Proposal for Energy Efficiency Improvement

1. Electric Arc Furnace (EAF) for steelmaking
2. Reheating Furnace (RHF) for rolling

(1) Operational skill
(2) Equipment improvement
(3) Advanced technology

November 2009
Japan External Trade Organization (JETRO)
JP Steel Plantech Co. (SPCO)
Discussion items : EAF

(1) Proposal for operational skill improvement
   1) Slag foaming
   2) Tapping temperature
   3) Minimization of de-slagging door opening
   4) Correlation of operation pattern record and results

(2) Proposal for equipment improvement
   1) Countermeasure for scrap overflow
   2) Improving the furnace wall coolers
   3) EBT

(3) Advanced technology
   1) High efficiency EAF (ECOARC)
(1) Proposal for operational skill improvement

1) Slag foaming

**Good Slag Forming**

Improve Efficiency of Arc Power Transfer

- **Open Arc**
  - Heat Loss → Large

- **Formy Slag**
  - Arc shrouded in “Formy Slag”
  - Heat Loss → Minimized

**Condition for Good Slag Forming**

- Basicity of Slag: 1.5 – 2.2
- FeO in Slag: 15 – 20%
(1) **Proposal for operational skill improvement**

2) **Tapping temperature**

 Tapping Temperature : ex) 1630 deg C
 → 1600 – 1610 deg C
※ \( \Delta 20 – 30 \) deg C = \( \Delta 10 – 15 \) kWh/t

Example in Japan

 Tapping Temperature : 1550 deg C
 Temp. at LF start : 1530 – 1535 deg C
 Temp. at LF finish : 1575 – 1585 deg C
(1) Proposal for operational skill improvement
3) Minimization of De-slagging door opening

Heat loss from off-gas:
70% of Total heat loss

Air infiltration from De-slagging door opening:
70 – 90% of total off-gas volume
(1) Proposal for operational skill improvement
4) Correlation of operation pattern record and results

Operation Pattern → Actual Results

- External Perturbation
- Manual Intervention by Operator

Analysis and Feedback

Example of Actual Result of a heat

Graph showing trend lines for Accumulated Electric Power, Oxygen flow rate, and C. Powder inj.
(2) Proposal for equipment improvement

1) Countermeasure for scrap overflow

1. Increase Shell Height

2. Adjustment of Shape of Refractory
(2) Proposal for equipment improvement

2) Improving the furnace wall coolers

Tube-gap-tube type water-cooled panel

Better for energy saving

Tube-to-tube type water-cooled panel
<table>
<thead>
<tr>
<th>Category</th>
<th>Item</th>
<th>Effect</th>
<th>Main factors</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td><strong>Effect of EBT</strong></td>
<td></td>
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<td></td>
<td><strong>Effect</strong></td>
<td><strong>Main factors</strong></td>
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<tr>
<td><strong>Cost</strong></td>
<td>1. Yield of Alloys</td>
<td>Si : 15 - 100%↑</td>
<td>Slag free tapping</td>
</tr>
<tr>
<td></td>
<td>2. Yield of Tapping</td>
<td>Fe : 1.1%↑</td>
<td>Slag free tapping, Hot heel</td>
</tr>
<tr>
<td></td>
<td>3. Electric power consumption</td>
<td>7 - 25 kWh/t↓</td>
<td>Hot heel</td>
</tr>
<tr>
<td></td>
<td>4. Electrode consumption</td>
<td>0.2 - 0.4 kg/t↓</td>
<td>Hot heel, Decrease of Electric power</td>
</tr>
<tr>
<td></td>
<td>5. Refractory consumption</td>
<td>Wall: 23 - 64%↓</td>
<td>Increase of water cooled area</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Ladle: 9 - 54%↓</td>
<td>Slag free tapping</td>
</tr>
<tr>
<td></td>
<td>6. Lime consumption</td>
<td>15 - 25%↓</td>
<td>Hot heel</td>
</tr>
<tr>
<td><strong>Productivity</strong></td>
<td>1. Tap - to - On</td>
<td>1.0 - 3.0 min.↓</td>
<td>Shortened Hot repair, Shortened Tilting for Tapping, Decrease of Electrode con.</td>
</tr>
<tr>
<td></td>
<td>2. On - to - Tap</td>
<td>1.0 - 7.2 min.↓</td>
<td></td>
</tr>
<tr>
<td><strong>Quality</strong></td>
<td>1. Dephosphorus</td>
<td>16 - 28%↑</td>
<td>Hot heel</td>
</tr>
<tr>
<td></td>
<td>2. Inclusion</td>
<td>Total [O] 1 - 3ppm↓</td>
<td>Slag free tapping</td>
</tr>
</tbody>
</table>
(3) **Advanced Technology**

