Management of Environmental Quality: An International Journal

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Received 29 January 2015
Revised 18 May 2015
Accepted 9 July 2015

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Abstract

Purpose – Cement production has advanced greatly in the last few decades. The traditional fuels used in traditional kilns include coal, oil, petroleum coke, and natural gas. Energy costs and environmental concerns have encouraged cement companies worldwide to evaluate to what extent conventional fuels can be replaced by waste materials, such as waste oils, mixtures of non-recycled plastics and paper, used tires, biomass wastes, and even wastewater sludge. The paper aims to discuss these issues.
Design/methodology/approach – The work is based on literature review.
Findings – The clinker firing process is well suited for various alternative fuels (AF); the goal is to optimize process control and alternative fuel consumption while maintaining clinker product quality. The potential is enormous since the global cement industry produces about 3.5 billion tons that consume nearly 350 million tons of coal-equivalent fossil and AF. This study has shown that several cement plants have replaced part of the fossil fuel used by AF, such waste recovered fuels. Many years of industrial experience have shown that the use of wastes as AF by cement plants is both ecologically and economically justified.
Originality/value – The substitution of fossil fuels by AF in the production of cement clinker is of great importance both for cement producers and for society because it conserves fossil fuel reserves and, in the case of biogenic wastes, reduces greenhouse gas emissions. In addition, the use of AF can help to reduce the costs of cement production.

Keywords Raw materials, Alternative fuels, Cement industry, Cement production, Municipal and industrial waste, Waste derived fuels
Paper type Literature review

1. Introduction

Cement is the key construction material for global housing and infrastructure needs. The cement industry worldwide is facing growing challenges in conserving material and energy resources, as well as reducing its CO_2 emissions. Cement producers are striving to increase energy efficiency and also the use of alternative raw materials and fuels. Therefore the use of alternative fuels (AF) has already increased significantly, but potential for further increases still exists (International Energy Agency (IEA), 1999).

The role of the cement industry in resource conservation and environmental protection has increased in recent years because of the rapid economic growth of large regions, such as China, India and Southeast Asia (Laszlo *et al.*, 2006). The cement industry is an energy-intensive industry with energy typically accounting for 30-40 per cent of production costs. Figure 1 presents the projected global cement demand in the future and Table I the expected future demand in selected areas of the world, according to Madlool *et al.* (2011). The energy consumption is estimated at approximately

A previous version of this paper has been presented in the 12th International Conference on Protection and Restoration of the Environment, Skiathos Island, Greece, June 29 to July 3, 2014.

Management of Environmental Quality: An International Journal
Vol. 27 No. 2, 2016
pp. 178-193

1477-7835
DOI 10.1108/MEQ-01-2015-0012

2 per cent of world total, and 5 per cent of industry total. The fuel mix in the industry is carbon intensive, and the calcination process itself produces CO_2, so that in total the cement industry contributes 5 per cent of the global CO_2 emissions (IEA, 1999; Madlool *et al.*, 2011).

The 2008 production of cement in the European Union was 200 Mt, approximately 7 per cent of the world production. In Europe, 158 Mt of CO_2 were emitted in 2008 from cement plants which corresponds to 38.5 per cent of all industrial emissions in Europe or 3.2 per cent of the total European CO_2 emissions. In a modern cement plant, 60 per cent of the CO_2 emitted by a cement plant results from the calcinations of limestone, 30 per cent from combustion of fuels in the kiln and 10 per cent from other downstream plant operations (Bosoaga *et al.*, 2009). Energy efficiency improvements (use of energy-efficient equipment, process modifications, etc.), fuel switching to waste as alternative fuel, and, cement blending using industrial by-products have helped decrease the CO_2 emissions associated with energy conversion (Bosoaga *et al.*, 2009). This paper presents a review of the basic AF used in cement industry.

2. AF in the cement industry

2.1 Classification of AF

Cement kilns use different sources of energy to produce the high temperatures necessary for the formation of clinker. The most common sources of fuel for the cement industry are: coal, fuel oil, petroleum coke, and natural gas (Singhi and Bhargava, 2010). AF are another source of energy used by cement producers around the world. These fuels are usually derived from the mixtures of industrial, municipal and hazardous wastes (Mokrzycki and Uliasz-Bochenczyk, 2003). AF used in cement industries can be solid or liquid. They are required to have an appropriate chemical content depending on the type of components and their organic contents. There are five groups of solid AF (Madlool *et al.*, 2011).

