	0	0.036	0.036	0.036	0.033	0.026
Air mass flow		(kg/h)	217	288	290	258	227	223
Steam to air		(kg/kg)	0	0	0	0.10	0	0
Primary air factor	λ	[-]	0.32	0.38	0.37	0.39	0.33	0.33
Higher heating value	HHV	(MJ/Nm^3)	4.64	3.98	3.82	3.27	3.89	3.46
Carbon conversion	η_c		98.1	96.6	97.3	98.5	89.7	92.3
Cold gas efficiency	η_{cg}		65.5	61.5	58.3	54.8	51.1	43.5
Pre pressure	p_p	(bar)	8.5	10	10	10	8.5	8.5
Pulse interval	t_i	(s)	180	180	180	180	600	600
Pulse time	t_p	(ms)	100	200	200	200	200	200
Filter temperature	T_f	(°C)	628	663	698	671	682	694
Mass flow ash		(kg/h)	1.2	5.5	4.0	3.2	11.1	8.5
Average press. drop	dp	(mbar)	25	59	46	10	12.7	18.7
Dust load in		(g/Nm^3)	4.1	15.1	11.0	9.2	37.4	29.1
Dust load out		(mg/Nm^3)	4.6	49.9	2.5	≈4.8	<1	7.8
Filter mass efficiency	η_f	(%)	99.89	99.67	99.98	≈99.95	>99.99	99.97

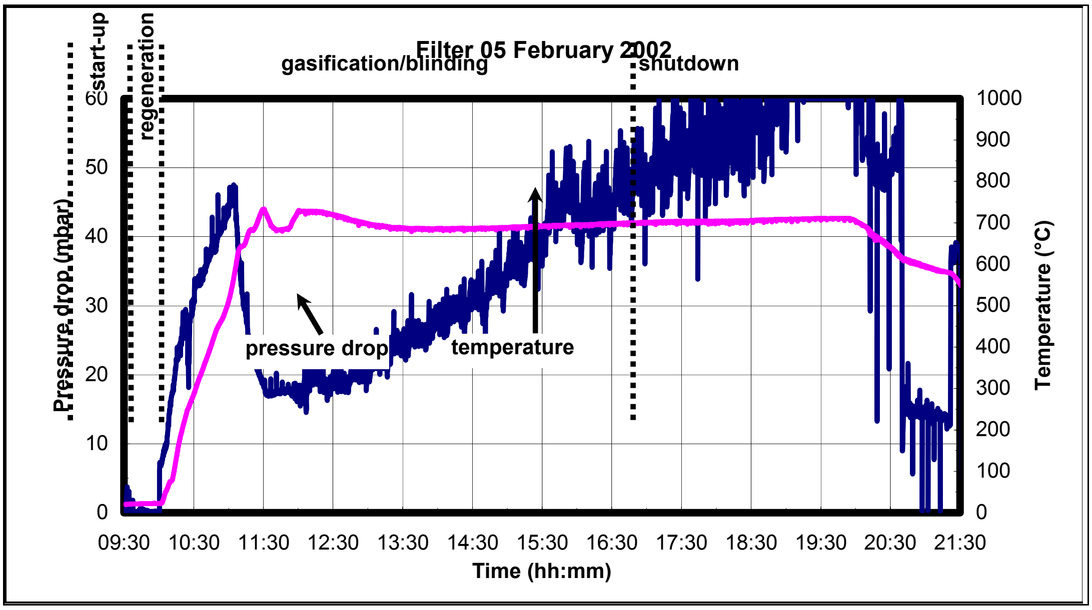


Figure 6: Pressure drop vs. time for wood gasification without steam.

Four different phases can be distinguished. The start-up phase in combustion mode from 10:00 to 11:00 h. is the first phase. After that the filter is regenerated with steam. The air to fuel ratio is kept just above the stoichiometric point. As a result the pressure drop decreases despite the increasing temperature. The regeneration takes app. ½ an hour from 11:00 to 11:30 h. After the regeneration the steam flow was cut and stable gasification was attained. Although the flow and temperature remain constant the pressure drop increases. Around 17:30 h the upper limit of the differential pressure sensor is reached at 60 mbar. The shutdown procedure was engaged at 20:00 h.

Soot was found in the samples taken behind the big ceramic filter. The dust was collected on quartz fibre filters (Schleicher & Schuell QF20, ∅ 150mm) from gas sampled at 600°C. The samples were later on analysed by SEM-EDX. Soot was only found in the wood gasification experiments without steam, i.e. experiments 1 through 4.

Normal filter operation

The dramatic increase in pressure drop displayed in Figure 6 could be prevented with the use of steam as shown in. There the filter pressure drop and temperature are shown for the test day of 20 February 2002 (experiment 5). Here the same four phases can be made out as in the test day of 05 February. Only in this case steam is added in a 0.10 (kg/kg) ratio with the air.