1) High efficiency EAF (ECOARC)

: Economical & Ecological EAF

(a) Scrap preheating with very high temperature ex-gas
(b) Small air infiltration with tight-seal mechanism

→ 250 kWh/ton-steel is possible
(3) **Advanced Technology**
   
   **1) High efficiency EAF (ECOARC)**

   Exhaust gas processing system matches to the guideline of incinerator exhaust gas treatment, most of the dioxin is eliminated to achieve less than 0.1 ng-TEQ/m³.
(3) Advanced Technology

1) High efficiency EAF (ECOARC)

There are three ECOARCs working in Japan, and another ECOARC is about to be ordered in South Korea.
Discussion items: RHF

(1) Proposal for operational skill improvement
   1) Knowledge on combustion technology
   2) Actual operation data collection
   3) Lowering billet heating temperature

(2) Proposal for equipment improvement
   1) Increasing the combustion air preheat temperature
   2) Use of ceramic fiber

(3) Advanced technology
   1) Regenerative combustion system
(1) Proposal for operational skill improvement of RHF

1) Knowledge on combustion technology

Theoretical combustion air : $A_0$ m$^3$/m$^3$ fuel
Theoretical exhaust gas : $G_0$ m$^3$/m$^3$ fuel

Actual combustion air : $A$ m$^3$/m$^3$ fuel
Air ratio : $m = A/A_0$

\[
A_0 = (0.5 \times H_2 + 0.5 \times CO + \sum (x + \frac{y}{4}) \times C_xH_y - O_2) / 0.21
\]

\[
G_0 = 0.790 \times A_0 + CO + CO_2 + H_2 + \sum (x + \frac{y}{2}) \times C_xH_y + N_2
\]

$A_0$ and $G_0$ is calculated by the formula below, for example

$H_2 + \frac{1}{2} - O_2 \rightarrow H_2O$
$CH_4 + 2-O_2 \rightarrow CO_2 + 2H_2O$

$O_2$ in the air = 0.21, $N_2$ in the air = 0.79
A0 and G0 for typical Mexican fuel (natural gas)

Fuel composition (assumed from the PEMEX data)
- CH₄ 88.00 %
- C₂H₆ 9.00 %
- C₃H₈ 3.00 %
- C₄H₁₀ 0.33 %

Calculated data from above
- Molecular weight : 18.10
- Density : 0.808 kg/m³
- Low calorific value : 9,547 kcal/m³

\[
A₀ = \frac{(2 \times 0.88 + 3.5 \times 0.09 + 5 \times 0.03)}{0.21} = 10.60 \text{ m₃N-air/m₃N-gas}
\]

\[
G₀ = 0.790 \times 10.60 + (3 \times 0.88 + 5 \times 0.09 + 7 \times 0.03) = 11.67 \text{ m₃N-ex_gas/m₃N-fuel}
\]
Air ratio control in Mexican mills

In most mills, Air/Fuel ratio is fixed as 10.0, which leads to the air ratio of 0.943;

$$\text{Air ratio} = \frac{10.0}{10.6} = 0.943$$

Air ratio less than 1.0 seems unnatural from the combustion phenomena. Optimum air ratio for natural gas is 1.05-1.10.

