The flexible design of the CT-121 FGD
– a perfect match for DONG Energy's
Asnæs Power Station

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1 Introduction

The two older coal fired boilers #2 and #4 at the Asnaes Power station are not equipped with flue gas desulphurization equipment. Therefore, as the latest emission requirements of the EU Large Combustion Plant Directive cannot be met, the two units can no longer be operated. The plant owner DONG Energy has decided to install a new FGD plant to treat the flue gas from the 147 MWe Unit 2 while Unit 4 has been mothballed. One design criteria for the new Unit 2 FGD has been that, with only minor modifications, the system must be able to treat the effluents from a possible future upgrade of the 400 MWe Unit 4.

Focus by the client has been on a simple though reliable low cost solution and a short project execution time of 23 months.

Among other things this scrubber will be the first outdoor FGD plant for a Danish utility boiler and also the first Danish FGD with a wet stack.

To overcome the pressure drop of the FGD system, a new booster fan will be installed in the A position, upstream the FGD (outside the scope of the FGD supply). There will be no by-pass system and the treated flue gas will be led directly from the FGD to the wet stack (also outside the FGD scope) without reheating .

At the absorber outlet, there will be an empty casing for a possible future flue gas reheater to be installed. The Jet Bubbling Reactor (JBR) itself plus mist eliminator and reheater casing will be made of flaked glass-lined carbon steel, the flue gas cooling inlet section will be made of solid Hastelloy C276, and the clean gas duct will be made of FRP.

2 The CT-121 jet bubbling process

The heart of the process is the Jet Bubbling Reactor (JBR). As opposed to the spray towers, flue gas is dispersed when introduced to the absorbent slurry through submerged sparger tubes. The SO_2 absorption occurs as the dispersed bubbles travel through the reaction zone of the JBR.

The untreated flue gas, adiabatically quenched in the gas cooler, enters the JBR inlet plenum, then flows down through the gas sparger tubes and into the jet bubbling zone. The liquid submergence in the JBR is 100 to 500 mm WC. In order to ensure reliable FGD operation, complete saturation of the flue gas in the gas cooler is a key design parameter.

