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Numerical evaluation of urea-mixing devices for the future selective catalytic reduction systems

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INTRODUCTION

Selective catalytic reduction (SCR) is an efficient and promising method for nitrogen oxides (NOx) reduction in flue gas from Diesel engines. The urea-water solution (UWS) is injected before the SCR and it converts to, among others, ammonia (NH_3). Ammonia is used to neutralise nitrogen oxides. **The proper work of SCR systems depends on the droplets' mixing with the exhaust gas**, which influences the uniformity of UWS droplets and ammonia entering the SCR catalyst. **A proper mixing performance under diverse conditions** is difficult to achieve; however, it is crucial for efficient work in a wide operating range. **Elongation of the droplets' residence time** is also important as it **enhances chemical UWS decomposition**. Moreover, downsizing of the urea-SCR system's volume enables the mitigation of the heat losses reducing solid deposits. Nonetheless, the small system's volume increases the risk of liquid film occurrence, and thus the risk of solid deposits.

OBJECTIVES OF THE RESEARCH

This research presents the numerical comparison of existing and conceptual urea-mixing systems used in urea-water solution-based selective catalytic reduction. The analysis was aimed at the assessment of urea-mixing devices that could considerably enhance the reduction of nitrogen oxides from the Diesel-engine combustion process under a wide range of operating conditions, including cold starts.

Numerical cases

- Gas mass flow rates:
  - 300 kg/h (**OP1**),
  - 150 kg/h (**OP2**),
- Gas temperature: 400 °C,
- NOx concentration: 150 ppm,
- Stoichiometric UWS dosing,
- Outlet gauge pressure: 0.1 bar.

METHODS

- Mixing performance evaluated by an averaged NH_3 uniformity index (UI_{NH3}) near the SDPF's inlet,
- Mixer's total pressure drops (Δp_{mixer}) investigated,
- Numerical simulations performed in the AVL FIRE™,
- Discrete droplet model (DDM) for spray representation,
- Birkhold's UWS decomposition model.

