Air Pollution Control Technology
In Steel Industry

March 2005

Overseas Environmental Cooperation Center, Japan
Air Pollution Control Technology in Steel Industry

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Steel mill lives close together with neighboring people
(Kobe Steel Kakogawa Plant)
1. Iron & Steel Making Process and Air Pollutants

- Iron ore & coking coal
- Sintering machine
- Coke oven
- Hot stove
- Blast furnace
- Converter
- Continuous casting
- Pre-heating furnace
- Continuous annealing furnace
- Hot rolling
- Cold rolling
- Hot role steel
- Cold role steel
- BFG
- COG
- Slag
- Dust
- SOx
- NOx
- Boiler

Diagrams showing the process flow and air pollutants.
2. Process of Electric Furnace Plant and Air Pollutants

EBT: Electric Bottom Tapping

EBT: Electric Bottom Tapping
3. Coarse Particle Scattering Prevention

3-1 Coal Handling Process

- Water sprinkling
- Chemical spraying
- Wind shelter fence
- Hopper
- Coal cargo
- Chemical dosing
- Coke oven
- Quenching tower
- Screening
- Storage bin
- Coke production facility
- Dust collector
- Dust collection
3. Coarse Particle Scattering Prevention

3-2-1 Coke Production  🏗️ Coal Charging Process
3. Coarse Particle Scattering Prevention

3-2-2 Coke Production  ▫ Coke Discharging Process

- Coke guide car
- Ground facilities
- connection valve
- Pre-duster
- bag filter
- stack
- quenching car
- suction hood
- coke guide car
- coke oven
- Ground facilities
3. Coarse Particle Scattering Prevention
3-3 Sintering Process

ESCS: Electrostatic Space Clear Super
3. Coarse Particle Scattering Prevention

3-4 Blast Furnace Process

- Coke bin
  - Bag filter
  - Wet scrubber

- Ore bin
  - Bag filter

- Surge hopper

- Charge conveyor

- Casting bed

- Torpedo car

- Slag ladle

- Hot stove

**Flows and Emissions**

- $Q = 13,000 \times 2 \, \text{m}^3/\text{m}$
  - 4 $\equiv 0.01 \, \text{mg/Nm}^3$

- $Q = 4,800 \, \text{m}^3/\text{m}$
  - 3 $\equiv 0.01 \, \text{mg/Nm}^3$

- $Q = 1,400 \, \text{m}^3/\text{m}$
  - 15 $\equiv 0.01 \, \text{mg/Nm}^3$

- $Q = 460 \, \text{m}^3/\text{m}$
  - 5-10 $\equiv 0.03 \, \text{mg/Nm}^3$

- $Q = 600 \, \text{m}^3/\text{m}$
  - 12-15 $\equiv 0.02 \, \text{mg/Nm}^3$
3. Coarse Particle Scattering Prevention

3-5 Steel Manufacturing Process (Converter)

- Bag filter
- EP

- Hot metal treatment center: 7,700 m³/m³, 5% 0.01 mg/Nm³
- Ladle repair: 4,000 m³/m³, 2% 0.03 mg/Nm³
- Desulphur slag scraper: 1,800 m³/m³, 20% 0.10 mg/Nm³
- Tundish yard: 7,500 m³/m³, 15% 0.01 mg/Nm³
- Desulphurization center: 7,500 m³/m³, 2% 0.03 mg/Nm³
- Hot metal pit: 7,500 m³/m³, 2% 0.03 mg/Nm³
- Ladle converter: 7,500 m³/m³, 2% 0.03 mg/Nm³
- Building exhaust: 14,200 x 2 m³/m³, 0.4% 0.03 mg/Nm³
3. Coarse Particle Scattering Prevention

3-6 Electric Furnace

- Roof exhausting system
- Bag filter
- Direct exhausting system

Conventional System

Doghouse System
4. Dust Collection System

4-1 Gravitational, Inertial & Centrifugal Dust Collector

Stokes’ Law

\[ V = \frac{g}{18 \mu}(\rho_1 - \rho) D^2 \text{ (cm/s)} \]