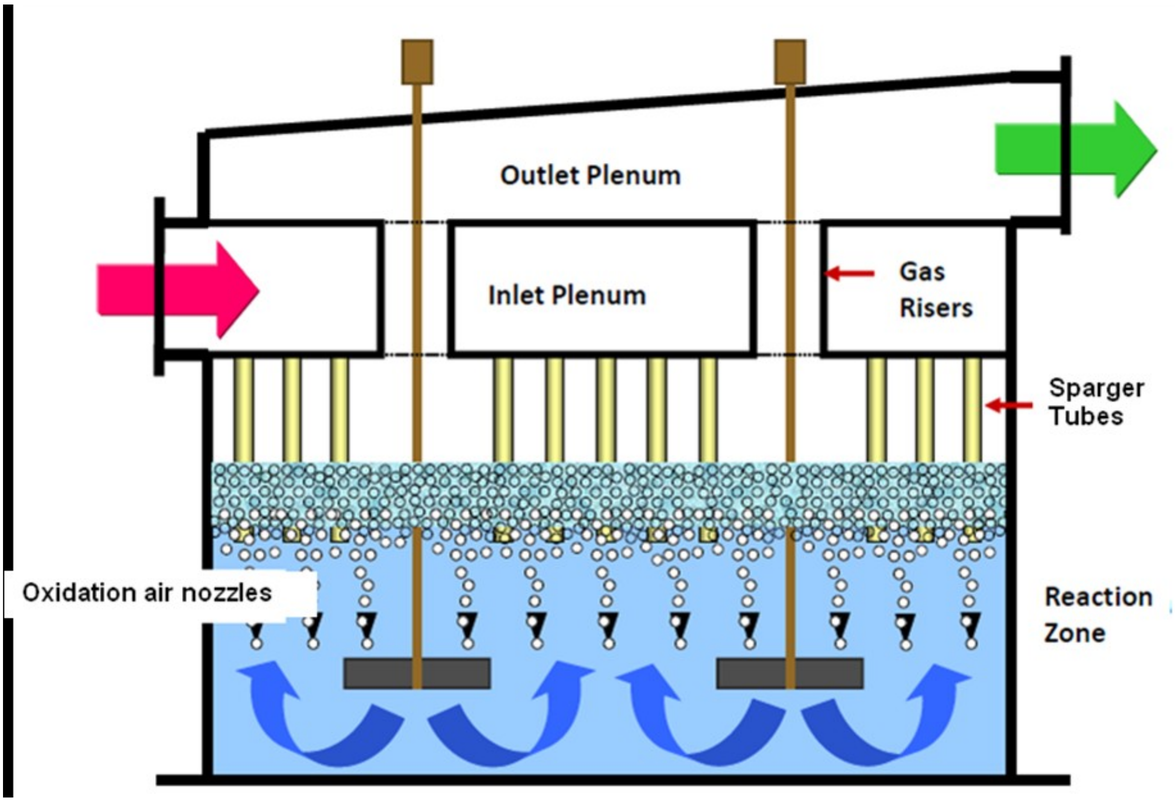

Figure 1   Schematics of the CT-121 Jet Bubbling Reactor

The CT-121 FGD process is a wet limestone gypsum process. Oxygen necessary to oxidize bisulphite for bisulphate is supplied from oxidation air blowers and is distributed in the reaction zone of the JBR through a set of air nozzles. Water is injected into each oxidation air line just before it enters the JBR to quench and humidify the air, effectively preventing scaling formation at the oxidation air lance tips.

Limestone slurry is injected into the JBR reaction zone through a set of nozzles to form gypsum and to maintain the absorber slurry pH at a constant level.

Flue gas leaving the froth zone passes upward through the gas risers into the outlet plenum. From here the gas flows through the mist eliminator to the stack.

