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Entrained flow gasification Part 1: Gasification of glycol in an atmospheric-pressure experimental rig

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ABSTRACT

Three coordinated papers are presented concerning entrained flow gasification of a liquid fuel under atmospheric conditions. The work is based on a detailed mapping of process parameters inside the entrained flow gasifier and at the gasifier outlet. In this paper the experimental setup and the experimental data are reported. Mono ethylene glycol (MEG) is used as a well-defined surrogate fuel for biogenic oils. The overall performance of the reactor is evaluated by measuring the gas-phase composition at the reactor outlet; radial profiles of gas-phase composition (CO_2, CO, H_2, CH_4, hydrocarbons) and temperature at 300 and 680 mm distances from the burner are measured to describe the mixing and reaction pattern in the gasifier. Global and local species balances are used to derive data that are not accessible by measurement. Characteristic parameters, i.e. stoichiometry, carbon conversion and water gas shift temperature, are derived to assess consistency of the measured data. Droplet size distribution and droplet velocity at the burner nozzle are reported based on atomization test rig experiments and direct measurements in the burner near field under gasification conditions. The experiments show a free jet with a strong outer recirculation zone as core gasification pattern. The measured species concentrations and temperatures provide an insight into both the mixing and the reactions in the burner near field. The water gas shift equilibrium is reached for a temperature of 1495 K upstream of the gasifier outlet. Hydrocarbons are not completely converted due to the low temperatures near the gasifier outlet.

The research work has been conducted within the research cooperation of the Helmholtz Virtual Institute HVIGasTech.

1. Introduction

Entrained flow gasifiers (EFG) dominate the gasification market worldwide [1,2]. The technology is suited for the production of a high quality syngas, with minimum amounts of hydrocarbons, tar and soot from solid and liquid fuels, as well as from suspension fuels (e.g. slurries consisting of a pyrolysis oil and a bio-char as applied in the bioliq® process [3]). The design and scale-up of EFG is mainly based on experience and to a lesser extent on a thorough understanding of the physical and thermo-chemical processes taking place in the gasifier. Especially for suspension fuels, the gasification process, as a three-phase high-temperature and high-pressure process, shows very complex interactions and overlapping of different physical and thermo-chemical process steps.

The researchers collaborating within the Helmholtz Virtual Institute for Gasification Technology, HVIGasTech [4], have focused on the development and validation of a numerical simulation tool for the mathematical description of the high-pressure entrained flow gasification process for suspension fuels. The tool is to be based on experimental data derived from both the atmospheric lab-scale gasifier (REGA) as well as the high pressure entrained flow pilot-scale gasifier of the bioliq® process [3]. The sub-models of the simulation tool describe the atomization of suspension fuels [5], the homogeneous and heterogeneous kinetics of the gasification of liquids and chars [6], the slag behavior [7] and the radiative heat transfer [8,9].

2. The physical and thermo-chemical sub-processes in entrained flow gasification of a suspension fuel

Entrained flow gasifiers processing liquid or suspension fuels

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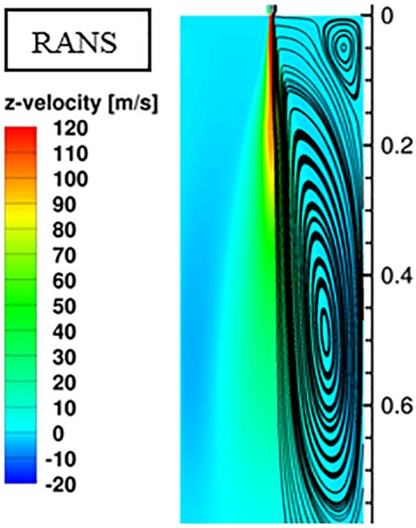

Fig. 1. Stream function from the RANS simulation for gasification of mono ethylene glycol in the atmospheric entrained flow gasifier [14].

(slurry) are typically equipped with twin-fluid atomizers. In the bioliq® process a suspension fuel which consists of pyrolysis oil and pyrolysis char from a fast pyrolysis process is converted to syngas in an entrained flow gasifier. The fuel is fed at a low velocity while the gasification medium is supplied at a significantly higher velocity to provide the required momentum for atomization. The burners may have different geometries especially with respect to the position of the fuel inlet; either central or annular nozzles are used and oxygen and steam are applied for atomization and gasification [10,11]. As the atomization process is driven by the momentum of the gasification medium, the overall stoichiometry in the gasifier, i.e. the oxygen/fuel ratio, is directly proportional to the gas-to-liquid ratio (GLR), which is a key parameter for the spray quality [12,13].

