Clean Coal Energy and Environment in China

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Zhejiang University, China

2005.8.22
## Low Per Capita Energy Reserves

### 2000年人均能源储量

<table>
<thead>
<tr>
<th>种类 项 Item</th>
<th>人均可开采储量 Per capita minable reserves</th>
<th>占世界平均值比例 Ratio to world average value</th>
</tr>
</thead>
<tbody>
<tr>
<td>石油 Petrol</td>
<td>2.6 t</td>
<td>11.1%</td>
</tr>
<tr>
<td>天然气 Natural Gas</td>
<td>1074 m³</td>
<td>4.3%</td>
</tr>
<tr>
<td>煤炭 Coal</td>
<td>90 t</td>
<td>55.4%</td>
</tr>
</tbody>
</table>
### Composition Ratio of Installed Capacity

<table>
<thead>
<tr>
<th>Year</th>
<th>Total GW</th>
<th>Hydro %</th>
<th>Coal %</th>
<th>Oil %</th>
<th>Gas %</th>
<th>Nuclear %</th>
<th>Renewable %</th>
</tr>
</thead>
<tbody>
<tr>
<td>2000</td>
<td>319</td>
<td>24.8</td>
<td>69.3</td>
<td>4.8</td>
<td>0.3</td>
<td>0.7</td>
<td>0.1</td>
</tr>
<tr>
<td>2005</td>
<td>430 (446)</td>
<td>25.5</td>
<td>66.6/</td>
<td>3.5</td>
<td>1.9</td>
<td>2.0</td>
<td>0.5</td>
</tr>
<tr>
<td>2010</td>
<td>550-590 (666)</td>
<td>25.8</td>
<td>63.6/ (72.7)</td>
<td>2.5</td>
<td>5.4</td>
<td>2.3</td>
<td>0.7</td>
</tr>
<tr>
<td>2015</td>
<td>710-760</td>
<td>26.3</td>
<td>60.8</td>
<td>2.0</td>
<td>6.9</td>
<td>3.1</td>
<td>0.9</td>
</tr>
<tr>
<td>2020</td>
<td>900-950</td>
<td>27.1</td>
<td>58.6</td>
<td>1.6</td>
<td>7.5</td>
<td>4.2</td>
<td>1.0</td>
</tr>
<tr>
<td>2020</td>
<td>1006GW</td>
<td>24.45%</td>
<td>61.9%</td>
<td>1.6</td>
<td>5.96%</td>
<td>3.58%</td>
<td>3.98%</td>
</tr>
</tbody>
</table>

Coal power needs 400 X 900 MW Super critical units which consume coal---2 billion ton.

燃煤发电净增 400 X 900 MW 超临界机组需消耗20亿吨煤
Gas emission of total world quantity resulted from coal combustion in China

<table>
<thead>
<tr>
<th></th>
<th>percent of total world quantitative</th>
<th>Percentage by coal (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy consumption</td>
<td>8~9 %</td>
<td></td>
</tr>
<tr>
<td>SO2</td>
<td>15.1 %</td>
<td>87 %</td>
</tr>
<tr>
<td>NOx</td>
<td>10.1 %</td>
<td>67 %</td>
</tr>
<tr>
<td>CO</td>
<td>9.6 %</td>
<td>71 %</td>
</tr>
<tr>
<td>CO2</td>
<td>13.5 %</td>
<td></td>
</tr>
</tbody>
</table>
The State of Art of Clean Coal technology and The Developing Trends

R & D, Application and Development of Clean Coal Technology

Coal washing and processing

a) Coal Washing
The Combustion, Gasification and Power Generation Technology of washing tailing sludge

b) Coal water slurry
Characteristics of coal washing sludge:
1. Particle size < 0.5mm, Ash > 40%, Moisture > 25%
2. Non-Newton fluid, heating value: 1000-3000 kcal/kg
Key Techniques and innovations

