BIOMASS OXY-GASIFICATION INTEGRATED INTO A COAL OXY- BOILER

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ABSTRACT: A biomass gasifier coupled to an oxy-combustion boiler is an attractive concept, enabling simultaneous production of syngas of medium heating value and carbon “capture” from concentrated CO_2 taken from the flue-gas of an oxyboiler. Pure oxygen is available for the gasifier, because it is produced for the oxyboiler, taking advantage of the economy of scale of the coal plant. A model of the gasifier is used to study the effect of process conditions on the gas composition and efficiency. The potential use of the gas produced for various applications (co-combustion in the oxyboiler, electricity production in gas engines and synthesis of chemicals with and without CO_2 separation are discussed. The capability of sequestration of green CO_2 (from biomass) is discussed. A 3 MW_{th} bubbling fluidized bed gasifier in León (Spain) has been erected to demonstrate the viability of this gasification process.
Keywords: gasification, waste, fluidized bed, pilot plant.

1 INTRODUCTION

One route towards the reduction of CO_2 emissions is carbon capture and storage (CCS). This involves production of CO_2 from the combustion, compression, and injection into a storage. An oxy-combustion system operates by burning coal with pure oxygen to avoid diluting the flue gas by nitrogen from air. The combustion temperatures reached in this configuration require recycling cooled flue gas back to the combustor for moderation [1]. The exit stream from the oxyboiler consists of mostly CO_2 and H_2O; from which H_2O can be removed prior to further compression and storage of CO_2.

Biomass utilization provides an additional way for CO_2 reduction. Gasification of biomass in particular, offers a flexible way to process the biomass, making it possible to use the energy in a variety of ways. Gasification carried out in a fluidized bed (FB) has several advantages over that in fixed/moving bed and entrained-flow gasifiers, because it enables conversion of fuel of varying quality and scale-up of the process, making it ideal for processing of biomass and waste [2]. Hence, integration of biomass gasification, using an FB, in an oxyboiler seems to be an efficient way to take advantage of the production of CO_2 for gas production. The purpose of this study is to explore the integration of a concept of a biomass/waste FB gasifier in an oxycombustion plant, with attention to the potential of reducing carbon dioxide emissions in the various utilization options of the gas produced.

2 CONCEPT

The concept is shown in Figure 1. The gasifier is coupled in parallel to the boiler utilizing the oxygen production plant and the CO_2-rich flue gas from the boiler. The advantage of coupling a biomass gasifier to an oxy-combustion boiler are: (i) the simultaneous production of syngas with medium heating value and carbon capture from concentrated CO_2 (taken from the flue-gas of the oxyboiler); (ii) pure oxygen is already available in the oxycombustion plant, and therefore, the gasifier takes advantage of the economy of scale of the coal plant. (iii) a gasification agent is available in the boiler’s off-gas (with high CO_2 concentration). This can be used instead of steam, avoiding the need for additional steam production, used in conventional gasification processes.

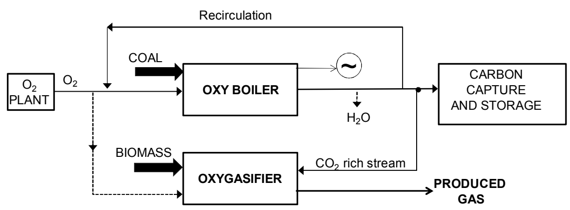

Figure 1: The concept of oxygasification integrated in an oxycombustion plant

3 GASIFICATION OF BIOMASS UNDER OXY-CONDITIONS

The gasification process with O_2 and CO_2 is similar to that of O_2 and H_2O. There are, some aspects that have to be taken into account:

- For a given fuel, the devolatilization in a CO_2-rich atmosphere yields more char, and the reactivity of the char is higher [3,4]
- For a given fuel, the yields and rates of fuel gas (CO, H_2,CH_2, C_2+) during devolatilization with CO_2 are similar to those with H_2O and N_2 [5]
- For a given char, the reaction rate of char with CO2 is several times slower than with H_2O [6,7]
- For a given char, the attrition rate of char during conversion with CO_2 is lower than with H2O [5]
- The rate of reforming of tars with CO_2 is lower than that with H_2O [6,8]

4 THE FIRST DEMONSTRATION PLANT

A 3 MW_{th} bubbling fluidised bed gasifier in Cubillos del Sil (León), using this concept, has been erected. In this plant the technological viability of this gasification procedure is to be evaluated. The gasifier has 1 m internal diameter and a height of 5 meters (bed and freebord). The first phase of the project was the construction of the gasifier island. The second phase will include the tar removal system.

