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Procedia Engineering 56 (2013) 393 – 400

Procedia Engineering

www.elsevier.com/locate/procedia

5th BSME International Conference on Thermal Engineering

Impact of alternative fuels on the cement manufacturing plant performance: an overview

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Abstract

Cement manufacturing is a high energy consuming and heavy polluting process. To reduce the energy and environmental costs cement producers are currently using a blend of alternative fuels with conventional fossil fuels. Alkaline environment, high temperature and long processing time allow cement kiln to burn a wide range of alternative fuels including waste and hazardous materials. This paper summarizes and reviews literatures on the usage of different types of alternative fuel and their impacts on the plant performance. The past research suggests that the maximum benefit can be derived by using an appropriate blend of different types of alternative fuels together with fossil fuels. However, the studies on quantification of appropriate mixing ratio of different alternative fuels to increase the plant performance are scant. Further study is required to determine the correct blending ratios. This literature review is focused on the relationship between performance and blending of different alternative fuels used by leading cement manufacturing groups.

Selection and peer review under responsibility of the Bangladesh Society of Mechanical Engineers

Keywords: Cement; alternative fuel; plant performance; energy efficiency

1. Introduction

The production of cement consumes large quantities of raw materials and energy (thermal and electricity). This process requires approximately 3.2 to 6.3 GJ of energy and 1.7 tons of raw materials (mainly limestone) per ton of clinker produced [1, 2]. Being an energy intensive industry, thermal energy used in cement industry accounts for about 20–25% of the production cost [3]. The typical electrical energy consumption of a modern cement plant is about 110–120kWh per ton of cement. In the manufacturing process thermal energy is used mainly during the burning process, while maximum share of electrical energy is used for cement grinding [3].

Generally fossil fuels such as coal, petroleum coke (petcoke) and natural gas provide the thermal energy required for cement industry. Usage of alternative fuel (AF) becomes more popular to the cement manufacturer due to increasing fossil fuel prices, limited fossil fuel resources and environmental concerns. AF cover all non-fossil fuels and waste from other industries including tire-derived fuels, biomass residues, sewage sludge and different commercial wastes [4].

The rotary kiln used in cement manufacturing is able to burn a wide range of materials due to the long exposure time at high temperatures, intrinsic ability of clinker to absorb and lock contaminants into the clinker and the alkalinity of the kiln environment. Materials like waste oils, plastics, waste tires and sewage sludge are often proposed as alternative fuels for the cement industry. Meat and bone meal are also considered now as alternative fuel [5]. Biomass waste and spent pot linings produced in aluminum smelters [6] are recently identified as potential alternative fuels for cement industry.

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Selection and peer review under responsibility of the Bangladesh Society of Mechanical Engineers
doi:10.1016/j.proeng.2013.03.138

Alternative fuels utilization in cement industry reduces the production cost and achieves higher thermal energy efficiency thus increase plant performance. The objective of this study is to review the available literature on the performance of cement manufacturing plants using different blends of alternative fuels. There are several key performance indicators to measure the performance of cement manufacturing plant and most of them are related to the thermal efficiency of the plant. This article summarizes the current practices of using alternative fuels in cement industry and attempts to draw a relationship between the usage percentage of AFs and the plant performance. A variety of research journals, conference proceedings, books, industrial sustainability reports and reliable websites are included in this review. A brief discussion has been appended to understand the correlation between the blended AFs and plant performance which might be useful for cement producers and the researchers.

2. Cement manufacturing process

The main process routes for the manufacturing of cement vary with respect to equipment design, method of operation and fuel consumption [7]. Cement manufacturing process basically includes quarry, raw meal preparation, preheating of raw meal, kiln, clinker cooling, grinding, storage and dispatch. Figure 1 shows a basic process flow of cement manufacturing. The basic chemistry of the cement manufacturing process begins with the decomposition of calcium carbonate ($CaCO_3$) at about 900°C to leave calcium oxide (CaO, lime) and liberate CO_2; this process is known as calcination. This is followed by the clinkering process in which the calcium oxide reacts at high temperature (typically 1,400°–1,500° C) with silica, alumina and ferrous oxide to form the silicates, aluminates and ferrites respectively which forms the clinker. This clinker is then ground together with gypsum and other additives to produce cement. Fuels are required to generate thermal energy during the process of calcination in preheater tower and during the clinkerization process in Kiln.