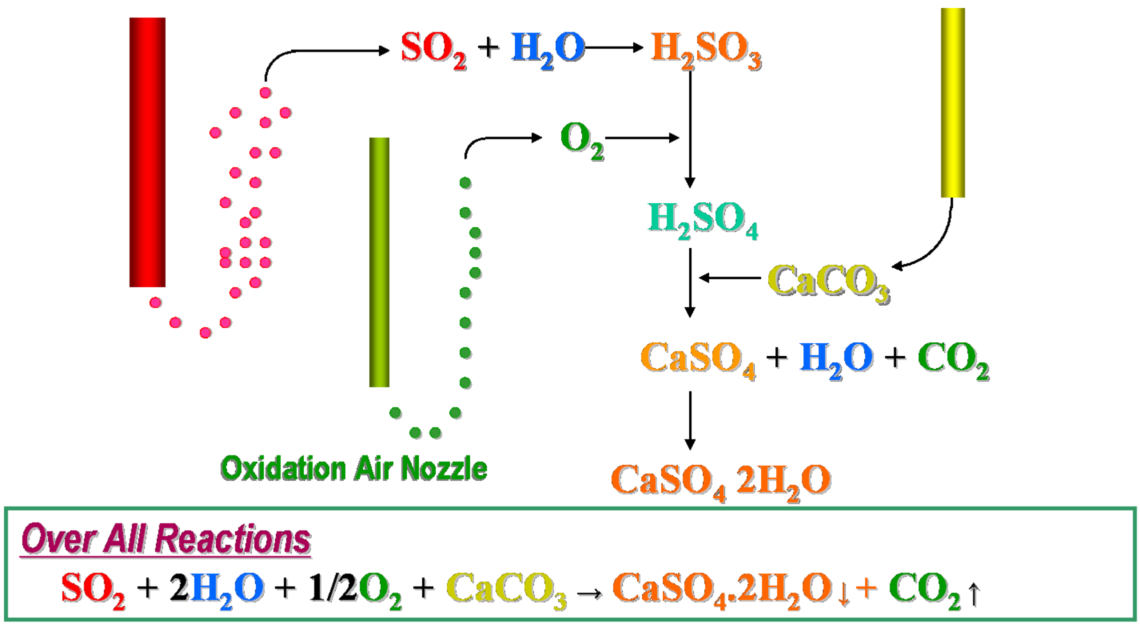

Figure 2 CT-121 chemical reactions

The Asnaes square shaped JBR is equipped with a single top-entry agitator to suspend gypsum and to distribute fresh oxidation air and limestone in the reaction zone. JBRs can be rectangular or circular. For this project a square design was chosen as it fits the limited space available and as this geometry allows for a large degree of pre-assembly and an easy final erection.

3 Design and performance data for the ASV2 FGD

Performance data valid for Unit 2 as well as for Unit 4 operation are summarized in Table 1 below:

Parameter	**Unit**	
SO_2-removal efficiency	%	≥ 98
SO_2+SO_3-emission (as SO_2)	mg/Nm^3 (d, 6% O_2)	< 135
Particulate emission	mg/Nm^3 (d, 6% O_2)	< 20
Gypsum purity	%, weight (dry)	> 95
Gypsum moisture	%, weight	< 10

Table 1 Asnaes 2 / 4 JBR performance data

4 Integration with the existing Unit 5 FGD

The Asnaes 700 MWe Unit 5 has been equipped with an FGD system for the last 15 years. Experience has shown that the existing auxiliary systems for limestone slurry preparation and gypsum dewatering have considerable excess capacity. In order to capitalize on this asset, it was a requirement from DONG Energy that the Unit 5 FGD limestone slurry preparation system should also service the new Unit 2 FGD, and that the Unit 2 dewatering equipment should be closely integrated with the Unit 5 dewatering system so that the redundancy of the Unit 5 FGD system could also be utilized by the Unit 2 FGD. Furthermore the existing Unit 5 hold-up tank will also service the new FGD unit during revision periods.

5 Plant layout, integration with existing structures

As is normally the case when retrofitting existing plants, the amount of space available for the new equipment was a major concern. In this case the situation was further complicated by the fact that space should also be reserved for the future upgrade of boiler Unit 4.

It became clear that the different subsystems of the FGD would have to be installed in different areas of the site. Space for the JBR was found next to the stack. Here a workshop could be demolished, and the JBR would then find a tight fit between a steam pipe bridge and a station road carrying a substantial amount of traffic.

The Unit 2 FGD dewatering equipment will be placed next to the Unit 5 dewatering system in the existing dewatering building. The Unit 2 gypsum by-product will go to the existing gypsum storage.

There will be no separate limestone slurry preparation system for FGD Unit 2. Instead the Unit 2 limestone dosing pumps will be connected directly to the Unit 5 limestone slurry tank and take absorbent from this system. Consequently filtrate from the Unit 2 FGD will have to be led to the Unit 5 limestone preparation system in order to maintain the water balance.

