Operating Experience of Circulating Fluidized Bed Scrubbing Technology in Utility Size Power Plants

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Abstract

Tightening environmental regulations are lowering the requirements for emissions from power plant and industrial facilities around the world. Newer, stricter standards are being required by more governments for pollutants that are already being regulated—SOx, NOx and particulate matter. In addition, metals, acid gases, and organic compounds are setting requirements for flue gas cleaning systems. USA’s EPA Mercury and Air Toxics Standards (MATS) rule enacted in December 2011 and the upcoming IED requirements become completely in force by January 2016 in Europe. Due to the new requirements for flue gas acids like SOx, HCl, HF, dust and many other multi-pollutants, owners of coal fired, oil fired and waste fired power plants are continuously evaluating the merits of adding back-end air quality control systems (AQCS).

This paper takes a special focus to the first operation experiences of Basin Dry Fork station project, which entered in commercial operation 2010, featuring best available dry scrubbing technology (BAT) for the first time worldwide in large unit size/1 unit for 420MWe plant. It will be shown how the technology is able to meet the strict emission requirements and even more. Furthermore, experiences from an oil-fired refinery boiler in Europe taken into operation in Jan.2012 are highlighted.

The Circulating Fluidized Bed Scrubbing (CFBS) is a viable pathway for addressing multi-pollutant control in a cost effective manner. Combining lime hydration and storage equipment, a circulating fluidized bed upflow reactor/absorber and downstream fabric filter, all CFBS system equipment can be installed in one building or outdoor. Construction costs can be reduced as the major system components can be pre-assembled on the ground and lifted into place during system erection. The technology provides high pollutant removal efficiencies to 99% for SO2, SO3, HCl and HF. Further on the absorber/fabric filter arrangement is highly adaptable for sorbent injection for removal of heavy metals including mercury.

Manuscript

Introduction

The Dry Fork Station of Basin Electric Power Corporation (BEPC) was planned in 2006 and 2007 and main contractors were Mitsubishi for the turbine and steam cycle, Babcock/Wilcox for the boiler, coal handling and the DeNOx (SCR) and Graf-Wulff in cooperation with Nooter/Eriksen for the FGD and dust removal. In 2011, Foster Wheeler purchased the Graf-Wulff company and is now offering the CFBS technology on the global market. Corporately with Sargent & Lundy (S&L) the FGD plant was designed and supervised until completion. During the planning phase, S&L together with BEPC have initially made a pre-decision for a semi-dry spray dryer absorption (SDA) and a circulating fluidized bed (CFB) FGD-process. The main advantages of these technologies are up to 30% less water consumption, compared to a wet FGD (WFGD), the high removal efficiencies in particular SO2, SO3 and H2SO4, the assured product utilisation for landfill at the nearby opencast coal mine (see Fig. 1) and significantly lower investment costs.
The final decision between the semi-dry SDA process and the CFB scrubber technology was due to its almost unlimited pollutant removal performance. The hydrated lime Ca(OH)$_2$ is fed as a dry powder into the CFB-Scrubber and the flue gas are conditioned by spraying water. Thus the requested high levels of 98% desulphurisation are safely maintained, and any emissions are reduced simultaneously below permitted and contracted limits.

Another advantage of the CFB technology is the high capability of buffering the effect of possible fluctuations of the SO$_2$ content (6:1) in the boiler flue gas, caused by the variable sulphur content of the fired PRB coal. Due to the independent water conditioning and hydrated lime input, all SO$_2$ concentrations in the flue gas are reduced at any time below required emission levels.

A further technical argument for the CFB technology was the possibility to maintain or exchange the water spraying equipment during operation, without interruption and any limitation to the emission levels. Moreover, there is no rotating mechanical equipment within the CFB-Scrubber, what would require maintenance.