Effect of additives

Also unexpected was the finding of Si in the form of micron sized spheres. This was already observed with the wood gasification experiments without steam and the browncoal experiments but not to such a large extent as with the addition of minphyl in the last miscanthus experiment. Minphyl consists mainly of Pyrophyllite $Al_2Si_4O_{10}(OH)_2$ and SiO_2. MacLaughlin (1990) indicated it as a possible alkali getter because the mineral is able to accommodate K or Na on the places of the hydroxy groups. From the SEM-EDX analyses of the bed material and fly ash it was found to react with the potassium from the miscanthus but also with the sand bed material, thereby volatilising silicon. The difference in the volatilised and recondensed amounts is significant as illustrated in Figure 8. Figure 8A shows captured dust from the 29 April 2002 and Figure 8B shows the catch of 05 May 2002.

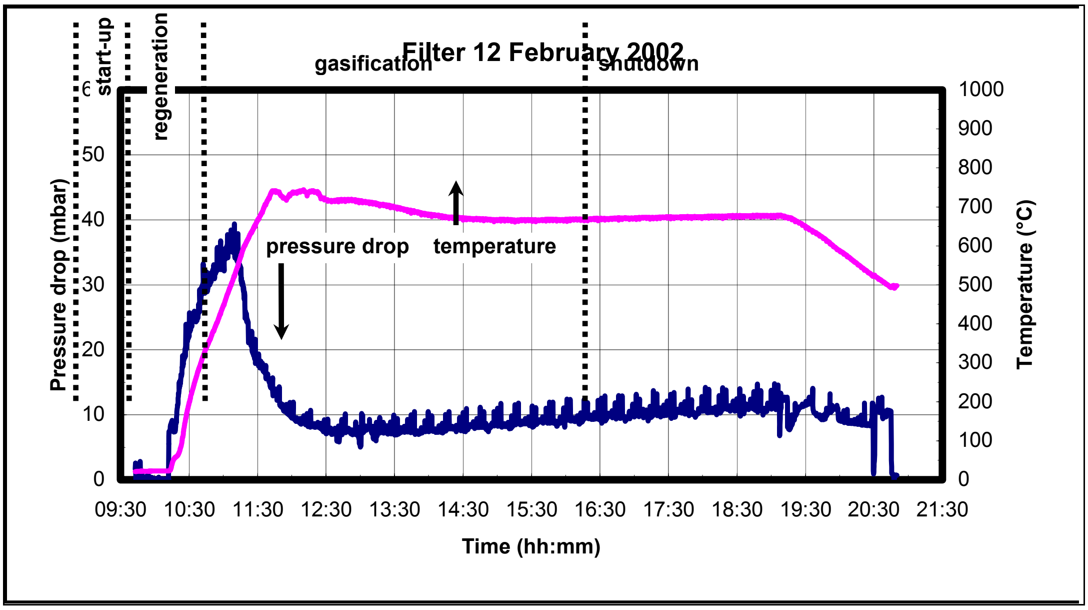
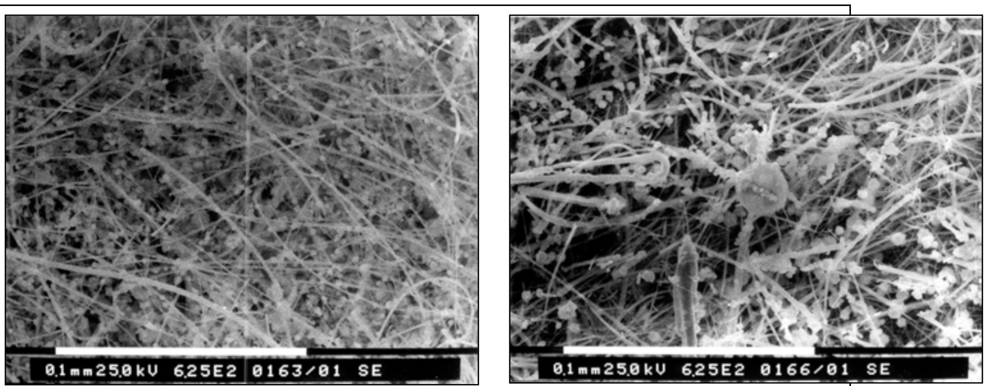


Figure 7: Pressure drop vs. time for wood gasification with steam.



A: magnification 625×, acceleration voltage25 kV B: magnification 625×, acceleration voltage25 kV

Figure 8A-B**:** SEM picture of silicon spheres on a quartz fibre filter behind the ceramic filter.