Large particles feeding at the top of furnace

Conglomerate sludge fired in CFB

Novel technique with different-density bed materials in CFB
Conglomerate sludge fired in CFB
煤泥凝聚团--异重流化床燃烧基础
• Now 25 power stations has been built

75t/h Slime Fired Boiler Structure in Dongdan Power Plant
东滩75t/h洗煤泥循环流化床锅炉简图
Replace oil by Coal Water Slurry
水煤浆代油燃烧技术

<table>
<thead>
<tr>
<th></th>
<th>2000年</th>
<th>2010年</th>
<th>2020年</th>
</tr>
</thead>
<tbody>
<tr>
<td>dependence on import (％)</td>
<td>31.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>institute of energy of state planning commission</td>
<td>45～52</td>
<td>59～62</td>
<td></td>
</tr>
<tr>
<td>IEA</td>
<td>61</td>
<td></td>
<td></td>
</tr>
<tr>
<td>IEA</td>
<td>54</td>
<td></td>
<td>72</td>
</tr>
</tbody>
</table>
## Supply and demand of oil in China

<table>
<thead>
<tr>
<th>Year</th>
<th>Import Price</th>
<th>Production Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>2005</td>
<td>180$/ton;</td>
<td>25.2 billion $;</td>
</tr>
<tr>
<td></td>
<td>476$/ton (65$/barrel)</td>
<td>66.6 billion $.</td>
</tr>
<tr>
<td>2010</td>
<td>25.2 billion $;</td>
<td>46.9 billion $;</td>
</tr>
<tr>
<td></td>
<td>123 billion $.</td>
<td></td>
</tr>
<tr>
<td>2015</td>
<td>81 billion $;</td>
<td>81 billion $;</td>
</tr>
<tr>
<td></td>
<td>214 billion $.</td>
<td></td>
</tr>
<tr>
<td>2020</td>
<td>131.5 billion $;</td>
<td>131.5 billion $;</td>
</tr>
<tr>
<td></td>
<td>345 billion $.</td>
<td></td>
</tr>
</tbody>
</table>
Replacement of oil by CWS

Standard quality of CWS:
- concentration: 65~70%;
- viscosity: ~1000CP;
- grain size: d<50 μm
- ash content: A<7%;
- sulfur content: S<0.5%.
水煤浆雾炬燃烧机理
Combustion mechanisms of CWS
3.52 MW pilot-scale test facility in Zhejiang University
670t/h (200MW) CWS fired boiler at Nanhai power plant, Guangdong, China
## Combustion efficiency of a 200t/h CWS fired boiler at Shantou power plant, Guangdong, China

<table>
<thead>
<tr>
<th>run</th>
<th>Load %</th>
<th>carbon in fly ash%</th>
<th>Carbon in bottom ash %</th>
<th>Thermal efficiency%</th>
<th>Combustion efficiency %</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>40</td>
<td>3.27</td>
<td>2.4</td>
<td>91.23</td>
<td>99.60</td>
</tr>
<tr>
<td>2</td>
<td>50</td>
<td>2.15</td>
<td>2.4</td>
<td>91.11</td>
<td>99.74</td>
</tr>
<tr>
<td>3</td>
<td>60</td>
<td>2.052</td>
<td>2.15</td>
<td>91.88</td>
<td>99.73</td>
</tr>
<tr>
<td>4</td>
<td>80</td>
<td>3.65</td>
<td>1.92</td>
<td>92.03</td>
<td>99.58</td>
</tr>
</tbody>
</table>
Pollution emission from a 220t/h CWS fired boiler at Maoming power plant

<table>
<thead>
<tr>
<th>term</th>
<th>unit</th>
<th>time</th>
<th>Ave-</th>
<th>state standard</th>
</tr>
</thead>
<tbody>
<tr>
<td>load</td>
<td>t/h</td>
<td>22nd, Jun 185</td>
<td>180</td>
<td>177</td>
</tr>
<tr>
<td></td>
<td></td>
<td>23rd, Jun 180</td>
<td>177</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>24th, Jun 177</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SO₂</td>
<td>mg/Nm³</td>
<td>634.3</td>
<td>585.1</td>
<td>585.1</td>
</tr>
<tr>
<td>NOₓ</td>
<td>mg/Nm³</td>
<td>351.7</td>
<td>359.4</td>
<td>359.4</td>
</tr>
<tr>
<td>Particle</td>
<td>mg/Nm³</td>
<td>30.67</td>
<td>25.64</td>
<td>25.64</td>
</tr>
</tbody>
</table>

