EMISSIONS REDUCTION

COMING CLEAN

To meet China's tough new emissions requirements, Tenneco used ANSYS CFD to optimize the design of a new selective catalytic reduction system.

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Although heavy trucks account for only about 5 percent of vehicles on China's roads, they account for about 80 percent of nitrogen oxides (NOx) emissions. China recently implemented demanding Stage IV emissions requirements that are nearly identical to the Euro 4 emissions standards. The new requirements reduce NOx emissions to 3.5 grams per kilowatt-hour (g/kWh), compared to 5.0 g/kWh in Stage III standards. Selective catalytic

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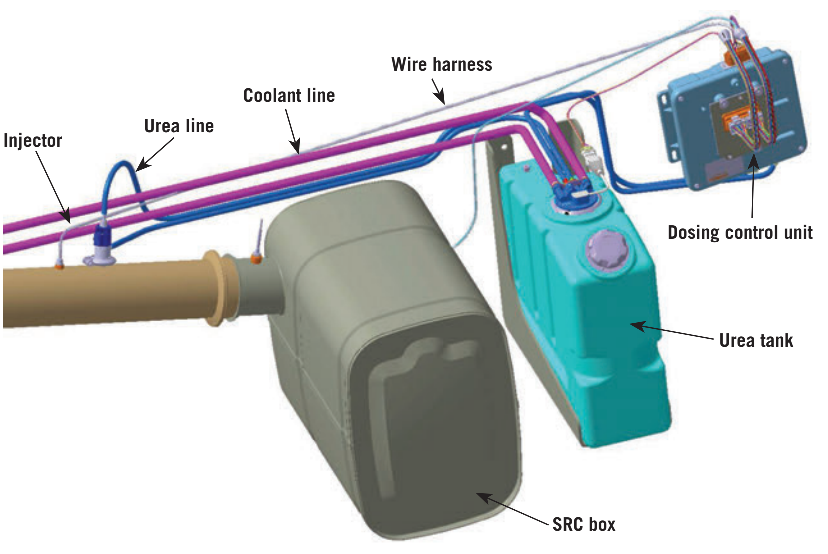
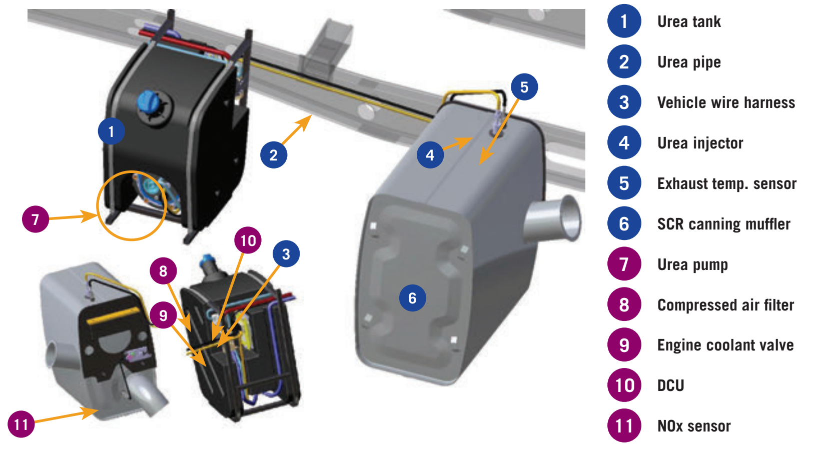
reduction (SCR) has become the go-to technology for meeting tough diesel-engine NOx emissions requirements. SCR technology involves injection of urea, a reducing agent, into the exhaust stream. The exhaust stream then flows through a catalyst, resulting in the reduction of nitrogen oxides into nitrogen, water and tiny amounts of carbon dioxide, all of which are natural components of air.

