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THE LT-CFB GASIFIER – FIRST TEST RESULTS FROM THE 500 KW TEST PLANT

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ABSTRACT: The Low Temperature Circulating Fluidised Bed (LT-CFB) gasification process is briefly described together with the first test results from the new 500 kW test plant. The process aims primarily at co-firing low grade biomass and waste products at power plants and offer several advantages to directly co-firing: E.g. the ashes of different fuels can be kept separate, and corrosion and fouling of the furnace can be drastically reduced. Three fuels have been tested so far on this plant: High ash straw (12% ash, dry), dry matter from pig manure (28% ash, dry) and dry matter from biogas residue based on pig manure (44% ash, dry). All the tests have been very stable and a steady state content of ash components, e.g. potassium, in the ash and bed material was reached. The low temperature (max. 750°C) ensures that there are no agglomeration problems, and that almost 100% of K, Si, Ca and P is kept in solid state, and can be separated from the gas using only a simple hot cyclone. Mass- and energy balances show that the conversion efficiency from fuel heating value to energy content in the product gas is more than 90% and even higher efficiencies are anticipated in upscaled plants.

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

1 INTRODUCTION

In these years there is an increasing attention around the world on the use of low grade biomass and waste products for production of electricity and heat. This is due to a developing political understanding for the need of reducing CO_2 emissions and being more independent of fossil fuels. Furthermore the low grade fuels are abundant and often available at a low price.

Straw and manure are two bioresources which is available in large quantities in many countries. In Denmark there is an energy potential of ~55 PJ/year for straw [1] (when the use for livestock is subtracted) and ~46 PJ/year for manure [2]. The electricity demand in Denmark is ~128 PJ/year [3]. Straw and manure are therefore potentially capable of contributing to ~32% of the Danish electricity demand (assuming 40 % electrical efficiency).

The use of these bioresources for efficient electricity production is today however limited due to corrosion, fouling and ash usability problems when (co-)firing the fuels in ordinary power plant boilers.

This paper deals with the Low Temperature Circulating Fluidised Bed (LT-CFB) gasification process, which is capable of converting even low grade fuels into a combustible gas and separate the trouble causing ash to a separate ash container. The gas can e.g. be burned in a modern power plant boiler producing electricity with up to ~50% electrical efficiency.

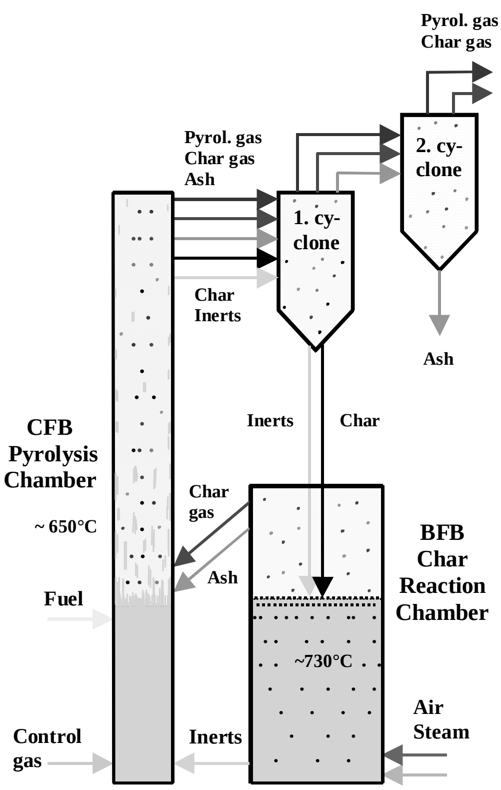

Figure 1: Flow diagram of the LT-CFB concept

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2 THE LT-CFB CONCEPT

The Low Temperature Circulating Fluidised Bed (LT-CFB) gasification process has been described in detail in earlier publications [4], [5] and [6] and will here only be described shortly.

In figure 1 the process flow diagram is shown. The crushed fuel enters the pyrolysis chamber and is rapidly pyrolysed due to the good thermal contact with the ~650°C fluidised sand bed. The residual char, the gasses and some sand is blown to the primary cyclone, which leads the char and sand to the char reactor. Here the char is gasified at typically ~730°C using air and steam. Due to the low temperature agglomeration problems can be avoided and most of the ash components (e.g. potassium and phosphorus) are kept in the solid state in the ash particles. These light ash particles are together with the char gas blown out of the top of the char reactor into the pyrolysis chamber, where it contributes to the high velocity in the upper part. The light ash particles will generally not be retained by the primary cyclone, but are led to the more efficient secondary cyclone, which separates the ash from the product gas to a separate ash container. In this simple way the product gas contains thereby nearly no gaseous nor solid ash components like potassium and phosphorus.

