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Applications Of Alternative Fuels With Help Reduce The Cost Of Cement Production

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Abstract
The manufacture of cement has significantly progressed in recent decades. Commonly employed in conventional kilns are traditional fuel sources such as coal, oil, petroleum coke, and natural gas. The replacement of fossil fuels with alternative fuels (AF) in the manufacturing of cement clinker is highly significant for both cement producers and society. This practice helps to preserve fossil fuel reserves and, in the case of biogenic wastes, decreases greenhouse gas emissions. Moreover, the utilization of alternative fuels can effectively decrease the expenses associated with cement manufacturing. Cement businesses globally are assessing the feasibility of substituting traditional fuels with waste materials, including waste oils, non-recycled plastics and paper mixes, used tyres, biomass wastes, and wastewater sludge, due to rising energy expenses and environmental considerations. The clinker burning process is very compatible with a range of other fuels. The objective is to enhance process control and minimize the use of alternative fuels, all while ensuring the quality of the clinker product remains unaffected. The potential is immense as the worldwide cement industry generates over 3.5 billion tones, which consumes nearly 350 million tones of coal-equivalent fossil and alternative fuels. This study has demonstrated that multiple cement plants have substituted a portion of their fossil fuel consumption with alternative fuels, such as waste recovered fuels. Extensive industrial experience has demonstrated that the utilization of waste materials as substitute fuels by cement plants is both environmentally and economically justified.

Keywords: *alternative fuels, municipal and industrial waste, cement industry, cement production, raw materials*

1. INDRODUCTION

Cement is the primary building material used for worldwide housing and infrastructure requirements. The global cement industry is currently seeing increasing difficulties in preserving material and energy resources, as well as mitigating its carbon dioxide emissions. Cement manufacturers are making efforts to enhance energy efficiency and promote the utilization of alternative raw materials and fuels. Hence, the utilization of alternative fuels has already experienced a substantial surge; however there remains untapped potential for additional growth [1]. The cement industry's contribution to resource conservation and environmental preservation has grown in recent years because to the rapid economic expansion of major regions, including China, India, and South-east Asia [2]. The cement business is characterised by its high energy consumption, with energy expenditures often representing 30-40% of total production expenses. Figure 1 illustrates the allocation of electricity use at each phase of the cement manufacturing process. The estimated energy consumption accounts for around 2% of the overall global energy consumption and 5% of the total energy consumption in the industry. The industrial sector relies heavily on carbon-intensive fuel sources, and the calcination process involved in cement production generates carbon dioxide (CO_2). As a result, the cement industry is responsible for 5% of the total global CO_2 emissions [1,3].

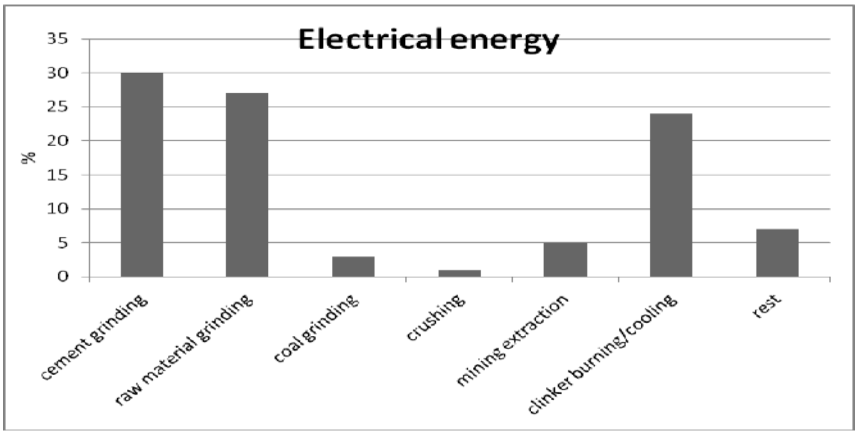

Figure 1 Use of electrical energy in cement production [1,4]