Air ratio should be controlled by oxygen content in the exhaust gas.
Gradient air ratio distribution

EXHAUST GAS 1000 degC

PREHEATING ZONE
(AIR RATIO = 1.10)

HEATING ZONE
(AIR RATIO = 1.05)

SOAKING ZONE
(AIR RATIO = 0.97)

CO\(\text{H}_2\) = 0.0 %
O\(_2\) = 1.5 %

CO\(\text{H}_2\) = 0.0 %
O\(_2\) = 0.0 %

CO\(\text{H}_2\) = 1.5 %
(1) Proposal for operational skill improvement of RHF

2) Actual operation data collection

Operation heat consumption data given from Mexican mills are usually monthly average, which includes heat-up and holding times. Data of stable operation should be organized to fix heat balance.

Data to be collected to evaluate RHF performance

Outside air temperature : degC
Billet charge rate : ton/h
Billet temperature at the inlet/outlet of the furnace : degC
Fuel gas flow rate of each zone : m3N/h
Combustion air flow rate of each zone : m3N/h
Combustion air temperature : degC
Exhaust gas temperature at the inlet/outlet of the Recuperator : degC
Exhaust gas component : % of O2, CO, CO2, N2, H2O
Furnace shell surface temperature : degC
Scale loss of billets : ton/h
### Sample of heat balance study

#### HEAT INPUT

<table>
<thead>
<tr>
<th>Material</th>
<th>Mcal/H</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heated Material Sensitive Heat</td>
<td>448.0</td>
<td>.81</td>
</tr>
<tr>
<td>Scale Generation</td>
<td>1067.9</td>
<td>1.92</td>
</tr>
<tr>
<td>Fuel Gas Combustion</td>
<td>55632.0</td>
<td>100.0</td>
</tr>
<tr>
<td>Fuel Gas Sensitive</td>
<td>133.1</td>
<td>.24</td>
</tr>
<tr>
<td>Comb. &amp; Dil. Air Sensitive Heat</td>
<td>386.4</td>
<td>.69</td>
</tr>
<tr>
<td>Purge Steam Sensitive Heat</td>
<td>0.0</td>
<td>.00</td>
</tr>
<tr>
<td>Recuperated Combustion Air Heat</td>
<td>11961.1</td>
<td>21.50</td>
</tr>
<tr>
<td><strong>Total Heat Input</strong></td>
<td>57667.4</td>
<td>103.66</td>
</tr>
</tbody>
</table>

#### HEAT OUTPUT

<table>
<thead>
<tr>
<th>Material</th>
<th>Mcal/H</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heated Material Sensitive Heat</td>
<td>40614.8</td>
<td>73.01</td>
</tr>
<tr>
<td>Generated Scale Sensitive Heat</td>
<td>251.6</td>
<td>.45</td>
</tr>
<tr>
<td>Ex. Gas Sensitive Heat at Stack</td>
<td>11073.3</td>
<td>19.90</td>
</tr>
<tr>
<td>Combustibles in Ex. Gas</td>
<td>0.0</td>
<td>.00</td>
</tr>
<tr>
<td>Skid Cooling Water Heat Loss</td>
<td>2749.4</td>
<td>4.94</td>
</tr>
<tr>
<td>Furnace Wall Heat Loss</td>
<td>1000.5</td>
<td>1.80</td>
</tr>
<tr>
<td>Charge/Discharge Door Heat Loss</td>
<td>311.4</td>
<td>.56</td>
</tr>
<tr>
<td>Hearth Openings Heat Loss</td>
<td>1168.2</td>
<td>2.10</td>
</tr>
<tr>
<td>Exhaust Gas Duct Wall Heat Loss</td>
<td>692.1</td>
<td>1.24</td>
</tr>
<tr>
<td>Piping &amp; Burners Heat Loss</td>
<td>314.6</td>
<td>.57</td>
</tr>
<tr>
<td>Other Loss &amp; Calculation Error</td>
<td>-508.4</td>
<td>-.91</td>
</tr>
<tr>
<td><strong>Total Heat Output</strong></td>
<td>57667.4</td>
<td>103.66</td>
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</table>
(1) Proposal for operational skill improvement of RHF

3) Lowering billet heating temperature

In Japan, typically: 1,050 - 1,100 degC for section mill
Mexican mills: 1,150 - 1,200 degC

High billet temperature: allows light rolling machines and low power, but it requires more thermal energy and causes larger scale loss.

