CONVENTIONAL CLINKER GRINDING - A NEW APPROACH TO THE PREDICTION OF POWER CONSUMPTION

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ENERGY IN CEMENT PRODUCTION

The estimate of the world energy consumption for cement production and its significance is:

- 2.11 billion tonnes cement x 4.0 GJ/tonne cement = 8.44×10^9 GJ (energy from fossil fuels) for a mean energy consumption of 4.0 GJ/tonne cement (CEMBUREAU, 2004).
- Additionally, 110 kWh/tonne cement electrical energy is consumed in cement production (raw meal crushing-grinding, homogenisation, clinker burning and cooling, finish milling, conveying, packing and loading, etc.).
- This power corresponds to: 2.11×10^9 tonnes cement x 110 kWh/tonne cement = 232.1×10^9 kWh = 0.835×10^9 GJ and it is produced from fossil fuels with thermal potential 0.835×10^9 GJ/0.4 = 2.088×10^9 GJ (assuming fuel combustion efficiency 40%).

ENERGY IN CEMENT PRODUCTION

Thus, the total energy consumed annually for the world cement production is:

(8.44×10^9 GJ+2.088×10^9 GJ) =**10.328×10^9 GJ**

- Since, the world total (2004) primary energy consumption was about **420 Quads Btu** corresponding to 443.1×10^9 GJ, the percentage of the energy consumed by the cement industry is: (10.328/443.1)x100 = 2.33%, from which **0.47%** refers to the electrical energy consumed in the cement making process.

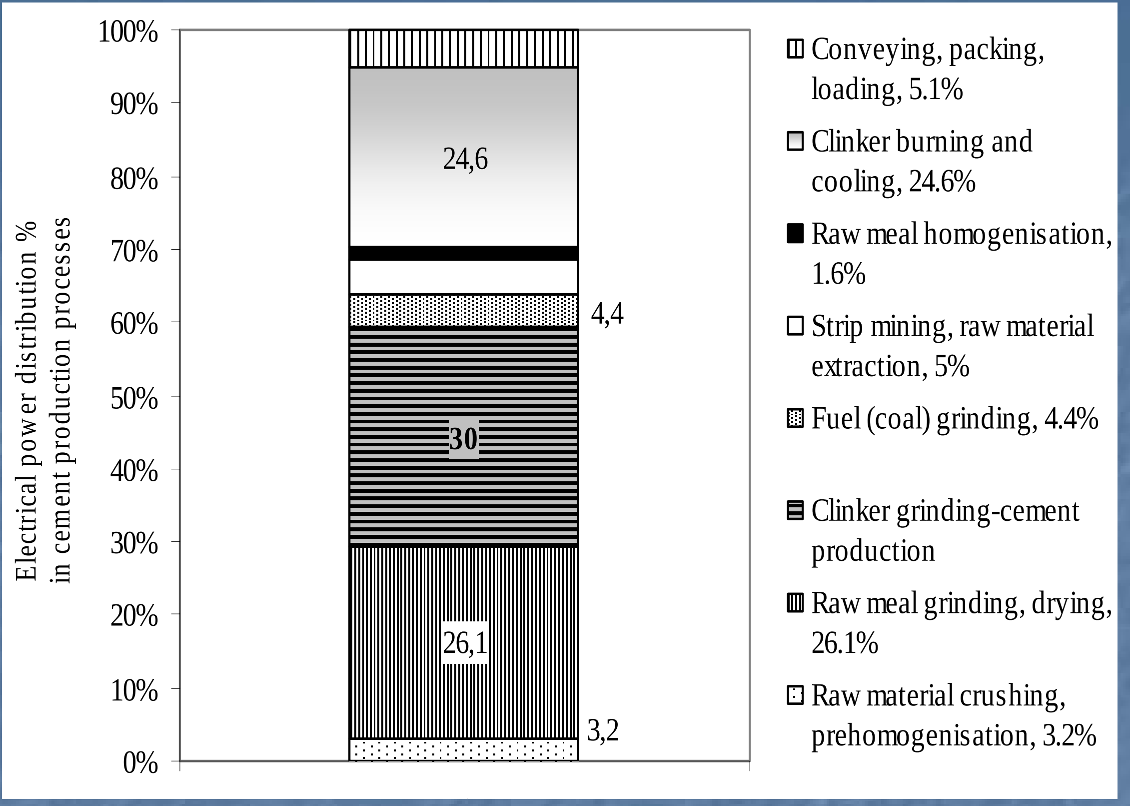


Figure. Electrical power distribution in cement production processes.

