1. Abstract

The Chiyoda Thoroughbred 121 (CT-121) flue gas desulphurisation (FGD) plant is recognised in Japan and the USA as the most competitive wet scrubbing technology currently on the market. The principles of the CT-121 FGD process and the unique Jet Bubbling Reactor (JBR) are discussed in this paper, comparisons are made to the more conventional wet limestone based FGD processes, and finally the advantages of the CT-121 are referred to.

2. Introduction

The CT-121 FGD process is a 2nd generation wet limestone based FGD process that combines the need of low investment and operational costs with an easy and reliable operation.

The CT-121 FGD process is the result of reversing the conventional concept for wet limestone based FGD. In the CT-121 design, the absorbent liquid is the continuous phase, and the flue gas is the dispersed phase. This is accomplished in the patented absorber, the Jet Bubbling Reactor (JBR), in which the flue gas is forced through the absorbent liquid. The principle is shown in Figure 1.

For more than two decades the CT-121 FGD process has been among the leading FGD technologies in the world. The list of references is extensive, and with a recent remarkable

Fig. 1: Schematic of the Jet Bubbling Reactor (JBR)
break-through in the USA and China, 46 units with a total capacity of more than 14,000 MW are in operation, and 18 units comprising approx. 11,000 MW are in the design and construction phase worldwide.

At present only a few units are operating in Europe, but Chiyoda Corporation, one of the world’s leading engineering and construction companies, has now entered into a license agreement for design and construction of CT-121 FGD Plants covering Europe with STF s.p.a., Italy, and their fully owned subsidiary, BWE A/S, Denmark.

Furthermore, the CT-121 process has been internationally honoured as an exceptional FGD technology and has received several international awards.

3. Principles of the CT-121 FGD process

3.1 Mass transfer mechanism

The key component of the CT-121 FGD plant is the unique JBR, in which all the critical reactions take place. The flue gas is quenched in a gas cooler prior to entry into the JBR inlet, from where it is forced through the absorbent liquid creating the crucial active area for mass transfer of pollutants from the gas phase to the liquid phase.

Additionally, absorbent liquid and oxidation air is introduced into the JBR enhancing the violent mixing of slurry. The cleaned flue gas proceeds to the upper part of the JBR and passes through a mist eliminator before it enters the stack, and the produced and fully oxidised gypsum is drawn off for dewatering. In this way, the CT-121 FGD process combines all reaction zones in the Jet Bubbling Reactor.

Figure 2 below shows in more detail the nature of the flue gas as it is forced through the numerous sparger pipes submerged below the liquid level in the JBR.

The overall chemical reactions are identical to those experienced in any other wet lime-stone based forced oxidation FGD process as can be seen from figure 3 below.
3.2 Process flexibility

A major advantage of the CT-121 process is its inherent operating flexibility. The process is designed for wide operating ranges of flue gas flow rates and SO$_2$-loads. SO$_2$ removals of 99% on SO$_2$-contents of 7,000 ppm have been demonstrated. Moreover, the flexibility of the CT-121 not only allows the process to fit a wide range of owner requirements, it also handles changing operating and regulatory requirements.

When designing an FGD plant the central consideration is how to remove the desired amount of sulphur at the minimum cost. The operating costs are mainly limestone and energy. Whereas there may be an advantage of a few percent in limestone consumption for the CT-121 compared to a conventional open spray tower FGD process, due to the lower possible operating pH, the advantage in power consumption can be significant.

The JBR relies on the liquid submergence of the sparger pipes (i.e. the absorber level) to generate the gas-liquid contact. The cost of this is pressure drop that has to be overcome by the flue gas fan. As the flue gas fan can be continuously controlled it is possible to optimise the JBR operation for any conceivable operating case within the design range.

A conventional open spray tower relies on large recirculation pumps to generate the gas/liquid contact required for SO$_2$ removal. The energy spent is the power consumption of the pumps and the fan power needed to overcome the pressure drop generated in the tower. As the pumps have to be operated on/off this means that the open spray tower is operated in steps and is only running at optimum conditions for the exact load cases for which the pumps are designed.

