AFTERTREATMENT SYSTEMS AND METHODS FOR TREATMENT OF EXHAUST GAS FROM DIESEL ENGINE [1]

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United States Patent No.: US 10,690,033B1, June 23, 2020, [1]**Department of Mechanical Engineering - Engineering Engineering Mechanics, Michigan Technological University**

Abstract

An aftertreatment system to treat exhaust gas from a diesel engine is provided. The aftertreatment system comprises a selective catalytic reduction catalyst on a diesel particulate filter (SCR-F); a first reductant injector connected to an exhaust gas passage upstream of the SCR-F; a downstream diesel oxidation catalyst (DOC) disposed downstream of the SCR-F; a selective catalyst reduction catalyst (SCR) disposed downstream of the downstream DOC; a second reductant injector coupled to an exhaust gas passage positioned between the downstream DOC and the SCR; and a controller to determine a desired particulate matter (PM) oxidation in the SCR-F and a desired system NO_x conversion based on engine conditions, and to control a first reductant flowrate from the first reductant injector and a second reductant flowrate from the second reductant injector based on the desired PM oxidation in the SCR-F and the desired system NO_x conversion.

Introduction

Selective catalytic reduction (SCR) technology has been used to reduce NO_x emissions from heavy-duty engines. The ultra-low NO_x emission standard for the heavy-duty diesel engine has been proposed by the California Air Resources Board (CARB). To meet the stringent regulatory NO_x emission standards for heavy-duty diesel truck engines, an ultra-low aftertreatment system needs to be developed. For example, an aftertreatment system has been studied that includes an upstream diesel oxidation catalyst (DOC), a selective catalytic reduction catalyst on a diesel particulate filter (SCR-F) and a selective catalyst reduction catalyst (SCR). The major factors that limit the performance of such aftertreatment system in terms of NO_x reduction are catalyst aging in the SCR-F, ash loading in the SCR-F, transport of the platinum group metals (PGM) from the upstream diesel oxidation catalyst (DOC) to the SCR-F and unfavorable NO_2 /NO_x ratio to the inlet at the downstream SCR, which can lead to reduction of the NO_x conversion of the downstream SCR and the system. Thus, there is need to improve the aftertreatment system such that the NO_x emission standards can be met at various engine operating conditions such as at cold start and hot conditions and the particulate matter (PM) oxidation rate in the SCR-F also needs to be increased at various engine operating conditions.

Aftertreatment System Description

Figure 1 shows the proposed system consisting of DOC, SCR-F, DOC_2, downstream SCR, AMOX and two urea injectors. For this system due to the addition of a second injector, the total urea flow rate is divided into components ANR_1 and ANR_2 which represents the ANR values at the two injectors. This system increases the NO_x conversion and the PM oxidation rate over the SCR-F system alone by leveraging the control system which determines the ANR_1 and ANR_2 based on NO_x conversion and PM oxidation rate targets. The downstream DOC_2 maintains a NO_2/NO_x ratio of 0.4-0.5 at SCR inlet for all engine conditions. Figure 2 shows the increase in NO_2/NO_x ratio at the SCR inlet due to the NO oxidation reaction in DOC_2. The resultant higher downstream SCR performance is used to develop an optimum control strategy for the two urea injectors in the system resulting in high NO_x conversion performance and high PM oxidation rate shown in Figure 3. The control system and results from Figure 2 and 3 are part of the research from [2][3][4].