- \( V \): settling velocity (cm/sec)
- \( \rho \): gas viscosity (kg/ms)
- \( g \): gravitational acceleration (cm/s²)
- \( \rho_1 \): particle density (g/cm³)
- \( \rho \): gas density (g/cm³)
- \( D \): particle diameter (cm)

Principle of dust collection:

Centrifugal force \( F = \frac{mv^2}{R} \) (N)

- \( m \): particle mass (kg)
- \( V \): particle velocity (m/s)
- \( R \): cyclone radius (m)
4. Dust Collection System

4-2 Scrubbing Dust collector

**Principle of Scrubber Dust Collector:**

**Scrubbers:**

- Reservoir type
- Pressurized water type
- Packed bed type
- Rotary type

Diagram showing dust droplets being dropped into water, forming a water film and impact disc, with water spray disc and fan runner.
4. Dust Collection System

4-3 Filter Type Dust Collector

Filtration Mechanism

Schematic of typical bag filter unit

Type:
(1) bag filter
(2) cartridge filter

Filter cloth:
(1) woven fabric
(2) non-woven fabric

Dust shake-off:
(1) intermittent
(2) continuous

Apparent filtration rate:
0.3~10 cm/s

\[ P_i = P_0 + P_{th} \]

- Pi: inlet dust pressure
- P: gas pressure
- Pd: dust pressure
- Pth: pressure loss to be shaken off

- Filter bag
- Filter cloth
- Dust layer to be shaken off
- Thin film dust

Aperture 50~10 μm

Twisting
4. Dust Collection System
   4-4 Electrostatic Precipitator

Principle of dust collection:

- **Structure of EP**
  - high voltage DC generator
  - manhole
  - hammering drive
  - gas distribution plate
  - hammering device
  - collecting electrode
  - hopper
4. Dust Collection System

4-5 Selection of Dust Collector

<table>
<thead>
<tr>
<th>Collector</th>
<th>Applicable Particle (㎛)</th>
<th>Δp (mmH₂O)</th>
<th>Removal rate (%)</th>
<th>Equipment Cost (¥/ yNm³/h)</th>
<th>Operating Cost (¥/ yNm³/h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gravity</td>
<td>1,000~50</td>
<td>10~15</td>
<td>40~60</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Inertial</td>
<td>100~10</td>
<td>30~70</td>
<td>50~70</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Centrifugal</td>
<td>100~3</td>
<td>50~150</td>
<td>85~95</td>
<td>300~2,200</td>
<td>100~1,000</td>
</tr>
<tr>
<td>Scrubbing</td>
<td>100~0.1</td>
<td>300~900</td>
<td>80~95</td>
<td>400~2,200</td>
<td>100~1,300</td>
</tr>
<tr>
<td>Filter</td>
<td>20~0.1</td>
<td>100~200</td>
<td>90~99</td>
<td>300~2,100</td>
<td>300~1,100</td>
</tr>
<tr>
<td>EP</td>
<td>20~0.05</td>
<td>10~20</td>
<td>90~99.9</td>
<td>400~4,400</td>
<td>100~1,000</td>
</tr>
</tbody>
</table>

**Parameter**

- particle distribution
- dust concentration
- specific gravity
- electric resistance rate
- flow rate
- due point
- gas temp.
5. Desulphurization Technology

