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Using Alternative Fuels in Cement Production, Reduction of Natural Fuel Resources Consumption and Environmental Pollutants: A Review

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Abstract

Cement production is one of the most energy-consuming production processes. The process requires about (3-5) MJ of energy per ton of clinker which accounts for about (20-24) % of the production cost. In order to reduce the consumption of natural energy resources, some cement producers use urban and industrial wastes as alternative fuels in cement factories. In this research, the latest developments in the use of alternative fuels in some cement production plants in the world and their effects on the environment are reviewed. Many of the research publications related to this study are reviewed and discussed in this paper, which covers the latest developments in the usage of alternative fuels in the cement industry. This review also covers studies on the impacts of alternative fuels on environmental emissions and provides an understanding of alternative fuels, their status, usage in the cement industry, and their environmental impact. This study will also be a guide in planning and usage of alternative fuel in Afghan cement factories and will support Afghanistan's cement producers in reducing the consumption of natural fuel resources. On the other hand, the usage of alternative fuels can help reduce environmental pollution, which is one of the most critical issues in Afghanistan. This research provides a roadmap for the planning and implementation of alternative fuel usage in the cement industry worldwide, especially in Afghanistan. According to this study, used tires are the best alternative fuel choice for the Afghan cement industry.

Keywords: Cement, kiln, alternative fuel, environmental.

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1. Introduction

Cement is an inorganic hydraulic binder that forms a paste after mixing with water. There are many types of cement due to different additives and application areas [1]. Cement production begins with the grinding of raw materials, pre-calcination, clinkering in the kiln, and converting the clinker into cement powder.

Materials containing limestone, calcium, silicon, aluminum, and iron oxide are crushed together in the grinding mill. The raw materials are then preheated in cyclones, where the decomposition of calcium carbonate ($CaCO_3$) into oxides occurs. The materials then enter the furnace where reactions between (CaO) calcium oxide and other elements take place to form calcium silicates and aluminates $1450^{o}C$. The reaction products then come out of the kiln, called clinker, and are then mixed with gypsum and other materials to produce cement powder [2].

The cement production process is one of the most energy-consuming processes, which consumes almost 60.69% of non-metallic industries. The highest amount of energy is used for clinker production in the kiln, while other processes use some other kind of energy such as electricity. The clinker production process consumes about 95% thermal energy and 5% electrical energy [3].

During the calcination, and combustion of (coal, oil, and natural gas) in the furnace carbon dioxide (CO_2) is produced as a result of chemical reactions between carbon and oxygen. Replacing fossil fuels with alternative fuels plays an important role in reducing carbon dioxide (CO_2) emissions and lowers the energy cost required for the process. The most important advantage of using alternative fuels is that it plays a positive role in protecting the environment [4]. It can be a great choice to use alternative fuel [5].

Millions of tons of plastic are disposed of every year worldwide, so if the cement industry uses these materials as an alternative fuel, it will be a good replacement for fossil fuels due to their high calorific value [6].

The calorific value of sewage sludge is $8293J/g$, and the total amount of energy using sewage sludge can be approximately $1.86GJ$ of fuel energy per ton of clinker, which can help cement manufacturers use it as an alternative fuel in the kiln [7].

The increase in municipal waste causes treatment difficulties and costs. According to the National Bureau of Statistics of China, 60.15% of municipal waste is disposed of in landfills. This type of waste contains a high amount of heat value.

Proper management of used tires and other wastes is required. Recent policies regarding the landfill of waste have made a ban because used tires can be used as alternative fuels or as fuel materials in many industries such as cement kilns [8]. Used tires are usually recommended as a powerful alternative, meat and bone meal is another valuable alternative fuel that can be used in cement production kilns due to its high calorific value [9].

This research aims to review the latest developments in the usage of alternative fuels in cement production plants and their effects on the environment. This study will also be a guide in the planning and implementation of alternative fuel usage in Afghanistan which will support Afghanistan's cement producers to reduce the consumption of natural fuel

resources. The utilization of alternative fuels in Afghan cement factories helps reduce the causes of environmental pollution.