RESULTS

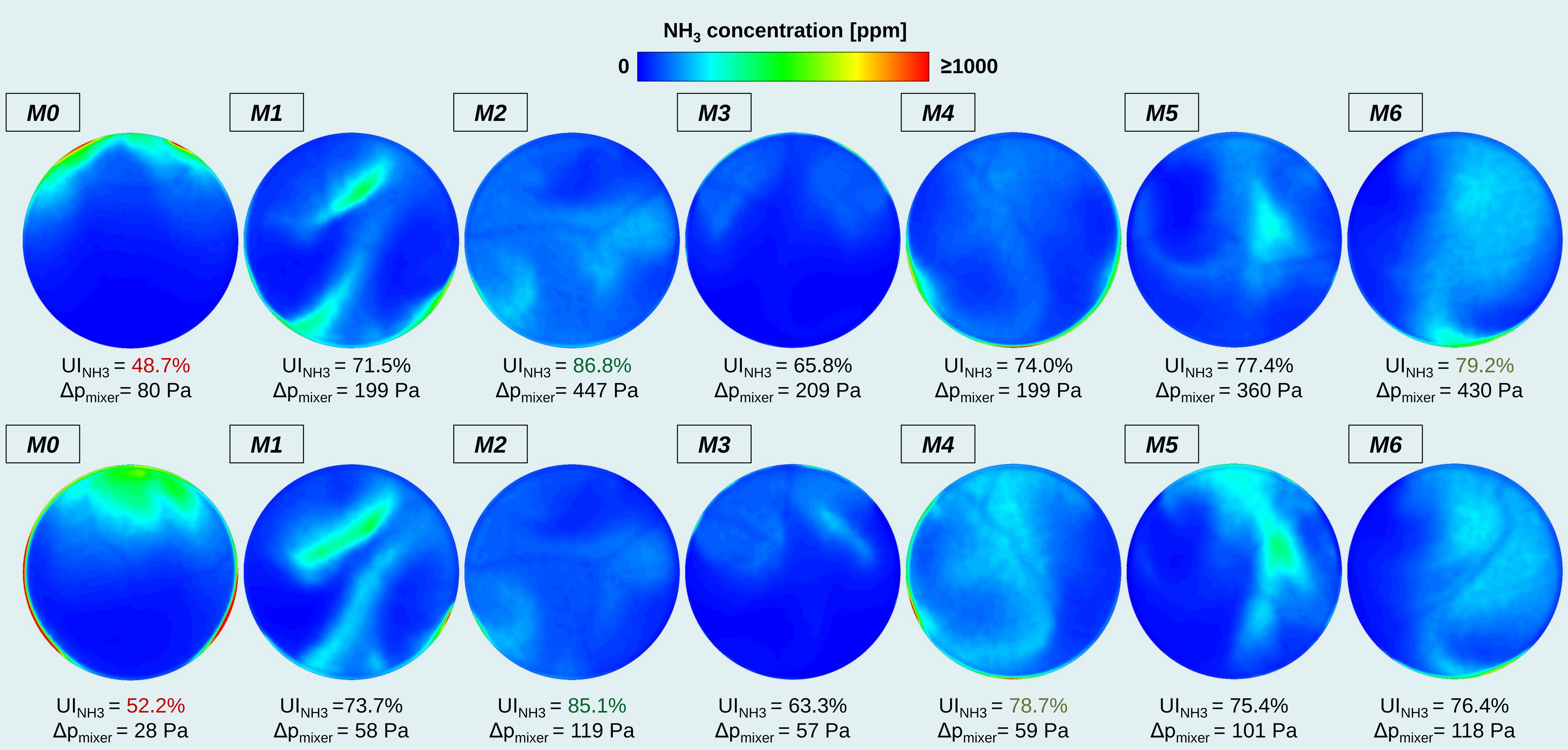

Fig. 8. The distribution of ammonia registered approximately 10 mm after the SDPF's inlet; **OP1** and **OP2** (respectively upper and bottom row); index of averaged NH_3 uniformity after four injections and the mixer's total pressure drops are presented below the graphs