3.3 Reactor design and materials

The CT-121 can be supplied in any of the normally applied materials of construction, e.g. carbon steel with resin/rubber lining, carbon steel with high alloy cladding, solid high alloy, concrete with Stebbins tile, or FRP. The final choice will depend on the client’s preferences, technical specifications and an overall economical assessment.

Furthermore the reactor shape can be either circular or rectangular. The general experience is that the rectangular absorber allows a simpler and more compact layout with a lower capital cost, and the large majority of the units that have been commissioned over the last 10 years have been of the rectangular type. In both designs the inlets and outlets can be rotated freely.

3.4 Superior gas flow distribution

A major uncertainty in operating large FGD absorbers at high SO$_2$ removal efficiencies is gas flow distribution. As the size of a gas processing unit increases, the potential for maldistribution of gas flow and thereby the risk of compromising the performance also increases. In any FGD system, good gas flow distribution at any gas flow rate is critical to achieve the desired SO$_2$ removal.

The JBR is a natural gas distribution device due to the differential pressure mainly resulting from the submerge of the sparger pipes. Since the spargers are evenly spaced in the JBR inlet plenum, the pressure drop guarantees, that the gas flow is evenly distributed.
The sparger pipes are standard pipes with a 150 mm diameter, and operate with essentially the same flue gas velocity. A CFD study demonstrating the uniform gas distribution in a JBR is shown in figure 4.

As mentioned, ensuring a good gas flow distribution is done through generation of a differential pressure across the JBR. This is at the same time the controlling parameter for SO2-removal efficiency. The relatively high JBR pressure drop generates increased booster fan work compared to a spray tower, but this is more than compensated by the lack of RC-pumps.

This results in a simpler, more flexible and trouble-free operation and control of the FGD-plant. From a process viewpoint, the CT-121 process can be operated from 10% load to 100% load without reduction in SO2 removal efficiency.

### 3.5 Oxidation system

The oxidation air system comprises air blowers and a distribution system for injection of air into the slurry in the bottom part of the absorber. The oxidation air is cooled and humidified before the injection to prevent dry-out scaling at the air nozzles.

The distribution pipe is installed horizontally above the absorber liquid level and the injection pipes enter the Absorber below liquid level. In this way neither flue gas nor absorber liquid can enter the pipe.

The combination of one or more top-mounted, slow-moving agitator(s), oxidation air distribution and gas sparging creates a very efficient agitation. Due to concerns of depositions in the corners of a rectangular JBR extensive investigations have been made to verify the tank agitation. CFD calculations and plant measurements have demonstrated that the agitation is most effective, and that there are no problems with deposition of solids in the corners of the rectangular absorbers.
4. Performance & capabilities

The unique gas/liquid contact mechanism not only allows a high SO2 removal efficiency, it also results in good performance in terms of removal of sulphuric acid, particulates and heavy metals.

SO2 removal efficiencies of above 99% can be received on a continuous basis in the full load range of the reactor. The typical overall performances can be summarised as follows:

- SO2 removal >99%
- Particulate removal >90%
- SO3 removal 40-60%
- Hg removal 20-50% elemental Hg
- Min. turn down ratio 10%
- Historical reliability >99.5%

Examples of recent installations in Japan are given in figures 5 and 6: The given examples are designed for coal firing with relatively low S-contents. There are numerous installations operating on high S coal. For a complete overview of CT-121 installations with operational data please obtain the reference list, see company details in section 7.
5. Comparison to conventional FGD processes

5.1 Absorber design
The JBR is in its nature quite different from a conventional spray type absorber. As the gas liquid contact is created in a submergence level typically in the range of 15-40 cm (compared to up to 15 m high absorption zone in a spray tower) the overall absorber height is minimized. This is advantageous, especially for in-door installations, and enables inspections and maintenance to be carried out without the need for extensive scaffolding. The two absorber types are compared in figure 7.

![Figure 7: Comparison of JBR and spray type absorber (350 MW)](image)

5.2 Absorbent quality & chloride levels
The CT-121 process can operate effectively in a pH range down to 4.5, i.e. significantly lower than the comfortable range for most other wet limestone based FGD processes. The operating pH of conventional FGD processes is typically 5.5 - 6.0. This relatively high range is required in order to generate the mass transfer rates required by the high desulphurisation efficiencies commonly specified today. The adverse effect is that the limestone is not completely dissolved even under the best conditions.