The flow pattern in an entrained flow gasifier is dominated by the high momentum of the gasification medium flow generating a highly turbulent enclosed jet. Within this jet the dominating physical and thermo-chemical sub-processes of entrained flow gasification take place. Fig. 1 shows both the streamlines and the axial velocities in an EFG from the RANS simulation [14], to underline the basic features of the flow. The high momentum gas jet drives an outer recirculation zone which carries hot syngas from the end of the gasification zone to the burner near field, where it reacts with the oxygen introduced as gasification and atomization medium, thus being responsible for the stabilization of the flame. The hot recirculated gases are entrained along the jet, affecting the temperature and species profiles in the jet zone.

In order to identify the physical and thermo-chemical process steps dominating entrained flow gasification Fig. 2 (left) depicts a typical droplet/particle trajectory pattern as derived from the numerical simulation of a slurry-fed EFG [12]. The colors of the trajectories represent different physical and thermo-chemical process steps which a fuel droplet experiences during the gasification process:

(a) **Atomization, heating-up, evaporation and decomposition** (light blue) of the liquid fuel releasing fuel vapors into the gas-phase.
(b) **Heating-up** and **pyrolysis** (orange) of the solid fuel particle (primary char) which is released from the slurry droplet. The volatiles are released into the gas-phase; the remaining solids are denoted as secondary char featuring different morphology and reactivity as compared to the original solid particle in the feed. The secondary char may also contain solids generated from the thermal degradation of the liquid-phase which may lead to the generation of cenospheres [6,15].
(c) **Gasification** (red) of the secondary-char, i.e. heterogeneous reactions of the secondary-char with steam and carbon dioxide [16].
(d) **Ash, slag-forming particles** (dark blue) impinging on the gasifier walls or leaving the gasifier with the syngas flow.

Fig. 2 (right) gives a detailed overview of the sequence of sub-processes and intermediate species relevant for EFG. The suspension fuel is atomized close to the burner nozzle within the highly turbulent gas jet which is enveloped by the gas flame burning recirculated syngas with oxygen at very high temperatures. The liquid fraction of the slurry evaporates; the vapors react with O_2, CO_2 and H_2O while the solid fuel fraction (primary char) undergoes a secondary pyrolysis and penetrates as secondary char, or as cenospheres, through this highly reactive zone into the downstream gasification zone where the endothermal gasification of the solid fuel components takes place, determining the syngas quality and fuel conversion efficiency.

3. Literature review

Detailed data from entrained flow gasification experiments is rare in literature. This chapter gives an overview of experimental data found in literature. A detailed discussion is omitted here, as this is included in the second part of three coordinated papers [14]. In Japan, a 200 t/d pilot scale updraft gasifier was operated by Mitsubishi Heavy Industries (MHI) within an IGCC development project. The syngas composition at the reactor outlet and centerline temperatures were measured for operation at 27 bar with pulverized coal [17,18]. Guo et al. [19] studied the influence of O/C and steam/C ratio on the performance of an entrained flow gasifier operated at 10–30 bar, feeding pulverized coal by diametrically opposed burners in the upper part of the reactor. More detailed experimental investigations were carried out in lab-scale gasifiers. Harris et al. [20] used a 20 bar entrained flow reactor with electrically heated walls to study the influence of O/C ratio, residence time and coal type on fuel conversion and product gas composition. By inserting an oil-cooled probe from the bottom and adjusting the height of the probe, partially reacted char and gas were sampled at variable residence times and temperatures. At the lab scale atmospheric entrained flow gasifier operated at Brigham Young University (BYU) radial profiles of gas phase composition and temperature were measured. Applying a water quench probe for gas and particle sampling the influence of coal type, particle size and operating conditions on fuel conversion, local mixing and reaction processes were investigated [21–23].The experimental data derived from the MHI and BYU gasifiers was used for validation of several simulations [17,18,24–26]. Tremel et al. [27] studied the pyrolysis and gasification behavior of different coal types in the Pressurized High Temperature Entrained Flow Reactor PITER varying pressure, temperature and residence time. Volatile yield was determined applying nitrogen as carrier gas. Fuel conversion was determined under gasification conditions from the gas phase composition measured at the reactor outlet.

For biogenic fuels data exists for laboratory scale downdraft entrained flow gasifiers operated with oxygen, air or steam under atmospheric pressure. Qin et al. [28] and Hernandez et al. [29] both used atmospheric, externally heated entrained flow gasifiers to investigate the influence of operating conditions on fuel conversion of different pulverized biomasses by sampling gas and particles at the reactor outlet. The data from the gasifier operated at Technical University of Denmark (DTU) [28] was used for validation of different simulation models [30,31]. Several studies were concerned with gasification of black liquor. Sricharoenchaikul et al. [32] investigated the gasification characteristics of black liquor in a laboratory scale, laminar entrained flow reactor with heated wall. Syngas taken from the reactor outlet was analyzed by FTIR. Experimental investigation at larger scale was carried out by Carlsson et al. [33] and Weiland et al. [34] using a 3 MW pressurized entrained flow gasifier. Measuring the syngas composition at the reactor outlet, the effect of operating conditions was studied. The