Click here to return to
Contents page

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Integration of biomass gasification in a gas-engine cogeneration system

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INTEGRATION OF BIOMASS GASIFICATION IN A GAS-ENGINE COGENERATION SYSTEM

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ABSTRACT

This project addresses the development and demonstration of an innovative concept for power production from co-gasification of coal and biomass, based on combined gas engine and steam cycle generation. A steam/air blown gasifier will be employed to produce a fuel gas using selected biomasses and solid wastes. Co-gasification with coal will enable processing of various sources of biomass and waste, thus providing considerable flexibility in the supplying of fuels, which may inherently be location-specific and intermittently unavailable. In particular, co-gasification of biological sludge from wastewater treatment processes, and inedible agricultural and slaughtering solid residues will be investigated in this project. By processing these residues, net emissions of carbon to the atmosphere will be reduced by rapid re-introduction in the carbon cycle through the food chain. As an integral part of the research proposed, new and cost-effective abatement technologies will be developed and tested for cleaning of gasification fuel gas. After cleaning, the fuel gas will be fed to a gas engine, which combined to steam generation, will ensure highly efficient conversion of fuel internal energy into electricity and heat (48% efficiency is expected). As a result, the outcome of the project will be a clean and efficient power production system based on integrated coal and renewable energy sources.

INTRODUCTION

Over the last two decades concerns over availability of non-renewable resource availability, energy security and the environment have spurred scattered efforts for a large scale use of biomass as a source of renewable environmentally sound and competitive fuels, heat and electricity. Recent energy projections indicate biomass as a major contributor to future energy supply (Hall and Scrase, 1998).

Biomass is suitable for a wide range of energy use. It can be burned directly to generate heat and electricity, or converted to intermediate solid, liquid or gaseous fuels. Gasification converts biomass to a low to medium calorific value (4-20 MJ/Nm^3) gaseous fuel, which can be used to generate heat and electricity by direct firing in engines, turbines and boilers (Kaltschmitt and Bridgwater, 1997; Kaltschmitt et al., 1998).

Alternatively, the product gas can be reformed to produce fuels such as methanol or hydrogen, which could then be used in fuel cells.

Addition of coal to biomass instead of using biomass only to generate heat and power offers several advantages (de Jong et al., 1999), in particular related to variations in availability of biomass, which can be met by changing the relative amounts of coal and biomass, and synergetic effects shown by gasification of mixtures of coal and biomass with respect to char reactivity, tar formation and emissions of harmful compounds.

Integrated biomass gasification and co-gasification systems for power generation are in the demonstration or early commercialization stage, and their market development will depend on a series of factors, including technical developments, energy market structure and government policies on energy security and environment. The application of advanced power cycles requires a sound understanding of the primary gasification process, the necessary gas clean-up, the conditioning processes as well as the interaction between these process units. This paper describes the development and demonstration of an innovative concept for power production from co-gasification of coal and biomass, based on combined gas engine and steam cycle generation.

POWER CYCLE

The system, designed, realized and tested on a pilot scale, consists of the following sections:

- Gasification
- Gas cleaning
- Desulphuration
- Shift conversion
- Carbon dioxide separation
- Hydrogen purification
- Internal combustion engine

Gasification

Thermochemical processing of solid fuels yields gaseous, liquid and solid products and offers a means of producing useful gaseous and/or liquid fuels. Gasification is a degradation process consisting of a sequence of thermal and thermochemical processes which convert the carbon in the solid fuel into gases, leaving an inert residue. The gas produced mainly consists of carbon monoxide, hydrogen, carbon dioxide, methane and nitrogen (if air is used as oxidizing agent), and contains impurities such as small char particles, ash, and tars.

In this project, un updraft, countercurrent gasifier was designed and tested on fuel mixtures of coal and biomass. In this system, the gasifying agent (air) is introduced from the reactor bottom and flows upward toward the top. The solid fuel is fed from the reactor top, move downwards and is extracted from the bottom. A diagram of an updraft gasifier is presented in Fig. 1. Saturated steam is added to the air to improve temperature control. Four sequential processes occurs in the reactor on going from the top to the bottom (see Fig.1): drying, pyrolysis, gasification and combustion. The latter process is needed to sustain the endothermic processes taking places in the upper part of the column (i.e. gasification, pyrolysis and drying).

