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2250-h long term operation of a water gas shift pilot plant processing tar-rich product gas from an industrial scale dual fluidized bed biomass steam gasification plant

Michael Kraussler [a,*], *Matthias Binder* [b], *Hermann Hofbauer* [a,b]

[a] *Bioenergy 2020+ GmbH, Wienerstrasse 49, 7540 Guessing, Austria*
[b] *TU Wien, Institute of Chemical Engineering, Getreidemarkt 9, 1060 Vienna, Austria*

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ABSTRACT

In this paper, the performance of a water gas shift (WGS) pilot plant which processed tar-rich product gas for about 2250 h is investigated. The WGS pilot plant employed a commercial Fe/Cr based catalyst (ShiftMax® 120). The product gas was generated by the industrial scale and commercial dual fluidized bed (DFB) biomass steam gasification plant in Oberwart, Austria. A partial flow of tar-rich product gas was extracted for the WGS pilot plant before the tar scrubber of the gasification plant. The extracted product gas had a temperature of about 150 °C and a GCMS tar content between 2.7 and 8.2 g m^{-3} (d.b.). In order to investigate the stability of the catalyst and to observe the performance of the WGS pilot plant, extensive chemical analyses were carried out: CO, CO_2, CH_4, N_2, O_2, C_2H_6, C_2H_4, C_2H_2, H_2S, COS, and C_4H_4S were measured. In addition, GCMS tar and NH_3 analyses were performed. Furthermore, the catalyst's activity was observed by measuring the temperature profiles along the reactors of the three stage WGS pilot plant. During the about 2250 h of operation, no significant catalyst deactivation could be observed. A CO conversion of up to 92% as well as a GCMS tar reduction along the WGS pilot plant was obtained. The results showed that the application of a commercial Fe/Cr based catalyst in a WGS unit seems to be a suitable way for increasing the hydrogen content in a product gas generated by dual fluidized bed biomass steam gasification. Furthermore, with such a technique, it is possible to optimally adjust the required CO/H_2 ratio for several synthesis reactions, for example, methanation and Fischer-Tropsch synthesis.

Introduction

Biomass is one of the most promising renewable resources. Besides its use as solid fuel for heating and combustion applications, it can be converted to gaseous and liquid fuels via gasification. Therefore, biomass is seen as a promising resource for the renewable production of different energy carriers and chemical products. One of these products, which is mostly needed by the chemical industry, is hydrogen [1–3].

A promising technology for biomass gasification is steam gasification, especially, the dual fluidized bed (DFB) process [4,5].

* *Corresponding author.*
E-mail address: michael.kraussler@bioenergy2020.eu (M. Kraussler).
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The commercial biomass steam gasification plants in Guessing and Oberwart have been using this technology for several years. Both plants generate a product gas from wood chips with an volumetric H_2 content of about 40%. The volumetric concentrations of the other main gas components are about 25% CO, 20% CO_2, and 10% CH_4 (all d.b.). In addition, the product gas contains small amounts of N_2, O_2, higher hydrocarbons, and a volumetric concentration of about 100 $cm^3\ m^{-3}$ H_2S and minor amounts of other sulfur components. The typical volumetric H_2O content of the product gas is between 30 and 40%.

The high volumetric H_2 content makes this product gas a promising CO_2 neutral H_2 source. A process which can further increase the hydrogen content in the product gas is the water gas shift (WGS) reaction (see Equation (1)).

$$CO + H_2O \rightleftharpoons H_2 + CO_2 \quad \Delta H = -41.1\ kJ \cdot mol^{-1} \tag{1}$$

It converts carbon monoxide and steam to hydrogen and carbon dioxide. At the industrial scale, a WGS unit usually consists of a high temperature stage and a low temperature stage. In order to reach economic reaction rates, catalysts are necessary. A suitable catalyst for the high temperature stage is an Fe/Cr based catalyst. The high temperature stage operates adiabatically with a gas inlet temperature of 350–550 °C and space velocities from 400 to 1200 h^{-1}. The operating pressure depends on the plant requirements [6]. Fe/Cr based catalysts seem to be robust against sulfur poisoning at the amounts of H_2S which are observed in the product gas of biomass steam gasification [7,8]. Catalysts for the low temperature stage (about 200 °C) are Co/Mo or Cu/Zn based catalysts. The Co/Mo catalyst is resistant to the presence of sulfur components but the amount of H_2S in the product gas of biomass steam gasification is too low for the Co/Mo catalyst to reach a high level of activity. In contrast, Cu/Zn catalysts are sensitive to sulfur poisoning [6].

