Mixing Performance Characterization for Optimization and Development on SCR Applications

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Summary

In the context of Selective Catalytic Reduction (SCR) system design, the fluework from an economizer outlet to the catalyst inlet becomes the framework of what is effectively a flue gas conditioning system. The purpose is to optimize blending of flue gas components and temperature, while maintaining reasonable flow uniformity at the catalyst entrance.

Numerous ammonia injection grid (AIG) and static mixing designs have been employed by the various system designers. When challenged to optimize a given system towards stringent uniformity standards, the designer has an essential need for methods of performance prediction. These prediction methodologies should indicate the performance of the discrete AIG and mixing devices, as well as their placement's impact on overall performance. Once performance characterization and benchmarking techniques are established, consistent comparisons and more rigorous analysis of design options can be made.

While temperature blending is often a concern, the primary focus in SCR mixing applications has been to achieve high levels of NH_3/NO_x molar ratio uniformity. Contemporary coal-fired applications typically limit outlet ammonia slip to 2 ppm average concentration by volume. For high NO_x reduction designs (90%), the molar ratio uniformity desired is usually for a coefficient of variation (Cv) of less than 5%. Ultra-high NOx removal designs (>90%) require distributions that are progressively more stringent and more difficult to maintain.

Whether for simple ammonia dispersion in an open duct, or for complex static mixing applications, establishing analytical parameters to describe mixing performance is critical. It is also important to establish parameters that describe separately the effectiveness and the efficiency of the process.

The first parameter, mixing effectiveness, is a measurement of how well the uniformity has been improved. This can be expressed by the ratio of the standard deviation of a measured component concentration profile entering a prescribed mixing zone to the standard deviation of that exiting. This form is useful when estimating the inherent performance of a device under rigid test stand performance conditions where the inlet profile can be accurately measured. Yet, it is seldom easy to assign this value for the mixer inlet standard deviation in the typical SCR system design, especially for the ammonia profile. Thus, an alternate expression can be useful.

Such an alternate effectiveness expression can be the ratio of the standard deviation of the measured component at a given assessment plane with a given AIG/mixer design installed, to that without a mixer or with an alternate AIG. The typical assessment plane being that located at the reactor inlet.

Space competition for SCR systems forces many arrangements to have non-ideal placements for the AIG and mixers. This alternate expression helps to that take the arrangement into account by providing some inherent connection of the overall performance relative to the available system length, actual geometry, and device placements within.

Subtracting the effectiveness ratios from unity will yield a simple and convenient scale of 0 to 1. For the former expression, a value of zero (0) represents the case where no mixing has occurred. For the latter alternate expression, a value of zero (0) indicates no mixing or improvement from one case to the other. In either case, a value of one (1) represents perfect mixing to complete homogeneity.

Effectiveness in improving homogeneity is only one aspect of system performance. Energy consumption and system mix length requirements are also very important. By determining the effectiveness per unit length or energy consumption, the spatial and energy efficiencies of the process can be better understood and manipulated.

Mixing time is reduced when operating at higher Reynolds numbers through the effect of increased velocity. For gas-gas applications, this time reduction appears to be nearly compensated for by the corresponding reduction in available travel time along the flow path. The result is a relatively constant mixing length requirement across a reasonable variation in average stream velocity. This effective independence of Reynolds number yields a degree of mixing across a given system that, in terms of energy consumption, becomes more a function of the mixer shock loss coefficient than the actual pressure drop. Operating or designing with a higher velocity will simply raise the pressure drop of the system, with little influence on the degree of blend. In other words, higher pressure drop does not necessarily translate into improved mixing.

When searching for a measurement of mixing efficiency, a dimensionless term falls from the above logic. The term is produced when a mixer shock loss coefficient is divided into the mixing effectiveness value. An indicator is produced that combines the energy consumption characteristic with the level of overall blending effectiveness achieved across the system.

Performance measurement parameters such as these allow comparison of the efficiencies of various device designs and placements throughout a range of arrangement contortions and lengths. The influence of bends, expansions and contractions along the mixing path can then be better understood, accounted for and/or exploited for optimization. System performance benchmarking also becomes more practical and consistent.

Measuring these values in standardized test stand arrangements can provide the indicators necessary to optimize or rank the performance of specific mixing devices and ammonia injection processes. Results from standardized physical test stand arrangements also offer excellent opportunities for validating numerical techniques. Numerical models enhance design development activities because they can be easily changed or initialize with different, but fixed and repeatable, inlet conditions. This allows improved flexibility over physical test approaches when analyzing a wide range of multiple case scenarios.

Ultimately, extensive physical and numerical testing provides the development platform needed for improved selection, advancement and optimization of mixer designs being applied to both new SCR projects and system retrofits.