In 2008, the European Union produced 200 million metric tonnes (Mt) of cement, accounting for roughly 7% of global production. Europe's cement plants emitted 158 million metric tonnes of CO2 in 2008, accounting for 38.5% of all industrial emissions in Europe or 3.2% of the total CO2 emissions in Europe. In a contemporary cement factory, the calcination of limestone accounts for 60% of the emitted CO2, while the combustion of fuels in the kiln contributes to 30% of the emissions. The remaining 10% of CO2 emissions originate from other processes in the downstream plant. Implementing energy efficiency measures such as employing energy efficient equipment and making process adjustments, as well as switching to waste as an alternative fuel and blending cement with industrial by-products, has successfully reduced the CO2 emissions linked to energy conversion [1-4]. This study provides an overview of the fundamental alternative fuels utilised in the cement industry.

MATERIALS AND METHODS

Cement kilns employ several energy sources to generate the elevated temperatures required for clinker production. The primary fuel sources utilized by the cement industry include coal, fuel oil, petroleum coke, and natural gas [5]. Cement makers worldwide utilize alternative fuels as an additional energy source. Typically, these fuels are produced from a combination of industrial, municipal, and hazardous wastes [6].
These fuels generally include:

- Agricultural biomass residues
- Non-agricultural biomass residues
- Petroleum based wastes
- Miscellaneous wastes and
- Chemical and hazardous wastes

The primary source of fuel consumption, and hence the main contributor to CO2 emissions,is in the calciner and clinker producing kiln. Replacing traditional fossil fuels with lowcarbon content fuel that has a high hydrogen-to-carbon (H/C) ratio can significantly reducethe rate of CO2 emissions. Furthermore, the use of alternative fuels not only results in adecreased emission of CO2, but also enhances the durability of refractory materials and decreases the pressure drop in the preheater tower [7]. A cement plant can utilise several types of alternative fuels, provided that the necessary equipment is installed. Utilising alternative fuels in cement factories also decreases emissions originating from landfills [8]. Thus, it is projected that the global utilisation of this particular fuel will grow by 1% annually[1,6,7,9]. The cement industry began utilising alternative fuels in the 1980s. Almost complete substitution of traditional fuel with alternative fuel in the pre-calciner stage of calciner lines was rapidly accomplished. Table 1 demonstrates that alternative fuels mostly consist of used tyres, animal wastes, sewage sludges, and waste oil. The final category consists of solid recovered fuels obtained from waste streams in industrial settings, and increasingly, from municipal sources as well. Refuse-derived fuels refer to pre-treated light fractions that have been processed using mechanical or air separation techniques. Waste-derived fuels are composed of shredded paper, plastics, foils, textiles, and rubber, which may also contain impurities in the form of metals or minerals. The utilisation of alternative fuels in cement kilns is still advancing. Although many kilns have successfully achieved substitution rates of up to 100%, other kilns are limited by local waste markets and regulatory constraints, preventing them from reaching higher rates of Alternative Fuel and Raw Material (AFR) usage. Regardless, the utilisation of AFR necessitates the adjustment of the combustion process. Contemporary multi-channel burners, specifically developed for utilising alternative fuels, along with thermograph systems, enable precise control over the form of the flame. This optimisation of the burning behaviour of the fuels and the burning conditions for the clinker is made possible. Table 2 displays the calorific values of different fuels utilised in the cement industry, whereas figure 2 illustrates a comparison with fossil fuels [9-12].