The most common waste management system application in Afghanistan includes open incineration, dumping, and landfilling. It is very difficult to use 3R (reduce, reuse, and recycle) programs for waste management. Similar to other cities in Afghanistan, Afghanistan's largest city, Kabul, cannot provide a waste management system [10]. A suitable waste collection system in Afghanistan and opportunities for using them as alternative fuels in the cement production process should be created. However, some preliminary preparation is required for the usage of municipal solid waste, as it helps to protect fossil fuel resources and the environment. According to this review, used tires are the best alternative due to the high calorific value and low cost of preparation before use in the cement kiln.

2. Cement Production Process

The cement industry is one of the largest consumers of energy, using (3-5) MJ of thermal energy during the separation and sintering of carbonate minerals to produce $1kg$ clinker [11]. Cement production is a process that emits high levels of greenhouse gases [12]. The chemistry of cement production begins with the decomposition of calcium carbonate, calcium oxide, and carbon dioxide at approximately 900^0C. This process is known as calcination and is followed by clinkering where calcium oxide reacts with silica, alumina, and ferrous oxide at a temperature (of 1400-1500)^0C to produce the silicates, aluminates, and ferrites of calcium that make up the clinker [13].

Depending on the type of cement to be produced, the following products can then be added to the dried limestone: Pyrite ash, fly ash from coal-fired power plants, sandy clay, and filter ash from the existing electrostatic precipitator. The resulting mixture is ground and then fired in a rotary kiln to produce clinkers. For heating, various fuels and other combustible materials, such as coal dust, and petroleum coke, are used. Depending on the type of preheating of materials, it is distinguished as grate and cyclone preheating, so that the starting materials are preheated from $(700-800)^0C$. Raw materials pass through the rotary kiln towards the flame. In the hottest zone, the temperature of the fired materials is reached about 1450^0C [14]. The clinker is then ground together with gypsum and other additives to produce cement [13]. The cement production process as illustrated in (Fig 1) [15], includes the following general steps: initial quarrying, raw material preparation, preheating and pre-calcining, clinkering, cooling, final grinding, storage, and transportation steps.

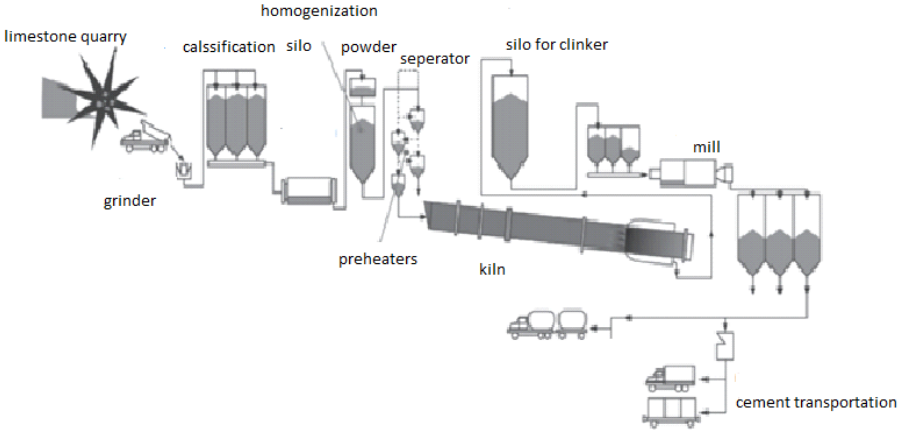


Fig.1. Cement production scheme [15]

The cement production process is different in terms of equipment design, operating method, and fuel consumption. Four basic processes can be classified as follows [13]:
1) Dry process: dry raw material is fed into the pre-calcination furnace.
2) Wet process: The raw slurry is fed into the rotary kiln.
3) Semi-dry process: Dry raw material is pelleted with water and preheated.
4) Semi-wet process: The raw slurry is first dewatered and then fed to the preheater, or in some plants, it is fed directly to a filling cake dryer for the production of a (dry) raw meal before preheating or pre-calcining.