The FW lime dry hydration plant (LDH) is an additional technical and economic advantage for the operation of the Dry Fork station. On the basis of burnt lime (CaO) and added water, the LDH produces a cost-effective hydrated lime with extremely favourable characteristics for the SO$_2$/SO$_3$ removal. The hydrated lime from the LDH’s is used both online in direct operation as well as in combination with the hydrated lime silo.
As shown in Fig. 2 the CFB-Scrubber is an up-flow absorber. Due to the specific design of the venturi nozzles at the inlet the flue gas is accelerated in the bottom zone of the CFB-scrubber and expands in the cylindrical part in such a way that it forms a circulating and refluxing fluidized bed, consisting of hydrated lime, fly ash and recirculated reaction products.

In connection with the SO₂ limits and the SO₂ content in the boiler flue gas, the required amount of hydrated lime produced in the LDH is blown pneumatically into the absorber. To increase the solid surface and the solid residence time the particles, leaving the CFB-Scrubber, are collected in the downstream bag house hoppers and recirculated into the scrubber multiple times by air-slides. The temperature optimized for the chemical reaction is obtained within the CFB-Scrubber by spraying water into the fluidized bed. Due to the fact that this water is used only for conditioning of the flue gas temperature the general water consumption is very low. This technology specific feature gives a high environmental benefit in this very arid area around the Dry Fork station. The final dust removal takes place in the bag house. Then all emissions of the clean gas are far lower than the required emission values.

The pressure in the boiler is controlled by the ID fans located in between the baghouse and the stack. The clean gas is leaving the stack with almost no emissions left.
**DESIGN AND SUPPLY**

The system basic design comprises the following main components (see Fig. 3):

Fig.3: 3D Model of the plant without stack

![3D Model of the plant without stack](image)

The footprint requirement of the entire system including the absorber, the baghouse, the LDH as well as the silos (burnt lime, hydrated lime), is only about 60m x 30m.

Starting at the air pre-heater outlet, two raw gas ducts lead up to the two inlets of the CFB-Scrubber. Downstream the CFB-Scrubber, 6-compartments FW baghouse serves as a process filter and final precipitator. Under each Filter compartment, a hopper is integrated as a buffer for the solids recirculation. Solids are recirculated by an air-slide with a flow control unit for each compartment. The cleaned flue gas from the baghouse is merged in two clean gas ducts and into the two ID fans, designed as a radial fan, and finally into the stack.

The additional equipment comprises essentially the conveying systems for the solids in- and output system, the water spraying system of the CFBS and two independently driven LDH plants. Due to possible bad weather conditions a lime silo with a capacity of 21 days is installed. In combination with the product utilisation a mixing screw conveyor is installed at the outlet of the product silo for mixing fly ash and reaction product homogeneously with water.
ERECTION, COMMISSIONING AND PERFORMANCE TEST

Start of erection was in February 2009, end of erection in December 2010. The plant was commissioned gradually, with all FGD components, until May 2011. During erection large components are preassembled on site and subsequently lifted into place of the steel construction. A snapshot while lifting a part of the baghouse is shown in Fig. 4.

![Fig. 4 lifting of a preassembled part of the baghouse](image)

Initial tests procedures on coal-fired boiler flue gas were executed and several common optimizations were made. During start-up only two major adjustments were made. Due to the 15% lower amount of boiler flue gas flow compared to the contract data, stabilizers were installed in the fluidized bed. Furthermore, the response times for the temperature control by means of water spraying, have been improved by the factor 10 by installing fast responding equipment. With these measures, a very stable and an at any time emission optimized operation, at all boiler loads, was achieved.

The first full operation of the FGD with all auxiliary equipment in operation, under compliance with all emission permits commenced in June 2011. During commissioning the minimum and maximum operating gas flow of the FGD was tested. The minimum gas flow without recirculation was tested with 1,500,000 m³/h and the maximum case was tested with 3,500,000 m³/h. The plant performance was stable over the complete range of gas flow. Operating the installed recirculation, the turndown rate of boiler flue gas could go down to a minimum value of 1,000,000 m³/h, corresponding to 25% - 30% of the boiler design load. The plant was shut down and inspected after complete commissioning and a continuous operation period. The inspection showed no changes compared to unused conditions, thus the plant could be restarted immediately and was ready for unlimited operation. The picture in Fig. 5 shows the FW plant after completion of erection.
During the initial operating period from late June until mid-October 2011 various operating and warranty measurements were carried out. The results are shown in Table 1 and 2. The performance test in October 2011 has shown that all emission limits in particular SO₂, solids and the opacity (due to mainly SO₃) are fully in compliance. In addition, without injection of activated carbon, a significant removal rate of mercury is achieved. Further details are given in Table 1 and 2.