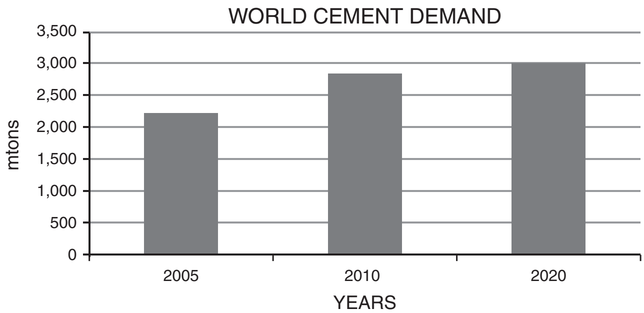


Figure 1. The trends of cement demand

Cement demand (mtons)	2010	2020	Growth (%)
World cement demand	2,836	3,000	4.7
Western Europe	236	350	2.2
North America	200	300	2.9
Other regions	500	600	4.7
Asia	1,900	2,200	5.2

Source: Madlool *et al.* (2011)

Table I. The cement demand in the future

These fuels generally include:

- agricultural biomass residues;
- non-agricultural biomass residues;
- petroleum-based wastes;
- miscellaneous wastes; and
- chemical and hazardous wastes.

The main part of fuel consumption, and consequently CO_2 generation, takes place in the calciner and clinker forming kiln. The utilization of low-carbon content fuel with high hydrogen-to-carbon (H/C) ratio instead of conventional fossil fuels can remarkably diminish the rate of CO_2 emissions in the process. In addition to producing a smaller amount of CO_2, the use of AF has been shown to improve refractory life and also reduce pressure drop in preheater tower (Grosse-Daldrup and Scheubel, 1996).

Various types of AF can be used in a cement plant, with the adequate equipment installed for the utiliszation. The use of AF in cement plants also reduces emissions from landfills. Therefore, it has been estimated that the utilization of this type of fuel will increase at the rate of 1 per cent per year worldwide (Grosse-Daldrup and Scheubel, 1996; Schneider *et al.*, 2011).

2.2 Alternative Fuel (AF)

Alternative fuel utilization in the cement industry started in the 1980s. Starting in calciner lines, up to almost 100 per cent alternative fuel firing at the pre-calciner stage was very quickly achieved. AF are mainly used tires, animal residues, sewage sludges (SS), and waste oil, as can be seen in Table II. The last are solid recovered fuels retrieved from industry waste streams, and to a growing extent also from municipal sources. These refuse derived fuels are pre-treated light fractions processed by mechanical or air separation. Waste derived fuels consist of shredded paper, plastics, foils, textiles and rubber and also contain metal or mineral impurities. Alternative fuel utilization in cement kilns is still progressing. While in some kilns up to 100 per cent substitution rates have been achieved, in others, local waste markets and permitting conditions do not allow for higher rates of Alternative Fuels and Raw Materials (AFR). In any case, AFR utilization requires the adaptation of the combustion process. Modern multi-channel burners designed for the use of AF and thermograph systems allow control of the flame shape to optimize the burning behaviour of the fuels and the burning conditions for the clinker. Table II presents different waste derived fuels based on their phase (solid, liquid or gaseous), Table III presents the calorific values of various fuels used in cement industry (Karstensen, 2007; Schneider *et al.*, 2011; Wirthwein and Emberger, 2010).

