Research Journal of Chemical and Environmental Sciences
Res J. Chem. Environ. Sci. Vol 4 [3] June 2016: 01-07
Online ISSN 2321-1040
CODEN: RJCEA2 [USA]

Website: www.aelsindia.com/rjces.htm

RJCES

REVIEW ARTICLE

Cement Manufacturing and Use of Biomass Energy: energy option for Greenhouse Gas Reduction

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ABSTRACT

Cement production is an energy-intensive process. Conventional fuels used in the cement industry, such as coal, petcock and furnace oil, are notoriously polluting to the environment in terms of greenhouse gas emissions. With suitably designed feeding and combustion systems, biomass fuels can be used in cement factories in considerable proportions, thereby replacing polluting fossil fuels with carbon-neutral biomass fuels. Switching to biomass fuels is attractive for the cement industry from both environmental and financial perspectives.
Key word: biomass fuels, Greenhouse gas, Emission reduction, clinker process

Received 11.02.2016 Accepted 20.04.2016

INTRODUCTION

Agricultural and agro-industrial residues constitute averagely 15-20% of the total energy consumed in Ethiopia. Residues are mostly used in the domestic sector for cooking and baking, using very low efficiency devices. Residue supply is seasonal and residue use as fuel is also seasonal [1].

In different parts of the country, various types of crops are cultivated and, as a result, a considerable volume of crop residues is also produced. Generally, for use as fuel, crops with a higher residue-to-seed ratio provide the largest volume of potential biomass [1].

Crop and agro-industrial residues have low bulk and energy density, and for these reasons cannot be transported far from production sites without some form of processing. Residues from large commercial farms and agro-industries can be converted to relatively high-quality and high-energy density fuels for use in the domestic, commercial and industrial sectors through a number of physical, biological and thermo-chemical conversion processes [1].

The financial and environmental benefits of fuel switching are attractive for most cement factories. Switching to biomass fuels of 15-20% in the short term, and a greater percentage in the longer term, is a feasible option for some cement factories in Ethiopia. Switching to biomass fuels will have financial benefits arising from the reduced cost of fuels [2].

Cement factories can potentially use alternative fuels, including biomass and biomass residues, to heat their kilns. The substitution of fossil fuel by biomass and biomass residues qualifies, in principle, for cleaner development mechanism, CDM carbon crediting. Biomass can substitute for approximately 20% of process heat requirements without the need for major capital investment. The production process of cement clinker is energy-intensive and requires a large amount of fuel. So, using available biomass is the promising solution.

The main objectives of this study is to replace the conventional Fuel (oil, coal etc) with agro-industrial wastes such as coffee husks, cotton stalks, saw dust, castor husks. This will significantly reduce the fossil fuel usage required to produce cement without compromising the clinker quality or quantity and greenhouse gas emission reductions through partial substitution.

