Process technology of cement manufacture

Cleaning work at the kiln inlet
Plant operation

CFD simulation of coincineration in the calciner

Alternative fuels (AF) such as prepared fractions of industrial, commercial and municipal waste, shredded tires and animal meal are used in the cement industry pre-calciners for reasons of cost. Precalcing plants therefore offer a special flexibility, as alternative fuels can be added to several hearths at different temperatures. Besides the economic criteria, the physical and chemical properties also play a decisive role as they may impact the kiln operation. For example, particle size, volatility, heating performance and the content of chlorine, sulphur, alkalis and nitrogen in the fuel impact the heat release progression, and therefore the deacidification process and emissions, e.g. due to changes in the formation of NOx. These changes are currently difficult to predetermine. As a result, experimental tests or optimisations and, in some cases, conversion activities are currently considered to be usual.

To better predict potential process changes in the calciner the Research Institute took part in an AIF research project with the objective of better analysing the processes in calciners using CFD simulation (computational fluid dynamics). Building on the knowledge from the simulation of combustion processes for coal, the processes with the application of fractions that are capable of becoming airborne from industrial and commercial waste, which constitute the majority of fuels applied in the calciner, were investigated. FIZ supervised this project in cooperation with the chair for energy plant and energy process technology (LEAT) of the Ruhr University, Bochum, and the chair for environmental process technology and plant technology (LUAT) of the University of Essen/Duisburg.

This involved the new development and adaptation of key submodels to describe the process. Individual submodels on the fluid-dynamic behaviour and the burnout of alternative fuels were verified based on the results of laboratory tests and unified under a single methodological concept. The results of the simulations were compared with actual results based on extensive operational measurements at an industrial plant. This showed that the gas concentration profile of O2, CO2 and CO in the calciner, as calculated by the simulation model, was in the values range of the measured data and that the NOx value was broadly correct (Fig. I-1).

Overall it became clear that the fundamental process values were correctly predicted as part of the measuring and modelling uncertainties. The developed simulation approach is therefore suitable to broadly predict various operating conditions for changed framework conditions, fuel changes or modifications to the plant geometry. Apart from comparing the values that can be measured, the simulation also offers additional possibilities for predicting and analysing process changes by changing the fuel mix.

For example, Fig. I-2 displays the calculated flow rate in the lower area of the calciner up to the tangential input of the tertiary air in the conic area. It is evident that speeds of up to 50 m/s can occur in the riser duct. The average flow rate is approx. 30 m/s. This high speed leads to an extremely short retention time of the input materials in the reduction zone of less than one second.

The tangential inflow of the tertiary air constricts the rising particle-containing flow
in the conical section and pushes it against the side wall across from the tertiary air inflow. A stagnation point is formed on the opposite side before the oxygen-rich tertiary air is also diverted upwards and it slowly mixes with the fuel-rich streaks. The high flow rate in the lower part of the calciner means that predominantly heavier particles remain here (in the reduction zone), while lighter particles are rapidly transported to the upper oxidation zone, due to the fluid-dynamic forces, where they burn out (Fig. I-3).

Overall, it is evident that the combination of measuring and simulation enables a more detailed and further-reaching analysis of the processes in the calciner under realistic conditions than would be the case solely by measuring. In addition, the developed methodology provides a tool for evaluating improvements in existing calciners as well as for new designs.

Possible starting points for optimisations with the aid of CFD simulations are provided in the following points:

- Calculation of the optimal degree of preparation (fineness) of the fuels with regard to the rate of descent and flight properties
- Determination of the optimal feed location for the various fuels with regard to retention time and burnout
- Optimisation of the constructive design of calciners with regard to streak formation and improved mixing

The specified optimisation criteria must be subjected to individual testing by the plant operators, given the fluctuating raw material and fuel qualities and various designs and modes of operation of the kiln plants. Detailed fuel characterisation is essential in this regard. The investigation of the interaction of the SNCR process with staged combustion and the investigation of a preferred location for buildup formation in the calcinator are planned in the medium term as further developments of the CFD simulation for the calcinators.