ZJU’s CWS combustion technology have been applied to over 70 boilers.
The State of Art of Clean Coal technology and The Developing Trends

Clean Coal Power Generation Technology

b) CFBC
d) IGCC

Combined clean coal utilization technologies
Circulated fluidized bed Combustor
CFB 降低SO₅排放
SOx emission reduced by CFB

Pulverized Coal
W/O Scrubber *

World Bank Standard *

US Clean Air Act Amendment 1995 Limit

European Community Standard *

US Clean Air Act Amendment 2000 Limit

Typical CFB (95% Removal) *

SOURCE: The World Bank Environment Guidelines

* Assumption
4wt% Sulfur Content
HHV=14MJ/kg
CFB 降低NO\textsubscript{x}排放
NO\textsubscript{x} emission reduced by CFB

SOURCE: The World Bank Environment Guidelines
R & D, Application and Development of Clean Coal Technology

Clean Coal Power Generation Technology

b) CFBC

International:
- 250MWe CFBC - commercial operation
- 400MWe CFBC - design

China:
- Over 1000 6MWe-125MWe CFBC - Operation
- Imported 300MWe CFBC - demonstration
R & D, Application and Development of Clean Coal Technology

Clean Coal Power Generation Technology

d) IGCC

International:
250MWe coal fired IGCC power plant put into operation

China:
- IGCC system and key technology research
- 300～400MWe IGCC demonstration project
发展多联产技术
Multi-product cogeneration technology

固体燃料 → 气化炉 (Gasifier) → 合成气 (CO+H₂) → 化工产品 (Chemical products)

固体燃料 → 气化炉 (Gasifier) → 合成气 (CO+H₂) → 液体燃料 (Liquid fuel)

固体燃料 → 气化炉 (Gasifier) → 合成气 (CO+H₂) → 供热 (Heat supply)

固体燃料 → 气化炉 (Gasifier) → 合成气 (CO+H₂) → 发电 (Power generation)
Prediction of Coal Clean Utilization

Coal washing (22.5%)

DeSOx 40-50%

Gasification (裂解气化)

heat & refrigeration

Semi coke
Power generation

Coal sludge & Coal rejects
Power generation

Sewage & mud co-fired
Municipal wastes & coal co-fired
Biomass & coal co-fired

Extract vanadium
Cement
Construction materials

ash

cold gas
Prediction of Coal Clean Utilization

80kg limestone
1 ton coal
Gasification
Combustion
Ash utilization

300Nm³ Fuel gas
80kg Tar
Residue Char

1500kWh Electric
6500MW Heat
1600MW Refrigeration

235kg cement
1MW循环流化床燃烧气化多联产试验平台

CFB boiler and gasifier based on Gas and Steam Cogeneration
试验装置系统流程图

Experiment diagram
浙大研制扬中75T/H多联产循环流化床锅炉
Yangzhong multi-generation CFB boiler
煤综合利用多联产系统
Multi-generation coal utilization system

石煤综合利用多联产系统简图
multi-generation stone coal utilization system
multi-product cogeneration for coal oil and electricity

Coal gasification → Synthetic gas → Flue gas → Synthetic oil

Gas turbine

Membrane separation → Fuel cell

Oil processing

Electricity power

Oil

Chemical Processing

Chemical
Near Zero Emissions
Coal Utilization
Near zero emissions coal utilization technology with combined gasification and combustion
CFB Gasifier
CO$_2$ acceptor gasification process (~25bar)