CEMENT MANUFACTURE PROCESS AND ENERGY USE

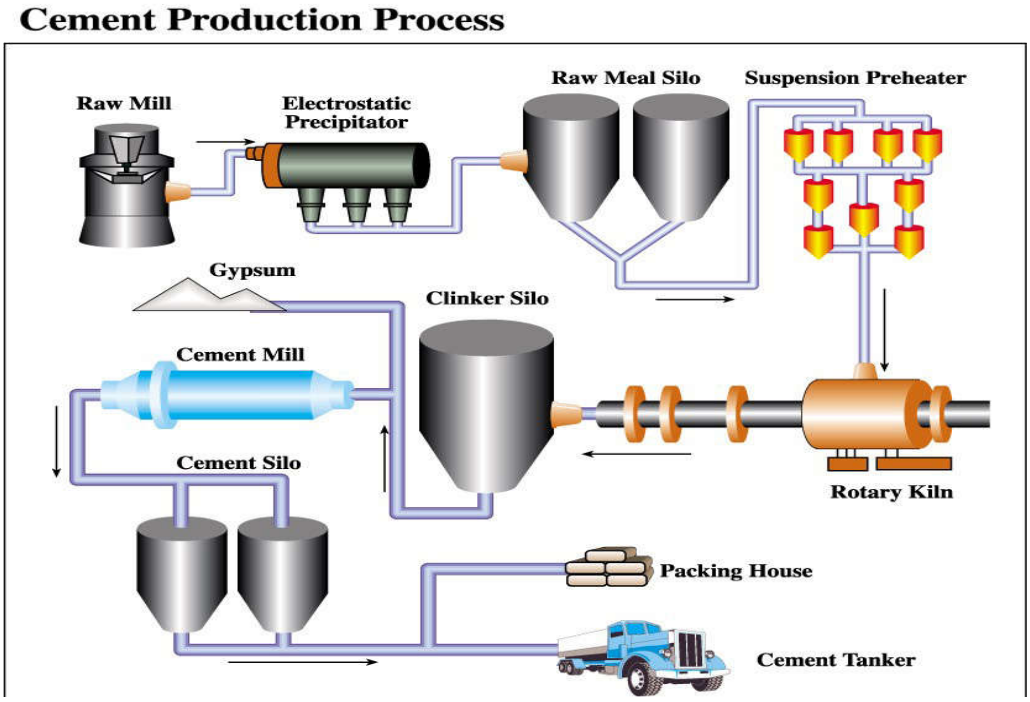

*Fig 1. General manufacturing process (*Lecture: 24 Cement industries. N. K. Patel)

Basically cement manufacturing involves the following steps

- Mixing of raw material
- Burning
- Grinding
- Storage and packaging

Mixing of raw material

Mixing can be done by any one of the following two processes

(a) Dry process

(b) Wet process

Dry Process

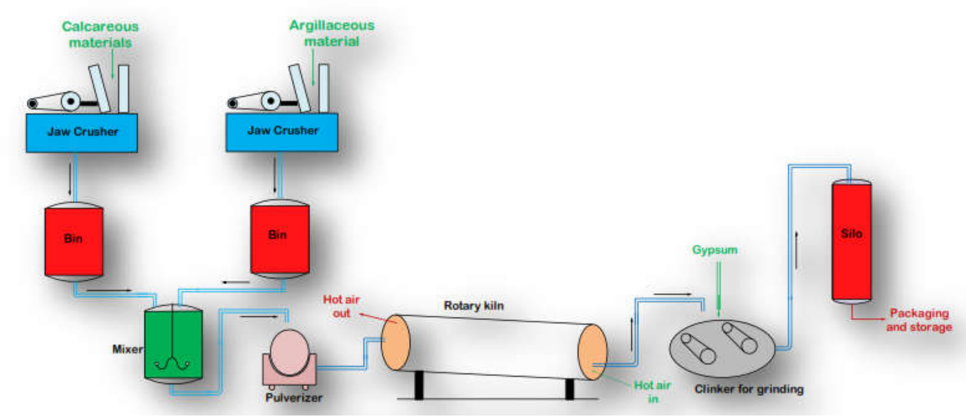

Figure 2: Manufacturing of Cement by Dry Process (Lecture: 24 Cement industries. N. K. Patel)

Lime stone or chalk and clay are crushed into gyratory crusher to get 2-5 cm size pieces. Crushed material is ground to get fine particle into ball mill or tube mill.

Each material after screening stored in a separate hopper. The powder is mixed in require proportions to get dry raw mix which is stored in silos (storage tank) and kept ready to be fed into the rotary kiln. Raw materials are mixed in required proportions so that average composition of the final product is maintained properly [4].

Wet process

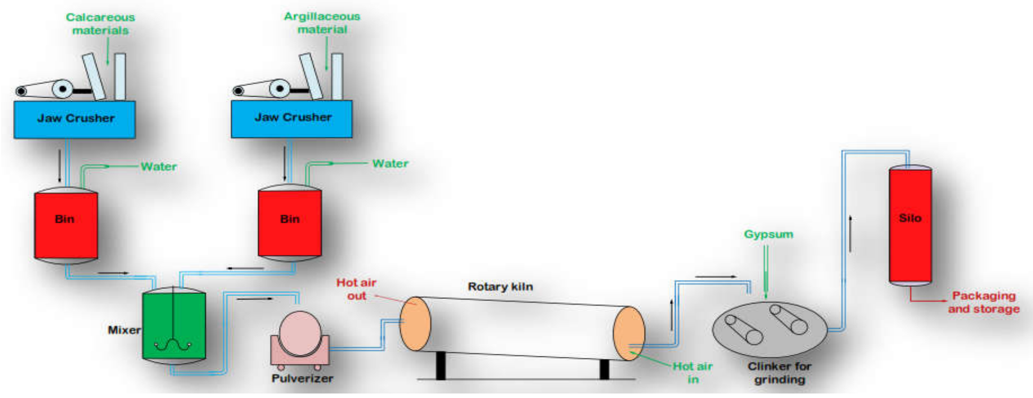

Figure 3: Manufacturing of Cement by Wet Process (lecture: 24 Cement industries. N. K. Patel)