Refractory material

The knowledge of refractory linings in rotary cement kilns compiled by the VDZ “Refractory Materials” task force and documented in VDZ code of practice Vt 16 (Fig. I-4) is a valuable guideline for industry practitioners. In particular, the detailed representations and descriptions of the applied methods and processes for the application of formed refractory products in rotary cement kilns and the exemplary representation of typical lining damage and aspects of occupational safety are valuable in practice. Furthermore, recommendations for incoming inspection are provided as well as a description of the techniques for diagnosing the status of refractory linings.

The durability of refractory linings in rotary kilns mainly depends on three different parameters, these are:

- The general operating conditions of the plant.
- The mechanical condition of the rotary kiln, in particular of the kiln shell ovality in the area of the kiln tires as well as the heating and cooling of the kiln, and
- The selection of refractory materials and their proper installation as well as their application in the relevant zones.

In view of the requirements and stresses to which the refractory material is exposed in a rotary cement kiln, the proper installation of the refractory lining helps to ensure a longer service life and exclude some of the stresses that usually cause premature wear. The lining methods used during installation play a key role in this regard.
The installation methods generally have to fulfill three requirements:

1. The safety of the installation personnel must be ensured.
2. The installation quality must be suitably high so that the lining is firmly positioned against the kiln shell and so that subsequent loosening or turning is prevented to the greatest possible extent.
3. An acceptable speed of lining construction must be realized in order to keep the plant’s down-time as short as possible.

The installation of bricks in the rotary kiln is either performed according to the spindle method or the bonding methods, with mortar, grating, sheeting or with the aid of wooden bows, pneumatic or hydraulic bow “pogo sticks”. In order to prevent spiral-shaped lining twisting in the rotary kiln, the bricks are bonded in the relevant area in some rotary kilns (Fig. I-5). The segments laid in the bonded area are a maximum of 5 m long. Longer bonded sections are not recommended in order to allow partial sections to be renewed in the event of damage.

The ridge lining is a lining that is constructed of various brick strengths. It is tasked with mixing the kiln feed, thereby enlarging the surface area of the kiln feed in order to improve the heat transfer when heating the raw material as well as when cooling the clinker.

Kiln heads of precalcining plants, which have very large areas to be lined with refractory material due to the connection to the tertiary air line, are constantly subject to premature wear of the lining. In order to prevent this, highly abrasion-resistant brick qualities with Al₂O₃ components of at least 50 % must be used in the lower area and approx. 60 to 65 % or 80 to 85 % in the upper area. The use of magnesia spinel bricks is also adequate in this area. Particular attention should be paid to the anchor points. Adequately high refractory steel qualities and a sufficient amount of anchors (at least 6 to 9 anchors per m²) should be used. Furthermore, the number, width and design of the expansion joints must be sufficiently dimensioned to prevent the premature failure of the lining segments.

It is important to decide on the right drying and heating procedure whether a completely newly lined kiln is to be heated or if refractory bricks have been exchanged just in sections of the rotary kiln. Drying and heating refractory materials in a completely new lined kiln plant is started by heating the preheater, tertiary air duct and clinker cooler. Special gas or light oil burners, which are supplied and operated by special companies, are used in this regard. The heating curves of the applied monolithic refractory, as provided by the manufacturer, must be complied with when heating. The gas temperatures after the plant part to be heated, are measured for this purpose. A temperature measurement is required for every cyclone stage.

Modern refractory linings are adapted to the changed firing conditions with the application of alternative fuels. An extension of the sintering zone must include the extension of the zone with highly refractory bricks that predominantly consist of magnesite-based materials. Today, kilns that consume a high amount of alternative fuel are generally lined with magnesite-based bricks. Due to continued research and new developments, the manufacturers of refractories offer today brick qualities that resist thermal, chemical, mechanical stresses and even combinations of these. The increased durability is provided by adjusting the pore quantity and size and the application of high-quality raw materials and mixtures thereof.

