Young Dong Unit 1 Oxyfuel Feasibility Study and FEED

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Abstract

It is proposed to demonstrate oxyfuel technology at the 100MWe scale in KOSEP’s 125MWe Young Dong Unit 1 Power Station. Prior to this it will be necessary to convert the existing boiler from anthracite firing to bituminous coal firing as the domestic anthracite source is nearing exhaustion. The oxyfuel demonstration project is being undertaken by a consortium of industrial companies, research agencies and universities, with the financial support of the Korean Government. Phase 2 of the project, the FEED, is nearing completion. Within this phase DPS have undertaken the design of the boiler plant. Key issues considered included the strategy to convert the boiler to bituminous coal, and a feasibility study investigated the various options. Having selected the preferred option the boiler thermal performance and burner operation under air and oxyfuel operation was determined. It was shown that it is technically viable to convert the boiler for oxyfuel operation.

1. Introduction

Young Dong Power Station has been firing domestically sourced Korean anthracite coals for a number of years. However the supply of this fuel is nearing exhaustion and is expected to be depleted by 2013. As a result the plant owners, Korea South East Power Co. (KOSEP), are investigating options to extend the life of the plant by converting it to fire world-traded bituminous and sub-bituminous coals. Furthermore the Korean Government, via Korea Electric Power Co. Research Institute (KEPRI), are seeking to upgrade the plant to facilitate oxyfuel firing for a demonstration period of one year, after which the unit will be returned to normal air-firing.

Oxyfuel combustion represents one of the more promising technologies currently being developed for CO₂ capture. In 2010 a full-scale 40MWt OxyCoal™ burner was successfully demonstrated by Doosan
Power Systems (DPS) in their test facility firing world-traded bituminous coal; the testing demonstrated the transition between air and oxyfuel firing, turndown performance from 100% to 40% load, and showed that safe and stable operation was possible over a wide operating envelope \(^{(1)}\). Further testing of the DPS OxyCoal\textsuperscript{TM} burner was undertaken over 2011 & 2012 at Vattenfall’s Oxyfuel Pilot Plant at Schwarze Pumpe; these tests were carried out at 30MWt firing locally sourced lignite \(^{(2)}\).

![Image](YoungDong.png)

**Fig. 1.** KOSEP’s Young Dong Unit #1, Gangneung, Gangwon

### 1.1 Young Dong Unit 1 Power Station

Young Dong Unit 1 is a 125MWe downshot fired utility boiler located in Gangneung, Gangwon in eastern Korea (see Figure 1). The unit entered service in 1973, and presently fires domestically sourced anthracite and heavy fuel oil. The boiler was built by Babcock-Hitachi KK under a license from DPS, and is of the single drum radiant furnace membrane wall type. Table 1 summarizes the main steam conditions.

For low volatile coal firing downshot vertical inter-tube burners are installed on the front and rear furnace shoulders to yield a “W” shaped firing configuration. To support the ignition of the low volatile coal the furnace walls in the lower furnace are partially covered with refractory; there is provision for up to 20% support from oil burners installed between the coal burner inlets. There are two stages of superheat, with spray attemporation between stages to control final steam temperature. Superheat and reheat surfaces run in parallel within the gas pass; reheat steam temperature control is achieved by biasing the gas flow between the superheat and reheat surfaces. A plain tube economizer is located downstream of the superheater. The boiler is designed for balanced draught operation.

<table>
<thead>
<tr>
<th>Table 1. Young Dong Unit 1 – Steam Conditions</th>
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<tbody>
<tr>
<td>Evaporation (tonnes/h)</td>
</tr>
<tr>
<td>Main Steam Temperature (°C)</td>
</tr>
<tr>
<td>Main Steam Pressure (bar)</td>
</tr>
<tr>
<td>Reheat Steam Temperature (°C)</td>
</tr>
<tr>
<td>Reheat Steam Pressure (bar)</td>
</tr>
<tr>
<td>Cycle Efficiency (%)</td>
</tr>
</tbody>
</table>
1.2 Korean Oxyfuel Project