<table>
<thead>
<tr>
<th>Flue Gas Data</th>
<th>Inlet Design</th>
<th>Outlet Design</th>
<th>Outlet Measured</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flue Gas Flow*</td>
<td>[m³/h]</td>
<td>3,045,000</td>
<td>2,630,000</td>
</tr>
<tr>
<td>SO₂</td>
<td>[mg/m³]</td>
<td>800-2,200</td>
<td>60 - 75</td>
</tr>
<tr>
<td>SO₃</td>
<td>[mg/m³]</td>
<td>25 - 42</td>
<td>1 - 2</td>
</tr>
<tr>
<td>HCl</td>
<td>[mg/m³]</td>
<td>8 - 15</td>
<td>4 - 6</td>
</tr>
<tr>
<td>Dust</td>
<td>[mg/m³]</td>
<td>4,000 – 6,000</td>
<td>12 - 17</td>
</tr>
<tr>
<td>Temperature</td>
<td>[°C]</td>
<td>146</td>
<td>70 - 80</td>
</tr>
<tr>
<td>Hg-removal rate</td>
<td>[%]</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

* 57 – 114 % of flue gas flow without recirculation
* 33 – 114% of flue gas flow with recirculation
** without AC injection
*** below detection limit

Table 1 Design values and operating measurements
In the first half of October 2011, the performance tests, in terms of emissions and fuel consumptions under contractually agreed criteria, were executed. These have shown that all consumptions were lower than stipulated, i.e. all consumption, especially electricity, water and lime, are 10 - 20% below the guaranteed values. Furthermore, all emission values were well below the guaranteed limits. The core emission values are summarized in the following table:
<table>
<thead>
<tr>
<th>Pollutants</th>
<th>Guaranteed Emission values</th>
<th>Measured Emission values</th>
</tr>
</thead>
<tbody>
<tr>
<td>SO₂ [mg/m³]</td>
<td>60 - 75</td>
<td>15 - 50</td>
</tr>
<tr>
<td>Dust content [mg/m³]</td>
<td>12 - 17</td>
<td>2 - 4</td>
</tr>
<tr>
<td>SO₃/Sulfate in total [mg/m³]</td>
<td>1 - 2</td>
<td>&lt; 1 - 2</td>
</tr>
<tr>
<td>HF [mg/m³]</td>
<td>0,5 - 1</td>
<td>&lt; 0,5 - 1</td>
</tr>
<tr>
<td>Opacity [%]</td>
<td>20</td>
<td>1</td>
</tr>
<tr>
<td>Mercury [µg/m³]</td>
<td>4-12</td>
<td>1-6</td>
</tr>
</tbody>
</table>

Table 2 Emission values

**OPERATION EXPERIENCE**
During more than 18 months operation since successful performance test has been demonstrated the FGD-Plant availability was close to 100% without any boiler operation restriction caused by the FGD technology itself.

The FGD plant has been operated in complete and continuous compliance with the emission limits (15% below permission limits) even from start up with the first coal fire, firing on the requested load, any turn down of the load as well as usual operation between 80-106% of the nominal boiler load.

During February 2012 for one month mercury removal has been tested including pulverised activated carbon (PAC) by flue gas duct injection upstream of the FGD-Plant [2]. It has been demonstrated during this operation period of 30 days that with approx. 20mg PAC/m³ flue gas the emission limit of 2µg total Hg/m³ (15% below permission limit) was safely in compliance with the mercury limit. With representative operation data the mercury removal rate has been 70% without AC and in addition up to 80-85% with AC. This leads to a total mercury removal rate of up to 95.5%.

Results of a new measurement campaign for further optimisation might be shown in the presentation.

Since the operation of the plant the FGD-Product has been utilized in the nearby coal mine for recultivation (see also Fig. 1).