Causes and reduction of corrosion damage in the exhaust gas path of rotary kiln plants

Corrosion causes millions of euros worth of avoidable damage in the cement industry every year. The entire clinker firing process plant is affected, with different types of corrosion arising in the various production process areas. The additional maintenance expense for the plant caused by corrosion represents an economic strain on the operation. This is primarily due to the additional material costs, the increased deployment of personnel and increased production losses due to unplanned and drawn-out downtimes. However, the removal of corrosion damage is still seen as an unavoidable cost factor in the area of general maintenance in many parts of the cement industry.

After constructive discussions with the industry, VDZ, in cooperation with the Department of Ferrous Metallurgy of RWTH Aachen, initiated a research project in order to investigate the causes of the corrosion phenomenon in the exhaust gas path of rotary kiln plants, the so-called low temperature corrosion. The results provided in this research project will help to formulate solution proposals to reduce corrosion, which will then be provided to the indus-
try. These recommendations should provide operators with a basis for suitable site-specific corrosion protection plans.

In practice, the problem of low temperature corrosion is well-known for the constant repair work it generates (Fig. I-6). Based on the operating experiences of the works, the kiln gas filter was identified as the most severely affected unit in the exhaust path. For this reason, the planned investigations will focus on this plant component.

The corrosion damage observed in the plants frequently displays the hallmarks of wet or acid corrosion. The cause generally involves a discussion on the occurrence of sulphuric acid, which arises when the acid dew point is reached or when it condenses from gaseous phase. However, to date, no reliable investigations have been carried out that clearly establish, either qualitatively or even quantitatively, amounts of SO₃ or H₂SO₄ in raw gas and clean gas. Furthermore, there is also the fundamental question of whether acids can even have a damaging effect in the prevailing environment and whether they are not immediately neutralised by the high quantities of available alkaline dusts. A new measuring technology to determine SO₃ in raw gas was therefore developed as part of the research project (Fig. I-7). The measuring method corresponds to VDI directive 2462, sheet 2 (dated 2010) and is designed for use in gases with high dust contents. This should enable us to measure the SO₃ and H₂SO₄ content in raw gas correctly for the first time. In addition, laboratory tests will be performed in order to investigate the acid absorption potential of various dusts.

A cooperation with the Department of Ferrous Metallurgy at the RWTH Aachen was established in order to process the metallurgical aspects of the research project. This will involve investigating plant parts that are already damaged as well as performing laboratory and exposure trials. The trials will test the corrosion resistance of various steel alloys with regard to the specific corrosive stresses occurring in the exhaust gases of rotary kiln plants. The long-term exposure trials will be performed in various cement plants with different exhaust gas conditions. The corrosion samples will be exposed to particularly severely affected areas of kiln exhaust filters and then, on expiration of a defined exposure time, investigated for their material loss. The compilation of the results of the Research Institute and those of the Department of Ferrous Metallurgy should provide a complete picture of the represented problems.

Even if metallic corrosion in rotary cement kilns is ultimately not able to be prevented based on material or operational measures, the objective will be to considerably reduce corrosion rates, which will lead to significantly increased lifetimes of the individual plant units.

Rotary kiln firing systems for the use of alternative fuels

More than 25 years ago the German cement industry started using substantial quantities of alternative fuels to cover the thermal energy demand of the clinker burning process. Due to their economic and envir-
These alternative fuels differ remarkably in consistency and combustion characteristics from conventional fossil fuels, especially from coal dust. The operational experience of the plants points out that high quantities of alternative fuels used in the rotary kiln firing system reduce the maximum flame temperature and can lead to higher temperatures in the kiln inlet. At high rates of these fuels used in the rotary kiln firing system, therefore, the demands on burner and on kiln operation increase.

