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The technical feasibility of biomass gasification for hydrogen production

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Abstract

Biomass gasification for energy or hydrogen production is a field in continuous evolution, due to the fact that biomass is a renewable and CO_2 neutral source. The ability to produce biomass-derived vehicle fuel on a large scale will help to reduce greenhouse gas and pollution, increase the security of European energy supplies, and enhance the use of renewable energy. The Värnamo Biomass Gassification Centre in Sweden is a unique plant and an important site for the development of innovative technologies for biomass transformation. At the moment, the Värnamo plant is the heart of the CHRISGAS European project, that aims to convert the produced gas for further upgrading to liquid fuels as dimethyl ether (DME), methanol or Fischer–Tropsch (F–T) derived diesel. The present work is an attempt to highlight the conditions for the reforming unit and the problems related to working with streams having high contents of sulphur and alkali metals.

Keywords: Biomass; Gasification; Power generation; Hydrogen; Autothermal reforming; Water gas shift

1. Introduction

Fossil fuels such as coal, oil and natural gas are used for generating a very large proportion of the electricity in the world today. Firing with these fuels gives rise to carbon dioxide (CO_2), which is a "greenhouse" gas discharged to atmosphere. So, there is keen interest in reducing the CO_2 emissions from sources such as fossil fuels. On the other hand, the carbon dioxide generated in the combustion of biofuels is not considered to give any net contribution to the CO_2 content of the atmosphere, since it is absorbed by photosynthesis when new biomass is growing [1,2]. However, the use of biofuels for power generation is more limited, although a number of smaller combined heat and powers (CHP) plants have been built in recent years [3]. The plants that have been built are based on conventional technology, i.e. a boiler plant and a steam turbine cycle. The electrical efficiency of these plants is around 30% [4] and the alpha value (the ratio of electrical energy to thermal energy generated) is around 0.5 or below. Although there is development potential for these plants, the electrical efficiency and the alpha value cannot be expected to increase to any significant extent. A technique that offers opportunities for achieving higher electrical efficiencies is based on the gasification of solid fuels and combustion of the gas thus produced in a gas turbine and a following steam cycle. These integrated gasification combined cycle (IGCC) plants were originally developed for fossil fuels, but the principle can also be applied to biofuels. Several studies [5] have shown that well optimized generation plants rated at 30–60 MW_e, based on pressurized gasification of wood fuel and integrated into a combined cycle can achieve net electrical efficiencies of 40–50% and an overall efficiency of 85–90%

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with competitive generation costs and low emission levels. The Värnamo IGCC demonstration plant in Sweden is the first of its kind in the world. It was constructed during 1991–1993, operated 1993–1999 and was an important step forward in developing highly efficient and environmentally acceptable technologies based on biomass. At the moment, the Värnamo plant is the heart of the CHRISGAS European project, that aims to convert the produced gas for further upgrading to liquid fuels as dimethyl ether (DME), methanol or Fischer–Tropsch (F–T) derived diesel.

2. The configuration of the existing plant

The existing plant configuration [6] has a biomass-fuelled pressurized IGCC for CHP production (Fig. 1). Several types of cellulosic biomasses (different wood chips, wood pellets, straw pellets and refuse derived fuel) were successfully tested with a feedstock rate of 4 tonnes/h (total fuel input equivalent to 18 MW). The dried and crushed biomass is pressurized in a lock-hopper system to a level determined by the pressure ratio of the gas turbine, and fed by screw feeders into the gasifier a few meters above the bottom. The operating temperature of the gasifier is 950–1000 °C and the pressure is approximately 18 bar (g) (Table 1; [7]). The gasifier is a circulating fluidized bed (CFB) and consists of the gasifier itself, cyclone and cyclone return leg. These three parts are fully refractory lined. The gasifier is air-blown. About 10% of the air is extracted from the gas turbine compressor, further compressed in a booster compressor, and then injected into the bottom of the gasifier. The fuel is dried, pyrolized and gasified on entering the gasifier. The gas produced transports the bed material, magnesite (MgO) and the remaining char to the top of the gasifier and into the cyclone. The magnesite has properties that make it highly resistant to sintering and bed agglomeration. Moreover, it is basic and does not react with alkali from the fuel. In the cyclone, most of the solids are separated from the gas and are returned to the bottom of the gasifier through the return leg. The recirculated solids contain some char, which is burned in the bottom zone where air is introduced into the gasifier. The combustion maintains the required temperature in the gasifier. After the cyclone, the gas produced flows to a gas cooler and a hot gas filter. The gas cooler is of a fire tube design and cools the gas to a temperature of 350–400 °C. After cooling, the gas enters the candle filter vessel where particulate clean up occurs. Ash is discharged from the candle filter, as well as from the bottom of the gasifier, and is cooled and depressurized. The gas produced is burned in the combustion chambers and expands through the gas turbine,