3. Combustion Fuel for Cement Production

Cement manufacturers use a variety of energy sources to produce cement, including coal, diesel, and natural gas [16]. Compared to other fuels, coal is the most used. The cement industry is the world's second-largest industry in terms of coal consumption [17]. Due to the high energy consumption during cement production, the cement industry is trying to use alternative fuels instead of fossil fuels. This important movement of the cement sector is very important both economically and environmentally [18].

4. Alternative Fuels

Many natural and artificial materials contain some energy that can be used by the cement industries to meet thermal energy needs. The usage of alternative fuels in the cement production process is of great importance for both the producers and the environment. The use of alternative fuels in the cement industry has a history of 30 years. Research shows that cement producers face restrictions in the use of alternative fuels due to some environmental, social, and product quality issues [2]. The usage of alternative fuels in cement kilns has some rules and regulations that should be taken into account. The guiding principle for the usage of alternative fuels in the cement kiln is presented in, tab. 1 [19].

Table 1. The guiding principle for co-processing of alternative fuels in cement kiln [19]

Principle	*Explanation*
Alternative fuel usage hierarchy in the cement industry	Alternative fuels are used only if they are not economical or harmful to the environment. They should be used by international standards.
The negative points of alternative fuel components should be taken into account in terms of human and environmental health.	The disadvantages of alternative fuel compounds when used in cement production should be reduced to zero or at least reduced.
The quality of the product should not be changed	otherwise, it should not be used by cement manufacturers

5. Alternative fuel types

Meat and bone meal

One of the most common ways to dispose of meat and bone meal is co-incineration in a cement kiln compared to coal. Meat and bone meal have lower fixed carbon but a higher amount of chlorine present as sodium chloride ($NaCl$). It contains a higher amount of ash compared to coal. The sulfur content of meat and bone meal is slightly lower than coal, but it has a calorific value, and high heat value (HHV) of about 14-17 MJ/kg, which is half that of coal. The higher Ca content in meat and bone meal may play a positive role in sequestering most of the SO_2 formed during the meat and bone meal combination. The amount of (N_2) nitrogen is 7-8 times higher than that of coal, and it can be expected to increase the amount of oxides of nitrogen (NO_x) [14].

Sewage sludge

Combustion of sludge organic matter occurs only at 200^0C, its calorific value $8293J/g$ $1990kcal/kg$ which is sufficient for it to be an alternative fuel. Phosphorus in the mud can increase the stability of the Belite structure and delay the crystallization of Alite. A technical advantage of sewage sludge is the reduction of free lime content in the clinker [7].

Plastic waste

Due to its widespread production and high calorific value, which is (29 - 40) MJ/kg, plastic trash is regarded as one of the most readily available alternative fuel resources in the cement industry. Municipal garbage and industrial waste both contain plastic waste. The chlorine content, which is primarily present in polyvinyl chloride (PVC), is the only drawback to utilizing it. Separating resources from plastic garbage costs more in terms of labor and money [20].

Urban solid waste

Urban solid waste is considered one of the most important challenges facing urban communities around the world. Municipal solid waste is a heterogeneous composition. The availability of urban solid waste could make it one of the desirable alternative fuels for cement plants [21]. Waste energy technology has received increased attention in the

last decade as part of the development of a more sustainable waste management practice. It is the process of energy recovery in the form of waste-to-energy, waste-to-energy in the form of heat/electricity. If municipal solid waste is used as a direct (waste-to-energy) input, the action can lead to an unstable working condition. As a result, refused-derived fuel, a treated form of municipal solid waste is used in the system [2]. The typical composition of municipal solid waste by materials is shown in, tab. 2 [14], and the chemical composition of municipal solid waste and refused derived waste is illustrated in, tab 3 [13].

