Air Pollution Control Technology
In
Steel Industry

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

Committee Members

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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

Air Pollutants:
- Dust
- SOx
- NOx

Other Outputs:
- BFG
- Slag
- COG
- Boiler
2. Process of Electric Furnace Plant and Air Pollutants

EBT: Electric Bottom Tapping

- Scrap preheater
- EBT
- Ladle refining furnace
- Ladle
- Tandish mold
- Continuous casting
- Dust

Pollutants:
- Soot
- Dust
- Odor
- White smoke
3. Coarse Particle Scattering Prevention

3-1 Coal Handling Process

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

3-2-1 Coke Production × Coal Charging Process

- Centrifugal decanter mounted on ground
- Tar decanter mounted on charging car
- Venturi scrubber mounted on ground
- Pre-duster
- Connection valve
- Water tank
- Venturi scrubber to stack
- COG dust collector
- Combustion chamber
- Bump ejector
- Spray nozzle
- COG
- Tar decanter
- Thickener
- Leveling bar
- Coking chamber
- Connection valve
- COG
- Centrifugal decanter
3. Coarse Particle Scattering Prevention

3-2-2 Coke Production  ▪ Coke Discharging Process

- Coke guide car
- Ground facilities
- Pre-duster
- Bag filter
- Stack
- Coke oven
- Suction hood
- Quenching car
- Connection valve
- Coke guide car
- 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 f.
  - $Q = 4,800 \text{ m}^3/\text{m}^3$
  - $3 \, \text{mg}/\text{Nm}^3$

- **Ore Bin**
  - Bag f.
  - $Q = 1,400 \text{ m}^3/\text{m}^3$
  - $15 \, \text{mg}/\text{Nm}^3$

- **Surge Hopper**
  - Wet s.
  - Bag f.
  - $Q = 460 \text{ m}^3/\text{m}^3$
  - $5-10 \, \text{mg}/\text{Nm}^3$

- **Hot Stove**
  - Torpedo car
  - Slag ladle
  - Casting bed
  - Bag f.
  - $Q = 13,000 \times 2 \text{ m}^3/\text{m}^3$
  - $4 \, \text{mg}/\text{Nm}^3$
3. Coarse Particle Scattering Prevention

3-5 Steel Manufacturing Process (Converter)

- Bag filter
- EP

- **hot metal**
- **Treatment center**
  - $7,700 \text{ m}^3/\text{m}^3$
  - 5 $\geq 0.01 \text{mg/Nm}^3$

- **desulphur slag scraper**
  - $4,000 \text{ m}^3/\text{m}^3$
  - 2 $\geq 0.03 \text{mg/Nm}^3$

- **tundish yard**
  - $1,800 \text{ m}^3/\text{m}^3$
  - 20 $\geq 0.10 \text{mg/Nm}^3$

- **hot metal pit**
  - $7,500 \text{ m}^3/\text{m}^3$
  - 15 $\geq 0.01 \text{mg/Nm}^3$

- **desulphurization center**
  - $7,500 \text{ m}^3/\text{m}^3$
  - 2 $\geq 0.03 \text{mg/Nm}^3$

- **ladle repair**
  - **alloy**

- **ladle converter**
  - $14,200 \times 2 \text{ m}^3/\text{m}^3$
  - 0.4 $\geq 0.03 \text{mg/Nm}^3$

- **building exhaust**
  - $7,500 \text{ m}^3/\text{m}^3$
  - 5 $\geq 0.01 \text{mg/Nm}^3$

  - $7,700 \text{ m}^3/\text{m}^3$
  - 15 $\geq 0.01 \text{mg/Nm}^3$

  - $4,000 \text{ m}^3/\text{m}^3$
  - 2 $\geq 0.03 \text{mg/Nm}^3$

  - $1,800 \text{ m}^3/\text{m}^3$
  - 20 $\geq 0.10 \text{mg/Nm}^3$
3. Coarse Particle Scattering Prevention

3-6 Electric Furnace

- Roof exhausting system
- Bag filter
- Direct exhausting system
- Conventional System
- Doghouse System