In traditional SCR design, the urea injector is mounted to the exhaust line leading into the SCR box that holds the catalyst. Tenneco — one of the world's leading designers, manufacturers and distributors of clean-air and ride-performance products and systems for the automotive, commercial truck and off-highway markets and the aftermarket — has developed a new injector-integrated SCR design in which urea is injected directly into the SCR box through an internal mixing pipe. The new design reduces the cost of the inlet pipe and improves design flexibility by eliminating restrictions on inlet pipe length and geometry. Tenneco engineers faced the challenge of optimizing the new design to eliminate the tendency for urea to build up on the mixing pipe in the SCR box. This buildup limits the life of the unit. They used ANSYS Fluent computational fluid dynamics (CFD) software to simulate the complex SCR physics, including droplet evaporation, droplet–wall interaction and NOx reduction. Engineers evaluated multiple design iterations and optimized the SCR design, eliminating urea deposits and meeting other design requirements.



▲ Traditional SCR design



▲ New design with injector fixed at SCR box

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SCR DESIGN CHALLENGES

SCR technology involves injecting aqueous urea into the exhaust system. Urea decomposes into ammonia and isocyanic acid and reacts with NOx on the surface of the SCR catalyst. A good SCR system has high NOx conversion efficiency, low urea consumption, long life, and no or little ammonia slip. Ammonia slip refers to ammonia that passes through the SCR without reacting with NOx. The first of two critical phases in the SCR operation is the mixing of ammonia and exhaust gases to achieve a uniform mixture prior to exposure to the catalyst. The second critical phase is the catalytic NOx reduction to optimize NOx conversion while minimizing ammonia usage and slip.

CFD modeling is used in the design process to ensure that a proposed SCR design delivers the required level of NOx reduction over the full operating cycle of specific engine models. The complex physics involved in SCR operation, including the interaction of gas and liquid phases, complex chemical reactions and spray–wall interaction, make it difficult to simulate. Another challenge is

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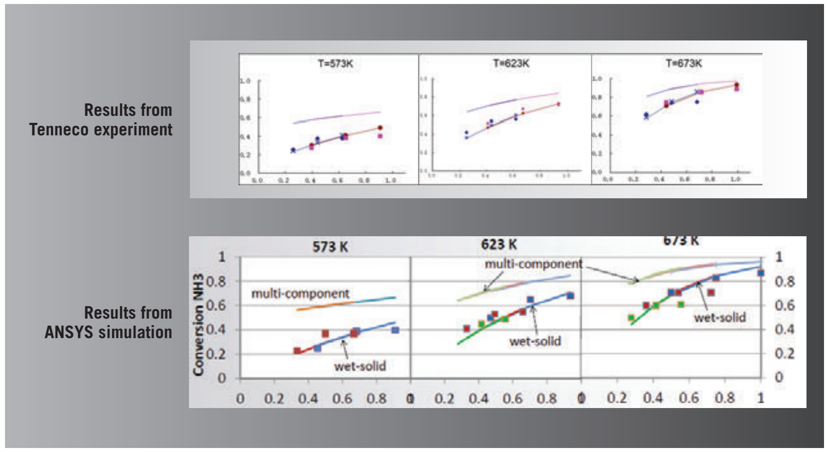
the wide range of time scales involved: Spray dynamics is measured in milliseconds, wall film formation in seconds and catalyst transients in minutes. In addition, there is a scarcity of validated physical models, lack of established simulation best practices, and the legislated need to validate design performance over test cycles that often last 30 minutes or more.