- Main reactions in gasifier:
  - $C + H_2O = CO + H_2 - 131.6\text{kJ/mol}$
  - $CH_4 + H_2O = CO + 3H_2 - 206.3\text{kJ/mol}$
  - $CO + H_2O = CO_2 + H_2 + 41.5\text{kJ/mol}$
  - $CaO + CO_2 = CaCO_3 + 178.1\text{kJ/mol}$
  - $H_2S + CaO = CaS + H_2O$
CFB Combustor

Char combustion
CaCO₃ calcination
Hydrogen combustion

Main reactions in CFB combustor:

\[
\text{CaCO}_3 = \text{CaO} + \text{CO}_2 - 178.1\text{kJ/mol}
\]

\[
\text{C} + \text{O}_2 = \text{CO}_2 + 393.791\text{kJ/mol}
\]

\[
\text{H}_2 + \frac{1}{2}\text{O}_2 = \text{H}_2\text{O} + 286\text{kJ/mol}
\]
**Efficiency calculation for a sample**

- **Power generation:** 400MW
- **Coal gasification ratio:** 0.7
- **Operation Pressure:** 25bar
- **Temperature in the gasifier (K):** 1205
- **Hydrogen production rate (kmol/s):** 1.42
- **System efficiency (%):** 66.52

<table>
<thead>
<tr>
<th>Proximate analysis/w%, ar</th>
<th>Ultimate analysis/w%, ar</th>
<th>Heat value/MJ/kg, ar</th>
</tr>
</thead>
<tbody>
<tr>
<td>M</td>
<td>V</td>
<td>A</td>
</tr>
<tr>
<td>2.7</td>
<td>25.17</td>
<td>21.62</td>
</tr>
</tbody>
</table>
Institute for Thermal Power Engineering
浙江大学热能所

Efficiency Improvement

Thermal Efficiency(%) HHV

With Time

FutureGEN1
FutureGEN2
FutureGEN3
HUSC
AGMCFC
IGMCFC
TC
IGHTA

Legend:
PFBC - Pressured fluidized-bed combustion
IGCC - Integrated gasification-combined cycle
IGHTA - Integrated gasification-humid-air turbine
IGMCFC - Integrated gasification-molten carbonate fuel cell
AGMCFC - Advanced gasification-molten carbonate fuel cell
USC - Ultra super critical
TC - Topping cycle

First Station

Pulverized Coal

Supercritical Boiler

Years

1880 1900 1920 1940 1960 1990 2000 2020
Control of Pollutant Emission

污染物排放控制
Mercury Emission and Control during Coal Combustion

Mercury transportation during coal combustion

- **Element Mercury**
- **Gaseous Mercury**
- **Oxidized Mercury**
- **Particulate Mercury**

**Elements**: Mercury, Oxidized Mercury, Gaseous Mercury, Particulate Mercury

**Steps**: Vaporization, Chlorination, Catalytic Oxidation, Sorption, Ash Formation

**Species**: Hg\(_0\)(g), Hg\(_{\text{Cl}_2}\)(g), Hg\(^2+\)\(X\)(g), Hg\(_{\text{Cl}_2}\)(g), Hg\((p)\) Species (HgCl\(_2\), HgO, HgSO\(_4\), HgS)

**Processes**: Coal Combustion, Postcombustion
Mercury Control Approach

- Captured in wet FGD scrubbers
- Adsorbed onto porous solids
- Subsequent collection in a PM control device

Gaseous Mercury
- Oxidized Mercury
- Element Mercury

Particulate Mercury
Mercury Control Technology in Zhejiang University

Coal → Air

Mercury Transportation

Hg\(^0\)\(_{(g)}\), Hg\(^2+\)\(_{(g)}\), Hg\(_x\)

Additives

Spray

Absorbents

Separator

Hg\(_{(s)}\)

Control system

Hg CEM
Hg removal research in a full-scale semi-dry reactor system
Hg removal in flue gas before fabric filter with different absorbents
Fluorine (F) emission and control during coal combustion

