CHAR QUALITY AND TAR FORMATION INTERDEPENDENCE: FIRST EXPERIMENTS IN A NEW TWO-STAGE GASIFIER.

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ABSTRACT: For small scale gasification for CHP purposes, it is of great importance that tar content in the gas remains below 10-50 mg/Nm^3. Such low tar concentrations have been reported with staged gasification processes operated for long periods by TK Energi A/S (TKE) and the Danish Technical University (DTU). But for production of syngas, tar concentration must be 1-2 orders of magnitude lower. Such a two-stage gasifier (75 kWth) has been recently installed at CIRAD facilities. The present paper deals with the description of this new equipment and the first pyrolysis tests results obtained. The general objectives of the work are to investigate the influence of the char quality on the gas quality (tar content) and to support the design of two-stage gasifiers and char beds for thermal gas cleaning.
Keywords: Gasification, biomass, CHP.

1 INTRODUCTION

For the decentralised use of biomass fuels, the combination of electrical and thermal energy productions seems promising from an economic point of view, but needs clean and robust technologies with high overall efficiency and maximum electricity yields. Despite progress in large-scale applications, the technology applied to small-scale applications (below 5 MW) still needs substantial research and development, especially in the gas cleaning area.

It seems today obvious that the two stages approach is the most attractive, indeed:

- Although they are very simple to operate, updraft gasifiers have a severe problem with the poor gas quality they produce, due to 2-30 g/Nm^3 tar in the gas.
- Tars and alkali contents in the gases are also one of the major constraints for large CHP plant based on fluidised bed gasifier.[1,2,3]
- Downdraft gasifiers are difficult to upscale and the maximum size is lower than 500 kWe.

Another problem mentioned by authors is the tolerance of the technologies as regards biomass quality and fuel preparation cost. Separating the pyrolysis stage from the gasification stage is also an interesting option for fuel homogenization prior to gasification. Appropriate pyrolysis technologies may reduce fuel preparation cost.

Stage divided gasifiers are further development of single staged downdraft gasifiers. In conventional stage divided gasifiers, biomass is fed into a pyrolysis unit generating char and pyrolysis gases. The char is then converted to gas, mainly through endothermic reactions in the char reduction reactor. The energy for char reduction is supplied by oxidising part of the pyrolysis gases in the oxidation zone, and by feeding the combusted gases into the char reduction zone through the char bed.

The experiments carried out at Cirad aims at characterizing this new pilot in order to:

- provide a better understanding of the process ;
- optimize the operating conditions and
- Support the design of new gasifiers.

2 PILOT PLANT DESCRIPTION

Figures 1, 2 present the experimental facility used.

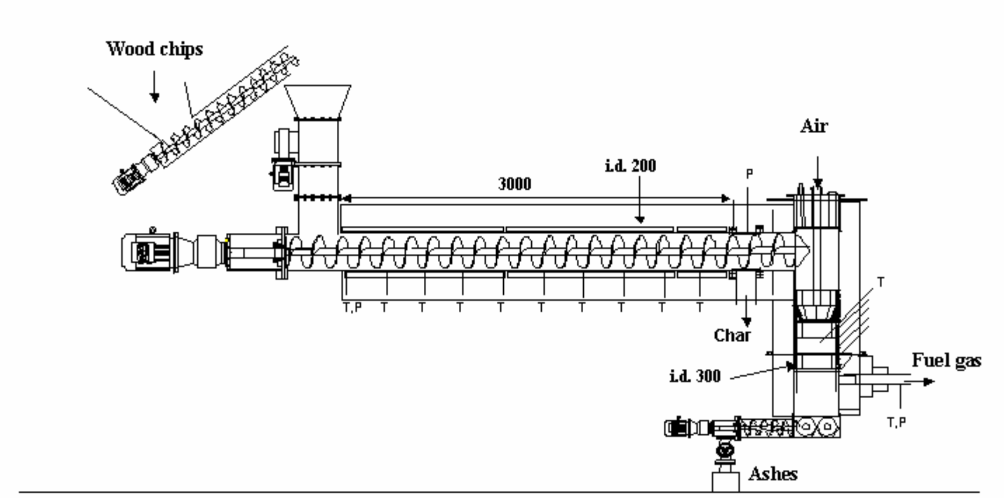

Figure 1: Diagram of the two - stage gasifier

Briefly, the biomass is fed into a screw pyrolysis reactor to be pyrolysed and thereby divided into char and pyrolysis gas. The char falls in the reduction zone, the char bed, while the pyrolysis gases are burnt in the upper part of this gasification reactor. This equipment has been designed for 15 kg/h nominal mass flow rate. Two alternative feeding valves are necessary in order to ensure a perfect gastightness of the process.

