The Low temperature CFB gasifier

Latest 50 kW test results and new 500 kW test plant

Stoholm, P.; Nielsen, Rasmus Glar; Fock, Martin W.; Jensen, Nina; Sander, Bo; Wolff, Lars; Richardt, Kai; Henriksen, Ulrik Birk

Published in:
Proceedings of The 16t. International Conference of Efficiency, Cost, Optimization, Simulation, and Environmental Impact of Energy Systems, ECOS 2003

Publication date:
2003

Document Version
Early version, also known as pre-print

Citation (APA):
Stoholm, P., Nielsen, R. G., Fock, M. W., Jensen, N., Sander, B., Wolff, L., ... Henriksen, U. B. (2003). The Low temperature CFB gasifier: Latest 50 kW test results and new 500 kW test plant. In Proceedings of The 16t. International Conference of Efficiency, Cost, Optimization, Simulation, and Environmental Impact of Energy Systems, ECOS 2003 (pp. 1113-1120). DTU, Denmark: Technical University of Denmark (DTU).

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

Peder Stoholm[1] and Rasmus Glar Nielsen
Danish Fluid Bed Technology ApS (DFBT)
c/o Center for Advanced Technology
Frederiksborgvej 399
DK-4000 Roskilde, Denmark

Martin W. Fock and Nina Jensen
dk-TEKNIK ENERGY&ENVIRONMENT
Gladsaxe Møllevej 15
DK-2860 Søborg, Denmark

Bo Sander and Lars Wolff
Tech-wise A/S
Kraftværksvej 53
DK-7000 Fredericia, Denmark

Kai Richardt
Rica-Tec Engineering A/S
Marielundvej 48 B
DK-2730 Herlev, Denmark

Ulrik Henriksen
Department of Mechanical Engineering
Technical University of Denmark (DTU)
DK-2800 Lyngby, Denmark

ABSTRACT

The *Low Temperature Circulating Fluidised Bed* (LT-CFB) gasification process aims at avoiding problems due to ash deposition and agglomeration when using difficult fuels such as agricultural biomass and many waste materials. This, as well as very simple gas cleaning, is achieved by pyrolysing the fuel at around 650°C in a CFB reaction chamber and subsequently gasifying the char at around 730°C in a slowly fluidised bubbling bed chamber located in the CFB particle recirculation path. In this paper the novel LT-CFB concept is further described together with the latest test results from the 50 kW LT-CFB test plant located at the Technical University of Denmark.

In the latest 10-hour experiment the fuel was wheat straw containing 1,3-1,6% potassium, 0,6% chlorine and 12,2% ash (dry basis), and the bed material was ordinary silica sand without additives. The bed material was reused from 45 hours of previous test runs thereby causing the initial content of potassium in the bed material to be around 4 to 4,5%. Besides avoiding deposition and agglomeration problems, the main result was a reduction in char loss to approx. 1,5 mass% of the supplied amount of straw as well as very effective (97%) particle separation by the hot secondary cyclone.

The next LT-CFB experiment, currently under preparation, is expected to be on either municipal/industrial waste or animal manure.

Eventually a 500 kW LT-CFB test plant scheduled for commission during summer 2003, and the anticipated primary LT-CFB applications and future project plans are also mentioned.

---

[1] Corresponding author: Phone: +45 46775907 Fax: +45 46321919 Email: Peder.Stoholm@CATScience.dk

INTRODUCTION

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

Since then 92 hours of operation has been performed primarily with wheat straw as fuel. The last 55 hours was within 4 tests in 2001/2002. Each time 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 present test results from especially the latest 10-hour experiment and the experiences gained. Also the LT-CFB concept, possible applications and future plans will be discussed briefly. The concept and earlier experiments is more thoroughly reported in [1], [2], [3] and [4].

BACKGROUND

Within the international energy sector a rising attention has been brought 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 other young 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.

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 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 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.

THE LT-CFB CONCEPT

The 50 kW test plant

Figure 1 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.

