Experimental investigation of coal gasification at very high temperature and pressure

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Abstract

The experimental analysis of gasification reactions at high pressure and high temperature is crucial for the development of reaction models. At TU München the Pressurized High Temperature Entrained Flow Reactor (PiTER) has been developed to provide the opportunity for gasification reaction to be studied at conditions relevant to industrial scale gasifiers. The facility operates at a temperature up to 1800°C and pressure up to 5.0 MPa.

Introduction

The Integrated Gasification Combined Cycle (IGCC) is a key technology for future coal-based power generation. This is due to its high efficiency and the possibility of separating CO₂ from a high pressure fuel gas stream. The first process step in an IGCC is the gasification of coal in an entrained flow gasifier that is operated at temperatures up to 1800 K and pressures up to 3.0 MPa [1]. For the understanding of current and future gasification technologies the knowledge of fundamental coal conversion reactions under relevant process conditions is required [2]. Experimental investigation of specific reaction processes are typically performed under conditions that are very different to those in an industrial gasifier. These studies lead to the development of predictive gasification models. In order to validate the models further experimental work in a realistic gasification environment (similar to that in an industrial gasifier) under controlled conditions is required. In addition to temperature and pressure a defined gas composition is part of controlled experimental conditions. Only models incorporating gasification kinetics within variable levels of CO₂, H₂O, H₂ and CO are directly relevant to gasifier performance evaluations [3].
Pressurized High Temperature Entrained Flow Reactor

At the Technische Universität München the Pressurized High Temperature Entrained Flow Reactor (PiTER) has been built to achieve experimental conditions comparable to industrial entrained flow gasifiers. This experimental facility is part of the research project HotVeGas that deals with high temperature gasification and synthesis gas cleaning for future IGCC technologies. The facility is shown in Figure 1.

The main part of the reactor is a ceramic reaction tube (inner diameter 70 mm, length 2.2 m) that is surrounded by electrical heating elements and a high temperature insulation. The heating unit is situated in a water cooled pressure vessel. The space between reaction tube and pressure vessel containing heater and insulation is flushed by nitrogen. The nitrogen pressure is set slightly above the pressure inside the reaction tube. The pressure control prevents reaction gases from leaving the ceramic tube and reacting with heating elements and/or insulation. The design enables coal gasification to be studied at temperatures up to 1800°C and pressures up to 5.0 MPa.

Before entering the reaction tube a gas mixture containing defined fractions of CO₂, H₂O, CO and H₂ is heated to 1600°C in a pre-heater tube that is situated inside the pressure vessel above the reaction tube. Pulverized coal is injected at the top of the reaction tube through a water cooled inlet. The time that the coal particles spend within the reaction tube can be adjusted by the gas flow velocity to vary in the range from 0.5 to 5 s. At the end of the reaction tube gas and particle samples can be collected using a water-cooled sampling probe. The main gas stream enters a water quench. After the gas is cooled it leaves the reactor through a pressure valve and is burned off in a furnace.

Directly after the reaction tube a part of the gas flow is fed to a cooling line that is connected to the main pressure vessel. The cooling line is not shown in Figure 1. By cooling the reaction gas using a defined temperature profile condensation reactions of ash components (especially alkali compounds) can be analysed.

The focus of the experiments is on pyrolysis, char gasification kinetics and alkali release at very high pressures and temperatures.
Optical measurements at PiTER

The reaction tube is equipped with four optical access levels. Each level consists of three optical ports that are arranged at 90° angles.

![Figure 2: Optical ports at one of the four access levels](image)

An optical port consists of a sapphire disc window. The disc is pressed against the reaction tube by a horizontal ceramic tube that is fixed to the outer pressure vessel. With that design both the optical accessibility and a certain gas proofness of the reaction tube is achieved.

Optical measurement techniques used include:

**Excimer Laser Induced Fluorescence Spectroscopy (ELIF)**
Gaseous alkali compounds are pumped to excited states by a UV laser. Upon relaxing to their ground states electromagnetic radiation is emitted that is characteristic of the alkali compounds. Potassium and sodium are the main analysis targets and measurements are possible down to a few ppm.

**Raman Spectroscopy (Raman)**
A UV laser is used for the excitation of gas molecules. The Raman effect leads to the emission of radiation and the main gas components can be detected over a wide range.

**Fourier Transformation Infrared Spectroscopy (FTIR)**
Due to high temperature the gas molecules are thermally excited. As they relax to their ground states infrared radiation is emitted. By analysing this radiation the concentration of the primary and trace gas compounds can be measured. The measurement technique is enhanced by Fourier Transformation calculations.

**Two-colour Pyrometry (2CP)**
The coal particles emit a characteristic thermal radiation dependent on their temperature. This radiation is collected with a lens system and is focused into an optical fibre. At two defined wavelength measurements are made with a pyrometer. This signal is used to determine the temperature and size of the particles.

The first aim of this project is to adapt the optical measurement systems to the complex geometry of the reactor. Radiation emitted within the reactor tube reaches the outer pressure shell only at small angles. In order to extract the radiation sophisticated lens and fibre systems are required that match the particular wavelength and intensity of the radiation. The particle load within the reaction tube has a negative effect on all optical techniques except the 2CP. Hence, the influence of particles has to be evaluated.

The second aim is to conduct measurements to analyse online and in-situ the gas composition and particle size and temperature within the reaction tube. To validate the optical measurements gas samples will be extracted from the reaction tube by a water cooled probe.
These gas samples will be analysed by external measuring instruments (i.e. gas chromatography, extern IR-spectroscopy) and compared to the in-situ data.

Conclusion

At TU München the PiTER facility is installed to provide the opportunity for the analysis of gasification reaction at very high pressure and temperature. Isothermal conditions within the reaction tube are achieved by an electrical heating unit that enable temperatures up to 1800°C. The reactor is situated within a pressure vessel that is designed for a pressure up to 5.0 MPa. The reaction tube is equipped with optical ports at four levels that enable optical measurements in-situ and on-line. The primarily aims of PiTER are the measurement of kinetic data for coal gasification and the adaption of optical measurement techniques.

Literature

