Energy consideration in cement grinding
Introduction

Reasons for energy considerations

- Rising consumption depleting energy resources
- Depleting resources escalating energy prices
- Consumption generates increasing green house gases
- Energy costs are a major expense in cement production
Energy consumption in cement production

**Energy Consumption of Cements Plants (Germany, 2003)**

- **Physical energy**
  - Total: 103,252,000 GJ/a
  - Thermal energy: 88%
  - Electricity: 12%

- **Equiv. primary energy**
  - Total: 125,902,000 GJ/a
  - Thermal energy: 72%
  - Electricity: 28%

- **Energy costs**
  - ~25% of cement sales
  - Thermal energy: 50%
  - Electricity: 50%
Energy consumption in cement production

- ~ 2% of the global primary energy, or 5% of global industrial energy, is consumed in cement production, of which:
  - 85 - 90% is thermal energy & 10 - 15% electricity;
- ~ 25% of cement cost is due to energy costs, of which:
- ~ 50% is for electricity, mainly for grinding.
Consumption of energy in cement plant
Dry process

Fuel: 650 – 850 kcal/kg Clinker
Electricity: 65 – 130 kWh/t Cement
Consumption of energy in cement plant

Dry process

- Modern plant able to achieve 3,000 kJ/kg clinker & 90 kWh/t cement
- Electricity required for crushing, raw materials / coal milling & finished grinding represents ~ 25% of overall primary consumed in cement production
- 65% of the electricity consumed is used in the grinding operations
Power consumption in cement plant

~ 65% of electricity in cement plants is consumed in the grinding processes.
Typical power requirement of finished ball mill

Example:
Total consumption 3333 kW, 104 t/h product
=>
Total Power Consumption
= 32,0 kWh/t
Mill Power Consumption
= 27,5 kWh/t (85.8 %)
Grinding inherently inefficient ...

Performance

**Diagram:**
- Absorbed
- Drive
- Power
- Losses: Heat, Friction Wear, Sound Noise, Vibration
- Grinding: Production Fineness
Grinding inherently inefficient ...

- Only < 2 - 5% of energy input is theoretically required to fracture particles; the bulk of the input energy ends up largely as heat & typically generates ~ 25 kcal of heat per kg cement ground.
- Mill temperature could rise to 140 °C and causes gypsum to dehydrate & produces “false set” in cement, as well as “media coating” which impairs grinding efficiency.
- Typically, ~ 0.8 m³ of cooling air is required to remove the heat.
Example: material grindability & correlation with ball mill
Evaluation of performance with help of Zeisel test

Guiding values for the grindability of an OPC cement 95/5 are
- 27-32 kWh/t at 3000 cm²/g acc. Blaine
- 39-47 kWh/t at 4000 cm²/g acc. Blaine
- 58-69 kWh/t at 5000 cm²/g acc. Blaine
Performance

Detrimental effects of feed moisture on energy consumption

- Typically, every 1% increase in moisture content above 0.5% increases energy consumption by >10%, especially at higher product fineness.

- At limiting moisture, e.g. above ~5% in limestone, a ball mill may not be operable!
Influence of media filling ratio on specific power consumption

Mill dimensions

- 2.8 × 10.5 m
- 3.0 × 11.0 m
- 3.2 × 10.6 m
- 3.4 × 10.6 m
- 3.4 × 13.0 m
- 3.8 × 13.2 m
- 3.6 × 14.5 m
- 4.2 × 14.8 m
- 4.4 × 14.0 m
- 4.6 × 14.5 m
- 4.6 × 15.3 m

Energy consumption in kWh/t

Ball charge filling ratio in %

$N_{rel} = \text{relative mill speed; } O_{ma} = \text{mass related surface of mill discharge product}$
Influence of equipment / process design

- Process / equipment configuration (mill L/D & speed, closed v open circuit, pregrinder & type, mechanical v pneumatic transport, ducting arrangement, dampers, etc)

- Equipment design including the separator, mill internals such as liners (lifter/classifying), diaphragm (flow control), media, etc

