ANDRITZ: CFD OPTIMIZED HIGH-VELOCITY SPRAY SCRUBBER

ANDRITZ is one of the world's leading suppliers of plants, machinery and services for many different branches of industry in the public, municipal and private sectors. The Group has its headquarters in Graz, Austria, and operates worldwide with around 29,700 employees at 280 locations. ANDRITZ has been successful in the air pollution control sector for more than 35 years, supplying wet and dry flue gas cleaning plants to remove SOx, NOx, particulates and other air contaminants.

Cleaning of exhaust gas from shipping is a challenge that is perfectly compatible with the comprehensive know-how ANDRITZ has gathered from supplying and optimising several hundred flue gas cleaning plants worldwide.

In the maritime sector, ANDRITZ offers proven technologies such as the open-loop and closed-loop wet scrubber as well as the hybrid design and is developing its product portfolio continuously in order to provide all customers with the perfect solution for their requirements. In addition, ANDRITZ offers dry exhaust gas cleaning technology for multi-pollutant control.

Hence, it is the only supplier worldwide able to offer dry and wet solutions for exhaust gas cleaning. To achieve the best results and fulfil customers' requirements, ANDRITZ uses its own computational fluid dynamics (CFD) simulation tools developed especially for scrubber design.

BACKGROUND

There are two different scrubber designs available for cleaning exhaust gases from maritime vessels: the I-type (or inline) scrubber is designed as a "spray scrubber" without any internals besides the spray bank; and the U-type (or bypass) scrubber can either be designed as a "packed tower" using random or structured packing or as an "open spray tower".


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The packed tower has some advantages, but also some drawbacks. One of the major advantages is the lower washwater flow required for the scrubbing process compared to spray scrubbers. But this advantage is only obtained by using high-performance packing with good gas/water interaction.

On the other hand, the drawback with this packing is the drop in pressure and a tendency towards clogging (due to fouling or salt build-up). "Free-flow" packings provide a larger free passage for the gas flow, which can avoid clogging. The drawback of this solution is that there is less washwater to gas contact area. This area is one of the major parameters for the absorption process. Less contact area has to be compensated with a higher washwater flow rate to achieve the same absorption efficiency. Also, the positive effect of low washwater flows is limited due to the maximum permitted pH value of the water discharged.

The size of the overboard pipes defines the pH value that can be discharged into the sea. So even if the washwater flow can be reduced to a chemical minimum, which will result in a pH value of around 2.5 in the discharge water, it is not permitted to discharge this acid liquid into the sea without further treatment to ensure a rapid neutralisation in the free water. The "standard" pH value of the discharge water is around three and, at this level, the washwater flow from ANDRITZ spray scrubbers is comparable to the flow from packed columns.

The advantages of a spray scrubber are manifold: a spray scrubber can operate with higher gas velocities, resulting in a smaller scrubber footprint. In addition, there is no risk of clogging because there are no large barriers installed in the column. The washwater flow is very similar to the flow in a packed column, with the advantage that there is less pressure drop. Hence, no additional fans are needed. This is also the reason why only a dry running mode is possible (and allowed by the classification society) for spray scrubbers or other designs without packing inside as soot and particles could form a blockage in a packed tower.

Due to all these advantages, ANDRITZ has decided to supply spray scrubbers for I-type, but also for U-type scrubbers. This decision is based on the know-how ANDRITZ has gained from the operation of numerous land-based scrubbers, as well packed towers operating as spray scrubbers. To achieve high SOx removal efficiency with a spray scrubber, it must be designed in the right way.

ANDRITZ was the first company worldwide to use CFD simulations for the liquid and gas flow distribution inside a spray scrubber and optimize flue gas cleaning performance on the basis of these simulations. This article illustrates and explains some of the common issues surrounding the design of spray scrubbers and discusses especially the help provided by a comprehensive and accurate CFD simulation.