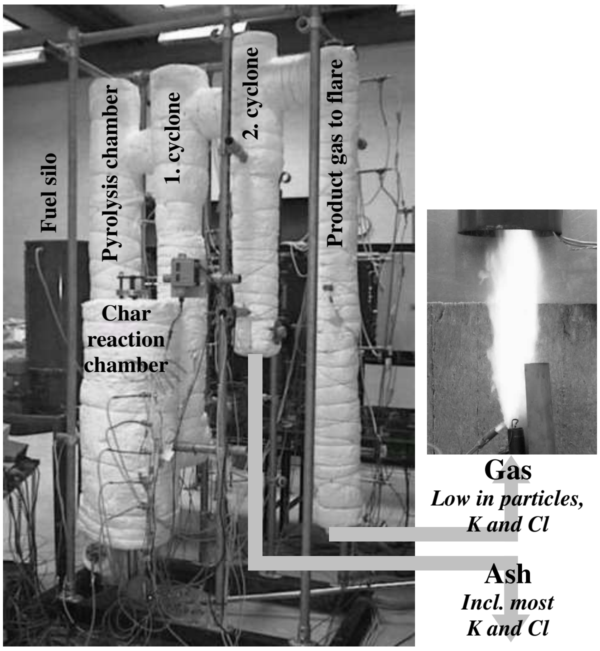

Figure 1: Picture of 50 kW LT-CFB test plant and flare burning product gas

The dark silo 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 as a dry powder from underneath the secondary cyclone.

The concept

Figure 2 shows a sketch of the concept with the intentional mass flows indicated as arrows (e.g. the char lost from the char reaction chamber and through the primary cyclone is not shown).

The fuel enters the pyrolysis chamber, where it is pyrolysed at ~650°C. The pyrolysis is fast due to the 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 upward in the pyrolysis chamber 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. Controlling the rate of sand circulation can thereby control the temperature difference between the two process chambers.

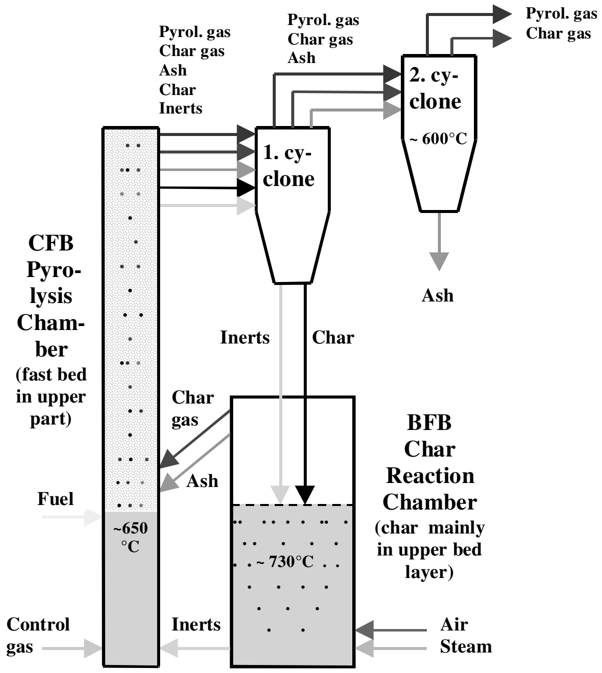

Figure 2: Flow diagram of LT-CFB concept

The sand is re-circulated from the bottom of the char reaction chamber along with only a small amount of char due to segregation of char and sand in the char bed. The segregation causes especially the small and otherwise hard to retain char particles to be left behind for a long retention time mainly in the upper part of the BFB.

The combination of the initially small char residue and the 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 the simple potassium and chlorine separation.

EXPERIMENTAL WORK

Since the 50 kW LT-CFB test plant was built in 1999, 92 hours of operation with fuel feeding has been performed, hereof 3 hours with wood and the rest with straw. The wheat straw used for the first 79 hours of experiments has been quite severe regarding content of potassium (1,8%) and chlorine (0,8%) and with 6,7% ash (dry basis). The last 10-hour experiment were done on another severe wheat straw with 12,2% ash and 1,3-1,6% potassium and 0,6% chlorine (dry basis). The bed-material has been ordinary silica sand (with no additives), which has been reused between all experiments for the last 55 hours of operation. Only small amounts of fresh sand have been added to compensate for sample taking and losses.

