Introduction

The use of waste-derived “alternative” raw materials and fuels can contribute greatly to resource conservation in industry and the implementation of an efficient national waste management system. The cement industry in particular, due to its nearly global presence and its process-inherent advantages, lends itself particularly well to co-processing such materials.

This module provides a short introduction to the basics of cement chemistry, cement process technology and the specific characteristics that make cement kilns rather unique for such applications.

Learning Targets

- Participants generally have a basic knowledge of the chemical, process-technological and environmental aspects of cement production.
- They also have the basic knowledge to understand and discuss the environmental dynamics of a modern cement kiln system.

Content

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- Cement production: chemistry
- Cement process technology
- Environmental features and aspects of cement production
1 Cement is made from „raw materials“

This slide introduces the term "cement raw materials" in a wider sense. Basically, raw materials can be subdivided into raw materials for clinker production and raw materials (including clinker) for cement production. Corrective materials are required to adjust the composition of a materials mix for the target values.

2 Examples of raw materials

Natural and alternative (waste derived) options exist for all "raw materials". These slides show several examples.

3 Raw materials naturally include minor and trace elements

Classical cement chemistry distinguishes main, minor and trace elements contributing to raw mix, clinker or cement composition. Composition ranges are given, particularly of trace elements, demonstrating that heavy metals occur naturally with other minerals and thus also in cement.

4 To turn raw materials into clinker, they need to undergo several treatments

These slides describe the process steps up to "clinker manufactured", particularly those that take place within the kiln system.

5 Cement making today: the process flow chart

The process flow chart explains current standard cement manufacturing technology, i.e., including a precalciner kiln and roller mills for raw materials and cement grinding, with mainly bag filter technology for dedusting.

Other (outmoded but still in use) processes are described in the annexes.

6 Clinker production today: the kiln flow chart

The kiln flow chart provides a closer look at the main equipment of any cement process – the kiln system – and introduces the respective terminology.
7 **Firing a cement kiln: feeding continuous streams of uniform quality combustible materials**

→ slide 12
This slide explains the desired main characteristics of conventional and alternative fuels, demonstrating that each and any fuel, prior to use (including co-processing) requires preparative processing (pre-processing) to optimize it for combustion.

8 **Fuel feed point in cement kiln systems**

→ slide 13
This slide shows all applicable feed points for fuel input to a cement kiln system.

9 **Cement and concrete production**

→ slide 14
This block diagram of clinker, cement and concrete manufacturing is shown alongside approximate material flow data to provide an impression of the important material flows linked to cement and concrete production.

10 **No. 1: high to very high system temperatures**

→ slide 16
The gas and material temperature profiles in the kiln system are critical. Of particular importance are the gas temperatures in the main flame (approx. 2000°C), in the precalciner (850 - 1100°C), and at the system exit (approx. 100°C), as well as the respective retention times and the oxidising atmosphere. The material temperatures approach the gas temperatures in the preheater/precancer, reaching 1450°C in the rotary kiln sintering zone.

Since even the most refractory organic compound cannot stand temperatures slightly above 800°C, the European Waste Incineration Directive requires a minimum temperature of 850°C for waste and of 1200°C for hazardous waste incineration.

11 **No. 2: process inherent multi-stage fluidized bed gas cleaning technology**

→ slide 17
Some minor and trace elements are evaporated (volatilized) in the hot kiln and travel with the kiln gases back to the cyclone preheater. There, they are recondensed (and solidified), attached to the pulverized raw meal and sent back to the rotary kiln. Finally, they leave the kiln or cement production system trapped in the clinker (and later cement). With the exception of traces of mercury, these are not emitted to the environment.
No. 3: huge retention capacity for SO\textsubscript{2} and Cl

Any sulphur imported to the high temperature part of the kiln system will be incorporated in the product (clinker and cement). Due to gypsum (calcium sulphate) formation in the calcining stage, this is not emitted. All SO\textsubscript{2} emissions stem from volatile sulphur compounds in the raw materials roasted off during preheating.