Raw materials are crushed, powdered and stored in silos. The clay is washed with water in wash mills to remove adhering organic matter. The washed clay is stored separately. Powdered lime stone and wet clay are allowed to flow in channel and transfer to grinding mills where they are intimately mixed and paste is formed known as slurry. Grinding may be done either in ball mill or tube mill or both. Then slurry is led to correcting basin where chemical composition may be adjusted. The slurry contains 38-40% water stored in storage tank and kept ready for feeding to a rotary kiln.

Table 1 Comparison of dry process and wet process (Lecture: 24 Cement industries. N. K. Patel).

Criteria	Dry process	Wet process
Hardness of raw material	Quite hard	any type of raw material
Fuel consumption	Low	high
Time of process	Lesser	higher
Quality	Inferior quality	Superior quality
Cost of production	high	low
Over all state	Costly	Cheaper
Physical state	Raw Mix(solid)	Slurry(liquid)

The remaining two operations burning and grinding are same for both the process.

Burning

Burning is carried out in rotary kiln which rotating at 1-2 rpm at its longitudinal axis. Rotary kiln is steel tubes having diameter in between 2.5-3.0 meter and length varies from 90-120meter. The inner side of kiln is lined with refractory bricks. The kiln is rested on roller bearing and supported columns of masonry or concrete in slightly inclined position at gradient of 1 in 25 to 1 in 30. The raw mix or corrected slurry is injected into the kiln from its upper end. Burning fuel like powdered coal or oil or hot gases are forced through the lower end of the kiln so long hot flame is produced. Due to inclined position and slow rotation of the kiln, the material charged from upper end is moving towards lower end (hottest zone) at a speed of 15meter/hour. As gradually descends the temperature is rises. In the upper part, water or moisture in the material is evaporated at 4000C temperature, so it is known as drying zone. In the central part (calcinations zone), temperature is around 10000C, where decomposition of lime stone takes place. After escapes of CO2, the remaining material in the forms small lumps called nodules [6].

$$CaCO_3 \rightarrow CaO + CO_2$$

The lower part (clinkering zone) have temperature in between 1500-17000c where lime and clay are reacts to yielding calcium aluminates and calcium silicates. This aluminates and silicates of calcium fuse to gather to form small and hard stones are known as clinkers. The size of the clinker is varies from 5-10mm [5].

$2CaO + SiO_2 \rightarrow Ca_2SiO_4\ (dicalcium\ silicate)$

$3CaO + SiO_2 \rightarrow Ca_3SiO_5\ (tricalcium\ silicate)$

As clinkers are coming from burning zone, they are very hot. The clinkers are cooled down by air admitting counter current direction at the base of rotary kiln. Resulting hot air is used for burning powdered coal or oil and cooled clinkers are collected in small trolleys or in small rotary kiln [3].

Grinding

Cooled clinkers are ground to fine powder in ball mill or tube mill. 2-3% powdered gypsum is added as retarding agent during final grinding. So that, resulting cement does not settle quickly, when comes in contact with water. After initial set, cement - water paste becomes stiff, but gypsum retards the dissolution of tri-calcium aluminates by forming tricalcium sulfoaluminate which is insoluble and prevents too early further reactions of setting and hardening [6].

$$3CaO.Al_2O_3 + xCaSO_4.7H_2O \rightarrow 3CaO.Al_2O_3.xCaSO_4.7H_2O$$

Energy use in the process

Pyroprocessing – the process of clinker production in the pre-heaters / pre-calciners, kilns and coolers – is a particularly energy-intensive system. Energy consumption of the pyroprocessing system is, however, dependent upon the technology of the production process. A considerable amount of energy is wasted at various stages of the pyroprocessing system. Depending upon the type of clinker production process, 7-38% of the energy consumption in the pyroprocessing system is wasted in the evaporation of moisture [4, 5].