Table 1
Technical data of the Värnamo plant

Power/heat generation	6 MW_e/9 MW_{th}
Fuel input (wood chips)	18 MW (85% dry substance)
Net electrical efficiency	32%
Total net efficiency	83%
Gasification pressure/temperature	18 bar (g)/950 °C
Lower calorific value of product gas	5 MJ/N m^3
Product gas steam pressure/temperature	40 bar (a)/455 °C

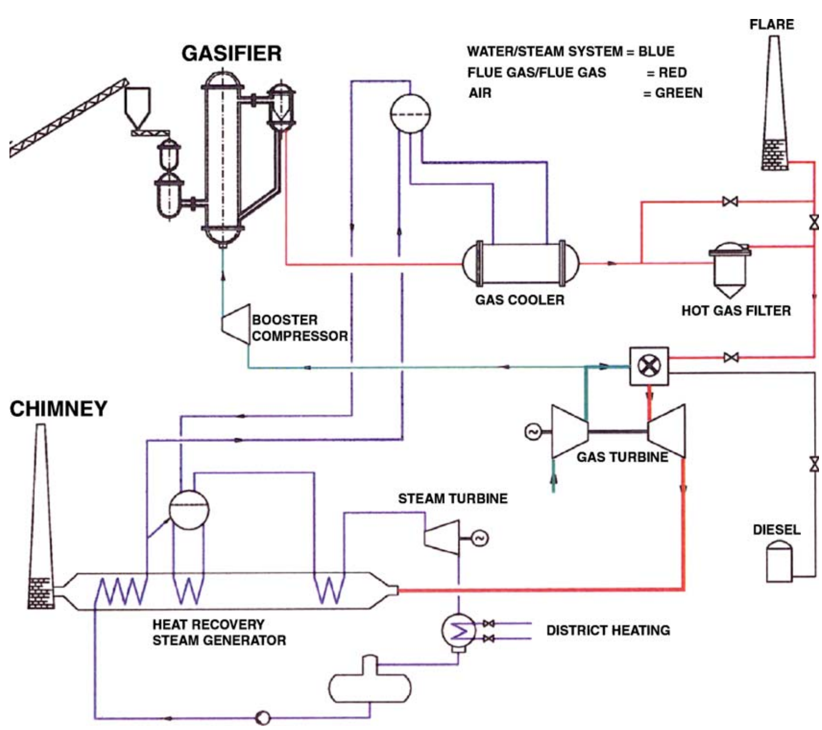

Fig. 1. IGCC process diagram as it stands today.

which is a single-shaft industrial unit. Its rated output is 4.2 MW and it can be run on both diesel oil and product gas. The former is used only for starting up the plant, when no gas is available. The fuel supply system, fuel injectors and the combustors have been redesigned to suit the low calorific value gas (5 MJ/N m^3). The hot fuel gas from the gas turbine is ducted to the heat recovery steam generator (HRSG), where the steam generated, along with steam from the gas cooler, is superheated and then supplied to a steam turbine (40 bar, 455 °C), generating 1.8 MW_e. The plant is equipped with a flare on the roof of the gasification building, which is used during start-up and to protect the gas turbine when testing less well-known conditions.