No. 4: atmospheric emissions result largely from roasting off of volatile raw material components

This slide clearly demonstrates that all emissions of a cement kiln system are from heat-volatilizable components in the raw materials (with the exception of NO\textsubscript{x}, which forms during high temperature combustion).

The need for emission regulation from modern cement kilns is therefore independent of the type of fuel used.

No. 5: all mineral input turned into product

All main, minor (and trace) elements imported with alternative materials (e.g., coal ash) are incorporated in the raw materials and contribute to the final product. Therefore, ash landfilling is unnecessary.

No. 6: all trace elements (heavy metals) are safely embedded in final product

Even heavy metals are safely embedded in clinker, cement and concrete, and do not leach out, i.e., do not travel back into the living environment. It is therefore be used (abused?!!) as a final storage medium for heavy metals; however, this strategy is detrimental to the interest of the cement industry, which aims to preserve the recyclability of concrete.

No. 7: high thermal efficiency

Modern cement kilns feature very high thermal efficiency. In most cases, they can burn alternative fuels with considerably higher thermal utilization factors than in other incinerating or co-processing industries.
17 No. 8: reduction of national CO$_2$ emissions through alternative fuel (AF) utilization

→ slide 24
Waste derived/alternative fuels are often biomass fuels or include biomass components. Using them therefore reduces fossil CO$_2$ emissions, effectively assisting national efforts to reduce CO$_2$ emissions.

18 Historic cement making processes (still in use)

→ slides 27 to 29
These flow charts show two processes which, though historic, are locally still in use: the wet process and the semi-dry process. For the sake of completeness, further process types (mainly of local significance) are listed in slide 29.

19 Emissions

→ slides 30 to 34
As a short introduction to the issue of atmospheric pollutants, slides 30-34 present rough information on effects, characteristics, historic cases and origins of various airborne pollutants within the cement industry.

20 Measuring emissions from a cement kiln

→ slide 35
Slide 35 briefly summarizes the Holcim Emissions Monitoring and Reporting scheme. All Holcim cement factories have been directed to use alternative fuels and raw materials. Continuous measurement is performed for dust, SO$_2$, NO$_2$ and VOCs and for other emission components at least once per year.

21 Air quality

→ slides 37 to 40
Basically, a country defines its air quality (or immission) target values (e.g., as proposed by the WHO) and measures them continuously via an air quality observation network (measuring stations).

If the target values are not achieved, the relevant authorities set specific air emission limits for various types of emitters and emission components. These authorities also define the emission measuring and evaluation methods.

If after some years (e.g., 10) the air quality targets are reached, regulatory officials may choose either to maintain their emission limits or to tighten them, depending on developments in related technology and stakeholder concerns.
FAQ

Q: What requirements do conventional and alternative cement raw materials and fuels need to fulfill to make them suitable for cement production?

A: Alternative raw materials and fuel ashes must be chemically compatible with the existing raw mix, i.e., the quality characteristics of the final product must fulfil defined standards.

Volatilizable components (pyritic sulphur, organics, mercury, etc.) should not elevate emissions above set limits or, in the case of alternative materials, significantly above baseline emissions, i.e., emissions without alternative materials. Alternative fuels should be low in chlorines and close to nil in mercury.

All materials (especially hazardous, alternative fuels) and their respective handling and process equipment) has to comply with all applicable OHS standards.

No materials used should impair the kiln’s operational stability or availability.

Q: Are heavy metal emissions a problem in the cement industry? Which factors influence heavy metal emissions from cement kiln stacks?

A: With the exception of a small number of isolated mercury cases, regarding European Waste Incineration Directive (WID) limits, heavy metal emissions from modern cement kilns pose no known problems.

For health reasons, chromium inputs the final product (concrete) should be minimized. Heavy metals occur naturally in raw materials and fuels. Those volatilized in the kiln system are trapped (adsorbed) by the pulverized raw materials in the preheater / precalciner / raw mill system and fed back into the process via the kiln dedusting equipment.