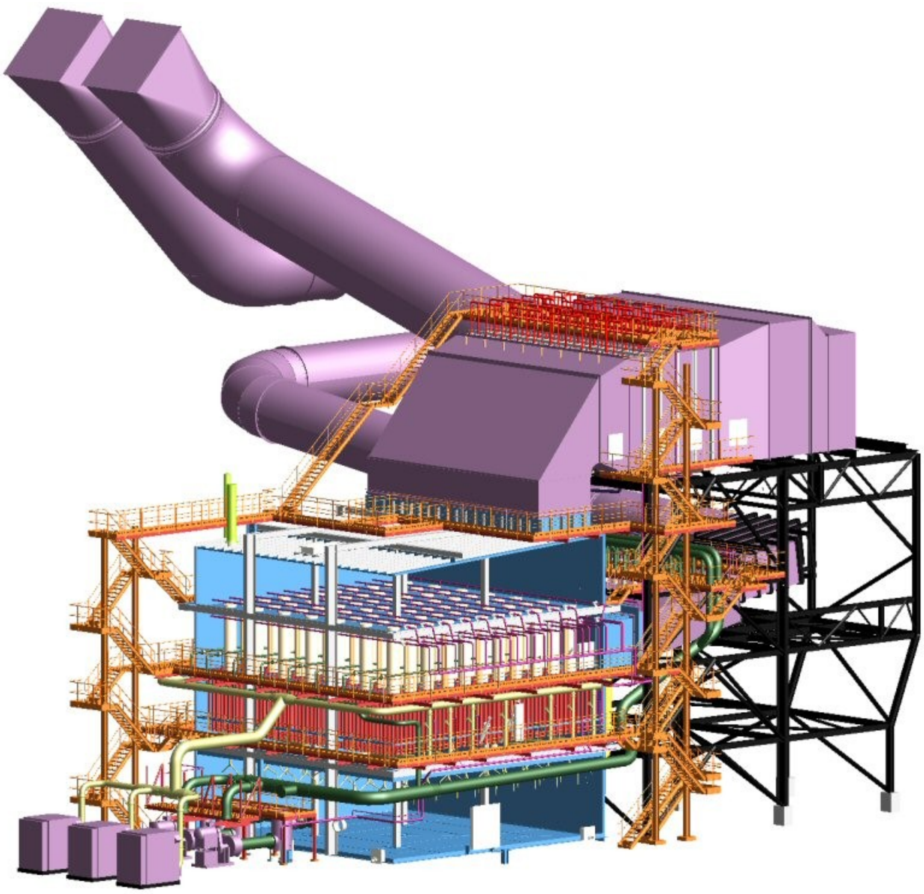

Figure 3   Cut view of the JBR with auxiliary installations

As the existing hold-up tank will also be used for the service of the Unit 2 FGD, it has not been necessary to find space for a hold-up tank for the new FGD.

The JBR will be placed with some distance to both boiler Unit 2 and boiler Unit 4. As a consequence of the distance and the restricted lay out, the flue gas ducting around the absorber has become complicated as indicated by figure 4.