SPCO has no quantitative data yet to evaluate which is better.
(2) Proposal for equipment improvement of RHF

1) Increasing combustion air temperature

![Graph showing preheated air temperature and heat consumption](image)
(2) Proposal for equipment improvement of RHF

1) Increasing combustion air temperature

High-grade metallic tube should be used to get high preheat air temperature. Below is the example used in Japan.

<table>
<thead>
<tr>
<th>Designation</th>
<th>C</th>
<th>Si</th>
<th>Mn</th>
<th>P</th>
<th>S</th>
<th>Cr</th>
<th>Al</th>
</tr>
</thead>
<tbody>
<tr>
<td>SIC 9</td>
<td>≤0.12</td>
<td>0.9~1.4</td>
<td>≤1.00</td>
<td>≤0.045</td>
<td>≤0.030</td>
<td>12.0~14.0</td>
<td>0.7~1.2</td>
</tr>
<tr>
<td>SIC 10</td>
<td>≤0.12</td>
<td>0.7~1.2</td>
<td>≤1.00</td>
<td>≤0.045</td>
<td>≤0.030</td>
<td>17.0~19.0</td>
<td>0.7~1.2</td>
</tr>
<tr>
<td>SIC 12</td>
<td>≤0.12</td>
<td>1.2~1.5</td>
<td>≤1.00</td>
<td>≤0.045</td>
<td>≤0.030</td>
<td>23.0~25.0</td>
<td>1.2~1.7</td>
</tr>
</tbody>
</table>

Oxidation resistance

Corrosion resistance to vanadium (V₂O₅) attack
(2) Proposal for equipment improvement of RHF
2) Use of ceramic fiber

Furnace lining comparison

<table>
<thead>
<tr>
<th></th>
<th>Dense fire brick lining</th>
<th>Isowool Unifelt veneering on fire brick lining</th>
<th>All ceramic fiber lining (Isowool lining)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heat loss (Kcal/m²h) (%)</td>
<td>868 (100)</td>
<td>615 (71)</td>
<td>465 (54)</td>
</tr>
<tr>
<td>Heat storage (Kcal/m²) (%)</td>
<td>91.310 (100)</td>
<td>71.180 (78)</td>
<td>2,880 (3)</td>
</tr>
</tbody>
</table>
(3) Advanced technology

1) Regenerative combustion system

Regenerative combustion system

(a) 10% energy saving from modern type RHF with very high preheat air temperature (furnace temperature – 60 degC)

(b) Low Nox content in exhaust gas, by using separate fuel nozzle

(c) High productivity, compact furnace size, desired temperature distribution along the furnace length
Principle of regenerative combustion system

<table>
<thead>
<tr>
<th>BURNER A (burning)</th>
<th>BURNER B (regenerating)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PREHEATED AIR 1150 degC</td>
<td>HOT FURNACE GAS 1250 degC</td>
</tr>
<tr>
<td>MAIN BURNER</td>
<td>FURNACE 1500 degC</td>
</tr>
<tr>
<td>PILOT BURNER</td>
<td>REGENERATOR</td>
</tr>
<tr>
<td>HEATED MATERIAL</td>
<td>EXHAUST GAS 150 degC</td>
</tr>
</tbody>
</table>

from COMBUSTION AIR BLOWER to EXHAUST GAS BLOWER

SWITCHING VALVE
Low Nox combustion

- Expanded Flame
- Hot Spot
  - High NOx ~500ppm (Experimental)
  - Ultra Low NOx ~40ppm (Experimental)
Conventional combustion system for RHF

- Conventional combustion system
- Air blower to exhaust gas blower
- Exhaust gas 300 degC
- Preheated air 500 degC
- Exhaust gas 1000 degC
- Recuperator
- Dilution air 750 degC
- Fuel
- Burner
- Hot furnace gas (1500 degC)
- Heated material
- 25 degC slab
- 1050 degC slab
Regenerative combustion system for RHF

- EXHAUST GAS 150 degC
- to EXHAUST GAS BLOWER
- from COMBUSTION AIR BLOWER
- FUEL
- REGENERATOR & BURNER
- HOT FURNACE GAS (1500 degC)
- HEATED MATERIAL
- 25 degC SLAB
- 1050 degC SLAB

HEATED MATERIAL