Table 1 Alternative fuels options for the cement industry [1, 9-12]

Liquid waste fuels	Solid waste fuels	Gaseous waste
petrochemical waste	battery cases	Landfill gas
asphalt slurry	plastic residues	pyrolysis gas
paint waste	wood waste	
Petroleum coke	rubber residues	

Table 2 Wastes used for alternative fuel sources and their energy content [11, 12]

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

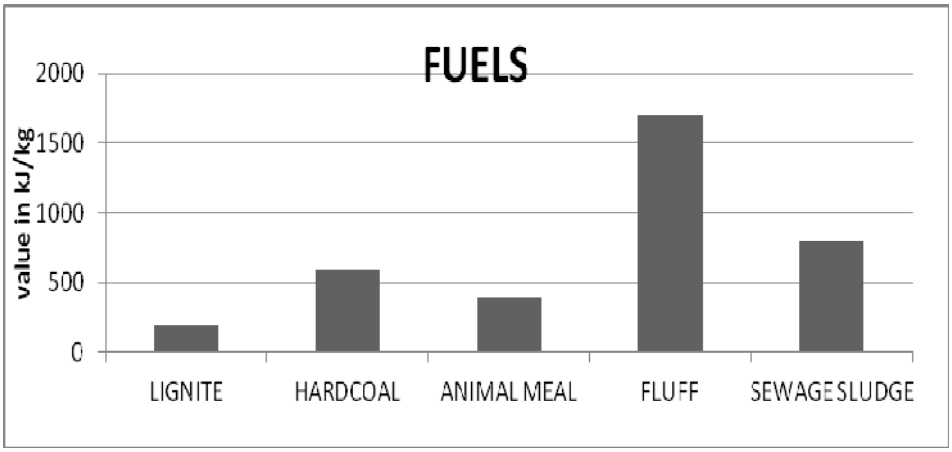

Figure 2 Comparison of the calorific values of various alternative fuels [3, 9, 10]

Refuse derived fuel (RDF)

The output of municipal solid waste (MSW) processing is commonly known as "refuse derived fuel."Refuse-derived fuel (RDF) is a widely used alternative fuel in several European countries. Italy, Belgium, Denmark, and The Netherlands are countries that possess at least one cement kiln engaged in the processing of Refuse Derived Fuel (RDF). MSW needs to be sorted in order to separate the recyclable and inert, and occasionally moist, fractions before it can be fed into cement kilns. Approximately 20-50% of the initial weight of the leftover material in MSW can be either burned directly or pelletized. Utilising RDF as an adjunct fuel in cement manufacturing is a financially feasible alternative for reducing fuel expenses and landfill waste. The impact of utilising RDF on the economy is subject to fluctuations in the cost of capital, coal, and waste disposal prices [12-14]. RDF has several benefits, including reducing CO2 emissions and ash residue, generating fuel with greater uniformity, including higher calorific value, and having lower moisture content. According to reports, in order to achieve a nett carbon offset by replacing coal with RDF, the water content must be below 15%. In this scenario, a nett decrease in emissions of 0.4 tonnes of CO2 per tonne of coal is achieved [15].The primary concern about the use of RDF by cement kilns is the chlorine concentration, as chlorine has a detrimental effect on the strength of cement and elevates the likelihood of corrosion in steel bars within reinforced concrete structures. It is important to minimise the use of alternative fuels with high chloride content, such as PVC. Optimising the fuel mixture is crucial for ensuring adequate heat value in the kiln and maintaining the quality of cement [16, 17].

The use of RDF (Refuse Derived Fuel) in the cement industry has been a regular practice in the European Union since 1993. Austria, Belgium, Denmark, Italy, and the Netherlands are some of the nations where this practice is prevalent. Based on the literature [18], approximately 115,000 tonnes per annum (tpa) of municipal solid waste (MSW) were burned together with cement in kilns in Europe in 1997. Additionally, more than 300,000 tpa of refuse-derived fuel (RDF) were burned in 2003 [18]. In Turkey, a recent paper [19] states that the aim for a single cement factory is 35000t/y for the usage of RDF [18, 19].Tyre derived fuel (TDF) is a highly promising alternative to the conventional fuels employed in the incineration process within the cement industry. The elevated temperature in a cement kiln guarantees the thorough annihilation of end-of-life tyres (ELT). Tyres are considered to be a highly potent alternative fuel due to their high energy content (over 30 MJ/kg), minimal variation in material composition, and low moisture levels. An analysis of the feasibility of utilising tyres in cement manufacturing processes has been conducted in recent years [17, 20]. Therefore, it is proven that the quantity of coal or petcoke needed is decreased, resulting in a reduction of the expenses related with their utilisation. Regarding atmospheric emissions of greenhouse gases (GHGs) and pollutants, it has been observed that the burning of ELT-fuel mixes results in slightly higher emissions of carbon monoxide (CO) and total hydrocarbons compared to non-ELT fire kilns. The numbers 17 and 20.