Table II. Alternative fuels options for the cement industry

Liquid waste fuels	Solid waste fuels	Gaseous waste
Sewage sludge	Industrial plastic	Landfill gas
Asphalt slurry	Plastic residues	Pyrolysis gas
Paint waste	Wood waste	
Petroleum coke	Rubber residues	
Waste oil	RDF plastic	
Petrochemical waste	Scrap paper	

Source: Karstensen (2007)

2.2.1 Refuse derived fuel (RDF). The product of municipal solid waste (MSW) processing is typically referred to as "refuse derived fuel", and is a common fuel alternative in many European countries. Italy, Belgium, Denmark and the Netherlands are among the countries that have at least one cement kiln processing RDF. MSW must be sorted to remove the recyclable and inert, and sometimes wet fractions before it is input into cement kilns. The remaining material accounts for about 20-50 per cent of the original MSW weight can be incinerated directly or pelletized. The RDFs from MSW have different physical and chemical properties depending on their sources, especially with respect to their ash, chlorine, sulphur, and water contents. There are notable differences among RDFs, and certain physical and chemical properties can cause difficulties in the kiln combustion process in cases where the RDF is introduced directly. Using RDF as a supplemental fuel in cement production is an economically viable option to minimize fuel costs and landfill disposals. The effect of using RDF on plants' economics is changing with the investment cost, coal and landfill disposal prices (Gendebien *et al.,* 2003; Junior, 2003; Wirthwein and Emberger, 2010).

There are many advantages of RDF such as minimizing CO_2 emission and ash residue, producing more homogeneous fuel, having higher calorific value content and a lower moisture content. It is reported that for a net carbon offset through the replacement of coal with RDF, water content must be less than 15 per cent and in this case net reduction in emissions is obtained as 0.4 tons CO_2/ton coal (Nakajima and Matsuyuki, 1981). The basic issue regarding the use of RDF by cement kilns is the chlorine content since chlorine weakens the cement and increase the risk of corrosion of steel bars in reinforced concrete structures. AF that have high amount of chloride like PVC should be used in limited amounts and fuel mix optimization is very critical in terms of sufficient heat value in kiln and cement quality. As an example in Germany and Austria the maximum total Cl content of the AFR should be less than 1.5 per cent (Murray and Price, 2008; MVW, 2010).

The utilization of RDF in cement industry is a common practice since 1993 in EU. Austria, Belgium, Denmark, Italy and the Netherlands are some of the indicative countries that the RDF utilization is common in the cement industry. According to literature (Gendebien *et al.,* 2003) around 115,000 tpa of MSW were co-incinerated in cement kilns in Europe in 1997 and more than 300,000 tpa of RDF in 2003. Also in Turkey, according to a recent publication the target for a single cement plant is the utilization of 35,000 t/y of RDF (Gendebien *et al.,* 2003; Ekincioglu *et al.*, 2013).

Wastes	Energy (MJ/kg)
Used tire	23.03
Husk	19.93
Industrial plastic	18.21
Waste oil	14.65
Scrap paper	14.23
Contaminated waste	14.23
RDF plastic	11.72
Sewage sludge	8.37

Source: Akcansa (2010)

Table III. Wastes used for alternative fuel sources and their energy content

2.2.2 Tire derived fuel (TDF). Tires are one of the most promising alternatives to the traditional fuels used in the incineration process in the cement industry. The high temperature in a cement kiln ensures the complete destruction of end-of-life tires (ELT). Moreover, tires are one of the most powerful AF because of their high energy content (above 30 MJ/kg), low degree of material diversification, and low moisture levels. The technical, environmental and economic viability of using tires in cement manufacturing processes has been analyzed in recent years (MVW, 2010). Consequently, it is demonstrated that the amount of coal or petcoke required is reduced and thus the costs associated with their use is also reduced. In regards to atmospheric emissions of greenhouse gases (GHGs) and pollutants, it is observed that the CO and total hydrocarbon emissions from the combustion of ELT-fuel mixtures are slightly higher compared to those from non-ELT firing kilns (Aranda *et al.*, 2012).

The environmental benefits of utilizing scrap tires as a supplemental fuel in the Portland cement manufacturing process are multifold. When whole tires are combusted in cement kilns, the steel belting which is the wire mesh supporting the rubber tire becomes a component of the clinker, replacing some or all of the iron required by the manufacturing process (Nakajima and Matsuyuki, 1981). Since tires contain no component deleterious to the quality of cement and, as proven from long experience in checking the quality of the product, there is no change in the quality of cement caused by feeding tires. Combustion residues of both tire and steel are not found in the finished cement. None of the differences in the emission data sets between TDF vs non-TDF firing kilns for sulfur dioxide, nitrogen oxides, total hydrocarbons, carbon monoxide, and metals were statistically significant (Karstensen, 2007; Pipilikaki *et al.*, 2005).

