

ASCR™: lower NOx removal costs without sacrificing performance

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ASCR™ Advanced SCR systems employ a “layered” approach, optimally combining three NOx reduction technologies. The three layers are: staged combustion (consisting of LNB (Low NOx burners) and OFA (over-fire air)); SNCR (Selective Non-Catalytic Reduction); and SCR (Selective Catalytic Reduction). The concept derives its advantages from the synergies that exist between these three technologies, particularly when their application is informed by advanced computational fluid dynamics, coupled with the considerable cost savings that arise from using a single-layer SCR installed in existing ductwork, suitably modified, and employing existing structural supports. This is much more cost effective than “going to ground,” i.e. building a stand-alone SCR facility with its own foundations and new structural steel, etc. It is estimated that ASCR systems will typically be able to achieve NOx removal rates of up to 85% at around half the total (capital plus operating) cost of stand-alone SCR. Capital costs are estimated to be in the range \$30-75 per kW for an ASCR installation, compared with about \$300 per kW for a full scale stand-alone SCR.

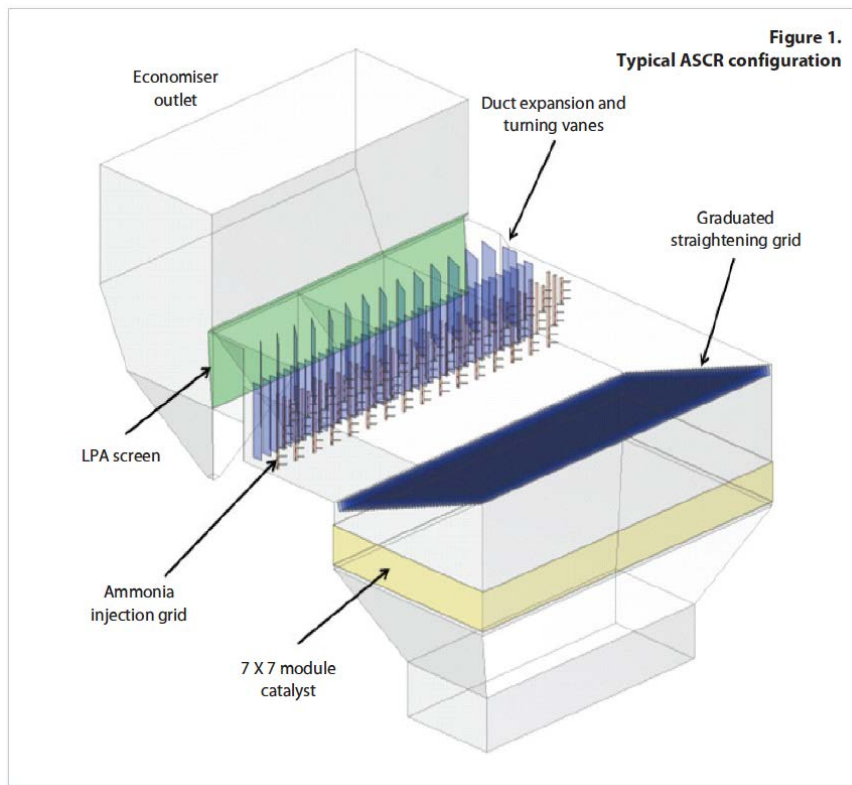


Figure 1 shows a typical ASCR configuration. The catalyst portion of the ASCR, which contains all the components of a typical SCR, is installed in an expanded section of the power plant’s existing vertical ductwork, located between the economizer outlet and the air preheater (APH) inlet. This arrangement is responsible for most of ASCR’s economic advantages over standard SCR installations.

Given typical components and the oversized structural steel and foundations normally found in power stations, these modifications and additions can usually be carried out without the need for new foundations or extensive modification of existing structural steel.

In addition, there is no need to relocate or modify the existing air preheater, which is sometimes a costly element of an SCR retrofit. ASCR systems (using a single layer of catalyst) uses less catalyst volume than a conventional SCR system, another contributor to lower capital costs, but it requires a higher rate of catalyst replacement and consumes more reagent. On the other hand the pressure drop associated with ASCR is lower than SCR. Overall, the total cost of ASCR is estimated to be lower than SCR except where power plant capacity factors are extremely high.



