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THE LOW TEMPERATURE CFB GASIFIER – FURTHER TEST RESULTS AND POSSIBLE APPLICATIONS

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ABSTRACT: The novel "Low Temperature Circulating Fluidised Bed" (LT-CFB) gasification process is described together with the most recent results from the 50 kW LT-CFB test plant located at the Technical University of Denmark.

The LT-CFB concept aims at avoiding problems due to ash sintering/agglomeration and corrosion when using difficult fuels such as agricultural biomass and many waste materials. This is achieved by pyrolysing the fuel at around 650°C in a circulating fluidised bed (CFB) chamber and subsequently gasifying the char down to only around 730°C in a slowly fluidised bubbling bed (BFB) chamber located in the CFB particle re-circulation path.

The 50 kW test plant was built and commissioned during 1999 and since then experiences have been gained from more than 80 hours of operation. Nearly all of the test work has been performed on fuel that is expected to be worst-case conditions, i.e. the fuel has mainly been Danish wheat straw containing 1,8 % potassium and 0,8 % chlorine (dry basis) and the bed material has been ordinary silica sand with no additives.

The test results have showed a high retention of potassium (73-98%) and chlorine (23-75%) in the ash. At the same time the char loss was approx. 3,5 mass% of supplied amount of fuel, and the content of PAH in the ash was only around 2 mg/kg. The most recent test results and anticipated applications are described in this paper.
Keywords: gasification, biomass conversion, circulating fluidised bed (CFB)

1 INTRODUCTION

In 1999 a 50 kW test plant based on the novel Low Temperature Circulating Fluidised Bed (LT-CFB) gasifier was build and commissioned.

Since then 82 hours of operation has been performed primarily with wheat straw as fuel. The last 45 hours was within 3 tests in 2001/2002. The bed material was fully reused in order to represent the severe conditions of long-term operation with minimised addition of fresh bed material.

The aim in this paper is to describe the LT-CFB concept, test results from the last 45 hours of operation, possible applications for the concept and future plans.

The concept and earlier experiments is formerly reported in [1], [2] and [3].

2 BACKGROUND

Within the international energy sector a rising attention has been brought to the utilization of biomass to reduce usage of fossil fuels and CO_2 emissions.

In Denmark cereal straw is the main biomass resource, but as most other agricultural and young woody bio-fuels it often contains high amounts of potassium and chlorine. These components give deposits and corrosion in furnaces, especially if the aim is to produce electricity at high efficiency.

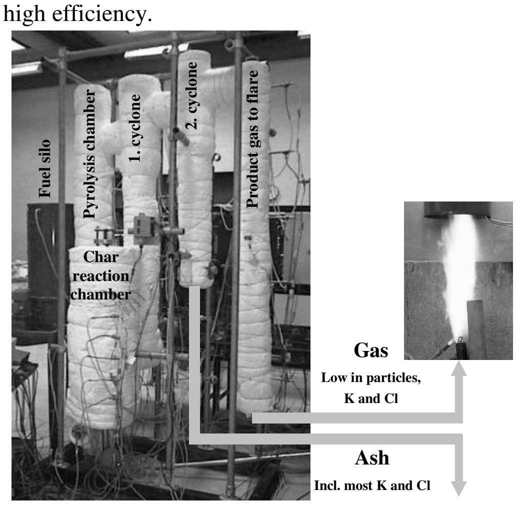

Figure 1: Picture of 50 kW LT-CFB test plant and flare burning product gas

Co-firing e.g. straw with coal can minimise these problems, but this may reduce the options for ash utilization and the ash may have to be deposited representing additional costs and loss of valuable resources. Furthermore there may have to be restrictions on the choice of coal, superheating temperatures and a potential high dust de-NOx catalyst may be de-activated.

The LT-CFB gasifier functions without in-situ ash-sintering and corrosion problems and most potassium and chlorine are simply retained in a separate biomass ash stream. In this way a clean fuel-gas, with a relatively high calorific value, is produced for e.g. a modern and highly efficient power plant boiler.

3 THE LT-CFB CONCEPT

3.1 The 50 kW test plant

Figure 1 shows a picture of the 50 kW LT-CFB test plant and of the flame burning the product gas under operation. On the picture to the left the low char reaction chamber is seen in the front while the 4 taller components from left to right is the pyrolysis chamber, primary cyclone, secondary cyclone and a vertical tube section for flow measurements and detection of potential particle deposition. The dark silo in the back to the left of the pyrolysis chamber contains the fuel (crushed wheat straw pellets for most of the performed tests). The ash is taken out from underneath the secondary cyclone. All of the hot components can be heated electrically for start-up purposes and to compensate for the relatively large heat loss due to the small dimensions.