Many studies conducted by the US governmental agencies and engineering consulting firms have also indicated that TDF firing either reduces or does not significantly affect emissions of various contaminants from cement kilns (Pipilikaki *et al.*, 2005). Tires have some limitations when they are introduced into the kiln directly because of the large quantity of Zn that remains in the ashes, which can modify the cement composition dramatically. To avoid this problem, replacement ratios under 30 per cent are suggested for the kiln fuel (Portland, 2009). The findings of these studies as can be observed present differences. These differences can be attributed to the cement production and the raw materials used in the processes involved as well to the different parameters evaluated in these studies.

TDF is one of the most commonly used AF in the cement industry in Europe with regular utilization in ten countries across EU. In Finland, Luxembourg and Portugal, TDF is the only AF utilized in cement kilns. According to literature (Gendebien *et al.,* 2003) around 550,000 tpa of TDF is co-incinerated in cement kilns in Europe. Also in Turkey according to a recent publication a single cement company have disposed 12.2 millions of scrap tires within last seven years in three kilns (Ekincioglu *et al.*, 2013).

2.2.3 Sewage Sludge (SS). The disposal of SS generated for sewage treatment plants is causing an important waste management problem. Cement companies are able to use SS with calorific energy potential as one of the alternative fuel sources. Therefore, dried sludge is also used as an alternative fuel in its rotary kilns. The use of SS does not generate additional emissions also of all proven technologies the co-processing of SS in a cement kiln offers the largest reduction of CO_2 equivalents per ton of dry sludge (Theulen and Szabo, 2010).

SS has high water content. This is an important aspect to be considered when SS is used in gasification and, especially, in combustion processes. The SS is dried before being used as an alternative fuel or raw material and the cost of this process is important. Normally, SS is dried using the waste heat from the cement kiln. It is placed in the main furnace of the cement kiln and burned as a fuel, or it is gasified beforehand and the gas produced is used as an alternative fuel in cement kilns, heaters, or pre-calciners. In both cases, the residual non-combustible components of the sludge are used as raw materials in cement production. If utilized properly, SS creates very little to zero environmental impacts (Akcansa, 2010; Theulen and Szabo, 2010).

Dewatered SS is utilized in the Europe's cement industry in three countries at least. According to literature around 50,000 tpa of SS is co-incinerated in cement kilns in Europe. Also in Turkey according to a recent publication a single cement company is using 45,000 tons of SS annually (Gendebien *et al.,* 2003; Ekincioglu *et al.*, 2013).

2.2.4 MSW. MSW production is increasing notably in Europe, and MSW has become a common alternative fuel in the cement industry. However, most cement plants do not directly burn unsorted MSW due the heterogeneous nature of the waste and the presence of components that could pose quality and environmental concerns. Instead they use RDFs like the ones mentioned above (Gendebien *et al.*, 2003; Wirthwein and Emberger, 2010).

2.2.5 Waste derived fuel PASr. Waste derived fuel named PASr is a product used in Malogoszcz Cement Plant, located in Poland. This fuel is produced by shedding the following types of waste to a grain size of 0-70 mm or 0-40 mm: paper, cardboard, foil, cloth, textile, plastic containers, tapes, cables and cleaning agent. The waste may be contaminated with oil, fat, lubricants, paint, etc. The fuel is characterized by the following quality parameters:

(1) average heating value – 24 MJ/kg (value dependent on fuel composition);

(2) average humidity content – 3.19 per cent;

(3) average ash content – 7.98 per cent;

(4) average chlorine content – 0.42 per cent; and

(5) average sulphur content – 0.23 per cent.

PASr fuel was fed to the furnace inlet and through the main burner of the furnace. The tests had positive results despite the technical and technological problems which occurred. After the tests were conducted, the following was noted:

(1) an increased CO_2 content in emissions when the fuel is fed to the furnace inlet, hence the fuel must be fed to the main burner of the furnace;

(2) the content of the main oxide components and the phase composition of clinker produced during the tests of PASr fuel is similar to clinkers produced without the addition of the fuel; and

(3) emissions to air, meeting the requirements of the approval decision.

