**Introduction**

The cement industry currently consumes 15% of the total energy used in the industrial sector globally. There are many technologies available which endeavor to reduce cement manufacturing costs by physical, chemical and logistical means.

From a physical perspective, high-efficiency roller mills, modern classifiers, multi-stage pre-heaters with a pre-calciner all help to bring down costs. The cement industry’s focus on energy reduction has made vertical roller mills particularly compelling as they are 30 to 50% more efficient than other grinding solutions. From a chemical perspective, utilization of alternative feedstocks such as refinery waste and landfill gases are partially replacing some traditional sources. In addition, the usage of lower cost pulverized and granulated sawdust, plastic and crushed tires provides a green solution. From a logistical perspective, smaller plants covering smaller local customer bases bringing in alternative fuels by truck and returning from the plant filled with fresh cement thus bringing down transport costs.

Our focus here is to look at the physical costs involved in creating cement and look at the most obvious ways to reduce those costs.
Cement energy costs

More than 1% of the world’s energy is used to grind cement to a certain fineness such that it is an appropriate size for its application. Mills are used to grind the cement down to a suitable size, but they are generally inefficient. Grinding systems in cement production make up approximately 85 to 90% of total plant electrical energy consumption but less than 5% of this energy is used effectively to grind the cement.

Coal accounts for 70% of the fuel used in cement production followed by oil (17%), gas (8%) and “other sources” making up the last (5%). In the future these “other sources” are going to be an increasing proportion of the total fuel used because many of these alternative fuels help to reduce the amount of environmental pollution. It is estimated that 100 - 200 kg of coal can produce one tonne of cement. The electrical energy required for the burning process during cement production is estimated to be 65 kWh/tonne and the thermal energy for grinding the cement is 2.72 GJ/tonne.

Figure 1. Fuel used in cement production

With global yearly cement production running at approximately 4,100 million metric tons/year for each of the last 7 years until 2020, there are plenty of savings to be made. In order to understand where the savings can be made, we need to learn more about the process.

Manufacturing process

The most common construction and building material is concrete and its key ingredient is cement, which is the binding agent that creates the formation of concrete. The most common cement is Ordinary Portland Cement (OPC) which is a grey powder, and there are other types produced for different applications.

Cement is produced by a 3-stage process that involves the following steps:

a) Initial raw milling of the limestone or other CaCO₃ based material in a primary crusher where the rocks are ground down to the size of baseballs followed by a secondary crusher that grinds them down to 2cm in size.

b) Clinkering involves the charging of this ground material with silica, iron ore, fly ash and sometimes alumina shale to a preheater. Its temperature increases from 80 to 800°C, a temperature at which it can be calcined, thus removing the CO₂. It is then fed into a roller mill to create the dry raw meal before being transported to the rotary kiln. This kiln heats all the ingredients to a temperature of 1450-1550°C whereupon a chemical reaction takes place driving off certain elements in gaseous form. The remaining elements form a grey material called clinker. A balance has to be maintained between insufficient heat that results in under burnt clinker containing unconverted lime and excessive heat that shortens the lifetime of the refractory bricks in the kiln.

c) Final grinding of the clinker takes place after cooling to produce a cement fineness of less than 45 μm. Gypsum is blended with the ground clinker to control the cement hydration rate such that its setting time is appropriate for the application. Significant amounts of electrical energy are required for milling. The total power demand depends on the fineness of the grind, the distribution of particle size, and the efficiency of separation of the finely ground particles. The finer the grind, the more reactive is the finished cement. Rapid-setting cements have smaller particle size than the
less reactive low heat of hydration cements. In general, reducing the particle size increases the rate of hydration and strength.

There are two methods of producing cement, the wet and the dry process, the cement industry is standardizing on the dry process because of the significant cost reduction. The production cost of the wet process is higher, as it requires a larger kiln, and it requires 350 kg of coal rather than 200 kg of coal per ton of cement required by the dry process. The capital cost of the dry process is higher but this is a small price to pay compared to the overall running costs of the wet process.

Cement energy costs can be reduced by good housekeeping, conversion to more energy-efficient processes and capital-intensive investments in upgrades to existing plant. However improved monitoring, control systems and equipment energy management are proven to provide the quickest returns on investment. The large power demands of finish milling mean that improvement in the efficiency of grinding and separation of the ground clinker can yield to significant energy efficiency improvements and cost savings. And the best way to achieve energy and cost saving, is by on-line analysis with real-time process measurement.

**Real-time process measurement**

We know laboratory-based laser particle sizing systems improve the quality of the cement but how can they be adapted to on-line to produce the most optimized cement fineness? The particle size is determined by a ruggedized version of the laser diffraction system used in cement labs but this on-line system is much more stable and resistant to the intense vibrations occurring in a cement plant environment.

Generally, there are 2 types of installation, the choice of which is governed by the plant throughput. For cement plants whose throughput is less than 50 Tones/Hour, a simple sampling flute and eductor are required to suck the sample from the process, measure the cement in seconds and then return the sample back to the process. If the tonnage is higher, then an auger should be installed at a transition point at the end of the cement air slide or other suitable sampling point. A sampling flute and eductor will then extract sample from the outlet of the variable speed auger.

The Bettersize BT-Online1 particle size analyzer can continually measure this representative quantity of sample in real time. Up to 10 kg of cement/hour is sub-sampled by the flute/eductor from the sampling point. As cement is an abrasive product, the sample flow path is ceramic lined up to and after the measuring cell. The measurement is similar to the laboratory operation in that the particles pass through the measuring cell, light is scattered and collected by the receiver lens and focused onto a detector where it is scanned, recorded and digitized at high speed for continuous real-time analysis (Figure 2).

