Biomass gasification in a 100kW fast internal circulating fluidised bed gasifier

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Abstract

At the University of Canterbury a 100 kW Fast Internal Circulating Fluidised Bed (FICFB) gasification system has been built, commissioned and is currently operating to characterize the product gas under a range of conditions. This system was chosen for its advantages over fixed bed gasifiers and was based on the successful design originally developed by the Vienna University of Technology. It incorporates two closely coupled fluid bed stages, a bubbling bed for gasification and a fast circulating bed for combustion. This duality provides a medium calorific value producer gas suitable for use as a fuel in a gas engine or gas turbine. Steam gasification is used in the bubbling fluid bed at approximately 800 °C to form a product gas which is rich in hydrogen. Residual char is transferred with bed material to the circulating fluid bed, where it is combusted along with LPG to heat the bed material. The hot bed material is circulated back to the gasification stage providing heat for the endothermic gasification reactions.

Currently the gas is being directly burnt in an afterburner but will require cleaning and removal of tars before it can be burnt in a gas engine for generating electricity. The results will be used to select suitable gas cleaning and tar removal technology and provide a database for scale up and computer modelling in support of the wider program. Variable conditions tested include the biomass to steam ratio, sand and char circulation rate, circulating bed material temperature and bubbling bed temperature. Moisture content and fuel type will be additional variables tested in future work but currently dry uniform moisture fuel is being used. Characteristics of the product gas measured include the gas composition and tar composition.

Introduction

As part of a large programme to develop the biomass gasification integrated combined cycle (BIGCC) system for electricity production, this paper focuses on work carried out to design, construct and commission a lab scale gasifier for testing radiata pine woody biomass. The design is based on a dual bed system known as the fast internal circulating fluidised bed (FICFB) gasification developed most notably in Austria by the Vienna University of Technology (Haufbauer *et al*., 2002).

This system was chosen as the preferred technology to further develop and adapt to local conditions. By separating out the combustion and gasification processes, steam can be used instead of air for gasification of the wood biomass in the form of either chips or pellets. The steam gasification avoids dilution with nitrogen from air and carbon dioxide from combustion, and results in a product gas with a higher calorific value. Reported lower gas heating values for the steam gasification derived syngas are in the range of 10-14 MJ/Nm^3 (Hoffbauer *et al*., 2002) whereas the heating value of the producer gas from air gasification is typically 5-7 MJ/Nm^3 (Kaiser *et al*., 2000; Bridgwater, 1995). This also means standard existing gas turbine and gas engine technology can be used with minor modifications to use the producer gas generated from this new gasifier.

The separation of combustion and gasification systems also leads to a high hydrogen concentration in the product gas meaning the process also lends itself toward Fischer Tropsch liquid fuels production and hydrogen separation in a longer term view. Dolomite lime or lime stone could be used in the bed material to absorb CO_2, further increasing the hydrogen concentration and reducing the need for down stream processing.

The aim of this part of the program is to get a reliable working prototype and compare its operation with other biomass gasification processes. Research work initially focused on getting a working gasifier and is now beginning to move into a new stage of experimentation, attempting to characterise and optimize the product gas composition and tar formation over a range of operating conditions. Optimising the operating conditions of the gasifier involves getting as high as possible a calorific value of the product gas while reducing tar contents as much as possible to minimise gas cleaning requirements. The tars are long chain hydrocarbons which condense on surfaces at temperature below 100°C and thus cause blockages in the gas engine and ducts. Conditions to be optimised include biomass feed rate, bed temperature and steam feed rate. Once gasifier operation is optimised gas cleaning technology is to be developed to remove tars and other unwanted material from the product gas stream so it is clean enough to use in a gas turbine or gas engine.

Options to be considered for tar reduction and removal include in-bed catalysis for reduction and down stream scrubbing. The program intends to use modified gas engine and gas turbine technology to generate electrical power from biomass syngas and focus resources on the gasification and gas cleaning parts of the process.

Design

The FICFB system uses dual beds to separate the combustion gases from the synthesis gas so as not to dilute it. The combustion gases provide the heat for the endothermic gasification reactions. Wood is fed in compressed pellet or chip form to the gasification column which is a bubbling bed fluidised with generated gases and steam. In this column at a temperature between 720°C and 850°C the volatiles in the wood react quickly with each other and with the steam to form the bulk of the

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product gas, leaving char in the bed material. The main reactions occurring here are pyrolysis reactions, however, the presence of steam encourages the shift reactions with carbon and carbon monoxide to increase the hydrogen content (Equations 1 and 2). Residual char mixes with the bed material and circulates through the chute, at the lower part of the gasification column, to the combustion column.

