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LOW TEMPERATURE CFB GASIFIER, CONCEPTUAL IDEAS, APPLICATIONS AND FIRST TEST RESULTS

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ABSTRACT: A novel "Low Temperature Circulating Fluidised Bed" (LT-CFB) gasification process for biomass and organic waste materials is described together with its potential applications and the first results from a 50 kW test plant. One of the aims is to avoid problems due to ash sintering and agglomeration. This is realized by pyrolysing the fuel at around 600 °C in the CFB chamber and subsequently gasifying the char at around 700 °C in a slowly fluidised bubbling bed located in the CFB particle re-circulation path. The first tests were performed on Danish wheat straw containing 1.8 % K and 0.6 % Cl and the bed material was silica sand without additives. In spite of these severe conditions, it was possible to avoid deposition and agglomeration problems during 8 hours of gasification. The amount of unconverted char was down to 1.5 % of the fuel mass flow, and a high retention of ash, K and probably also Cl was achieved by cleaning the uncooled gas in a secondary cyclone.

1. PURPOSE OF THE WORK

The purpose of the work has been to test and further develop the LT-CFB gasification process and to identify its potential applications.

2. BACKGROUND

Energy production based on biomass is considered one of the main options for reducing the emission of CO_2 in Denmark. Straw is the main biomass resource, but unfortunately combustion and gasification of straw is known to give problems such as process fluctuations, fouling/slagging, agglomeration and corrosion. Similar problems are seen when using other types of especially agricultural biomass, with high content of Si, K and Cl.

Co-firing or gasifying the biomass together with coal may be a solution and this way the larger investment for separate biomass boilers can be avoided. However, the opportunities for utilizing the (mixed) ashes may be reduced and a potential de-NO_x catalyst may be deactivated by potassium.

One of several alternatives considered is gasifying the straw in a Circulating Fluidised Bed (CFB) gasifier and cleaning the raw gas in order to burn it in e.g. large power plant boilers. The ideas for the new LT-CFB gasifier was in the first place developed for this purpose but many applications in much smaller scale seems also feasible.

3. CONCEPTUAL IDEAS

A somewhat simplified version of the LT-CFB concept is illustrated in figure 1. The 3 main components are:

- A Circulating Fluidized Bed (CFB) pyrolysis chamber.
- A particle separator (cyclone).
- A Bubbling Fluidized Bed (BFB) char gasification chamber.

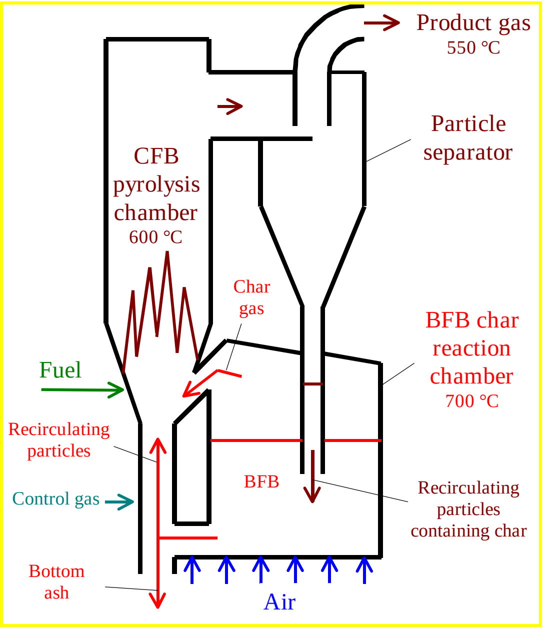

Figure 1. Illustration of the LT-CFB concept.

One of the main ideas is to avoid problems due to ash sintering, deposition and agglomeration by gasifying the fuel at a low temperature level. This is realized by achieving a high degree of fuel conversion through fast pyrolysis in the CFB chamber and by giving the resulting small and reactive char residue a high retention time in the BFB chamber.

The gasification agent (usually air) is added to the BFB chamber as a fluidizing gas and the resulting low calorific char gas is utilized as a carrier gas in the CFB chamber. Therefore, the product gas leaving at around 550 °C becomes a mixture of the char gas and the much more energetic and partly condensable pyrolysis gas.

The indicated particle circulation between the two chambers carry energy released by the mainly exothermic reactions in the BFB chamber to the mainly endothermic reactions in the CFB chamber. Hence, the temperature in the BFB char reaction chamber may be controlled at e.g. 700 °C by adjusting the air addition while the temperature in the CFB pyrolysis chamber is controlled at around 600 °C by adjusting the particle circulation. The particle circulation may be controlled by adding “control gas” to the duct interconnecting the two reaction chambers.

Further information are included in the patent application [1].

