1. Initial position

Due to the continuing energy cost fluctuations and the discussions on the sustainable protection of resources the German cement industry has hardly enabled to reduce its entire energy and power demand as a result of technical optimisation of its cement production.

After the first oil crisis, for cutting the costs the cement industry switched first from oil to coal and lignite and, due to its high energy content and relatively easy handling, to waste oil and used tyres. Later, this was followed by solvents, Fuller’s earths and oil sludges. Very similar to lignite solid alternative fuels of production-specific commercial wastes, wood, sewage sludges and – since the ban of feeding meat and bone meal or the ban of landfilling of methane arising trash-different waste were identified and specified as well as pre-processed to alternative fuels which have to meet the requirements of the main burner, the kiln inlet or – if installed – the calciner. Additionally mineral based residues like precipitated filter press cake, foundry sand, mill scale or contaminated soil are used for blending to Alternative Raw Materials (ARM) which replaces natural mineral compounds.

Until the cement industry realized, raw waste streams have to be classified, managed and pre-processed for matching the requirements the use of well pre-processed fuels provably have no effect on the emission of the process or on clinker burning process or product quality. The wastes may now also be processed for the use of its energy contends as well as the ash contends to create clinker, co-processing shortly means valorisation of energy and mineral contend.

In the meantime, the alternative fuel production and use have been established especially in countries, extremely dependent on external energy resources increasingly take into account to integrate waste management into a country wide energy concept. In order to implement
such concepts, naturally also cement plants come into focus. Frequently, however, this makes us forget that cement is a standardised mass product of a highly energy-efficient production process.

In most of the thinking, alternative fuel still implies cheap disposal to the extent that even legislation talks about co-combustion. But actually, these are highly complex physical-chemical conversion processes, which have not yet been entirely clarified even with regard to the combustion of natural coal [2, 3].

Recognizing combustion is a diffusion controlled combustion process (Figure 1) it can be simplified by the four steps of drying, pyrolysis, ignition and coke burnout in a decreasing oxygen concentration. With an increasing thermal substitution rate, this sequence dominates the combustion process and in consequent the entire cement-clinker process.

![Figure 1: Simplified operational sequence regarding the conversion of fuels with subsequent coke burnout (Baier 2009). Depending on the quality, it is possible that during the conversion of liquid fuels the residual coke combustion can also be turned to zero.](image)

Usually, commercial waste, rejects from production and fractions of high calorific value are separately or jointly pre-processed while opening and comminution by shredder, if present screened and separated by appropriate devices to remove disruptives, impurities or other harmful constituents.

Solid alternative fuels with an average lump size of $d_{\text{max}}$ 250 or 80 mm to be fed via kiln inlet or a calciner to the rotary kiln, therefore, are subject to a different sample preparation procedure and quality management than those fuels, which must be fed via main burner (Figure 2). For a better burnout, these compounds must be comminuted into finer particles ($d_{\text{max}}$ 25 or 3 mm) still coming to several powers of ten compared to coal dust. If the requirements should be finer yet, the pre-processing reaches increasingly technical and economic limits.

Normally, in the cement plant solid fuels are transported pneumatically to the respective firing point. Especially, if they are fed via the main burner, the inhomogeneous alternative fuel mixtures are differentiated again into individual particle trajectories burning at different levels: While thin, large-area particles (e.g. packaging film of 2 – 500 µm thickness) are consumed by the flame floating, three-dimensional particles of hard plastic, rubber, wood, etc. and its coke, form the tip of the flame or even fly through its ending into the clinker material and leading to reductive clinker burning conditions and form sulphuric cycles.

For these reasons fuel mixtures < 80 mm can be pre-processed mechanically, while large and very large-sized alternative fuels up to 250 mm can be processed thermally.
2. Mechanical processing for the use in a Main Burner

Regarding the insulating effect, geometry and other surface effects, the diffusions in fuel particles and the combustion speed proceed at different speeds. Mechanically, the diffusion path can be shortened by decreasing the particle size, respectively to enlarge the surface of the fuel particles [4].