- Degree of automation such as fuzzy logic / total feed / sonic control, auto sampling, etc
Performance

Optimising mill internals

- Feed grindability / consistency (physical & chemical characteristics)
- Lifter liners to provide optimum impact force in 1st chamber
- Media filling ratio, composition & quality to enhance impact forces in 1st chamber & attrition energy in 2nd chamber
- Material fill & retention time
- Optimum L/D ratio, mill speed & installed power to maximize mill efficiency
- Flow control diaphragm to ensure optimum material fill & grinding time in the 2 chambers
- Classifying liners to ensure maximum surface production in 2nd chamber
- Good ventilation to ensure rapid product & heat removal

Well designed / upgrade of mill internals may improve mill output, product quality & specific power consumption by 10 - 20%.
The new CPB separator generation: OptiTromp

First results with the new QDK technology
New QDK separator: design basis

Result of CFD analysis: improvement of air flow pattern
New QDK separator: design basis

Changes in air guide vanes and rotating cage

- **Guide vanes**
  - Number increased, directed tangentially to rotating cage

- **Cage rods**
  - Number increased, free cage surface area approx. 90%, backwards curved cage rods
Separating zone

Former

Actuel

High efficiency separator QDK
New QDK separator: design basis

Changes in design of spiral casing

Approximation of an ideal spiral design

Leading to an almost ideal distribution of separation air into the separation zone
Separator efficiency

Trompcurve $T(x)$

<table>
<thead>
<tr>
<th>Material</th>
<th>CEM I 32,5 R</th>
<th>CEM I 42,5 R</th>
<th>CEM II/A-LL 32,5 R</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bypass [%]</td>
<td>3,9</td>
<td>6,9</td>
<td>5,7</td>
</tr>
<tr>
<td>$O_m$ [cm$^2$/g]</td>
<td>670</td>
<td>720</td>
<td>620</td>
</tr>
<tr>
<td>rejects</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$O_m$ [cm$^2$/g]</td>
<td>3510</td>
<td>4260</td>
<td>4140</td>
</tr>
<tr>
<td>cement</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$O_m$ [cm$^2$/g]</td>
<td>2080</td>
<td>1970</td>
<td>2230</td>
</tr>
<tr>
<td>feed</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Functioning of mill shell liners

1\textsuperscript{st} compartment

2\textsuperscript{nd} compartment
1st compartment liners: activator liners

Conventional liner

Activator liner

Lifting height -decreasing-

Lifting height -maintained-
1st compartment activator liners
2\textsuperscript{nd} compartment classifying liners
CPB mill diaphragms

- Intermediate Diaphragm (ID)
- Discharge Diaphragm (DD)

- **Functions & requirements**
  - Retain media in 1\(^{st}\) / 2\(^{nd}\) compartments for different grinding actions
  - Regulate material flow & particle size to maximize grinding efficiency
  - Mill ventilation not obstructed (low ΔP)
  - Low maintenance (constant slot opening, no breakage or loosening of plates)
  - Structure stability & long useful life
A strong, rigidly welded steel frame affixed to mill shell via “Tie Plates“ to avoid direct rotational stress transmission from mill shell & ensures an exceptionally long useful life & maintenance-free operation.
Provides further cost reduction opportunity

Easy conversion from 3 to 4 plates division
Maximum free diaphragm area

= Lower $\Delta p$ & maximum mill ventilation / optimum air velocity

Calculated air velocity above ball charge

$v = 1.8 \text{ m/s}$

$\Delta p = 2.4 \text{ mbar}$
Material flow control

Allows optimization of material levels in 1\textsuperscript{st} & 2\textsuperscript{nd} compartments & ensures maximum grinding efficiency
Air-material separation

Negates particles “throw” & maximizes effective grinding length

- Older design
- 旧的设计

- Current design
- 现在的设计
Efficient grinding can only be achieved by maximizing the feed throughput, rapid removal of the desired fines to avoid over-grinding, transferring of optimum impact / shearing forces from the grinding media to the materials being ground & minimize generation of wasteful heat, wear, vibration & noise.
Performance