After the appropriate installations have been constructed, the fuel is fed to the furnace through the main burner since June 2002. The target combustion will amount to ca.45 thousand tonnes of fuel annually (Mokrzycki and Uliasz-Bochenczyk, 2003; Mokrzycki *et al.*, 2003).

2.2.6 Waste derived fuel PASi. Waste derived fuel named PASr is a product used in Malogoszcz cement plant, located in Poland. The fuel is the result of mixing the sorbent, in the form of sawdust or tobacco dust, with waste originating from paint, varnish, heavy post-distillation fractions, diatomaceous earth contaminated with petroleum-based waste, etc. This fuel is based on several waste types that can be considered hazardous. The fuel is characterized by the following quality parameters:

(1) average heating value – 9.1 MJ/kg (value dependent on fuel composition);

(2) average humidity content – 30.45 per cent;

(3) average ash content – 24.13 per cent;

(4) average chlorine content – 0.24 per cent; and

(5) average sulphur content – 0.28 per cent.

The PASi alternative fuel was fed to the lift chamber of the furnace. The tests had positive results despite, as in the case of the PASr fuel, the technological problems. As in the case of PASr, it was stated that the content of the main oxide components and the phase composition of the clinker produced during the tests on the combustion of PASr fuels are similar to those for clinkers produced without the addition of the fuel. The target is to burn ca. 35,000 tones of the alternative fuel (PASi) annually (Mokrzycki and Uliasz-Bochenczyk, 2003; Mokrzycki *et al.*, 2003)

3. Result and discussion

3.1 Global carbon dioxide emissions from cement making

Many opportunities exist for CO_2 emission reduction in the cement industry. Improvement of energy efficiency minimizes the emissions of CO_2 from fuel and electricity uses and may reduce the costs of producing cement. Improvement may be attained by using more energy-efficient equipment and by replacing old installations with new ones or shifting to new types of cement production processes. The largest proportion of energy consumed in cement manufacture consists of fuel that is used to heat the kiln. Therefore, the greatest gain in reducing energy input may come from improved fuel efficiency. In general, the dry process is more energy efficient than the wet process. The processes are exchangeable to a large extent, but the applicability may be limited by the raw material available (i.e. moisture content). The main opportunities in the kiln are the conversion to more energy-efficient process variants (e.g. from a wet process to a dry process with preheaters and pre-calciner), optimization of the clinker cooler, improvement of preheating efficiency, improved burners as well as process control and management systems. Electricity use can be reduced through improved grinding systems, high-efficiency classifiers, high-efficiency motor systems, and process control systems (Martin *et al.*, 1999).

Carbon dioxide emissions in cement manufacturing come directly from combustion of fossil fuels and from calcining the limestone in the raw mix. An indirect and significantly smaller source of CO_2 is from consumption of electricity, assuming that the electricity is generated from fossil fuels. (Chopra and Kumar, 2012). Roughly half of the emitted CO_2 originates from combustion of the fuel and half originates from the conversion of the raw material. Not accounted for are the CO_2 emissions attributable to mobile equipment used for mining of raw material, transport of raw material and cement, and used on the plant site. Current emissions estimates for the cement industry are based on the assumed clinker production and exclude emissions due to energy use.

These energy related emissions are included in the estimates for the emissions from energy usage, and are not allocated to cement production (Chopra and Kumar, 2012; Worrell *et al.*, 2001; Worrell *et al.*, 2008). Figure 2 presents a schematic diagram of cement production focusing on CO_2 emissions.