With the technical evolution of rotary kiln burners some significant changes have taken place due to their adaption to the respective fuels used. Today, the widely used multi-channel rotary kiln burners enable the simultaneous combustion of several fuels with different combustion properties. Modern rotary kiln burners are characterized by a variety of lances, tubes and annular channels that flexibly allow the combustion of coarse, ground, liquid, viscous and gaseous fuels. Swirling systems individually designed to the used fuels mix the alternative fuels into the flame.

Conventional fuels are retrieved from naturally resources like coal, mineral oil or natural gas. After an appropriate conditioning, these can be directly used as coal dust, fuel oil or heating gas. Alternative fuels often retrieved from materials that were produced or used for other purposes and that are thermally utilized at the end of their useful life. Alternative fuels are typically graded as waste-derived fuels consisting of fossil and organic materials or as biofuels retrieved from biomass. In contradiction to coal dust, which has homogeneous properties and a high specific surface, solid alternative fuels are characterized by a comparably higher heterogeneity (Fig. I-8), a higher moisture content, a lower specific surface and a considerable distribution of physical and chemical properties affecting the combustion. Fig. I-9 displays exemplarily the fluctuation of the moisture content of a solid alternative fuel (fluff) in a rotary kiln firing system over the course of a day. The heterogeneity of the fuels should vary within certain limits. Typical requirements for the consistency of fluffy alternative fuels have been proven to be successful for the use in rotary kiln firing systems:

- Calorific value (fuel mix): 19 to 25 MJ/kg
- Moisture content: 10 to 25 % by weight
- Particle shape: preferred 2-dimensional particles
- Particle size:
  - 2-dimensional material: max. 30 mm edge length
  - 3-dimensional material: max. 20 mm diameter
- Bulk density: 0.1 to 0.2 t/m³

The rotary kiln firing system setting has to be adapted to the used fuel or the used fuel mix, respectively. By means of adjustable burner air, in many burners divided into several air flows, the flame shape and the fuel combustion can be actively controlled. The geometry of the emanation system at the burner tip and the adjustment of the burner air enable a dedicated setting of the length, divergence and twisting of the flame which in turn influence the combustion by mixing the fuels with the secondary air.

**Gasification of heterogeneous fuels**

The pyrolysis of the fuel using a plasma burner offers onepossibility for stabilising the kiln operation when using low-calorific, inhomogeneous alternative fuels. Ionised gas molecules – the plasma created by an electric arc – can be used to achieve extremely high temperatures in order to pyrolyse alternative fuels, as well as other materials. This creates a combustible gas that contains a large amount of carbon monoxide and hydrogen due to the low-oxygen atmosphere. This combustible gas can be used in the calciner of a rotary cement kiln at temperatures of up to 1000 °C. This operation is more stable and has lower process fluctuations than the direct application of heterogeneous fuels in the calciner, as the differences in composition and moisture content are homogenised. The generation of an arc requires a relatively high supply of electrical energy. This expense must be considered in light of the positive benefits; the homogenisation of the kiln operation and the fuel and CO₂ saving.

Extensive simulation studies based on a process model developed at the FIZ for evaluating the application of combustible gas originating in the clinker process have
been carried out at the Research Institute of the Cement Industry as part of a European research project (abbreviation EDE-FU). Experimental investigations on gasification using plasma were performed on fuel samples of sewage sludge, animal meal and RDF by a project partner. The combustible gas compositions and temperatures determined as a result form the input data for the process modelling. The simulations therefore allow specific statements to be made on the effects of the generated combustible gases on the plant operation.

In principle it is possible for the calciner’s entire energy requirement to be provided by the combustible gas from the plasma burner due to its lower temperature level with regard to the sintering zone. The combustible gas has a lower calorific value than the original fuel but it has a high amount of sensible heat due to the plasma energy input. A lower fuel amount therefore needs to be gasified in order to generate the same energy level of direct combustion. Based on this, a theoretical reduction of 7 % of the CO₂ emissions arising in the process was generated compared to the combustion of fossil fuels. This recorded positive effect predominantly depends on the inlet temperature of the combustible gas, as more than 40 % of the energy is supplied to the calciner by sensible heat. The required energy quantity (and therefore gas quantity) can no longer be ensured at combustible gas temperatures under 750 °C. The fuel ash that cannot be fed directly into the kiln feed for this technology can be added to the raw material from the separate gasification. An extremely good burnout is required in this regard.