- 1st charge
  - Melting
- 2nd charge
  - Melting
- Oxidation
- Reduction
- Tapping

- Roof evacuation
- Direct evacuation
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)
- \( \mu \): gas viscosity (kg/ms)
- \( g \): gravitational acceleration (cm/s^2)
- \( \rho_1 \): particle density (g/cm^3)
- \( \rho \): gas density (g/cm^3)
- \( D \): particle diameter (cm)

Principle of dust collection:

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

- \( m \): 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
4. Dust Collection System

4-3 Filter Type Dust Collector

Filtration Mechanism

\[
P_{i} = P + P_{th} + P_{d}
\]

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
4. Dust Collection System
4-4 Electrostatic Precipitator

**Principle of dust collection:**

- **Discharge electrode**
- **Dust collecting electrode**
- **Gas distribution plate**
- **Hammering device**
- **Collecting electrode**
- **Manhole**
- **Hammering drive**
- **High voltage DC generator**
- **Hopper**

**Structure of EP**
4. Dust Collection System

4-5 Selection of Dust Collector

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

<table>
<thead>
<tr>
<th>Collector</th>
<th>Applicable Particle (μm)</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>
## 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>$\text{SO}_2 + \text{H}_2\text{O} + \frac{1}{2}\text{O}_2 \rightarrow \text{H}_2\text{SO}_4$</td>
<td>$\text{H}_2\text{SO}_4$</td>
</tr>
</tbody>
</table>
| Caustic soda    | $2\text{NaOH} + \text{SO}_2 \rightarrow \text{Na}_2\text{SO}_3 + \text{H}_2\text{O}$  
$\text{Na}_2\text{SO}_3 + \text{H}_2\text{O} + \text{SO}_2 \rightarrow 2\text{NaHSO}_3$ | $\text{Na}_2\text{SO}_4$ |
| Ammonia         | $2\text{NH}_4\text{OH} + \text{SO}_2 \rightarrow (\text{NH}_4)_2\text{SO}_3 + \text{H}_2\text{O}$  
$(\text{NH}_4)_2\text{SO}_3 + \text{SO}_3 + \text{SO}_2 + \text{H}_2\text{O} \rightarrow 2\text{NH}_4\text{HSO}_3 + \text{H}_2$ | $(\text{NH}_4)_2\text{SO}_4$ |
| Slaked lime     | $\text{CaO} + \text{SO}_2 \rightarrow \text{CaSO}_3$  
$\text{CaSO}_3 + \text{O}_2 \rightarrow 2\text{CaSO}_4$ | $\text{CaSO}_4$ |

### Limestone - Gypsum Process
- SOx Rem. > 90%
- Most popularly used method in Japan
- Limestone is cheap
- Initial & operating cost is economical
- Systems stability is stable & safe
- Gypsum is marketable
5. Desulphurization Technology

5-2 Limestone-Gypsum Process

\[ \text{Reaction} \]

\[
\begin{align*}
\text{SO}_2 + \text{CaO} & \rightarrow \text{CaSO}_3 \\
2\text{CaSO}_3 + \text{O}_2 & \rightarrow 2\text{CaSO}_4 \\
\text{CaCO}_3 + \text{SO}_2 & \rightarrow \text{CaSO}_3 + \text{CO}_2
\end{align*}
\]
## 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>NH$_3$</td>
<td>naphtoquinone salfonic acid soda</td>
<td>(NH$_4$)$_2$SO$_4$ + H$_2$SO$_4$</td>
</tr>
<tr>
<td>Takahax-Reduction Decomposition</td>
<td>Na$_2$CO$_3$</td>
<td>naphtoquinone salfonic acid soda</td>
<td>crude S</td>
</tr>
<tr>
<td>Fumax-Hemibau</td>
<td>NH$_3$</td>
<td>picric acid</td>
<td>H$_2$SO$_4$</td>
</tr>
<tr>
<td>Stred Ford-Combax flue gas De-Sox</td>
<td>Na$_2$CO$_3$</td>
<td>anthoroquinone sulfonic acid soda metavanadate soda Tartaric acid soda</td>
<td>gypsum</td>
</tr>
<tr>
<td>Diamox-claus</td>
<td>NH$_3$</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**