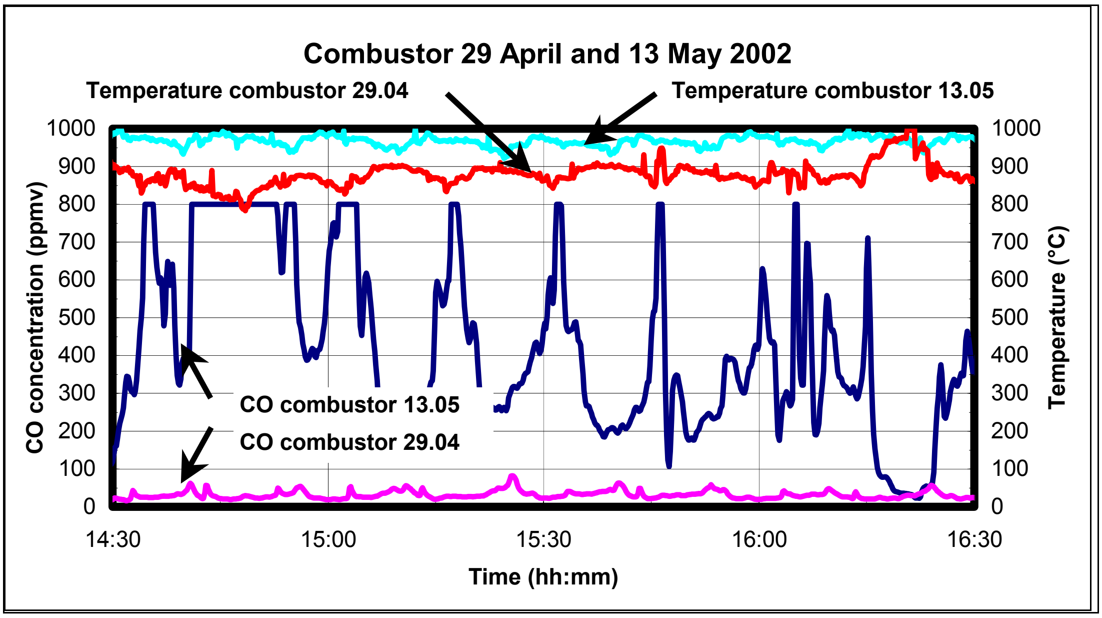


Figure 9: Combustor outlet temperature and CO emission in miscanthus gasification.

Potential consequences for downstream equipment in gasification processes can be shown from the differences in combustor behaviour in the last two experiments as shown in Figure 9.

The CO level on 13 May is much higher compared to the level of 29 April while the gas quality and air stoichiometry are comparable. Also the disturbance by the filter cleaning pulses is more severe. The pre-pressure, cycling time and pulse length were the same for both experiments. They were 8.5 bar, 600 s and 200ms respectively.

4 Conclusions

Wood, miscanthus and two different additives were used in the tests. A number of interesting results have been found.

The first result was the blinding and successful regeneration of the hot gas filters. The filter blinding and soot formation only occurred in wood gasification without steam. With steam soot was not observed behind the ceramic filters and blocking of the filters did not occur.

Two different additives were compared in the miscanthus gasification experiments. The used additives were dolomite and minphyl (pyrophyllite). The additives had no visible effect on the pressure drop and ash removal. However with minphyl the dust loading behind the ceramic filter was much higher. Inspection with SEM-EDX of the dust sampled behind the ceramic filter revealed condensed micron sized silicon spheres. This dust had a marked effect on the behaviour of the combustor. The CO levels were much higher than in the comparable test where dolomite additive was used. The influence of the pulse cleaning on the CO level was also much more noticeable.

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References

Andries J., Ünal Ö., Jong W. de, Hoppesteyn P.D.J., 2001. Operating experience with a ceramic channel-flow filter downstream of a coal-biomass fuelled pressurized bubbling fluidized bed gasifier., In: D.W. Geiling (eds.); Proceedings of the 16th international conference on fluidized bed combustion, Reno, USA, , pp. 1-11.

Bishop B., Raskin N., 1996. High temperature gas cleaning using a honeycomb barrier filter in a coal-fired circulating fluidised bed combustor. In: Proceedings of the third international symposium on gas cleaning at high temperatures, Karlsruhe, Germany.

Jong W. de, Ünal Ö., Hoppesteyn P.D.J., Andries J., Hein K.R.G.; 2001. Pressurised gasification of biomass and fossil fuels in fluidised bed gasifiers, hot gas cleanup using ceramic filters and pressurised product gas combustion. In: A.V. Bridgwater (eds.); Progress in thermochemical biomass conversion, Vol. 1. Blackwell, London, pp 473-487.

MacLaughlin J., 1990. The removal of volatile alkali salt vapours from hot coal-derived gases. PhD-Thesis, University of Surrey, Surrey.

Sydkraft, 2001. The Värnamo demonstration plant. Sydkraft report, Malmö.

Woudstra Th., Woudstra N, 1995. Exergy analysis of hot-gas clean-up in IGCC systems, Journal of the institute of energy, Vol. 68, pp 157-166.