Among the synergies contributing to the surprisingly high, “SCR-like”, NO_x removal efficiencies that ASCR is capable of are the following:

- Close coupling of the SNCR design to the design of the combustion modifications helps improve SNCR performance. Thanks to CFD modeling and field-testing, a deep understanding is gained of boiler dynamics, both before and after combustion modifications are installed, enabling the SNCR systems to achieve previously unattainable levels of performance.
- SNCR performance is further improved due to the presence of the catalyst layer. Current limitations on SNCR performance arise from the amount of “ammonia slip” allowed, typically of the order of 2-10 ppm. Performance can be pushed to achieve greater NO_x removal efficiencies and lower urea consumption rates by relaxing this requirement. The existence of the downstream catalyst layer in the ASCR configuration allows such a relaxation, with the catalyst design itself taking this additional NH₃ source into account and the catalyst acting as a “mop” for NH₃. Basically, the ammonia slip from the SNCR provides the reagent for the catalytic reactions, supplemented with an Ammonia Injection Grid (AIG).
- Catalyst performance is improved because of the lower NO_x levels it sees (due to the upstream NO_x removal technologies), coupled with the extensive use of CFD modeling, together with highly evolved flow distribution devices such as static mixer, ammonia injection grid, and Fuel Tech’s patent pending GSG™ Graduated Straightening Grid.

The importance of CFD

A key factor enabling ASCR to now be deployed as a proven technology has been the rapid development of CFD modeling tools over the past ten years or so. This in turn has been made possible by the continuous march of computing hardware improvements (as reflected in Moore’s Law (published in 1965, which states that the number of transistors that can be squeezed on to an integrated circuit doubles every two years) and the remarkable increase in computing power of the typical engineering work station computer.

At heart, coal combustion is the result of a variety of mechanisms, including mixing, evaporation, pyrolysis, and multiple chemical reactions, primarily the exothermic oxidation reactions of volatile matter. The process of creating computational models of such a complicated process is not without its challenges and is continually evolving. The combustion process consists of moisture being driven out of the coal particle via evaporation, light volatile gases (methane, etc.) being driven off via devolatilisation, the light volatiles reacting on many parallel pathways, and the remaining volatile matter (C, H, O, N) reacting in the form of solid char oxidation reactions until only ash remains. The NO_x created during the process can be classified in terms of its origin: “Thermal NO_x”(high temperature oxidation of atmospheric nitrogen, via the “Zeldovich mechanisms”); “Fuel NO_x ” (formed from nitrogen in the fuel via a complex process with many reversible reactions and intermediate species); and “Prompt NO_x ” (also formed from atmospheric nitrogen in the air, but via different mechanisms), which is not normally considered as it is a small percentage of the total.

There are hundreds of intermediate species and reaction pathways involved in the combustion of coal. Therefore, even with today’s computing hardware, simplifications are still needed for the computational problem to be tractable. The trick is to have sufficient complexity in the model to capture the important processes while at the same time maintaining solvability. We typically reduce the reaction set to Arrhenius type reactions. As for coal combustion, it is widely recognized that there are hundreds of intermediate species and reaction pathways involved in the SNCR NO_x reduction process.

And again we simplify, employing the two-step reaction simplification first proposed by Ostberg et al in 1997, which has been shown to produce realistic NO_x reduction estimates over a wide range of boiler conditions. Similar to the oxidation reactions already discussed, the reactions in this two-step SNCR mechanism are modeled with Arrhenius type reaction rates, with the same form.

Compared with coal combustion and SNCR, the CFD modeling of SCR is relatively straightforward, although the design and implementation of an efficient system is complex. In particular, the NO_x removal efficiency is highly dependent upon the incoming distributions of NO_x, NH₃, temperature and velocity. Failure to achieve homogeneous distributions is perhaps the most common reason for underperformance of SCRs. These dependencies are evident in the reaction mechanism across the catalyst (as first proposed by Wendt et al in 2001). Instead of an Arrhenius type reaction, we model the SCR NO_x reduction mechanism as a Langmuir–Hinshelwood type rate equation.

Modeling the ASCR

Looking at the SCR portion of the ASCR, as previously mentioned, the concentrations of NO_x and NH₃, the temperature profiles, and the velocity patterns exiting the boiler are critical to effective design. If the NO_x and NH₃ profiles are highly skewed exiting the boiler, one or more static mixers may be required to achieve the required distributions entering the catalyst. If the NO_x and NH₃ profiles are relatively homogeneous, a tunable ammonia injection grid may be sufficient.

