Performance of the Regenerative Burners in BaoSteel 2050 Hot Strip Mill Furnace
Baoshan, China

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Key Words
Combustion
Regenerative Burners
Reheat Furnace
Fuel Savings

Background
In late 2003 the Bao Steel Company embarked on an energy savings program for its 2050 hot strip mill in Baoshan, China. In February of 2004, eleven pairs of regenerative burners were purchased to replace the burners in the bottom heat 1 (Zone 4) and bottom heat 2 (Zone 6) zones of the No. 2 walking beam furnace. The burners were installed during the mill shutdown in September of 2004 and were immediately put into production. The burners were provided by Bloom Engineering Company. The combustion system was engineered by Bloom Combustion Products Ltd. of Shanghai, China. It was installed by Beijing Phoenix Company. Beijing Phoenix also made all required furnace modifications. Commissioning and testing was done by and Bloom Combustion Products Ltd. and Bloom Engineering Company.

Regenerative Burners
Regenerative burners are typically installed in pairs. As shown in Figure 1, when one burner fires, the other is exhausting through the burner head, media and media case. The hot exhaust gases transfer heat to the media where it is stored until the cycle reverses. After reversal, the burner that was firing becomes the flue, while the burner that was exhausting now begins to fire. The cold combustion air passes through the heated media where the stored energy is recovered. Air preheat levels within 200°F-400°F of the products of combustion in the furnace are typically achieved, making the regenerative burners extremely efficient.

Figure 1
Furnace Description

The 2050 hot strip mill furnace is an eight zone, top and bottom fired walking beam furnace. The rated capacity is 350 metric tons per hour. The furnace was built by Stein Heurtey in 1984. The burners are fired with mixed gas having a higher heating value of 225 BTU/SCF and hot air. Three of the bottom zones were originally longitudinally fired from doghouses. The air preheat temperature is 950°F. The discharge temperature varies between 2200°F and 2300°F. Typical furnace setpoints are 2200°F for the heat 1 zones, 2270°F for the heat 2 zones and 2300°F for the soak zones. The preheat zones are presently not in use. A longitudinal section of the furnace is shown in Figure 2.

The furnace is controlled by an ABB PC/PLC based Control System.

![Furnace Layout Diagram](image)

**Figure 2**

Burner Description

The burners in the bottom heat 1 (zone 4) and bottom heat 2 (zone 6) zones were replaced by eleven pairs of Bloom regenerative burners. Six pairs were installed in zone 6 and five pairs were installed in zone 4. The burners in zone four have a nominal capacity of 15 MMBTU/Hr. giving the zone a nominal capacity of 60 MMBTU/Hr. The burners in zone six have a nominal capacity of 10 MMBTU/Hr. giving the zone a nominal capacity of 60 MMBTU/Hr. The burners were supplied with oversized media cases, so that the firing rate could be pushed over the nominal capacity if required. The media for air preheating is comprised of ¾" diameter alumina ceramic balls.

The actual burner placement in zones four and six can be seen in Figure 3.
The burners are air staged to minimize NOx emissions. The hottest region of the flame is the location where the majority of thermal NOx is created. These areas typically occur where the flame front is propagated. In order to reduce this peak flame temperature, the burner geometry is optimized to recirculate waste gases into this area. (See Figure 4) The recirculation reduces the peak temperatures, thus significantly reducing NOx formation. Bulk flame temperatures are relatively unchanged. By utilizing this technique, Flame luminosity can be maintained without increasing NOx emissions and exhaust gas recirculation is not required.
The regenerative system utilizes pneumatically operated cycling valves for the exhaust and air and electrically operated cycling valves for the gas. The air and exhaust valves are heavy duty step seat butterfly valves. The cycling time is 40 seconds.

Project Description

The combustion system was purchased in February of 2004. The equipment was delivered to the site in October of 2004. All piping installation that could be done while the furnace was running was completed prior to shutdown. The regenerative burners were placed in the sidewalls replacing the longitudinally fired burners that were fired from doghouses. The following are pictures showing the area that the regenerative burners were installed.
The following is a picture of the step seat valve for air and exhaust.