For this reason, using a certain grinding technology, so far not wildly adapted to be used on alternative fuels, the average grain size of $d_{\text{max}} \leq 80$ mm can be reduced to 100 % to $< 3$ mm by a vortex mill (Figure 3). Depending on the grinding resistance, reduction rates of up to $> 100:1$ are possible.
Research tests at different alternative fuel meals performed at the Institute of Energy Process and Fuel Technology of the TU Clausthal (IEVB) showed temperatures of ignition delay (TZ) ranging between 680 °C and 711 °C and located in the transition zone between lignite dust at TZ 620 °C and hard coal dust at TZ 760 °C (Figure 4). Thus, the alternative fuel meals show an ignition delay less than of hard coal dust and insignificantly more than lignite dust.

This process is perfectly applicable to particles, which are three-dimensional, hard or brittle and so far have led to problems in kiln charge material. They are comminuted quickly and effectively, whereby thin two-dimensional particles are barely subjected to a comminution, which is also not required with regard to the burnout behaviour of coke.

While the water content as well as grain sizes reduce 100 % to < 3 mm in size, the chemical properties of the substitute fuel components remain unchanged. The physical properties of the substitute fuel meal with regard to its flow and ignition behaviour are now comparable to well known lignite dust.

3. Optimised clinkering zone firing system at the rotary kiln

If alternative fuels are to be fed via the so-called main burner, further they must be comminuted to $d_{\text{max}} < 30 \text{ mm}$ separated from tree-dimensional heavy disruptives for an improved burnout. In order to react appropriately to different fuel properties, also the burner must be designed according to the physical requirements.
An adopted main burner is designed to burn primary fuels as well as SRF with a thermal output of 10 MW up to 300 MW and has been especially designed for (Figure 5). Thus, with alternative fuels with an average grain size of $d_{\text{max.}} < 25$ mm it has already been possible to achieve highest thermal substitution rates.

Figure 5:

Front view of an adopted main burner

During operation, the primary air nozzles are selectively adjustable radially and – independently – also tangentially so that any random swirl and divergence are possible and can be adjusted to the flow path of the SRF particles. These variable nozzles act as injectors and thus, allow for a specific reaction to fluctuating fuel properties, whereby e.g. a formation of rings and undesirable coatings inside the kiln can be counteracted.

An adapted particle size and intense mixing of fuel and combustion air ensures a quick and complete conversion and significantly shortens the reaction zone. This behaviour is especially important for slow-reacting, difficult ignitable secondary fuels or even anthracite coal [5].

In order to be able to design the burner optimally, the multi-component mixtures of the solid alternative fuels must first be analysed in a classifier and chemically [6]. In the process, the fuel particles separate into particle fractions (Figure 6), in which the same properties result from equivalent solids of revolution, densities or grain shapes, i.e. the particles move on identical trajectories.

Figure 6: Air classification of alternative fuels (SBS) by means of separation from identical particle fractions of high calorific value from a fuel producing MBT
Now, this method results in statements regarding the flight behaviour or the quality of pre-processing and the composition of the waste becomes clearly perceptible, even the suitability of the fuel for the advised main burner. At relevant individual particle fractions, it is now also possible to determine the oxygen requirement or the ignition behaviour [2].

4. Use of alternative fuels at the calciner

In modern plants with calciners roughly 40 % of the thermal output is covered by the main burner, while 60 % of the thermal heat demand is covered by one or more firing points at the calciner. In the process, the necessary combustion air is fed via the tertiary air duct from the recuperation section of the clinker cooler to the firing points inside the calciner. With regard to reaction, the calciner requires only a temperature of 850 to 900 °C to calcine the limestone fraction. Inside the calciner, the 1,000 – 1,200 °C hot flue gases of the rotary kiln and the 800 – 1,000 °C hot tertiary air mix, whereby safe ignition and burning are also ensured by slow-reacting, large-sized alternative fuels.

However, especially the burning of various and slow-reacting fuels takes significantly longer time (approx. 4 to 8 s) than the preheating and calcining of the raw meal and is consequently the determining factor for the calciners dimension. For this reason, various suspension flow calciners are available according to fuel properties (Figure 7). These will allow a control of the combustion temperature and atmosphere so that it is also possible to reduce the NOx emissions.