The electrical energy consumed in the cement making process is in the order of 110 kWh/tonne, about 30% of which is used for the raw materials preparation (crushing, grinding) and about 30% for the finish milling (CEMBUREAU, 2004) of clinker and additives (cement production).

EMPIRICAL MODEL DEVELOPMENT

The electrical energy consumed in the clinker fine grinding for cement production depends on:

- the **size of the clinker particles** (feed),
- the mechanical characteristics of the clinker (**hardness, work index, density**)
- the **particle size distribution** of the cement produced being in close relationship with its specific surface (Blaine fineness),
- the **mill dimensions** (length, diameter, L/D ratio), and finally
- the **mill operating conditions** (fraction of the mill filling f_L , mill critical speed f_C, mill grinding load).

EMPIRICAL MODEL DEVELOPMENT

- In the present paper, applying multiple linear regression to data received from mill manufacturers, the following empirical model was developed:

$$E = 10^{1.74\times10^{-4}\times F_{Bl}+0.035\times w_i+0.4714}$$

where,

E is the specific grinding energy (kWh/tonne),
F_{Bl} is the cement fineness (Blaine) in cm^2/g and
w_i is the clinker work index (kWh/short ton)

ESTIMATING THE d_{80} SIZE OF THE CEMENT PRODUCT

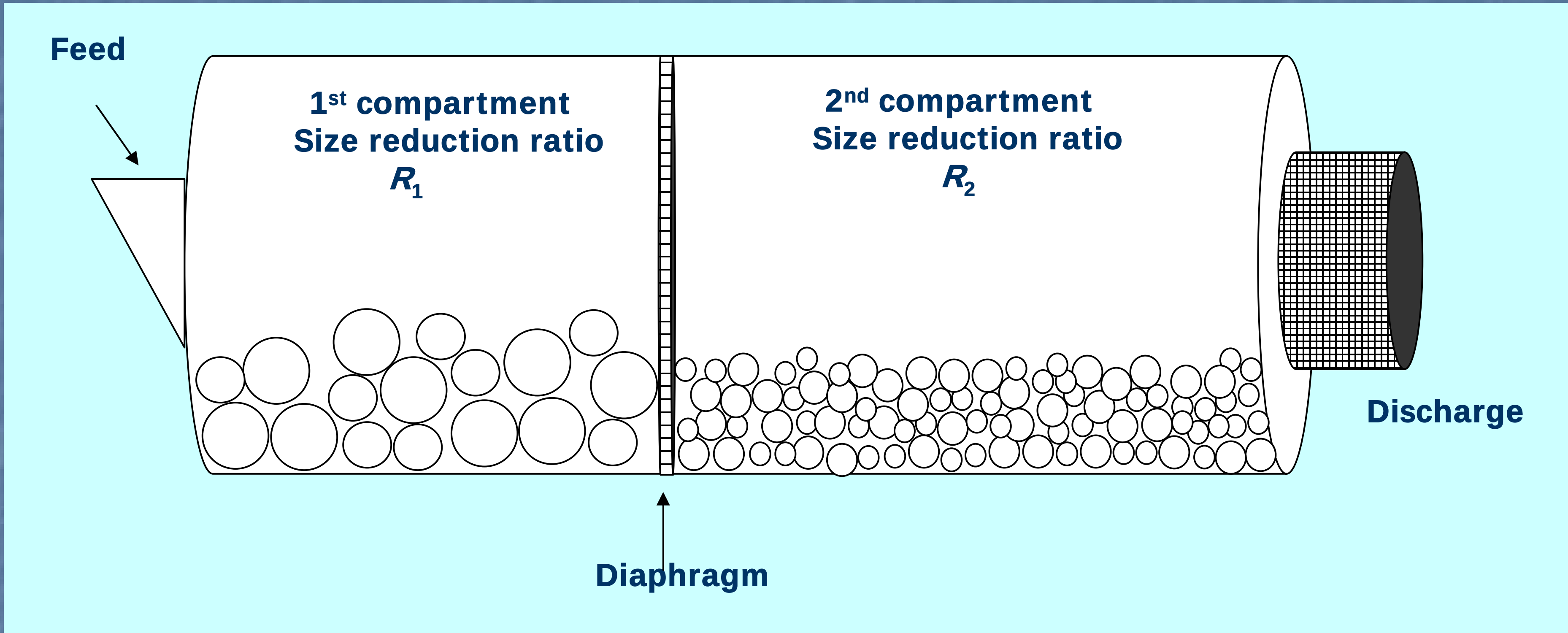
- It has been also previously shown that the specific grinding energy *E* (kWh/tonne) is given by:
- $$E = 23.7 \times w_i \times R^{0.193} \times d_{80}^{-0.769}$$ where
- E, w_i as previously defined
- $R = D_f / d_{80}$ is the particle reduction ratio
- D_f is the particle size of the feed in µm (80% passing) and
- d_{80} is the particle size of the product in µm (80% passing).

