Novel Ultra-low NO_x Aftertreatment System

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(US Patent 10,690,033 B1)

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System Overview:

Based on research performed at Michigan Technological University Heavy Duty Diesel Engine Aftertreatment Consortium we have developed an aftertreatment system that is capable of achieving the proposed ultra-low NOx standard being proposed by the CARB. This particular system consists of a novel combination of a SCR catalyst on a DPF (Diesel Particulate Filter), DOC (Diesel Oxidation Catalyst) and SCR (Selective catalytic reduction) as shown in Figure 1. We would like to propose this system as a possible approach to achieve the Ultra-low NO_x standard being proposed by CARB for heavy duty diesel engines in the 2027 regulation.

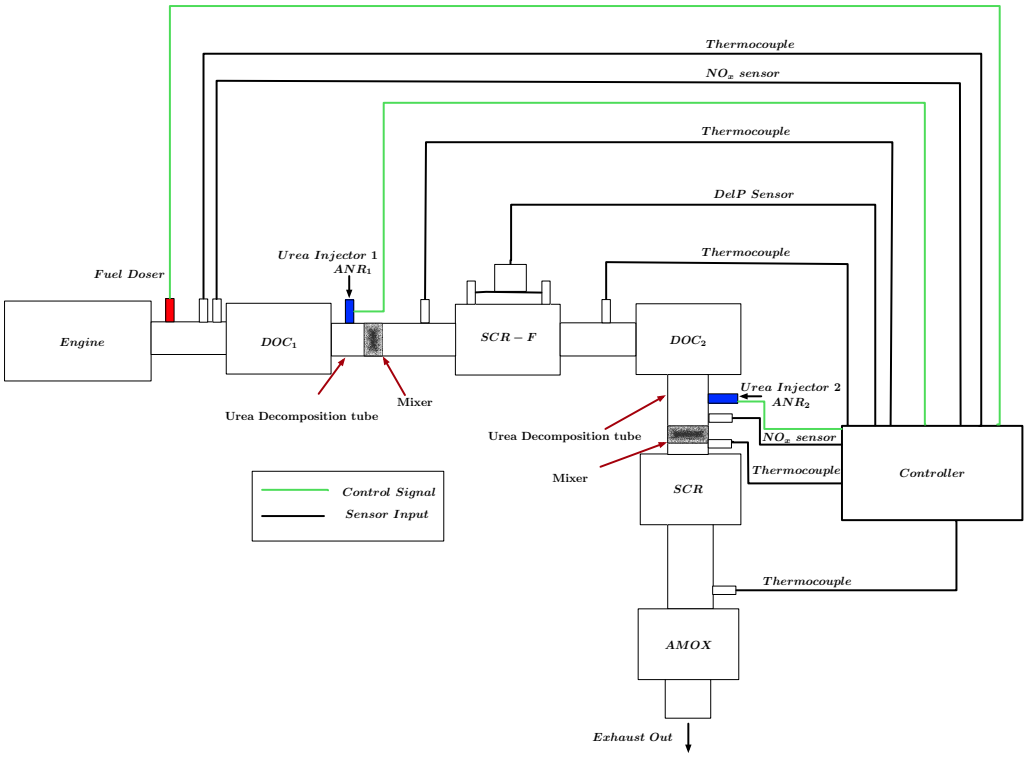

Figure 1 Proposed aftertreatment system with a SCR-F, a downstream DOC_2 and a SCR with two injectors

The system in Figure 1 consists of a DOC, SCR-F, DOC_2 downstream of the SCR-F, SCR and ASC, along with two urea injectors and urea decomposition tubes. The addition of DOC_2 downstream of the SCR-F enables oxidation of the SCR-F outlet NO to NO_2 in order to increase the NO_x conversion efficiency of the SCR and the overall NO_x conversion efficiency of the system. The system in Figure 1 consists of a DOC_2 downstream of the SCR-F along with the two urea injectors and urea decomposition tubes to overcome all the deficiencies of the SCR-F only and the SCR-F+SCR system. The novel aspect of this system is the addition of the DOC_2 downstream of the SCR-F to oxidize the NO to NO_2 at the SCR-F outlet in order to increase the NO_x conversion efficiency of the SCR and the overall NO_x conversion efficiency of the system and to increase the SCR-F passive PM oxidation rate compared to the SCR-F only and the SCR-F+SCR systems.

