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THE LOW TEMPERATURE CFB GASIFIER
LATEST 50 KW TEST RESULTS AND NEW 500 KW PLANT

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ABSTRACT: The Low Temperature Circulating Fluidised Bed (LT-CFB) gasification process is described together with the 50 kW and the 500 kW test plants and latest test results. The LT-CFB process is especially developed for medium and large scale (few to >100 MW) gasification of problematic bio-fuels like straw, animal manure and waste and for co-firing the product gas in existing, e.g. coal fired power plant boilers. The aim is to prevent fouling, agglomeration and high temperature corrosion caused by potassium and chlorine and other fuel components when producing electricity. So far 92 hours of experiments with the 50 kW test plant with two extremely difficult types of straw has shown low char losses and high retentions of ash including e.g. potassium. Latest 27 hours of experiments with dried, high ash pig- and hen manure has further indicated the concepts high fuel flexibility. The new 500 kW test plant is currently under construction and will be commissioned during the summer 2004.

Keywords: biomass conversion, gasification, circulating fluidised bed (CFB),

1 INTRODUCTION

In 1999 a 50 kW test plant was built based on the novel Low Temperature Circulating Fluidised Bed (LT-CFB) thermal gasification technology. Since then more than 120 hours of experiments has been conducted primarily with straw but lately also with pig- and hen manure.

1.1 Straw as a bio-energy resource

Within the international community an increasing attention has been paid to the utilization of biomass and waste fuels in order to reduce CO_2 emissions and the usage of fossil fuels.

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

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

The LT-CFB gasifier functions without in-situ ash-sintering and corrosion problems and most potassium and chlorine is 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.

1.2 Animal manure as a bio-resource

In many rural areas there are high concentrations of livestock and the manure is normally spread out on the farmland. This causes environmental problems due to wash out of nutrients, and in Denmark a limitation of the size of the livestock farms is therefore introduced.

Conventional biological gasification does not solve this problem because the excessive nutrients are still present in the wet fiber residue, which is expensive to distribute. Moreover, the energy production potential is only utilized to a small extend.

The LT-CFB plant is able to almost fully convert the organic content of manure into a combustible gas low in dust and corrosive components. The nutrients in the manure are separated from the gas and retained in an ash container. This ash product is a fine, dry powder with a high concentration of phosphorus, potassium and magnesium. It is therefore very suitable as a fertilizer, and it can compactly be transported to areas needing the nutrients. Hence, the wash out of nutrients as well as the size limitations on animal farms can be reduced.

2 THE LT-CFB CONCEPT

Figure 1 shows a simple version of the concept with all major mass flows indicated as arrows.

The fuel enters the pyrolysis chamber, where it is pyrolysed at ~650°C. The pyrolysis is fast due to the

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good thermal contact between fuel and hot sand and results in a small and highly reactive char residue. The gas lifts the char and sand upwards and into a primary cyclone, where char and sand is separated from the gas and led to the char reaction chamber.

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

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

Silica sand is used as a heat carrier between the overall exothermic char gasification and the endothermic pyrolysis. The rate of sand circulation is therefore controlling the temperature difference between the two process chambers.

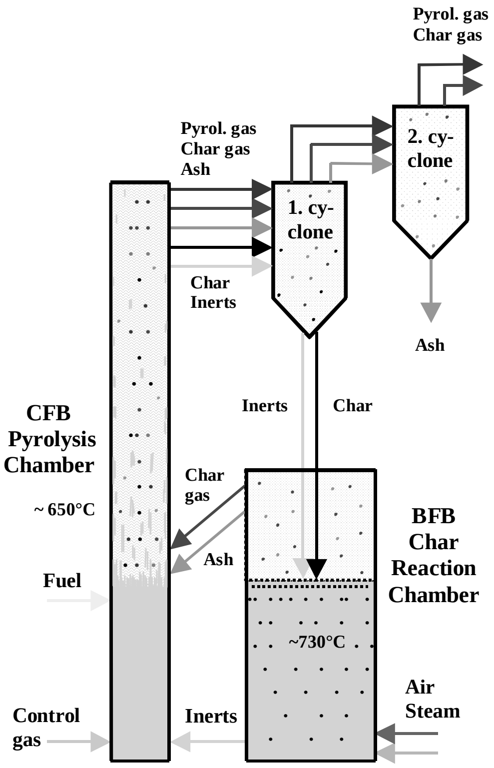

Figure 1: Flow diagram of LT-CFB concept

The sand is re-circulated from the bottom of the char reaction chamber, because due to segregation, especially the small and hard to retain char particles are this way left behind for a long retention time and mainly in the upper part of the BFB.

The combination of the initially small char residue, high char reactivity and good char retention in the BFB allows the char to be efficiently converted at a relatively low temperature. The combination of the low process temperatures and a relatively high char concentration counteracts deposition and agglomeration problems.

The mainly small and light ash particles produced in the char reaction chamber will typically not be retained by the primary cyclone, but the main part will be retained by the more effective secondary cyclone.

