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The effect of a H_2/CO mixture at varying ratios on the diesel particulate filter regeneration process: Towards an optimised fuel reformer design – Diesel engine aftertreatment system

S. Hemmings*[,1], A. Megaritis[2]

School of Engineering and Design, Brunel University, Kingston Lane, Uxbridge, Middlesex UB8 3PH, United Kingdom

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ABSTRACT

The work described in this paper aims to assist in the development of an exhaust gas fuel reformer for the enhancement of diesel particulate filter (DPF) aftertreatment performance. This was achieved by introducing H_2 and CO at various mixture ratios at a concentration of 6% (v/v) to a standardised DPF regeneration process in order to identify an optimised mixture ratio. In addition to this, emission measurements were performed pre and post filter to identify the impact of the additional mixtures on various emission components. A mixture ratio of 60% H_2 balanced with CO was identified as the optimised mixture ratio. This was due to this configuration demonstrating one of the most proficient regeneration profiles at a relatively low mean filter temperature of approximately 630 °C. Further to this, it was also noted that the addition of H_2 or H_2 and CO to the regeneration process resulted in an increase in NOx post filter while total hydrocarbons were reduced. Furthermore, the H_2/CO mixture addition resulted in an increase in CO_2 post filter, the levels of which were proportional to the volume of CO contained within the introduced mixture.

1. Introduction

Past research has demonstrated that the use of hydrogen as a dual fuel for a diesel engine can provide beneficial effects on both engine performance and emissions [1–3]. However, the addition of hydrogen can also significantly enhance the performance of a number of diesel aftertreatment devices when applied directly including; catalytic converters, diesel particulate filters and NOx traps [4–6]. These factors have led to the development of the Exhaust Gas Fuel Reforming process, a technique that allows for production of hydrogen rich reformate ‘on board’ the vehicle.

During the exhaust gas fuel reforming process, diesel fuel is reformed catalytically when directly contacted with oxygen and steam already present in the exhaust gas. As a result hydrogen rich reformate is produced. The volume of hydrogen produced when using this method is dependent upon the rate of the steam, oxygen and fuel as well as the exhaust gas temperature. As a result, the operating conditions of the engine greatly influence the H_2 production [7,8].

During the reforming process, a number of reactions occur consecutively at different stages along the catalyst. These include oxidation, partial oxidation, steam reforming, dry reforming and water gas shift. The first reaction, oxidation, occurs at the initial section of the catalyst bed. This process generates water that can then be used to form H_2 via steam reforming (equation (3)). Partial oxidation between diesel and

* Corresponding author. Tel.: +44 (0) 7599104751; fax: +44 (0) 1923 492440.
E-mail addresses: stephen.hemmings@brunel.ac.uk (S. Hemmings), thanos.megaritis@brunel.ac.uk (A. Megaritis).
[1] 80 Hillcroft Crescent, Oxhey, Watford, Hertfordshire WD19 4NY, United Kingdom.
[2] Room H120, Brunel University, Uxbridge UB8 3PH, United Kingdom.

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oxygen can also occur on the catalyst bed. This exothermic reaction produces H_2 directly [8].

$$\text{Oxidation}: C_nH_{1.88n} + 1.47_nO_2 \rightarrow {}_nCO_2 + 0.94_nH_2O \quad (1)$$

$$\text{Partial oxidation}: C_nH_{1.88n} + 1/2O_2 \rightarrow {}_nCO + 0.94_nH_2 \quad (2)$$

$$\text{Steam reforming}: C_nH_{1.88n} + {}_nH_2O \rightarrow {}_nCO + 1.94_nH_2 \quad (3)$$

where n is the number of carbon atoms in the fuel molecule.

It is apparent from both the steam reforming and partial oxidation formulae that CO is formed as a by-product during H_2 production. However, if the CO content is sufficient it can be utilised to form both CO_2 and further additional H_2 (see equation (4)). This is recognised as the water gas shift [4].

$$\text{Water gas shift}: CO + H_2O \rightarrow CO_2 + H_2 \quad (4)$$

The previously mentioned dry reforming reaction refers to an endothermic reaction between the diesel fuel and CO_2. When exposed to temperatures in excess of 800 °C, such a reaction can also produce additional H_2.

It is evident from these reactions that an exhaust gas fuel reformer can generate both H_2 and CO. For a number of after-treatment systems, both species can be adopted to enhance the performance of that system. Past research into the development of selective catalyst reduction (SCR) systems has identified that, with the addition of H_2 to the feed gas, hydrocarbon reduction can occur at lower exhaust gas temperatures. However, to obtain these benefits a small concentration of CO must also be introduced to the gas feed [9].