The Korean oxyfuel project was initiated in 2007 with the overall objective of the “demonstration of carbon capture and storage readiness for coal fired plants by 2018”. In the longer term the intention is to establish a commercial scale technology (i.e. ~500MW) with a cost of less than 30€/tCO₂. The project is supported financially by the Korean Government; a list of the project participants is presented in the “Acknowledgements”. The project is to be undertaken over three discrete phases, as follows:

1. Development of conceptual design of oxyfuel combustor (October 2007 – October 2009)
2. Basic design of oxyfuel combustor (October 2010 – September 2012)
3. Detailed design and construction of 100MWe oxyfuel power plant (October 2012 – September 2015)

The results presented here are based upon work undertaken by DPS within Phase 2 of the project. DPS, through their parent company Doosan Heavy Industries & Construction (DHIC), were responsible for the boiler design.

Table 2. Options for feasibility study

<table>
<thead>
<tr>
<th>Case</th>
<th>Feasibility Cases</th>
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<tbody>
<tr>
<td>Case 1</td>
<td>Retrofit</td>
</tr>
<tr>
<td>Case 2</td>
<td>Retrofit</td>
</tr>
<tr>
<td>Case 3-1</td>
<td>Retrofit</td>
</tr>
<tr>
<td>Case 3-2</td>
<td>Brownfield</td>
</tr>
</tbody>
</table>

2. Feasibility Study

In considering the application of oxyfuel technology to the Young Dong Unit 1 plant there are a number of possible strategies; these are summarized in Table 2. The options range from the minimal modifications indicated in Case 1, through to a new-build on the existing brownfield site (Case 3). A technical and economic assessment of each option was undertaken in order to indentify which case would be taken on to the Front End Engineering Design (FEED) stage.

2.1 Case 1 Retrofit – Downshot Firing

Case 1 represents the “least change” option, and minimizes the modifications required (and therefore the retrofit cost). Circular burners for bituminous coal firing are installed in the furnace arches, and replace the existing low volatile inter-tube burners; as a result there are only minor modifications to the tube-sets local to the burner inlets. A total of 10 new burners would be installed for this option. The existing furnace dimensions impose a layout constraint which both limits the burner capacity and prevents a greater number of burners, and as a result the plant will be required to operate with all burners in-
service at 125MWe load. There are a number of other technical concerns arising from the downshot firing of bituminous coal; due to the faster heat release from the higher volatile fuel it is expected that the utilization of the lower furnace will be reduced; this in turn leads to increased superheater spray flows and reduced combustion efficiency. In spite of having the lowest cost Case 1 was the least preferred option from a technical perspective.

2.2 Case 2 Retrofit – Wall Firing

Case 2 retains the furnace envelope and convective pass surfaces, but the burners are relocated to a wall-firing configuration. A total of 16 burners are proposed, these will be arranged in two tiers of 4 burners each in the front and rear walls of the furnace; the layout constraints of Case 1 are removed and full load operation can be achieved with 12 burners in-service. While more expensive than Case 1, Case 2 is technically superior – utilization of the lower furnace is optimized (lower superheater spray flows, better combustion efficiency), conventional in-furnace NOx control technology (low NOx burners, overfire air) can be deployed, and the lower centre of heat input improves the circulation characteristics of the boiler. However because the existing boiler is retained its design may not be optimal.

2.3 Case 3-1 Retrofit, New Wall Fired Boiler

In Case 3-1 it is proposed to replace the existing boiler with a new boiler that delivers the same steam conditions to the existing (retained) steam turbine. There is minimal modification to the remaining plant infrastructure (draught plant, air heaters, coal & ash handling, structure, etc.), except where upgrades to the existing equipment will lead to quantifiable improvements to efficiency or performance. The new boiler is of conventional two-pass design with 16 low NOx burners arranged for opposed wall firing; overfire air gives a further NOx reduction. Within Case 3-1 there is potential to optimize the air-fired boiler performance to deliver improved thermal and combustion efficiency, and the new boiler will also have inherently lower tramp air ingress; air and flue gas volume flow rates will be reduced as a result. However Case 3.1 has considerably higher costs compared to Case 2. It is also noted that the new boiler will have a working life of 30 to 40 years, whereas the remaining plant (turbine, etc.) has already seen many years service; overall plant availability is unlikely to be improved significantly beyond current levels and the economic benefit of the new boiler is questionable.