This study showed that the energy requirement of calciners can be covered by a combustible gas of corresponding quality with the simultaneous reduction of process fluctuations and CO₂ emissions. The overall result depends on the electrical energy requirement of the plasma burner and the resulting indirect CO₂ emissions. The evaluation of the benefits will be determined in the following project sections.

Modelling the grinding media movement in ball mills
The electrical energy expense for cement production averages at approx. 110 kWh/t cement in Germany, where about 38 % is used for grinding clinker and cement additives. Ball mills are usually used for cement grinding. Despite their comparably lower efficiency, they are distinguished by higher operational safety as well as a broader grain size distribution of the ground cement. For this reason it is not expected that the ball mill will be fully replaced by another grinding process even in the long term. The use of all of the available optimisation potentials is therefore considered expedient. However, the interaction of the various operating parameters and their impact on the mill filling is difficult to estimate as, in particular, the mill interior cannot be accessed for measurement. However, direct particle simulation represents a promising tool for the energetic optimisation of cement grinding.

Efficient methods for calculating and visualising bulk material have existed since the end of the 1990s. These are generally summarised under the heading “Discrete element methods” (DEM). This allows complex systems, such as the filling of a ball mill, to be simulated. A two and three dimensional model were applied at the FIZ in order to facilitate a detailed investigation of the processes in the ball mill interior. Fig. I-10 provides an example visualisation of results of the three-dimensional model.

The simulation enables sizes to be determined that could not be measured in reality. Of particular interest are velocity and pressure distributions, which allow conclusions to be drawn about the comminution process.
While simulations theoretically enable access to systems that cannot be measured, they always represent a simplification of reality. The prediction quality therefore ultimately depends on the precise validation of the applied model. The simulation calculations (numerical experiments) are therefore always performed in combination with extensive trials on a demonstration mill with armoured glass walls (Fig. I-11) and the semi-technical FIZ closed circuit grinding plant.

Apart from the kinematic simulation of the grinding media fill, the comminution process, depending on the material properties of the milled product, is also decisive for an effective optimisation. This requires a connection between the calculated energy distributions and the measurable comminution results to be established. Extensive investigations to determine the material characteristics were carried out for this purpose. Besides fracture tests, the grindability tester according to Zeisel proved itself to be a suitable measuring apparatus. Fig. I-12 shows the parameters of the RRSB distribution for cement clinker, which was stressed under various conditions in grindability testers according to Zeisel and in a ball mill in continuous operation. A generally good conformity of the crushing results can be identified in the considered range. The broader distribution of values during grinding in the ball mill can be explained by the influence of various operating parameters such as retention time for example. These parameters are explicitly investigated by systematic trial series in mills in discontinuous operation. Furthermore, a process to precisely determine the specific energy expenditure of the comminution in the test device according to Zeisel was also developed. The measurement of the power consumption was performed by a load cell rather than a protractor. The comminution progress is determined by laser granulometry.

The determined results form a promising basis for the complete description of comminution in ball mills. The development of an optimisation tool for increasing the energy efficiency of operating mills is planned based on these results.

Grindability testing according to Zeisel

A new testing apparatus for determining grindability according to Zeisel was installed at the Research Institute in 2010.

The test equipment manufactured by the TU Clausthal according to the “Tonindustrie” design replaced an apparatus from the 1960s that worked on the same principles. The device fundamentally consists of a grinding bowl in which seven steel balls are rotated by a die (Fig. I-13). The balls crush the added sample material through pressure and friction. The targeted fineness and the required energy are determined during the test. Significant differences between the new and old device are particularly apparent in the measurement data acquisition. The integral power value is no longer measured by an electric meter, rather the angle of deflection created by the rotation of the die against a spring force is measured, which can then be converted into the initiated torque by a preceding calibration.