![Figure 2](image-url) Front and back view of BT-Online1 with a sampling flute shown by the arrow.
Cement plant optimization

What are the immediate benefits of having an on-line sensor in place in the production process? The definitive answer to this question is determined by whether the plant is working at full capacity or not. If the plant is not working at full capacity then the economic gains are reduced energy costs and a reduction in the proportion of off-specification product especially during product changeovers. If the plant is working at full capacity an increased cement throughput can be achieved by minimizing over-grinding and reducing residence time of the cement in the mill. The plant can hence achieve a greater throughput in addition to reducing the proportion of off-specification product during product changeovers. The Bettersize BT-Online1 particle size analyzer measures the fineness measurement in production in real time, producing a 5-7% increase in throughput or a reduction in energy costs for those plants not working at capacity. How is this achieved?

![Figure 3](image-url) Cement production with no feedback control: not optimized grinding and thus not in control

When grinding cement to smaller sizes, additional energy costs are incurred, so it is critical to measure and control the size of the final product, not too coarse and definitely not too fine. Cement is milled to an appropriate fineness for the grade but insurance/safety over-grinding usually takes place in order to ensure it is in specification.

Why is this the case? Laboratory measurements for fineness are made in the lab typically every 2 hours (Figure 3). As there is no control of the grind within that 2-hour time frame, the cement may be too coarse (under grinding) and need to be re-worked (The Rejects scenario). Alternatively, there may be over grinding resulting in higher energy costs and an excess of fines which can also be detrimental to the final product as the setting time is reduced and the cement cures too fast.
The key advantage of an on-line fineness analysis is not only the capability to perform measurements every minute but also to optimise the separator speed based on those on-line measurements. A benefit of that is to create a just in specification product all the time with a much tighter tolerance (Figure 4) by closing the loop. We understand that insurance overgrinding is expensive but necessary if there is no feedback control for the process.

However, what if there was no need to wait for results from the laboratory to control the process? What if there was a particle size analyzer in the laboratory for quality control and product release, and an on-line cement fineness analyzer sending a control output signal to the separator in real time? How would this benefit you?

Firstly, all energy expended in insurance over grinding could be thus eliminated or minimized. An added advantage to this is that the residence time of the cement in the mill is reduced such that cement throughput could be increased by 5-7%,

Figure 4. Cement production with feedback control: tighter tolerances and thus more consistent product

Figure 5. Cement throughput higher with classifier feedback control: optimized grinding and thus lower milling costs
which would mean it could satisfy increased customer demand by the extra capacity provided. Therefore, with this on-line analyzer, a system payback time of between six months and a year can be obtained. Another advantage is a decreased response time and silo contamination reduction caused by changing over from 1 cement type to another. In addition, a lower standard deviation in cement fineness leads to a more stable product in terms of the short-term and long-term compressive strength.

**Comparison of on-line to laboratory results**

In order to showcase the consistency of results, Bettersize has done tests comparing results measured on both their laboratory laser diffraction system and the on-line system. Due to the different optical systems and algorithms used by the on-line and laboratory instruments, there is a slight difference in the measurement results. It should be noted that good consistency of results can be obtained by both different types of instruments so a good correlation between results can be achieved while the absolute values are not always exactly equal.

It can be seen from Figures 6 and 7 that the typical particle size values and contents of cements of different strength grades measured by the on-line and laboratory systems are quite consistent. As the compressive strength of cement increases, the average particle size (D50) obtained by both instruments gradually decreases, and the content of 3-32μm (the most important contribution to the 28-day strength of cement) increases slowly. Therefore, the measurement results produce a good correlation.

![Figure 6. Mean particle size (D50) of different cements obtained by laboratory and on-line systems](image1)

![Figure 7. Content of 3-32 μm of different cements obtained by laboratory and on-line systems](image2)
The important thing though is to check that the sieve results track the on-line process results and as can be seen in Figure 8, comparing the on-line results with those measured by sieves, they tracked with great success. If there was an increase in the percentage of particles above 45 μm on the BT-Online1, then there was also a proportional increase on the sieves and vice versa. Ultimately though their on-line analysis tracks the changes in the classifier speed (Figure 9) in real time and with that control they can really optimise the on-line classification process to provide real cement control management.

Figure 8. The wet sieve results and the on-line process results of above 45μm cement content distribution

Figure 9. Particle size distribution of cement under different classifier speeds
Conclusions

To meet today’s production demand, a fully automated analysis and control solution would be beneficial to cement manufacturers, and a ruggedized on-line laser system can provide that solution.

Bettersize on-line laser system BT-Online1 offers multiple benefits to manufacturers, including a higher return on investment, reduced energy consumption, better and real-time quality control. BT-Online1 can measure the cement fineness providing key parameters such as the % < 3 µm, % > 3µm and < 32 µm, % > 45 µm in real time. It can compare these current values to the optimal values saved in the computer placed in the cement control room. Two automated user settable 4-20 mA control outputs can then be used to control the separator by optimizing the classifier speed and hence increase the % > 3µm and < 32 µm to 70% (ideal percentage) in a controlled way.

To conclude, with on-line laser system, measurement, control, automation and optimization of the grinding circuit lowers production costs and ensures that consistent high-quality products are produced all the time with the resulting increased profitability of the cement plant.

Further information on the technique of laser diffraction can be found at https://www.bettersizeinstruments.com

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