Table 2: Thermal Energy Balances of Clinker Production in Process Kilns (Choate, 2003)

Energy Use Area	Wet Kiln		Dry Kiln		Pre-heater Kiln	
	MJ/tonne	%	**MJ/tonne**	%	**MJ/tonne**	%
Theoretical Requirement	1,773.0	30.5	1,815.2	36.6	1,751.9	50
Exit Gas Losses	742.3	12.9	1,372.1	27.7	1,751.9	10
Evaporation of Moisture	2,226.7	38.3	300.7	6.0	225.3	7
Dust in Exit Gas	11.3	0.2	13.0	0.3	1.3	0
Clinker Discharge	56.7	1.0	61.2	1.2	65.8	2
Clinker Stack	189.9	3.3	580.8	11.8	604.0	18
Kiln Shell	667.3	11.6	606.7	12.1	175.1	5
Calcinations of Waste Dust	40.7	0.7	18.5	0.4	6.2	0
Unaccounted Losses	88.9	1.5	182.0	3.8	163.0	5
TOTAL	**5,800.8**	100	**4,954.6**	100	**3,512.5**	100

A substantial capacity increase can be obtained with pre-calciner kilns with a second combustion device between the rotary kiln and the pre-heater section. In the precalciner, up to 60% of the total fuel of the kiln system can be burnt. At an exit temperature of about 880°C, the hot meal is calcined to a degree of around 90% when entering the rotary kiln. Kiln systems with 5 or 6 stage cyclone pre-heater and pre-calciners are considered

Standard technology for new plants today, as the extra cyclone stages improve thermal efficiency [6].

CO_2 Emission and reduction measures

CO_2 emissions from cement plants originate from two sources. The first, and major, source of CO_2 emission is the de-carbonization of the raw material at high temperature:

$CaCO_3 \rightarrow CaO + CO_2$

The second source of CO_2 emissions is the combustion of carbon fuels in the kiln according to the following simplified form of chemical reaction:

$C + O_2 \rightarrow CO_2$

Reduction methods with regard to de-carbonization of the calcinaceous raw material can be:

I. By reducing the proportion of clinker in the cement mix by blending the clinker with additives such as fly ash, gypsum or slag. The use of these materials will serve to reduce carbon emissions originating from the use of lime in proportion to the amount of lime that is displaced.

II. By using alternative raw materials for clinker production that do not contain carbonates. Such as, waste ash from fuel consumption in thermal power plants, blast furnace slag.

Reduction methods with regard to emissions from the combustion of carbon fuels in the kiln can be [7]:

Fuel-switching

Alternative biomass fuels have lower energy-specific CO_2 emissions than conventional fuels. Hence, absolute carbon content does not provide the rationale for switching from coal to biomass. Rather, the critical aspect of biomass in this regard is that it can, in certain circumstances, be regarded as a *net zero-emission* fuel-source, even if CO_2 is liberated during its combustion. If biomass, or biomass residues, is/are cultivated sustainably – that is, if the rate of biomass extraction is not higher than the rate of biomass re-planting or replenishment – then the biomass is considered to be 'carbon-neutral'. The logic is that the biomass grown to replace the combusted biomass is considered to absorb CO_2 from the atmosphere while growing, thereby in effect 'cancelling out' the CO_2 emissions associated with the combustion of the cultivated biomass: the net effect on the atmospheric carbon balance is zero. Sustainably-cultivated biomass has, in effect, an emission factor of zero. It is evident, that fuel switching, particularly to carbon-neutral biomass, can significantly reduce net CO_2 emissions [5]. CO_2 emissions from the combustion of some commonly-used and alternative fuels are shown in Table 3.