The heat for the endothermic pyrolysis process is supplied by the exothermic reactions in the char reactor by the circulating sand. This way neither the gasification process nor the simple gas cleaning needs any external heating or cooling.

The LT-CFB concept aims at using problematic biomass and waste products (e.g. straw, manure, horticultural residues, etc.) for primarily co-firing with e.g. coal at new or existing power plants. The main advantages of this are:

- 90-95% of the ash from the fuel can be kept out of the boiler and utilized separately
- The gas can be burned in a boiler with high steam temperature and –pressure thereby producing electricity at high efficiency (up to 50%)
- Plant sizes of 5-100 MWth are anticipated using a wide range of various biomass and waste fuels

Based on more intensive gas cleaning the LT-CFB gasification process can also produce gas for more demanding applications, and production of liquid fuels are also considered.

Figure 2: 500 kW LT-CFB plant at DTU

2.1 The 500 kW test plant at DTU

In 1999 a 50 kW LT-CFB test plant was built at DTU and since then, this small plant has been tested with a range of different fuels for more than 120 hours.

In December 2004 a new 500 kW LT-CFB plant was commissioned at DTU. The photo shown in figure 2 is from a recent test on pig manure. Notice the gas flare at the top of the building.

3 TEST RESULTS

3.1 Fuels and test overview

So far 4 tests have been made on the 500 kW plant (see table I).

Fuel/ Month	Ash dry	HHV raw MJ/kg	Operation with fuel feed	Operation with >700°C
Straw Dec.04+ Feb.05	12%	15,8	25+34 h	10+25 h
Pig manure May.05	28%	15,2	53 h	42 h
Biogas residue Sep.05	44%	9,6	76 h	59 h
Total	-	-	188 h	136 h

Table I: Fuel and operation hours for 500 kW tests

The 3 fuels tested was wheat straw with exceptionally high ash content, dewatered and dried pig manure and dewatered and dried biogas residue based on pig manure. All the fuel was dried to 8-18% water content and pelletised and afterwards crushed (pelletising and crushing is not a process requirement but a way to avoid feeding problems in the test plant).

The straw tests were done adding mainly 520 kW and 485 kW straw in the end. During the pig manure test 3 loads were tested: 420, 486 and 552 kW and during the biogas residue test a high load of 614 kW were applied and a few hours at 335 kW with un-pelletised fuel (all values are based on higher heating value).

The plant is initially mainly heated up by inserting a gas burner in the pyrolysis chamber and later by adding fuel and air. After 700°C is reached in the char reactor, the plant is considered in operation.

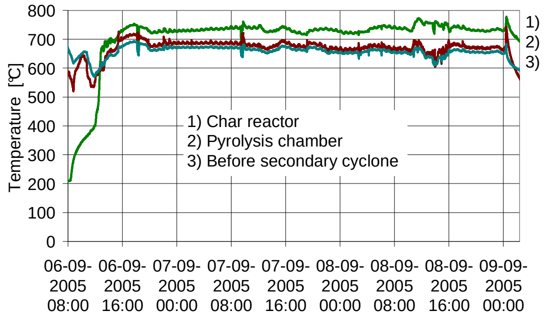

Figure 3: Process temperatures during biogas residue test

The process is basically extremely stable and easy to control. Figure 3 shows three temperatures measured in the gasifier during the entire test with biogas residue as fuel in September 2005.

3.2 Mass and energy balance

The mass- and energy balances shown in figure 4 and 5 are from the test on pig manure in may 2005.

