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Effect of static mixer geometry on flow mixing and pressure drop in marine SCR applications

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ABSTRACT: *Flow mixing and pressure drop characteristics for marine selective catalytic reduction applications were investigated numerically to develop an efficient static mixer. Two different mixers, line- and swirl-type, were considered. The effect of vane angles on the relative intensity, uniformity index, and pressure drop was investigated in a swirl-type mixer; these parameters are dramatically affected by the mixer geometry. The presence of a mixer, regardless of the mixer type, led to an improvement of approximately 20% in the mixing performance behind the mixer in comparison to not having a mixer. In particular, there was a tradeoff relationship between the uniformity and the pressure drop. Considering the mixing performance and the pressure drop, the swirl-type mixer was more suitable than the line-type mixer in this study.*

KEY WORDS: Selective catalytic reduction; Static mixer; Uniformity index; Pressure drop; Marine diesel engine.

INTODUCTION

In order to meet stringent future emission regulations from the environmental protection agency (EPA), especially with respect to reducing nitrogen oxides (NO_x), various technologies such as basic internal engine modifications, fuel switching, direct water injection, exhaust gas recirculation (EGR), and selective catalytic reduction (SCR) have been recommended for marine diesel engines. The international maritime organization (IMO) has regulated NO_x emissions from marine vessels. The IMO's Tier III standard requires that marine vessels must reduce NO_x emissions by 80% between 2010 and 2016 (DieselNet, 2008). SCR is one of the most promising technologies for accomplishing this aggressive regulation. As a reducing agent, urea is preferred in marine SCR applications because of its safety and low toxicity. Urea water solution (UWS), containing 32.5*wt%* urea, is injected into the hot gas stream from exhaust manifolds, and then, NH_3 is generated by dewatering, thermolysis, and hydrolysis processes. The urea-SCR reactor should be controlled to ensure high de-NO_x performance, low NH_3 slip, and low urea consumption. To maximize the de-NO_x efficiency and minimize the NH_3 slip, a controlled turbulent mixing process for two-phase flow, such as UWS with the exhaust gas stream, and a highly uniform flow in front of the SCR reactor must be obtained.

Flow mixing is a common device unit operation in a large number of processes, and it is used in many different applications

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where a defined degree of homogeneity of a fluid is desired (Regner et al., 2006). In particular, a mixing device, e.g., a static mixer is usually installed to improve the rate of decomposition for urea to NH_3 and to enhance the uniformity of the spatial distribution of NH_3 and isocyanic acid (HNCO) (Munnannur and Liu, 2010). However, the increase in the system pressure drop because of mixing must be minimized.

There have been many attempts to develop static mixers for mobile SCR applications, and computational fluid dynamics (CFD) has been widely used in the design optimization of spray nozzles, flow mixing characteristics, NO_x reduction processes, and urea decomposition (Thakur et al., 2003; Zheng et al., 2009; Zheng et al., 2010; Zhang et al., 2006; Zhang and Romzek, 2007; Birkhold et al., 2007; Nguyen et al., 2010; Larmi and Tiainen, 2003; Chen and Williams, 2005; Battoei et al., 2006). Thakur et al. (2003) provided an extensive review of static mixers in the processing industry, presenting guidelines for the selection of static mixers. Zheng et al. (2009) developed several types of mixers, including cone, 2-stage, and butterfly mixers. They also investigated the effect of in-pipe mixing devices on urea deposits with respect to mixer configurations and various exhaust gas temperatures. Zhang et al. (2006) introduced a simple flow mixer with twisted blades based on an original delta wing mixer for the purpose of creating both swirling and turbulent flows. Turbulent flow has a dominant effect on the flow mixing index or uniformity index in the short distance immediately behind the flow mixer (Zhang et al., 2006; Zhang and Romzek, 2007).

In allowing a sufficient mixing length by reducing the occupied space, it is necessary to develop a proper static mixer with a high mixing performance as well as a low pressure drop. However, there is insufficient research on the relationship between flow mixing characteristics and pressure drops in the marine engine fields.

In this study, both line- and swirl-type mixers were considered; each mixer was divided into three cases of vane angles: 30º, 45º, and 60º. The effects of a mixer's geometric structure on the flow mixing characteristics and the resulting pressure drop were investigated numerically using a commercial finite volume, three-dimensional (3-D) CFD code; FLUENT (version 6.3.26). The purpose of this study was to evaluate the effect of mixer geometry on the relative intensity, uniformity index, and pressure drop with the objective of enhancing the de-NO_x efficiency. Additionally, information pertaining to the selection of proper static mixers was provided based on the correlation between the uniformity index and the pressure drop.

NUMERICAL METHODS AND CONDITIONS

Analysis model

The geometry of the SCR system, which includes the position of the spray injector, mixer, SCR reactor, and measuring points, is shown in Fig. 1. Line-type and swirl-type mixers, as shown in Fig. 2, have 36 vanes each. A swirl-type mixer was developed in this study with several unique features: a simple design for production; a variable vane angle to generate different swirl flows; and the flexibility for installation and to control the mixer volume in the pipe. Both types of mixers with various vane angles were simulated in 3-D to investigate the flow pattern, turbulence characteristics, and uniformity of water, which is assumed to be UWS at the SCR catalyst entrance.

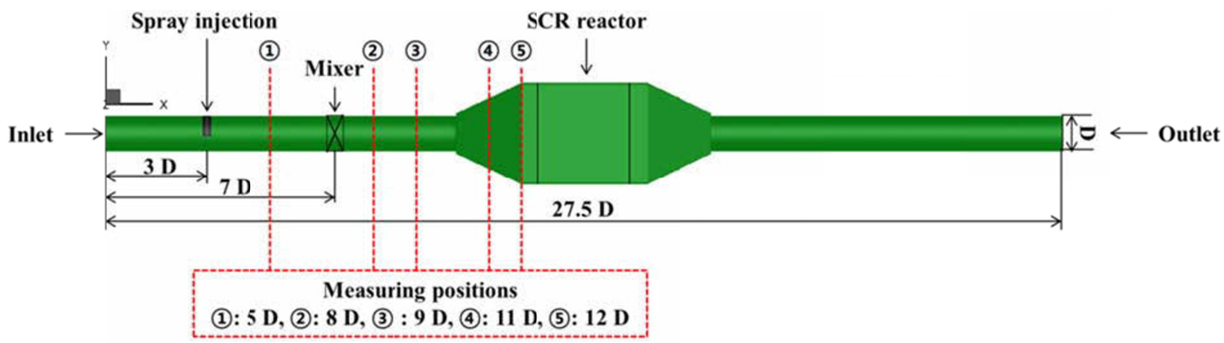

Fig. 1 Computational domain for the SCR system.

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