IMPROVING DRY SORBENT INJECTION WITH COMPUTATIONAL FLUID DYNAMICS

A COST EFFECTIVE EMISSION CONTROL TECHNOLOGY

Dry Sorbent Injection (DSI) is a cost effective emission control technology in which pollutants are removed from a flue gas by injection of a reactive powdered sorbent. Computational fluid dynamics (CFD) is an important tool to optimize the DSI performance for specific customer applications.

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DSI PROCESS

Reaction

In general, a DSI process consists of the direct injection of dry powdered high performance hydrated lime, for example Sorbacal® SP & SPS, inside the flue gas duct prior to the dust collection system (bag house filter or electrostatic precipitator). The acidic gases undergo a neutralization reaction at the interface of the solid reagent particles, forming the corresponding calcium salts that remain within the porous texture of the reagent. In order to be fully efficient, this technology requires sufficient retention time and proper dispersion of the solid reagent in the gas phase.

Case

The application presented in this paper relates to the improved removal of acidic gaseous pollutants, HCl and SO_2, from the stack flue gas of a cement plant in Belgium. The CFD modelling with COMSOL was first used to assess the DSI performance and was secondly used to design a new gas mixing system leading to a significantly improved performance of the DSI process.

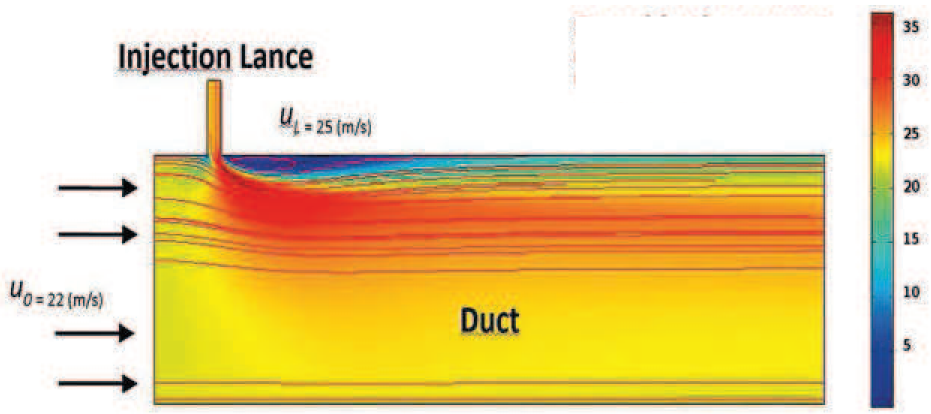

Figure 1 – Velocity field for injection of Sorbacal® SP into the duct using a wall mounted injection lance

REAGENT DISPERSION

Low dispersion

In the cement plant, an industrial trial was carried out by injecting the reactive sorbent into the duct work using a single injection point and while measuring the concentration of SO_2 and HCl at the stack. The initial trial results showed flue gas cleaning performance well below expectations, i.e. the concentrations of SO_2 and HCl at the stack were not sufficiently lowered by the sorbent injection. It was assumed that this poor performance was caused by insufficient dispersion of the reagent into the flue gas duct. Such a poor dispersion of reagent may be the consequence of:

- the large amount of flue gas to be treated (more than 400.000 Nm^3/h per kiln);
- the subsequent large size of the flue gas duct;
- the poor penetration of the injection flow into the main gas flow;
- the lack of macro-turbulence, which would contribute to the blending of the flue gas streams.

Low conversion

In the event that the solid reagent does not cover the whole cross section of the duct, i.e. the dispersion of the solid phase is low, the contact of the solid with the gaseous pollutant is insufficient which leads to a too low conversion.

