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Unit operations for production of clean hydrogen-rich synthesis gas from gasified biomass

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ABSTRACT

The rebuild of the Växjö Värnamo Biomass Gasification Center (VVBGC) integrated gasification combined cycle (IGCC) plant into a plant for production of a clean hydrogen rich synthesis gas requires an extensive adaptation of conventional techniques to the special chemical and physical needs found in a gasified biomass environment. The CHRISGAS project has, in a multitude of areas, been responsible for the research and development activities associated with the rebuild. In this paper the present status and some of the issues concerning the upgrading of the product gas from gasified biomass into synthesis gas are addressed. The purpose is to serve as an introduction to the scientific papers written by the partners in the consortium concerning the unit operations of the process.

1. Introduction

The CHRISGAS project, financed by the European Commission and the Swedish Energy Agency, has carried out research and development activities in a multitude of areas for over 5 years concerning the rebuild. In this paper the present status and issues concerning the upgrading of the product gas from gasified biomass into synthesis gas are addressed. The purpose is to serve as an introduction to the scientific papers produced by the partners in the consortium concerning the unit operations. The aim of the CHRISGAS (Clean Hydrogen-Rich Synthesis Gas) project was to support the rebuild of the VVBGC (Växjö Värnamo Biomass Gasification Center) demonstration plant from an IGCC (Integrated Gasification Combustion Cycle) plant into a synthesis producing unit with research and development [1]. Synthesis gas is a gas mixture of carbon monoxide, carbon dioxide and hydrogen which can be used for synthesis of different chemicals, for instance, synthetic liquid fuels such as methanol, di-methyl ether (DME) or Fischer-Tropsch diesel [5]. The ratio between the different gases may vary depending on what synthesis process is used. Traditionally, synthesis gas is produced from fossil fuels such as natural gas or coal, but any carbon based fuel can be used. At the VVBGC plant the synthesis gas is to be produced by gasification of biomass – a renewable energy source.

Fig. 1 shows the configuration of the VVBGC plant after the planned rebuild. Modifications of old and introduction of new unit operations include:

1) The gasifier
2) The hot gas filter

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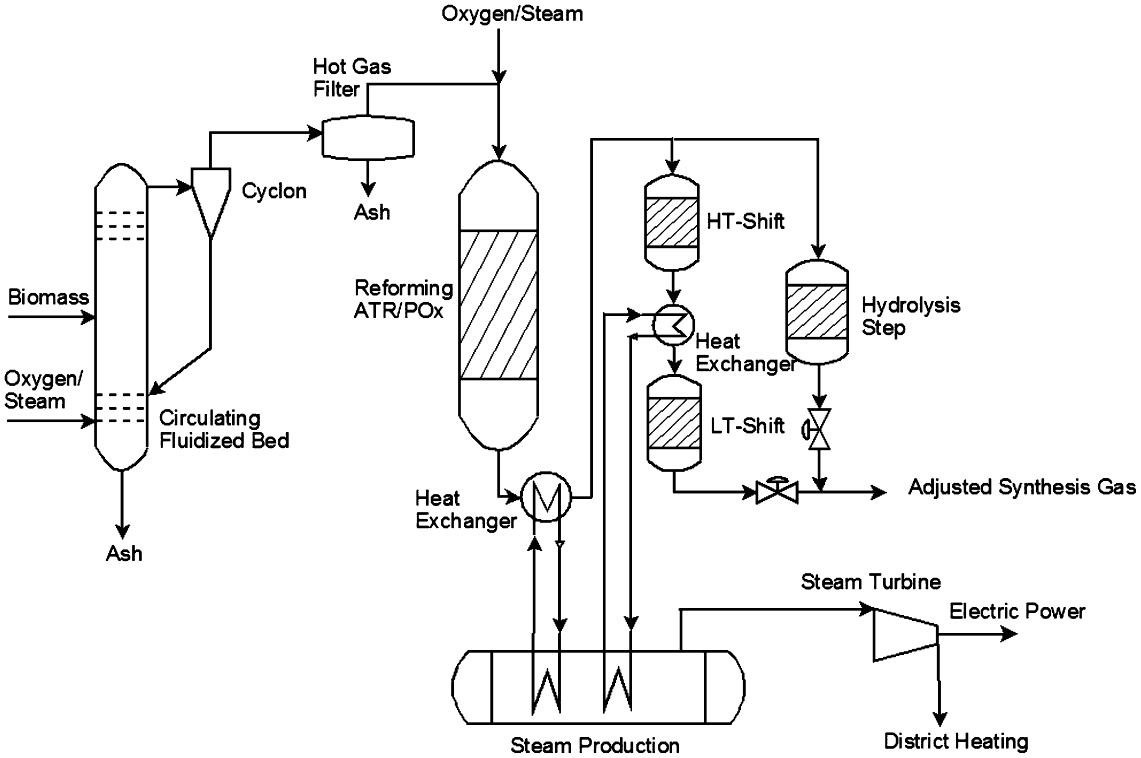