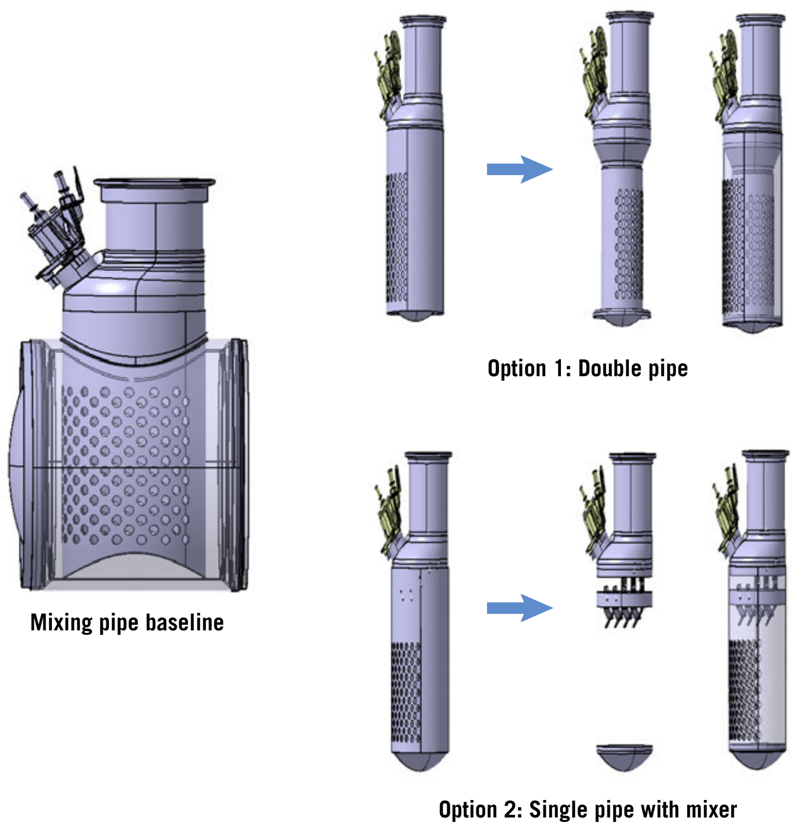
A typical SCR design includes the urea delivery system, SCR box and dosing control unit. The injector is traditionally placed at the inlet pipe. In Tenneco's injector-integrated SCR design, the injector is fixed at the SCR box. The new design provides a significant cost reduction by avoiding the need to use high-grade steel for the inlet pipe. Also, by not mounting the injector on the inlet pipe, engineers can be flexible with their inlet pipe design, making it easier to adapt the SCR to different engine and truck configurations. On the other hand, in the new design, the mixing pipe extends into the SCR box; it must be constructed so that urea does not deposit on the pipe and lead to premature failure of the SCR system.

VALIDATING CFD FOR SCR DESIGN

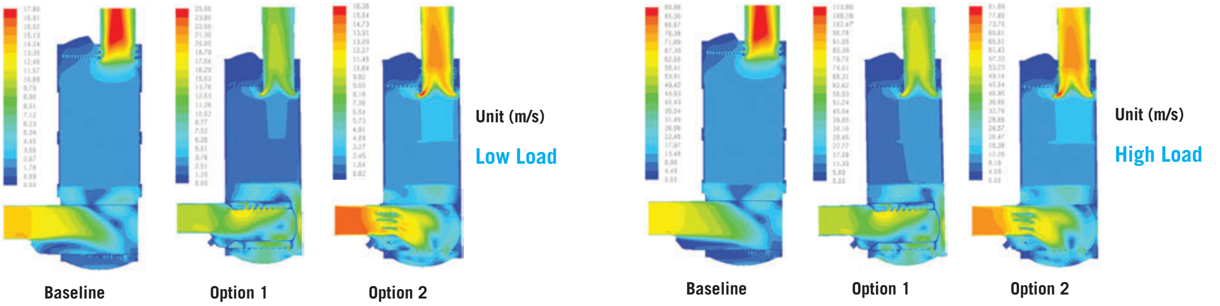
Prior to analyzing the new design, Tenneco engineers validated the accuracy of their simulation methods by performing physical experiments and simulating the test setup for CFD. Individual urea droplets were suspended on the tip of a fiber in a heated environment. Images of the evaporating droplet were recorded with high-speed cameras. The droplets were 32.5 percent urea by weight. Measurements were conducted while changing droplet ambient temperature by 50 K. In the CFD simulation, the droplets were held in the same position for the duration of the evaporation process. The evaporating droplet diameter and time history were evaluated. A simple 3-D planar mesh was created, and the droplet was positioned at its center. Multi-component and wet-solid



Results from the ANSYS CFD simulation (bottom) closely matched experimental results from Tenneco (top) using the urea reaction model.