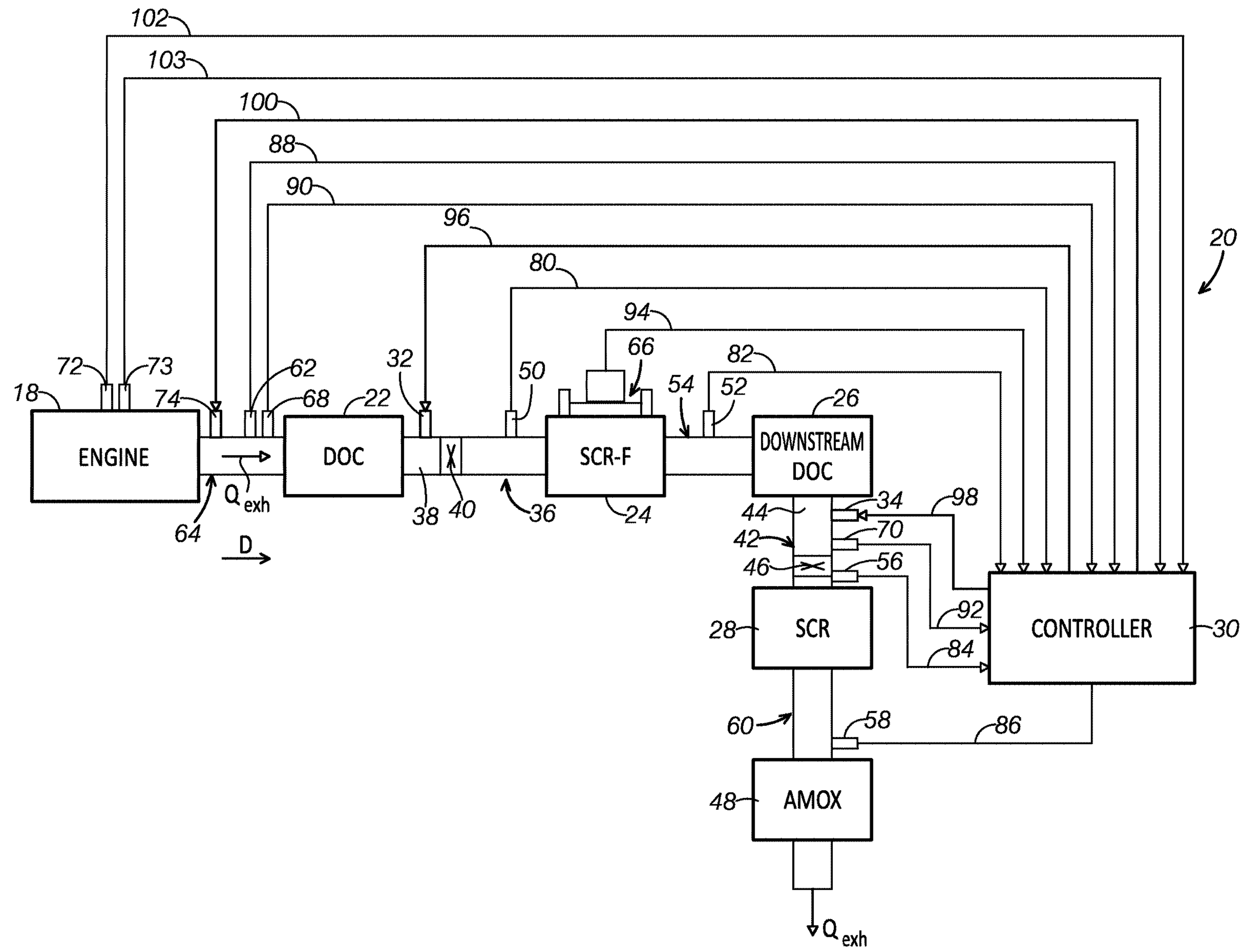

Figure 1. Aftertreatment system with SCR-F, a downstream DOC_2, SCR and two urea injectors