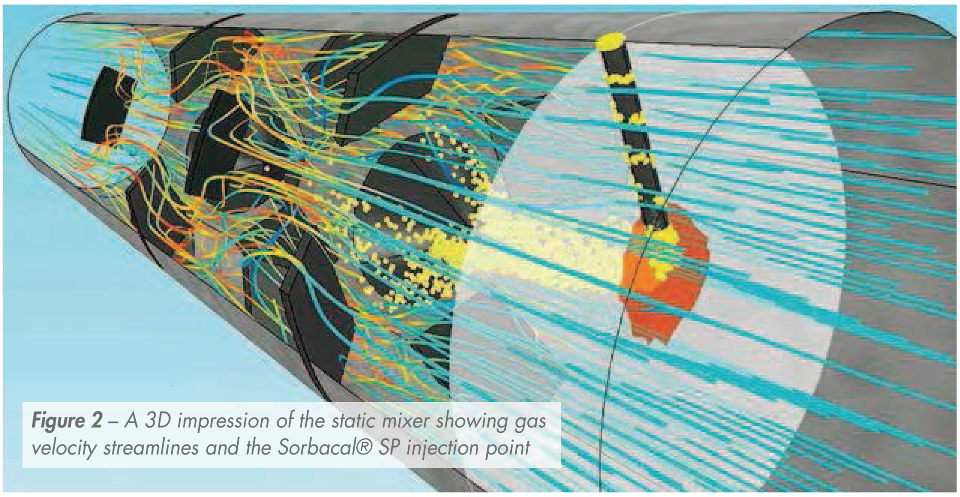

Figure 2 – A 3D impression of the static mixer showing gas velocity streamlines and the Sorbacal® SP injection point

CFD ANALYSIS

The DSI system in the cement process was modelled with COMSOL CFD in order to:

- improve the understanding of the flue gas flow patterns inside the duct;

- optimize the location and the number of injection points / lances;
- design and optimize a static mixer to improve gas mixing.

Conditions

CFD was carried out by application of the 3D mixture model in stationary mode, with the fluid phase being the flue gas and the injection air while the solid phase represents Sorbacal® SP particles. Assumptions and boundary conditions:

- the gas phase has properties of air;
- isothermal conditions (T = 473K);
- flat gas velocity profile at the inlet sections;
- relative outlet pressure = 0 Pa;
- no slip on external walls;
- the fly ash content in the incoming flue gas is not taken into consideration;
- duct flow inlet section : velocity = 22 (m/s), $\psi_p = 0$;
- lance flow inlet section: velocity = 25 (m/s); $\psi_p = 0.1$;
- mono-disperse solid phase, d_p = 10 (μm), with ρ_p= 1600 (kg/m^3).

Variables

The following variables were calculated:

- gas velocity profile calculated with the k-ε Reynolds averaging model,
- pressure profile,
- the volumetric fraction of solid phase,
- particle tracking enabling to visualize the particle flow in the static mixer and the duct.

Perfect dispersion

The dispersion of the solid phase was visualized by plotting of the 3D particle dispersion profile, which is defined as the iso-surface with ψ_d = 0.5 $\psi_{p,ideal}$. Thus, the iso-surface bounds the volume where the dispersion is 50% of the value corresponding to perfect mixing. The perfect mixing dispersion value $\psi_{p,ideal}$ is calculated from the initial concentration at the sorbent injection lance $\psi_{d,inlet}$ and the ratio of flow rates Q:

$$\psi_{p,ideal} = \frac{\psi_{p,inlet} * Q_{Lance}}{Q_{Lance} + Q_{Duct}}$$

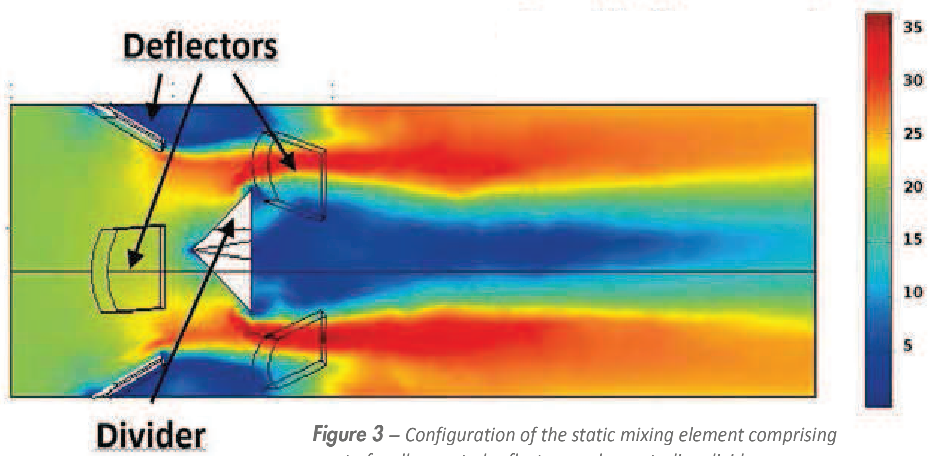

Figure 3 – *Configuration of the static mixing element comprising a set of wall mounted reflectors and a centerline divider*

RESULTS

Figure 1 shows the simulated injection of Sorbacal® SP via an injection lance which is flush mounted on the duct wall. The simulation shows that the penetration of the injection stream into the main duct flow is quite shallow. Such a situation will lead to a poor distribution of the solid phase in to main gas flow. Calculations have shown that due to the size of the duct and the low radial mixing, injection with a lance protruding into the center of the duct will only provide a partial solution because the solids flow will remain located in the center of the duct work. The use of multiple wall mounted injection devices will improve the dispersion but will not be able to penetrate into the center of the gas flow.