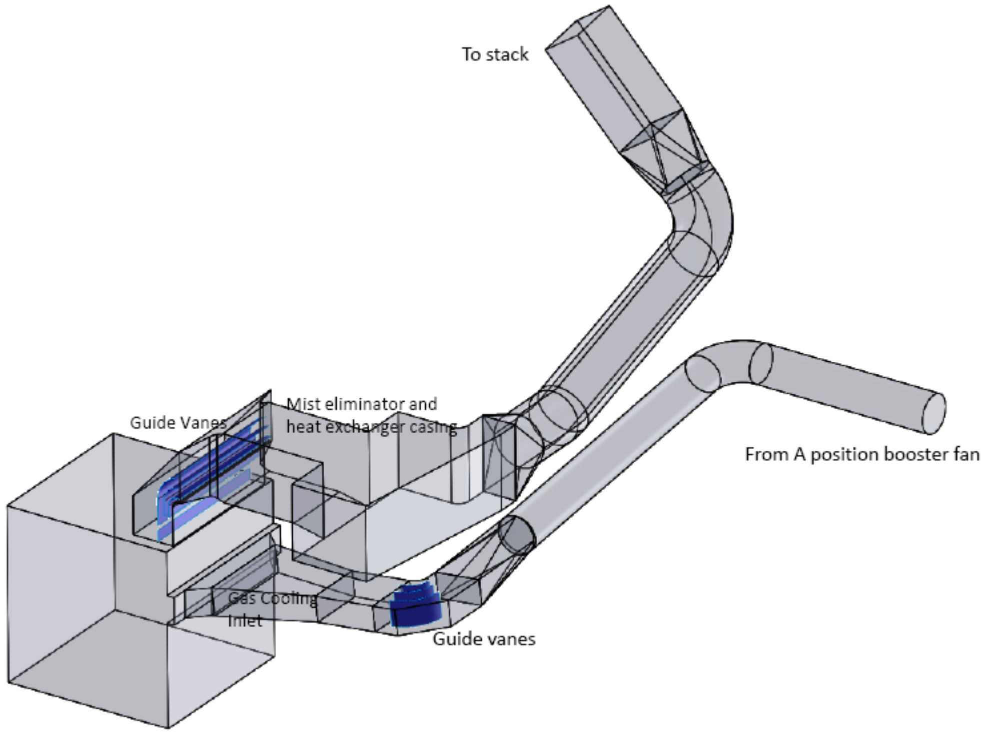

Figure 4   Sketch of JBR inlet and outlet ducts

6 CFD modeling as a tool for duct design

In order to ensure reliable FGD operation, it is important that the flue gas is fully saturated with water when entering the sparger tubes. The saturation occurs in the inlet gas cooler which is an integral part of the CT-121 FGD system. Absorber slurry is extracted from the JBR by the gas cooling pumps and sprayed into the gas cooler through atomization nozzles arranged in two sections of nozzle headers. A condition for the optimal functioning of the gas cooler is an even flue gas distribution over the gas cooler cross section.

The duct routing dictated by the layout restrictions (see figure 4) could lead to a very uneven flow profile in the gas cooler, whereas the gas flow at the battery limit is quite even as the gas from the booster fan outlet passes a silencer and then flows to the supply limit in a long straight duct section.

It was decided to use either a guide vane system or a perforated plate to ensure a good distribution. An experienced consultant company was hired to perform a CFD study of these options.