SPRAY SCRUBBER DESIGN

The following mentions important issues that have to be considered when designing a spray scrubber. Some of them can be resolved by means of CFD simulations and some of them can be handled with the right knowledge and experience.

ANDRITZ started to optimise spray scrubbers in the early 1990s, so every aspect of designing this equipment with computer-aided technologies such as CFD is not new, but has already been standard engineering practice at ANDRITZ for many years now. The CFD tools enable ANDRITZ to simulate the fluid dynamics as well as SO_2 removal with each scrubber type and optimise performance substantially.

MALDISTRIBUTION

One of the most important design criteria for spray scrubbers is to avoid maldistribution of the gas and liquid phases in the scrubber. Maldistribution is caused by an unequal velocity distribution of the continuous gas phase over the spray scrubber cross-section. This leads to a bypass effect, where exhaust gas with high velocity can pass through the spray region without being sufficiently cleaned. In this case, it is not possible to remove sufficient sulphur in the scrubber — or only by applying huge amounts of wash water.

The proper scrubber design results in uniform gas velocity distribution, generates more interaction by the reacting elements, requires less washwater flow and ensures a lower pressure drop in the scrubber, resulting in less power consumption by the system and thus better overall performance throughout the scrubber.

To enhance distribution of the gas, ANDRITZ has developed and patented the so-called FGD+ layer, with special tube orientation above the gas inlet into the scrubber. The FGD+ layer also provides better SO_2 removal efficiency, increased particulate removal and an additional silencing effect. For the I-type scrubbers in particular, ANDRITZ has developed a special inlet section that also ensures better distribution of the gas in combination with low pressure loss. ANDRITZ has also patented this device.

When it comes to more complex scrubber designs, such as rectangular or square shapes instead of circular ones, gas distribution is even more important. In particular, channelling of the gas in the corners of the scrubber could lead to serious performance problems in terms of absorption efficiency, especially for high SO_2 removal areas such as Emission Control Areas. The FGD+ layer also helps in this case and is one of the reasons why ANDRITZ can offer any shape of scrubber design (circular, square or rectangular).

Figure 1 shows the results of a CFD analysis of the exhaust gas flow inside a square-shaped scrubber. The goal of the analysis is to improve the exhaust gas flow distribution inside the scrubber. Particular attention is given to the flow near the walls and the corner regions.

The image on the left-hand side of figure 1 shows the exhaust gas flow velocity on a plane cut through the scrubber in the initial design phase. It reveals high flow velocities near the walls and in between the nozzle arrangement. The image on the right-hand side illustrates the exhaust gas flow behaviour after optimising the scrubber design. The optimised, final design shows a much more uniform flow distribution than the initial one.

NOZZLES AND SPRAY BANK DESIGN

Distribution of the gas in the scrubber is defined not only by the inlet part of a scrubber, but also by the positioning of the nozzles over the cross-section and by the nozzle type. There are various design criteria that have an impact on good distribution and proper removal performance by the scrubber. Successful operation thus depends on the nozzle type (hollow cone or full cone), nozzle spray angle (45-120°), droplet size of the distributed wash water (d32 = 0.5-4mm), distance between the spray banks (1-2.5m), nozzle orientation (different installation angles), number of nozzles, and location in the spray banks (in line or distributed).

All of these parameters can be optimised using CFD simulation. As this is a multi-parameter simulation, experience and know-how are the key factors in the proper design. ANDRITZ provides scrubbers operating at higher velocities to save space and reduce the footprint. It can do this because it has a proven scrubber simulation tool.

To obtain even more reliable simulation results, ANDRITZ has also developed its own wall film model (backsplash of droplets and wall film generation), droplet-droplet model (generating of secondary droplets, which influence separation efficiency and pressure loss) and a physical and chemical SO_2 absorption model. All these simulation models have been developed by ANDRITZ on the basis of its long-time experience with these kinds of scrubbers and are not available commercially. What is more, the experience of the experts in the company's CFD department ensures ongoing optimisation of all parts of the scrubber.

