Earth Science & Climatic Change

Hoveidi et al., J Earth Sci Clim Change 2013, 4:4
http://dx.doi.org/10.4172/2157-7617.1000147

Research Article Open Access

Appropriate Measures to Reduce Greenhouse Gases' Emissions from Iran's Cement Industry

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Abstract

Cement industries are among the major industries in the production of greenhouse gases. The large amount of such gases released is due to two reasons: First, cement production and second, the high amount of energy consumption. The released CO_2 is the most important source of non-energy industrial processes. Globally, cement production holds 2.4% of the total CO_2 released in industrial sectors. Carbon dioxide is released during clinker production and by its intermediate products. In the energy section as well, the fuel mostly used by cement factories is Mazut and natural gas, also used as an alternative fuel. Right now there are 54 active cement factories in Iran and regarding the increasing demand for cement in the country, the number of such factories is increasing. Therefore, the necessity of studies like the current one is totally justified. Results show that the amount of CO_2 released in cement production (calcination), is much more than its amount released due to consumption of energy in thermal and electric forms. As a result, corrective measurements for reducing the amount of CO_2 released during cement production can be effective. The amount of CO_2 released in cement production is 830 kg per each ton of cement production. Considering the important role of cement and the general approach of Iran's increasing cement production capacity, environmental issues related to this industry must be studied.

Keywords: Cement; Greenhouses gases; Energy optimization

Introduction

Since the Industrial revolution in the early nineteenth century and the consequent increase in human need for energy and consumption of various fossil fuels such as coal, oil and natural gas, certain gases such as carbon dioxide, Methane, Nitrogen oxides, carbon monoxide and destructive substances have risen in the ozone layer.

The necessity to decrease greenhouse gases, and preventing climate change, has made International Institutions to conclude the climate change convention and Kyoto protocol in 1997 to make countries to reduce greenhouse gases [1]. Beside the obligations that the convention and protocol has determined for the member countries, specially developed countries, opportunities and resources under the title of Clean Development Methods (CDM) have been considered to help developing countries in their programs to decrease greenhouse gas release (IPCC, 2001; IPCC, 2000).

Release of greenhouse gases by developing countries has increased in a way that may even go beyond the amount released by developed countries between 2010 and 2020 (IPCC, 2001; IPIECA, 1991).

Protecting the environment against various pollutants is so important that up to now several International and regional contracts have been made; by legislating essential n acts, especially in Europe in the past 20 Years the amount of energy consumption for producing one ton of cement has decreased up to 80%, which subsequently, decreases the pollutants [2,3]. Among various greenhouse gases including vapor (H_2O), Carbon dioxide (CO_2), Methane (CH_4), Nitrogen Oxide (N_2O), and Halo carbons (HFCS, PFCS), in cement production only the amount of CO_2 produced is considerable; in a way that nowadays, cement and steel industries have been considered as the main sources of CO_2 release worldwide (IPCC, 2001).

Cement industry is one of the subcategories of non-metallic mineral Industrial. Among industrial products, cement has the greatest amount and its production record goes back to 75 years ago. The relative advantages of this product are: rich mines with appropriate scattering in all major parts of Iran, the case in access to cheap energy, geographic location and Iran's access to open waters. Furthermore, free markets in the region and the educated and professional human resource have encouraged the government to invest in this industry and thus have resulted in the increase of this product.

Despite the fact that its demand in the year 1400 has been predicted at least 75 million tons, regarding the growth rate of about 7% and population growth (to about 90 million) and the necessity to invest in the mentioned industry to cover the civil demands of the country, Cement industry is an energy consuming industry. It alone consumes about 3.5-4% of the total electrical energy produced in the country, and around 40% of cement cost is devoted to energy. On the other hand, cement industry has been recognized as a threat to environment as it produces and releases pollutants and greenhouse gases such as NOx, CO_2, SO_2 … and causes heavy social costs in terms of compensating the damages imposed. Obviously, under such circumstances one of the main concerns of the cement industry would be the environment and its conservation. The major important greenhouses gases comprise CO_2, CH_4, and N_2O, while the first two are carbonated gases and have the most greenhouse effects. CO_2 is the most abundant gas in the atmosphere, that its concentration has increased to 360 ppm after the Industrial revolution and it's growth rate is about 1.5 ppm per year, so it's concentration has soared to about 30% (IPCC, 2000). The major increase in the atmospheric CO_2 started in the 1850s. Fossil fuel combustion and changes in the land usage are among the two main human factors to increase greenhouse gases [1].

CO_2 released from cement industries is related to fossil fuel

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Received June 17, 2013; **Accepted** July 12, 2013; **Published** July 17, 2013

Citation: Hoveidi H, Pazoki M, Hadizadeh H, Nasri A (2013) Appropriate Measures to Reduce Greenhouse Gases` Emissions from Iran's Cement Industry. J Earth Sci Clim Change 4: 147. doi:10.4172/2157-7617.1000147

combustion and limestone calcination process being mixed in raw materials. About half of CO_2 produced, is from the fuel and half rest is from raw material conversions to Clinker. The total amount of CO_2 produced in the production process mainly depends on the type of process and the fuel type (Thermal – Electrical). The amount of CO_2 released from Portland process is mainly from two mechanisms. Fuel combustion to bake cement releases a great deal of carbon dioxide. In addition, a large quantity of (SO_2) is released from limestone calcinations on other phenomena. In calcinations process, calcium carbonate is analyzed to calcium oxide and carbon dioxide through heat.

Normally, Portland cement includes 68.5 percent of calcium oxide (CaO). Therefore 1.135 units of calcium carbonate is needed to produce one ton of cement and the amount of carbon dioxide released in the thermal process depends on the amount of energy consumed which is usually about 0.85-1.35 Ton (SO_2) per each ton of clinker [4].