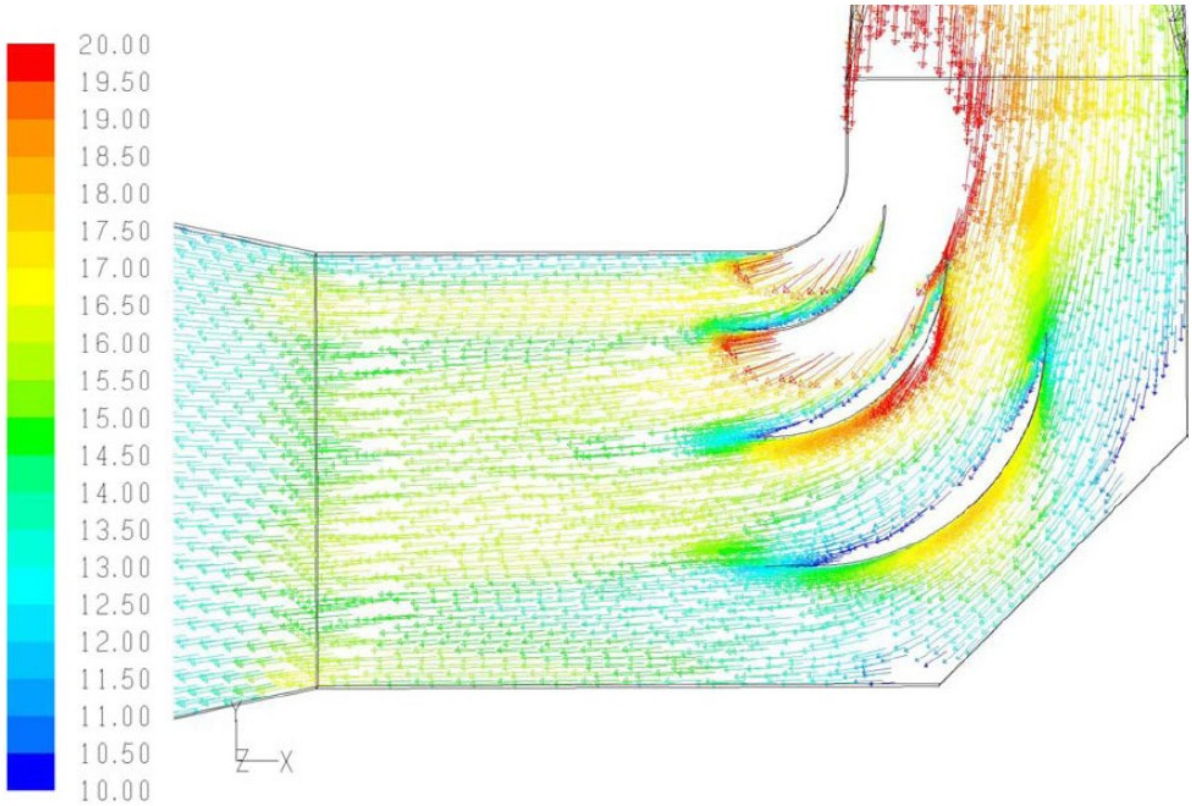

Figure 5 Velocity plot at the duct centre horizontal plane upstream of the Gas Cooling Section, m/s

As a result of the study, a solution based on the installation of three guide vanes has been implemented. The resulting flow profile as well as the geometry of the guide vanes is shown in figure 5. Guide vanes were preferred to the perforated plate solution as the pressure loss of the guide vane system is considerably lower, and in fact lower than the pressure loss of the duct bend without any flow straightening device.

The performance of mist eliminators also depends on the flow profile. This part of the system was therefore also analyzed by CFD and a system of guide vanes upstream the mist eliminators was designed to ensure a proper flow distribution.

7 Considerations regarding a future upgrade from 147 to 400 MWe

The wide load pattern specified for the new Asnaes FGD has raised a number of design issues to be addressed. In the future Unit 4 configuration, the FGD will be capable of handling approximately 1,100,000 Nm^3/h of flue gas. The full load gas flow in Unit 2 operation will be approximately 440,000 Nm^3/h. Furthermore the plant will experience extended periods of reduced load operation, e.g. in the summertime when there is no demand for the unit's electricity production, but the obligations to supply steam and district heating to the neighboring city and industries must still be fulfilled. Therefore, in the first phase, the plant will be able to operate continuously at a flue gas flow of only 100.000 Nm^3/h. This means that in reality there is a need for a turn down ration of 10 to 1 for the FGD based on flue gas flow and even wider if also considering the variation in fuel sulphur.

7.1 Jet Bubbling Reactor sizing

Obviously, once the reactor including reaction zone, inlet and outlet plenum area, tank agitator, and number of sparger tubes has been sized, it is not possible to change this design at a later stage. Therefore it was clear that the JBR would have to be sized, from the very beginning, for the anticipated future 400 MWe boiler.

In Unit 2 operation the load of the JBR will be between 9 and 40 % of design load. As such, low load is not a problem for the JBR. The gas velocity in the sparger tubes will be quite low in the initial phase and will result in a reduced pressure loss in the sparger tubes. The gypsum residence time in the reaction zone will be considerably longer than what is normally applied, but, due to the low speed agitator, it has been shown that this has no detrimental effect on the size distribution of the gypsum crystals.

For the extreme low load operation, the ratio of inner surface area of the reactor to the amount of flue gas becomes high. This can cause problems with the water balance, as inlet and outlet plenum deck requires intermittent washing with process water. This has been analyzed in detail and it was found that this problem can be handled through a tightly controlled water balance.

7.2 The gas cooling section

In order to quench and saturate the inlet flue gas, absorbent slurry is sprayed into the gas cooler through atomization nozzles. For the best effect a reasonable gas velocity is preferable. Therefore it was decided that the gas cooling should be designed for operation of Unit 2. However, a flexible solution has been found. The complete gas cooling duct sized for Unit 4 operation is built, but the duct will be sectioned by inner walls so that only part of the cross section will be used for the Unit 2 operation. Later, when Unit 4 is connected to the FGD, the inner walls will be removed and the full cross section of the gas cooler will be used.

Two gas cooling pumps will be installed from day one, but in the initial phase one of the pumps will be a stand-by pump. In Unit 4 operation, both pumps will be in running in order to treat the larger gas flow. There is a space reserved for the future installation of a stand-by pump.