This has been done by mixing a fraction of FGD-Product with fraction of fly ash and water as follows:
Due to missing precipitator after the boiler the full amount of fly ash is continuously introduced with the flue gas from the Boiler in to the CFB-Scrubber and there homogeneous mixed. The mixture of approximate 60-70% fly ash and 30-40% FGD-Product takes place within the CFB-Scrubber with simultaneous desulfurization.

The mixed dry Product is collected in the hoppers of the baghouse and pneumatically transported into the Product Silo.

The outlet of the Product Silo is equipped with a moistening screw-mixer and approximate 30-35% water of low quality is mixed into the FGD-product to start the stabilization of the final product. The final product is loaded into an open truck and taken for stabilized landfill in the close by area of an open pit coal mine (see Fig. 6).
The approximate product fractions are:
- 20-30% FGD-Product
- 40-50% fly ash
- 30-35% water

After a few days (3-7 days) at the open mine this product is stabilized to a lean concrete with fixation of any species due to a low permeability.

**CONCLUSION**
With installation and operation of this FGD plant, it is demonstrated that the FW CFB scrubber technology is suitable of every power plant application up to 500MWe-range. It is also commercially available for power plants of larger capacity (up to 700MWe), with single-train flue gas cleaning systems, where removal rates are achieved, which are today still not required in power plants in Europe – e.g. for SO$_x$ and also for the removal of mercury (Hg). In addition the utilization of the FGD-Product as landfill without installation of further equipment has been demonstrated on a large scale.
OPERATING AND EMISSION EXPERIENCES FROM A FWGW FGD-UNIT IN A REFINERY

The same dry CFB-scrubber technology as described previously is also installed in an oil fired (several waste streams in a refinery) boiler unit (two lines) to clean the flue gases. The process is basically shown in the following simplified block diagram (see Fig.7):

![Simplified block scheme of an FGD-unit inside a refinery application](image)

In this plant concept the FGD-unit is placed behind an ID-fan (what controls the boiler pressure) and is independently from the boiler controlled by an own ID-fan. After cleaning process between high sulfur loaded flue gases with the absorbent hydrated lime produced from quick lime CaO in an installed FW Hydration unit and the recirculated product the clean gases leave the bag house and achieve the target emission limits and even lower as shown in the following table:
Boiler specification and FGS Design Data  
(Concentrations based on 6% O₂-reference value)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>RCFB-diameter</td>
<td>(m) 4.7</td>
</tr>
<tr>
<td>Particulate-Collector</td>
<td>2 compartments</td>
</tr>
<tr>
<td>Boiler and FGS Configuration</td>
<td>1 Heavy Fuel Oil Fired Boiler + 1 FGS train</td>
</tr>
<tr>
<td>Fuel Sulfur Content</td>
<td>(%daf) 1 - 5</td>
</tr>
<tr>
<td>Firing-capacity</td>
<td>(MWth) 175</td>
</tr>
<tr>
<td>FGS Inlet</td>
<td></td>
</tr>
<tr>
<td>FGS Outlet</td>
<td></td>
</tr>
<tr>
<td>Flue gas flow, each FGS</td>
<td>(Nm³/h) 227.000</td>
</tr>
<tr>
<td>Flue gas temperature</td>
<td>(°C) 180</td>
</tr>
<tr>
<td>SO₂-content</td>
<td>(mg/Nm³) 1.880 - 7.340</td>
</tr>
<tr>
<td>SO₃-content</td>
<td>(mg/Nm³) 50 - 970</td>
</tr>
<tr>
<td>Particulate-content</td>
<td>(mg/Nm³) 65</td>
</tr>
</tbody>
</table>

Since the commissioning was successfully finished in spring 2012 the FGD-plant operated close to 100% availability without interruptions related to the FGD-operation.

REFERENCES
1. Sargent & Lundy LLC and Basin Electric Power Cooperative, Publication “Selection of the Sulfur Dioxide Control Technology for a New Coal-Fired Generation Station” (2009)
2. Sargent & Lundy LLC, Report “Dry Fork Station – Unit 1 Mercury Control Optimization Study” (April 2012)

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