- Notice that the mass flow and the heating value of the product gas are not measured but calculated by difference.
- The values are from the last most stable part of the test where the supplied higher heating value of manure was 552 kW.
- Due to the very high ash content in the fuel and the fact that the secondary cyclone was not fully optimized (efficiency ~80%) there is a considerable amount of dust in the product gas. The dust is considered having the same oxidizable content as the cyclone ash.
- N_2 is added only as purge gas to the fuel silo and pressure measurements.
- Approx. ¾ of the water was added as steam (~100°C) and ¼ as liquid water (~25°C).
- Due to the fact that upscaled plants will have a smaller specific heat loss, some of the heat loss is compensated with electric heating and the uncompensated heat loss is ~3% of supplied higher heating value with the fuel.
- The oxidizable content of the ash at 550°C was measured to ~14%, which related to the fuel input is ~4,5% of supplied higher heating value.
- The gas leaves the plant at ~600°C and "Gas thermal" is the energy yield if the gas is cooled down to 25°C. "Gas chemical" is therefore the higher heating value at 25°C.

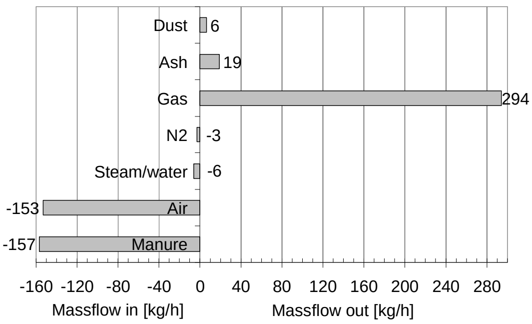

Figure 4: Mass flows from manure test

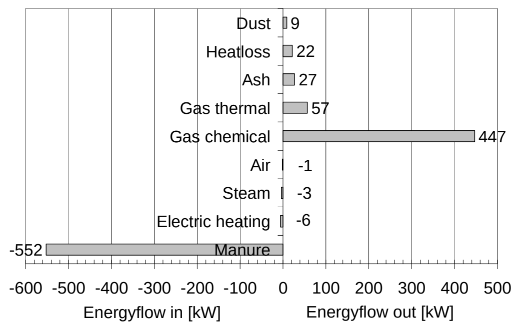

Figure 5: Energy flows from manure test

The overall efficiency of the plant is therefore above 90%. For future upscaled plants values above 95% are anticipated.

Based on the mass- and energybalances a heating value of the gas has been calculated to ~7 MJ/Nm^3.

3.3 Retention of ash components

Elemental analyses of the fuel, ash and bed material has shown that near steady state conditions regarding buildup of ash components in the bed material can be reached after ~30 operating hours.

All of the tests were done using ordinary silica sand as bed material, and without adding fresh sand or other additives during operation.

Elemental balances showed that during the test with straw almost 100% of the K, Si, Ca and P from the straw ash was found on solid state in either the ash container or in the dust in the gas. These components are thereby not on gaseous form, and the product gas can therefore be free of these components simply by removing the ash particles.

Around 66% of the Cl and 12% of the S from the straw ash was also retained on solid state.

4 DISCUSSION

4.1 Optimization possibilities

The tests reported here are the first with the 500 kW LT-CFB plant and between each test some of the auxiliary equipment and procedures were upgraded. There is however still things that can be improved during the next tests:

- The char loss will mainly be lowered by optimizing the steam addition and by better control of the bed height in the char reactor. Furthermore, tests with ash recirculation and post-oxidation are considered.
- The ash separation will be improved by adding a high efficiency tertiary cyclone, so that the separation efficiency hopefully will increase from 80-90% to 90-95%.
- The plant is now manually operated and requires 3-4 people to operate it. It will be more automated during the next tests, so that 0-2 people are sufficient.
- An automatic system for taking out and adding bed material (and allowing proper bed particle management) will be implemented and tested.
- The process will also be tested on other fuels such as e.g. industrial waste, household waste, sewage sludge etc.

4.2 Fuel flexibility

The LT-CFB process is very fuel flexible, and so far it has been tested with different kinds of straw, wood, pig and hen manure and biogas residue (marked with dark in figure 6). This during worst case conditions regarding the content of ash, potassium, phosphor, chlorine, etc in the fuel and using only ordinary silica sand as bed material and no additives. The tests have also been so long, that near steady state conditions regarding content of e.g. potassium in the bed material were reached.

It is anticipated, that the LT-CFB process also will be suitable for other low grade biomass and waste materials, as shown in figure 6.

It is also anticipated, that different fuels can be mixed, which will make large LT-CFB plants (50-100 MW) more economically feasible by enabling the use of e.g. animal manure, that are locally available in only smaller quantities.

4.3 Applications for the LT-CFB process

At this stage the primary application for the LT-CFB process is mainly co-firing in large scale (50-100 MW) at e.g. existing coal fired power plants (see figure 6). Thereby coal can be partly substituted by low cost and CO_2 neutral low grade biomass and/or waste products.