Table 3. CO_2 Emissions of Commonly-Used and Alternative Fuels In the Cement Industry (Tokheim, 2007)

Fuel	Low heating value (GJ/t)	Fossil fraction	Net CO_2 emission factor (Kg/GJ)	Net emission factor
Coal	29.3	100%	96	2.8
Petcoke	33.9	100%	92.8	3.1
Waste oil	34.0	100%	74	2.5
Plastic	37.7	100%	75	2.8
Solid hazardous waste	14.9	100%	74	1.1
Liquid hazardous waste	15.7	100%	74	1.2
Refused derived fuels	**13.5**	**10%**	**8.7**	**0.1**
waste wood	***12.6***	***0%***	***0***	***0***
Animal meal	***16.8***	***0%***	***0***	***0***
Wood	***15.7***	***0%***	***0***	***0***

ENERGY EFFICIENCY

Net CO_2 emissions are proportional to the energy consumption of the pyroprocessing system (expressed in GJ/tonne of cement) and to the net emission factor (expressed in $kgCO_2/GJ$). Improving the efficiency of the pyroprocessing system can reduce energy consumption and hence CO_2 emissions (t_{CO2} /t) considerably. Measures to improve energy efficiency in cement production can include (Choate, 2003):

a) Lower kiln exit gas losses

- Install devices to provide better conductive heat transfer from the gases to the materials (e.g. kiln chains).
- Operate at optimal oxygen levels (control combustion air input) and optimize burner flame shape and temperature.
- Improve or add pre-heater capacity.

b) Reduce moisture absorption opportunities for raw meal and fuels (avoiding the need to evaporate adsorbed water).

c) Reduce dust in flue gases by minimizing gas turbulence. (Dust carries energy away from the kiln where it is captured in dust collectors. The dust is recycled into the raw meal and fed into the kiln where it is re-heated.)

d) Lower the clinker cooler stack temperature:

- Recycle excess cooler air.
- Reclaim cooler air by using it for drying raw materials and fuels or preheating Fuel or air.

e) Lower kiln radiation losses by using the correct mix and more energy efficient refractory to control kiln temperature zones.

f) Optimize kiln operations to avoid process disruptions and downtime.

g) Upgrade existing technology: the addition of pre-heater sections, precalcination sections or more efficient clinker coolers serves to maximize heat recovery.

h) Cogeneration: large industrial thermal energy demand offers opportunities for cogeneration of electricity and/or steam production, particularly if the cogeneration system is part of the initial plant design [9].

POTENTIAL SOURCE OF BIOMASS

Coffee husk

Coffee is a major commodity export-earner for Ethiopia, accounting for 61% (by value) of the country's annual commodity exports. It is estimated that the total area covered by coffee is approximately 400,000 hectares, with a total production of 200,000 tonnes of clean coffee per year (Gemechu, 2009). Parallel to this the residue is very huge [3].

Cotton residue

State farm plantations, mostly concentrated in the Awash River Basin, metema, humera dominate cotton production in Ethiopia. At present, the residues are not utilized but are burnt in the field to control pathogen and insect infestation of the following crops and are then ploughed under. Based on studies conducted by the Ethiopian Rural Energy Development & Promotion Centre (EREDPC, 2000), the total volume of residues from cotton plantations (state farms) is estimated to be 89,000 tonnes per year [5].

Saw dust

Residues generated in sawmills located in remote areas of the country have insignificant economic value and are usually dumped or piled up and allowed to rot. According to this survey, the average annual log (wood) processed in these mills varies from as little as 1,000 m^3 to a high of 3,500 m^3/year. Some of the sawmills located in remote areas (away from large towns) might nonetheless be of interest as these mills have already piled up a considerable amount of residue for lack of alternative uses [8, 10].

Jatropha

The Jatropha plant is widely distributed in Ethiopia, existing in many low-lying areas of the country. Large volumes of residue are expected to be available from the biofuel processing industry over the coming years. The husk (outer cover) of the Jatropha seed has high fibre content and has potential use as fuel – in briquette form – in the same way as coffee husks. The Ethiopian Government is promoting Jatropha as an alternative fuel source to help reduce the country's dependence on costly imported fossil fuel. Increasing the bio-diesel blend will require processing of more Jatropha seeds, resulting in a corresponding increase in the volume of waste that can be tapped for biomass briquetting. Promoting production and use of briquettes in this way will help people realise profit from Jatropha waste .If the husk is used properly, this represents a significant energy source. But it can also pose serious disposal and environmental problems if it is not [8].