Relationship between power consumption & product fineness

For every 100 cm²/g increase in fineness increases power consumption by 1-2 kWh/t for closed circuit mill & 2-3 kWh/t for open circuit mill.
Good practices in operations & maintenance

- Maintain maximum, continuous feed without over-fill of material which cushions & absorbs the impact energy in 1\textsuperscript{st} chamber or lifts media & causes reverse or even de-classification of media in the 2\textsuperscript{nd} Chamber
- Avoid meal starvation - eg at feed inlet, in front & behind intermediate diaphragm- & wasteful metal to metal contact between the grinding elements causing wear & tear, generate heat & noise
- Conduct regular mill sampling/analysis to maximise feed & periodic technical audit to ensure optimum process conditions
- Maintain optimum milling temperature (ventilation/water spray) & use grinding aid (if cost effective) to minimise media coating & particles re-agglomeration
- Adhere to a well design planned maintenance programme
Use of additives & grinding aids

- Use appropriate grinding aid such as air entrainer or strength enhancer.
- Provide water injection to maintain optimum milling temperature; water also acts as a grinding aid.
- Reduce clinker factor & use filler such as limestone and/or extenders such as slag, fly-ash or other pozzolans.
Energy Improvement Potentials in Grinding

- Pre-grinding (e.g. roll press) => 10 - 30 %
- Separator upgrade => 5 - 25 %
- New mill internals (liners / diaphragm) => 5 - 20 %
- Mill operations & maintenance => 5 - 10 %
- Using grinding aids => 3 - 10 %
- Using fillers / Extenders => 10 - 50 %*

* Based on total energy consideration
Performance

Case example 1: Results of mill internal upgrade

<table>
<thead>
<tr>
<th>Customer:</th>
<th>Cement Plant, Spain</th>
</tr>
</thead>
<tbody>
<tr>
<td>Existing grinding plant:</td>
<td>Cement mill No. 6 - 4.0 m Øx 13.5 m</td>
</tr>
<tr>
<td></td>
<td>two compartments, closed circuit, mill supplier: FLS</td>
</tr>
<tr>
<td>Scope of modification in 1995:</td>
<td>New mill internals consisting of:</td>
</tr>
<tr>
<td></td>
<td>- mill inlet</td>
</tr>
<tr>
<td></td>
<td>- CPB lining 1st compartment, semi-bolted version</td>
</tr>
<tr>
<td></td>
<td>- CPB intermediate diaphragm of 3rd generation</td>
</tr>
<tr>
<td></td>
<td>- CPB discharge diaphragm of 3rd generation</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Mill performance:</th>
<th>before modification</th>
<th>after modification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cement type produced:</td>
<td>II F 35 A</td>
<td>II F 35 A</td>
</tr>
<tr>
<td>Fineness acc. Blaine:</td>
<td>3,900 cm²/g</td>
<td>3,900 cm²/g</td>
</tr>
<tr>
<td>Production:</td>
<td>97.76 t/h</td>
<td>117 t/h (+ 19.3 %)</td>
</tr>
<tr>
<td>Energy consumption*:</td>
<td>28.9 kWh/t</td>
<td>24.3 kWh/t (- 15.9 %)</td>
</tr>
</tbody>
</table>

(* considering mill main drive)
Case example 2: Results of conversion to high performance QDK

**Customer:**
Cement Plant, Germany

**Existing grinding plant:**
Cement mill No. 9 – 4.2 m Ø x 15.0 m length
Two compartments, closed circuit with two 1st generation separators

**Scope of modification in 1999:**
Replacement of the existing 1st generation separators by installing High Performance Separator, type QDK 29-N with Hurriclon