Solution requirements

For this customer, the key concept in improving the solid phase dispersion is to enhance the bulk gas phase mixing inside the duct. The possible solutions needed to meet a number of plant requirements: low cost, low maintenance, no adverse impact on the process and small increase in pressure drop. The chosen solution was a static mixing device (no moving parts, low maintenance) consisting of steel plates that could be welded into the existing ductwork (low cost, no impact on process). The static mixer consists of wall mounted deflector planes that direct the flow toward the center of the duct and diverter sections mounted in the center of the duct that direct the flow towards the walls. **Figure 3** shows a simulation of the static mixer with two rows of deflectors and one centerline divider. Extensive CFD work has been carried out to simulate the improvement of the solid dispersion while maintaining an acceptable pressure loss. The size, position, angle and number of deflectors and dividers have been investigated in these CFD studies.

Reaction simulation

Although multiple injection points were taken into perspective, a single injector was found to be sufficient. Results were simulated by theoretically changing the form, position and number of the deflector plates. By the increased mixing of the static mixer solution, the sorbent consumption decreased by 20% compared to the previous wall mounted injection system.

Industrial implementation

The actual static mixer as designed by Lhoist has been installed into the flue gas duct of both cement kilns by the plant operator, see **Figure 2**. After installing the static mixer, the measured pressure drop was found to be in agreement with the prediction of the model. The mixer, enhancing dry sorbent injection process, has now been operated successfully for more than three years. As a result the cement plant is able to meet emission limits with a low cost DSI solution. ❑

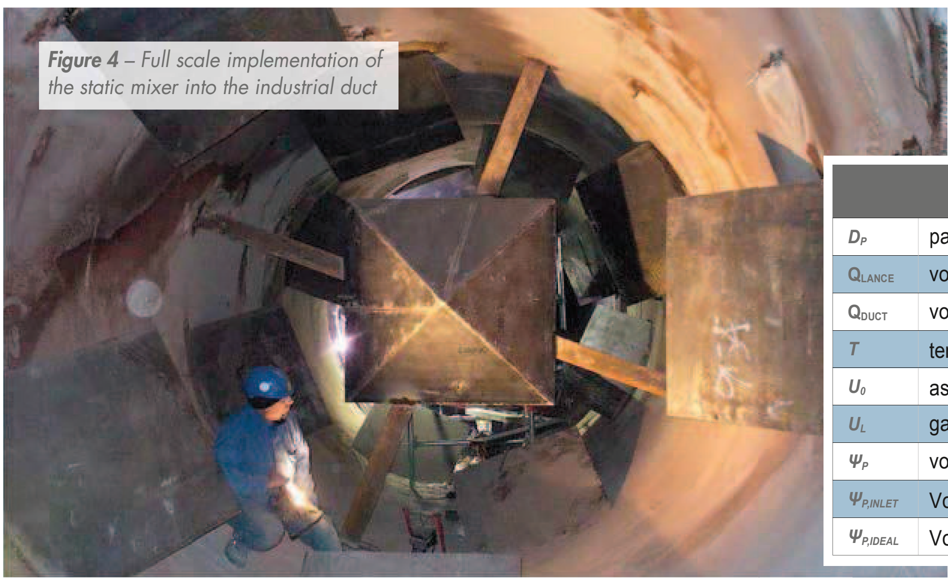

Figure 4 – *Full scale implementation of the static mixer into the industrial duct*

NOTATION		
D_P	particle diameter	μm
Q_{LANCE}	volumetric flow rate of injection lance	m^3/hr
Q_{DUCT}	volumetric flow rate of flue gas flow inside duct	m^3/hr
T	temperature of the gas phase	°C
U_0	as velocity at inlet of the duct	m/s
U_L	gas velocity at the injection lance	m/s
Ψ_P	volume fraction of particle phase	m^3/m^3
$\Psi_{P,INLET}$	Vol. fract. of particle phase in the injection lance	m^3/m^3
$\Psi_{P,IDEAL}$	Vol. fract. of particle phase for perfect mixing	m^3/m^3