BIOMASS USES AS ENERGY IN CEMENT INDUSTRY

Direct combustion in pre-heaters, pre-calciners and kilns

The technical implications of using biomass in the pyroprocessing system of cement plants are challenging. Biomass fuels have to be cleaned, prepared, dried and homogenized to have uniform heating value. Biomass fuels prepared in pieces of up to 150 mm diameter or in pellet or in briquette form can be directly burned in combustion chambers arranged between pre-heaters / pre-calciners and the kiln [10].

Modification of the kiln and the pre-heaters / pre-calciners, particularly the combustion chamber, is mostly necessary to be able to use biomass fuels in the pyroprocessing system. Fuel preparation and cleaning units have to be designed and integrated into the plant. Biomass can be utilized in pulverized or in lump solid form. The fuel-feed system and plant modification have to be designed according to the form of solid biomass [10].

Gasification

Gasification is a process of converting carbonaceous materials by partial oxidation into gaseous fuels (producer gas) of low heating value, containing carbon monoxide, hydrogen, methane and traces of higher hydrocarbons such as ethane (Cioni *et al*,2002).

All biomass fuels can be converted into producer gas for use in cement plants.

Producer gas can be co-fired with fuel oil (furnace oil) in the rotary kilns. Existing plants have to be modified by adding a gasification reactor and a gas injection and firing system into the kiln. The most utilized gasification technology for industrial-scale applications is the fluidized bed gasifier. Fluidized bed technology offers the following benefits [9]:

- Relatively simple construction and operation
- Tolerance to different particle size, feedstock heating value and composition
- High carbon conversion and good quality of raw gas produced (low tar)
- Good temperature control and high reaction rate
- Feasibility of retrofitting in existing plants

The high thermal capacity due to the inert bed and the high mass transfer rate due to the good mixing of the solid phase leads to carbon conversion approaching 100% within the bed [6].

As the most feasible option for its specific technical requirements, the plant should be installed a fluidized bed gasification reactor between the raw mill and the kiln. This made it possible to convert a variety of residues, such as those containing carbon with high mineral proportions and fuels with high or low heating values, into producer gas. The gas is fed without any treatment to the calciners of the cement kiln where two-thirds of the total fuel demand of the kiln plant is supplied. As secondary fuel, shredded used wood and light recycling materials are principally used. The burnt out ash is conveyed through an ash cooler into the raw mill, where it is accurately metered into the raw mill as a feed component. By using a fluidized bed, it is possible to completely convert waste into a resource material for cement production, in the form of both energy and as feed material [6, 9, 10].

CONCLUSION AND RECOMMENDATION

Fuel switching, from conventional fossil fuels to biomass, is a feasible and attractive option for Ethiopian cement plants. Biomass fuel switching of even 20% can be financially rewarding, with the financial benefits accruing from the reduced cost of fuel and the revenue from the clean development mechanism.

Biomass fuel switching in the cement industry, in addition to the financial revenues flowing to the cement factories, has nationwide benefits such as:

- Reduced foreign exchange requirements
- The creation of considerable job opportunities in biomass fuel development, preparation and transportation.
- Degen Cement has a unique opportunity to switch to biomass fuels, especially in the third line where pre-calciners will be added. Similarly, most new cement factories have ample opportunity to incorporate into their design pre-calciners fitted with special combustion chambers for biomass fuel utilization.

Cement plants in Ethiopia have to consider the option of utilizing biomass fuels and thereby replacing some portion of the fossil fuels they are currently using.

Cement factories need to study what types of biomass fuels are available in their locality and what can effectively be utilized in the short term and in the longer term. They must consider plant modification requirements and the option of developing new dedicated energy plantations (possibly in old quarries or other disused land) so that they can supply themselves with a considerable portion of their biomass fuel requirement.

Cement factory especially, which faces the possibility of switching to biomass fuel in the first two production lines and particularly in the new third line, should pursue a biomass fuel-switch policy. Similarly, all upcoming cement factories should consider in their design a flexible fuel use so that they can exercise the option of using biomass in greater proportions.

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Tadele Assefa Aragaw. Cement Manufacturing and Use of Biomass Energy: energy option for Greenhouse Gas Reduction. Res. J. Chem. Env. Sci. Vol 4 [3] June 2016. 01-07