An estimated 80% of heavy metal traces in clean gas dusts remain below detectable limits.

Heavy metal emission changes result mainly from variations in dedusting efficiency.

Q: In what respect does the pre-modern cement production processes used in some areas differ from current standard processes (process technology, energy consumption, environmental friendliness)?

A: Some processes use wet raw material preparation or dry preparation with subsequent water-based raw meal granulation, all of which are thermally less efficient than modern processes. Also, none of their preheater solutions can match the cyclone preheater / precalciner regarding retention of emission components. Current standard cement production technology is clearly the best available technology (BAT).

Q: What is adequate pre-processing of fuels? Why is it so important?

A: A cement kiln requires an oxidizing atmosphere. To minimize thermal exhaust gas
FAQ

losses, however, the oxygen content has to be strictly regulated. This requires fuels that can be metered reliably and accurately. Adequate preparation of fuel prevents sudden fluctuations in its combustion-related characteristics, including the temperature of combustion, water content, and residual ash.

The higher the share of a fuel type in the total fuel mix, the better the preparation (pre-processing) of that fuel needs to be.

Q: Are there other advantages of cement kilns for co-processing selected waste streams? What are the disadvantages?

A: One important factor in favour of cement kiln co-processing has not been mentioned: the economic advantage of using existing equipment for new value-adding processes.

As for disadvantages, there are few, but public perception is an important variable. Some people fear, for example, that a cement kiln solution for selected waste streams would not be a BAT solution, would be operated irresponsibly / unprofessionally or would delay total solutions for all waste streams.

Q: It is difficult to believe that emissions will not worsen, even if everything is done correctly. Have there been cases where AFR use had to be stopped for any reason, or where permits (or permit renewals) were denied?

A: Yes, a few such cases are known. They usually result from the opposition of people living near cement plants with poor environmental practices (dirty stacks, buildings, roads) and correspondingly poor communication behaviour.

Q: Sometimes the term "bypass technology" is used together with co-processing. What does this mean?

A: The cement industry uses two types of bypass systems: the kiln bypass and the "DOM-dust-to-cement-mill" bypass.

A kiln bypass guides part of the rotary kiln dust and gases to a quenching and dedusting system. For operational reasons, the aim is to limit chlorine and sulphur circulation in the kiln system.

The extracted dust absorbs volatile gases – mainly chlorines and sulphur after which it is added to the cement mill (final product) or landfilled.

The DOM-dust bypass extracts the "direct operation mode" dust from the main dedusting equipment and feeds it to the cement mill. This limits the enrichment of volatile elements (mainly heavy metals and organics) in the fine dust fraction, reducing potential emissions and OHS issues).
FAQ

Q: How can alternative fuel utilization contribute to CO₂ reduction of an industry or a country?

A: Some alternative fuels are renewable, i.e., their carbon content originates from the CO₂ in the atmosphere (biomass such as, e.g., waste wood, rice husks, nutshell, animal meal, etc.). In addition, CO₂ and other greenhouse gases from waste disposal and incineration are not currently counted in national CO₂ balances. Therefore, using biomass and waste-derived alternative fuels contributes to low emission figures.

Q: If cement kiln emissions "do not change" when using AFRs, why do authorities often impose special emission regulations on them and issue/require special permits for their use?

A: Various countries still have poorly developed environmental legislation. In such cases, local, regional, or national authorities may hope to profit from the opportunity to correct their systems’ shortcomings. Some may also believe that emission increases would inevitably accompany any alternative fuel co-processing scheme, or that stakeholder/public pressure would compel them to play an active role. Finally, the cement plant operator may, in fact, benefit from emission limits, as they afford an opportunity to demonstrate compliance with responsible and efficient lawmaking.

References & further information

- Holcim Cement Manufacturing Course
- Holcim Course on Environment
- Holcim-GIZ Guidelines on Co-Processing Waste Materials in Cement Production
- Other Holcim internal documents