7.3 Oxidation air system

The amount of air necessary for the forced oxidation of bisulphite to bisulphate is proportional to the mass flow of sulphur dioxide entering the FGD. Therefore a considerable amount of power may be saved by reducing the oxidation air flow during Unit 2 operation. The CT-121 JBR design ensures an efficient distribution of oxidation air throughout the reaction zone. This is achieved by a distributed net of air nozzles.

The oxidation air is introduced into the absorbent slurry through air nozzles which are in effect drilled holes in a tapered FRP pipe. It was decided to install a full size air piping system for Unit 4 operation, but with the number of air nozzles scaled down to the actual oxidation air flow for Unit 2. Later when the JBR is upgraded for Unit 4 operation, the tips of the FRP air nozzles will simply have to be modified.

Three oxidation air blowers of the Root’s type will be installed. Two of the blowers will be operating at reduced capacity and the third blower will be a stand-by unit. When upgrading for Unit 4 operation, the gearing of the blowers will be changed and the three blowers will then be able to supply the amount of oxidation air necessary for Unit 4 operation.

7.4 Mist eliminators

The mist eliminator is a three-stage chevron type. In the mist eliminators liquid droplets are removed from the flue gas stream by impact with the mist eliminator blades. Good droplet removal requires that the droplet cannot follow the flue gas through the passes in the elements, and therefore a certain gas velocity through the elements is preferred. A large turn down factor will therefore not be beneficial.

As a result the mist eliminator cross section is designed for the actual gas flow which has to be treated. A solution similar to the one chosen for the gas cooling section has been applied. By the installation inner walls in the absorber outlet duct, a part of the cross section has been blinded off whereby the proper flow velocity can be maintained.

When the plant is converted to Unit 4 service, the blinding walls will be removed and mist eliminator elements will have to be installed across the entire duct cross section.

DONG Energy has decided to carry out a study of different construction materials for the mist eliminator blades as some reports indicate that polysulphone should be a sturdier material, easier to maintain, but also more costly than polypropylene. Therefore half of the active mist eliminator area will be fitted with polysulphone elements and the other half will be fitted with polypropylene elements.

7.5 Limestone supply system and dewatering system

The existing limestone slurry preparation system will also serve the JBR. The new system will be equipped with a dedicated limestone feed system including a stand-by pump. As the cost of the limestone supply system is only modestly sensitive to the capacity of the feed system, it was decided to design this system for the upgraded Unit 4.

A different approach was chosen for the dewatering system. At first there will be only one dewatering line consisting of a hydro cyclone battery and a vacuum belt filter dedicated to the Unit 2 scrubber and sized only for Unit 2 operation. However, a spare hydrocyclone battery will be installed. In case of failure of the Unit 2 vacuum belt filter, gypsum slurry can be directed to the spare cyclone battery and on to an existing vacuum belt filter also for the Unit 5 FGD.

When upgrading Unit 4, the entire dewatering system will have to be reconsidered.

8 Time schedule

The overall time schedule of only 23 months for the Asnaes 2 FGD project is very short. Within the same timeframe the client will have to carry out concrete works for the FGD, install the booster fan and modify the stack with a new FRP liner.

This operation requires very close coordination between BWE and DONG energy.

In order to meet the tight schedule, the pre-assembly of the process steel work started at the site at the same time as the client started to prepare the JBR foundation and erected the auxiliary building next to the JBR. As soon as foundation was ready and the bottom plates in place, the pre-assembled absorber wall panels were lifted into place.