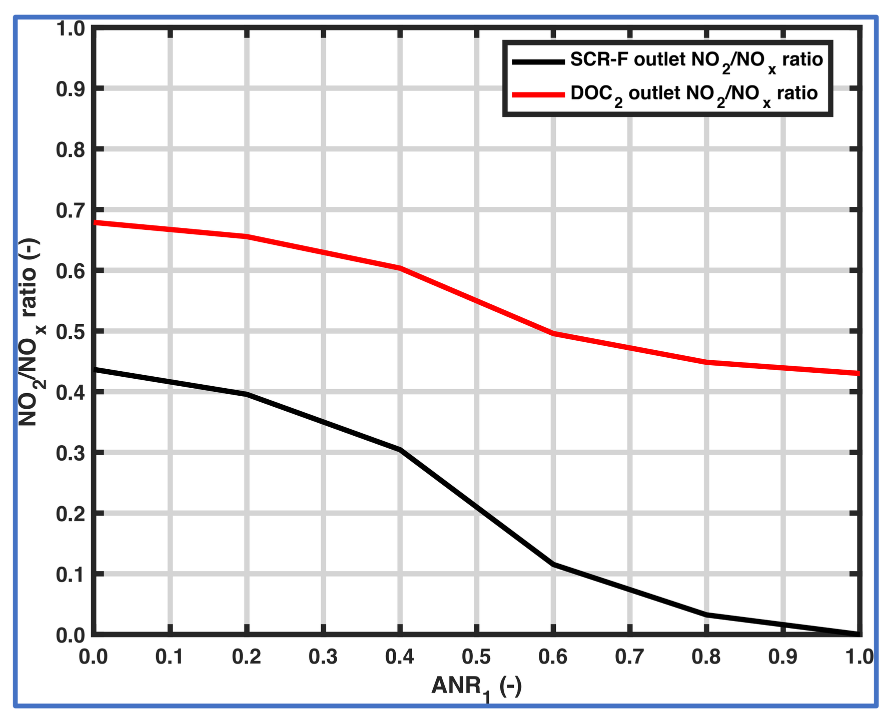

Figure 2. NO_2/NO_x ratio vs ANR_1 at engine condition C (SCR-F+DOC_2+SCR with 2 urea injectors)