The main objective of the last 55 hours of operation (4 separate experiments) has been to lower the char loss from the process, whilst showing a high retention of primarily particles and potassium.

Prior to the 10-hour experiment the char reactor height was increased from 750 mm to 1165 mm. This was done to increase the freeboard height to around 525 mm whilst also allowing a slightly increased bed height of around 640 mm. This was mainly expected to reduce the loss of particles due to splashing from the bed surface. Fine char particles lost from the char reactor in this way is difficult for the primary cyclone to separate and therefore it easily ends up as a loss in the cyclone ash.

RESULTS

Process temperatures and agglomeration

Figure 3 show some characteristic temperatures measured throughout the 10-hour experiment. 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 to the ash particles.

The experiment was planned to consist of 4 parts each lasting ~3 hours. Between each part the plant was closed down shortly for sample taking and refilling of the fuel silo. The first part was used for stabilizing temperatures and conditions, while steadier operation prevailed for the 2 next parts (16:30-23:00).

The planned fourth part had to be aborted during the startup phase around 0:00 o'clock. Apparently straw/char made a blockade just inside the feeding point in the relatively narrow (ø 83 mm) pyrolysis chamber. This caused the particle circulation to stop and the following temperature overshoot in the char reactor caused the char bed to agglomerate at ~770°C.

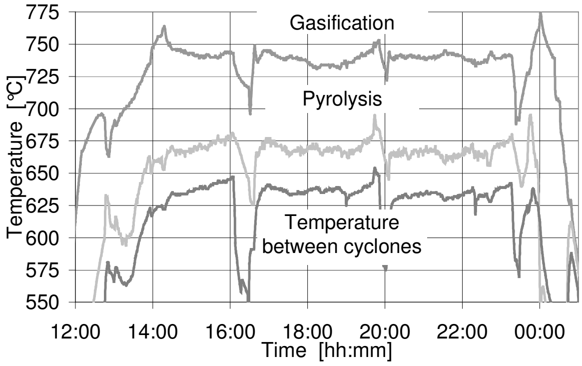

Figure 3: Temperature measurements

Agglomeration during operation has not earlier been encountered until 825°C. The lowered agglomeration temperature was apparently caused by a combination of accumulation of straw ash (further explained in section: Ash handling) and very low char content in the bed.

It is well known, that char has an anti-agglomerating effect in fluid beds. The normal experimental procedure is therefore to avoid too low char concentrations. But due to a fault in the pressure measuring system the low char content in the bed material was first known after the experiment.

The problems encountered in the fourth part of the experiment could easily have been avoided by:

- Moderated initiation of fuel feeding, thereby allowing the sand circulation to get started
- Avoiding the temperature overshoot in the char bed
- Closer monitoring of the char content in the char bed and not allowing an inert/char mass ratio above ~30 (normally 15-20)

In addition, the larger dimensions and higher fluidisation velocities in scaled up plants are expected to increase the margin between the agglomeration temperature and the operation temperature.

Ash behavior and handling

During the earlier experiments essentially all straw ash and some bed material exited through the primary cyclone, but during the 10-hour experiment at least 30% of the straw ash was retained in the bed-material (since the ratio between sand and ash in the bed and cyclone material is unknown, the retained amount of ash was higher to the extend of sand particles lost through the primary cyclone).

The higher ash retention in the bed material this time is probably caused by a combination of:

- The increased bed and freeboard heights
- A relatively low fluidisation velocity
- The low char content in the bed material
- The very high ash content in the fuel
- Low melting components in the straw

Some straw ash accumulated in the bed material, could be seen as 0,5-1 mm gray particles with grains of sand (~0,1 mm) attached to the surface, and therefore some of the ash retention in the bed material was probably caused by a limited degree of ash melting and sintering. This has probably contributed to less ash elutriation from the char bed and to a high ash separation performance of both cyclones.

The tendency to ash accumulation may easily decline/disappear due to e.g. the combination of the intended higher gas velocities and char content in the char bed. The tendency to particle sintering/growth indicates however, that some kind of bed particle size management has to be performed in order to be able to gasify a fuel like the straw used on a long-term basis.