There are multiple environmental advantages to using recycled tyres as an additional source of fuel in the Portland cement making process. When tyres are burned in cement kilns, the steel belting, which is the wire mesh that supports the rubber tyre, becomes part of the clinker. It can replace some or all of the iron needed in the production process [15]. Tyres do not contain any harmful components that would affect the quality of cement. Extensive testing has shown that using tyres as a component in cement does not create any changes in its quality. The resulting cement does not contain any combustion leftovers from either tyres or steel [15]. The emission data sets for sulphur dioxide, nitrogen oxides, total hydrocarbons, carbon monoxide, and metals did not show any statistically significant differences between tyre derived fuel (TDF) and non-TDF firing kilns [12, 15, 22].Several studies undertaken by U.S. governmental organisations and engineering consulting firms have shown that the use of TDF (Tire-Derived Fuel) in cement kilns either decreases or has no significant impact on the release of different pollutants [22]. TDF, short for Tire-Derived Fuel, is a widely utilised alternative fuel in the cement industry in Europe. It is regularly utilised in 10 nations across the European Union. Only TDF is used as an alternative fuel in cement kilns in Finland, Luxembourg, and Portugal. According to the research cited in reference [18], about 550,000 tonnes per annum (tpa) of Tire-Derived Fuel (TDF) is burned with other materials in cement kilns across Europe. In Turkey, a recent publication [19] reported that a single cement business had disposed of 12.2 million scrap tyres in three kilns during the past seven years [18, 19].

2.2.3 Sewage sludge refers to the residual material that remains after wastewater treatment. The disposal of sewage sludge produced by sewage treatment plants is posing a significant waste management issue. Cement businesses can utilise sewage sludge, which has a high calorific energy potential, as an alternative fuel source. Consequently, desiccated sediment is also employed as a substitute source of energy in its rotary kilns.The utilisation of sewage sludge does not result in any additional emissions. Among all established technologies, the co-processing of sewage sludge in a cement kiln provides the greatest decrease in CO2 equivalents per metric tonne of dry sludge [24].

Sewage sludge (SS) contains a significant amount of water. When using SS in gasification and combustion processes, it is crucial to consider this factor. Prior to its utilisation as an alternative fuel or raw material, the SS is subjected to a drying process, the expense of which is significant. Typically, SS is dehydrated by utilising the excess heat generated by the cement kiln. The waste material is introduced into the primary chamber of the cement kiln and incinerated as a source of energy. Alternatively, it can be converted into gas before being utilised as an alternative fuel in cement kilns, heaters, or pre-calciners. Both scenarios include utilising the remaining non-combustible elements of the sludge as inputs for cement manufacturing. When sewage sludge is used correctly, it has few to no negative effects on the environment [11, 24].

Dewatered sewage sludge is used in the cement industry in at least three countries in Europe. Based on the literature [18], approximately 50,000 tonnes per annum (tpa) of sewage sludge (SS) is burned together with other materials in cement kilns in Europe. In Turkey, a recent publication [19] reported that a single cement firm is utilising 45000 tonnes of SS (solid waste) on an annual basis. The numbers 18 and 19.