Numerous comparison measurements were performed in order to ensure the conformity of the two testing facilities. Furthermore, investigations with regard to the machine parameters and additional variables on grindability were also performed, whereby the quantity of the feed material,
the die load, the influence of the calibration and the fraction of the feed material were varied. In addition, numerous additional comparison measurements were performed with regard to the reproducibility of the grindability determinations according to Zeisel.

Another measuring process, which eliminated the inertia arising from the pivoted grinding dish, was established as part of the research activities on grinding media movement in ball mills. The torque measurement using an angle sensor was replaced by a force sensor. Fig. I-14 shows the load cell that is connected to the grinding dish by way of a lever arm. This enables a considerably higher resolution observation of the triggered torque and therefore the power demand. The mostly inertia-free measuring method no longer shows the uniform torque progression influenced by the spring, but short, clearly delineated force impacts against the direction of rotation that could not be recorded previously. A large number of grindability tests performed using both processes have provided a possible dependency between the two measuring processes, which is to be investigated in more detail. Overall, the results provide a number of starting points for the further development of the entire process and for determining the parameters of comminution models.

Energy efficiency

The issue of energy efficiency is on the political agenda at both the European as well as at the national level. During the introduction of CO₂ emissions trading, energy efficiency was cited as a measure to reduce CO₂ emissions of energy-intensive sectors of industry. This has gained additional momentum with the European strategies for resource and energy efficiency. In Germany these strategies are being implemented by way of various legal undertakings as part of the new energy strategy. Energy efficiency and the introduction of energy management systems in the industry, together with the renewable energies law and the revision of the eco-tax legislation, therefore play a vital role.

For energy-intensive industrial sectors such as the cement industry this discussion is not without problems: Energy consumption has always been optimised for economic reasons, so remaining potentials are very low. In 2010 the “Cement Technology Roadmap” of the International Energy Agency (IEA) showed that, at a global level, energy efficiency can only contribute a maximum of 10 % towards the reduction of CO₂ emissions of the global cement industry. This estimate corresponds with the earlier considerations of the Research Institute of the Cement Industry as, even the new construction of all kiln plants in Germany “on greenfield sites”, would only lead to a maximum 7 % saving of the fuel requirement of German rotary kiln plants.

Fig. I-15 shows the distribution of energy consumption in the German cement industry in 2011. This shows that – with regard to the total energy consumption – alternative fuels now contribute considerably more than 50 % to the energy requirement. In contrast, electricity only contributes about 12 % to overall energy consumption. Although the energy optimisation of plant units such as cement grinding displays certain potentials for optimisation with regard to the electrical energy requirement, this is only of limited use as an energy efficiency parameter.
The reason for this is that:

- The increasing requirements of the performance of cement and concrete generally require finer grinding and therefore a higher demand for electrical energy.
- The targeted reduction of CO₂ emissions by reducing the clinker-cement ratio requires the increased use of blastfurnace slag which is difficult to grind.
- The improved environmental situation requires an increasing demand for electrical energy for exhaust gas cleaning, e.g. for NOₓ or dust abatement.

Cement companies have no direct access to this increased demand.

The key variables for thermal energy efficiency in cement production have been the subject of many investigations. Plant technology, plant operation, raw material and fuel properties as well as the cement-clinker ratio play an important role in this regard. The Research Institute of the Cement Industry had already referred to the efficiency but takes the specific boundary conditions of the sector, including all energy uses, into account.