UREA-SCR SYSTEMS

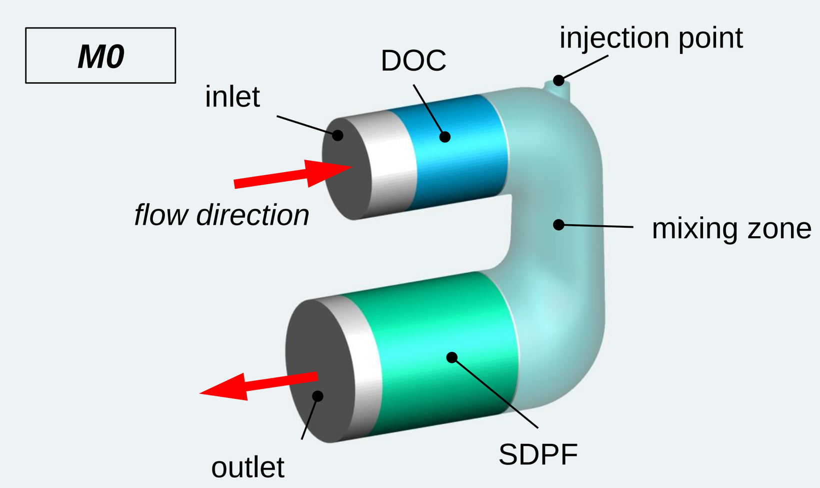

Fig. 1. The basic closed-coupled SCR system

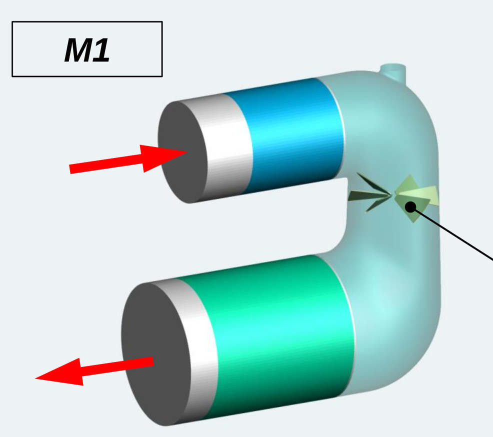

Fig. 2. The SCR system with a single **blade mixer**

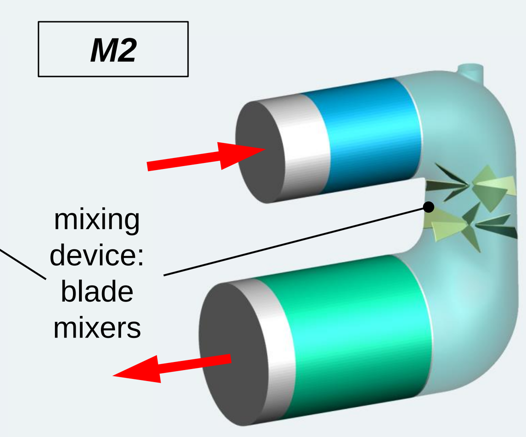

Fig. 3. The SCR system with two, **counter-rotating blade mixers**

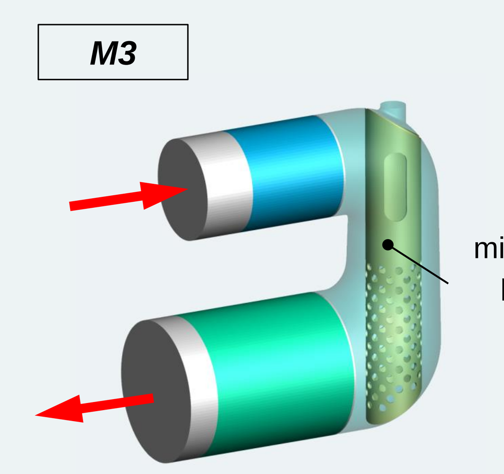

Fig. 4. The SCR system with the **perforated mixer**

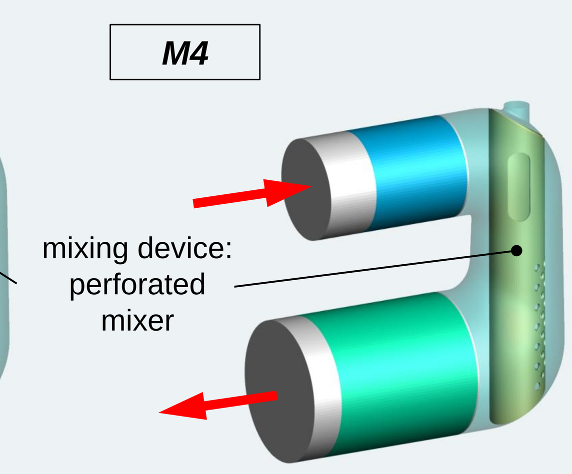

Fig. 5. The SCR system with the **partially perforated mixer**

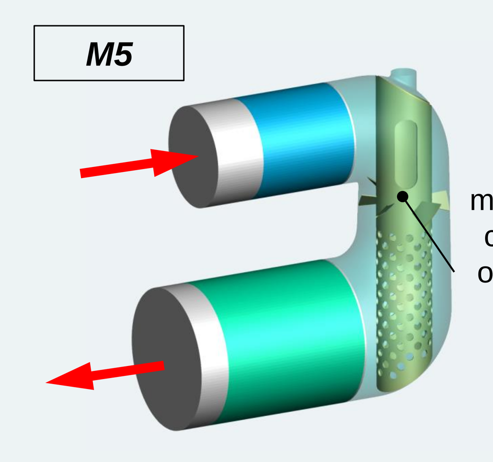

Fig. 6. The SCR system with the **hybrid, blade-perforated mixer**

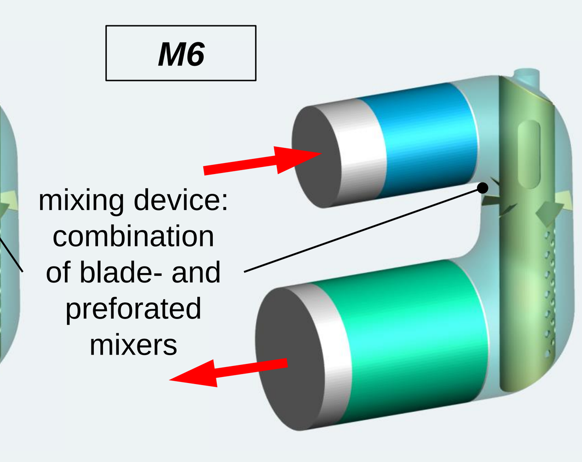

Fig. 7. The SCR system with the **hybrid, blade-perforated mixer**

CONCLUSIONS

- Each urea mixer improved the ammonia uniformity index near the SCR's inlet,
- The mixing of UWS droplets and ammonia was mostly improved for double, counter-rotating blade mixers (M2) and partly perforated mixers (M4, M6),
- Counter-rotating blade mixers (M2) and hybrid mixers (M5, M6) generated the highest rise in total pressure drop,
- The rise in pressure drop was similar for simple blade and perforated mixers,
- All systems were insensitive to changes in operating conditions (exhaust gas mass flow rates),
- Properly designed hybrid mixers (for instance M6) may provide excellent mixing performance under a wide range of operating conditions. However, such complex designs generate high pressure drops.

<u>Perforated mixers alone are supposed to be used in future SCR systems as a compromise between production difficulties and great mixing performance</u>

ACKNOWLEDGEMENTS

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