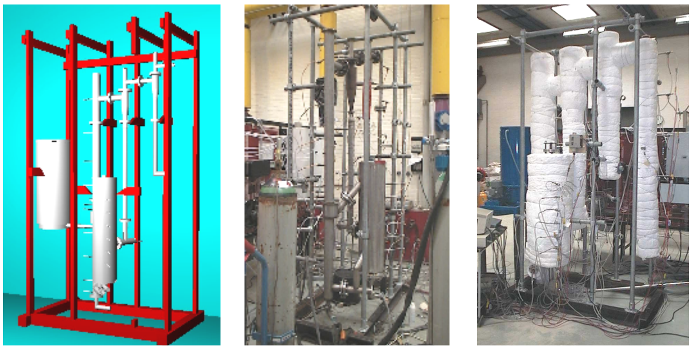

Figure 2. The 50 kW LT-CFB test plat at DTU through 3-D computer modeling, leak testing and adding insulation and instrumentation.

4. ADVANTAGES

Due to the described characteristics, a number of advantages are obtained compared to a single chamber type CFB gasifier :

- High char conversion at low temperature.
- Improved capability of using fuels with low ash softening temperature.
- No/reduced need for air-preheating and for cooling the fouling and corrosive raw gas.
- No/reduced thermal losses relation to gas cooling and start up/cooling down.
- Low content of gaseous alkaline and chlorine components in the (uncooled) raw gas, so that these components can be removed by a secondary particle separator, which in many cases may be a reliable and readily available secondary cyclone.
- Low sensitivity to fluctuations in fuel feeding.
- High heating value of the product gas and therefore also small specific square sections in the riser and down stream components.
- Low building height (which is particularly important in order to avoid an uneconomic shape in small scale).
- Reduced manufacturing and maintenance costs.

In comparison to several known two chamber CFBG-concepts some typical differences are:

- The low temperatures in both of the two chambers.
- Simplicity due to usually only one off-gas line (the char reaction chamber is usually a combustor, that liberate more heat and produce a separate gas stream).
- Increased char hold up due to low gas velocity in the char reaction chamber and re-circulating the particles from the bottom of this chamber (where the concentration of small easy-to-lose char particles is lower than in the top).

The previous paper [2] elaborates further on the expected advantages.

5. THE 50 kW LT-CFB TEST PLANT AT DTU

A 50 kW LT-CFB test plant has been build and commissioned at ET, DTU. The “creation process” starting with a 3-D computer model, through leak testing and adding insulation and instrumentation can be followed from left to right in figure 2. If looking at the last picture, the BFB char reaction chamber is in the front while the 4 taller insulated components are (from the left to the right): the CFB pyrolysis chamber, the primary cyclone, the secondary cyclone and a vertical tube section for measurement the gas flow rate and for detection of potential particle deposition.

The insulated components except the lower part of the last mentioned tube section can be heated electrically.

The cylinder in the background to the left is the fuel silo and finally it can be mentioned that the total height of the framework is a little less than 3 m.

6. FIRST TEST RESULTS

6.1 Test work performed in 1999

The 50 kW LT-CFB test plant was operated for several hours already when fuel was added for the first time in June 1999. After properly (i.e. manually) adjusting the valves etc. there was hardly anything to do the last hour except watching very constant process signals and a beautiful straw gas flame until the fuel silo went empty. The bright flame and two of the 3 participating DTU students are seen in figure 3.

Figure 3. The bright straw gas flame during the first start-up of the 50 kW LT-CFB plant at DTU.

A second and a third start up revealed various problems, that had to be resolved, but the fourth test was again very successful. Hence, fuel was then added for 8 hours of well controlled gasification.

The four tests were performed on Danish wheat straw containing 1.8 % potassium and 0.6 % chlorine (dry basis). The straw was fed as crushed ø 6 mm pellets containing a little less than 10 % moisture. The bed material was ordinary silica sand and no additives were used.

Three characteristic temperatures measured during the test no. 4 can be seen in figure 4. T3 is measured in the BFB char reaction chamber, while T9 and T14 are measured in the lower and the upper part of the CFB pyrolysis chamber respectively. The small periodic temperature variations, indicates that the gasifier was stopped for approx. 10 minutes every approx. 30 minutes of operation. This was to take out samples of cyclone ash and bed material etc. and in this way enough data were obtained to set up mass and energy balances and to calculate important performance data.

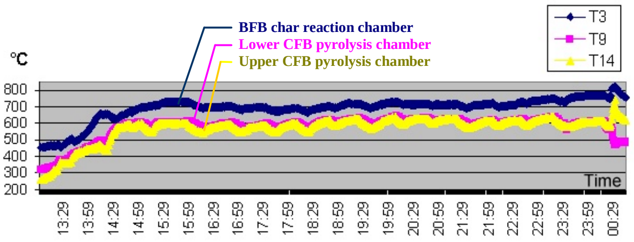

Figure 4. Characteristic temperatures from test no. 4. T3 is measured in the BFB and T9/T14 in the lower/upper part of the CFB chamber.