- coke oven
- primary cooler
- booster
- De-SOx
- naphthalene scrubber
- benzene scrubber
- refined COG
- (NH$_4$)$_2$SO$_4$ saturator
- final cooler
- EP
5. Desulphurization Technology

5-4 Takahax-Hirohax Process

**Reaction**

\[ \text{NH}_3 + \text{H}_2\text{O} \rightarrow \text{NH}_4\text{OH} \]
\[ \text{NH}_4\text{OH} + \text{H}_2\text{S} \rightarrow \text{NH}_4\text{HS} + \text{H}_2\text{O} \]
\[ \text{NH}_4\text{OH} + \text{HCN} \rightarrow \text{NH}_4\text{CN} + \text{H}_2\text{O} \]
\[ \text{NH}_4\text{HS} + \frac{1}{2}\text{O}_2 \rightarrow \text{NH}_4\text{OH} + \text{S} \]
\[ \text{NH}_4\text{CN} + \text{S} \rightarrow \text{NH}_4\text{NCS} \]

**Removal rate**

S, CN > 90~99%
5. Desulphurization Technology

5-5 Fumax Process

Absorption

\[
\begin{align*}
\text{NH}_3 + \text{H}_2\text{O} & \rightarrow \text{NH}_4\text{OH} \\
\text{NH}_4\text{OH} + \text{H}_2\text{S} & \rightarrow \text{NH}_4\text{HS} + \text{H}_2\text{O}
\end{align*}
\]

Regeneration

\[
\begin{align*}
\text{NH}_4\text{HS} + \frac{1}{2}\text{O}_2 & \rightarrow \text{NH}_4\text{OH} + \text{S}
\end{align*}
\]

\[
\begin{align*}
\text{S} + \text{O}_2 & \rightarrow \text{SO}_2 \\
\text{SO}_2 + \frac{1}{2}\text{O}_2 & \rightarrow \text{SO}_3 \\
\text{SO}_3 + \text{H}_2\text{O} & \rightarrow \text{H}_2\text{SO}_4
\end{align*}
\]

Picric acid

COG

Absorber

Alkaline sol.

Regenerator

Mist catcher

H$_2$S scrubber

NH$_3$ scrubber

Evaporator

CF

Mixing t.

to H$_2$SO$_4$ plant

Absorber

AIR

H$_2$SO$_4$ recovery

H$_2$SO$_4$ plant
6. NOx Control Technology

6-1-1 NOx Generation

**Thermal NOx Generation**

![Graph showing Thermal NOx generation](image)

<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>Gas g/Nm³</td>
<td></td>
<td></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
6. NOx Control Technology

6-1-2 Factors in NOx Generation & Reduction

**Causes of generation**

- **N in fuel**
  - low N fuel
- **O₂ con.**
  - lower O₂
- **Flame temp.**
  - lower temp.
- **Retention time**
  - shorter retention

**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

**Improvement by Fuel**

**Improvement by combustion**
6. NOx Control Technology

6-2-1 Fuel Improvement
1. Use of low N and low S fuel \( S \leq N \)
2. Denitrification of COG \( N = 1 \sim 9 \text{ g/m}^3 \) 800~1,000 \( \square \), 4~6 sec.

6-2-2 Combustion Improvement
1. Low air ratio operation \( O_2 \ 1\% \) \( \square \) \( \text{NOx} \ 10\% \) \( \square \)
2. Multistage combustion \( 1^{st} \) stage air ratio; 80~90\%
   rest air \( \square \) \( 2^{nd} \) stage combustion \( \square \) \( \square \) \( 20\% \)
3. Steam or Water injection flame temp. \( \square \) \( \text{Nox} \) \( \square \)
   no-change in generated calorie

4. Exhaust gas circulation

![Graph showing NOx ppm and Flame temp. vs Gas circulation %]
6. NOx Control Technology