Table 2. Urban solid waste composition by materials [13]

Ingredients	*Weight percent*	*percent by volume*
Pulp and cardboard	37.5	37.0
Glass	6.7	2.3
ferrous metal	6.3	8.8
Aluminum	1.4	3.1
plastics	8.3	18.3
textile	2.8	5.4
Wood	6.3	5.9
food waste	6.7	2.7
garden waste	17.9	9.2
others	3.7	1.5

Table 3. The chemical composition of municipal solid waste and refused derived waste [13]

Components	*Municial dry solids*	*Fuel from waste %*
Carbon	34.88	47.1
Hydrogen	4.65	7.1
Nitrogen	1.02	0.7
Sulfur	0.15	0.24
Chlorine	1.02	0.6
Oxygen	23.11	29.4
Moisture	31.2	15
Ash	35.17	10.9
Heating value	15.4 MJ/kg	21.2 MJ/kg

Urban solid waste includes household waste, garbage-derived fuel, solid recovered fuels, and waste-derived fuels. Studies show that its usage reduces methane and carbon dioxide (CO_2) emissions compared to fossil fuel combustion. Many studies show a reduction in oxides of nitrogen (NO_x) and oxides of Sulphur (SO_x) emissions as well. On the other hand, the cost of urban solid waste is lower than fossil fuel, and it should be noted that the cost of coal grinding is also reduced when using urban solid waste in the furnace [22]. In the cement production process by using alternative fuels, climate change and environmental pollution will be reduced by 12% for all cement types [23]. The conversion of municipal solid waste into refused derived fuel is illustrated in, Fig. 2[22].

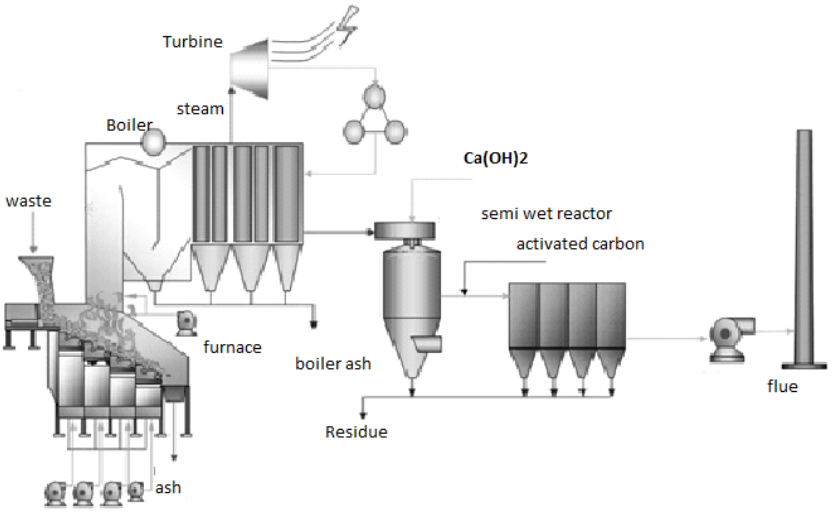


Fig.2. Example layout of the municipal waste incineration plant [22].

Used Tires

Used tires in cement factories can be used as an alternative fuel, the tires used are completely burned without waste and ash. Since the metals that come out of the tires during combustion in a cement kiln are bound to the clinker and improve their properties, the risk of harmful emissions will also be eliminated. It should be kept in mind that only specially designed installations at the right temperature should be used for tire combustion. Because low-combustion heat results in the release of numerous toxic compounds into the atmosphere (they cannot be burned in a house stove, which is regrettably still a very widespread practice in Poland). Due to the presence of heavy metals in their content, particularly zinc, the use of tires as fuel is, however, restricted to a maximum of 30% for the cement industry [24]. Therefore, burning tires in a cement kiln is completely safe for the environment [25]. The most important parts of cars, the tires, are the only parts that make direct contact with the road. The maximum number of years a tire can be used before needing to be replaced is now specified by tire manufacturers. Variations in temperature and humidity have the biggest effects on how quickly tiers age [26].

Tires are one of the most powerful alternative fuels due to their high energy content (over 30 MJ/kg). It shows that in the cement kiln, gaseous gasoline tends to be preserved to replace (25 – 30) % of normal fuel such as natural gas and coal. It is recommended to use in the chip structures of tires to prevent the dispersion of harmful metals such as zinc and chromium. The use of waste tires as optional fuel in the cement kiln reduces carbon dioxide (CO_2) and oxides of nitrogen (NO_x) output, saving energy and ecological costs. The extent of sulfur and sulfur compounds discharged from the cement plant can be reduced by using waste tires instead of coal and natural gas as fuel [27]. The calorific value of used tires and some other wastes are summarized in, tab.4 [25].

