Investigation of Ammonia Synthesis for Large Scale SCR-Applications by Means of a Hot Gas Test Rig

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Abstract
Selective catalytic reduction (SCR) of nitric oxides will play an important role to fulfil actual TIER III emission limits for ships. In order to apply the SCR-technology successfully to marine engines, further research is needed, especially regarding the synthesis of ammonia from aqueous urea solution. Therefore a hot gas test rig was built up at ITV. The test rig offers a broad optical accessibility allowing various measurement techniques to study injection of urea as well as the occurring chemical reactions. The current work focusses on measuring droplet diameters by PDA as well as by a self-developed direct imaging technique.

Introduction

Selective catalytic reduction (SCR) was originally developed for industrial furnaces [1] and has become an established method to reduce nitric oxide emissions of trucks and heavy diesel cars [2]. In January 2016, the next step of emission standards for marine shipping came into operation (Tier III) [3]. Also in this field, SCR will play an important role to fulfil the limits for nitric oxides, as they have decreased to approximately 25% of the former values. Applying the SCR technology to ship engines requires further research and detailed development of such large scale systems. Especially the synthesis of ammonia from aqueous urea solution has to be studied in detail. Therefore, a hot gas test rig was built up at ITV, which is the basis for comprehensive investigations of the urea decomposition. All measurement activities can be divided in the characterisation of the spray process and the investigation of the occurring chemical reactions. The present work presents the hot gas test rig as well as first measurements of droplet spectra by phase-Doppler anemometry (PDA) and direct droplet imaging.

Selective catalytic reduction

SCR is a way to reduce nitric oxides by means of a catalyst and reducing agent, typically ammonia (NH_3). As the reduction is selective, nitric oxides can be removed from gases with excess oxygen. Thus the method is particularly suitable for diesel engines. The Ammonia is provided from aqueous urea solution, which is safer to be stored especially for automotive applications. The urea solution is sprayed into the hot exhaust gas where the water evaporates from the droplets first [2]. The remaining urea is decomposed into ammonia and isocyanic acid (HNCO). HNCO reacts with water and forms ammonia and carbon dioxide.

Thermolysis:
$$(NH_2)_2CO \rightarrow NH_3 + HNCO \quad (1)$$

Hydrolysis:
$$HNCO + H_2O \rightarrow NH_3 + CO_2 \quad (2)$$

The three steps, evaporation, thermolysis and hydrolysis are crucially important and have to be designed in order to have evenly distributed ammonia supply to the catalyst and to prevent unwanted wall interactions which can lead to deposits.

Hot gas test rig

The hot gas test rig consists of tube elements with an inner diameter of approximately 300 mm. It offers the possibility to investigate the whole process chain of ammonia synthesis by a broad optical accessibility. The test rig is unitized in order to achieve maximum flexibility. The sketch of the test rig is shown in Figure 1.

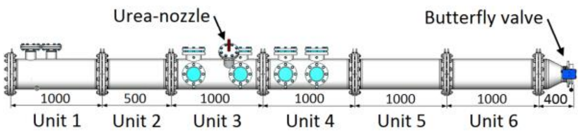

Figure 1: Sketch of unitized hot gas test rig

The first unit contains an oil burner, which provides a hot gas flow up to a temperature of 500°C. The desired operating points, consisting of temperature and gas velocity, are achieved by tuning thermal output of the burner together with secondary air mass flow. Due to this combination, the thermal power output has to cover a range of 1:10, which is achieved without hardware changes in the burner setup. The hot air passes a flow straightener (unit 2) before the actual measurement section start with unit 3. This unit includes the urea nozzle, which currently is a two fluid nozzle. The unit has two measurements planes, which consist of a set of three optical windows. Two windows are facing each other with the third one perpendicular to them. One measurement plane is upstream the nozzle in order to measure the flow field e.g. as boundary condition for numerical simulations. The second plane allows observing the near field of the nozzle. Unit 4 contains two sets of measurement planes as well. This unit can be placed instead of the blind units 5 and 6, which yields further measurement positions shown in Figure 2.

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