The Energy Management and Emission Control with Chinese Cement Industry

Wang Lan
China Building Materials Academy
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Cement production process (1)

Drying, crushing and mixing raw material → Preheating, burning and cooling → Clinker formation → Cement grinding → Portland cement → Blended cement

Energy consumption percentage:
- Heat energy + power 8%
- Heat energy + power 82%
- Power 10%

Cement (intermediate product) → Grinding and mixing with adding gypsum
Cement production process (2)

Main sources of CO2:
- Power consumed for raw materials grinding
- Fuel for drying raw materials

In modern plants, exhaust gas heat from burning process is used for drying raw materials

Main stack gas: CO2, NOx, SOx, Dust

Alternative raw materials: Blast furnace slag, ashes

Use of alternative .......... Raw materials (wastes And by-products)
Main Sources of CO2:
- Power consumed for cement grinding
- Fuel for drying admixtures

Use of admixture (by-products)
Main sources of CO2:
- Fuels for burning (max temperature: 1,450 deg. C)
- Calcination of CaCO3
- Power for drives
- Power for coal grinding

Alternative fuels:
- Waste plastics, tires, oil

What’s Pre-heater?:
- Heat exchanger between kiln exhaust gas and raw meal
- Natural desulfurization tower
  CaO + SO3 = CaSO4

Use of cementitious Materials Fuel (wastes and by-products)
Cement manufacturing process

- **Raw materials consumption**
  - 1.5 tons of raw materials, 0.05 ton of gypsum and 0.2 ton of cementitious materials (fly ash, GGBS, etc.)/ton of cement

- **Fuel consumption**
  - 0.12 ton of standard coal (7000kcal/kg)/ton of cement

- **Electrical power consumption**
  - 110 kWh power/ton of cement

- **GHG (mainly CO₂) emission**
  - 0.85 (limestone decomposition 0.5 ton, fuel combustion 0.3 ton, power use 0.05 ton)/ton of cement

- **Dust emission**
  - 0.02 ton/ton of cement
Current Status of cement industry in China

The growth of GDP and cement output in China

In 2006: cement production 1,240 million tons
National GDP 20.94 million millions RMB

In 2007: cement production 1,360 (109.7%) million tons
National GDP 23.31 (111.3%) million millions RMB
## Sino-America comparison

<table>
<thead>
<tr>
<th>Country</th>
<th>Population ($10^9$)</th>
<th>GPD ($10^9$ US$)</th>
<th>Cement output ($10^9$ tons)</th>
<th>Cement amount per capita (ton)</th>
<th>Cement accumulative amount per capita (tons)</th>
</tr>
</thead>
<tbody>
<tr>
<td>China</td>
<td>13.1</td>
<td>23,318</td>
<td>13.6</td>
<td>0.946</td>
<td>21.2</td>
</tr>
<tr>
<td>USA</td>
<td>3.01</td>
<td>130,500</td>
<td>~1.0</td>
<td>0.332</td>
<td>21.6</td>
</tr>
</tbody>
</table>
Current Status of cement industry in China

The current situation analysis

Use of $13.1 \times 10^9$ tons of limestone and $2.1 \times 10^9$ tons of other natural materials

More than $9.5 \times 10^9$ tons of CO$_2$ emission, about 25% of whole release in China

Use of $1.8 \times 10^9$ tons of standard coal, i.e. average electric consumption – 110 kWh/t-cement, average fuel consumption – 128kg standard coal/t-cement

Cement Industry in China: Mixed dry processes reach up to 50% of whole output, with average capacity of single line equaling to 3500t/d; Backward VSK keeps 45% of whole output

The comprehensive energy consumption of unit cement product being 1.3 times of that of international advanced level

Use of $0.3 \times 10^9$ tons of FA
Use of $0.5 \times 10^9$ tons of GGBS

Cement output – $12 \times 10^9$ tons
Clinker strength – 50 MPa
**Whole national efforts**

- **Energy Law**
  2. Energy management
  6. Energy saving

- **Energy Conservation Law**
  2. Energy saving management
  3.2 Industry energy saving

- **Environment Protection Law**
  3. Protection and Improvement of the Environment
  4. Prevention and Control of Environmental Pollution and Other Public Hazards
Whole national efforts

- “Energy saving and emission reduction comprehensive work plan” issued by the State Council
- “National special program to deal with the weather change” issued by the State Council
- Energy saving and emission reduction of cement industry have been listed as government’s top priority