The impact of H_2/CO mixture addition on the DPF regeneration process has been researched previously, at a mixture ratio of 60% H_2 (v/v) balanced with CO [10]. The primary objective of this study is to take this further by identifying an optimised H_2/CO mixture ratio, achieved by varying the mixture ratio incrementally and analysing the resultant impact on filter temperature and both regeneration rate and quality.

The secondary aim of this research is to adopt Fourier transform infrared spectroscopy (FTIR) emission measurement methodology to identify the impact of introducing various mixture ratios on the chemical composition of the exhaust gas post filter. Due to the FTIR measurement technique having the capability to continually measure the concentration of any gas compound that absorbs infrared, this technique allows for the behaviour of many nonlegislated exhaust gas components to be easily quantified. As a result of this characteristic and a variety of other continuous improvements, the application of FTIR technology has increased significantly within the automotive industry and is now routinely adopted for measurement of both legislated and nonlegislated exhaust gas components [11–16].

2. Experimental setup and test procedure

2.1. *Testing rig*

Fig. 1 demonstrates the test rig adopted throughout testing. The engine used was a Ford 'Puma' which featured

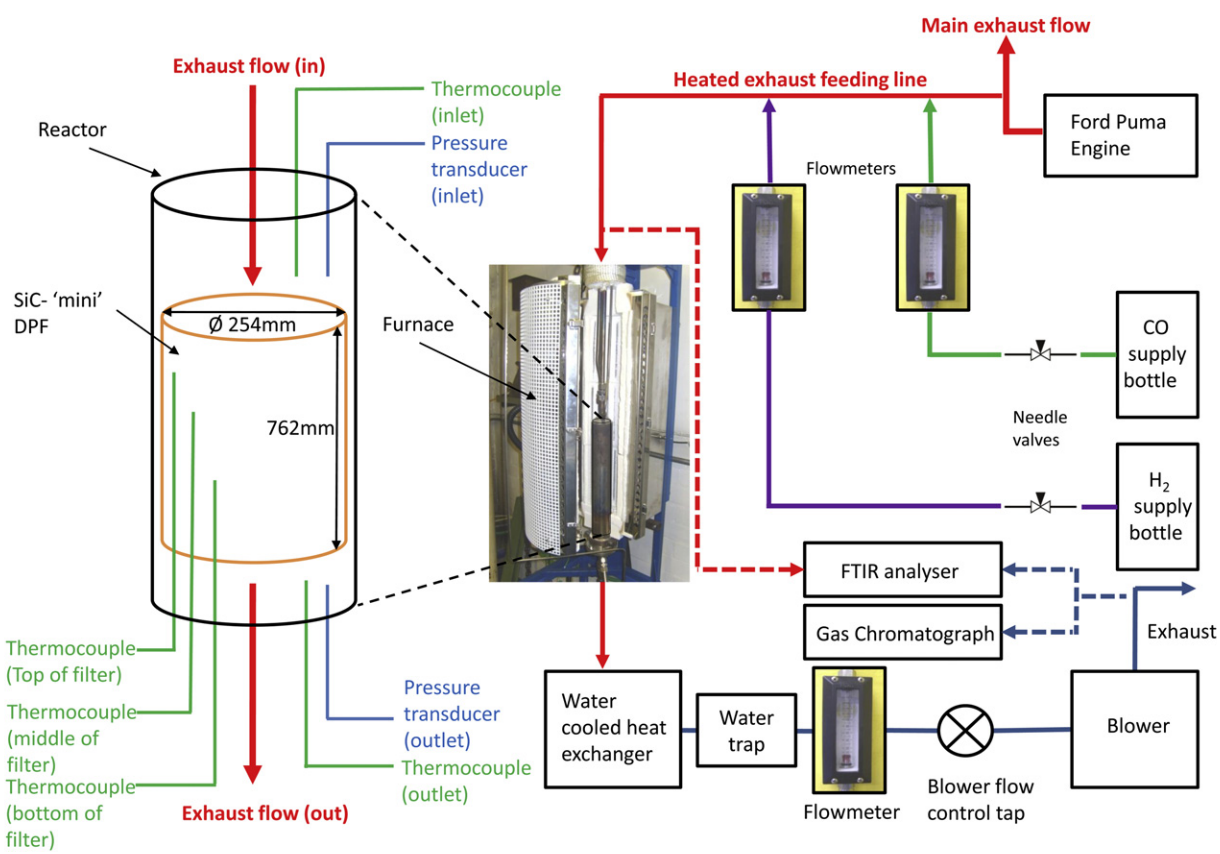

Fig. 1 – Diesel particulate filter testing rig.