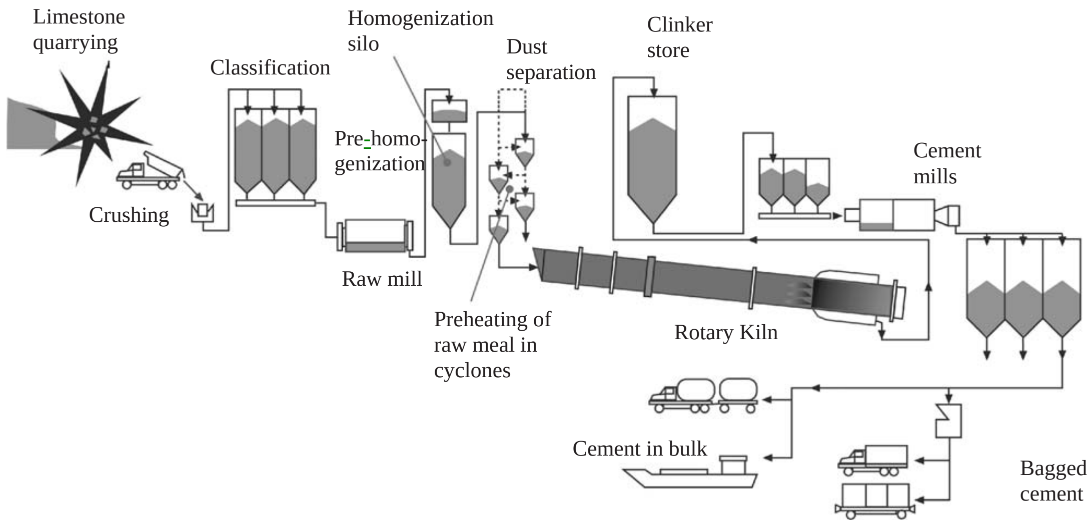

Fig. 1. Cement manufacturing process (Kaantee et al., 2004)

3. Alternative fuels

Most natural and artificial materials contain some energy which can be utilized by the cement industries to meet the requirement of the thermal energy. The use of AF for cement clinker production is of high importance for the cement manufacturers as well as for the environment. Alternative fuel utilization at commercial level in cement industry is as old as about 30 years now. In calciner lines, close to 100% alternative fuel firing at the precalciner was achieved at very early stage [8]. Use of AFs in rotary kilns is still in progress. Reports show that in some kilns up to 100% substitution rates have been achieved [9], while others are facing some limitations regarding environmental, social and product quality issues. In any case, AF utilization requires adaptation by the cement industry. Modern multi-channel burners and thermograph systems are in use these days which help in controlling the AF feed rate and the flame shape to optimize the burning behavior of the fuels [8].

Generally the cement producers choose the AFs on the basis of price and their availability but these criteria of selecting AFs are not adequate. Composition of the fuel including the energy content, moisture and volatile contents are very important criteria to select an AF. It is also important to consider all forms of AFs such as: liquid, solid, semi-solid, powdered or in the form of big lumps. Different types of AFs require a flexible fuel feeding system, through which AF could be fed either directly into the burning zone at kiln or in the pre-heating system [5].

3.1 Criteria of alternative fuel

There are no set criteria for selecting AFs today. The specific criteria that a material must meet in order to be considered as a fuel is typically set by the individual cement producer according to their own needs. AFs are generally a mixture of various wastes and therefore consistency in their composition cannot be guaranteed. There is a need for ensuring the chemical contents of the AF that meets regulatory requirements for environmental protection. The following properties are expected to be considered as alternative fuels [3, 10]:

- Physical state of the fuel (solid, liquid, gaseous),
- Content of circulating elements (Na, K, Cl, S),
- Toxicity (organic compounds, heavy metals),
- Composition and content of ash and content of volatiles,
- Calorific value — over 14.0 MJ/kg,
- Chlorine content — less than 0.2% and Sulfur content — less than 2.5%,
- PCB content—less than 50 ppm, heavy-metals content — less than 2500ppm [out of which: mercury (Hg) less than 10 ppm, and total cadmium (Cd), thallium (Tl) and mercury (Hg) less than 100 ppm].
- Physical properties (scrap size, density, homogeneity),
- Grinding properties,
- Moisture content,
- Proportioning technology,
- The emissions released,
- The cement quality and its compatibility with the environment must not decrease,
- Alternative fuels must be economically viable.
- Availability