- One of key sectors in top-1000 enterprises energy saving action;
- Involving in an activity of key industrial energy efficiency benchmark;
- One of Ten key Energy saving Projects during the “11th Five-year Plan;
- Involving in Energy use quota standards of 26 energy intensive product;
## Cement industry energy consumption standard

### The norm of energy consumption per unit products of cement

<table>
<thead>
<tr>
<th>Capacity (t/d)</th>
<th>Comparable standard coal consumption of clinker burning (kg/t)</th>
<th>Comparable comprehensive electricity consumption of clinker burning (kWh/t)</th>
<th>Comparable comprehensive electricity consumption of cement (kWh/t)</th>
</tr>
</thead>
<tbody>
<tr>
<td>≥ 5000</td>
<td>≤ 125 (existing) ≤ 106 (new) ≤ 104 (future)</td>
<td>≤ 70</td>
<td>≤ 105</td>
</tr>
<tr>
<td></td>
<td></td>
<td>≤ 60</td>
<td>≤ 90</td>
</tr>
<tr>
<td></td>
<td></td>
<td>≤ 58</td>
<td>≤ 85</td>
</tr>
<tr>
<td>≥ 2000</td>
<td>≤ 130 ≤ 112 ≤ 106</td>
<td>≤ 75</td>
<td>≤ 110</td>
</tr>
<tr>
<td></td>
<td></td>
<td>≤ 65</td>
<td>≤ 93</td>
</tr>
<tr>
<td></td>
<td></td>
<td>≤ 60</td>
<td>≤ 90</td>
</tr>
<tr>
<td>≥ 1000</td>
<td>≤ 135 ≤ 120 ≤ 112</td>
<td>≤ 78</td>
<td>≤ 115</td>
</tr>
<tr>
<td></td>
<td></td>
<td>≤ 68</td>
<td>≤ 95</td>
</tr>
<tr>
<td></td>
<td></td>
<td>≤ 62</td>
<td>≤ 92</td>
</tr>
<tr>
<td>≤ 1000</td>
<td>≤ 140 - ≤ 115</td>
<td>≤ 80</td>
<td>≤ 120</td>
</tr>
<tr>
<td></td>
<td></td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td></td>
<td>≤ 65</td>
<td>≤ 95</td>
</tr>
<tr>
<td>VSK</td>
<td>≤ 140 - ≤ 105</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td></td>
<td>-</td>
<td>≤ 65</td>
</tr>
</tbody>
</table>
Newly developed precalcining kilns with high energy efficiency and low NOx emission widely used

120 cement production lines of installed power co-generation system recently

Power co-generation system

Cement manufacturing line (6000t/d)
Technology Development

Bag house dust collector & electrostatic precipitator used in most cement plants,
Result in:
\[ \leq 20 \text{ mg/Nm}^3 \]
Best available technology (BAT)

<table>
<thead>
<tr>
<th>No.</th>
<th>BAT</th>
<th>Note</th>
</tr>
</thead>
<tbody>
<tr>
<td>01</td>
<td>Efficient transport system</td>
<td>Mechanical conveyors use less power than pneumatic system</td>
</tr>
<tr>
<td>02</td>
<td>High-efficiency roller mills</td>
<td>Energy saving of about 17 kWh/t is available</td>
</tr>
<tr>
<td>03</td>
<td>High-efficiency classifiers</td>
<td>Energy saving of about 3 kWh/t is available</td>
</tr>
<tr>
<td>04</td>
<td>Kiln combustion system</td>
<td>Fuel saving of about 2-10% is available</td>
</tr>
<tr>
<td>05</td>
<td>High-efficiency coolers</td>
<td>Energy saving of about 2 kWh/t is available</td>
</tr>
<tr>
<td>06</td>
<td>Heat recovery for power generation</td>
<td>Power generation varies between 20-35 kWh/t-clinker</td>
</tr>
<tr>
<td>07</td>
<td>Oxygen enrichment combustion</td>
<td>-</td>
</tr>
<tr>
<td>08</td>
<td>High-efficiency grinding system</td>
<td>Energy saving of about 10 kWh/t is available</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>BAT (under developing)</th>
<th>Note</th>
</tr>
</thead>
<tbody>
<tr>
<td>09</td>
<td>Increase production 30%, and decrease energy consumption 20%</td>
</tr>
<tr>
<td>10</td>
<td>Adding 1% more of supplementary cementitious materials means the saving of 2kWh/t and 1.3kg standard coal/t</td>
</tr>
<tr>
<td>11</td>
<td>Energy saving depends on the rate of substitution</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>No.</th>
<th>BAT</th>
<th>Note</th>
</tr>
</thead>
<tbody>
<tr>
<td>12</td>
<td>Energy management</td>
<td>10% of energy saving is highly possible</td>
</tr>
</tbody>
</table>
Technology development – AFR (alternative fuel and raw materials)