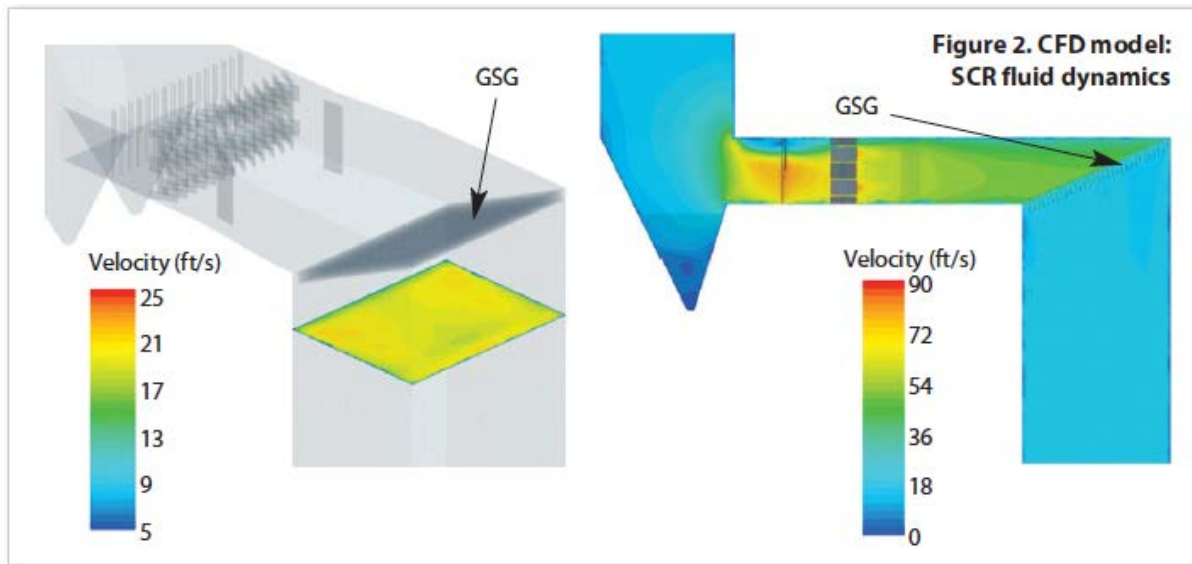


Figure 2 shows the effect of the patent pending Fuel Tech Inc. technology known as the GSG™ Graduated Straightening Grid, used to provide optimally distributed and uniform gas velocities into the catalyst. Indeed, the GSG can provide flows into the catalyst that were previously unrealizable in a confined space such as this. We believe the GSG technology is a breakthrough that will enable the evolution of the ASCR concept from being a marginally useful tool where space is not a problem to being applicable, and highly efficient, across a wide range of units.