3.2 Advantages and disadvantages

Alternative fuels are generally cheaper than the fossil fuels because most of the AFs are generated from wastes which only require some processing cost. A mixture of fossil fuels and AF in optimal proportion is used to produce the thermal energy required in cement industry. The significant advantage of alternative fuel substitution is the preservation of non-renewable energy sources [11] and the reduction of waste disposal sites. Switching to alternatives fuels presents several challenges as they have different characteristics compared to the conventional fuels. Poor heat distribution, unstable precalciner operation, blockages in the preheater cyclones, build-ups in the kiln riser ducts, higher SO_2, NO_X, and CO emissions, and dusty kilns are some of the major challenges which need to be addressed [12]. One potential constraint on the implementation of alternative fuels is the final clinker composition since the combustion by-products are incorporated into clinker [13]. The substitution of AFs inherently requires initial investment costs associated with adjustment or replacement of burner, establishment of alternative fuel delivery systems, new fuel storage facilities, and fuel distribution systems [14].

3.3. Usage of alternative fuel

The cement manufacturing industry is under increasing pressure from the environmental protection agencies to reduce the emissions. The usage of AFs in cement manufacturing not only helps to reduce the emission but also has significant ecological benefits of conserving non-renewable resources [12]. The substitution rate of fossil fuel by AFs varies from country to country. Most of the European countries are way ahead in the usage percentage of AFs than the rest of the world. The substitution rate of different countries is shown in Table 1 [15]. World's leading cement producers are currently using AFs in a large extent and pursuing to increase it even more by 2020. Conventional fossil fuel substitution rate and the percentage of different AFs usage by different cement production group are available in their sustainable development reports. Table 2 summarizes the percentage of different wastes which are currently being used as AFs in five selected leading cement producer groups [16-21]. Cemex group are currently using industrial and household waste as a major portion of their AFs. Heidelberg, Holcim and Italcementi group are using range of AFs but Lafarge group is utilizing only four types of AFs. It is also found from Table 2 that most common AF is used tires which are utilized by all the selected manufacturing group up to some extent.

Table 1: Usage of AFs in different countries [15]

Country or Region	% Substitution	Country or Region	% Substitution
Netherlands	83	Czech Republic	24
Switzerland	47.8	EU (prior to expansion in 2004)	12
Austria	46	Japan	10
Norway	35	United States	8
France	34.1	Australia	6
Belgium	30	United Kingdom	6
Germany	42	Denmark	4
Sweden	29	Hungary	3
Luxembourg	25	Finland	3

Table 2: Percentage of different type of waste used as AF

Waste type used as Alternative fuel (%)	Holcim Group (2011)	Cemex Group (2011)	Heidelberg Group (2011)	Italcementi Group (2011)	Lafarge Group (2011)
Waste oil	5		3.7	8.5	22.1
Solvent & liquid waste	11		4.7	21.9	
Tires	10	16	11.6	14.9	19.7
Impregnated sawdust	6				
Plastic	9		26.4	4.7	33.1
Industrial & household waste (solid)		65		13.8	
Industrial waste & other fossil based fuel	30				
MBM	2	4	6.1	15.7	
Agricultural Waste	9	10	4.2	11.1	
Wood chip & Other Biomass	15	5	24.5		25.1
Sewage sludge	2		4.2	1.7	
RDF				7.8	
Other alternative fuel			14.6		

4. Plant performance indicator

The cement industry needs to ensure sustainable and environmentally friendly use of natural resources while increasing profit margins. This is the responsibility of the cement producers to develop new strategies that will optimize the performance of the manufacturing process in response to the changing conditions. To measure the performance of the manufacturing process a number of companies utilize some Key Performance Indicators (KPI). Selecting appropriate KPIs at the company level and implementing them in the operational level is also a new challenge faced by the cement industry.

To move towards the sustainable development an important requirement for the cement companies is the performance measurement. Investigation of cement plant's performance requires data from different sources, which need to be collected and evaluated properly. The raw data from the sources are often unavailable due to the confidentiality policy of the plant. Inconsistent data because of the limited accuracy of the instruments are also another problem [22]. Within the cement industry, many companies are operating environmental indicators as facility level KPIs and some companies have introduced indicators based on energy efficiency and the usage of AFs and raw materials [23]. Base lining and benchmarking are two related approaches for performance measurement. Base lining involves comparing plant performance over time, while benchmarking involves comparing performance relative to an established best practice level of performance [24].