3.2 The concept

Figure 2 shows a sketch of the concept with the intentional mass flows shown (e.g. the char loss from the primary cyclone is not shown).

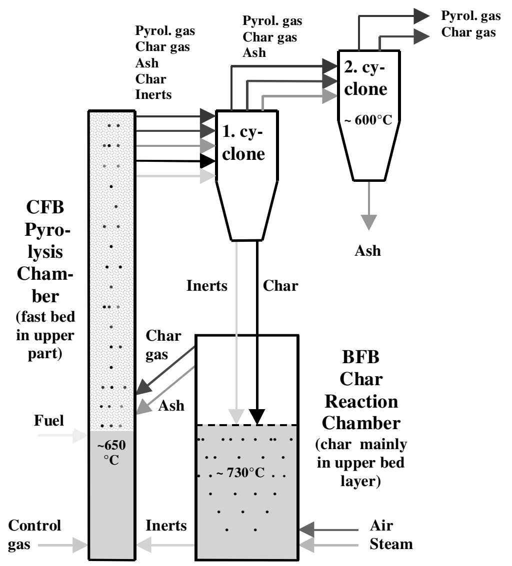

Figure 2: Flow diagram of LT-CFB concept

The fuel enters the pyrolysis chamber, and is pyrolysed at ~650°C. This pyrolysis is fast due to the good thermal contact between fuel and hot sand/bed material and results in a small and highly reactive char residue. The gas lifts the char and sand upwards in the pyrolysis chamber and in a primary cyclone char and sand is separated from the gas and lead to the char reaction chamber.

The char is gasified in a slowly bubbling fluidised bed (BFB) in the char reaction chamber at ~730°C using air and steam as gasification agents. The produced char gas is lead to the pyrolysis chamber, where the gas will contribute to the high velocity in the upper part.

The produced small and light ash particles will not be retained by the primary cyclone, but will follow the gas stream and instead be retained by the secondary cyclone, which is smaller and thereby more effective.

Silica sand is used as a heat carrier between the overall exothermic reactions during the gasification to the endothermic pyrolysis. The sand is lead from the bottom of the char reaction chamber to the pyrolysis chamber and circulated back via the primary cyclone. Segregation in the bed causes the small char particles, that are hard to retain, to flow to the top of the BFB thereby giving them a high retention time.

Due to the low temperatures most potassium and some chlorine are retained in the ash separated by the secondary cyclone. The temperature decrease due to the endothermic pyrolysis avoids the need for gas cooling prior to potassium and chlorine separation.

Due to the fast pyrolysis at low temperature a high amount of heavy hydrocarbons are present in the product gas, thereby giving the gas a relatively high calorific value on volumetric basis.

4 EXPERIMENTEL WORK

Since the 50 kW LT-CFB test plant was built in 1999 82 hours of operation with fuel feed has been performed, hereof 3 hours with wood and the rest with straw. The first ~35 hours of operation was mainly commissioning, verification of the fundamental principles in the concept and short preliminary parameter variations to find the most suitable set points of the input parameters. The last three experiments were performed in a row with full reuse of the bed material to show the plants performance during long-time testing. These three experiments lasted 24, 13½ and 7½ hours giving a total of 45 hours, during which 440 kg wheat straw was gasified.

By using wheat straw harvested in 1995 with 1,8% potassium and 0,8% chlorine (dry basis), ordinary silica sand as bed material and by excluding the use of bed additives such as limestone and caoline, worst case conditions was represented.

During the 45 hour testing only 12 kg of fresh sand was supplied to up weigh 7 kg of samples of the bed material and losses through the primary cyclone. In order to further enhance the accumulation of potassium and chlorine in the bed material, no fresh sand was added the last 14 hours and not even formerly used bed material was added during the last 7½ hours.

A large amount of data including mass flow rates, temperatures, pressures and gas compositions was logged during operation, whilst samples from especially the cyclone ash and the bed material were taken during short stops for re-loading the fuel feeder every 1,5 to 3 hours. Results from the subsequent analysis work e.g. mass and energy balances as well as many more specific results have been obtained for documentation and as a basis for further optimisation.

5 RESULTS

5.1 Process temperatures, deposits and agglomeration

The 3 tests reported have shown that the LT-CFB gasifier performs close to the best prior intentions. In particular no deposits were observed during any of the internal inspections of the plant.

Sintering and agglomeration of the fluidised bed material was only encountered intentionally after a controlled temperature rise in the char reaction chamber to 825°C. This experiment performed at the end of the 24 hour test, as well as steady operation at 800°C on the same bed material at the end of the 13,5 hour test, showed that there is a good margin from the normal operating temperature at ~730°C to the agglomeration temperature. This is believed to be mainly due to good temperature control and the anti-agglomerating influence of the char particles in the char reaction chamber.