- Fluorides are one of the most hazardous in the atmosphere.
- Its toxicity is 10~100 times higher than sulfur dioxide and nitrogen oxide.
- 1ppb~5ppb of fluorine in the atmosphere is probably harmful to some impressionable plants.
**Fluorine in Coal**

Fluorine concentration values for coals analyzed from China (dry basis)

<table>
<thead>
<tr>
<th>Coal rank</th>
<th>Range (ppm)</th>
<th>Average value (ppm)</th>
<th>Number of sample</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bituminous coal</td>
<td>17~696</td>
<td>173</td>
<td>81</td>
</tr>
<tr>
<td>Anthracite</td>
<td>61~1800</td>
<td>308</td>
<td>28</td>
</tr>
<tr>
<td>Lignite</td>
<td>151~615</td>
<td>241</td>
<td>7</td>
</tr>
<tr>
<td>Stone coal</td>
<td>193~3313</td>
<td>1058</td>
<td>31</td>
</tr>
<tr>
<td>Gangue</td>
<td>259~1956</td>
<td>794</td>
<td>33</td>
</tr>
</tbody>
</table>
Fluorine Emission during Coal Combustion

★ Fluorine release rapidly with increase of temperature
★ The transfer ratio of fluorine is:
  ● about 95% for PC boiler
  ● about 80 ~ 85% for grate-chain boiler
  ● about 70~80% for FBC
<table>
<thead>
<tr>
<th></th>
<th>First class</th>
<th>Second class</th>
<th>Third class</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>old boiler</strong></td>
<td>9  mg/Nm³</td>
<td>15 mg/Nm³</td>
<td>50 mg/Nm³</td>
</tr>
<tr>
<td><strong>corresponding fluorine in coal</strong></td>
<td>101〜112 ppm</td>
<td>169〜187 ppm</td>
<td>407〜452 ppm</td>
</tr>
<tr>
<td><strong>Ratio over standard</strong></td>
<td>Bituminous coal</td>
<td>42%</td>
<td>19%</td>
</tr>
<tr>
<td></td>
<td>anthracite</td>
<td>40%</td>
<td>30%</td>
</tr>
<tr>
<td></td>
<td>lignite</td>
<td>90%</td>
<td>31%</td>
</tr>
<tr>
<td></td>
<td>meager coal</td>
<td>45%</td>
<td>14%</td>
</tr>
</tbody>
</table>

Attention: Fluorine transfer ratio is assumed at 80%
<table>
<thead>
<tr>
<th>sorbent</th>
<th>CaO</th>
<th>SiO₂</th>
<th>Al₂O₃</th>
<th>Fe₂O₃</th>
<th>MgO</th>
<th>TiO₂</th>
<th>SO₃</th>
<th>K₂O</th>
<th>Na₂O</th>
</tr>
</thead>
<tbody>
<tr>
<td>石灰矿渣 limekiln residue</td>
<td>53.98</td>
<td>1.62</td>
<td>0.2</td>
<td>0.2</td>
<td>0.29</td>
<td>0.00</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>钢渣 carbide slag</td>
<td>60.98</td>
<td>5.42</td>
<td>3.00</td>
<td>0.19</td>
<td>0.00</td>
<td>0.08</td>
<td>0.28</td>
<td>0.07</td>
<td>0.05</td>
</tr>
<tr>
<td>钢渣 steel residue</td>
<td>30.35</td>
<td>18.5</td>
<td>3.42</td>
<td>22.8</td>
<td>16.35</td>
<td>0.039</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>造纸厂白泥 white mud</td>
<td>49.44</td>
<td>5.98</td>
<td>0.37</td>
<td>0.06</td>
<td>0.03</td>
<td>0.00</td>
<td>0.07</td>
<td>0.16</td>
<td>1.90</td>
</tr>
</tbody>
</table>
Effect of temperature on fluorine retention

- **1# sorbent**
- **2# sorbent**

Efficiency of fluorine retention (%) vs. Fuel-bed temp. (³C)
Dioxins emission and control during MSW and coal co-fired process
Open burning
大气 → 空气中传播 → 沉积
- 再飞散
- 焚烧
- 直接排放
- 浸蚀排放
- 废气