6.2 Mass and energy balances

From the accumulating mass flow curves in fig. 5 it can be seen that for the first few hours only approximately 1.1 kg of air per kg straw was added as gasification agent. Thereafter 1 kg of steam per hour and some additional air was added. The additional relatively high amount of N_2 was added mainly to the bottom of the pyrolysis chamber. This was for security reasons and in order to keep things simple.

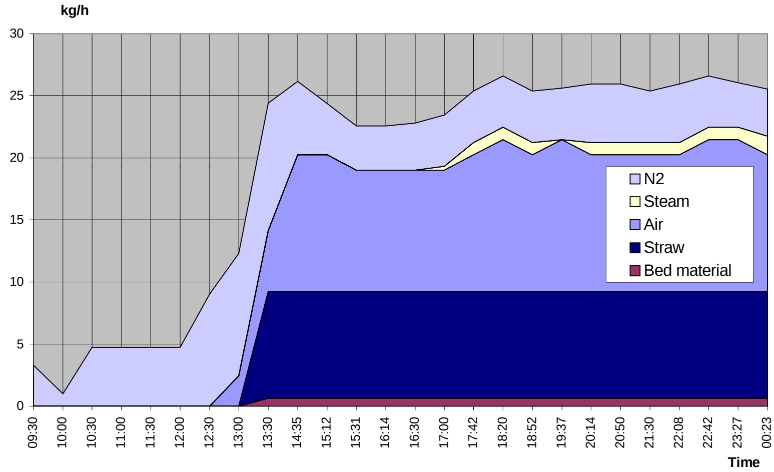

Figure 5. Input mass flows during test no. 4.

The addition of steam was done because it was believed that the rather black cyclone ash was mainly unconverted carbon. However, the following analysis showed that the combustible part was down to below 15 % corresponding to only 1.3 % of the fuel mass flow. Moreover, the best results were achieved prior to adding steam, which means that it may be possible to go to even lower air to fuel ratios while retaining a low loss of cyclone char.

A mass balance calculated for the inert and ash particles flowing in and out of the system revealed that in average only approximately 10 % of the inert/ash passing the primary cyclone was lost along with the product gas passing through the secondary cyclone.

This good performance of the secondary cyclone is probably due to the low process temperatures that make K stay in or condense on the char/inert particles, which this way become heavier and more mechanically stable.

The retention of char in the primary cyclone as well as the char reactivity may also benefit from this K-behavior.

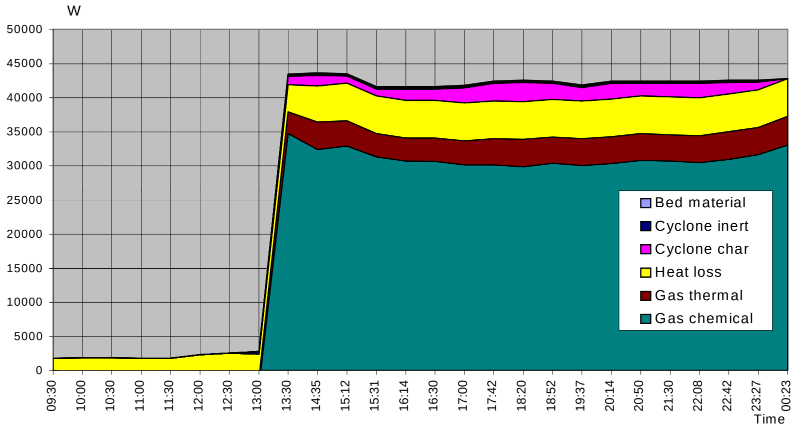

Figure 6. Output energy flows during test no. 4.

The energy streams out of the system is illustrated in figure 6. It should be noticed that “Gas chemical” is calculated by difference, and therefore it includes the heating value of char particles following the product gas through the secondary cyclone. However, assuming the same low relative loss of char as for inert/ash through the secondary cyclone, this further loss of combustible char is only around 0.2 % of the fuel mass flow. Hence, the total amount of unconverted char was down to approximately 1.5 % corresponding to an energy loss of only 2-3 % of the upper heating value of the fuel. This is in spite of the small dimensions of the test plant and many unused options for optimizing the process. E.g. the results may be further improved by :

- Avoiding the relative large added stream of N_2.
- Reduced addition of steam and/or air.
- Decreasing the specific heat loss by better insulation and by scaling up the process.

In particular, it is not considered a problem to reach the nominal 50 kW total energy input/output by decreasing the gas flows through the system as mentioned above.