**Mill performance:**

<table>
<thead>
<tr>
<th>Mill performance:</th>
<th>before modification</th>
<th>after modification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cement type produced:</td>
<td>PZ 45</td>
<td>PZ 45</td>
</tr>
<tr>
<td></td>
<td>HOZ 45</td>
<td>HOZ 45</td>
</tr>
<tr>
<td>Fineness acc. Blaine:</td>
<td>3,800 cm²/g</td>
<td>3,800 cm²/g</td>
</tr>
<tr>
<td></td>
<td>3,500 cm²/g</td>
<td>3,500 cm²/g</td>
</tr>
<tr>
<td>Production:</td>
<td>64 t/h</td>
<td>95 t/h</td>
</tr>
<tr>
<td></td>
<td>63 t/h</td>
<td>80 t/h</td>
</tr>
<tr>
<td>Energy consumpnt*:</td>
<td>54.8 kWh/t</td>
<td>37 kWh/t</td>
</tr>
<tr>
<td></td>
<td>55.7 kWh/t</td>
<td>42 kWh/t</td>
</tr>
</tbody>
</table>

* considering mill drives, QDK separator, Elevator and separator fan

 (+48/+27%)

 (-32/-24%)
Case example 3: Operational results of QDK conversion & mill internals upgrade

Customer: Cement Plant, East Europe

Existing grinding plant: Cement mill 2.66 m Ø x 13.0 m length
Three compartments, open circuit, mill supplier: Wolgacemasch

Scope of modification in 1997:
1. Conversion from open into closed circuit by installing High Performance Separator, type QDK 16.-5N
2. Conversion from 3 compartments into two compartments by installing new Pfeiffer linings in 1st and 2nd grinding compartment and Pfeiffer diaphragms

Mill performance:

<table>
<thead>
<tr>
<th></th>
<th>before modification</th>
<th>after modification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cement type produced:</td>
<td>OPC (CEM I)</td>
<td>OPC (CEMI)</td>
</tr>
<tr>
<td>Fineness acc. Blaine:</td>
<td>2,900 cm²/g</td>
<td>3,000 – 3,200 cm²/g</td>
</tr>
<tr>
<td>Production:</td>
<td>23 t/h</td>
<td>35 t/h (+ 52 %)</td>
</tr>
<tr>
<td>Energy consumption*:</td>
<td>41.3 kWh/t</td>
<td>29.3 kWh/t (∗)</td>
</tr>
<tr>
<td>Cement temperature:</td>
<td>120 - 130 °C</td>
<td>70 - 80 °C (∗)</td>
</tr>
</tbody>
</table>
## Performance

### Case example 4: Results of the russian plant upgrade

<table>
<thead>
<tr>
<th></th>
<th>Before upgrade</th>
<th>After upgrade</th>
<th>After upgrade</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Cement type</strong></td>
<td>CEM400 D0</td>
<td>CEM400 D0</td>
<td>CEM400 D0</td>
</tr>
<tr>
<td><strong>Product fineness [Blaine]</strong></td>
<td>2.800 cm²/g</td>
<td>2.800 cm²/g</td>
<td>3.160 cm²/g</td>
</tr>
<tr>
<td><strong>Average production rate</strong></td>
<td>76,0 t/h</td>
<td>103,0 t/h</td>
<td>88,0 t/h</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(- 35,5 %)</td>
<td>(- 15,8 %)</td>
</tr>
<tr>
<td><strong>Specific energy consumption of mill drive (at counter)</strong></td>
<td>36,0 kWh/t</td>
<td>26,6 kWh/t</td>
<td>31,1 kWh/t</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(- 26,0 %)</td>
<td>(- 15,7 %)</td>
</tr>
<tr>
<td><strong>Cement strength after 28 days</strong></td>
<td>44,2 MPa</td>
<td>44,2 MPa</td>
<td>44,2 MPa</td>
</tr>
</tbody>
</table>

Significant reduction in specific power consumption of the mill was achieved despite relatively coarse products.
Conclusions

- Energy consideration in cement grinding makes sense: it decreases production cost, increases output & reduces greenhouse gas emission;
- Proven technology available for both new & existing plant / equipment upgrade to generate attractive ROI;
- Energy consideration should be regarded a basic responsibility of cement producers to help conserve the fast depleting fossil fuels & minimize impact of GHG on the environment to ensure a sustainable development of the cement industry.
Any questions?
Feel free to ask!

Thank you for your kind attention.