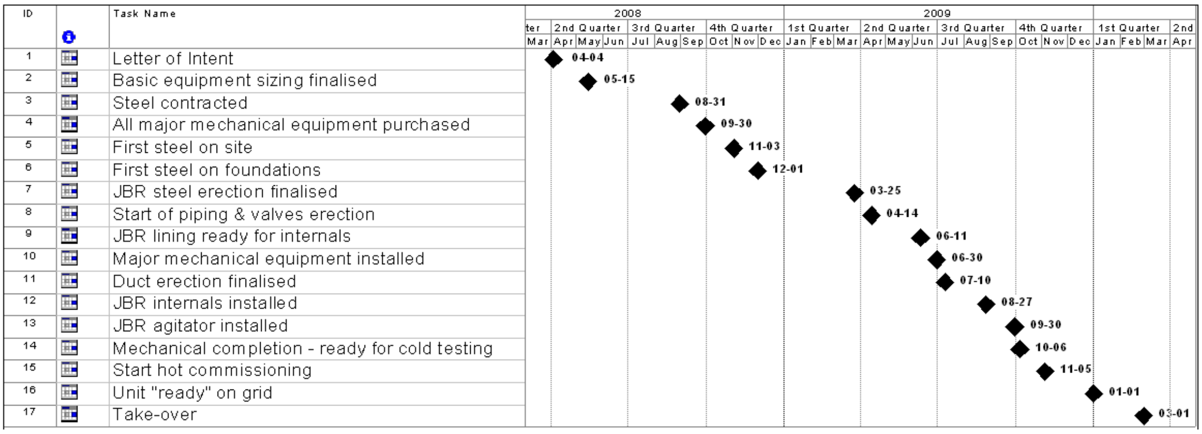

Figure 6 Main time schedule

A detailed project execution time schedule was developed already during the tendering stage, having a special focus on supply times and erection sequences dictated by the layout. This allowed the procurement process to be planned in a proper way, ensuring all critical components to be supplied in proper time for erection. Major milestones are shown in Fig. 6.

It was a clear precondition at contract award that the time schedule would not allow any major post-contract changes to the design. Specifically, the procurement, supply and erection of the JBR steel structure are on the critical path and no changes were allowed.

In order to meet the tight schedule demands, it was decided to contract the detailed steel design including workshop drawings from an experienced steel consulting company. In addition it was decided to award the steel supply and the steel erection as one package to an experienced company.

This procedure allowed the first steel (of fit-for-lining quality) to be on site 7 months after contract award.

9 Status

As of January 25, 2009, the erection is ongoing, according to schedule.

The absorber walls have been pre-assembled as planned, and lifting them in place started in the last half of January 2009. Figure 7 below shows a wall section being lifted into place.

Figure 7 The third JBR wall is lifted into place on January 26, 2009

All major mechanical equipment and other packages have been contracted according to schedule.

At present the project is on schedule and is foreseen to remain on schedule throughout the project.

10 Conclusions

Whereas the project is still under construction, we foresee the Mechanical Completion to be on target, and based on previous experience we foresee no problems in meeting the Take-Over deadline. The conclusion is therefore that a project execution of 23 months is possible for a wet FGD system for a European supply, provided that the following preconditions are met:

- The project should be build “as sold”, i.e. no major post-contract changes are accepted.
- A detailed time schedule recognizing the main critical path must be in place at contract award and must be kept as a “live” document throughout the project.
- An experienced and well-integrated project organization must be in place from the very beginning.
- A flat project organization structure must be implemented, delegating as much responsibility as possible in order to speed up the decision processes.
- A sizeable pre-assembly area must be available close to the erection area.
- The amount of pre-fabrication in workshops should be maximized.

That being said, it should also be clear that 23 months is an ambitious time schedule for a wet FGD plant, and without a dedicated effort from both the FGD supplier and the client, it is not feasible.

It is therefore important that the contract conditions are such that both parties have proper incentives for meeting the project deadlines.

In relation to process performance it was possible to design a system to meet DONG Energy’s requirements for an easy upgrade with limited outage time. This was made easier by the nature of the CT-121 FGD process, as the performance can be optimized for any given load case within the design window through the adjustment of the liquid submergence level and the continuous control allowed by the booster fan.

The upgrade will therefore be limited to the following work:

- Verification of the existing gypsum dewatering and upgrade as necessary (before outage).
- Modification of raw gas and clean gas duct connections.
- Removal of blinding plates in gas cooler.
- Removal of blinding plates and installation of new elements in the mist eliminator.
- Replacement of the FRP tips of the oxidation air nozzles.