

## 7 Thermal conversion of switchgrass

D. van den Berg and P. de Visser et al.

BTG (Biomass Technology Group), Enschede, The Netherlands.

### 7.1 Switchgrass analysis

A switchgrass sample of variety Alamo originating from the ENEA experiment station in Trisaia, Italy, has been analysed and the results are compared to the results of a switchgrass sample from England and with analysis results from literature. Secondly the composition of switchgrass has been compared to averaged analysis results for *Miscanthus*.

Composition of switchgrass is typical for a biomass that on the average comprises of 50% carbon, 43% oxygen and 6% hydrogen with 1% ash. Switchgrass has however a considerable higher ash content, up to 4%, which can be explained by the higher share of leaves material.

Switchgrass samples from Italy and England are very much the same. Main difference is in the ash melting temperatures, which are 130 to 190 °C higher for the English sample. This can be explained from the higher K content in the Italian sample because K tends to reduce ash melting temperatures.

Comparison with the average values of four *Miscanthus* samples shows that the composition of *Miscanthus* is largely the same as of switchgrass. The four *Miscanthus* samples show a large variation in chlorine content, from 0.5 to 0.03. This spread can be explained from the location where the *Miscanthus* is grown. Areas close to the sea tend to produce *Miscanthus* with higher chlorine contents. The same may be true for switchgrass.

Ash melting temperatures for *Miscanthus* are lower than for switchgrass, but no data on the K content of *Miscanthus* is provided.

### 7.2 Fouling, slagging and corrosion

Biomass contains inorganic elements, which are released from the ash during combustion and deposit on the surfaces of the combustion unit. This is called fouling. Slagging relates to the melting of these deposits, forming a glassy layer. Interaction of the deposits with the metal surfaces can accelerate corrosion, which gradually destroys the metal surface, leading to increased maintenance requirements and reduced service life of the installation.

Deposit formation, which results in slagging, fouling and corrosion, is a complex phenomenon, which involves alkali metal release during combustion, gas phase reactions, transport phenomena, gas and surface temperatures and surface interactions and chemical reactions. In spite of intensive research over the last years, the deposition mechanisms are not yet known in detail. However, there is general agreement on some parts of the mechanism.

Initial mechanism of deposition is condensation of KCl and  $K_2SO_4$ , formed by volatile elements such as K, S, and Cl, which vaporise during combustion. This initial layer will melt and become sticky, thus trapping non-volatile elements like Si, Ca and Mg.

K reacts with Si to form alkali silicates, which have significantly reduced melting points. The other elements form eutectics with low melting points, where mixtures with high K concentrations display the lowest melting points. Next to K, Cl is a major factor in deposit formation.

Corrosion of metal surfaces can be accelerated by alkalis and chlorine because the protective oxide layer on the metal can be destroyed.

So the formation of deposits is closely related to corrosion. This means that a decrease in deposit formation will also reduce corrosion problems.

The concentration of K and Cl in switchgrass, 0.21 and 0.23% is in the order of magnitude as for *Miscanthus*, higher than for wood, but lower than for straw or grass. On the basis of this analysis a moderate corrosion behaviour for switchgrass can be expected.

### 7.3 Corrosion tests

Corrosion tests were conducted in a special test rig of BTG, consisting of an oven in which two metal samples have been exposed to biomass vapors (in this case switchgrass vapors) at high temperatures (from 500 to 850 °C). These samples have been analysed and following conclusions can be drawn.

During combustion of switchgrass high concentrations of potassium and sulfur occur in the gaseous phase and condensate on the colder surfaces. In these areas, characterised by a green/yellow color, much sulfur, oxygen and, to a lesser extent, potassium are present in the metal.

The results also show a clear reduction of the chrome intensity. Because chrome is withdrawn from the inside material, (chrome diffuses to the surface to react with sulfur, space is created for sulfur and oxygen to react inside the material with other metals like molybdenum, nickel etc. On the long term this will lead to serious corrosion and reduction in the thickness of the material.

On spots of the material where no yellow/green deposit has settled, the surface and the oxide layer show a lot of metaloxides, like iron oxide and chromium oxide, where chromium oxide forms a closed oxide layer which will protect the metal.

About the consequences of the test results for the practical situation little can be said. The duration of the tests of two weeks is too short to expect serious corrosion. The analyses results indicate a reduction in material thickness of 15 to 26  $\mu\text{m}$ . From previous, long term experiments can be concluded that on spots where sulfidation occurs, on the long run serious corrosion and material reduction will arise.

#### **7.4 Gasification of switchgrass**

Gasification is a process in which organic material is converted to a combustible gas, called producer gas. This producer gas mainly consists of  $\text{H}_2$ ,  $\text{N}_2$ ,  $\text{CH}_4$ ,  $\text{CO}$  and  $\text{CO}_2$ . The producer gas then can be used as a fuel to generate electricity, for example by means of a gas engine or gas turbine or generator.

For biomass gasification several technologies can be applied, depending on scale, fuel type, ash content and ash melting behavior. For the gasification of switchgrass, a fluidized bed seems to be the best applicable technology, because it can handle biomass types with a very low bulk density as well as low ash melting temperatures.