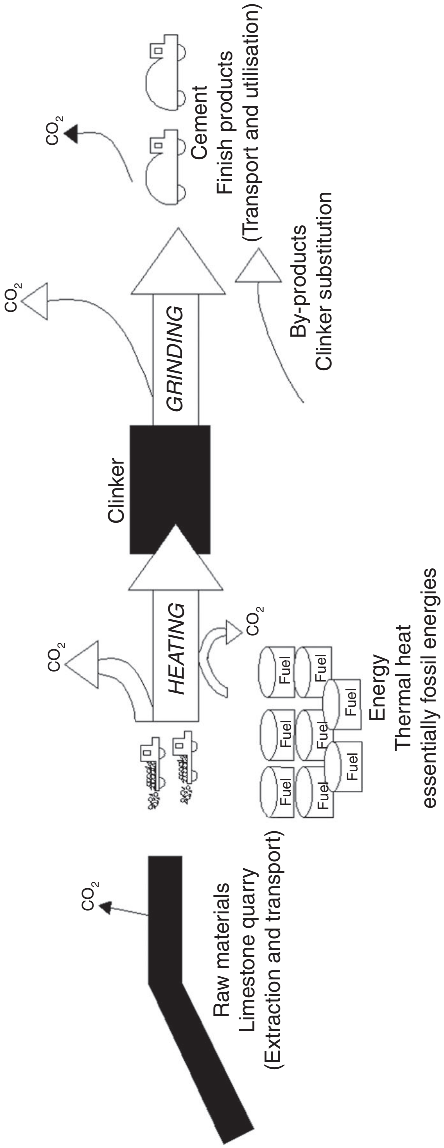
3.1.1 Carbon dioxide emissions from fuel use. Virtually all fuel is used during pyro-processing: fuel is burned in the kiln. The amount of CO_2 which is emitted during this process is influenced by the type of fuel used (coal, fuel oil, natural gas, petroleum coke, AF). CO_2 emission factors ($EFCO_2$) of fuels are based on emission factors defined by the Inter government Panel on Climate Change. The direct $EFCO_2$ of waste fuels is estimated to be zero, because the input of waste replaces an equivalent amount of fossil fuel – derived energy, and the CO_2 would probably have been released (in the short or long-term) to the atmosphere without useful application of the energy content. If the waste is used in competition with alternative uses, the replacement of fossil fuel and the avoidance of CO_2 emissions should be considered deeper (IEA, 1999; IPCC, 1996).

3.1.2 High-carbon fuels are replaced by low-carbon fuels. One alternative for lowering CO_2 emissions is to minimize the carbon content of the fuel, e.g., shifting from coal to natural gas or even better to AF such as waste derived fuels, which are presenting lower carbon content. A major opportunity to reduce the long-cycle carbon emission is the application of waste derived fuels. This could diminish the disposal of waste material and reduce the use of fossil fuels. A number of issues can be regarded when using waste derived fuels: first, energy efficiency of waste combustion in cement kilns; second, constant cement product and fuel quality; third, emissions to atmosphere; fourth, trace elements and heavy metals; fifth, alternative fate of waste; and sixth, production of secondary waste. Disadvantages may be the adverse effects on the cement quality and emission which is increased of harmful gases. It should be noted that emissions generally depend more on kiln operation conditions than on type of fuel. AF may be gaseous (e.g. landfill gas), liquid (e.g. halogen-free spent solvents, distillation residues, waste oils), or solid (e.g. waste wood, dried SS, plastics, tires). The net emission reduction depends on the nature and characteristics of the wastes and on the waste-treatment process that is displaced. Waste processing in the cement industries is feasible and is a current practice. Cement plants are using waste as alternative fuel (Hendriks *et al.*, 1999; Hendriks *et al.*, 2002).

3.2 Adaptability of alternative and waste derived fuels

The burning of various types of wastes requires the detailed control and adaptation of technological processes to each type of waste. For this reason, AF are derived from wastes having similar composition and properties. Following properties should be examined before the burning of AF is undertaken:

- physical state of the fuel (solid, liquid, gaseous);
- content of circulating elements;
- toxicity (organic compounds, heavy metals);
- composition and content of ash;
- volatile content;
- calorific value;
- physical properties (scrap size, density, homogeneity);



Source: Habert *et al.* (2010)

Figure 2.
Simplified cement production process, with a specific interest in the CO_2 emissions

- grinding properties;
- humidity content; and
- proportioning technology.