工业过程

人类食物链
二噁英（Dioxin）

一 所谓二噁英是对多氯二苯并二噁英 (polychlorinated dibenzo-p-dioxin, 简称PCDD)和多氯二苯并呋喃 (polychlorinated dibenzofuran,简称PCDF)的俗称。

一 PCDDs和PCDFs分别由75个和135个同族体构成
### Dioxins emission data from different zones in the world (g I-TEQ/y)

<table>
<thead>
<tr>
<th>Zone</th>
<th>Total emission</th>
<th>1987</th>
<th>1995年</th>
<th>2000年</th>
<th>2005年</th>
</tr>
</thead>
<tbody>
<tr>
<td>European</td>
<td>Total emission</td>
<td>3685~6469</td>
<td>2434~4659</td>
<td>1960~3833</td>
<td></td>
</tr>
<tr>
<td></td>
<td>MSW incineration</td>
<td>1102~1434</td>
<td>538~706</td>
<td>294~419</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Percentage%</td>
<td>22%~29%</td>
<td>15%~22%</td>
<td>10%~15%</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Power plant boiler</td>
<td>151~530</td>
<td>141~442</td>
<td>132~404</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Percentage%</td>
<td>4.1%~8.2%</td>
<td>5.8%~9.5%</td>
<td>6.7%~10.9%</td>
<td></td>
</tr>
<tr>
<td>U.S.A</td>
<td>Total emission</td>
<td>12331</td>
<td>2888</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>MSW incineration</td>
<td>7915</td>
<td>1100</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Percentage%</td>
<td>64%</td>
<td>38%</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Power plant boiler</td>
<td>51.4</td>
<td>60.9</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Percentage%</td>
<td>0.4%</td>
<td>2.1%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Taiwan</td>
<td>Total emission</td>
<td></td>
<td></td>
<td>67.25</td>
<td></td>
</tr>
<tr>
<td></td>
<td>MSW incineration</td>
<td></td>
<td></td>
<td>3.745</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Percentage%</td>
<td></td>
<td></td>
<td>5.6%</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Power plant boiler</td>
<td></td>
<td></td>
<td>3.365</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Percentage%</td>
<td></td>
<td></td>
<td>5.0%</td>
<td></td>
</tr>
</tbody>
</table>
Pilot Scale Multi-Function MSW Incineration Furnace 10t/d
10吨/天多功能垃圾焚烧中试试验台
高分辨率色谱质谱联用仪（HRGC/HRMS）
The overall look of the 800 t/d MSW incineration plant
# Dioxin Emission from Qiaosi MSW Incineration Plant in Hangzhou

杭州乔司垃圾焚烧厂的二噁英排放测试结果

## 2004-1-12

<table>
<thead>
<tr>
<th>设备</th>
<th>1＃焚烧炉 Boiler 1</th>
<th>3＃焚烧炉 Boiler 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>负荷Load</td>
<td>100％</td>
<td>106％</td>
</tr>
<tr>
<td>燃料比例（垃圾：煤） fuel (MSW: coal)</td>
<td>84: 16</td>
<td>78: 22</td>
</tr>
<tr>
<td>测试日期date</td>
<td>2003-12-24</td>
<td>2003-12-23</td>
</tr>
<tr>
<td>烟气含氧量％ (oxygen)</td>
<td>10.1~12.4</td>
<td>5.6~11.1</td>
</tr>
<tr>
<td>烟气（比利时SGS实验测试结果 I-TEQ ng/Nm3）flue gas</td>
<td>0.0068</td>
<td>0.0025， 0.0082</td>
</tr>
<tr>
<td>烟气（省环境监测中心测试结果 I-TEQ ng/Nm3）flue gas</td>
<td>0.034</td>
<td>0.009， 0.077</td>
</tr>
<tr>
<td>废气控制标准 standard I-TEQ ng/Nm3</td>
<td>1</td>
<td></td>
</tr>
</tbody>
</table>
Dioxins emission from Power Plant Boilers in China

We suppose

- 0.1 ng I-TEQ/Nm³ (0.5 ng I-TEQ/kg coal) EU regulation
- 1 ng I-TEQ/Nm³ (5 ng I-TEQ/kg coal) National regulation

In 2020, total consumption of standard coal will reach 3 billion tons.