The potential KPIs for cement plant performance can be categorized by energy efficiency, environmental performance, economical benefits, social performance etc. According to the WBCSD report on sustainable cement industry [23], the most important KPIs are;

- Tonnes of cement per mega joule of energy
- Fuel & raw material substitution rates (%)
- Non-product output (kg of waste) per tonne of cement
- Net CO_2 (kg) per tonne of cement
- Incident rate (injury, illness) per 200,000 hours

Apart from the last one on the list all are directly involved with the fuel source hence with the AFs. In this article the impacts of AFs are studied on the basis of available data from different sources. Five selected cement manufacturing group's data has been analyzed to understand the influence of alternative fuel on plant performance.

5. Data & analysis

There is variability in the data due to both differences in company performance and differences in kiln process. To illustrate that, Table 3 represents specific thermal energy consumption of clinker manufacturing with different kiln process [25]. Still several literatures try to figure out the baseline of the performance measurement. Table 4 gives an example of such effort [23].

Table 3: Specific thermal energy consumption in different kiln process [25]

Kiln process	**Thermal energy consumption (GJ/tonne clinker)**
Wet process with internals	5.86–6.28
Long dry process with internals	4.60
1-stage cyclone pre-heater	4.18
2-stage cyclone pre-heater	3.77
4-stage cyclone pre-heater	3.55
4-stage cyclone pre-heater plus calciner	3.14
5-stage pre-heater plus calciner plus high efficiency cooler	3.01
6-stage pre-heater plus calciner plus high efficiency cooler	<2.93

Table 4: Baseline Performance of the Cement Industry [23]

Indicator	**Approximate Value**
Tonnes of cement per MJ	Each tonne of cement consumes roughly 3000 MJ of total electrical and thermal energy
Fuel & raw material substitution rates (%)	Fuel ranges from 0 to 25% Raw material from 0 to 10%
Non-product output (waste per ton of cement)	Airborne and waterborne releases are generally known, but definitions of solid waste vary
Net CO_2 (kg) per ton of cement	Each tonne of Cement generates approximately 900 kg of net CO_2 emissions
Incident rate (injury, illness) per 200,000 hours	Ranges from 1 to 5 incidents per 200,000 hours

Three out of the five world's largest cement producers are located in the EU-27: Lafarge (France), Heidelberg Cement (Germany) and Italcementi (Italy), with the other two being Holcim (Switzerland) and Cemex, (Mexico) [26]. As the plant level data is not available in literature the group level data [16-21] for the aforementioned cement manufacturing companies have been considered for the current study. Table 5 summarized the percentage of AFs in fuel mix and the average thermal energy efficiency of the manufacturing group. The annual sale of cement is also included to indicate the annual production of the groups. Apart from Heidelberg group all have increased the percentage of AFs in their fuel mix. Thermal energy efficiency was achieved with the increment of AF usage with an exception for Cemex group.

Table 5: Thermal efficiency of cement manufacturing group

Company	Sales of cement (million tons)		% of thermal energy from alternative fuel		Thermal energy efficiency (MJ/ton clinker)	
Year	2009	2011	2009	2011	2009	2011
Holcim Group	131.9	144.3	12.0	12.2	3606	3510
Cemex Group	72	75	16.4	24.7	3693	3757
Heidelberg Group	79.3	87.8	22.7	21.2	3793	3797
Italcementi Group	55.7	51.1	5.4	5.8	3970	3805
Lafarge Group	149.4	160	10.9	13	3670	3657

Most important KPI for cement manufacturing plant from the environmental point of view is the gross and specific CO_2 emission. This and other KPIs for the cement manufacturing group are assembled in Table 6. In the table air emission data includes the amount of NO_X, SO_2, dust and other heavy metal and organic components. Clinker cement ratio is also included in the table as it is also considered as an important KPI [23] and directly involved with the thermal energy consumption and CO_2 emission rate. Lafarge group manage to improve their clinker cement ratio and in the course they manage to reduce net CO_2 emission which occurs during the calcinations process of clinker production.