The following are pictures of the regenerative burners installed in the furnace:
Of particular interest is the next picture. Because the furnace was initially designed for longitudinal firing, the firing lanes for side firing were limited. The fuel distribution of the furnace required that a burner be placed in an area where there was a row of skid posts. The solution was to split the burner head into two smaller burner heads that would straddle the existing skid posts. These smaller burner heads generated smaller flame diameters as well and flame impingement on the skid posts was avoided and overall product uniformity was maintained.
The following is a picture of the pilot and mixer assembly:

Performance Requirements

The following criteria were evaluated to determine the performance of the regenerative burners:

- Burner Turndown
- Waste Gas Temperature
- Air Preheat Temperature
- NOx Emissions
- Media Ball Life
- Furnace Temperature Uniformity
- Fuel Savings

**BURNER TURNDOWN**

The requirement for burner turndown was 4:1 with a stable flame at 5% excess air.

Each burner exhibited a stable flame at a 4:1 turndown without requiring more than 5% excess air.

**WASTE GAS TEMPERATURE**

The waste gas temperature exiting the regenerative burners is to be less than 200 deg C. The chart below is the historical trend for both zone 4 and zone 6 during the performance test period.

### Zone 4 Exhaust Temperature Chart

![Graph showing Zone 4 Exhaust Temperature Chart]
AIR PREHEAT TEMPERATURE

Under normal furnace operating conditions the preheated air temperature will be maintained over 1000 deg C.

The above curves show lab data for a typical regenerative burner under normal operating conditions as these burners on the No. 2 furnace. The curves reflect the temperature measured in the burner head.
between the baffle and the media case. This was by agreement between Bao Steel and Bloom Engineering, since actual measurement of these temperatures under production conditions is cumbersome.

**NOx EMISSIONS**

Bloom’s performance criteria for NOx emissions was to achieve < 59.0 ppm at 11% O2 with all the regenerative burners operating with a furnace temperature in Zone 4 at 1220 deg C and Zone 6 at 1270 deg C.

The table below is the data recorded by Bloom using a TESTO T-350XL Emission analyzer.

**Bao Steel No. 2 Furnace 2050 Performance Test NOx Data**

**Date: March 14, 2005**

**Analyzer Used: TESTO T350 XL SN. 00974028 Bloom Combustion Products Shanghai**

<table>
<thead>
<tr>
<th>Sample No.</th>
<th>Time</th>
<th>PPM Nox</th>
<th>PPM Nox @11% O2</th>
<th>% Oxygen</th>
<th>PPM CO</th>
<th>% CO2</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>16:18:00</td>
<td>37.7</td>
<td>53.7</td>
<td>13.98</td>
<td>3.0</td>
<td>3.9</td>
</tr>
<tr>
<td>2</td>
<td>16:19:46</td>
<td>53.1</td>
<td>49.9</td>
<td>10.35</td>
<td>2.0</td>
<td>5.9</td>
</tr>
<tr>
<td>3</td>
<td>16:23:43</td>
<td>31.2</td>
<td>48.9</td>
<td>14.62</td>
<td>0.0</td>
<td>3.5</td>
</tr>
<tr>
<td>4</td>
<td>16:24:26</td>
<td>55.9</td>
<td>56.2</td>
<td>11.06</td>
<td>0.0</td>
<td>5.5</td>
</tr>
<tr>
<td>5</td>
<td>16:25:12</td>
<td>51.4</td>
<td>46.0</td>
<td>9.82</td>
<td>0.0</td>
<td>6.2</td>
</tr>
<tr>
<td>6</td>
<td>16:26:11</td>
<td>64.8</td>
<td>53.6</td>
<td>8.92</td>
<td>0.0</td>
<td>6.7</td>
</tr>
<tr>
<td>7</td>
<td>16:27:46</td>
<td>49.2</td>
<td>44.3</td>
<td>9.89</td>
<td>0.0</td>
<td>6.2</td>
</tr>
<tr>
<td>8</td>
<td>16:28:39</td>
<td>58.8</td>
<td>41.8</td>
<td>6.92</td>
<td>0.0</td>
<td>6.9</td>
</tr>
<tr>
<td>9</td>
<td>16:29:46</td>
<td>53.0</td>
<td>42.3</td>
<td>8.46</td>
<td>0.0</td>
<td>7.0</td>
</tr>
<tr>
<td>10</td>
<td>16:30:05</td>
<td>55.1</td>
<td>46.2</td>
<td>9.07</td>
<td>0.0</td>
<td>6.6</td>
</tr>
<tr>
<td>11</td>
<td>16:31:45</td>
<td>53.6</td>
<td>42.7</td>
<td>8.46</td>
<td>0.0</td>
<td>7.0</td>
</tr>
<tr>
<td>12</td>
<td>16:32:45</td>
<td>46.7</td>
<td>43.3</td>
<td>10.21</td>
<td>3.0</td>
<td>6.0</td>
</tr>
</tbody>
</table>