This can be done by draining out particles from the bottom of the char reactor, where most of the large ash particles eventually will end up. Because of the observed significant difference in size and density of ash and sand particles, these can probably simply be separated. The sand particles can then be re-circulated to the bed material, thereby minimizing the need for addition of fresh sand and limiting the content of components with low melting temperature.

Char loss

Some fine char particles will follow the gas and ash particles out of the primary cyclone, and will be separated by the secondary cyclone and led to the ashbin. This amount has been between 5,8 and 3,4 mass% of supplied amount of raw straw during the 3 prior experiments. Due to the increase of the freeboard height above the char bed, a higher retention of particles, including char and ash, in the char bed was obtained. This led to a better char conversion in the char bed and a lower char loss to the cyclone ash of 1,2-1,8 mass% of supplied amount of straw. Figure 4 shows the char loss to the cyclone ash throughout the experiment.

The declining char loss throughout the experiment was caused by a decrease in the char content in the bed material, as a result of a lower thermal load than expected. This was due to a higher moisture and ash content in the straw and lower supplied amount from the feeder than expected on the new type of straw used for this experiment. The thermal fuel input was therefore only 35 kW instead of the anticipated 43-48 kW as earlier.

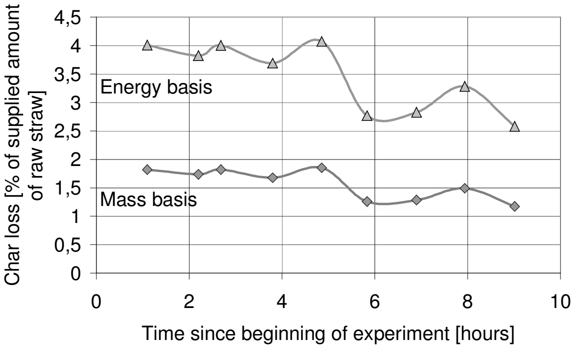

Figure 4: Char loss to cyclone ash

At the intended higher thermal load an increase in char loss must be anticipated, but due to the higher freeboard this increase is not expected to be significant. Moreover, a major reduction of the char loss is expected due to much larger bed and freeboard heights in up scaled plants.

Dust particles in the product gas

Two dust measurements were performed in the product gas stream after the secondary cyclone. This was done iso-kinetically with a heated probe to avoid tar condensation in the probe filter.

The measurements showed a particle retention efficiency of the secondary cyclone of 97 %, which is highly satisfactory. The stream of particles in the product gas was only 1,4-1,5 g/Nm^3 dry gas, and the dry gas stream was approx. 16 Nm^3/h.

Oxidation of the collected dust samples showed a combustible share of 33%. This is higher than the share found in the cyclone ash, which in average was measured to 15%. The lower share in the cyclone ash is probably caused by a higher content of heavier sand and ash particles, which is easier retained by the cyclone.

The combustible share of the dust particles in the product gas equals to only 0,09 mass% of supplied amount of straw. The energy contained in these particles is however not lost, because the particles will be burned together with the product gas.

Retention of potassium

No analyses for potassium has yet been made on the samples taken during the 10-hour experiment, but earlier test results have shown, that the retention normally is around the same value as the secondary cyclone efficiency, which was 97%.

Earlier 73-98% of supplied amount of potassium with the straw was retained in the cyclone ash.

In-stationary build up or release of potassium in/from the bed material may influence the potassium retention. The main part of the bed material used for the 10-hour experiment was however re-used from the previous 7,5-hour experiment where a high saturation concentration of 5,3% potassium in the bed-material was obtained by neglecting to compensate for samples and losses of bed material [2]. The initial addition of a make-up portion of less exposed bed particles from an earlier experiment (but no fresh sand) reduced the initial average potassium concentration in the bed material to approx. 4-4,5 %. Towards the end of the experiment a higher potassium concentration in the bed material is however possible due to the considerable ash accumulation in the bed material.

Energy flows and gas quality

Figure 5 shows the main energy flows out of the 50 kW plant during the 10-hour experiment. Other flows constitute to less than 1% (e.g. samples and particles in gas).