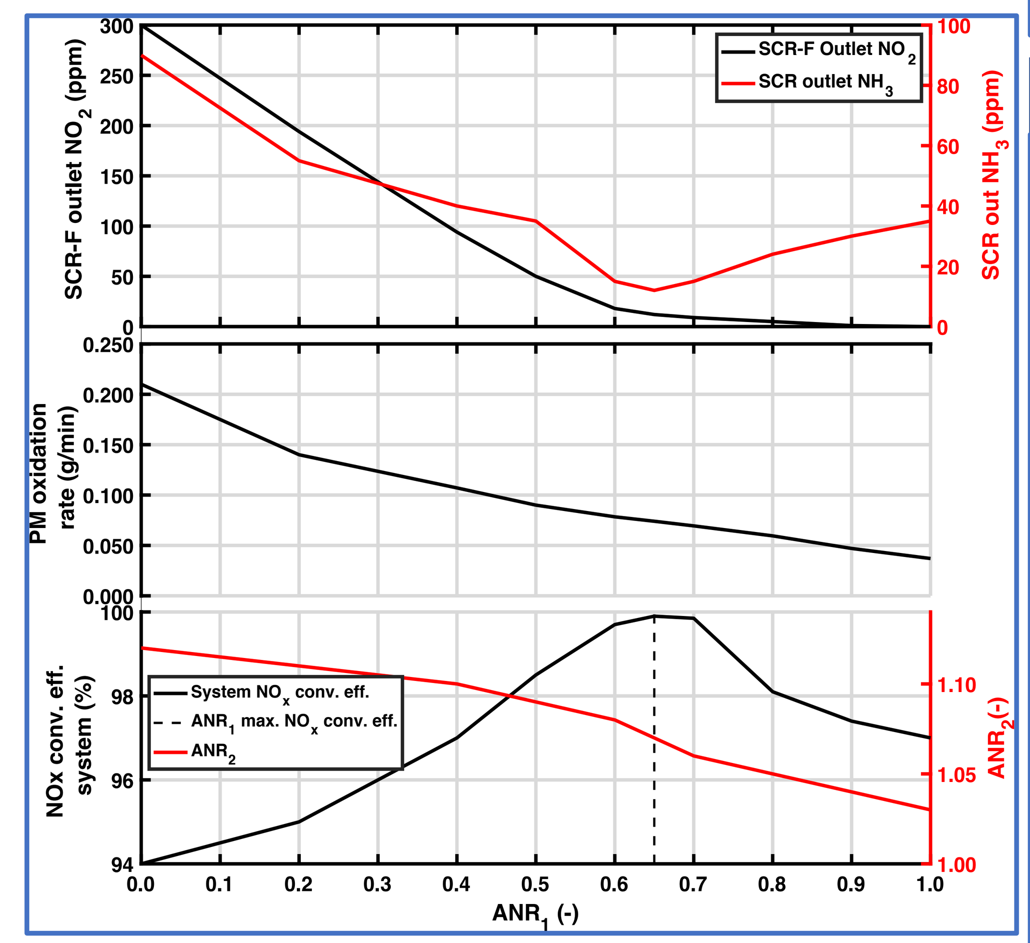

Figure 3. NO_x conversion efficiency, ANR_2 , PM oxidation rate, SCR-F outlet NO_2 and SCR outlet NH_3 concentration vs ANR_1 at engine condition C (SCR-F+DOC_2+SCR with 2 urea injectors)

Advantages of the System

The different embodiments and examples of the aftertreatment system for a diesel engine and the method to control or operate the aftertreatment system described herein provide several advantages over known solutions for improve PM oxidation rate and the system NO_x conversion efficiency. For example, illustrative embodiments and examples described herein includes a DOC which is directly upstream of a SCR. 60 The inclusion of this DOC increases local NO_2/NO_x ratio to optimum values (e.g., NO_2/NO_x ratio of 0.5) at the downstream SCR, which leads to higher fast SCR reactions and thus greater than 99.5% system *NOx* conversion efficiency. The downstream SCR performance in this system is increased by 30 -60% depending on engine operation conditions. Additionally, and among other benefits, illustrative embodiments and examples described herein allow better control of inlet ANR_I for the SCR-F and ANR_2 for the SCR, which lead to accurate control of NH3 coverage fraction in both the SCR-F and the SCR.

Patent Claims

What is claimed is: 1. An aftertreatment system to treat exhaust gas from a diesel engine, comprising: a selective catalytic reduction catalyst on a diesel particulate filter (SCR-F);a first reductant injector connected to an exhaust gas passage upstream of the SCR-F; a downstream diesel oxidation catalyst (DOC) disposed downstream of the SCR-F; a selective catalytic reduction catalyst (SCR) disposed downstream of the downstream DOC; a second reductant injector coupled to an exhaust gas passage positioned between the downstream DOC and the SCR;
a controller to determine a desired particulate matter (PM) oxidation rate in the SCR-F and a desired system NOx conversion based on engine conditions, and to control a first reductant flowrate from the first reductant injector and a second reductant flowrate from the second reductant injector based on the desired PM oxidation rate in the SCR-F and the desired system NOx conversion; 2. ….18

Conclusions

The advantages of the SCR-F+DOC_2+SCR system components (2 injectors) are:

1) The proposed system has a 99.2 to 99.9 % NO_x conversion efficiency as for all the engine conditions
2) The proposed system has a 0.013 to 0.070 g/min PM oxidation rate as compared to 0.005 to 0.040 g/min for the SCR-F only for all the engine conditions
3) The SCR-F+DOC_2+SCR system components enables 3 - 4 times higher PM oxidation rate as compared to the SCR-F system when ANR_1 = 0 which is used in engine conditions where a higher PM oxidation rate and 91 - 95% NOx conversion efficiency is desirable.
4) The tradeoff between PM oxidation rate and NO_x conversion efficiency can be determined by the control algorithm in the SCR-F+DOC_2+SCR system, which can operate over a limited range of ANR_1 (0.72+/-0.08) and ANR_2 (1.04+/-0.02) conditions without a loss in NO_x conversion efficiency and PM oxidation.
5) Aftertreatment systems inline with this system without the DOC after the SCR-F are being considered for light duty diesel applications by BMW [5], VW [6] and Eaton [7]

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