Figure 2: The two - stage gasifier

The pyrolysis unit is an externally heated screw conveyer. It consists in a tubular reactor of 280 mm diameter and 3,86m length. This reactor can be heated to 800 °C thanks to surrounding heating elements fitted all around the outer part of the pipe. Three independently controlled zones (total power: 23 kW) allow a good temperature homogeneity along the reactor, as shown the profile temperature presented in figure 3. The residence time of the solid is fixed by the screw velocity from 120 s to some hours. The residence time is independent from the shape and size of solids as well as from their density.

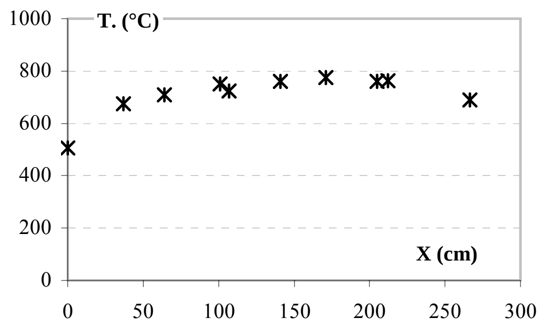

Figure 3 : Temperature profile in the pyrolysis reactor

At pyrolysis unit outlet, the char and pyrolysis gases enter in the second reactor, the gasifier, where the gases are oxidized in the high temperature zone (1000-1300 °C).

The char falls into the bottom part of the gasifier unit where it is gasified by the hot reacting gases. In this part the temperature range goes from 850ºC to 950ºC. Then the temperature decreases in the fixed bed, until reaching about 600ºC where the ashes are extracted from the gasifier. Two conic screws in the bottom of the bed are used to extract the ashes/char from the gasifier.

3 EXPERIMENTS

3.1 Experimental procedure

Two sets of experiments are carrying out.

In a first step, pyrolysis unit alone has been tested with wood chips. Objective was to evaluate influence of operating conditions on:

- Char/gas/tar repartition (mass balance) ;
- char quality (ultimate/proximate analysis, structure characterization) ;
- Non condensable gases composition ;
- Tar composition

In a second step, the pyrolysis reactor will be coupled with the gasification bed. Objective of this set of tests will be to characterize the whole gasification process in terms of:

- Gas composition and heating value ;
- Tar composition and amount ;
- Residual ashes composition.

The optimization of the process will be investigated by studying the influence of:

- Pyrolysis operating conditions (temperature, residence time);
- Wood chips mass flow rate ;
- Air flow rate in the reduction zone ;
- Char bed height.

3.2 Biomass feedstock

The tests have been carried out on pine wood chips. The ultimate and proximate analyses are given on Table I. The particle size of the raw material is in accordance with the regulation existing in France for wood boilers.

Table I: Pine wood chips characteristics

Proximate analysis (on dry basis)		
Moisture content		15%
Volatile Matter rate		81,3%
Fixed carbon		18,5%
Ashes rate		0,2%
Heating value(superior calorific value)		19,3Mj/kg
Ultimate analysis (on daf basis)		
	C	45,28%
	H	5,68%
	O	42,75%
	N	<0,30%
	S	<0,10%
Granulometry (average)	length	3 cm
	width	1,5 cm
	thickness	5 mm

3.3 Results and discussions

After characterization and optimisation of the prototype, pyrolysis and gasification reactors have been separated in order to test the pyrolysis unit alone.

Tests were performed with the following operating conditions:

- Temperature: from 450 to 750°C
- Residence time: from 15 to 60 min.
- Wood chips mass flow-rate: from 10 to 20 kg/h.

At pyrolysis unit outlet, charcoal and gases are collected.

Charcoal is analysed in terms of volatile matters, ashes, moisture and fixed carbon.
Tars are condensed according to tar protocol, weighted and analysed. Non condensable gases are on-line analysed thanks to a Gaseous Phase Chromatography analyser.
During each experiment, charcoal and oils are weighted. The ratio of liquid/gas is then calculated, as the repartition charcoal/gas/oils during pyrolysis.

Charcoal yield and composition
In figure 4 is shown the influence of temperature on charcoal yield and composition. First of all, the ashes contents in charcoal remains very low (about 1.2 %) and is consequently not really sensitive to temperature.
The charcoal yield and composition decrease when the temperature increases. These results are very classical as have been observed by other authors [4, 5]. The charcoal yield decreases from 32 to less than 20 % when the temperature varies from 450 to 750°C [8,9].

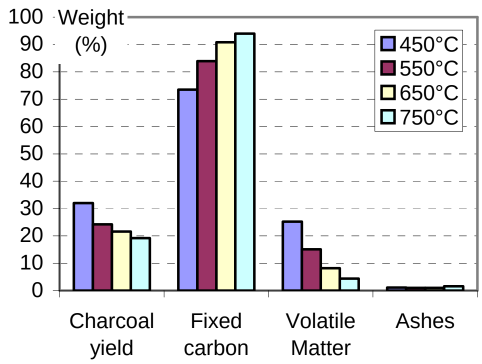

Figure 4: Charcoal yield and char quality after pyrolysis at different temperatures (Residence time: 1h; Wood chips flow-rate: 15kg/h).