The system leverages the higher contribution of fast SCR reaction in the downstream SCR by maintaining an optimum NO_2/NO_x ratio = 0.5 at the downstream SCR inlet using the NO oxidation reaction in the DOC_2. This leads to higher NO_x conversion in the SCR which enables the system to attain maximum NO_x conversion efficiency. Using this higher downstream SCR NO_x conversion rate, the system is capable of achieving > 99.5% overall NO_x conversion at T > 200°C as described in references [1, 2]. The addition of the second urea injector allows control of both the SCR-F and SCR's NH_3 storage to purposely decrease NO_x conversion in the SCR-F while enhancing its passive PM oxidation functions while the SCR removes the remaining NO_x from the exhaust gas. This leads to a reduction in urea consumption, higher NO_x conversion efficiency at all temperatures and flow rates, reduced NH_3 slip and reduced PM retained over the SCR-F only system. This particular system was recently granted US Patent 10,690,033 B1, June 23, 2020 [3]. The system in Figure 1 can also be coupled with a dCSC™ [4, 5] upstream of the SCR-F instead of the DOC to enable NO_x storage during cold start resulting in lower NO_x emissions for the entire Federal Test Procedure (FTP). Such a setup would make it easier to meet the future California ultra-low NO_x standards. Figure 2 shows the setup with a dCSC™ [4, 5]. The system performance was evaluated based on simulation performed on steady state engine tests described in reference [6, 7] and models described in references [8, 9, 10].