Table 4. Comparison of the calorific value of waste tires with other combustion materials [25]

combustion material	*Caloric value MJ/Kg*
Biomass	15.1
paper/cardboard	17.4
Fabrics	18.4
Coal	26.4
used tires	31.4
Oil	39.5

According to the statistics of the Afghanistan Traffic Department, there are about 700 thousand vehicles in this country, of which 300 thousand do not have traffic documents [28]. The head of Afghanistan's Environment Department said that the department, in collaboration with other institutions, has identified old tire warehouses in various parts of Kabul, including a 500 field with a 500-ton capacity in the Tank-e-Tel Logar area of Kabul city. He added that old tires are sold illegally in Kabul. The price of old tires is 4-5 times cheaper than coal, that's why it is used for heating in the winter [29].

6. Criteria of Alternative Fuels

Apart from the energy value, there are a few facts to consider when choosing the best alternative fuel. Cement manufacturers mostly prefer alternative fuels according to some criteria [13]. All waste has a controllable amount of calorific value. Approximate and final analyses, (LHV) lower heating values as well as (HHV) the higher heating value of some alternative fuels used in cement production are shown in, tab. 5 [11].

Table 5. Approximate and final analyses and heating values of some alternative fuels used in cement production [11]

Fuel type	*Proximate Analysis (as %wt)*			*Final Analysis (wt% dry basis)*							*Alkali*		*LHV*	*HHV*
	Moisture	Fixed Carbon	volatile material	ash	C	H	N	S	Cl	O	Na	K	MJ/kg MMBTU /ton	MJ/kg MMBTU /ton
fuel from waste	3.7-20	71.9 - 76	3.9-13.2	10.2 - 13.8	41.7-50.2	4.4 - 7.8	0.75-1.65	0.1-0.76	0.7 - 1.13	28.5-36.3	0-0.93	0-0.37	15.9*-1.7* 13.7-14.6	17.5-18.4 15.1-15.9
used tires	0.7-4	63.8 - 68.7	24-31.1	2.2 -8.2	76.7-89.4	7-7.8	0.2-0.5	0.8-2.2	≈0-0.1	0.4-4.5	0-0.9	0-1.1	32-35.6 28.4-30.7	34.6*-37.3 29.8-32.1
Meat and bone meal	1.4-8.1	64.5 - 79.7	7.2-9.7	10.4 - 28.3	42.1-55.7	5.8 -8	7.2-8.9	0.05-0.4	0.2	15.3-38.4	1.5	0.3	15.7 19.6-28.8* 16.9-24.8	17. 1 21*-30.6 18.1-26.4
PVC	≈0-0.2	85.9 - 91	6.3-9	1-7.6	35.9-38	4.4 -5	0-0.11	≈0	57	≈0	N/A	N/A	17.1* 14.7	18.1 15.6
sewage sludge	5.2-5.6	40.5 - 85	5-10.1	17.9 - 29.5	36.4-40.5	4.7 -7	0.84-5.0	0.1-0.6	≈ 0-1	22	≈0	≈0	9.3-15.8 8.0-13.6	10.4*-17.5 9.0-15.1
pet coke	0.8-1.5	7.6-10	88.6-89.6	0.5-1	89.5-92.7	2.4 - 3.7	1.2-1.7	1.5-4	≈0	1.1-1.2	≈0	≈0	33.5-35.4* 28.9-30.5	34.4* 36.2 29.6-31.2
Coal (19, 25-27)	1.1-3.3	23-35.3	44.2-66.8	6.4-15.5	65.3-80.9	3.7 - 5.1	1.2-1.41	0.6-5.5	≈0-0.33	5.9-12.5	0-0.03	0-0.19	25.4-31.8* 21.9-27.4	26.3* 32.9 22.7-28.3

However, to be economically viable, they must meet some of the most important criteria as listed below [30]:

1) presence
2) Physical state of the fuel (gas, liquid, solid)
3) Toxicity (organic compounds, heavy metals)
4) The composition and content of the ash.
5) Content of volatile substances.
6) Calorific value (typically over 8 MJ/kg required)
7) Physical properties (scrap size/density, homogeneity).