5-1 Flue Gas Desulphurization in Steel Mill

<table>
<thead>
<tr>
<th>Method</th>
<th>Reaction</th>
<th>Byproduct</th>
</tr>
</thead>
<tbody>
<tr>
<td>Activated carbon</td>
<td>$\text{SO}_2 + \text{H}_2\text{O} + 1/2\text{O}_2 \xrightarrow{\text{β}} \text{H}_2\text{SO}_4$</td>
<td>$\text{H}_2\text{SO}_4$</td>
</tr>
</tbody>
</table>
| Caustic soda      | $2\text{NaOH} + \text{SO}_2 \xrightarrow{\text{β}} \text{Na}_2\text{SO}_3 + \text{H}_2\text{O}$  
$\text{Na}_2\text{SO}_3 + \text{H}_2\text{O} + \text{SO}_2 \xrightarrow{\text{β}} 2\text{NaHSO}_3$ | $\text{Na}_2\text{SO}_4$ |
| Ammonia           | $2\text{NH}_4\text{OH} + \text{SO}_2 \xrightarrow{\text{β}} (\text{NH}_4)_2\text{SO}_3 + \text{H}_2\text{O}$  
$(\text{NH}_4)_2\text{SO}_3 + \text{SO}_3 + \text{SO}_2 + \text{H}_2\text{O} \xrightarrow{\text{β}} 2\text{NH}_4\text{HSO}_3 + \text{H}_2$ | $(\text{NH}_4)_2\text{SO}_4$ |
| Slaked lime       | $\text{CaO} + \text{SO}_2 \xrightarrow{\text{β}} \text{CaSO}_3$  
$\text{CaSO}_3 + \text{O}_2 \xrightarrow{\text{β}} 2\text{CaSO}_4$ | $\text{CaSO}_4$ |

Limestone - Gypsum Process

SOx Rem. > 90%

- most popularly used method
- In Japan

- limestone 便宜
- initial & operating cost 经济
- systems stability 稳定 & 安全
- gypsum 市场
5. Desulphurization Technology
5-2 Limestone-Gypsum Process

**Reaction**

\[
\begin{align*}
SO_2 + CaO & \rightarrow CaSO_3 \\
2CaSO_3 + O_2 & \rightarrow 2CaSO_4 \\
CaCO_3 + SO_2 & \rightarrow CaSO_3 + CO_2
\end{align*}
\]
## 5. Desulphurization Technology

### 5-3 Coke Oven Gas Desulphurization Process

<table>
<thead>
<tr>
<th>System</th>
<th>DeSOx-chemical</th>
<th>Catalyst</th>
<th>Byproduct</th>
</tr>
</thead>
<tbody>
<tr>
<td>Takahax-Hirohax</td>
<td>NH₃</td>
<td>naphtoquinone salfonic acid soda</td>
<td>(NH₄)₂SO₄ + H₂SO₄</td>
</tr>
<tr>
<td>Takahax-Reduction Decomposition</td>
<td>Na₂CO₃</td>
<td>naphtoquinone salfonic acid soda</td>
<td>crude S</td>
</tr>
<tr>
<td>Fumax-Hemibau</td>
<td>NH₃</td>
<td>picric acid</td>
<td>H₂SO₄</td>
</tr>
<tr>
<td>Stred Ford-Combax flue gas De-Sox</td>
<td>Na₂CO₃</td>
<td>anthoraquinone sulfonic acid soda metavanadate soda Tartaric acid soda</td>
<td>gypsum</td>
</tr>
<tr>
<td>Diamox-claus</td>
<td>NH₃</td>
<td>none</td>
<td>pure S</td>
</tr>
<tr>
<td>Salfiban-claus</td>
<td>alkanol amine</td>
<td>none</td>
<td>pure S</td>
</tr>
</tbody>
</table>

**COG refining process**

1. Coke oven
2. Primary cooler
3. Booster
4. De-SOx saturator
5. Naphthalene scrubber
6. Benzene scrubber
7. Final cooler
8. Refined COG
5. Desulphurization Technology

5-4 Takahax-Hirohax Process

Desulphurized COG

Absorber

Oxidation tower

Service tank

Heat exchanger

Reaction tower

Gas washer

Gas washer

COG

EP

wastewater

air

wastewater

waste gas

water

Air

Reaction

\[ NH_3 + H_2O \rightarrow NH_4OH \]

\[ NH_4OH + H_2S \rightarrow NH_4HS + H_2O \]

\[ NH_4OH + HCN \rightarrow NH_4CN + H_2O \]

\[ NH_4HS + 1/2O_2 \rightarrow NH_4OH + S \]

\[ NH_4CN + S \rightarrow NH_4NCS \]