In open spray tower processes the SO\(_2\) removal depends on dissolved alkalinity, which in turn depends on limestone dissolution rate, normally measured as limestone reactivity. At the operating pH of CT-121 the limestone is almost completely dissolved, and the driving force for SO\(_2\) removal is maintained by efficient sulphite oxidation rather than dissolved alkalinity. The JBR simply operates closer to the sulphite oxidation optimum, which in turn ensures excellent gypsum quality.

High concentrations of dissolved chloride significantly suppress the pH in the absorber slurry and may reduce SO\(_2\) removal. High ionic strength caused by the high chloride
concentration has an adverse effect on the transport of H\(^+\) to the surface of the limestone particles, an important step in the limestone dissolution process.

The CT-121 FGD process is relatively unaffected of this phenomenon, whereas the response to high dissolved chloride level in other FGD processes is to increase the dissolved alkalinity to maintain the required SO\(_2\) removal. But increased alkalinity requires increased amounts of un-dissolved (residual) limestone in the scrubbing slurry. This increases the operating costs as well as the scaling potential, and even risks compromising the gypsum quality.

At Hekinan power station, Japan, 3 different FGD processes are installed at identical boilers, each 700 MW installed power. Units 1 & 2 are equipped with spray towers, unit 3 is equipped with a CT-121 FGD process. An extensive measurement programme for comparison of the three FGD processes have been made, with the following results:

<table>
<thead>
<tr>
<th>Unit</th>
<th>Inlet SO(_2)-emission</th>
<th>Operating Power, MW</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unit 1, &quot;A&quot; Spray Tower</td>
<td>300 ppm</td>
<td>9.4</td>
</tr>
<tr>
<td>Unit 2, &quot;B&quot; Spray Tower</td>
<td>400 ppm</td>
<td>10.4</td>
</tr>
<tr>
<td>Unit 3, CT-121</td>
<td>500 ppm</td>
<td>11.1</td>
</tr>
</tbody>
</table>

![Figure 8: Operation costs for CT-121 vs. spray towers](image)

The measurement programme was performed in the period November 2002 to February 2003. The three FGD units were operated at identical inlet conditions, and to a SO\(_2\)-emission of 16 ppm.

### 5.3 Mist carry-over

The low disengagement velocity from the froth zone in the absorber combined with the fact that the process does not include spray nozzles giving very fine droplets upstream of the mist eliminator results in very limited carry-over of slurry to the mist eliminator. As a consequence the water consumption for mist washing can be reduced significantly, allowing a more flexible overall water balance.

### 5.4 Gypsum dewatering

The dewatering equipment is the same as for competing FGD processes, i.e. typically basket centrifuges or vacuum belt filters. The design will normally include hydro cyclones for pre-thickening.
Experience shows that the JBR produces larger gypsum particles than a typical spray tower. It is commonly accepted that smaller particle sizes makes satisfactory dewatering difficult. An example is given in figure 9.

![Figure 9: Gypsum particles for CT-121 (left) vs. spray tower (right)](image)

One reason to this is that the recirculation rate in an open spray tower will expose the gypsum particles to severe degradation in the recirculation pumps. The typical open spray tower has a residence time of 2 - 4 minutes between recirculation (i.e. the hourly recirculation rate is 15 - 30 times the tank volume), meaning that an average gypsum particle will be sent through the recirculation pump as much as 500 times before being dewatered. For a CT-121 process this value is typically much less than 100 times.

5.5 Particulate removal

The intense contact between gas and liquid in the JBR also results in excellent particulate removal performance. Typical performance is shown in figure 10 below.

![Figure 10: CT-121 particulate removal](image)
6. **Summary of advantages**

There are many advantages in favour of the CT-121 Process over other FGD processes. The most important are summarized as follows:

- The CT-121 process routinely achieves almost 100% reliability.
- Low capital and O&M costs
- The CT-121 does not include multiple large spray pumps and valves requiring heavy maintenance.
- The CT-121 has near-infinite turndown compared to a spray tower.
- Easy maintenance access to all internals without the need for scaffolding
- Excellent particulate removal performance due to the intense gas/liquid contact.
- Very good sulphuric acid and heavy metals removal
- Very low mist load on the mist eliminator

7. **Company details**

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