ESTIMATING THE d_{80} SIZE OF THE CEMENT PRODUCT

or

$$E = 23.7 \times w_i \times D_f^{0.193} \times d_{80}^{-0.962}$$

The ball mills used for clinker finish milling are equipped with two separate compartments. Due to the diaphragm separating the two compartments of the mill, it can be thought, without any significant error, that the size reduction process actually takes place in two successive grinding stages. The first **size reduction phase** happens in the first compartment, where the great balls are present, and the **second** in the subsequent with the small balls. The reduction ratio prevailing in the first compartment is supposed to be R_1 and in the second R_2.
The overall reduction ratio R is the product of the two ($\boldsymbol{R = R_1 \times R_2}$) and the product of the first size reduction stage, designated as d_{in}, is the feed of the next.



Conventional ball mill for clinker grinding

Thus, when ***E_1*** is the energy needed for the first size reduction phase and ***E_2*** is the energy needed in the second grinding phase for the clinker grinding in conventional ball mills, we have: **Total** ***$E = E_1 + E_2$*** and is given by:

$$E = 23.7 \times w_i \times D_f^{0.193} \times d_{in}^{-0.962} + 0.87 \times 23.7 \times w_i \times d_{in}^{0.193} \times d_{80}^{-0.962}$$

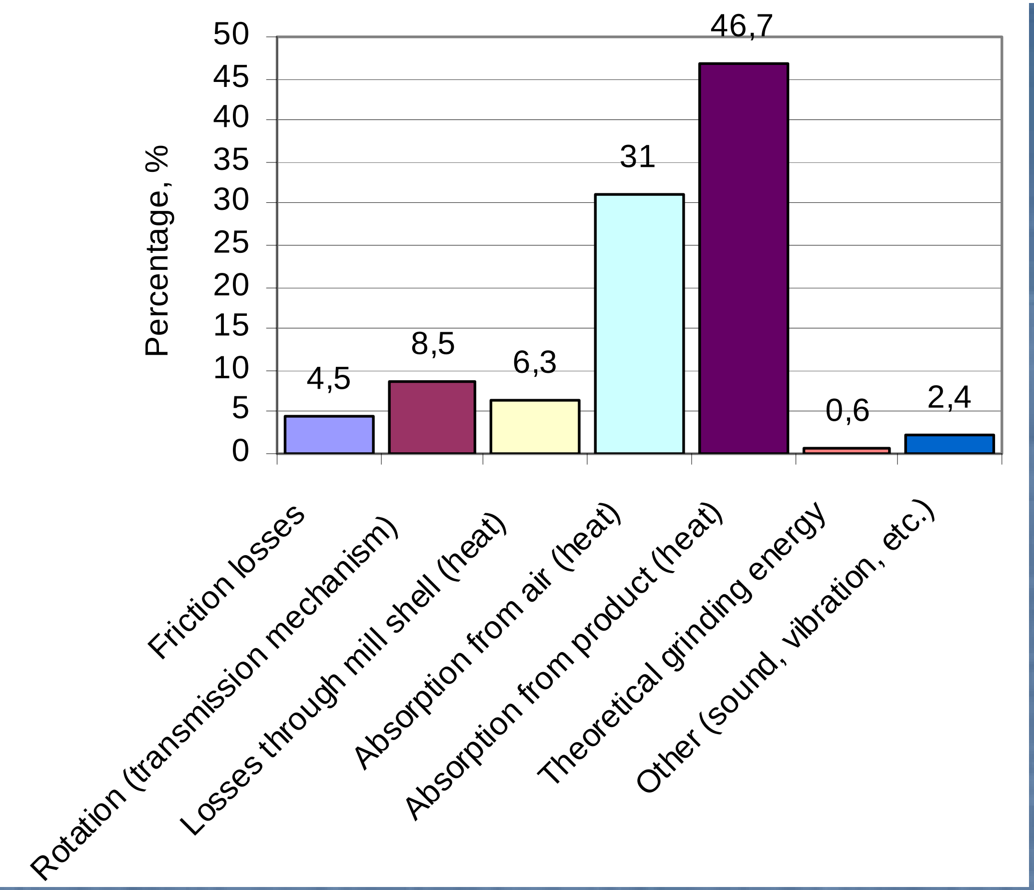


Figure. Approximate electrical power distribution in conventional cement mills (ball mills).

The factor **0.87** derived from the above figure, because there are not any additional mill rotation mechanism or friction losses corresponding to the second mill compartment. These losses, approximately estimated to 13% (i.e., **8.5+4.5**), have already been accounted in the first equation.

Data from bibliography			Equal reduction ratio r = $R^{0.5}$ (assumed)			Assumed initial reduction ratio (arbitrary)		
Blaine fineness, F_{Bl}, cm^2/g	d_{80} observed, μm	Overall reduction ratio, R calculated	Initial $R_1 = R^{0.5}$	d_{80} predicted, μm	Overall reduction ratio R, calculated	Initial R_1 = 15	d_{80} predicted, μm	Overall reduction ratio R, calculated
