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Monitoring of spraying in semi-dry desulfurization processes in coal fired power plants

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Abstract: The overall objective of the study is to improve usability and efficiency of desulphurization processes by providing assistance for plant operators by indicating arising issues. This paper introduces an indirect method to monitor spraying in semi-dry desulphurization processes, which is based on energy balance and first principle models. The method can e.g. be used to estimate flue gas exit temperature of the rector, which is the main control variable in the process, and slurry flows to reactors. The temperature estimate indicates what should be the exit temperature if spraying is functioning properly. The method was tested with process data collected from an industrial power plant, and the simulation results state that the method is able to predict the reactor exit temperature by error of typically less than few degrees Celsius regardless of the process state.

Keywords: Process monitoring, emissions, power plant, diagnostics, sulphur dioxide, desulfurization

1. INTRODUCTION

There is an increasing demand to restrict polluting emissions to environment. One harmful emission is sulphur oxides (SO_x), of which vast majority is sulphur dioxide (SO_2) that has unfavourable health and environmental effects. SO_2 emissions are formed primarily in combustion of fuels that contain sulphur, i.e. coal and heavy fuel oil, and in some industrial processes. In such combustion applications, the vast majority of sulphur oxidises, and the amount of SO_2 emissions is dependent on the fuel consumption and fuel sulphur content (Flagan & Seinfeld, 1988). Currently in European Union, the combustion originated SO_2 emissions exceed emission standards even with low sulphur coals. Therefore, SO_2 reduction methods have been applied since 1980's after the first SO_2 emission limits were set for coal fired power plants (Miller, 2011). Lately, the SO_2, NO_x and dust emission limits are further tightened from current Large Combustion Plant directive (LCP; 2001/80/EC) to Industrial Emission Directive (IED; 2010/75/EU), which will come into effect in 2016 for existing power plants. According to IED, the SO_2 emission limits will be lowered for existing large scale coal fired power plants from 400 to 200 mg/Nm^3. In several EU countries, the new emission limits are applied step wisely according to transitional national plans under IED to moderate investment burden. In parallel, after the release of new LCP BAT (Best Available Technology) document new requirements are expected to adopt in EU after a few years. As the sulphur content of inexpensive coals is not likely to decrease, the new emission limits are met only with more effective sulphur removal in existing desulphurization processes or with new installations. As costs are high with new installations, operational improvements in existing systems are extremely beneficial.

There are a few types of post combustion flue gas desulfurization (FGD) techniques. The second most applied method worldwide after wet scrubbing is based on spray dry or semi-dry absorption method which was applied intensively in the 1980's (Córdoba, 2015); (Jamil *et al.*, 2013). There, slurry constituting of water, calcium hydroxide $Ca(OH)_2$ and recycled reaction products are used for sulphur removal. The economic background of the method is effective recycling of end product in the process, which causes, unfortunately, several dynamical issues. The challenge with the process is a slow and nonlinear response from manipulated variables to the controlled process state variables. It may take hours before the results of the control actions made to the chemical feeds and flow rates will be seen in the states of the process. Furthermore, the origin of the detected behaviour of the process is often unclear; the reason can be found inside the desulphurization plant or it can be found in the operation of the combustion process as changed flue gas properties. This uncertainty causes easily problems, because the FGD process is sensitive to defective control actions which contribute to limited performance and might even lead to unexpected shut downs of the whole system caused e.g. by clogging of the lime slurry lines, spraying nozzles or by overloaded mixers. As spray-dray absorption type FGD can remove 85–90 % of SO_2 emissions (Jamil *et al.*, 2013) and more than 97 % of fine particle emissions from the flue gas flow escaping the coal fired boilers (Saarnio *et al.*, 2014), the ensuring of proper functioning of FGD process is a necessity. At the same time, the penetration of intermittent renewable energy sources (e.g. wind and solar power) set new dynamical requirements to conventional power plants that also flue gas cleaning processes must tackle. Additionally, co-combustion of biomasses, e.g. wood pellets, along with coal set new requirements also for flue gas cleaning processes (Judl *et al.*,

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2014). Hence, securing reliable operation efficiencies of sulphur removal processes are getting increased attention, and indirect monitoring can provide assistance in this task.

The monitoring methods require a model, which can be based on data or first principle models. The former approach is applied for FGD's e.g. by (Nikula *et al.*, 2012); (Nikula *et al.*, 2013). There are quite a few publications covering first principle modelling of spray dry absorption process, e.g. (Brogren & Karlsson, 1997); (Scala *et al.*, 2004); (Bandyopadhyay & Biswas, 2007); (Marocco, 2010). However, most of the models are phenomenal studies of processes made from process research perspective. Instead, the objective of this paper is to present a first principle model based monitoring method that utilize process measurements to provide additional and redundant information that can be compared with other measurements and hopefully used to assist the plant personnel in day-to-day optimization of the process. First draft of the approach was presented in (Korpela *et al.*, 2015), which is improved here. In the present approach, the special concern in process operation is with the slurry injection, where the spray nozzles (Fig. 1) have a tendency to get clogged up and/or forming obstructions that hinders efficient spraying. In those cases, the droplets are so large that the droplet falls to the bottom of the reactor with several undesired effects, of which the most negative is lowered SO_2 removal. Unfortunately, it cannot be concluded directly if the spraying is functioning adequately or not at all the nozzles. Therefore, an indirect monitoring method of slurry injection was developed, which is described in this paper. The method was developed for Salmisaari power plant (Power Plant) located in Helsinki, Finland. Still, the approach is generic and can be applied in any spray dry absorption process.