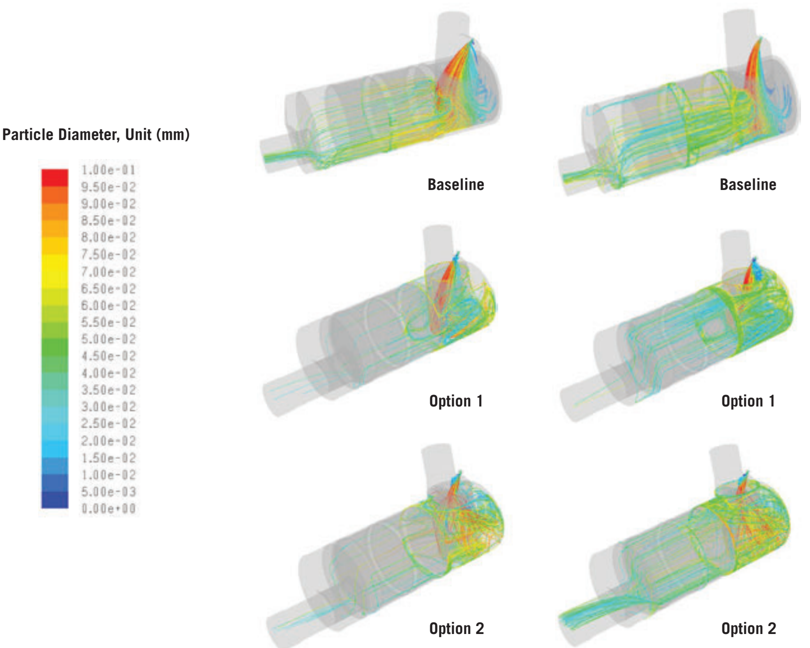
Proposed design alternatives



▲ Velocity contours under two load points

material properties were selected from Fluent's property database. The simulation results closely matched the experimental measurements.

Tenneco performed another droplet evaporation experiment based on work by J.Y. Kim in spray-induced mixing and thermal decomposition of urea solution in an SCR system. An aqueous solution containing 40 percent urea by weight was injected in the hot gas stream flowing inside a circular duct and was converted to ammonia. The ammonia concentration was measured at three downstream sampling points to determine conversion. CFD simulation results closely matched the experimental measurements.



▲ Particle trajectories

▲ Urea deposit in bottom of pipe in original design (left). New design eliminates urea deposits (right).

OPTIMIZING DESIGN OF NEW SCR

Tenneco engineers recently designed an injector-integrated SCR for a 12-liter diesel engine. The prototype of the original design showed urea deposits at the bottom of the pipe during the specified cycles run for emissions testing. Tenneco engineers proposed two new designs as potential solutions to the urea deposit problem. One design used a double mixing pipe with two pipes concentric to each other; the other design used a single pipe with a static mixer near the inlet.

Tenneco engineers used ANSYS CFD to simulate the baseline, double pipe and mixer cases. CFD results showed the velocity contours and particle trajectories for the three cases. Based on a comparison of the results from the three cases, Tenneco engineers felt confident that the double-pipe design would solve the problem. They built a prototype of this design and found that it eliminated the urea deposits. This case is one of several in which Tenneco engineers have successfully used CFD to optimize the design of SCR systems, helping the company to continually improve its products and competitive position in the heavy truck market through innovative engineering.

Reference

Kim, J.Y.; Ryu, S.H.; Ha, J.S. Numerical Prediction on the Characteristics of Spray-Induced Mixing and Thermal Decomposition of Urea Solution in SCR System. Proceedings of ICEFA04. *ASME 2004 Internal Combustion Engine Division Fall Technical Conference*. **2014**. pp. 165–170.