300MW Boiler stack gas emission
0.01352 ng I-TEQ/kg coal

= 1500 g I-TEQ/y EU regulation
15000 g I-TEQ/y National regulation

Equals

4.6 billion tons MSW incineration annual at 0.1 ng I-TEQ/Nm³ emission regulation
Removal of Multi-pollutants From Flue Gas by Ozone
The Removal Mechanism of Several Pollutants From Flue Gas

\[ SO_2 + O \rightarrow SO_3 \]
\[ SO_2 + OH \rightarrow HSO_3 \]
\[ SO_2 + HO_2 \rightarrow SO_3 + OH \]
\[ HSO_3 + O_2 \rightarrow SO_3 + HO_2 \]
\[ HSO_3 + OH \rightarrow H_2SO_4 \]
\[ SO_3 + H_2O \rightarrow H_2SO_4 \]
\[ Hg + O \rightarrow HgO \]
\[ Hg + O_3 \rightarrow HgO + O_2 \]
\[ O + NO \rightarrow NO_2 \]
\[ NO + O_3 \rightarrow NO_2 + O_2 \]
\[ NO + HO_2 \rightarrow NO_2 + OH \]
\[ NO + OH + N_2 \rightarrow HNO_2 + N_2 \]
\[ NO_2 + OH + N_2 \rightarrow HNO_3 + N_2 \]
\[ Hg + NO_3 \rightarrow HgO + NO_2 \]
\[ Hg + H_2O_2 \rightarrow HgO + H_2O \]

Can be high efficiency removed by wet scrubber
Lifetime of $\text{O}_3$

- At the 150°C, the decomposition of $\text{O}_3$ is about 28% at 10s.
- The decomposition rate is keeping increased when temperature moved up.

Lifetime of the free radical is usually very short.
Reaction time needed by O3/NO reaction

- $T = 150°C$
- At this temperature 0.1s is necessary for the conversion of NO.
- SO, the O3’s lifetime is enough for the reaction.
NO removal by O₃

- T=100°C;
- Resident time is 0.09s;
- NO, NO₂, N₂O was measured by Rosemount NGA2000 continue emission monitor systems (CEMS) at 5s/scan.
- More than 80% NO can be oxidized
• It found that CO doesn’t react with O3 below 300℃
**O3 with NO, SO2 reactions**

- SO2 doesn’t have good performance like NO.
- How to improve the SO2 oxidization should be further studied.
## Power consumption by O₃ at 300MW power plant

<table>
<thead>
<tr>
<th></th>
<th>By O₃</th>
<th>By Electro Beam</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power generated</td>
<td>MW</td>
<td>300</td>
</tr>
<tr>
<td>Flue gas</td>
<td>Nm³</td>
<td>1.35 Million</td>
</tr>
<tr>
<td>NO removed</td>
<td>ppm</td>
<td>100</td>
</tr>
<tr>
<td>O₃ needed</td>
<td>Kg/h</td>
<td>289.3</td>
</tr>
<tr>
<td>O₃ generated power</td>
<td>kW/kgO₃</td>
<td>6</td>
</tr>
<tr>
<td>O₂ generated power</td>
<td>Kw/m³O₂</td>
<td>0.38</td>
</tr>
<tr>
<td>Average power consumption</td>
<td>W/Nm³</td>
<td>1.91</td>
</tr>
<tr>
<td>Total energy</td>
<td>kw</td>
<td>2581</td>
</tr>
<tr>
<td>%</td>
<td>%</td>
<td>0.86</td>
</tr>
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</table>
Thank you