$$C + H_20 => H_2 + CO \quad (1)$$

$$CO + H_2O => H_2 + CO_2 \quad (2)$$

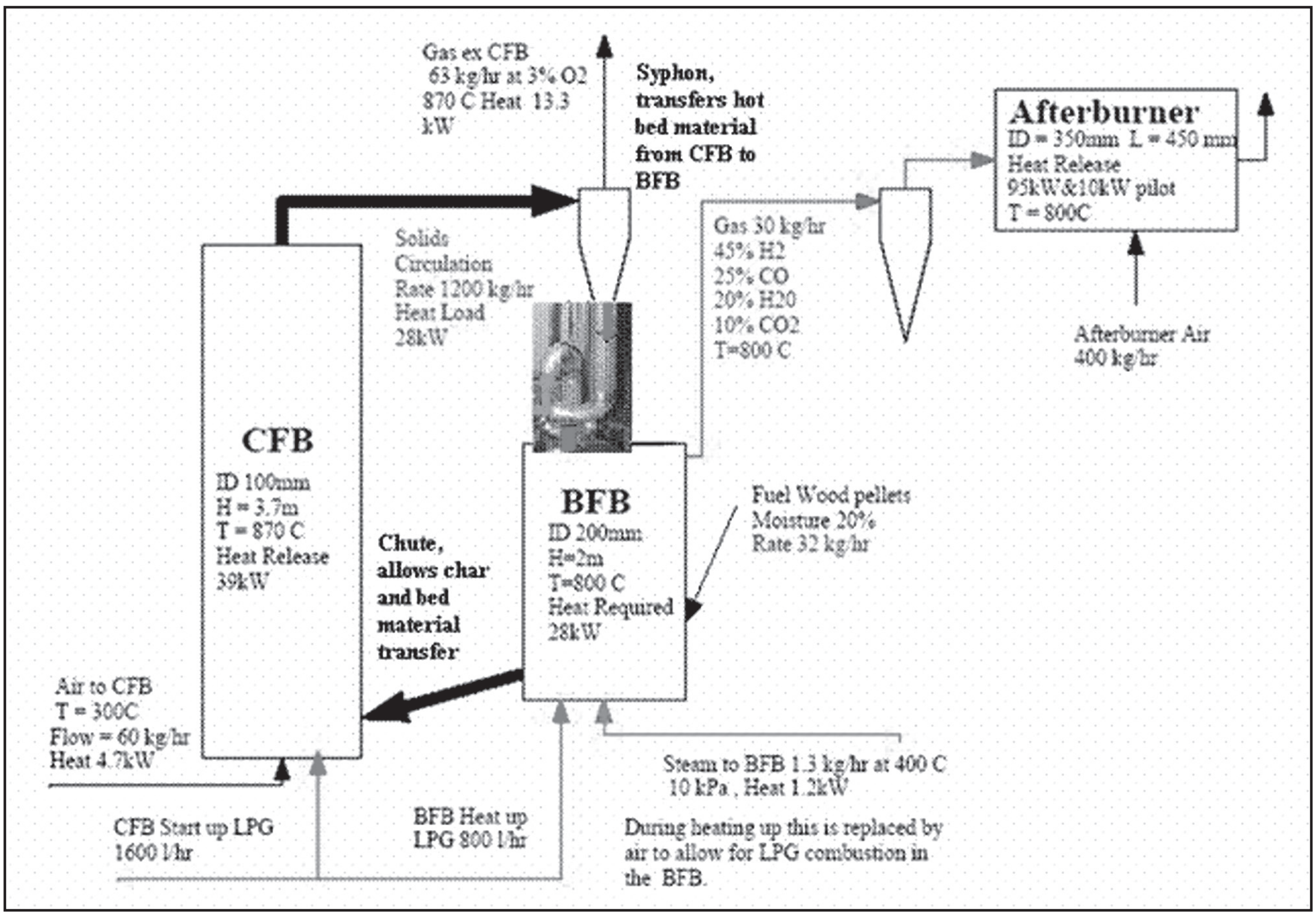
The combustion column consists of a circulating fluidised bed, fluidised with air fed at three heights in the bed. Char remaining after the gasification reactions are complete is supplemented with LPG and combusts to heat the bed material to a temperature as high as 900 °C. LPG is used to help control the bed material temperature; however this is being minimised with operational experience. The hot bed material then circulates with the combustion gases to a cyclone where they are separated with the hot bed material dropping into a syphon. The combustion gases, leaving from the top of the cyclone, pass out of the system through heat exchangers to pre-heat the feed combustion air improving the overall efficiency of the process. The bed material circulates through the syphon and to the top of the gasification column, supplying the heat for the endothermic gasification reactions. Figure 1 shows the gasifier flow diagram, and the heat and mass balances with design parameters.