8) Moisture content.
9) The content of circulating elements sodium, chlorine, and Sulphur (Na, Cl, S).

Alternative fuels are cheaper than fossil fuels, thus encouraging cement producers to use them. The important advantages of alternative fuel substitution are the protection of non-renewable energy sources, protection of the environment, and reduction of waste disposal areas. Many European countries use alternative fuels in their cement factories and they are far ahead of other countries [31]. The usage of alternative fuels in some countries in the world is listed in, tab. 6 [13].

Table 6. The usage of alternative fuels in some countries in the world [13]

Alternative fuel use in different countries			
Country	*Displacement %*	*Country*	*Displacement %*
Australia (2013)	7.8	Germany	53.6
Japan (2012)	15.5	EU	18
Sweden (2012)	45	Poland	45
Swiss (2012)	41	Spain	22.4
Netherlands (2012)	85	Belgium	60
Canada (2011)	11.3	USA	8

7. Afghanistan Cement Production Facilities

Ghori I and Ghori II are the famous cement production factories in Afghanistan. Ghori I has two furnaces with a daily capacity of 400 metric tons, through Ghori's 1st furnace dust-laden gases are released into the atmosphere. In addition, there are no fugitive particulate matter collection facilities between the furnace and the atmosphere, and thermal energy exhaust is not returned or recycled for preheating the raw materials in the cyclones. Ghori II also has two furnaces with a capacity (1000-1200 Ton /day), both Ghori I and II use coal powder as furnace combustion material.

However, Pul-e-Khomri produces only a tiny fraction of the current demand in Afghanistan. The Jabal-e-Sarj plant is a wet process plant producing 100 Tons/day, but a huge fraction of cement is imported from other countries, although Afghanistan has an abundant source of domestic raw materials. Afghan cement production cannot compete with imported products without modernizing and expanding its capacity. In the factory, coal is used as the main fuel for the furnace. With each metric ton of clinker production, 0.59 tons of carbon dioxide (CO_2) is produced, of which 0.5 tons comes from the decomposition of raw materials and about 0.08 tons from fuel combustion. However, these values are related to the condition and type of fuel and the process. In 2016-2017 As a result of the combustion of fuel in the cement production process, 20664.60 CO_2 eq, carbon mono oxide (CO) emissions increased strongly by 1.79 and (SO_2) emissions by 2.45 times from 1990 to 2017 [32].

8. Conclusion

In this review, many alternative fuels and their criteria in terms of thermal values, environmental and economic effects, chemical composition, chlorine (CI_2) content, calorific value, nitrogen (N_2), and Sulphur (S_2) content, that are likely to produce oxides of Sulphur (SO_x) and oxides of nitrogen (NO_x) during the combustion of raw material is summarized. Studies show that due to the low operating costs, high alternative ratios, and being less harmful to the environment, used tires are the most attractive alternative fuel for cement manufacturers. As hazards produced from the tires during a complete combustion in a cement kiln are stably connected with clinker, strengthening its characteristics, this action minimizes the risk of emission into the atmosphere.

Furthermore, the number of vehicles rises in Afghanistan every day. While the condition of roads and climate in Afghanistan cause, automobile tires to wear out faster than normal. On the other hand, old tires, which are sold at very low prices in the market, are used as fuel without considering international environmental standards, if these tires replace coal by 30% in the Afghan cement kilns, it will reduce environmental pollutants and prevent the loss of coal. The usage of old tires as fuel in cement kilns, in Afghanistan will be considered a positive step if the factories can provide complete combustion conditions of these alternative fuels inside the kiln, and instead of releasing the gases into the atmosphere, recirculate them into the preheaters of the kiln.

Urban solid waste, meat bone, meal, plastics, and sewage sludge also have high energy content like fossil fuels. However, their initial preparation before using them as fuel in the cement kiln is more expensive.

However, the usage of alternative fuels in cement kilns needs further research on some other important criteria of waste. According to this review used tiers are recommended as the most practical alternative fuel for the cement manufacturers in Afghanistan.

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