The figures 5 and 6 show the charcoal yield and composition versus residence time. It appears clearly (figure 5), that residence time for high pyrolysis temperature (750°C), is without influence on charcoal yield and composition. But, when the temperature is lowered to 450 °C (figure 6), the volatile matters content and the charcoal yield seems much more sensitive to the residence time.

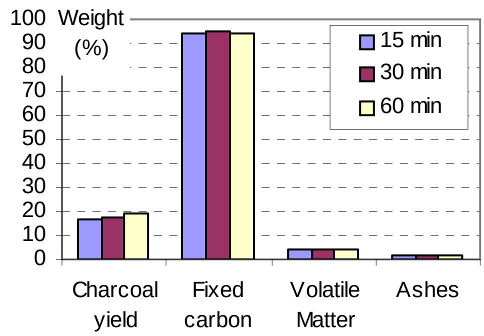

Figure 5: Charcoal yield and char quality after pyrolysis at different Residence time - **T°: 750 °C**.

Pyrolysis gases analysis
The figure 7 shows the influence of gas temperature on non condensable gas composition.

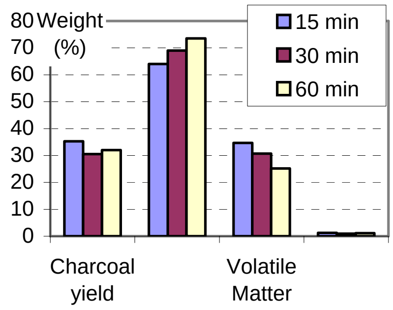

Figure 6: Charcoal yield and char quality after pyrolysis at different Residence time - **T°: 450 °C.**

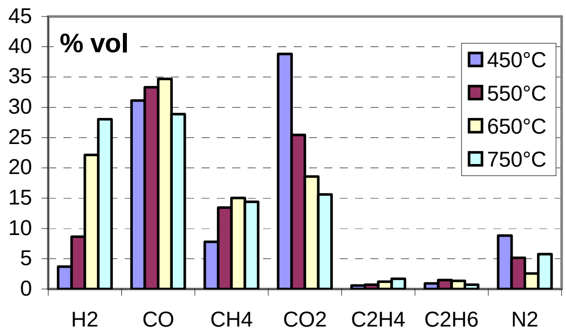

Figure 7: Non condensable gas analyses during pyrolysis (Residence time: 1h; Wood chips flow-rate: 15kg/h).

The molar concentrations of H_2, CO, CH_4 increase when the temperature increase. The high concentrations of H_2 (higher than 20 %) for temperature above 650 °C can be due to partial gasification in the pyrolysis reactor because of the long residence time. This is confirmed by the observation of the figure 8, showing the influence of residence time on non condensable gases produced during a 750°C pyrolysis. H_2 concentration increases continuously when the residence time increases. At 750°C, H_2 and CO contents are comparable. On the contrary, CO content decreases when the residence time increases.

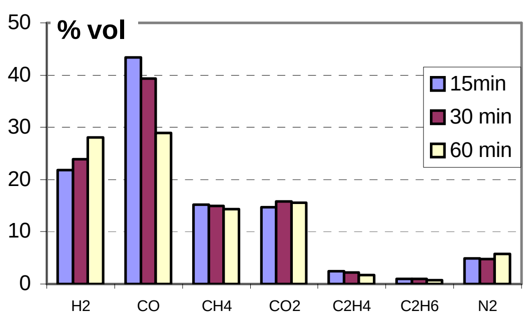

Figure 8: Non condensable gas concentrations versus residence time in the reactor – **T°: 750 °C**.

4 CONCLUSIONS

A new 75 kWth two-stage gasifier has been implemented at Cirad.

The pyrolysis unit has been separated from the gasification reactor in order to study the pyrolysis reaction alone and to precisely characterised the products (charcoal, gases and oils).

A characterisation of the pyrolysis reactor has been carried out, with the measurements of the temperature profiles along the reactor, the wood chips mass flow-rates and the solid residence times.

Next, a complete parametric study of the pyrolysis in this reactor has been carried out, varying the temperature, wood chip flow-rate, and residence time.

Some experimental results are presented, showing the high sensitivity of charcoal yield and composition, and gas concentration to the temperature. H_2 and CO concentrations are relatively important at high temperature (about 30 %) due to a partial gasification occurring together with the pyrolysis reaction. That has also been confirmed by the increase of H_2 concentration with residence time of the solid in the reactor. At lower temperature (450°C), the gas concentrations are not sensitive to the residence time which influences slightly the charcoal quality.

This parametric study carried out will be very useful in the future of this project. Indeed, in the other stages of the gasification process, these products - which have been precisely characterised for different operating conditions - are going to be gasified (charcoal), oxidised (gas) or cracked (tar).

The next step of this project is to couple again the pyrolysis and the gasification reactor in order to test the whole unit, to characterise the tar cracking in the char bed and to optimise the two-stage gasification processes.

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