The chute provides the link between the bottoms of the bubbling bed and the circulating bed allowing cooler bed material and char to flow under gravity from the former column to the latter column. The syphon connects the tops of the circulating bed column and the bubbling bed column acting like a non return valve allowing bed material passage but preventing back flow of combustion gases.

The product gases leave the freeboard above the bubbling fluidised bed (BFB) after gasification and pass into a duct which feeds another cyclone separating out particulate matter from the gases. Particulate matter consisting of char, ash and fine bed material becomes entrained in the gas flow during gasification. At this point samples of the product synthesis gas are taken for analysis of gas composition and tar contents. The gas is then combusted in an after burner which includes a pilot LPG burner and two air supply points. The main air supply mixes with the product gases at the entry point and dilution air is used to maintain temperature at design levels.

The combustion and gasification columns are both constructed from a combination of refractory sections and stainless steel. Steel sections, lined with high alumina refractory to handle the high temperatures and abrasion of the bed material, make up the main part of both columns. These are insulated with vermiculite and calcium silicate board and the steel sections are bolted together. The tops

Figure 1 Heat and Mass balances and design parameters of the FICFB biomass gasifier.



of both columns including the cyclones, syphon and heat exchangers are constructed from 253 MA grade stainless steel in the circulating fluidised bed (CFB) to resist the high temperature and 310 grade stainless steel in the BFB to resist the temperature and reducing atmosphere. These sections are insulated on the outside with kaowool blanket. The cyclones and syphon were constructed from stainless steel because it made manufacture much easier and has the added benefit of reducing the thermal mass and hence heat up time.

Commissioning and Operation

Commissioning with cold testing of fluidised beds and LPG pilot burners was conducted before the whole construction had finished. The cold testing of the fluidised beds proved that the syphon system worked and the bed material circulated between the beds as expected. It also gave an idea of the maximum circulation rate and therefore one of the main operational constraints of the system. The design circulation rate under gasification conditions is 1200 kg/h (see Figure 1). Under cold conditions the maximum circulation rate for the bed material was measured to be 600 kg/h which is about half of the designed circulation rate. However, under hot gasification conditions the circulation rate of the bed material is calculated as 400 kg/h. Currently, the low circulation rate at hot, gasification conditions is restricted to prevent char by passing the CFB cyclone at higher air rates and requires the CFB to be operated at higher temperatures than design to maintain gasification temperature.

Both of the fluidised beds are heated to operating temperature using LPG heating schemes, with ignition above the beds and LPG/air distributors injecting a combustible mixture into the bottom of the beds. Initially the flame management system used pilot burners situated above the beds with flame rods to control ignition of main LPG input in bottom of beds and O2 sensors to check the combustion mixture. This method is very effective in the BFB, however, in a circulating fluid bed flame rods are not very effective because bed material can easily snuff out the pilot burner or get between the flame rod and earth breaking the signal to the controller and therefore stopping LPG supply.

The burners have been shielded in stainless steel tubes to give them protection from the fluidised bed material. Increased LPG and compressed air rates have increased the velocity and temperature in the burner tube decreasing the amount of bed material getting to the flames and sensors, improving the signal to the controller. During heat up these changes stabilised the operation of the CFB (combustor) pilot, however under gasification conditions the high potassium content of the wood ash combined with the high temperature in the pilot burner led to slag forming in this region, destabilising the pilot burner, causing the controller to intermittently stop the LPG feed. Currently modifications to the design of the ignition source and combustion detection method in this region are being undertaken which will reduce temperatures and eliminate the cause. The changes are igniting combustible gases with a continuous arc and flame detection with a photocell.

The feed fuels are wood chips sourced from a local saw mill and standard wood pellets available in New Zealand from Solid Energy, under the trade name Natures Flame. In the preliminary tests, the pellets are used because of their consistency, which makes experimental work comparable with other publications. The chips give an idea how the gasifier performs with a real fuel similar to what would be used in practice. Table 1 shows the proximate and ultimate analysis of the two fuels.

During gasification, char accumulates in the gasifier to a steady state amount, particularly in the BFB (gasifier) where gasification occurs due to segregation of the bed material and the char. Further experience is required to show if this behaviour effects gasifier performance. Measurement of char burn out show that char builds up to 7% by mass of material in the BFB (gasifier), which is equivalent to 60% by volume due to the lower density of the char. The cause of this problem is believed to be a result of top feeding of the fuel and the density difference between the char and bed material.

Another possible cause for this accumulation is low reactivity of the wood char with steam. Other researchers have recently shown that biomass derived chars react at only about 20% of the rates achieved by untreated coal derived chars. (Clemens *et al*, 2002). This is contrary to common held beliefs that wood chars are more reactive to steam than coal chars. Their gasification studies on various biomass derived chars showed biomass gasification to be largely a pyrolysis process rather than a true gasification process.