The experimental set-up for the gasification experiments consisted of the fluidized bed gasifier with feeding system, gas cleaning and cooling and a gas engine coupled with an electricity generator. To study the gasification behavior of switchgrass, the plant was operated without gas cleaning and gas engine.

The feeding system was calibrated for the use of grinded switchgrass and the gasifier preheated to  $650^\circ\text{C}$ . The experiment starts when the air is adjusted to the desired amount of  $10 \text{ Nm}^3/\text{h}$ . Next biomass feed rate is increased and gasification starts.

The amount of gas produced was measured with a gas meter. By means of side stream condensation, the water, tar and dust content were determined. A gas chromatograph was used to determine the gas composition and the tar composition was determined by solid particle analysis (SPA).

Gas production over the experiment was reasonably constant, with 5%  $\text{H}_2$ , 3%  $\text{CH}_4$  and 11%  $\text{CO}$  as main combustible components. Lower heating value of the gas was  $4 \text{ MJ}/\text{Nm}^3$ . Tar produced mainly consists of light tar components. Ash production was high, meaning that the ash still contains carbon. No ash melting was observed.

Gasification of switchgrass in a fluidized bed is an perfectly viable option. Feeding causes no problems and the producer gas is of good quality. Tar formation is limited to light tars and no ash slagging occurs. The only point of attention is the relatively high amount of carbon in the ash.

#### **7.5 Pyrolysis of switchgrass**

Switchgrass was pyrolysed in a  $250 \text{ kg}/\text{h}$  flash pyrolysis plant based on the rotating cone technology. In the rotating cone reactor sand of ca.  $550^\circ\text{C}$ , acting as the heat carrier, and switchgrass are mixed together and flash pyrolysis (instant evaporation) of the switchgrass particles occurs. Pyrolysis of switchgrass yields non-condensable gases, a condensable bio-oil and charcoal as products. Typically in this type of reactor, biomass decomposes into 70 weight % condensable vapors, 15 weight % non-condensable gases and 15 weight % char. The charcoal is fed back to the system and serves as heating fuel, rendering the process endothermic.

The switchgrass was crushed in a hammermill with a screen size of 5 mm. Subsequently it was dried to a moisture content of 2% by weight.

A gas chromatograph was used to determine the gas composition. Gas production over the experiment was reasonably constant, with 5%  $\text{CH}_4$  and 32%  $\text{CO}$  as main combustible components. Lower heating value of the gas was  $5.9 \text{ MJ}/\text{kg}$ .

The bio oil was combusted in the BTG combustion rig. In this rig air atomization nozzles are used. Secondary air is injected around the nozzle. The unit is preheated to  $800^\circ\text{C}$  by means of a propane flame.

At 800 °C the propane is slowly replaced by bio-oil. Temperature profiles and emissions are monitored during the experiment.

Switchgrass is a suitable feedstock for pyrolysis oil. A stable oil is formed and can be used in oil burners. Emissions are comparable to emissions from diesel combustion. An oilyield is obtained of 64wt.% of the original feedstock. The analysis of the pyrolysis gases shows a combustible gas with a LHV of 5.9 MJ/kg, which, after removing the aerosols, can be used in, for example, a gas engine.

## 7.6 The combustion of switchgrass

The combustion in a high temperature furnace environment has been investigated.

When combusting switchgrass the conversion process consists of two phases, first a flaming pyrolysis phase in which rapid devolatilization of the switchgrass occurs, and a slow burn-out phase. This burn-out time depends on particle size and geometry and proper designed combustors take the slow char burn-out phase into account.

The experimental setup consists of a stainless steel tube, which has an opening to insert a switchgrass particle. Air can be blown into the pipe at any desired velocity. Prior to each experiment the tube is heated to a stationary temperature by means of a large electrical current. Temperature is monitored by a thermocouple. When a switchgrass particle is inserted in the hot zone, the particle pyrolyses with the emission of flaming volatiles in 1 to 2 seconds. There after the slower char burn-out follows, which takes about 5 to 10 seconds. The complete cycle is recorded on video, so exact conversion times can be determined by detailed inspection of the videotape.

Experiments have been conducted on switchgrass particles with a well defined geometry (3\*5\*0.8 mm) and on a random sample of milled particles.

Increased air velocity leads to a smaller char burn-out time and less scatter of the experimental outcome. Char combustion time varies between 2 and 7 seconds so a properly designed furnace for the combustion of this type of switchgrass particles (with a flake thickness of 0.6 mm) must have a minimum gas residence time of 10 seconds. For existing boilers, with residence times of less than 3 seconds, the flake like switchgrass particles must be milled to 0.3 mm thickness.

In case switchgrass is milled in a hammer mill to needle like particles with a diameter not larger than 0.5 mm, the conversion time will be less than 3 seconds. These particles can be co-fired in pulverized coal combustors, CFB combustors or entrained flow combustors.

Melting and sintering of the ash has been visually observed at temperatures higher than 1000 °C, so slagging combustion of switchgrass is to be expected.