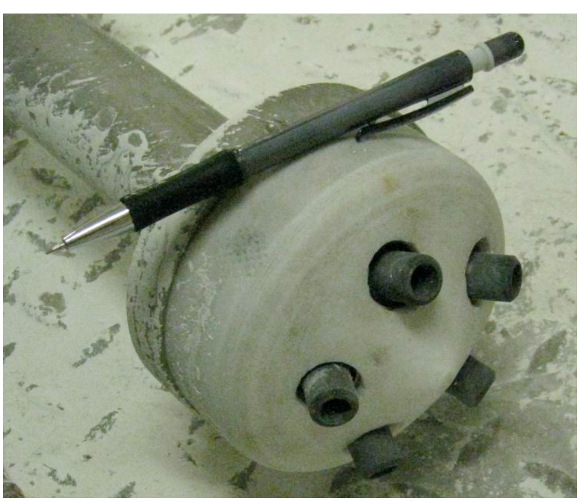

Fig. 1. Nozzle head with five nozzles in Power Plant.

2. SPRAY DRY ABSORPTION PROCESS

Fig. 2 presents a scheme of a spray dry absorption type desulphurization process. There, slurry constituting of water, calcium hydroxide $Ca(OH)_2$ and recycled reaction products is used for sulphur removal. In the process, slurry suspension is injected by compressed air through nozzles (Fig. 1) into reactor towers, where acid components of the flue gas, i.e. SO_2 and HCl, are rapidly absorbed into the alkaline droplets to form calcium sulphite ($CaSO_3$), sulphate ($CaSO_4$) and calcium chloride ($CaCl_2$) while the water of the slurry vaporizes. The main overall reactions in the reactor are (Córdoba, 2015); (Flagan & Seinfeld, 1988)

$$Ca(OH)_2 + SO_2 + H_2O \rightarrow CaSO_3 \cdot 2H_2O \quad \text{(R1)}$$

$$CaCO_3 + SO_2 + 2H_2O \rightarrow CaSO_3 \cdot 2H_2O + CO_2 \quad \text{(R2)}$$

$$CaSO_3 \cdot 2H_2O + 0.5O_2 \rightarrow CaSO_4 \cdot 2H_2O \quad \text{(R3)}$$

$$Ca(OH)_2 + 2HCl \rightarrow CaCl_2 \cdot 2H_2O, \quad \text{(R4)}$$

where the phrasing '$\cdot H_2O$' stand for chemically bound water. With appropriate control of gas distribution, slurry flow rate and droplet size, the droplets are dried by the time they reach the flue gas exit near the bottom of the reactor tower. Some of the dried products, that contain desirably maximum proportion of end products $CaSO_3$, $CaSO_4$ and $CaCl_2$, minimum amounts of reactive $Ca(OH)_2$ and calcium carbonite ($CaCO_3$); and water and ash, fall to the bottom of the reactor, while most of the solid particles moves along with the flue gas to bag filters. The filter fabric slowly collects the reaction products, and SO_2 removal continues there if the moisture content of the flue gas is at adequate level. Ultra sound and compressed air pulses can be used to shake the reaction products to the bottom of the fabric filter units. After that, most of the solid products are recycled to the slurry production system and the rest is discarded as unusable end product. At the end, the purified flue gas flows out to chimney via an exhaust gas fan.

The slurry injection is controlled in a way that the moisture content of the flue gas is within desired range that the sulphur removal continues at the surface of the bag filters. In practice, this is implemented by controlling the temperature of the flue gas at the bottom of the reactor by slurry flow injection.

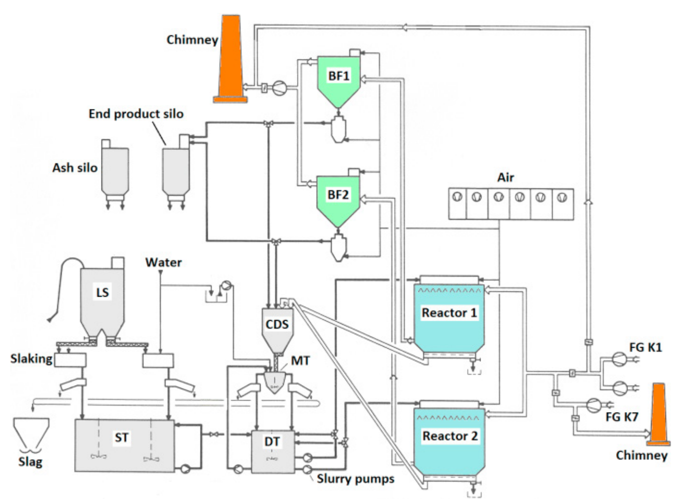

Fig. 2. FGD in Power Plant. Abbreviations: FG ≡ flue gas, BF ≡ bag filter, CDS ≡ circulating dust silo, MT ≡ mixing tank, DT ≡ dosing tank, ST ≡ storage tank, LS ≡ lime storage.

3. MODELLING OF SULPHUR REMOVAL

The proposed method to monitor functioning of spraying is based on energy balance. The fundamental idea is that by estimating the flows, contents and temperatures of injected flue gas, slurry and compressed air, the energy balance of the