• Huge population, swift economy growth and enormous output of waste materials

• 600 million tons of industrial wastes and 136 million tons of municipal wastes each year, accumulative amount of 6000 million tons of waste materials

• Including: city’s waste, sludge, mining residues, industrial byproduct, polluted soils, etc.

• Untreated waste materials pollute environment and threat the development of economy and human’s health living
Technology development

- Cement kiln can be used to treat some kind of waste materials with several advantages: low investment and operation cost, high environment protection standard.
- Organic polluters decomposed due to inside high temperature (1800°C).
- Certain kinds of heavy metal elements be solidified by cement clinker and finally by cement paste.
- Mineral elements (CaO, SiO₂, etc.) used as raw materials, composition with heat value used as alternative fuel.
Energy management

**Energy saving plan with XX cement plant**

- **General**
  - Gist (establishing a policy)
  - Outline of the plant
  - Developing plan in 11.5
  - Present situation and tasks
- **Plan goals**
  - Guidance
  - Principles
  - Plan goals (setting goals)
  - Basic ideas
- **System analysis (developing a system – tracking energy use)**
  - Basic information
  - Power system
  - Manufacturing processes
- **Problems’ identification (conducting audits)**
- **Energy saving measures**
  - Technical approach
  - Main methods
- **Measures in detail (Collecting data, Statistic model, Plant benchmarking – Energy Performance Indicator – Plant input and output, Scope of EPI – from quarrying to dispatch ,Model – energy use, labor hours, quality – data source, Waste fuel correlation)**
- **Conducting steps (establishing a action plans)**
- **Guaranteeing conditions**
- **Inspection and summary**
- **Report**
International Cooperation

Increasing Energy Efficiency and Reducing Emissions from China’s Cement Kilns
Persistent Organic Pollutants (POPs)

- POPs are a set of toxic chemicals, including DDT, chlordane, PCBs, dioxins and furans.
- POPs have been linked to adverse effects on human health and animals, such as cancer, etc.
- POPs persist for a long time and travel to regions far from their source of origin.
- Some POPs are certain chemical byproducts, such as dioxins and furans.
- They are produced unintentionally from most forms of combustion, including industrial processes.
- Cement clinker burning in kilns is one of these pyro-industrial processes.
China-US Bilateral Cooperation on Persistent Organic Pollutants

- China ratified Stockholm Convention on Persistent Organic Pollutants (POPs) in 2004
- EPA signed Memorandum of Understanding with SEPA December 2003
- Comprehensive management of dioxins/furans from cement kilns
- Goal: Reduce emissions of dioxins/furans from cement kilns
  - Accurate emissions factors for rotary and vertical shaft kilns
  - Source inventory of dioxins/furans from cement kilns in pilot provinces
  - China's National Implementation Plan (NIP) for reducing dioxins/furans emissions from cement production
  - Financing mechanisms and incentives for private sector investment to improve combustion efficiency and control particulate emissions from cement kilns
- Dioxin/furan sampling from 8 Chinese cement kilns in 2006
Our Partners
(Formal Cooperation Agreements and Informal Network)

- State Environmental Protection Administration (SEPA) – reducing pollution, especially of persistent bio-accumulative toxics (dioxins and other POPs; mercury)
  China Building Materials Academy (CBMA), Key Dioxin Labs, Provincial Environmental Protection Bureaus

- Lawrence Berkeley National Laboratory (LBNL) – benchmarking energy performance; economic and environmental co-benefits
  CBMA, Energy Research Institute, Institute of Technical Information for the Building Materials Industry of China, US DOE, others

- US Business Council for Sustainable Development (US BCSD) – Cement Sustainability Initiative implementation; by-product synergy/AFR; biofuels
  China BCSD, World BCSD