### Energy requirement

**Kiln plants**

The approved kiln capacity of the German cement industry was reduced from 111 400 t/d (2009) to 107 160 t/d in 2011. The operating permits of four kiln plants expired and the total number of approved kiln plants was reduced from 57 to 53. The overwhelming majority are operated using the dry and semi-dry process. Permits for eight shaft kilns also currently exist. The average kiln capacity of the rotary kilns rose slightly from 2 249 t/d in 2009 to 2 355 t/d in 2011. **Table I-1** provides an overview of the available kiln plants and their capacities. This means that 98.9 % of the approved total capacity is used by plants with cyclone and grate preheaters. The share of the installed approved kiln capacity of German cement works due to their comparably larger kiln capacity. The capacity utilization of the kiln plants rose slightly from the low level of 65 % in 2009 and 2010, due to the economic crisis, to 72 % in 2011. The capacity utilization information was based on an assumed availability of 320 days per year.

**Fuel energy demand**

Fuel energy for cement production is predominantly expended on burning the cement clinker. Low quantities of thermal energy are used for drying additional main cement constituents such as blastfurnace slag. To produce a cement clinker with its characteristic properties, the raw materials, primarily limestone marl and clay, are burnt at temperatures of 1 400 to 1 450 °C. Due to the product requirements which require a high-temperature process the cement industry is one of the energy-intensive sectors in Germany. The cement industry has constantly attempted to lower its energy demand in order to reduce the high fuel energy costs. This is reflected in the development of the fuel energy consumed per kg clinker from 1950 to 2011 (Fig. I-17). A small temporary rise in 1987 was due to the addition of the new federal states. Until about 1990 the burning process has been optimised to such an extent that the fuel demand has remained almost constant since then.

**Initial voluntary commitment to climate protection fulfilled**

In 1995 the German cement industry, together with other energy-intensive industry sectors, committed to making a contribution to the reduction of CO₂ emission in Germany. This initial voluntary commitment of the cement industry included a re-
duction of the specific energy demand by 20% in the period from 1987 to 2008. The cement industry achieved this objective in 2005, with 2786 kJ/kg cement (Fig. I-18). In 2011 a ton of cement was produced with an average of 2759 kJ.

The Research Institute of the Cement Industry has been collecting the production and energy demand data of the German cement industry since 1995. A summarised version of this data is submitted to the Rheinisch-Westfälisches Institut für Wirtschaftsforschung (RWI) for plausibility testing.

Over the past decades the German cement industry has constantly improved its specific fuel energy demand by modernising its kiln and grinding plants. This endeavour received a particular push after the German reunification as the East German cement works were brought into line with the current state of technology in just a few years. But also several old plants were replaced in the old Western German states. Another key measure in the reduction of the fuel energy demand per ton of cement was the production of cements with several main constituents, which led to a reduction in the clinker ratio.

The absolute fuel energy demand of the German cement industry fell from 1987 to 2011 due to a severely reduced cement production by about a fifth in the period under review. Another reason for this steep fall was the reduction of the specific thermal energy demand per ton by about 20% during the same period (Fig. I-18). While the specific thermal energy demand of rotary kiln plants was at 3,500 kJ/kg cement in 1987, this reduced to only 2,759 kJ/kg cement in 2011. This was primarily the result of the reduction of the clinker/cement factor. This was 86% in 1987 and was reduced to 73% by 2011.

**Fuel mix**

The proportions of the various fuels used in the German cement industry have continued to undergo considerable changes in previous years. The overall fuel consumption was reduced from 119.9 million GJ/a in 1987 to 94.4 million GJ/a in 2011 due to the sharp fall in production, among other things. This corresponds to an absolute reduction of 21.2%. The proportion of alternative fuels continued to rise in the reporting period (Fig. I-19) and amounted to 61.1% in 2011 compared to 23.0% in 1999. The increased use of alternative fuels predominantly replaced lignite in the reporting period. The consumption of other...
fossil fuels (fuel oil EL, fuel oil S and natural gas) remains low. They are primarily used for kiln start-up.