Removal rate

\( S, \text{CN} > 90\sim99\% \)
5. Desulphurization Technology

5-5 Fumax Process

Absorption

\[ \text{NH}_3 + \text{H}_2\text{O} \rightarrow \text{NH}_4\text{OH} \]
\[ \text{NH}_4\text{OH} + \text{H}_2\text{S} \rightarrow \text{NH}_4\text{HS} + \text{H}_2\text{O} \]

Regeneration

\[ \text{NH}_4\text{HS} + \frac{1}{2}\text{O}_2 \rightarrow \text{NH}_4\text{OH} + \text{S} \]

\[ \text{S} + \text{O}_2 \rightarrow \text{SO}_2 \]
\[ \text{SO}_2 + \frac{1}{2}\text{O}_2 \rightarrow \text{SO}_3 \]
\[ \text{SO}_3 + \text{H}_2\text{O} \rightarrow \text{H}_2\text{SO}_4 \]

Picric acid:

COG

Absorber

Regenerator

Evaporator

AIR

Mist catcher

H\textsubscript{2}S scrubber

NH\textsubscript{3} scrubber

Mixing t.

to H\textsubscript{2}SO\textsubscript{4} plant

H\textsubscript{2}SO\textsubscript{4} recovery
6. NOx Control Technology

6-1-1 NOx Generation

N & S Contents in Fuels

<table>
<thead>
<tr>
<th>Fuel</th>
<th>N</th>
<th>S</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solid wt%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>coal</td>
<td>0.7~2.2</td>
<td>0.3~2.6</td>
</tr>
<tr>
<td>coke</td>
<td>0.6~1.4</td>
<td>0.2~1.0</td>
</tr>
<tr>
<td>crude oil</td>
<td>0.03~0.34</td>
<td>0.1~3.0</td>
</tr>
<tr>
<td>C-oil</td>
<td>0.2~0.4</td>
<td>0.2~0.3</td>
</tr>
<tr>
<td>B-oil</td>
<td>0.08~0.35</td>
<td>0.2~0.3</td>
</tr>
<tr>
<td>A-oil</td>
<td>0.005~0.08</td>
<td>0.2~0.3</td>
</tr>
<tr>
<td>light oil</td>
<td>0.004~0.006</td>
<td>0.03~0.5</td>
</tr>
<tr>
<td>kerosene</td>
<td>0.0005~0.01</td>
<td>0.001~0.2</td>
</tr>
<tr>
<td>COG-crude</td>
<td>0~9</td>
<td>1.5~7</td>
</tr>
<tr>
<td>COG-fine</td>
<td>0.02~0.5</td>
<td>0.05~0.7</td>
</tr>
<tr>
<td>BFG</td>
<td>tr</td>
<td>tr</td>
</tr>
<tr>
<td>LDG</td>
<td>tr</td>
<td>tr</td>
</tr>
<tr>
<td>LPG, LNG</td>
<td>tr</td>
<td>tr</td>
</tr>
</tbody>
</table>

- JIS K2205 kinematic viscosity (cSt, mm2/s)
- C-heavy oil: 50 ~1,000, B-heavy oil: 20~50, A-heavy oil: 20~20
6. NOx Control Technology

6-1-2 Factors in NOx Generation & Reduction

**Causes of generation**

- N in fuel
- O₂ con.
- Flame temp.
- Retention time

**Reduction methods**

- Fuel alternation
  - Change of fuel
    - heavy oil → light oil → gas

- Fuel denitrification
  - Denitrification of COG

- Changing operating conditions
  - Low air ratio combustion
  - Lowering dry hot air temperature
  - Changing thermal load

- Remodeling combustion system
  - Multistage combustion
  - Recirculation of exhaust gas
  - Addition of steam or water
  - Low NOx burner
6. NOx Control Technology

6-2-1 Fuel Improvement
1. Use of low N and low S fuel  (S  N)
2. Denitrification of COG  N 1~9 g/m³  800~1,000 º, 4~6 sec.