Table 6: KPIs of cement manufacturing groups

Company	Gross CO_2 emission (Million tons)		Net CO_2 (Kg) per ton of cement		Air emission (kg of waste) per ton of cement		Clinker cement ratio	
Year	2009	2011	2009	2011	2009	2011	2009	2011
Holcim Group	92.6	102.0	613	608	1.43	1.34	70.7	70.9
Cemex Group	41.7	43.3	658	660	1.58	1.53	75.1	75.1
Heidelberg Group	41.8	47.4	649.3	650.5	2.15	2.40	76.4	75.5
Italcementi Group	35.03	34.43	717	708	2.14	2.12	81.6	81.3
Lafarge Group	93	98	628	611	2.57	2.21	75	73

6. Discussion

The usage of AFs in cement industry increases day by day to meet the objectives of sustainable development, however it should not impose an adverse effect on the plant performance. Five selected cement manufacturing groups' data has been presented in this paper to understand the link between the usage percentage of AF and the plant performance. Four major KPIs have been scrutinized from the available data. Percentage of different wastes which are currently used in cement industry as AF has also been analyzed to understand the correlation between them and the plant performance.

Among the selected groups, Cemex Group was found to be the highest fossil fuel substitution rate achiever. Industrial and household solid wastes constitute the major part of AFs used by Cemex group. Generally Industrial and household solid wastes contains more moisture than coal and hence the thermal energy requirement per ton of clinker production is higher for Cemex group. The positive side was the reduction of waste per ton of cement production (reduces about 3% in two years).

Holcim group secured second place by the sale margin in year 2009 and 2011. The percentage of AFs usage remains almost same during those two years along with the ratio of different waste materials. The thermal energy efficiency for the Holcim group drop from 3606 MJ/t to 3510 MJ/t. Specific air emission of Holcim group reduced slightly while gross CO_2 emission increased due to the increase of cement production.

Lafarge group posted highest sale of cement both in year 2009 and 2011. They also increased the fossil fuel substitution rate by AFs from 10.9 to 13 in two years. Their AFs include solvent & liquid waste, tires, industrial & household waste and biomass almost in equal proportion. Thermal energy consumption for Lafarge group was reduced from 3670MJ/t to 3657MJ/t. The most commendable achievement of Lafarge group is the net CO_2 emission per ton of cement which dropped from 628 kg to 611kg in two years.

Percentage of thermal energy from AFs in Heidelberg group reduced to 21.2 in 2011 from 22.7 in 2009. Thermal energy consumption increased slightly from 3793MJ/t to 3797MJ/t. Air emission per ton of cement was also increased during that period by 10%. Similar increment was found in the figure of gross and net CO_2 emission.

Italcementi group was way behind in using AFs in cement manufacturing compared to other cement manufacturing groups. It also reflected on their thermal energy consumption and air emission data. Italcementi group also had some trouble regarding the clinker cement ratio compared to other manufacturing groups. It is pertinent to mention here that the net CO2 emission for all the groups are way below the base line as mentioned in Table 4. Still cement manufacturer try hard to reduce it even more along with the reduction of other emissions (NO_X, SO_2 and dust).

From the above study it is clear that usage percentage of alternative fuel can influence the plant performance in terms of their thermal efficiency. Still the magnitudes of its influence need to be determined quantitatively through extensive study with specific plant data. The percentages of waste that are currently being used as alternative fuel by the cement producer groups are available in literature. However, it is difficult to establish a relationship between the percentage of waste and plant performance on the basis of available data.

Currently, authors are undertaking a project to investigate the feasibility of using different wastes as alternative fuel for cement industry and to optimize their usage. Process engineering software ASPEN PLUS is being used to model the heating system of a full-scale cement plant, using different alternative fuels on the basis of combustion mechanism. This software is focused on clinker chemistry, thermodynamics in the rotary kiln and also the effect of alternative fuels on material flow, emissions and product quality. Through simulation the usage of wastes will be maximized along with controlling the above factors. ASPEN PLUS could also be used to calculate the heat balance of the entire process using established thermodynamics principles of material and energy conservation. In the process of optimizing the usage of alternative fuel, the plant performance will be determined through most suitable KPIs.

7. Concluding remarks

In this study, group level data of the leading cement manufacturer have been analyzed and discussed to draw a relationship between the usage of AFs and plant performance. The analysis reveals that CO_2 emission and other air emissions such as NO_X, SO_2 and dust can be reduced by increasing the usage of AFs. Thermal energy consumption of the plant can also be reduced by using certain wastes as AFs. Extensive study is required to find out the degree of the impact on the plant performance by the usage of AFs. A research group at Central Queensland University is studying different alternative fuels based on their intrinsic properties available from the local cement plant/s to improve the performance of the manufacturing process.

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