The gas fed to the gasifier will be taken from one or both of the two oxy-boilers (20 MW_{th} pulverized coal and 30 MW_{th} circulating fluidized bed boiler), which are currently under construction. The aim of the first phase of the project is to characterize the gas produced to explore the best utilization options and to optimize future units employing this concept.

A model of the FBG was developed based on Ref. [6] with the aim of studying the effect of process conditions on the gas composition and conversion efficiency. With this input, the FBG was designed. The model takes into account both the fuel conversion processes and the fluid-dynamics of the bed. The inputs for the simulation were obtained from dedicated measurements in the lab [5,7].

At a given flow rate (600 kg/h) of biomass (wood pellets), the process was optimised by adjusting two ratios: the flow rates of oxygen to biomass and the rates of gas recirculation to biomass. For a given operation of the gasifier, the two ratios must be adjusted to give sufficiently high temperature to fully convert the char with CO_2 (with O_2 the conversion of tar is minor because the O_2 is rapidly consumed by the volatiles) minimizing the tar in the gas. The risk of sintering with wood pellets was low, so the maximum temperature was not a limitation for this fuel. In principle steam can be used together with the CO_2 as gasification agent but for the following calculations the gasification agent is supposed to be pure CO_2.

An existing model [6] was used to simulate the conversion of 600 kg/h in the demonstration FBG for various ratios of O_2/wood and CO_2 / O_2. At a typical operational point the results show that, in the conditions of a fluidized bed, gasification of a typical biomass yields a gas with a volumetric CO/H_2 ratio in the order of 3, having a volumetric concentration of CO_2 around 50%. In the gasifier, the net conversion of CO_2 is negative (10%-20%). The low heating value of the produced gas is around 7 MJ/Nm^3 (with CO_2 included) an almost twice this value if the CO_2 is separated.

5 GAS UTILIZATION

The feasibility of the process depends on the mode of integration, i.e. the way in which the gas is used. In the concept proposed the gas can be used in a variety of ways: (i) direct firing in the oxyboiler, i.e. co-combustion; (ii) burning of the gas in external devices, such as gas engines, and (iii) synthesis of chemicals, with or without CO_2 separation. The various utilization options are illustrated in Fig. 2. The advantages and disadvantages of each option are discussed in the following. Direct firing in a dedicated boiler to produce electricity is an additional option (not indicated in the figure), but it is not considered because it seems to be a concept with lower efficiency than gas engines in the ranges of scale and supply feasible for biomass. Direct combustion presents lower risk than power production by engines, but it is expected that the latter technology will be fully available in short term, so is not considered here where we look at medium to long term scenarios.

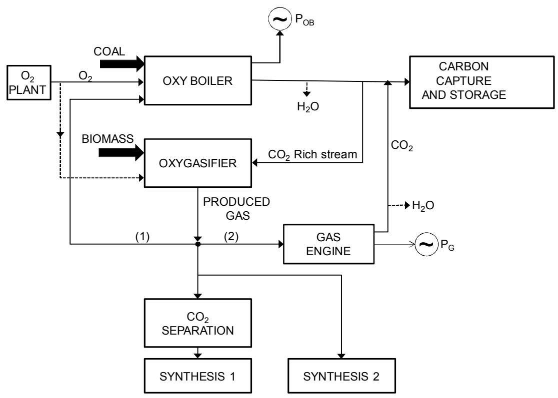

Figure 2: Utilization options of a biomass gasifiers coupled to a oxy-combustion plant

5.1 Co-firing of gas in the oxyboiler

In co-firing, the gas is burnt in an existing boiler to partially replace the primary fuel of the boiler [9]. Co-firing is interesting as the overall costs are relatively low due to the available power cycle. The great advantage is that the biofuels are utilized with high efficiency, since the gasifier is connected to a large conventional boiler, having a high-efficiency steam cycle (typically 40%). An additional advantage is that the ash of the biomass is not mixed with the coal ash, in contrast to direct co-combustion where the biomass fuels are mixed with coal before or during the combustion process. This allows using the existing market for ash as a construction material together with the ashes from the boiler. In pulverized coal oxy-boiler addition, the problem of milling of biomass is avoided. In reburning applications in air-boilers, when fuel gas in introduced almost at the top of the coal boiler, it has been shown that the environmental performance of the power station is significantly improved, in addition to the replacement of fossil fuel by renewable biomass fuel.