The production of municipal solid waste (MSW) is experiencing a significant increase in Europe, and it is now commonly used as an alternative fuel in the cement industry. However, the majority of cement plants refrain from immediately incinerating unsorted municipal solid waste (MSW) because of its diverse composition and the potential existence of substances that may raise concerns regarding quality and the environment. Instead, they utilise RDFs similar to the ones stated above. The RDFs obtained from municipal solid waste (MSW) exhibit varying physical and chemical characteristics, primarily in relation to their ash, chlorine, sulphur, and water concentrations, which are influenced by their respective sources. RDFs exhibit distinct variations, and certain physical and chemical characteristics can provide challenges throughout the kiln combustion process when RDF is directly supplied [6, 10, 12, 18].

Waste Derived Fuel PASr is a type of fuel that is derived from waste materials. PASr is a fuel that is utilised at the Malogoszcz Cement Plant in Poland. This fuel is generated by reducing various forms of trash, such as paper, cardboard, foil, cloth, textile, plastic containers, tapes, cables, and cleaning agent, to a grain size of either 0-70 mm or 0-40 mm. The waste may be tainted with substances such as oil, fat, lubricants, paint, and other similar materials. The fuel possesses the subsequent quality parameters:

1. The average heating value is 24 MJ/kg, and this number varies depending on the nature of the fuel.
The average humidity content is 3.19%.
The average ash content is 7.98%.
The average chlorine content is 0.42%.
The average sulphur concentration is 0.23%.
PASr fuel was supplied to the furnace entrance and directed into the main burner of the furnace. The testing yielded positive findings despite the occurrence of technical and technological issues. Upon completion of the tests, the following observations were made:

1. The emissions contain a higher concentration of CO2 when the fuel is introduced into the furnace entrance, so the fuel should be supplied to the primary burner of the furnace.
The principal oxide components and phase composition of clinker produced during the experiments of PASr fuel are comparable to clinkers produced without the addition of the fuel.

3. Air emissions that comply with the approval decision's conditions.
Once the necessary installations have been built, the fuel will be supplied to the furnace via the main burner, starting from June 2002. The intended combustion will be around 45 thousand tonnes of fuel per year [6, 25].Waste Derived Fuel PASi is a type of fuel that is derived from waste materials. PASr is a fuel utilised at the Malogoszcz Cement Plant, which is situated in Poland. The fuel is produced by combining the sorbent, such as sawdust or tobacco dust, with waste materials derived from paint, varnish, heavy post-distillation residues, and diatomaceous earth polluted with petroleum-based waste. The fuel possesses the subsequent quality parameters:
1. average heating value —9.1 MJ/kg (value dependent on fuel composition)
2. average humidity content—30.45%
3. average ash content—24.13%
4. average chlorine content—0.24%
5. average sulphur content —0.28%
6. The PASi alternative fuel was introduced into the lift chamber of the furnace. The testing yielded positive results, notwithstanding the technological issues encountered, such as those with the PASr fuel. Regarding PASr, it was indicated that the primary oxide components and phase composition of the clinker produced during the combustion tests of PASr fuels are comparable to those of clinkers produced without the fuel additive. The objective is to incinerate approximately 35 thousand metric tonnes of the alternative fuel (PASi) on a yearly basis [6, 25].

3. RESULTS AND DISCUSSION

Following properties should be examined before the burning of alternative fuels 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),
- grinding properties,
- humidity content,
- Proportioning technology.

Alternative fuels, which are composed of a combination of different types of waste, must be manufactured in accordance with specific regulations. The initial regulation mandates that the chemical composition of the fuel must adhere to specified requirements in order to ensure environmental preservation. The calorific value must exhibit sufficient stability to enable precise regulation of the energy supply to the kiln. The ultimate goal is to achieve a relatively uniform composition. Additionally, the physical characteristics of the material must facilitate convenient transportation and ensure a consistent and adjustable flow within the cement plant [12, 26, 27].Advantages of incinerating alternative fuels Environmental advantages The cement industry has demonstrated through years of experience that utilising waste as alternative fuels is economically and environmentally justified. Firstly, the primary objective is to decrease the utilisation of non-renewable fossil fuels, such as coal, and mitigate the environmental consequences linked to coal mining. Moreover, by substituting the usage of fossil fuels with materials that would otherwise be burnt, we may effectively reduce emissions of greenhouse gases and the resulting wastes. The entirety of the energy is utilised exclusively within the kiln for the purpose of producing clinker [1, 14, 18, 26].