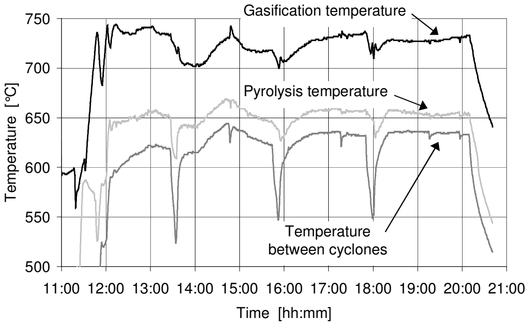

Figure 3: Temperature measurements in pyrolysis- and gasification chamber and in between the cyclones

Figure 3 show some characteristic temperatures measured throughout the latest 7½ hour experiment. The experiment consisted of 4 parts, in between which the plant was closed down shortly for taking particle samples and refilling the fuel silo. The first two parts were primarily used for stabilising the conditions and during the two last parts more steady operation prevailed. The plotted "Temperature between cyclones" is measured just before particle separation in the secondary cyclone. This is thereby "last chance" for gaseous potassium and chlorine to condensate on the ash particles.

Steam is added to the char reaction chamber as a char conversion and gas quality enhancer. Despite the low gasification temperature 30-50% of the supplied steam reacted, when 0,5-2 kg/h of steam was added. This is believed to be due to good contact conditions in the BFB and high char reactivity due to the fast pyrolysis and the large content of catalytic material (e.g. potassium) in the char and bed particles.

The temperature in the char bed could be efficiently controlled mainly by adjusting the supplied airflow, whilst the temperature in the pyrolysis chamber was controlled by adjusting the particle recirculation rate. The char content in the bed could be controlled by adjusting the steam flow rate and/or the amount of (electrically) uncompensated heat loss. The char content was monitored by measuring internal pressure losses in the char bed and afterwards also by analysing particles sampled from different levels in the bed.

5.2 Potassium and chlorine

In Figure 4 the accumulation of potassium and chlorine in the bed material throughout the testing period is shown. The first data points show the amount of these components in the fresh sand. During the 13½ hour experiment no analysis for potassium and chlorine was made. In the top of the figure the amount of samples taken and supplied amount of make up bed particles is shown. The 3 kg supplied before the 7½ hour experiment was not fresh sand as earlier, but previously used bed material. By avoiding the diluting addition of fresh sand within the last 13 hours stable concentrations of potassium and chlorine was reached at the levels 5,3% and 0,7% respectively.

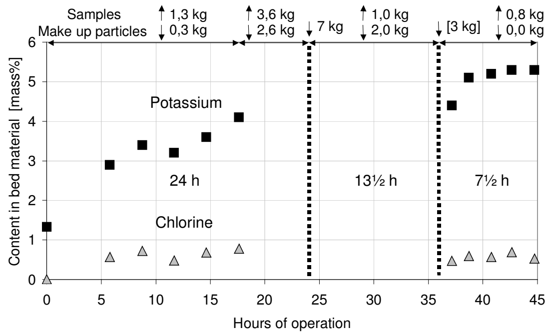

Figure 4: Amount of potassium and chlorine in bed material

In Figure 5 the retention of potassium is shown. By isokinetic dust measurements during the 7½ hour test the efficiency of the secondary cyclone was found to be ~95% and it was estimated the same for the 24 hour test. The content of potassium in the particles in the gas is assumed to be the same as in the separated ash for the 24 hour test, but was measured for the 7½ hour test.

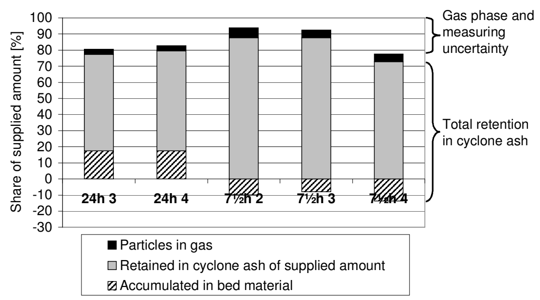

Figure 5: Retention of potassium in cyclone ash, loss with particles in the gas and accumulated in bed material

During most of the 24h test, potassium was accumulated in the bed material, but in the 7½ hour test a steady concentration was obtained (Figure 4). Due to a decrease in total mass of bed material potassium was released during the 7½ hour test.