Continued from previous slide

5. Low-NOx burner

Wide-angle burner tile

Double-stage combustion burner

Self-circulate combustion burner

- primary air
- secondary air
- gas
- oil
- fuel
- ring nozzle
- circulating gas

NOx ppm

<table>
<thead>
<tr>
<th>tile angle (degree)</th>
<th>30</th>
<th>60</th>
</tr>
</thead>
<tbody>
<tr>
<td>250</td>
<td></td>
<td></td>
</tr>
<tr>
<td>200</td>
<td></td>
<td></td>
</tr>
<tr>
<td>150</td>
<td></td>
<td></td>
</tr>
<tr>
<td>100</td>
<td></td>
<td></td>
</tr>
<tr>
<td>50</td>
<td></td>
<td></td>
</tr>
<tr>
<td>total air ratio : 1.1</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

COG

<table>
<thead>
<tr>
<th>primary air ratio</th>
<th>1.0</th>
<th>0.8</th>
</tr>
</thead>
<tbody>
<tr>
<td>150</td>
<td></td>
<td></td>
</tr>
<tr>
<td>100</td>
<td></td>
<td></td>
</tr>
<tr>
<td>50</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

O2 in exhaust gas %

<table>
<thead>
<tr>
<th>O2 in exhaust gas %</th>
<th>1.0</th>
<th>4.0</th>
</tr>
</thead>
<tbody>
<tr>
<td>75</td>
<td></td>
<td></td>
</tr>
<tr>
<td>50</td>
<td></td>
<td></td>
</tr>
<tr>
<td>25</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
6. NOx Control Technology

6-3 Denitrification of Exhaust Gas

De-NOx: Dry Type Selective Contact Reduction using NH₃

\[
\begin{align*}
6\text{NO} + 4\text{NH}_3 &\rightarrow 5\text{N}_2 + 6\text{H}_2\text{O} \\
6\text{NO}_2 + 8\text{NH}_3 &\rightarrow 7\text{N}_2 + 12\text{H}_2\text{O}
\end{align*}
\]
7. Environmental Management System (1/2)

**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**

**Diagram:**
- EMS
- ISO14001
- Plan
- Do
- Action
  - Reviewing by plant manager
- Environmental principles
- Plan
- Check
  - Confirmation & collective measures
- Enforcement & application
- to next step

**Internal inspection**

**Graphical representation:**
- EMS
- ISO14001
- Plan
- Do
- Action
  - Reviewing by plant manager
- Environmental principles
- Plan
- Check
  - Confirmation & collective measures
- Enforcement & application
- to next step
### Measurement Items

<table>
<thead>
<tr>
<th>Pollutants</th>
<th>Emission Standard</th>
<th>EQS</th>
</tr>
</thead>
<tbody>
<tr>
<td>dust</td>
<td></td>
<td>Suspended particle matter</td>
</tr>
<tr>
<td>sulfur oxide</td>
<td></td>
<td>SO₂ (sulfur oxide)</td>
</tr>
<tr>
<td>nitrogen oxide</td>
<td></td>
<td>NO₂ (nitrogen oxide)</td>
</tr>
<tr>
<td>Cd, its compounds</td>
<td></td>
<td>CO</td>
</tr>
<tr>
<td>Cl, HCl</td>
<td></td>
<td>Photochemical oxidant</td>
</tr>
<tr>
<td>F, HF, SiₙF₂n+2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pb, its compounds</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Telemeter System

- Q SO₅ NOₓ (automatic measurements)
- Q SO₅ NOₓ
- 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 Iron</td>
<td>111,000</td>
<td>38,000</td>
<td>149,000 (61%)</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 (％)**

- **Electricity**: 41.1
- **Coal**: 25.3
- **Heavy oil**: 22.0
- **Coke**: 14.5
- **Others**: 11.5

**Integrated Steel Production**

**Non-Integrated Steel Production**

**Energy saving Method**

- High efficient equipment & improving operation
- Reducing the number of unit operations & changing to continuous process
- Waste heat recovery