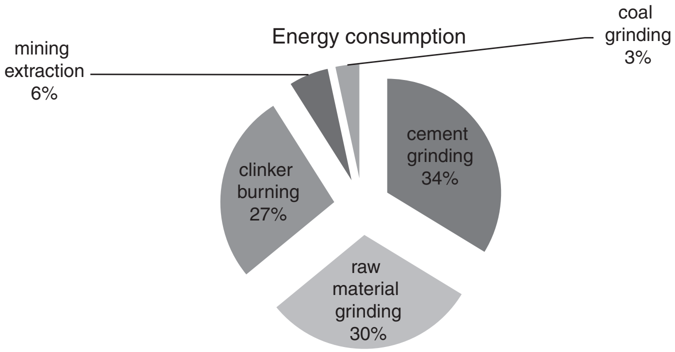
As a mixture of various wastes, AF must be produced in conformity with certain rules. The chemical quality of the fuel must meet regulatory standards assuring environmental protection, is the first rule. The calorific value must be stable enough to allow the control of the energy supply to the kiln, the objective being to arrive at a fairly homogeneous composition, and the physical form must allow easy handling of the material for transportation and a stable, adjustable flow of material in the cement plant (Karstensen, 2008; Lemarchand, 2000).

3.3 Benefits of using waste derived fuels

3.3.1 Ecological benefits. Several years of experience with the use of waste as AF by the cement industry have shown that their application is justified both from an economic and an ecological point-of-view. First, the reduction of the use of non-renewable fossil fuels such as coal as well as the environmental impacts associated with coal mining. Furthermore, the contribution towards a lowering of emissions such as GHGs by replacing the use of fossil fuels with materials that would otherwise have to be incinerated with corresponding emissions and final residues. All the energy is used directly in the kiln for clinker production (IEA, 1999; Junior, 2003). Figure 3 describes schematically the cement production process and associated CO_2 emissions at different sections of a cement manufacturing process (Habert *et al.*, 2010).

The use of AF in cement furnaces is also dictated by the broadly understood term environmental protection, as not only primary sources of energy are spared, but also waste is used, which would otherwise have to be disposed of on waste disposal sites, or burnt in specially constructed incineration plants. Application of AF made from waste may allow one to reduce the amount of waste to be disposed of by up to 50 per cent. Both incineration plants and waste disposal sites may have significant negative impacts on components of the environment. One must be aware that the acquisition of primary sources of energy also negatively influences the environment (IEA, 1999; Junior, 2003; Pipilikaki *et al.*, 2005).

3.3.2 Technological benefits. Flame temperature at 2,000°C and material temperature at around 1,400°C which together with residence time of 4-5 seconds in



Source: IEA (1999)

Figure 3.
The main energy consumption for cement production

an oxygen rich atmosphere ensures destruction of organic components in any residues. The neutralization of any acid gaseous formed during combustion by the alkaline nature of raw material and subsequent incorporation in the clinker. Interaction of flue gases and the raw material present in the kiln ensures that the non-combustible part, if any is reduced. On total life cycle concept, it is superior in comparison with the specialized incinerator or any other mode (Karstensen, 2008; Pipilikaki *et al.*, 2005).

3.3.3 Economic and social benefits. The use of AF by the cement industry is related to the energy-consuming process of clinker production. On average, the energy required for the production of one tonne of cement amounts to some 3.3 GJ, which corresponds to about 120 kg of coal. The costs of energy consist about 30-40 per cent of the total costs of cement production. Applications of AF will therefore allow one to reduce the production costs. The use of fuels made from waste in cement plants results not only in financial benefits for the industry, but also for society. Owing to such waste management, smaller quantities of waste will be disposed of in, or directed to, incineration plants. This will lead to a reduced number of new disposal sites, a limitation of the expansion of existing sites and will avoid the necessity to build incineration plants (IEA, 1999; Laszlo *et al.*, 2006). There are many social benefits such as the implementation in rural area would contribute to overall development of the area and employment. In addition generates additional revenue for economically backward and frequent drought affected farmers of the region and aids rural upliftment and ameliorating their economic status (Karstensen, 2008; Pipilikaki *et al.*, 2005)

3.4 Policy instruments and their role in enhancing the use of waste derived fuels

There is growing awareness that the cement industry is an important contributor to global carbon dioxide (CO_2) emissions. This industry will come under pressures to reduce its emissions and contribute more aggressively to mitigating global warming. It is worth to say that the industry's stakeholders become more familiar with GHG emission and global warming issues, along with emerging policies that may affect the future of the industry. The mechanisms of the Kyoto Protocol and clean development have affected the cement industry globally. The applicability, effectiveness and potential impact of these policy instruments for the global cement industry could support the replacement of fossil fuels with waste derived fuels (Rehan and Nehdi, 2005).