**Average Nox :** 47.4
The flue gas sampling for the emission testing was taken from the exhaust flue duct near the recuperator. A thermocouple in the flue duct was removed which allowed access to the flue duct where the probe was inserted.

MEDIA BALL LIFE

The life of the Media Balls will be greater than or equal to 1 year.

The Media Balls used in Bloom regenerative burners are a nearly pure tabular alumina material (>99.0 % Al2O3). They have a bulk density of 2,010 kg/m3 with a cold crushing strength of 1,500 kgf minimum. The nominal ball size is 19.0 mm. The melting temperature of the Media Balls is in excess of 2,000 deg C.

The following picture shows the media balls after 10 months of service. The picture is of the actual media case with the top hatch removed. There is a small amount of dust on the top of the bed. Bao Steel elected not to clean the media at this point.
FURNACE TEMPERATURE UNIFORMITY

The guarantee condition for this project is as follows:

Under condition of normal operation, furnace temperature difference of each pair of burners over the furnace width of 12.8 meters to be within +/- 30 deg C.
The above graph (Bottom Gas After) is from the embedded thermocouple study that was performed on March 14, 2005. The bottom blue curve depicts the delta temperature difference from side to side in the furnace. Less than a 60 deg C delta is achieved in zones 4 and 6, this even with a much wider temperature spread in the zone just before the regenerative burner zones. These data show that the temperature uniformity improved greatly as the slab traveled through zones 4 and 6. The higher temperature difference at the beginning of zone four is due to the influx of colder burner protection air in zone 2 that is introduced into the dormant burners of that zone.

The above graph (Bottom Gas Before) is from an imbedded thermocouple study performed on the same furnace prior to the regenerative burner retrofit. The bottom blue curve shows a similar high delta
temperature difference from side to side before entry into zones 4 and 6, and greater improved temperature uniformity as the slab travels through zones 4 and 6.

FUEL SAVINGS

Bloom had guaranteed a fuel savings of at least 8.1% when operating at 350 MTPH and heating an average slab temperature of 1250 deg C.

A pretest was performed by representatives from Bloom Engineering Company (Pittsburgh) and Bloom Combustion Products (Shanghai) under the supervision of Bao Steel personnel on August 4, 2004. This test was done under the prevailing production conditions on August 4.

A performance test with the regenerative burners in place was done on March 14, 2005. This test was done under the same conditions as the pretest but under the prevailing production conditions of March 14.

For the pretest and the performance test, the production rates were significantly below the maximum design production rate of the furnace of 350 MTPH where the fuel rate guarantee’s were made. With this in mind, the expected fuel savings should be adjusted (See Figure Below).

Fuel Summary

Below is the summary of the data collected for both the pretest on No. 2 furnace and the after test for the same furnace.
Also there is a comparison of the performance data for No. 2 furnace compared to No. 3 furnace on the same day and test period.