For this research, a WGS pilot plant employing a commercial Fe/Cr based catalyst was operated with tar-rich product gas from the industrial scale and commercial biomass steam gasification plant in Oberwart, Austria. The WGS pilot plant was continuously operated for about 2250 h. Some authors ([8–10]) showed that an operation with product gas with a low tar content is possible. In addition, Kraussler et al. ([11]) showed that a short term operation with tar-rich product gas for about 100 h is possible. This paper investigates the long term performance of the WGS pilot plant which processed tar-rich product gas extracted before a rapeseed methyl ester (RME) gas scrubber.

Materials and methods

The experimental work was carried out at the site of the biomass steam gasification plant in Oberwart, Austria, where the WGS pilot plant is located. The pilot plant consists of three reactors in series which employ an Fe/Cr based catalyst. The gas compositions and the steam contents were measured before and after each reactor. GCMS tar and NH_3 analyses were performed by the Test Laboratory for Combustion Systems at the TU Wien. The temperature profile along each reactor was recorded. This allowed judging the activity of the Fe/Cr based catalyst.

The biomass steam gasification plant in Oberwart

The WGS pilot plant processed product gas from the combined heat and power (CHP) plant in Oberwart. Fig. 1 shows a simplified flowchart of the process employed.

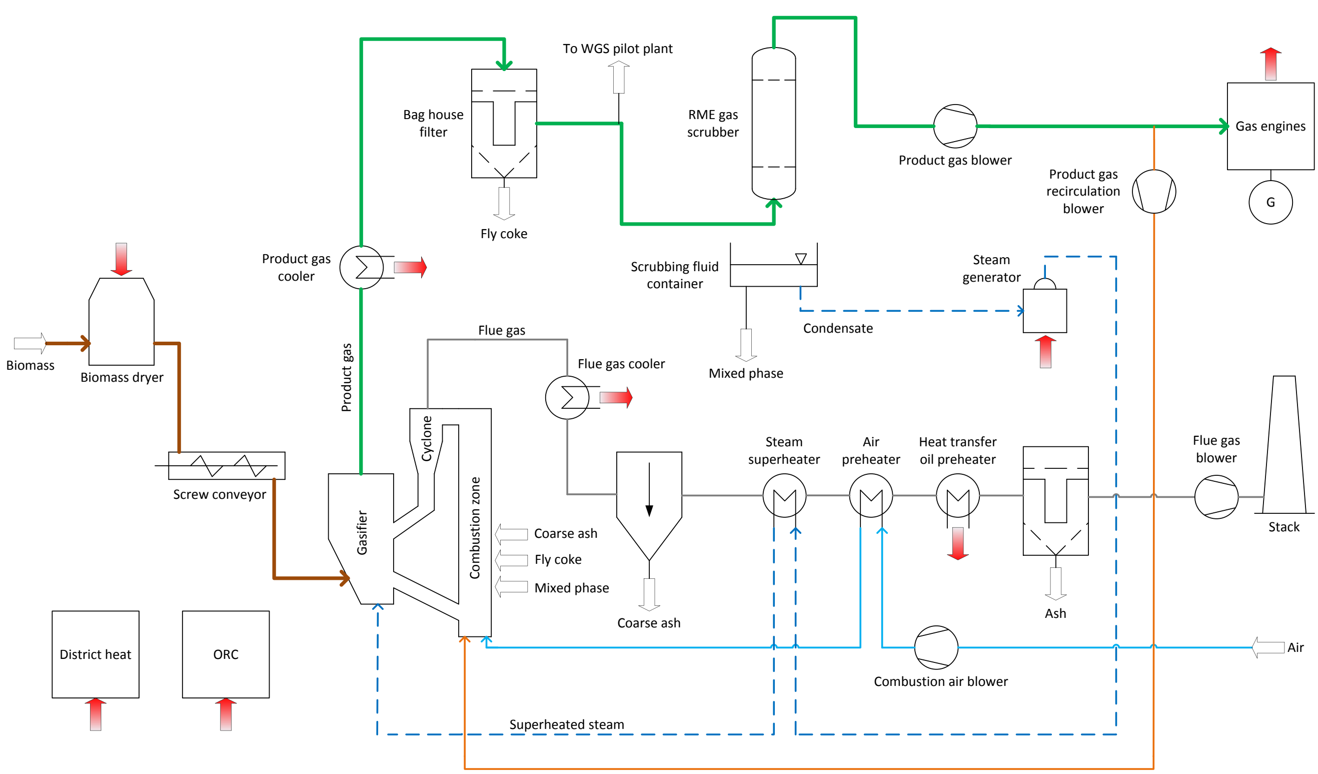

Fig. 1 – Simplified flowchart of the CHP plant in Oberwart, Austria, showing the extraction point of the product gas for the operation of the WGS pilot plant.