2.4 Case 3-2 Brownfield, New Wall Fired Boiler

Case 3-2 follows the same basic principles as used to develop Case 3-1, but extends them to the complete replacement of the boiler island and its associated infrastructure (draught plant, air heaters, coal & ash handling, structure, etc.). This approach removes all constraints on the boiler design, but with significant cost. As for Case 3-1 the economic justification is difficult.

2.5 Selected Option for FEED

The capital cost and project duration for each option is compared in Table 3. As might be expected, there is a clear correlation between the two parameters. However Case 1, with the lowest capital cost and shortest duration was not identified as the optimum solution due to the technical compromises this option entails.
Table 3. Capital cost and project duration comparison for Young Dong Unit 1 upgrade options

<table>
<thead>
<tr>
<th></th>
<th>Capital Cost</th>
<th>Design &amp; Manufacture</th>
<th>Demolition &amp; Construction</th>
<th>Commissioning &amp; Demonstration</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Case 1</td>
<td>0.177</td>
<td>11</td>
<td>3</td>
<td>12</td>
<td>26</td>
</tr>
<tr>
<td>Case 2</td>
<td>0.207</td>
<td>12</td>
<td>4</td>
<td>12</td>
<td>28</td>
</tr>
<tr>
<td>Case 3-1</td>
<td>0.876</td>
<td>16</td>
<td>8</td>
<td>12</td>
<td>36</td>
</tr>
<tr>
<td>Case 3-2</td>
<td>1.000</td>
<td>22</td>
<td>10</td>
<td>12</td>
<td>44</td>
</tr>
</tbody>
</table>

Based on technical and financial considerations it was decided to adopt Case 2 “Retrofit – Wall Firing” for the FEED. The wall firing arrangement offers the best furnace utilization, the best combustion efficiency, and is best suited to bituminous coal firing; these benefits far outweigh the small cost increase compared to Case 1.

3. Front End Engineering Design (FEED)

3.1 Basis of Design

The overall process design and development of the Process Flow Diagram (PFD) was the responsibility of KEPRI (supported by KOSEP), with DHIC/DPS being responsible for the boiler island, the Air Separation Unit (ASU) by Daesung Industrial Gases Co. Ltd, and the emission equipment by Korea Institute of Machinery & Material (KIMM) with KC Cottrell (3). Table 4 summarizes the basis of the oxyfuel design (6); the major process parameters (oxygen purity, excess oxygen, flue gas recycle rate, CO2 capture rate, and CO2 purity) are all comparable to previous design studies, for example.

Table 4. Design basis and oxyfuel PFD

3.2 Thermal Performance

In applying oxyfuel technology to an existing power plant it is important to understand the impact of the process on the boiler thermal performance, in particular it is necessary to ensure that the modified boiler can still deliver steam to the turbine at the required conditions so that gross generating capacity is maintained. DPS undertook a detailed thermal performance assessment of the Young Dong Unit 1 boiler
across the full load range for both air and oxyfuel firing conditions using in-house developed engineering performance models.

The models were initially calibrated to the current plant thermal performance when firing anthracite coal in the as-built downshot configuration to establish representative dirt-factors; a number of data-sets for the as-found plant were analyzed. Following this, the performance of the modified boiler (conversion to opposed wall arrangement) firing the design world-traded bituminous coal was predicted. Compared to a boiler designed for wall firing from the outset, the downshot furnace volume is large (driven by the requirement for adequate residence time to fully combust the anthracite coal, and to accommodate the comparatively long flames typical of the inter-tube burners commonly used for this application). As a result there was a concern that when the boiler is converted to opposed-wall firing the furnace heat extraction would be too high, leading to the final steam temperature failing to reach its design value. This was indeed found to be the case, and remedial measures were taken to rebalance the split between evaporation and superheat. By adopting these measures it was shown that the boiler could deliver the design superheat and reheat steam conditions (temperature, pressure, and mass flow) across the full operating range, and therefore that the conversion of the boiler from anthracite firing to bituminous coal firing was technically viable.

