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Conversion of fuel nitrogen in a dual fluidized bed steam gasifier

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HIGHLIGHTS

- ▶ Experimental investigation of nitrogen conversion in the dual fluidized bed gasifier.
- ▶ Six different materials (waste wood, bark and plastic residues) tested.
- ▶ Linear relationship of fuel nitrogen and ammonia formation.
- ▶ Nitrogen conversion occurs almost exclusively in the gasification reactor.

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ABSTRACT

During gasification, fuel nitrogen is converted into gaseous species, such as NH_3, HCN and others. Several materials are gasified in the dual fluidized bed gasification pilot plant in order to assess the conversion of fuel nitrogen. The fuels tested in this study are different kinds of waste wood, bark and plastic residues. The nitrogen content of these materials ranges from 0.05 to 2.70 wt.-%. Detailed measurements of NH_3, N_2, HCN, NO and nitrogenous tars are carried out during the test runs. It is found that the vast majority of nitrogen is present in the form of NH_3. There is a linear relationship with high accuracy between fuel nitrogen and NH_3 in the producer gas. The nitrogen balance of the dual fluidized bed gasification system shows the distribution of nitrogen in the two coupled reactors of the gasification system. It is assessed that nitrogen conversion occurs almost exclusively in the gasification reactor. Only minor amounts of nitrogen are found in the char, which is transported to the combustion reactor and is converted to NO there. This result provides important information for the gas cleaning requirements when nitrogen-rich fuels are gasified.

1. Introduction

Gasification is an innovative technology for the conversion of solid fuels into a combustible gas. The gas is used for efficient heat and power generation, and synthesis applications, such as Fischer–Tropsch synthesis or methanation to synthetic natural gas. Various carbonaceous materials are of interest for gasification processes, ranging from biomass or coal to residues and waste. Among these materials there are also nitrogen-rich fuels. During gasification, fuel-bound nitrogen is converted into ammonia and other nitrogenous compounds. When producer gas is combusted, these nitrogen compounds are oxidized to nitrogen oxides (NO, NO_2, etc.). As they form acid rain, photochemical smog, and other environmentally damaging products, there are severe emission limit values for nitrogen oxides in flue gases from combustion processes. In contrast to combustion, gasification processes provide the possibility of producer gas cleaning prior to its application (combustion, synthesis) and thus, precursors of harmful emissions can be removed.

Several studies on nitrogen conversion in different gasification processes are available in the literature. Most commonly, atmospheric bubbling fluidized bed gasifiers are used [1–5], but there is also some information on nitrogen conversion in circulating fluidized beds [6] and dual fluidized bed systems [7]. Different gasification agents are applied: air [1,2,6], oxygen [4,5] or steam [3,7]. A number of studies focus on pressurized air gasification, such as [8–10]. It is commonly agreed on that NH_3 is the main conversion product and that the concentration of NH_3 in the producer gas is mainly determined by the concentration of nitrogen in the feedstock.

This paper describes the conversion of fuel nitrogen in the dual fluidized bed (DFB) gasifier, which is a atmospheric steam blown gasifier. As the DFB gasifier consists of two coupled reactors, nitrogen can be distributed in the two reactors which makes the situation more complex. Several fuels with varying nitrogen content are gasified in the DFB pilot plant, such as different kinds of waste wood, plastic residues and bark. Detailed measurements are

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carried out during the gasification tests. A nitrogen balance of the DFB gasifier is set up in order to trace the pathway of nitrogen conversion in both reactors of the DFB gasification plant, which determines the requirements for gas cleaning.

2. Dual fluidized bed gasification

The DFB gasification system has been developed at the Vienna University of Technology since the 1990s in order to generate high-quality producer gas from biomass. In 2001 the demonstration plant went into operation in Güssing (Austria) and has exceeded an operation time of approximately 60,000 h since. By now this technology is commercially available and several other industrial gasifiers based on the dual fluidized bed technology are in operation or currently under construction. There is more information on the industrial gasifiers in Austria and other European countries available in the literatures [11–15].

In the DFB gasifier, biomass is gasified with steam. Due to steam gasification, there is virtually no nitrogen in the producer gas and the hydrogen content amounts to about 40%. The average heating value is around 12–14 MJ/Nm^3 (Nm^3 = at 273.15 K and 101.325 Pa, referred to as dry gas). Producer gas from steam gasification is well suitable not only for heat and electricity production, but also for chemical synthesis. Current research focuses on synthesis application such as Fischer–Tropsch synthesis [16], synthetic natural gas production [17] or synthesis of mixed alcohols [18]. In the industrial DFB gasifiers a gas engine is used for power generation and heat is fed into the local district heating grid.

Gasification is an endothermal process, which requires a heat supply. The DFB gasifier consists of two reactors, where gasification and combustion take place separately. Both reactors are thermally connected by the circulating bed material. The basic principle is shown in Fig. 1. Feedstock is inserted into the gasification reactor and gasified with steam. Some ungasified char remains, which is transported to the combustion reactor together with the circulating bed material. There, the char is combusted with air in a highly expanded fast fluidized bed. Hot bed material is separated from the flue gas and supplies the heat for the endothermic gasification reactions. Two different gas streams are yielded: producer gas with high calorific value and conventional flue gas.