The break-down of the consumption of alternative fuels in 2009 and 2011 shows that the quantities of used tires applied again increased, while the consumption of traditional waste oil fuel continued to decrease (Table I-2). The consumption of used tires rose from 245 000 to 286 000 t/a, while the amount of waste oil consumed fell from 73 000 to 66 000 t/a. The consumption of fractions from industrial and commercial waste remained practically unchanged at 1 643 000 t/a (2011) compared to 1 652 000 t/a (2009). In contrast, the consumption of treated fractions of municipal waste at 336 000 t/a in 2011 was considerably higher than the 188 000 t/a in 2009. The consumption of animal meal and fat is also falling due to competing consumption in other co-firing plants such as power stations. This fell from 204 000 t/a in 2009 to 187 000 t/a in 2011.

**Table I-2: Application of alternative fuels in the German cement industry**

<table>
<thead>
<tr>
<th>Alternative fuels</th>
<th>2009 in 1 000 t/a</th>
<th>2011 in 1 000 t/a</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tires</td>
<td>245</td>
<td>286</td>
</tr>
<tr>
<td>Waste oil</td>
<td>73</td>
<td>66</td>
</tr>
<tr>
<td>Fractions from industrial/commercial waste, of which:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pulp, paper and cardboard</td>
<td>1 652</td>
<td>1 643</td>
</tr>
<tr>
<td>Plastic</td>
<td>175</td>
<td>63</td>
</tr>
<tr>
<td>Packaging</td>
<td>556</td>
<td>474</td>
</tr>
<tr>
<td>Waste from the textile industry</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Other</td>
<td>911</td>
<td>1 096</td>
</tr>
<tr>
<td>Animal meal and fat</td>
<td>204</td>
<td>187</td>
</tr>
<tr>
<td>Treated fractions from municipal waste</td>
<td>188</td>
<td>336</td>
</tr>
<tr>
<td>Scrap wood</td>
<td>13</td>
<td>8</td>
</tr>
<tr>
<td>Solvents</td>
<td>81</td>
<td>104</td>
</tr>
<tr>
<td>Fuller earth</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Sewage sludge</td>
<td>263</td>
<td>304</td>
</tr>
<tr>
<td>Others, such as oil sludge or distillation residues</td>
<td>78</td>
<td>125</td>
</tr>
</tbody>
</table>

**Electricity consumption**

Electrical energy is primarily used in cement production for preparing the raw material (about 35 %), for burning and cooling the clinker (about 22 %) and for cement grinding (about 38 %). The development of the specific electricity input per ton of cement for a German cement work reached a peak of 110 kWh/t in 1987 after rising for many years (Fig. I-20). This trend was reversed after the reunification of Germany until electricity consumption stabilised between 100 and 102 kWh/t cement in about 2005. The electricity consumption once again rose to about 110 kWh/t cement in 2010 and 2011. The key reason for this is likely to be the increased demand of the building materials industry for finely ground strong cements.

For cement with additional main constituents besides clinker, such as blastfurnace slag or limestone, the grinding power consumption depends on the grindability of these materials. For example, blastfurnace slag is more difficult to grind while limestone is easier compared to clinker. This requires increased grinding power consumption as these substances have to be ground more finely than clinker in order to achieve the same cement quality. On the other hand, it saves the equivalent electrical energy demand to produce the substituted clinker (raw material preparation, burning process). The application of more energy efficient mill types, such as high-pressure grinding rolls, has been largely implemented in the cement industry. However, as the performance characteristics of cements from these mills do not correspond to those of conventional ball mills, secondary grinding in ball mills is generally still required. This means that the potential energy saving can still not be fully harnessed.

Also separate grinding of the various main constituents and their subsequent mixing in mixing plants does not seem to enable a significant reduction in energy demand within the scope of normal operating possibilities.

A forward-looking possibility for saving power from the public network is provided by the utilisation of waste heat from the clinker burning process for conversion into electricity. The first plant applying energy recovery from kiln exhaust gas became operational in Germany in 2012. A large number of modern cement kiln plants have been equipped with this technology in some Asian countries, where uncertain power supply and/or high energy prices frequently force cement companies to supply their own power.