The low process temperatures ensure that most potassium and some chlorine are kept in the solid state and therefore separated along with the ash particles. The temperature decrease due to the endothermic pyrolysis helps to avoid the need for gas cooling prior to this simple potassium and chlorine separation.

2.1 The 50 kW test plant

Figure 2 shows a picture of the 50 kW LT-CFB test plant and of the flare burning the product gas during 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. All of these hot components can be heated electrically for start-up purposes and to compensate for the relatively large heat loss due to the small dimensions. The dark silo to the left of the pyrolysis chamber contains the fuel (crushed pellets for most of the performed tests). The ash is taken out as a dry powder from underneath the secondary cyclone.

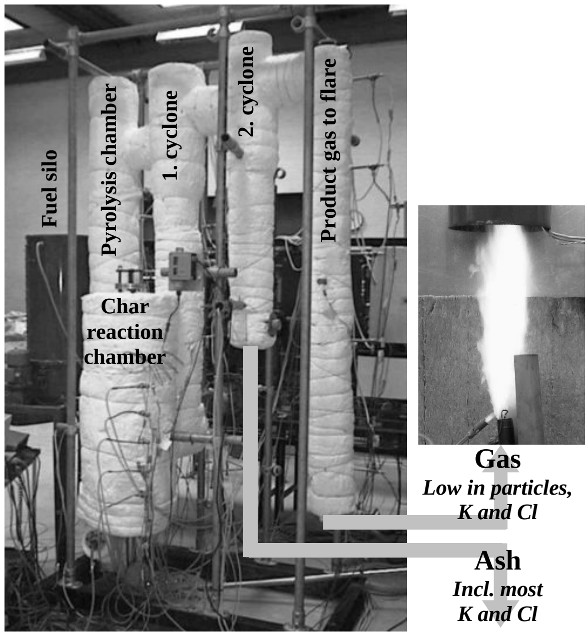

Figure 2: Picture of 50 kW LT-CFB test plant and flare burning product gas

2.2 The 500 kW test plant

Based on the experiences gained from the 50 kW plant a new 500 kW test plant is under construction at DTU, Copenhagen (Figure 3). This new plant is scheduled for commissioning June 2004 and the first tests will be with the same difficult straw as in an earlier reported 50 kW test [1], i.e. crushed straw pellets containing 12.2% ash and 1.7% potassium (dry basis).

The 500 kW plant is built with a design closer to future scaled up plants, i.e. plants from a few to >100 MW. The differences to the small 50 kW plant are primarily, an almost fully refractory lined construction and that the use of pure N_2 has almost been eliminated.

The larger char reactor (and char retention time) and elimination of the use of diluting N_2 in the 500 kW plant, are expected to give the product gas a heating value, that is 10-20% higher than for the 50 kW plant.

Figure 3: The 500 kW LT-CFB test plant at DTU

3 RESULTS FROM EARLIER 50 kW STRAW EXPERIMENTS

Until 2003 92 hours of experiments with straw has been conducted with the following significant results:

- High ash retention (~95%) in a separate ash container using only a simple secondary cyclone
- High potassium (73-98%) and chlorine retention (23-75%) in ash
- Only ~2 mg/kg PAH in ash
- Low char loss (down to 1,1 mass% of fuel flow) at down to around 730°C in the BFB
- Higher heating value of product gas:
  4,5-6 MJ/kg ~ 5,5-7 MJ/Nm^3
- No problems due to agglomeration and sintering in spite of using ordinary silica sand as bed material and not using additives.

All of the straw experiments have been carried out using crushed pellets. The aim in scaled up plants though is to use loose straw. This will probably give an even lower char loss due to a lower amount of fine dust in the fuel.

4 RESULTS FROM 50 kW ANIMAL MANURE EXPERIMENTS

4.1 Experiment description

Two types of manure have been tested: Pig manure and manure from hens bred for egg production. The pig manure was dried, pelletised and crushed prior to the experiment. The hen manure was just dried and crushed. The higher heating values in table 1 are based on calculations using [2] and not analysis's.

Table 1: Pig- and hen manure composition

	HHV [MJ/kg]	Moisture	Ash (dry)	Potassium (dry)
Pig	~14	8%	26%	0,9%
Hen	~11	21%	25%	-

The particle circulation was somewhat unstable during the pig manure experiment due to a leaking gasket in the upper L-valve. The experiment was however conducted according to the plan for ~12 hours of feeding with three different loadings (42.5 – 45.3 – 52 kW) and promising results were achieved in spite of the instabilities. The hen manure experiment where carried out in two halves with 6 and 9 hours of fuel input, i.e. to a total of 15 hours. Some of the measured temperatures are shown in figure 4. The temperature "between cyclones" is measured just before the secondary cyclone, and is thereby "last chance" for gaseous components like e.g. potassium to condensate and be separated from the gas.