2500	**55**	290.9	17.06	**57.15**	280		**57.70**	277.30
3000	**41**	390.24	19.75	**44.70**	357.94		**45.84**	349.04
4000	**30**	533.33	23.06	**27.76**	576.37		**29.28**	546.45
5000	**23**	695.7	26.38	**17.41**	919.01		**18.91**	846.11

From the above table it is observed that, the proposed procedure predicts satisfactorily the d_{80} values corresponding to the fineness of the various cements. There is no significant error when an arbitrary initial reduction ratio is chosen. These values are indicative, due to the fact previously explained, that cements of the same fineness could have quite different particle size distributions.

CONCLUSIONS

In the present work, an empirical model was derived, which gives the specific grinding energy ***E*** as a function of the cement fineness F_{Bl} (Blaine) in cm^2/g and the clinker Bond work index w_i (kWh/short ton).

- The equation was connected with a previously proposed model giving the specific grinding energy ***E*** as a function of the Bond work index w_i, the size reduction ratio
- $R = D_f / d_{80}$, and the d_{80} size of the product.
- From the procedure developed, it is possible to correlate the cement fineness F_{Bl} with the size d_{80} of the cement product.

CONCLUSIONS

The calculated d_{80} values are indicative due to the fact that cements of the same fineness could have quite different particle size distributions. However, for the examples presented here, the predicted d_{80} values are close to those derived from the cement particle size distributions.

The whole methodology contributes to the specific grinding energy prediction, the calculation of the cement grinding cost, and serves successfully in the modeling of the cement grinding process. Additionally, it offers acceptable indications for the expected d_{80} size of the product, and is helpful in foreseeing the performance of the cement produced.