The requirements on gas quality in this option are not extremely strict, especially when the gas remains at high temperature during transportation to the burner, which prevents tars and alkaline metals to condense. The above is true for clean biomass, but is questionable for contaminated biomass or waste. For waste gasification, especially for high-alkali fuels, such as agroresidues, energy crops or waste-derived fuels, gas cleaning is recommended to avoid severe fouling and corrosion in the boiler as well as emissions of pollutants in the flue gas generated after combustion of the producer gas. It must be noted that, after burning the producer gas, the flow rate of the flue gas increases, so, if the producer gas is heavily contaminated, it is, in principle, a good option to clean the gas before burning [2]. In this case the CO_2 capture is almost 200% (biomass+CCS).

5.2 Electricity production in gas engines

Internal combustion engines of the otto or diesel type can be operated with gas produced by gasification of biomass. Standard natural gas engines can be used with gas from biomass, but some changes are still necessary to adapt the engines to the considerably lower heating value of the gas according to some operation experience with landfill gas and biogas [2].

Currently, the main problem is the efficient removal of tar because the engine manufacturers have not been able to design more robust engines, which can tolerate tar in the gas. The essential devices for gas cleaning are tar cracker/reformer, gas cooler, and a filter unit at medium temperature. The gas is further cooled before introduction in the engines. Cold gas cleaning based on water or solvent absorption has also been implemented. In this case, the gas is first cooled, filtered, and finally scrubbed. Gas cooling and contaminated effluent streams are the main operational problems when water is used as a scrubbing liquid. When organic solvents are used, the cost is high, and installation requires a certain size to be feasible. In this case the excess CO_2 will be lost from capture unless the exhaust gas can be recoducted to the boiler's CCS system.

5.3 Utilization of the gas for synthesis of fuels or chemicals

Synthesis gas with H_2 and a high proportion of CO is produced in the gas as the fuel compounds. After steam removal the dry gas can be used to produce different types of final products: diesel oil based on FTL, methanol mixed alcohols, H_2, Synthetic Natural Gas (SNG) [9]. The advantage of these chemicals is that they can be processed to liquid transport fuel additives such as dimethylether (DME) and dimethoxymethane (DMM). However, these applications need complex gas cleaning and synthesis stages, which need to be economically assessed. In principle, it seems that the gas produced in the oxygasifier contains too much CO_2 and this compound need to be removed before sending it to the synthesis process.

This can be done by conventional amine washing but there are also other methods proposed, such as biological applications which convert the CO_2 [10]. The bacteria in this process consume CO_2 in water environment producing CO and H_2. The degree of gas cleaning required for this application seems to be less restrictive compared to other chemical synthesis process. Besides the state of development of the process, this utilization option seems to be attractive for this type of gas.

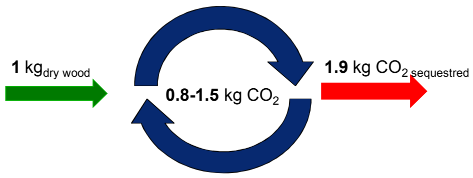

Figure 3: Sequestration of CO2 by biomass gasification in a process where the exit gas is recycled to the oxycombustion plant (co-firing or production of electricity)

5.4 CO_2-capture capability

In Fig. 3 a diagram showing the capability of CO_2-sequestration of the options where the gas from the gasifiers is returned to the oxycombustion plant is presented. From 1 kg dry wood almost 2 kg of CO2 are come into the oxycombustion plant to be sequestrated. It is also shown that the system requires a continuous recirculation stream of 0.8 to 1.5 kg of CO_2, depending on the CO_2 to O_2 ratio used in the gasifier.

6 CONCLUSIONS AND OUTLOOK

A biomass gasifier coupled to an oxy-combustion boiler is an attractive concept, enabling simultaneous production of syngas with medium heating value and carbon capture from concentrated CO_2. Simulation of the gasifier enabled a preliminary assessment of the process and allowed evaluation of the properties of the gas and the efficiency of the gasification process. Based on the model results, utilization options for the gas were identified. Technological viability of the various options needs to be analyzed further, taking into account the economy and technical development of the processes. The first demonstration unit has been constructed in Spain based to demonstrate the technology.

7 ACKNOWLEDGEMENTS

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