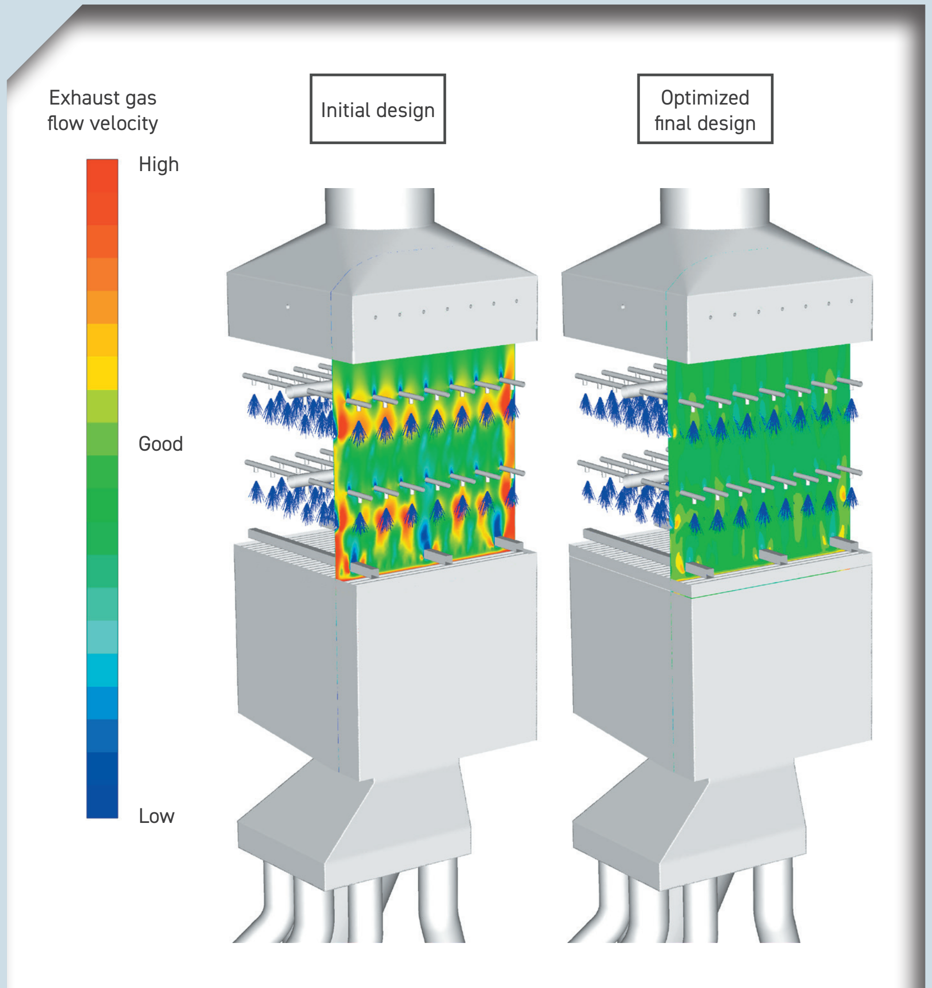

Figure 1: Exhaust gas flow optimisation inside the scrubber by means of CFD

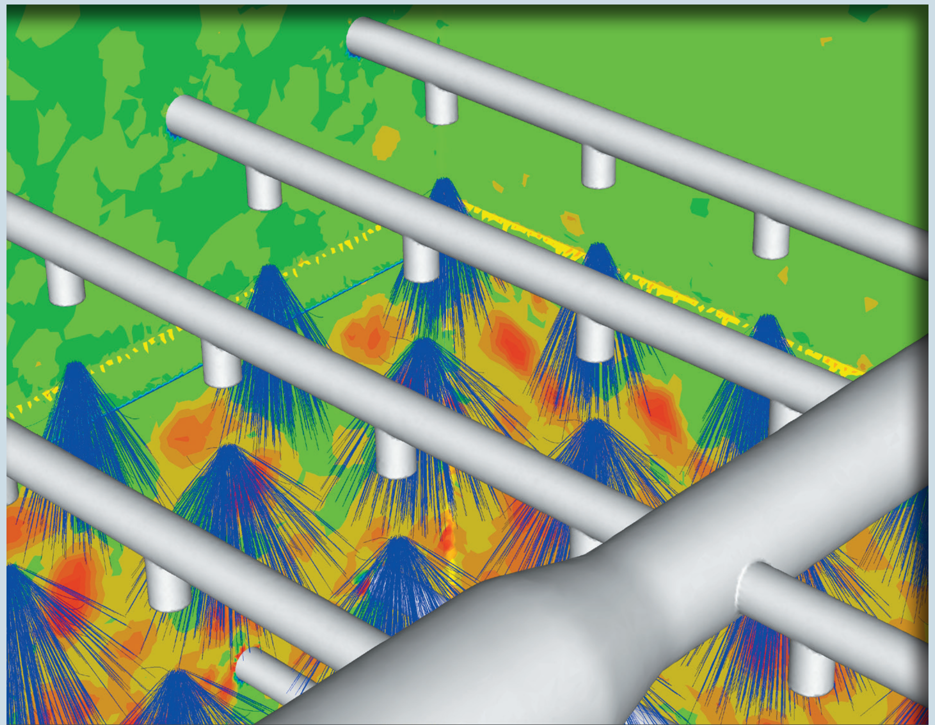

Figure 2: enhanced in-house scrubber CFD modelling approach — combined simulation of washwater droplets and wall-film

WALL EFFECT

The design of a spray scrubber, especially small ones with diameters up to 2.5m, has to take account of the fact that a lot of the washwater droplets are already hitting the surface of the scrubber at a short distance below the spray nozzles. So a substantial portion of the washwater is "lost" because it runs down the wall.

In this case, the mass transfer surface between gas and liquid is diminished, causing poor performance by the scrubber or — even worse — difficulties in achieving the required SO_2 removal efficiency. To overcome this problem, CFD simulation is the right tool because it can be used to investigate measures to reduce the wall film, for example with correct orientation of the nozzles, and also ways of redirecting the wall film into the centre of the scrubber.

PART LOAD

Part load is a well-known issue for all scrubber types, but especially for inline scrubbers. In most cases, the scrubbers have to be designed for a high engine load (up to 85% or more load) and high sulphur content in the fuel (normally 3.5%). In reality, many scrubbers are operated in slow steaming mode or at low engine load (25–50%) with a sulphur content of 2.5%.

In this case, the scrubber is over-dimensioned by more than 100%. It is obvious that the scrubber cannot operate under optimum conditions if this "standard" load was not taken into account during the design phase. So the scrubber builder has to find a compromise between these two extremes.

A spray scrubber that is designed for a maximum load could have problems with gas velocity distribution in part-load mode. The same applies to scrubbers designed for lower loads, which could have problems with too high velocities at maximum load.

With a CFD simulation, multiple-load cases can be investigated and optimised to find the best configuration for all loads.

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LATEST NEWS FROM OUR DRY SCRUBBER ON THE PIANA OPERATED BY LA MÉRIDIONALE

Detailed emission measurements were done by Company CERTAM in October 2019. The results exceeded the expectations by far.

The measurements proofed particulate reduction in mass of > 99.9% for PM1, PM2.5 and PM10 as well as reduction in number of > 99.9% for PM1.

SO_2 emission was proofed to be well below 4.3 ppmSO_2/%CO_2

As a next step, the implementation of a NOx removal system will be tested till May 2020.

So, SeaSOx$_{dry}$ will be a multi pollutant control technology for removal of SOx, particulates, black carbon and NOx.