Having established the air firing performance the models were run in oxyfuel firing mode. Figure 2 compares the heat absorbed by the various surfaces in the boiler for air and oxyfuel firing conditions.

![Figure 2. Heat absorption to boiler surfaces](image)

The predictions showed that the heat absorption distribution through the boiler was more-or-less the same for air firing and oxyfuel firing; in order to achieve this result it was necessary to make some adjustments to the oxyfuel operational parameters. Furthermore it was shown that the incident heat flux vs. furnace height was broadly similar for air and oxyfuel firing, and therefore that the oxyfuel process will not have any negative impact on boiler circulation. It was therefore shown that the Young Dong Unit 1 boiler could be operated in oxyfuel firing mode without any modification to the heat transfer surfaces.

### 3.3 Burner Performance

Building upon the full-scale burner testing experience (1,2) DPS undertook CFD modeling of the proposed Young Dong oxyfuel burner in order to further establish the turndown performance with respect to flame shape and stability. The motivation for this study was to provide assurance that the operational
The flexibility of the plant would not be affected by any constraints imposed by the combustion system supplied by DPS. The CFD model considered a single burner so that the level of geometric detail required for accurate simulation could be accommodated. Models were run for a range of burner conditions, ranging from 100% burner load down to 40% burner load; testing undertaken in Renfrew had previously established that the DPS OxyCoal™ burner could be safely and reliably operated across this load range(1).

Figure 3 presents typical CFD model temperature predictions for air and oxyfuel firing. The predictions showed that the flame was both stable and well rooted to the burner for all loads modeled. At like-for-like conditions the flame shape for oxyfuel firing was comparable to that obtained under air firing operation. Predicted carbon in ash (CIA) levels were lower for oxyfuel firing, this partly arises from the increased oxygen partial pressure in the near burner region. NOx emissions, expressed on a mass per unit heat input basis, were lower for oxyfuel compared to air firing. The CFD model findings were consistent with DPS’ experimental test experience of firing full-scale OxyCoal™ burners(1,2).

Figure 3. Predicted temperature profiles for the OxyCoal™ burner for (a) air firing, and (b) oxyfuel firing

4. Concluding Remarks

With the domestic anthracite supply to the Young Dong Unit 1 plant becoming unviable a number of options to convert the unit to world-traded bituminous coals were explored. Based upon a technical and economic assessment the optimum solution was identified; this comprises the conversion of the unit to an opposed-wall fired arrangement with retention of the existing furnace envelope.

The Young Dong Unit 1 plant is the nominated host site for a proposed 100MWe demonstration of oxyfuel firing technology. Based on extensive experience of the oxyfuel technology, including the demonstration of a full-scale OxyCoal™ burner, DPS undertook the FEED for the boiler island. Through the use of engineering models the anticipated thermal performance for the Young Dong Unit 1 boiler was determined for air and oxyfuel firing across the boiler load range; it was shown that the design steam conditions could be delivered. CFD modeling of the proposed OxyCoal™ burner was also undertaken.

The conversion of the Young Dong Unit 1 boiler to bituminous coal firing and its ability to operate under oxyfuel firing conditions was shown to be technically viable.

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Material (KIMM), KC Cottrell, Korean Institute of Geoscience & Mineral Resources (KIGAM), Daesung Industrial Gases Co. Ltd, Yonsei University, Korea Advanced Institute of Science & Technology (KAIST), and Doosan Heavy Industries & Construction (DHIC). The authors acknowledge the support of all these parties.

References