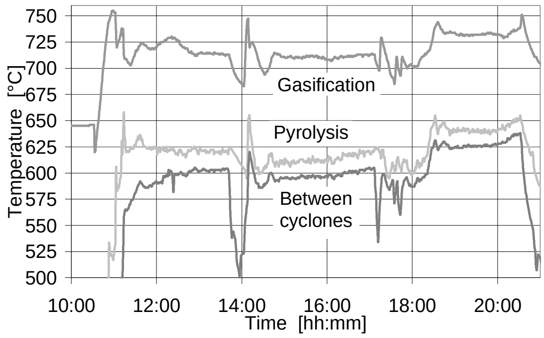

Figure 4: Measured temperatures from second hen manure experiment.

Every three hours the plant is shut down, and the fuel silo is refilled, and samples of the bed material are taken out. Different temperature levels in the char reactor and pyrolysis chamber were chosen during each of the 3 hour periods but each time the temperatures stabilised within narrow limits.

4.2 Mass and energy flows

Figure 5 shows the outgoing energy flows during the last 3 hour period of the experiment with hen manure where the supplied fuel higher heating value input was 50,2 kW. The gas leaves the plant at ~600°C with a heat capacity flow constituting 13% of the input. But the only lost energy streams will be the char loss to the ash container and the surface heat loss, so the overall efficiency was around 92%. This experiment was the first carried out on hen manure, and the aim was not primarily to optimize for a low char loss, so smaller losses are expected in future tests. Earlier results on straw have shown char losses down to ~3% on energy basis.

The chemical energy content in the gas (79%) is calculated by difference, i.e. as the term closing the energy balance.

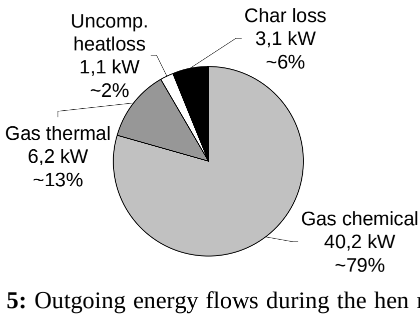

Figure 5: Outgoing energy flows during the hen manure experiment

5 DISCUSSION

5.1 Optimization possibilities

The 50 kW test facility is only a small proto-type plant, where the most suitable sizes for the concept probably is from a few to about 100 MW. Some of the many possible improvements that will naturally follow, or be considered during the scale up process are:

- Elimination of the present nitrogen usage which will enhance the gas quality by 10-20%
- Increase of the char reactor height to further improve the char conversion and gas quality
- Use of loose straw instead of the more expensive pellets are also expected to give a lower char loss due to a lower production of small char particles
- Ash recirculation or post oxidation may further minimise the char loss and make the ash more suited for various purposes
- Addition of a bed particle drain system with the capability of predominantly removing bottom ash and oversize particles will better allow for optimal and undisturbed long term operation
- Optimising the gas clean up by adding a tertiary cyclone or an even more effective filter
- Earlier a PAH content of 2 mg/kg was measured in the cyclone ash. This low value will probably be further minimised due to optimised char conversion and by avoiding condensation of gaseous PAH in the cold ash bin

It is however also a primary goal to keep the process as simple as possible, and the new 500 kW plant will therefore be nearly as simple as the 50 kW plant.

5.2 Other fuels and applications

The plans for further tests also include other fuels such as sewage sludge, municipal and industrial 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 from e.g. future energy forestry 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 generator of a hot but relatively clean fuel gas for:

- Existing and new coal-, oil- or gas fired boilers, e.g. for large scale co-firing
- Existing and new waste incineration boilers, e.g. for expanding the fuel flexibility of the plant to salty or high heating value products and/or for boosting the superheating temperature
- Indirectly fired gas-turbines or Stirling engines

Based on more intensive gas filtration and either pressurisation of the gasifier or the combination of tar cracking, gas cooling and gas compression, the LT-CFB gasifier may also produce gas for directly fired gas turbines (including IGCC), combustion engines and fuel cells. Moreover quite different applications such as production of liquid fuels or more valuable chemicals (based on lower pyrolysis temperature and gas quenching) are also considered.

6 CONCLUSION

The test results from the 50 kW plant with 92 hours with straw and 27 hours with animal manure has indicated a high fuel flexibility of the concept and no problems with agglomeration. This is in spite of using ordinary silica sand as bed material and no additives and in spite of simulating long term operation by reusing the bed material between experiments.

The high retention of ash and potassium of typically >90% also proves the concept to be suitable for e.g. co-firing a variety of problematic bio-fuels into existing and modern power plant boilers, thereby producing environmentally clean electricity with a high efficiency and with minimal problems regarding fouling, corrosion and ash utilisation.

The experiences to be gained with the new 500 kW plant will hopefully lead to a next 5-10 MW plant, and thereafter also too many even bigger bio-energy plants within the farming-, industry-, waste management- and power utility sectors.

7 ACKNOWLEDGEMENTS

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