The Kyoto Protocol introduced three international market-based instruments through which reduction in GHG emissions could be reached: clean development mechanism (CDM), joint implementation (JI), and emissions trading (ET). Allowing trading of GHG emission permits globally, these instruments enable countries to reduce emissions or enhance "carbon sinks" at lower costs. Though different estimates exist, expects the value of the global market that can emerge for these transactions to be in the tens of billions of USD annually. Ambiguities of the flexible mechanisms in the original protocol were addressed in 2001 when the Marrakech Accords were adopted at the seventh CoP in Morocco (UNFCCC, 2003). These accords stipulate that there will be no quantitative limits on the extent to which these instruments could be utilized, yet Annex I countries have to ensure that domestic measures should constitute a significant portion of their efforts. Annex I countries are the industrialized countries that have binding targets under the Kyoto Protocol and include countries that were members of the Organization for Economic Co-operation and Development in 1992 plus countries with economies in transition, including those of the former Soviet Union and Eastern Europe. Recognizing that climate change is a global problem and emission reductions are desirable regardless of the place where these are made, the Kyoto Protocol has envisaged three market-based mechanisms: CDM, JI and ET (Janssen, 2003).

3.4.1 Mechanism of clean development. Article 12 of the Kyoto Protocol provides for the CDM. Through the CDM, countries with emission targets can invest in emission control projects in developing countries with no targets, thus earning credits for the reductions in GHG emissions in the host country. These certified emission reductions could then be applied to meet the investor country's own emission targets. To guide and oversee practical arrangements of the CDM, a CDM executive board was elected during CoP 7. The CDM has potential benefits for both investor as well as host countries. For an investor country, such benefits could be follow-up exports of goods, services and ancillary products to the host country, while a host country would benefit from the inward investments and technology transfer (See, 2001). On the other hand, CDM projects could have more transaction costs due to additional requirements of validation, verification and certification (Janssen, 2003). Prospects for the cement industry under the CDM are promising. Developing countries are major producers of cement. For instance in 2001, China produced about 626 million tons of cement (37 per cent of the world's production) while India produced about 100 million tons. Both the countries have no emission targets under the Protocol, and both are expected to increase their cement production significantly in the future. Since major reductions in GHG emissions of cement manufacturing are possible through the use of alternative and waste derived fuels, large amounts of emission credits could be earned by investing in the cement industry of such developing countries. China and India also happen to be the countries with the largest resources of wastes and by-products that can be used for the production of alternative or waste derived fuels for the cement industry (Van Oss, 2001).

5. Conclusions

Many years of experience have shown that the use of wastes as AF by cement plants is both ecologically and economically justified. The use of AF will help reduce the costs of cement production. The average energy demand for the production of one ton of cement is about 3.3 GJ, which corresponds to 120 kg of coal with a calorific value of 27.5 MJ per kg. Energy costs account for 30-40 per cent of the total costs of cement production. The substitution of AF for fossil fuels will help reduce energy costs, providing a competitive edge for a cement plant using this source of energy. Furthermore, less waste will have to be dumped or burnt, which will mean less dumping sites. Therefore, the use of waste derived AF by cement plants will be also beneficial to the environment. The conditions in rotary kilns, such as high temperature, the high speed of the gas stream and the long particle-storage period, guarantee that the use of AF is ecologically safe. Co-processing in the cement industry is the optimum way of recovering energy and material from waste. It offers a safe and sound solution for society, the environment and the cement industry, by substituting non-renewable resources with societal waste under strictly controlled conditions. The desired waste material, to be used as a fuel, is available usually within the state or the country. The cost of waste being used as fuel does not exceed the cost of fossil fuels.

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