The utilisation of alternative fuels in cement furnaces is driven by the concept of environmental conservation. This approach not only conserves primary energy sources but also repurposeswaste that would otherwise require disposal in landfills or incineration in dedicated facilities.The utilisation of alternative fuels derived from trash has the potential to decrease the quantity of garbage that needs to be disposed of by as much as 50%. Both incineration facilities and trash disposal sites can have substantial adverse effects on various aspects of the environment. It is important to note that obtaining primary sources of energy has a detrimental impact on the environment [1, 14, 18, 22, 26].Advantages of technology The flame temperature is set at 2000°C, while the material temperature is approximately 1400°C. These high temperatures, together with a residence time of 4-5 seconds in an oxygen-rich atmosphere, guarantee the complete destruction of all organic components in the leftovers.The alkaline composition of the raw material neutralises any acid gases created during combustion, and these gases are then incorporated into the clinker. The interaction between flue gases and the raw material in the kiln guarantees the reduction of any non-combustible components, if present. In terms of the complete life cycle idea, it surpasses specialised incinerators and other methods. The adoption of social benefits in rural areas would significantly help to the overall development of the area and increase employment opportunities. Furthermore, it generates supplementary income for financially disadvantaged farmers who are frequently afflicted by drought in the region, contributing to the improvement of rural areas and enhancing their economic condition [1, 18, 22, 26].

Financial advantages

The cement industry's utilisation of alternative fuels is directly linked to the energy-intensive process of clinker manufacturing. Typically, the manufacturing of one tonne of cement requires approximately 3.3 gigajoules (GJ) of energy, equivalent to around 120 kilogrammes of coal. Energy expenses account for around 30-40% of the overall expenses in cement manufacturing. Utilising alternative fuels can effectively lower production costs. Utilising waste-derived fuels in cement plants yields not only economic advantages for the industry, but also for society as a whole. As a result of implementing this waste management system, lesser amounts of waste will be disposed of in, or sent to, incineration facilities. As a result, there will be fewer new disposal sites, restrictions on the extension of current sites, and averted need for constructing incinerator units [1, 2, 18, 26].

CONCLUSIONS

Extensive experience has demonstrated that cement mills can effectively utilise waste materials as alternative fuels. Both ecologically and economically justified. Utilising alternative fuels will effectively decrease the expenses associated with cement manufacturing. The mean energy requirement for the manufacturing of one metric tonne of cement is about 3.3 gigajoules (GJ), equivalent to 120 kilogrammes of coal with a calorific value of 27.5 megajoules (MJ) per kilogramme. The energy expenses are 30-40% of the overall expenses incurred in the production of cement. Replacing fossil fuels with alternative fuels will lower energy expenses, giving a cement mill that utilises this energy source a competitive advantage. Moreover, there will be a reduction in the amount of garbage that needs to be disposed of by dumping or incineration, resulting in a decrease in the number of landfill sites. Consequently, the use of waste-derived alternative fuels by cement factories will likewise have positive effects on the environment. The circumstances present in rotary kilns, including elevated temperatures, high gas streamvelocities, and extended particle storage durations, ensure the ecological safety of utilising alternative fuels. Co-processing in the cement industry is the most efficient method for extracting energy and materials from waste. It provides a secure and effective solution for society, the environment, and the cement industry by replacing non-renewable resources with waste from society, all under tightly regulated conditions. The required waste material, intended for use as a fuel, is readily accessible inside the state. The cost of utilising garbage as a fuel source is not higher than the cost of fossil fuels.

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