In the same time, it seems realistic to reach an upper heating value of the product gas of around 10 MJ/Nm^3. In combination with the low gas exit temperature, this corresponds to only about half the specific volume of product gas compared to using dry biomass fuels in usual CFB gasifiers.

6.3 Gas composition

A typical content of light gas components measured by on-line instruments and batch wise by a mass spectrometer and a gas chromatograph (MS/GC-FID at Risø National Laboratory) was:

O_2= 0, CO= 8, CO_2= 17, H_2= 2, CH_4= 2, C_2H_x = 0.6, C_3H_x= 0.2

(vol % in gas extracted through a water column and two serial twist filters).

The only measured major impact of the addition of 1 kg steam per hour was that the H_2 concentration approximately doubled. This, and other results indicate that the steam is reacting with the char in spite of the low process temperature. Hence, the char must be very reactive, and it has been confirmed that, if necessary, steam addition can be used to control the process temperature.

As can be seen from the measured gas composition, the high calculated heating value can not be explained by the content of light combustible gas components. Hence, the explanation must be a high content of the heavier (and partly condensable) components known to be present in gas produced by fast pyrolysis at low temperatures. This part of characterizing the gas remains to be done.

6.4 Retention of K and Cl

3 measurements of the total (gaseous and solid/condensed) K and Cl in the hot product gas have been performed based on assistance from the CHEC group at DTU. The measured concentrations corresponds to retentions of 90 - 97 % K and 47 - 73 % Cl, i.e. in the cyclone ash or bed material.

Also these results are very encouraging considering the use of only a simple “hot” cyclone for gas cleaning and that no sorbent material was added. However, especially the Cl-measurements are rather uncertain and therefore they must be confirmed by further measurements.

6.5 Deposition and agglomeration

The particle samples from the bottom of the char gasification chamber and the secondary cyclone did not contain agglomerates and no other indication of ash melting were detected during the test. Therefore, the temperature in the BFB chamber was slowly increased in the last part of the test (see T3 in figure 4), in order to find a temperature limit.

The first signs of defluidisation in the BFB chamber were detected when restarting after the first stop after midnight. Just before this stop the temperature reached approx. 765 °C.

It is interesting that this is very close to the melting point of pure KCl (771 °C), which is assumed to be the main K component accumulating in the bed material. This result is seen as an indication, that the particularly well controlled process conditions in the LT-CFB gasifier effectively counteract the ash melting point suppression and subsequent agglomeration often seen in FB gasifiers using biomass fuels with a high content of salt.

More detailed test results are reported in [3].

7. APPLICATIONS

The work is also focused on identifying the most interesting applications for the LT-CFB process and on developing and demonstrating proper designs for commercial units. E.g. the new gasifier may be used for producing hot fuel gas for e.g.:

- Large scale power plant boilers.
- Small to medium scale solid fuel boilers (as a solution to problems concerning combustion quality as well as ash deposition and corrosion), or which may be replaced by cheaper type boilers.
- Waste incineration boilers for which e.g. the most salt containing part of the waste is gasified, so that the steam data can be improved.
- Small to medium scale natural gas and oil fired boilers, i.e. allowing firing/co-firing of biomass.
- Industrial processes such as drying and calcination.
- Indirectly fired gas turbines and Stirling engines.
- Fuel cells (with prior or internal gasreforming).

Gas cleaning in simple hot cyclones will be sufficient for some of these applications while others demand a more advanced and less proven type of filter.

Alternatively or additionally, the heavy tar components in the product gas could be cracked in order to avoid that they condense when cooling the gas in order to use it in internal combustion engines or (directly fired) gas turbines.

Eventually, the product gas could also be quenched in order to produce liquid products such as “bio-oil” and more valuable chemicals.

7. CONCLUSION

A 50 kW LT-CFB test plant has been built and operated on difficult (high Si, K and Cl) wheat straw. Based on gasifying this fuel in up to 8 hours in a bed of silica sand with no additives it has been shown that:

- The process is easy and safe to start, control, stop, and restart.
- The amount of unconverted char was down to 1.5 % of the mass flow of fuel.
- Around 90 % inert/ash retention could be achieved using an ordinary secondary cyclone.
- The K- and Cl retentions were 90–97 % and 47–73 % respectively (however especially the Cl-measurements are uncertain and must be confirmed).
- After 8 hours of gasification there was still a good margin between the temperature giving an efficient fuel conversion and the agglomeration temperature.

The good test results have been achieved in spite of the choice of fuel and bed material, the small scale and not using several possible optimization methods. Also due to a broad range of possible applications, the LT-CFB gasifier is expected to open important new opportunities for the efficient utilization of biomass and organic waste materials.

ACKNOWLEDGEMENT

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