A. No. 2 Furnace Compared with itself – Pretest vs. Performance Test

<table>
<thead>
<tr>
<th></th>
<th>August 4, 2005 Pretest</th>
<th>March 14, 2005 Performance Test</th>
</tr>
</thead>
<tbody>
<tr>
<td>MTPH</td>
<td>178</td>
<td>230</td>
</tr>
<tr>
<td>Discharge Temperature Deg C</td>
<td>1210</td>
<td>1223</td>
</tr>
<tr>
<td>Charge Temperature Deg C</td>
<td>63</td>
<td>91</td>
</tr>
<tr>
<td>Fuel (NM3/Hr)</td>
<td>22527</td>
<td>23681</td>
</tr>
<tr>
<td>Fuel Rate (Kcal/Kg)</td>
<td>304.42</td>
<td>247.15</td>
</tr>
</tbody>
</table>

Savings: \[
\frac{(304.42 - 247.15)}{304.42} \times 100 = 18.81\%
\]

- 18.81% Fuel Savings

NOTE: Temperature and tonnage adjustments are all negligible compared to the actual savings. The No. 2 furnace was monitored for the same time period.

B. No. 2 Furnace Compared with No.3 Furnace for the same time period on March 14, 2005

<table>
<thead>
<tr>
<th></th>
<th>Furnace No. 2</th>
<th>Furnace No. 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>MTPH</td>
<td>230</td>
<td>228</td>
</tr>
<tr>
<td>Discharge Temperature Deg C</td>
<td>1223</td>
<td>Not Provided</td>
</tr>
<tr>
<td>Charge Temperature Deg C</td>
<td>91</td>
<td>Not Provided</td>
</tr>
<tr>
<td>Fuel (NM3/Hr)</td>
<td>23711</td>
<td>26231</td>
</tr>
<tr>
<td>Fuel Rate (Kcal/Kg)</td>
<td>247.15</td>
<td>276.41</td>
</tr>
</tbody>
</table>

- Fuel Consumed by Furnace No. 2 during test in March 14, 2005: 23711 NM³/Hr
- Fuel Consumed by Furnace No. 3 during test in March 14, 2005: 26231 NM³/Hr
- \(1 - \frac{23711}{26231} \times 100 = 9.6\%\)
- **9.6% Fuel Savings**

The following is a fuel flow chart for the pretest conditions for Furnace No. 2:

The following is a fuel flow chart for Furnace the performance test for Furnace No. 2:
The following is a fuel flow chart for furnace No. 3 on the day of the performance test:
The average fuel consumed when comparing the pretest data to the performance test data both on the No. 2 furnace shows a fuel savings of 18.81%, this additional fuel savings is primarily due to the difference in production rate between the two tests.

The average fuel consumed when comparing the No. 2 furnace to the No. 3 furnace during the same test period on March 14th, 2005 shows a fuel savings of 9.6%.

In either test case above, the fuel savings observed exceeds the projected fuel savings of 8.1% at a production rate of 350 MTPH or the projected fuel savings of 6.2% at a production rate of 247 MTPH.
**Conclusions**

The following summarized the performance testing of the Bao Steel No.2 2050 Hot Strip Mill Furnace:

<table>
<thead>
<tr>
<th>Criterion</th>
<th>Guarantee</th>
<th>Performance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Turndown</td>
<td>4:1</td>
<td>4:1</td>
</tr>
<tr>
<td>Waste Gas Temperature</td>
<td>200 C</td>
<td>140 C (ave.)</td>
</tr>
<tr>
<td>Air Preheat Temperature</td>
<td>1000 C</td>
<td>1110 C (ave.)</td>
</tr>
<tr>
<td>NOx Emissions</td>
<td>60 ppm</td>
<td>47 ppm</td>
</tr>
<tr>
<td>Media Ball Life</td>
<td>1 year</td>
<td>10 months very good condition</td>
</tr>
<tr>
<td>Furnace Uniformity</td>
<td>+/-30 C</td>
<td>+/-25 C</td>
</tr>
<tr>
<td>Fuel Savings</td>
<td>8.1%</td>
<td>9.6%/18.8%</td>
</tr>
</tbody>
</table>

The results of the testing were accepted by Bao Steel in April of 2005. All testing was preformed under the Guidelines on Ordering and Acceptance of Fuel Fired and Heat Treatment Furnaces as published in the Communication No. 545 of the Heat Working Group of German Iron founders Association, 2nd Edition (1965).