The uncompensated heat loss (2,6 kW ~7%) is given by the actual heat loss (4,9 kW value based on prior heat loss experiments) minus supplied power to heat tracing (2,3 kW). The magnitude of the increased heat loss due to the higher char reactor was not known prior to the experiment, and therefore the power to the heat tracing was not increased accordingly. Earlier the uncompensated heat loss has only been ~4%.

One of the main features in the LT-CFB concept is, that it does not need problematic raw gas cooling, i.e. it allows directly use of the

~600°C gas in e.g. a boiler furnace. The thermal energy contained in the gas ($\dot{Q}_{th} = \dot{m} \cdot c_p \cdot \Delta T$, in this case constituting ~12 %) is therefore not to be considered a thermal loss. Therefore the useable energy from this experiment was 90%.

Moreover, the only losses expected for large up-scaled plants are 0-3% char loss and 1-2% surface heat loss. The case of "0" char loss indicates the possibility of adding an ash post-oxidation process, which may also be interesting for obtaining a highly mineralized ash product.

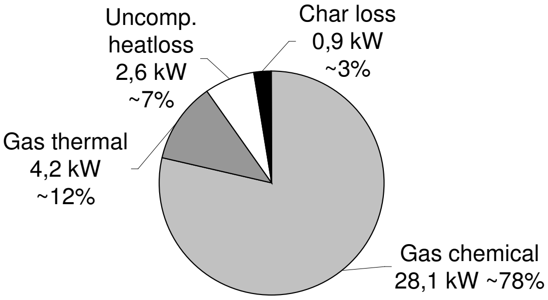

Figure 5: Energy streams out during 10-hour exp.

The chemical energy in the gas corresponds to a higher heating value of ~5,2 MJ/Nm^3 of wet gas, while heating values up to ~7 MJ/Nm^3 earlier has been observed at higher thermal loads of the plant.

In future up scaled LT-CFB plants gas heating values of up to ~10 MJ/Nm^3 is expected due to lower/no N_2 usage, as well as higher CO/CO_2 ratio and steam utilization caused by higher gas and char residence time in the char bed. The relatively high volumetric values is possible due to the high content of heavy hydrocarbons in the product gas.

NEW ACTIVITIES

50 kW experiment with alternative fuel

The next LT-CFB experiment with the 50 kW plant, now being prepared, will be on animal manure, municipal waste or industrial waste.

The first two of these fuels are also known to be difficult because of potentially high contents of low melting and corroding components. Therefore the LT-CFB gasifier can be a solution for very much the same reasons as in the case of straw.

The industrial waste in focus is mainly composed of paper, cardboard, plastic and wood and it is therefore not problematic in the same way. However, this waste stream causes problems because of too high combustion temperatures when fed into grate fired waste incineration boilers.

The LT-CFB offers two different solutions to this problem:

1. The product gas may be burned in the waste incineration boiler after moderating the gas heating value by introducing an (e.g. steam producing) heat absorption surface in the gasification process
2. The relatively non corroding LT-CFB product gas can be burned in a separate furnace, that boost the plant efficiency by increasing the steam superheating temperature.

The aim of the nearby as well as further experiments is also to show, that the LT-CFB concept is extremely flexible regarding the choice of fuel, and that a good performance can be achieved regarding char loss and retention of ash and problematic components like potassium and chlorine.

The 500 kW LT-CFB plant

During the summer 2003 a 500 kW LT-CFB plant will be built and commissioned at DTU. This plant, which is roughly indicated in fig. 6, will include a few new features based on experiences gained from the 50 kW plant, and first of all the design will be closer to typical real-sized plants (from several MW to perhaps beyond 100 MW).