Fig. 1 – Schematics of the Värnamo plant after planned rebuilding.

3) The reformer unit
4) The shift reactor

Subsequent gas cleaning systems for removing contaminates such as sulphur, tars, ammonia etc., prior to the expected synthesis step(s) were not included in the CHRISGAS project.

2. The gasifier [1,2]

In principle, thermochemical conversion of a biomass particle always begins with a drying step followed by a pyrolysis step, i.e. heating in an inert atmosphere. If the heating rate of the particle is fast, these processes will more or less coincide. Three phases are obtained in pyrolysis: a solid residue, char, consisting mainly of carbon and ash; a gas phase containing mainly carbon monoxide, carbon dioxide, hydrogen, methane, some C2-C3 hydrocarbons and light aromates; and a condensable phase consisting of tar and water. If more or less reactive gases such as oxygen, steam or carbon dioxide are present, the carbon in the solid residue will react with these and eventually also become gaseous. The final product gas composition will thus be the result of a multitude of different parallel and sequential heterogeneous as well as homogenous reactions. Char conversion takes place through a number of reactions, the most important being:

$$C + CO_2 \Leftrightarrow 2CO + 172\text{kJ mole}^{-1} \qquad \text{(R1)}$$

$$C + H_2O(g) \Leftrightarrow CO + H_2 + 130\text{kJ mole}^{-1} \qquad \text{(R2)}$$

$$CO + H_2O(g) \Leftrightarrow CO_2 + H_2 - 42\text{kJ mole}^{-1} \qquad \text{(R3)}$$

$$C + 2H_2 \Leftrightarrow CH_4 - 71\text{kJ mole}^{-1} \qquad \text{(R4)}$$

The first two reactions are the main gasification reactions, indicating that gasification consumes energy. This energy may be obtained by letting oxygen react with part of the char as follows:

$$C + 1/2O_2 \Leftrightarrow CO - 190\text{kJ mole}^{-1} \qquad \text{(R5)}$$

$$C + O_2 \Leftrightarrow CO_2 - 390\text{kJ mole}^{-1} \qquad \text{(R6)}$$

The energy needed for the endothermic gasification reactions (R1) and (R2) above may also be supplied via sensible or indirect heat. If air is used as gasification agent the product gas will be diluted by nitrogen. Air gasification gives a relatively poor-quality gas (4–6 MJ m^{-3} (at 0 °C and 101 kPa)) which is suitable for boilers but not for engine and turbine operation. One alternative to improve the gas quality, i.e. increase the heating value of the gas is to employ oxygen/steam instead of air as the gasification agent. Oxygen/steam gasification gives a better-quality gas (10–15 MJ m^{-3} (at 0 °C and 101 kPa)) which is more suited for use as synthesis gas for subsequent upgrading to transportation fuel liquids or chemicals. Additionally, oxygen/steam gasification, in contrast to air gasification, gives a product gas with higher hydrogen content and also allows for a better possibility to tune the gas composition. Gas of this higher quality can also be produced through steam gasification, if the energy is externally supplied.

Many types of gasifiers with varying schemes for both reactor design and reaction media may be found [3]. The most