Table 2
Calculated compositions (%, v/v) of the exit gases from the plant units

	After gasifier (%)	After ATR (%)	After WGS (%)
C_2H_6	0.08	0.00	0.00
C_2H_4	1.53	0.00	0.00
CH_4	8.17	0.80	0.72
CO	11.86	21.48	6.45
CO_2	27.92	20.85	32.09
H_2	11.79	23.36	34.38
H_2O	37.69	33.15	26.01
N_2	0.06	0.05	0.04
Ar	0.06	0.07	0.07
NH_3	0.29	0.23	0.21
H_2S	0.01	0.01	0.01
BTX	0.26	0.01	0.01
Tars	0.27	0.00	0.00

3. The configuration plant after rebuild

The new syngas process requires rebuilding of the plant (Fig. 2). The first modification that will be introduced is the use of an oxygen/steam flow as gasifying agent. The product gas (calculations on stream compositions are listed in Table 2) is free from N_2, it has a higher heating value, a lower content of tars and a higher yield in H_2 than the air gasification. Since steam gasification is endothermic, the use of some amount of oxygen can provide the necessary heat for gasification and then the gasifier works as an autothermal reactor. A further modification is the installation of a hot gas filter before the reforming unit, operating above 650 °C to avoid loss of heat. The filter must operate at high pressure and high temperature and must be resistant to abrasive impurities contained in the product gas (such as alkali metals). The choice for the reforming unit is an oxygen blown authothermal reforming (ATR), which is commonly applied in secondary units of combined reforming plants [8], since the stream coming from the gasifier may be assimilated to a pre-reformed gas. If the lifetime of nickel based commercial catalysts is too short (due to the traces of poisoning species, such as heavy and alkali metals, SH_2, COS and SO_2), a non-catalytic partial oxidation (POX) will be chosen instead. Since the CHRISGAS project aims to convert the produced gas from biomass to a synthesis gas for applications that may require different H_2/CO ratios, the reformed gas may be ducted to a conventional water gas shift (WGS) to obtain the H_2 purity required for fuel cells, or directly to a hydrogenation/hydrogenolysis (HYD) unit (to convert the residual hydrocarbons, in particular aromatic compounds and olefins) for applications requiring a H_2/CO ratio close to 2 (DME, methanol, F–T synthesis). Sulphided Co-Mo and Ni-Mo catalysts must be used in high temperature (HT) and low temperature (LT) shift converters and in the HYD unit, being unaffected by the presence of H_2S that irreversibly poison the conventional catalysts [9]. The plant is planned to be ready for operation during 2008 when testing of the pilot plant systems will commence.

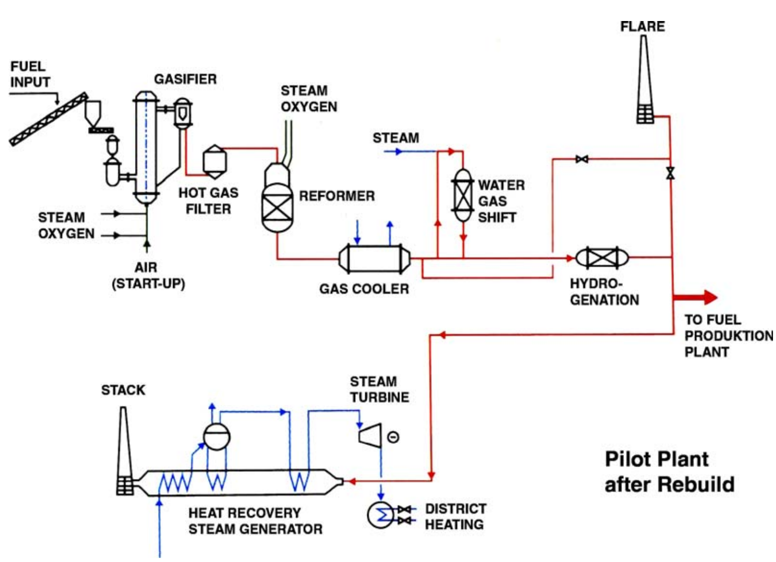

Fig. 2. IGCC process scheme after the proposed rebuilding.

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