- Asia Pacific Partnership Cement Task Force (APP CTF) – promoting clean development and reducing climate impacts
  Portland Cement Association, US Department of Commerce, LBNL; CBMA, National Development and Reform Commission, China Cement Association
China-US Bilateral Cooperation on Persistent Organic Pollutants

**Sampling Sites**

<table>
<thead>
<tr>
<th>Kiln #</th>
<th>Province</th>
<th>Kiln Type</th>
<th>Production Volume (t/y)</th>
<th>APCD</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Shandong</td>
<td>5 stage PH/PC</td>
<td>1.55 M</td>
<td>ESP</td>
</tr>
<tr>
<td>2</td>
<td>Shandong</td>
<td>VSK</td>
<td>150,000</td>
<td>FF</td>
</tr>
<tr>
<td>3</td>
<td>Shandong</td>
<td>VSK</td>
<td>1.5 M</td>
<td>FF</td>
</tr>
<tr>
<td>4</td>
<td>Henan</td>
<td>PH/PC dry</td>
<td>135,000</td>
<td>FF</td>
</tr>
<tr>
<td>5</td>
<td>Hebei</td>
<td>VSK</td>
<td>100,000</td>
<td>Water spray</td>
</tr>
<tr>
<td>6</td>
<td>Xinjiang</td>
<td>VSK</td>
<td>700,000</td>
<td>FF</td>
</tr>
<tr>
<td>7</td>
<td>Xinjiang</td>
<td>Dry</td>
<td>200,000</td>
<td>ESP</td>
</tr>
<tr>
<td>8</td>
<td>Xinjiang</td>
<td>Wet</td>
<td></td>
<td>ESP</td>
</tr>
</tbody>
</table>

**Preliminary Results**

<table>
<thead>
<tr>
<th>Pollutant</th>
<th>Unit</th>
<th>Emission Factors (based on tests of 5 Chinese kilns)</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Small Vertical Shaft</td>
<td>Large Rotary Dry</td>
<td>Chinese Emission Standards</td>
</tr>
<tr>
<td>PCDDs/PCDFs&lt;sup&gt;1&lt;/sup&gt;</td>
<td>ng TEQ/m3</td>
<td>0.041 - 1.591</td>
<td>0.035 - 0.518</td>
<td>0.1 ng TEQ/m3</td>
</tr>
</tbody>
</table>

<sup>1</sup>Polychlorinated dibenzodioxins and polychlorinated dibenzofurans, in nanogram toxic equivalence (TEQ).
<sup>2</sup>Based on industry-wide emissions from the national emissions inventory.
<sup>3</sup>This is based on the regulatory limit. It is assumed all kilns are below this limit.
Luzhong Cement Plant: Vertical Shaft Kiln

- Large drum set vertically with a packed mixture of raw material and fuel traveling down through it under gravity.
- Kiln is entirely filled with a mixture of raw materials and fuel, with air entering the bottom of the kilns and exhaust gases exiting at the top.
- Raw material goes through the various pyroprocessing stages as it travels from the top of the kiln to the outlet at the bottom.
- Shaft kilns require constant attention from operators on a platform at the top of the kiln, who monitor burning conditions, control the rate of kiln feed, open and close vent doors, and manipulate the burning material at the kiln surface with long steel poles.
## Luzhong Cement Plant: Vertical Shaft Kiln

### CBMA Report Results

<table>
<thead>
<tr>
<th>Heat Loss Category</th>
<th>Percentage of Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>The heat in clinker formation</td>
<td>50.1</td>
</tr>
<tr>
<td>Heat with discharged clinker</td>
<td>5.2</td>
</tr>
<tr>
<td>Heat for vaporization of water *</td>
<td>8.3</td>
</tr>
<tr>
<td>Mechanically incomplete combustion heat loss</td>
<td>7.3</td>
</tr>
<tr>
<td>Chemically incomplete combustion heat loss</td>
<td>12.2</td>
</tr>
<tr>
<td>Heat loss from the surface of kiln</td>
<td>1.2</td>
</tr>
<tr>
<td>Exhaust gas loss</td>
<td>10.0</td>
</tr>
<tr>
<td>Heat for vaporization of water *</td>
<td>5.9</td>
</tr>
<tr>
<td><strong>Total with rounding error</strong></td>
<td><strong>100.2</strong></td>
</tr>
</tbody>
</table>