In order to ensure the burnout of slow-reacting alternative or primary fuels it is not only necessary to support the retention time inside the calciner with a suitable distance required for calcination and burnout but if necessary, by using an additional burning chamber. For fuels with a very long retention time, such as biomass, petroleum coke, anthracite or RDF, the combustion chamber (Figure 7) fits best, where in the centre of a vortex flow and with an initial supply of pure tertiary air high temperatures develop starting drying, pyroprocessing, combustion and burn out. For the use of low calorific, large-sized alternative fuels the retention time in the short hot zone is insufficient. Therefore, a combustion chamber, the so-called step combustor, has been especially developed for a high feed rate of low calorific, large-sized alternative fuels (Figure 8).
Figure 8: Principle of the Step Combustor

The typical retention time of 4 – 8 seconds of a previously described suspension flow calciner (cf. Figure 7) is grossly insufficient for the safe burnout of such slow-reacting alternative large-sized fuels. Therefore, in the step combustor and as a function of the alternative fuel quality, the transport and discharge rates can be separately controlled, and thus the retention time extended totally of up to 15 minutes. An elegant side effect is that due to the transport control by means of air blast nozzles no mechanical internal fittings or moving parts are necessary inside this reaction chamber.

5. Handling and Storage

Cement processing requires a constant mass flow of equal quality of raw material as well as regular fuels; consequently AFR has to be per-processed in an appropriate manner to get a constant quality and has to be handled in a constant mass flow, too.

Therefore different types of truck unloading stations had been developed as a compact reception device. Walking floor trucks or tipping trucks can unload solid alternative fuels, which will be transported to the following chain of storage and dosage. The receiving station is covered completely for keeping the dust emission in the external area as low as possible. The truck driver initiates the truck unloading procedure, automatically also the material conveying to the silo box selected by the control room operator will start. After the rear doors of the truck are closed the device is in progress. The respective silo has to be selected from the control room before the material receiving can be carried out and the correct material is conveyed to the right silo intended for.

The loading and discharge conveyor consists of a distribution conveyor with the drive that can be moved up and down with steel wire ropes using a lifting device with drive that has
two different speeds. The storage usually filled and discharged with AFR material nearly simultaneously. Additionally, during filling or discharge the storage material could be sampled by a subsequent sampling station.

Figure 9: Truck unloading station for reception and storage as well as feeding the calciner process with max. 80 mm RDF at preheating or supply refined SRF to the main burner

By means of the recent established joint-venture of Polysius and Vecoplan, FuelTrack offers the total chain from identification and sourcing, pre-processing to appropriate alternative fuels for the preheater or refining for the main burner to co-process AFR. A tailor-made storage concept (Figure 9), quality monitoring and dosing arrangements up to adaptations of calciner, main burner or clinker production process itself completes the range from one hand for the clients target to save money as a long lasting effect [7].

6. Abstract

The availability of resources and its economical access is the driving force for searching for cheaper alternatives worldwide. Initially the cement industry has started after the oil crisis in the early 80s to use Residue Derived Fuels (RDF), mainly used oil and whole tyres, and has increased to a worldwide average about 10 % of the thermal energy demand in 2010, based on different types of hazardous and non-hazardous waste out of production, industry and municipal origin [1].

This trend is intended to maintain as well within the coming years due to ecologic and private and as well public economic benefits, and due to the necessity to significantly cut of GHG of the cement industry’s emissions, which contribute nearly 5 % to the total worldwide CO₂ production.

The article focuses on the main aspects of pre-processing of waste and co-processing of RDF in cement kilns, by identification, waste management, pre-processing and utilization in the cement clinker process (co-processing) with sophisticated techniques for starting with simple procedures for mono-stuff-streams as well as mechanical-biological treatment for mixed municipal solid waste.
The process of clinker burning has to be assessed with regard to technical options and defaults. The pre-processing and handling concept within the cement plant as well as the impact of RDF on the valorising clinker burning process will be emphasised. Of major importance in this context are pretreating and pyroprocessing (conversion of fuel) at its point of entrance, conversion and impact on product and emission.

Based on these prerequisites, some particular techniques for the RDF use in pre-calciniers and rotary kiln main burners are presented, mainly featuring an intelligent fuel mix management, additional measures such as mechanical or thermal pre-processing, and process-integrated measures such as modified calciners or main burners or process parameter adoptions in case of direct RDF feeding into the step combustor.

In the article, concepts are introduced based on the mechanical, physical and thermal processing of alternative fuels.

7. References