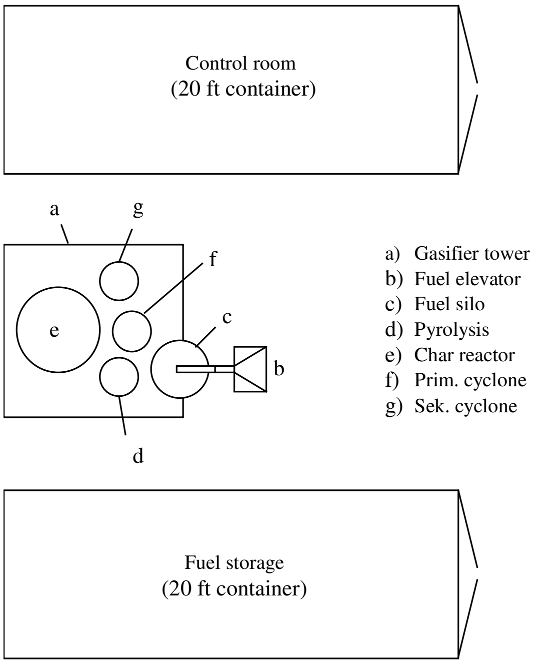

Figure 6: 500 kW LT-CFB plant at DTU, plan view.

The 500 kW gasifier will be an almost fully refractory lined construction in order to allow for long-term operation (distinct from the 50 kW plant made from stainless steel). Moreover, the former relatively high N_2 usage will be nearly eliminated.

The plant will be commissioned and initially tested on the same straw used for the 10-hour experiment, and thereafter on other, at present, unspecified fuels.

A next 5-10 MW plant

The next step planned within a new PSO-2003 project includes the selection of a proper site for an approximately 5-10 MW LT-CFB gasifier, as well as developing the matching design and proper integration of the gasifier.

The mentioned size range is not big enough for the primarily intended use of the gasifier i.e. co-firing straw at full scale power plants, but the type of site and fuel etc. will be chosen in order to obtain a basis for such later large scale use of the LT-CFB gasifier.

DISCUSSION

Optimisation possibilities

The 50 kW test facility is only a small prototype plant, where the most suitable sizes for the concept probably is from a few to above 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%
- Further increase of the char reactor height to further improve the char conversion and gas quality
- Use of loose or chopped straw instead of the more expensive pellets are also expected to give a lower char loss due to a lower production of tiny char particles
- Larger cross sections in the pyrolysis chamber and L-valve etc. will lower the risk of blockages preventing free circulation of bed material
- 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
- Ash re-circulation or post-oxidation may further minimise the char loss and make the ash more suited for various purposes
- 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 ashbin

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.

Alternative fuels and applications

The plans for further tests include other fuels such as municipal or industrial waste, manure 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 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 large 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.

CONCLUSION

The latest 10-hour experiment with the improved 50 kW LT-CFB test facility and a not previously used high ash, K and Cl wheat straw was a success regarding:

- Process stability
- Avoiding agglomeration and deposition problems in spite of the severe conditions
- Effective char conversion
- Effective gas cleaning by the hot secondary cyclone

The much better char conversion compared to earlier tests was primarily achieved due to an increase in the char reactor freeboard height, but a lower than intended thermal input was also influencing.

These results as well as many other experiences gained from the 50 kW test plant forms the basis for the new 500 kW LT-CFB plant, which will be built and commissioned at DTU in summer 2003.

In the mean time at least one further experiment with the 50 kW plant is scheduled in order to gain experiences on another type of difficult bio-fuel and to further prove that the LT-CFB process is very versatile concerning the choice of fuel and process/plant applications.

ACKNOWLEDGEMENTS

The PSO R&D program conducted by the Danish transmission system operator Eltra and the Danish Energy Agency economically supports the ongoing R&D efforts including the experimental activities presented, whilst earlier activities was financially supported by the Danish Energy Agency.

REFERENCES

[1] Stoholm, Nielsen, Nygaard, Tobiasen, Fock, Richardt and Henriksen. *Low temperature CFB gasifier, conceptual ideas, applications and first test results.* 1st World Conference and Exhibition on Biomass for Energy and Industry. Sevilla, Spain, June 2000.

[2] Stoholm, Nielsen, Sarbæk, Tobiasen, Fock, Richardt, Sander, Wolff and Henriksen. *The Low Temperature CFB Gasifier – Further test results and possible applications.* World Conference and Exhibition on Biomass for Energy and Industry. Amsterdam, Holland, June 2002.

[3] EPO Patent application no. 98958839.7-2104

[4] Homepage of Biomass Gasification Group, Department of Mechanical Engineering, Technical University of Denmark. http://bgg.mek.dtu.dk