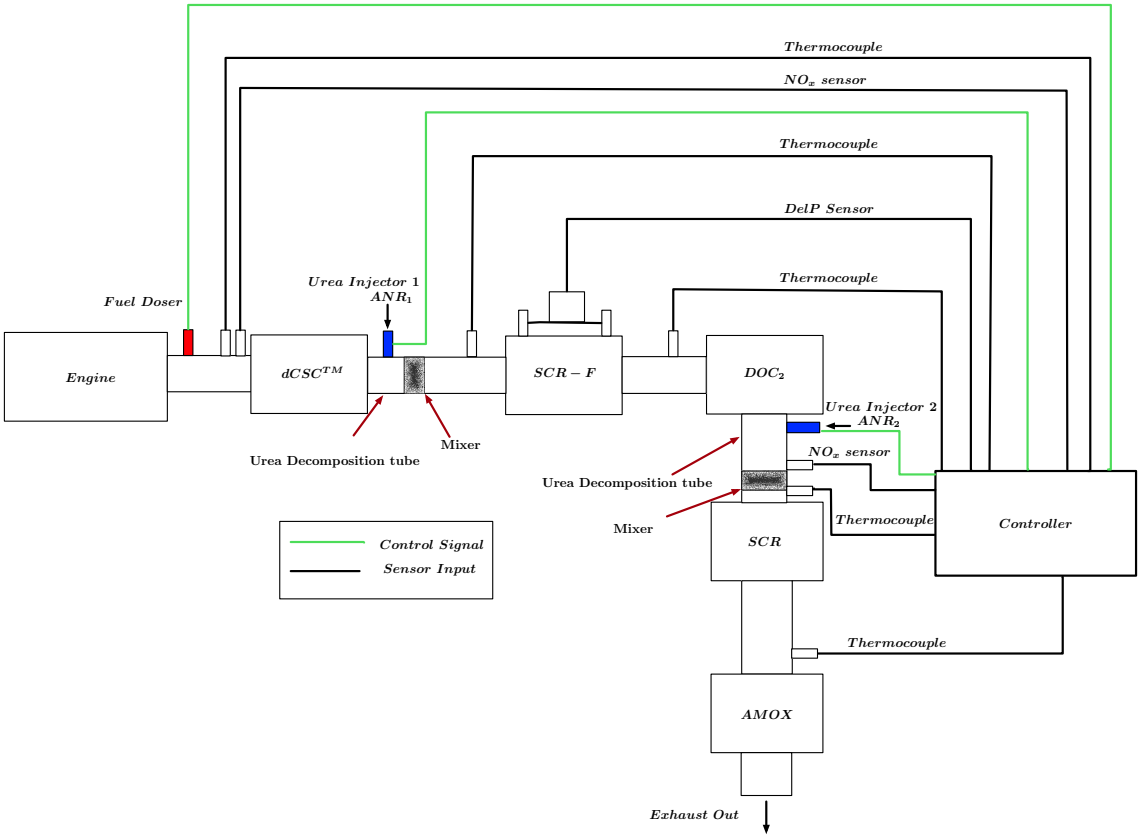

Figure 2 Aftertreatment system with dCSC™, SCR-F, downstream DOC_2 and SCR with two injectors

Benefits of the System:

The proposed system has following advantages:

1) The proposed system has a 99.2 to 99.9 % NO_x conversion efficiency for exhaust gas temperatures > 200°C

2) The proposed system is capable of 3-4 times higher PM oxidation compared to SCR-F only system for typical engine operating conditions

3) The proposed system has better controllability due to precise control of NO_2/NO_x ratio for the downstream SCR enabling real world driving emissions (RDE) compliance

Further Development:

Systems with SCR-F + SCR with two urea injectors are being developed for light duty applications as described in references [11, 12, 13]. These systems primarily consist of SCR-F + SCR systems with kinetics-based models for accurate control of NO_x conversion performance of SCR-F and SCR. Figure 3 from reference [] shows a typical system being developed for light duty applications. This system can be further improved using the DOC_2 being proposed in this work.

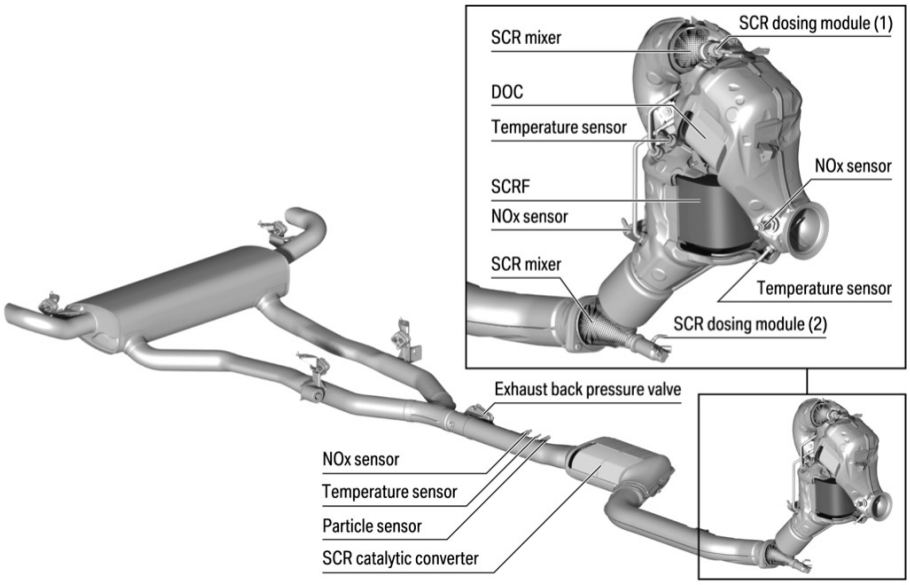

Figure 3 Exhaust system of the revised 6-cylinder diesel engines (example X5) [13]

Based on these advantages we believe this system would be a good candidate that can be developed to meet the heavy duty ultra-low NO_x standards through further development and system optimization. Unlike the light duty this system requires extensive development for heavy duty applications which can act as an alternate pathway to achieving the Ultra-Low NO_x standard based on a SCR-F based system in place of the existing catalyzed particulate filter (CPF) based system. This development for heavy duty system could be funded by government organizations since the industry is focused on CPF based systems. Further details about the system are described in the SAE Journal [1] and Patent [3] enclosed with this document.

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