2.1. Pilot plant

At the Vienna University of Technology a 100 kW gasification pilot plant is operated for scientific purposes in order to further develop the DFB gasifier. The pilot plant is similar in design to the industrial gasifiers and is illustrated in Fig. 2. Research activities focus on the use of alternative feedstock [19–22], bed materials [23–25] and the continuous development of the gasification system itself [26].

The gasification reactor has a rectangular cross section with an equivalent diameter of 304 mm (circle with equal surface) in the upper part of the reactor. Feedstock is stored in several gas-tight hoppers and is transported into the gasifier by screw feeding systems. According to the position of the hopper, the material is either inserted directly into the fluidized bed or it is thrown onto the fluidized bed. In the DFB gasifier olivine is used as bed material, because olivine shows moderate tar-cracking activity and has good mechanical stability [27]. The temperature in the center of the fluidized bed amounts to 850 °C. Superheated steam is used as a fluidization agent in the bubbling fluidized bed of the gasification reactor. The gasification and the combustion reactor are connected by loop seals. The loop seals are also fluidized with steam, thus transport of solids is promoted and gas leakage is prevented efficiently.

The combustion reactor has an inner diameter of 98 mm. Air is used as fluidization agent. Primary air is injected at the bottom of the combustor, where a dense fluidized bed is formed. Secondary air is injected at a higher level in order to transport particles to the top of the combustion reactor. Ungasified char is combusted and provides heat for the gasification reactions. In addition to char from the feedstock, light fuel oil is injected into the combustion reactor, so that the temperature in the gasifier can be controlled. If no fuel is added to the combustion reactor, the temperature in

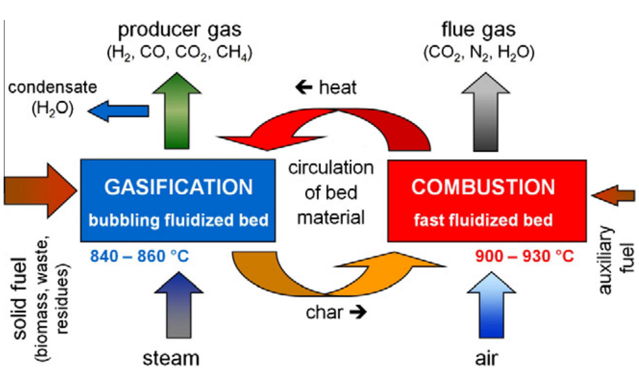

Fig. 1. Basic principle of the DFB gasifier.

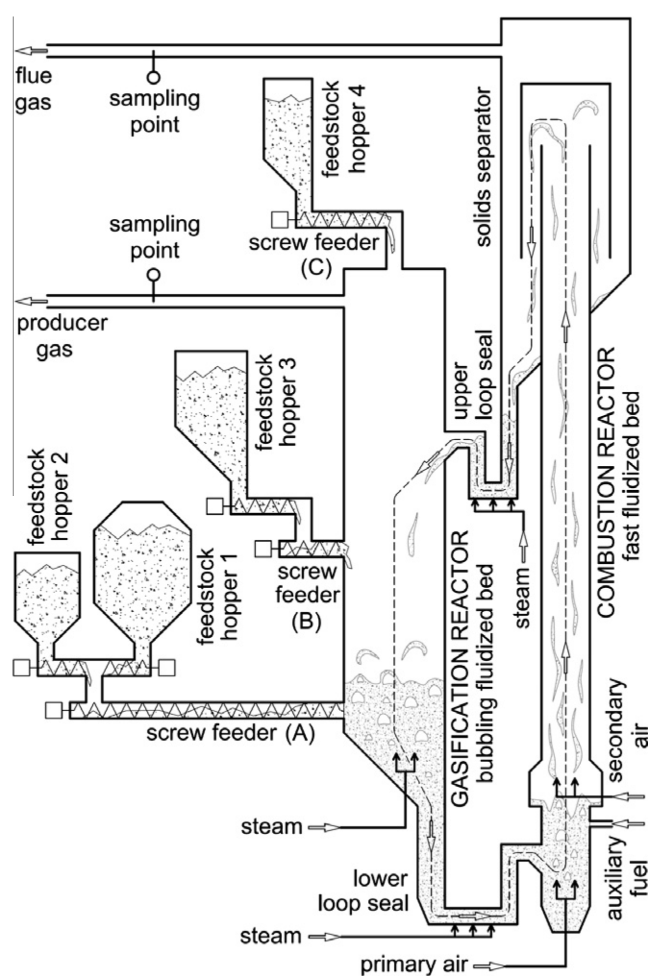

Fig. 2. 100 kW pilot plant at the Vienna University of Technology.