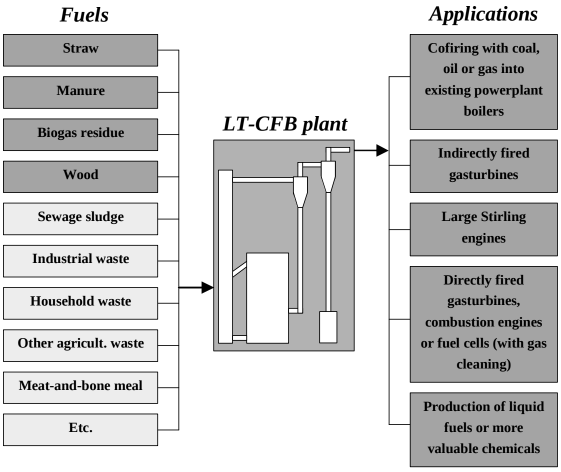

Figure 6: Fuels and applications for the LT-CFB concept

The advantages of applying an LT-CFB process instead of using directly co-firing in a coal fired furnace is mainly:

- The ashes from the biomass/waste and the coal are kept separate, so that the coal ash still can be used for concrete or other purposes and the biomass/waste ash can e.g. be distributed on farm land as valuable fertilizer. This even when using high shares of cofired biomass/waste compared to coal.
- The ash from the biomass/waste will only enter the furnace in very small amounts and thereby cause much less corrosion and fouling problems. It is therefore possible to co-fire a higher share of biomass/waste and/or to use higher steam data in order to produce electricity at higher efficiency.
- A high dust deNOx catalyst will to a much lower extend be poisoned with e.g. potassium or phosphorus from the biomass/waste ash.

The LT-CFB process is also considered suitable for smaller (~5-10 MW) decentralized e.g. district heating or industrial plants fired with manure or industrial waste.

Other applications based on more intensive gasfiltration/cleaning is also considered for e.g. gas turbines, but also for producing bio-oil and/or syngas for liquid fuels based on low grade biomass or waste products. There is a big potential in this, due to that these kinds of fuels are available in vast amounts scattered around many countries at a low price.

4.4 Future work

More tests will be done with the 500 kW plant, and it will gradually be more automated, and longer tests will be conducted. At this stage the main focus is on manure and biogas residue, but other fuels will also be tested.

A particle population model of the LT-CFB process is being developed, and it will be tested and calibrated with the data from the 500 kW tests.

A 5-10 MW LT-CFB plant based on animal manure is now being sketched and a feasibility study including the economics is being made. Several specific locations for this and other demo plants, representing first generation LT-CFB technology are being considered.

5 CONCLUSION

The first 500 kW LT-CFB tests comprising more than 130 hours of stable operation have shown:

- Very good results on difficult straw, animal manure and biogas residue. Based on these experiences a wide range of other low grade biomass and waste products are also considered applicable.
- The process conditions have been very stable, and the sand circulation and process temperatures can easily be controlled.
- No problems regarding agglomeration have been encountered, even though only ordinary silica sand and no additives have been used as bed material for many hours of operation.
- It has been measured that close to 100% of K, Si, Ca and P from the fuel ash is kept in solid state due to the low temperatures in the process. It has therefore been possible to retain 80-90% of these components in a separate ash stream using only simple cyclone separation at ~650°C without prior raw gas cooling. It is anticipated, that this value can be increased to 90-95% in future plants.
- The char loss has been reduced to ~4-5% of supplied higher heating value with the fuel at nominal load, and several possibilities for further reduction has been identified.

The test results have shown that the LT-CFB gasification process is suitable for e.g. co-firing low grade biomass and waste products at coal fired power plants. The process is expected feasible at sizes from ~5-100 MW depending on the fuel and possible fuel mixtures.

The process has several major advantages to directly co-firing e.g. the ashes of different fuels can be kept separate and corrosion and fouling of the boiler furnace can be drastically reduced.

A 5-10 MW LT-CFB demo plant with manure as fuel is currently being sketched, and several hosts for this and similar LT-CFB demo plants are considered.

Also other applications are considered featuring more intensive gas cleaning and production of bio-oil and/or other types of liquid fuels.

6 ACKNOWLEDGEMENTS

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