Modifications and experiments are planned to investigate this char accumulation behaviour further.

Synthesis gas samples are pumped from the top of the

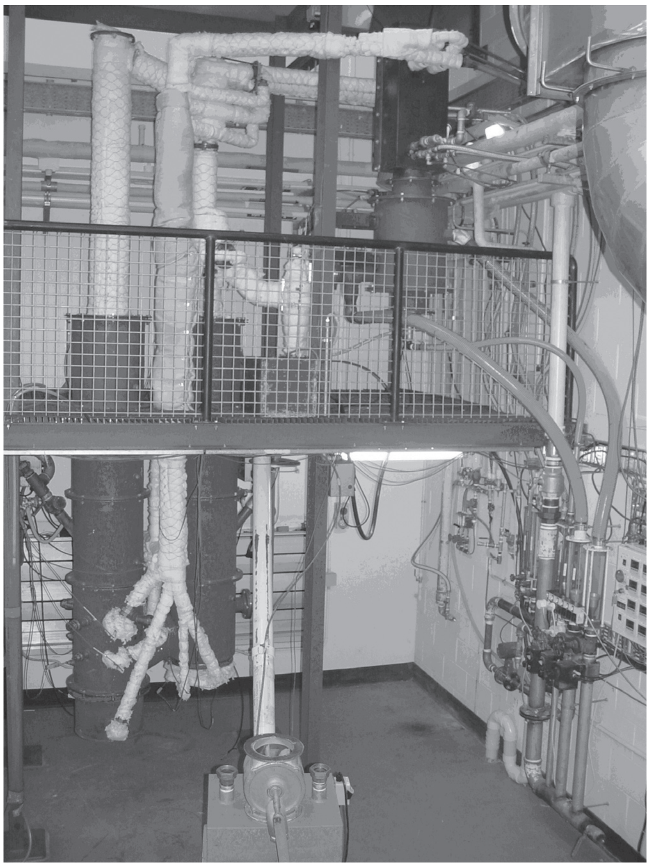
Table 1 Proximate and Ultimate analysis of the gasifier fuels on as received basis in wt%.

Component	Pellets	Chips
Proximate Analysis (as received basis)		
Moisture	8.0	52.6
Ash	0.4	0.2
Volatile	77.4	39.8
Fixed Carbon	14.2	7.4
Gross Calorific Value	18.62 MJ/kg	9.53 MJ/kg
Ultimate Analysis (as received basis)		
Carbon	47.2	24.3
Hydrogen	5.35	2.87
Nitrogen	<0.2	<0.1
Sulphur	0.01	0.01
Oxygen	38.7	20.0

BFB (gasifier) cyclone through a gas conditioning train to a micro gas chromatograph. The gas conditioning train is modelled on the European Union guideline for sampling and analysis of tars from biomass producers gases (Neeft *et al*., 2002). The train consists of a quartz thimble filter for removing particulates and wash bottles in series filled with iso-propanol in a water bath maintained below 20°C to remove moisture, tars and particulates.

The tars are collected using amino solid phase extraction (SPE) columns under the method proposed by Brage *et al*., 1997 and refined by Devenish, 2006 for the system operated at the University of Canterbury. 100 mL samples of synthesis gas are passed through a 100 mg amino phase SPE column (commercially available from J.T. Baker). Tars adsorbed on to the SPE columns are washed off firstly with iso-propanol (IPA) then with dichloromethane (DCM). These are then analysed using HPLC with a method developed by Devenish (2006). Initial analysis shows that the tar material contains many compounds but the main ones include naphthalene, acenaphthalene, phenanthrene, anthracene, fluoranthrene, pyrene. Eighteen of the major compounds detected have been identified leaving five unknown.

Figure 2 University of Canterbury's FICFB Biomass Gasifier.



Conclusions and Further Experimental Work

Initial experimental work has shown behaviour not considered in the original design and modifications have remedied these so the gasifier can be operated successfully. However it has also shown that the process shows promise in being able to produce a combustible gas for electrical generation. Experimental work will continue with the aim of knowing how parameters such as gasification temperature, wood and steam rates effect gas composition and tar formation. Further identification and quantification of compounds in the tar material is required to build on the current data library. There are several areas that need attention in order to operate the system as a continuous process capable of running for long periods. These include:

1. Modify the pilot burner design and flame failure system to prevent slag formation by eliminating high temperature zones.
2. Modify the feed system so fuel is fed into the side of the bed rather than on to the top in an attempt to reduce segregation of char and bed material in bubbling bed.
3. Increase circulation of char material within the bubbling bed to reduce its accumulation here.
4. Optimise the operation for product gas yield and quality.

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