6-2-2 Combustion Improvement
1. Low air ratio operation  O₂ 1%  NOx 10% 
2. Multistage combustion  1ˢᵗ stage air ratio: 80~90%  NOx 
   rest air  2ⁿᵈ stage combustion  20%
3. Steam or Water injection  flame temp.  NOx 
   no-change in generated calorie

4. Exhaust gas circulation

Injected steam
6. NOx Control Technology

5. Low-NOx burner

**Wide-angle burner tile**

**Double-stage combustion burner**

**Self-circulate combustion burner**

- **tile angle (degree)**
- **primary air ratio**
- **total air ratio: 1.1**
- **O₂ in exhaust gas %**

---

- **tile angle**
- **exhaust gas**
- **primary air**
- **secondary air**
- **gas**
- **oil**
- **fuel**
- **ring nozzle**
- **circulating gas**
6. NOx Control Technology

6-3 Denitrification of Exhaust Gas

De-NOx: Dry Type Selective Contact Reduction using NH₃

\[
6\text{NO} + 4\text{NH}_3 \rightarrow 5\text{N}_2 + 6\text{H}_2\text{O} \\
6\text{NO}_2 + 8\text{NH}_3 \rightarrow 7\text{N}_2 + 12\text{H}_2\text{O}
\]
Items to be considered at factory construction & operation
1. Environmental impact assessment
2. Environmental standards & emission standards
3. Planning of plant & air pollution control equipment
4. Operation control & worker training
5. Environmental monitoring
6. Environmental management system
### Measurement Items

<table>
<thead>
<tr>
<th>Pollutants</th>
<th>Emission Standard</th>
<th>EQS</th>
</tr>
</thead>
<tbody>
<tr>
<td>dust</td>
<td>Suspended particle matter</td>
<td></td>
</tr>
<tr>
<td>sulfur oxide</td>
<td>SO$_2$ (sulfur oxide)</td>
<td></td>
</tr>
<tr>
<td>nitrogen oxide</td>
<td>NO$_2$ (nitrogen oxide)</td>
<td></td>
</tr>
<tr>
<td>Cd, its compounds</td>
<td>CO</td>
<td></td>
</tr>
<tr>
<td>Cl, HCl</td>
<td>Photochemical oxidant</td>
<td></td>
</tr>
<tr>
<td>F, HF, Si$<em>n$F$</em>{2n+2}$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pb, its compounds</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Telemeter System

- **Q SO$_x$ NO$_x$**
- **Q SO$_x$ NO$_x$**
- automatic measurements
- site center
- administration center
8. Resources Saving

*Dust Generation & Utilization*

*Dust Generation at 3 million-ton Crude Steel Production (t / y)*

<table>
<thead>
<tr>
<th>Process</th>
<th>Dry Dust Collector</th>
<th>Wet Dust Collector</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Material / Pig</td>
<td>111,000</td>
<td>38,000</td>
<td>149,000 (61%)</td>
</tr>
<tr>
<td>Iron</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Steel</td>
<td>33,000</td>
<td>60,000</td>
<td>93,000 (38%)</td>
</tr>
<tr>
<td>Rolling</td>
<td>2,700</td>
<td>300</td>
<td>3,000 (1%)</td>
</tr>
<tr>
<td>Total</td>
<td>146,700 (60%)</td>
<td>98,300 (40%)</td>
<td>245,000 (100%)</td>
</tr>
</tbody>
</table>

- Dust generation in Integrated Iron Works: 4.9% of crude steel
- Ingredient of Dust: Iron Oxide, Limestone, etc.
- Utilization: Raw Material for
  Sintering, Zn, ZnCO3, Neutralizing wastewater, BF
9. Energy Saving

Energy source ratio (%)

Integrated Steel Production
- electricity: 11.5%
- heavy oil: 25.3%
- coke: 41.1%
- coal: 14.5%
- others: 7.6%

Non-Integrated Steel Production
- electricity: 51.7%
- fuel oil: 34.5%
- LPG: 4.4%
- light oil: 7.9%
- others: 1.5%

Energy saving Method
- high efficient equipment & improving operation
- reducing the number of unit operations & changing to continuous process
- waste heat recovery