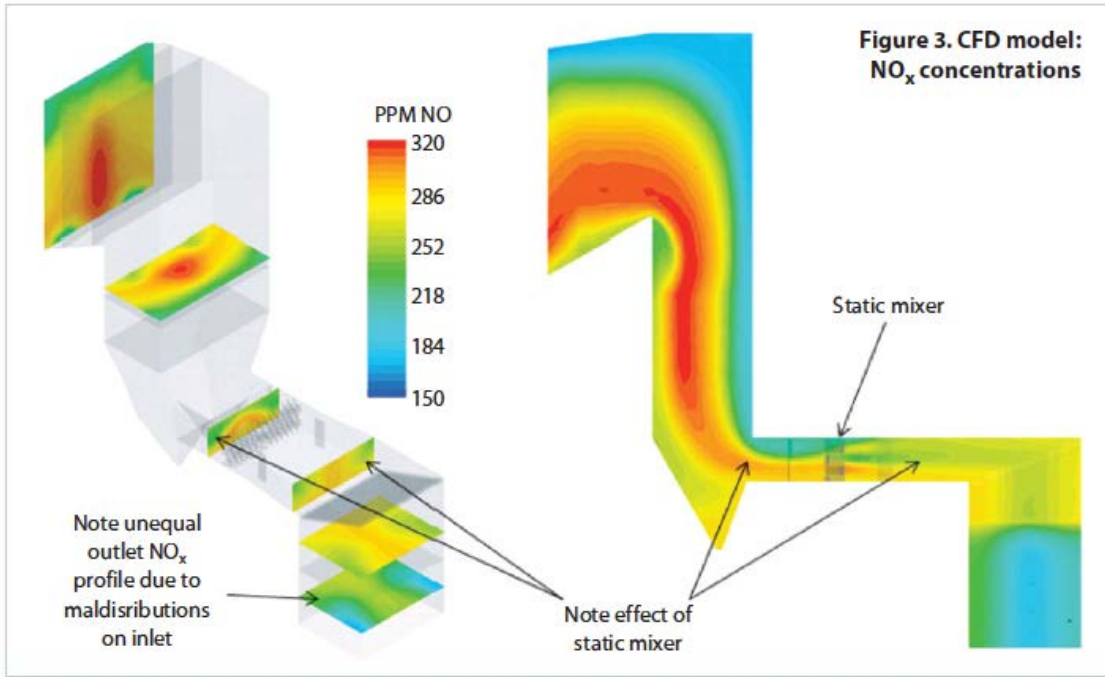


Figure 3 shows the evolution of the NO_x profile as the flue gas moves through the catalyst portion of the ASCR, with various contour planes throughout shown in the isometric view on the left, and the center-line contour plot shown in elevation on the right of the following figure.

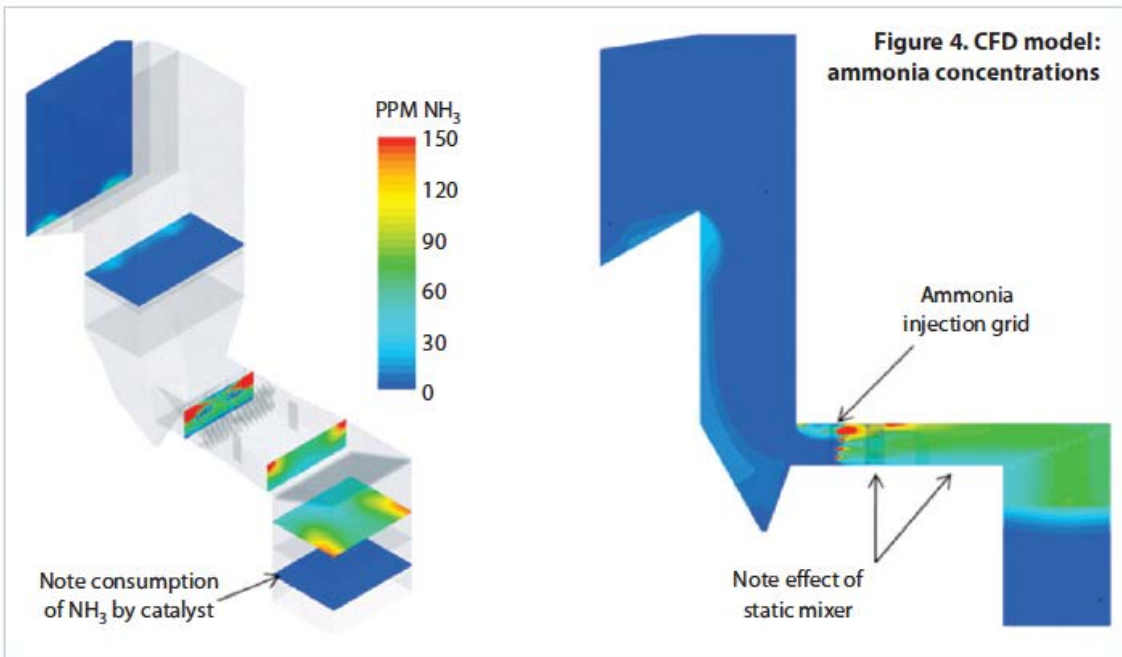


Figure 4 shows the evolution of the NH₃ profile as the flue gas moves through the catalyst portion of the ASCR. The results shown here are after only a few iterations upon the design have been performed, whereas during a typical design project as many as 50 iterations would be expected. Thus the results are “unoptimised” and we would expect the distributions to be improved upon. In addition, the AIG has not been tuned and is injecting equal volumes of NH₃ in all zones.

Application in China

A project at Castle Peak B, a 4 x 685 MW bituminous coal fired plant in Hong Kong, China, has successfully employed many elements of ASCR, including advanced CFD modeling, BOFA, in-duct SCR, AIG (located in the cavity of the economizer), static mixer and Graduated Straightening Grid, but not SNCR. A test rig was also used to check CFD results experimentally.