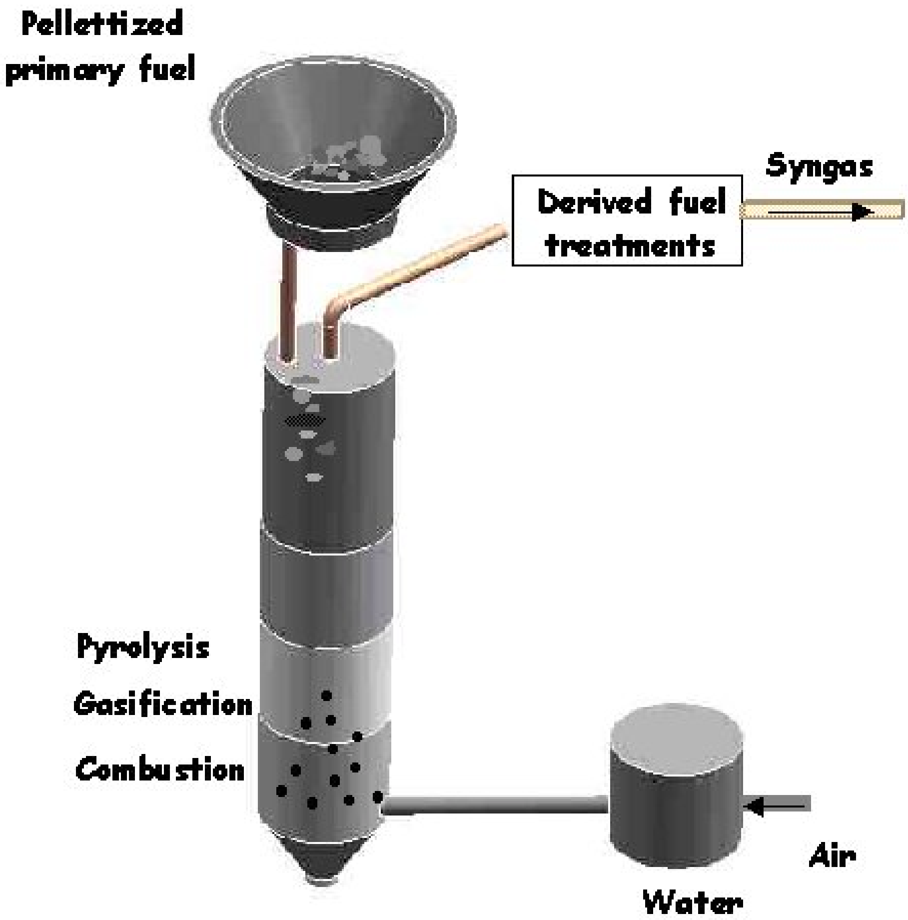

Fig 1 Counter current, fixed bed gasifier with oxygen enrichment

Water contained in the feed leaves the top of the reactor as a fraction of gaseous compound produced.

The mixture of air and steam introduced at the reactor bottom is uniformly distributed throughout the reactor by a moving grate, which also ensure the collection of ashes at the bottom of the reactor. The gaseous stream flowing upwards in the reactor gets richer in gases produced by gasification of the solid fuel.

Updraft gasifiers may process fuels with high water content (up to 50 % of mass fraction), without requiring any pre-drying. The process is characterized by a high thermal efficiency, and can be applied for generating power in the range 0.2 – 50 MW.

The energy necessary to sustain the gasification process is obtained from the partial combustion of the feed with oxygen. The process can be realized at lower temperature by using oxidizing agents such or steam, which allows an higher yield in hydrogen produced.

To reduce the nitrogen content in the syngas produced, use of air enriched in oxygen is tested to reduce the amount of inert gases to be separated in the downstream sections.

Gas cleaning

Raw syngas produced in the updraft gasifier is treated to reduce ash, tar and chlorides (which may be contained in the syngas depending on the composition of the feedstock) and obtain a clean gas which can be used in the downstream sections of the power cycle. To this end, an electrostatic precipitator is used for the wet removal of tar and ash, while acidic compounds, such as hydrochloric acid or sulphur oxides, are removed by wet scrubbing with water or alkaline solutions. Since the optimal working temperature for the electrostatic precipitator is around 80-90 °C, the syngas exiting the gasifier is cooled down in a heat exchanger designed on purpose to minimize tar fouling. Scrubbing is realized in a series of packed towers, where any trace of tar not retained in the precipitator will be removed from the gas together with any water-soluble component.