### PHAST Report Results

<table>
<thead>
<tr>
<th>Heat Loss Category</th>
<th>Percentage of Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Net load weight heat</td>
<td>62.2</td>
</tr>
<tr>
<td>Other losses</td>
<td>20.2</td>
</tr>
<tr>
<td>Wall losses</td>
<td>1.2</td>
</tr>
<tr>
<td>Atmosphere loss (CO2 heat)</td>
<td>16.4</td>
</tr>
<tr>
<td>Flue gas loss</td>
<td>1.7</td>
</tr>
<tr>
<td><strong>Total with rounding error</strong></td>
<td><strong>100.0</strong></td>
</tr>
</tbody>
</table>

* Notes:
Total heat for vaporization of water in nodules is divided for heat required to evaporate water from nodules and heat in flue gases due to combustion of volatiles etc. from fuel. Total heat remains 14.1% as reported in CBMA report.

![Kiln Heat Loss % Pie Chart](chart.png)
Project Phase Two – Energy Assessment
(LZ Cement Plant - VSK)

Exhaust gas composition

<table>
<thead>
<tr>
<th></th>
<th>CO₂</th>
<th>O₂</th>
<th>CO</th>
<th>N₂</th>
</tr>
</thead>
<tbody>
<tr>
<td>23.6</td>
<td>4.5</td>
<td>1.9</td>
<td>70</td>
<td></td>
</tr>
<tr>
<td>28.1</td>
<td>3.8</td>
<td>2.8</td>
<td>65.3</td>
<td></td>
</tr>
<tr>
<td>25.7</td>
<td>3.7</td>
<td>2.5</td>
<td>68.1</td>
<td></td>
</tr>
<tr>
<td>25.8</td>
<td>4.0</td>
<td>2.4</td>
<td>67.8</td>
<td></td>
</tr>
</tbody>
</table>

- The energy consumption is higher than average
- The exhaust gas contains certain amount of CO
- The existence of CO means the energy loss and possible formation of POPs
Luzhong Cement Plant: Vertical Shaft Kiln

- Audit Findings
  - Energy consumption is 802 kcal/kg clinker

- Suggested Actions to Improve Combustion Efficiency
  - Reduce the water content of the raw meal nodules
  - Reduce the amount of incomplete combustion
  - Reduce and use exhaust gas heat
  - Reduce kiln wall losses by applying an insulating layer to the kiln
Plant energy saving retrofitting

Initial improvement: Kiln body insulation
Reducing the water addition
Seals
Now energy consumption 760 kcal/kg
Reduction 5%

Large-scale modification will be carried out soon
As demonstration line for whole cement industry
## The development of Chinese cement industry

### The evolution of resources for cement manufacturing

<table>
<thead>
<tr>
<th></th>
<th>Past</th>
<th>Present</th>
<th>Future</th>
</tr>
</thead>
<tbody>
<tr>
<td>Raw materials</td>
<td>Limestone, Clay minerals</td>
<td>Limestone, Clay minerals, Industrial by-products</td>
<td>Alternative raw Materials (AR)</td>
</tr>
<tr>
<td>Fuels</td>
<td>Oil</td>
<td>Coal</td>
<td>Alternative fuels (AF)</td>
</tr>
<tr>
<td>Admixtures</td>
<td></td>
<td>20% FA, 40% GGBS</td>
<td>40% FA, 80% GGBS</td>
</tr>
<tr>
<td>CO₂ release</td>
<td>1t/t-cement</td>
<td>0.8t/t-cement</td>
<td>0.4t/t-cement</td>
</tr>
</tbody>
</table>
The Future of Cement Industry in China

Modern dry processes reach up to 95%
Single lines with capacity of 5000t/d exceeds 50%

- Use of $3 \times 10^9$ tons of AFR, including sludge, etc
- Use of $3 \times 10^9$ tons of FA
- Use of $1 \times 10^9$ tons of GGBS
- Use of $1 \times 10^9$ tons of other by-products
- Less than $4 \times 10^9$ tons of CO$_2$ emission
- Cement output – $10 \times 10^9$ tons
  Clinker strength – 80 MPa (28d)
  Admixture addition – 40% FA, 80% GGBS
Thanks 谢谢！

Prof. Wang Lan  Ph.D  P.E.
汪澜教授，博士生导师
China Building Materials Academy
中国建筑材料科学研究总院
Tel（电话）: 86-10-51167474, 86-13552299116
Email: wanglan@cbmamail.com.cn
www.lsa999@hotmail.com