The highly efficient retention of ash and potassium (including the part periodically released from the bed) confirm that this combination of low temperature gasification and very simple gas cleaning will be well suited for e.g. co-firing straw at modern power plants.

5.3 Char loss, PAH and gas quality

As shown in figure 6 the char loss to the cyclone ash was reduced to 3,5% on a mass basis and 6,5% on energy basis compared with supplied amount of straw (raw basis). This for the most stable period during the last 7½ hour experiment. Further reductions are expected based on various planed enhancements of the 50 kW test plant, and on the much better char and gas retention times anticipated in up-scaled plants.

Measurements of PAH in the cyclone ash showed only around 3,5 mg/kg. Moreover approximately half of the stated PAH result is naphthalene, which probably can be avoided by e.g. keeping the temperature of the ash-bin above the naphthalene dew point.

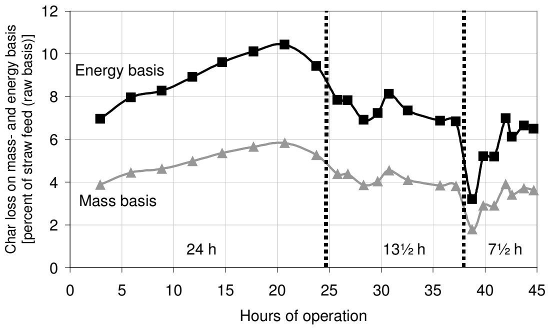

Figure 6: Char loss to cyclone ash

The product gas had a higher heating value of 4,5-6 MJ/kg, which is presumably up to around 7 MJ/Nm^3. A high amount of heavy and partly condensable hydrocarbons in the gas contributes significantly to especially the volumetric heating value.

6 DISCUSSION

6.1 Optimisation possibilities

The 50 kW test facility is a small proto-type plant, where the most suitable sizes for the concept probably is from 1-5 MW up to above 100 MW. The following improvements are expected due to this extensive scale up:

- A higher bed in the char reaction chamber will give a lower char loss and better gas quality due to longer gas and char retention times in the bed (the present char bed is only around 500 mm high). This will give a higher CO/CO_2 ratio and allow a higher amount of the steam to react. This will decrease the need for steam and the specific gas flow rate will be smaller
- A higher freeboard height will decrease the amount of fine char particles lost due to particle splash from the bed surface (present freeboard is only 250 mm)
- Elimination of the present nitrogen usage under test operation will enhance the gas quality by 10-20%, which together with the above improvements are expected to give a higher heating value of the gas up to around 10 MJ/Nm^3
- The low content of PAH in the cyclone ash will probably be further minimised due to optimised char conversion and by avoiding the condensation of gaseous PAH in the cold ash-bin

A 500 kW LT-CFB plant including these and other improvements is now being designed and this plant is expected to be commissioned late 2002.

6.2 Alternative fuels and applications

The plan for further tests includes other fuels such as municipal solid waste and meat-and-bone meal. Moreover many other volatile types of problem fuels such as waste streams from the production of sugar, cotton, rice, olive and plant oils are “good candidates” for the LT-CFB gasifier. In addition also woody fuels may be applied e.g. as a back up fuel and/or considering that especially young woody products may also contain elevated amounts of potassium and chlorine.

Possible system applications for the LT-CFB concept in the energy sector are mainly as a pre-treatment plant for such problematic fuels and e.g. in combination with :

- Existing and new coal-, oil- or gas fired boilers, e.g. as a co-firing scheme
- Indirectly fired gas-turbines or large Stirling engines
- Directly fired gas turbines, combustion engines or fuel cells. These options, however, require intensive gas filtration and either efficient tar cracking or pressurisation of the LT-CFB gasifier

Moreover quite different applications such as producing liquid fuels or more valuable chemicals are also considered (based on lower pyrolysis temperature and gas quenching).

7 CONCLUSION

Tests have shown that the LT-CFB test facility is easy to operate, and that the temperatures, char conversion etc. can be well controlled.

No ash deposition or bed agglomeration problems were encountered during normal operation in spite of establishing long term and otherwise worst-case conditions regarding fuel and bed material.

Retention of potassium in the cyclone ash was 73-98% and of chlorine 23-75%.

The char loss has been reduced to 3,5% on a mass basis and further improvements are expected through further optimisation and much better retention times due to scale up.

A very low and probably further reduceable amount of PAH was measured in the cyclone ash.

The very high fuel flexibility, indicated by the good results on extremely difficult wheat straw as well as the anticipated broad range of sizes and system applications, strengthen the hope that the LT-CFB gasifier will greatly improve the possibilities of efficient and environmentally clean use of biomass and volatile waste fuels.

ACKNOWLEDGEMENTS

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