Desulphuration

Traces of sulphur compounds other than sulphur oxides (removed by wet scrubbing), such as COS, are catalytically converted to hydrogen sulphide. To this end, syngas temperature after cleaning in the electrostatic precipitator and wet scrubber, is raised to a temperature of about 120 °C (or up to 175 °C if HCN is present). The conversion occurs in fixed bed catalytic reactors.

Hydroged sulphide produced by the conversion is removed through hybrid (physical and chemical) absorption in a solvent based on methyl-ethanol-ammine e sulfolane.

Shift conversion

After cleaning, saturated or superheated steam is added to the syngas to realize the shift conversion of carbon monoxide in carbon dioxide with production of hydrogen. The amount of steam added depends on the syngas composition. In order to obtain a high hydrogen conversion yield, the shift reaction is realized in two steps at different temperature. The gas produced after the shift conversion is constituted by hydrogen, carbon dioxide, steam, nitrogen and traces of carbon monoxide. The shift conversion cannot be considered as an innovative process, as it is widely applied in the chemical and petrochemical industry, but its application to syngas has not been tested yet.

Carbon dioxide separation and Hydrogen purification

Gas from the shift conversion undergoes further processing for the separation of carbon dioxide from hydrogen. Chemical processes (based on absorption with ammines) and physical processes (based on absorption with methanol) are employed to remove carbon dioxide from the gas stream containing hydrogen.

The fuel gas produced is mainly made up of hydrogen and steam. Water is then removed by condensation. Hydrogen will be fed to the purification unit.

Internal combustion engine

An internal combustion engine is used to convert both syngas and hydrogen into energy.

EXPECTED RESULTS

Gasification

The updraft gasifier will be loaded with mixtures of coal and biomass. When using coal, the reactor will be charged with 700 kg/h of fuel with a heating value higher than 4500 kcal/kg and an apparent density of 850 kg/m3. The expected gasification efficiency is 90-92 %, with a syngas flow rate of 1.300 Nm3/h. Typical values expected for syngas composition when using coal as feedstock are reported in Table1. On a mass basis, the syngas produced to coal fed ratio is around 2.

Table 1. Expected composition of syngas produced in the updraft gasification of coal

Compound	Mole fraction
H_2	17
CO	25
CH_4	1.5
C_2H_6	< 0.2
C_2H_4	< 0.2
C_3H_8	< 0.1
C_2H_6	< 0.1
CO_2	6
N_2	50
Sulphur compounds	< 0.2
LHV	4500 kJ/Nm3

Gas cleaning

After electrostatic precipitation and wet scrubbing, particulate matter and tar content will be reduced to less than 10 mg/Nm3.

Desulphurisation

The innovative technologies employed to remove sulphur compounds from the syngas will ensure a content of total sulphur compounds lower than 100 ppm (on a volume basis).

Shift conversion

The multistage shift conversion process will reduce the concentration of carbon monoxide to 1-2 %.

Carbon dioxide separation and Hydrogen purification

Physical and chemical absorption processes designed to separate carbon dioxide from hydrogen after shift conversion of carbon monoxide are expected to have a separation efficiency of 90 %, with a selectivity in recovered carbon dioxide of 97 %. Hydrogen mole fraction in the fuel gas to be used for energy production is expected to be around 80 %.

Internal combustion engine

Efficiency is expected from 40 to 45 % in simple cycle with fuel gas enriched in hydrogen.

CONCLUSIONS

A number of technical issues need to be addressed before integrated gasification systems for power generation can reach full commercialization. Demonstration projects such as that presented in this paper are valuable in this respect, as they may help to overcome major obstacles to the development of biomass gasification for power generation. This project shows that integrated gasification systems can offer efficiency gains, features such as higher power to heat ratios and environmental benefits which could enhance its viability compared to other systems, in particular direct combustion systems. In particular, the updraft gasification technology presented in this paper offer the following benefits:

- Low cost of installed power (250 keuro/MW)
- Small land area requirements
- Simple operation
- High efficiency (90-92 %)
- Low temperature of syngas produced
- Modular, multi-fuel installations

These research activities will be developed in a “test facility” that Ansaldo Ricerche, Sotacarbo, ENEA and Department of Mechanical Engineering, University of Cagliari will design and build. This test facility will be localised in Carbonia, Sardinia, near the Sotacarbo Research Centre on advanced coal technology that at present is under construction. The pilot plant will allow technology development of coal syngas production and processing for production and utilisation of energy vectors with high environmental value, like methanol and particularly hydrogen.

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