The SCR catalyst is located immediately above the air heater. One layer of catalyst provides 8000 hours of catalyst lifetime, with NO_x removal efficiency varying from 40% at the beginning and 30% at the end of life. The reactor is designed for 7.5 m/s catalyst face velocity. One of the four systems has now been in operation for over 1 year and has exceeded all performance criteria.

Figure 5. Castle Peak power plant (photo CLP)



Figure 6. Components modelled in Castle Peak case, economiser to air preheater inlet

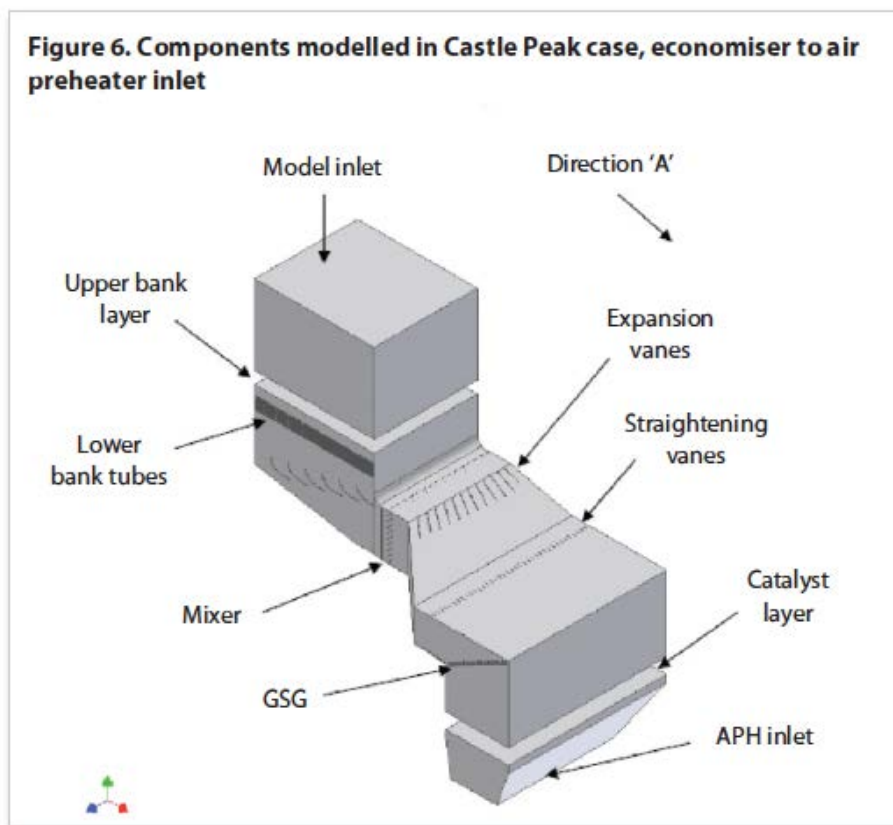


Figure 5 shows Castle Peak and Figure 6 the components modeled with CFD in the Castle Peak case, economizer to air preheater inlet.

Figure 7. Experimental test rig for the Castle Peak project



Figure 7 shows the experimental test rig. Modeling has also been carried out on a potential ASCR installation at the Longannet power plant in the UK.

Recently, an order for a complete ASCR retrofit (combustion modifications, SNCR and SCR) has been received by Fuel Tech and is to be installed on a 75 MW power boiler in Kaohsiung, Taiwan.

System-wide approach

In summary, ASCR, by making maximum use of existing ductwork and structural supports, instead of “going to ground”, is a way of realizing the performance benefits of SCR while minimizing the high costs associated with it. In addition, the existing capital and operating cost advantages of combustion modification and SNCR are exploited to the full.

Also, the performance of each NO_x reduction component in the system is optimized by taking a system-wide design approach and making extensive use of advanced CFD modeling (which, in fact, be seen as an enabling technology, underpinning the ASCR concept) . Inputs to and outputs from each component are not considered as isolated events, but as feed forward and backward inputs to the other components, to be optimized.

In addition highly effective flow distribution devices are used, such as static mixing, AIG and the Graduated Straightening Grid. The latter is particularly important in providing optimal flow through the catalyst where space is limited, ensuring that the catalyst portion of the ASCR installation operates at maximum possible efficiency.