Beside (SO_2) released, Fuel combustion in Portland cement unit released a wide spectrum of other pollutants in low values and amounts. If the combustion reactions are not accomplished, CO and organic volatile pollutant, generally called TOCs, are also released.

Materials and Methods

In making cement, CO_2 is released while clinker is being produced. Clinker is an intermediate product, that finally is made into powder mixed with calcium sulfate ($CaSO_4$. $2H_2O$) or anhydrous gypsum ($CaSO_4$) which exist in Hydraulic cements (especially Portland cement). During clinker production, limestone which is mainly made of $CaCO_3$ (Calcium carbonate), is calcinated so that time (CaO) and CO_2 are produced as intervals , then later CaO interacts with silicate (SiO_2), Aluminates (Al_2O_3) and ferrous oxide Fe_2O_3 which exist in base materials to produce clinker minerals (specially calcium silicates). Carbonates percentage is very low in raw materials except $CaCO_3$ [5].

In this research, firstly the information from cement industry is collected. These information include the number of industrial factories, and their situation in the existing technology, fuel type, main processes, the amount and type of products, the construction year and other information. The assumption of CO_2 released from cement production process is done through Emission Factor (EF) which is the amount of CO_2 released per each ton of clinker.

Results

Greenhouse gases emission in cement industry

Cement and steel have been considered as the major and main sources of CO_2 globally (IPCC, 2001). In this research the amount of SO_2 during cement production has been estimated. Greenhouse gases in cement production process are released in two separate sections:

1) Cement production process

2) Energy consumption (in two different forms of thermal and electrical)

The CO_2 released during cement production process is the most important non-energy source for CO_2 compared with fuel combustion. Carbon dioxide is produced during clinker production process and interval cement products. The high temperature in cement furnaces turns the raw materials into clinker chemically specially , $CaCO_3$ existing in limestone , gypsum or other materials enriched with calcium is heated and changes into live (calcium oxide) CaO and CO_2 in a process called calcination.

$$CaCO_3 + \text{heat} \rightarrow CaO + CO_2 \quad (1)$$

The important point is that when the concrete is being formed, some CO_2 is absorbed by it from the air, the amount of which is very low compared to the amount released form cement production (Liu et al., 1995). The major cement produced in the world is in port land type which consists of 60-67% lime where as other types of cement have less time. Taking into consideration that the CO_2 released from cement production directly returns to time, there is current research being carried out on cement formulation, for which less time is used to produce. Because CO_2 is released when clinker is produced, emission estimation should be based on lime content and clinker produced. Also in the energy section the major fuel used by Iran's cement factory is Mazut , which through certain procedures this fuel is being replaced by Natural gas , and the country factories mainly use two types of fuels. The amount of greenhouse gases emission by fuel consumption in cement factories is noticeable, since cement industry in an energy consuming industry in Iran (Report of domestic cement industry, 2006).

CO_2 produced in calcination process

CO_2 estimation through cement production is done by Emission factor (EF) which is the amount of CO_2 released per each ton of clinker produced. According to formula and table presented, the amount of CO_2 produced per each ton calcination of $CaCO_3$ in IPCC Guidelines for National greenhouse gas inventories (2006), is about 0.43971. The following formula which is presented in IPCC guidelines for National Greenhouse gases was used for further computations:

$$CaCO_3 \rightarrow CaO + CO_2 \quad (2)$$

100% 56.03% + 43.97%

EF Clinker = fraction CaO* (43.97 g/mol CO_2/56.03 g/mol CaO).

Assuming 0.65 ton of CaO to be present in one ton of clinker which is an acceptable global assumption, the amount of CO_2 produced per each ton of clinker can be measured by the following method (Table 1).

CO_2 produced per one ton of clinker EF = 0.51. Considering the amount of calculated EF and also the amount of clinker produced in the year 2008 that was about 44400000 tons. The amount of CO_2 produced through calcination process per total cement produced in the year 2008 equals 22644000 tons.

CO_2 Emission = EF Clinker * clinker production

The amount of clinker produced (ton): $44400000 \times 0.51 = 22644000$

CO_2 produced in electrical section

In cement factories, the index for specific energy consumption is defined based on Kwh/ton cement. According to the information collected from various factories by Iran's energy efficiency department, the average index in electrical sections of cement factories in the year 2003 had been 112 $kwh/_{ton}$ cement, while the global electrical average index is 80 kwh/ton cement. Considering the conversion tables of energy balance sheet in the year 2006 , and the cement production estimation in the year 2008 , which is about 44456000 tons , and also with considering the emission factor of CO_2 , per fuel consumption the

x	1	Ton $CaCO_3$
0.56	0.56	Cao%
1.1601	1	Ton $CaCO_3$
EF	0.4397	CO_2 ton

Table 1: Typical calculation of the amount of CO_2 produced per each ton of clinke.

amount of CO_2 produced as a result of energy consumption to produce cement equals 4979072000 tons .

CO_2 Emission = EF Clinker* clinker production

The amount of clinker produced (ton) 44400000 × 0.51 = 22644000

44456000 × 112 = 4979072000

As a result, the emission rate index is 0.57 which means per each Kwh/$_h$ of electricity consumption, 0.57 Kg of CO_2 is being produced. Therefore the amount of CO_2 released by using electricity in the cement factories (4979072000 Kwh) is about 2838071.04 tons (in the year 2008).

CO_2 produced in thermal section

According to the latest estimation of the Iranian Ministry of Industries and Mines (2008), the amount of clinker production is about 44400000 Tons. Considering the thermal heat consumption index (900 kcal/kg of clinker) which has been announced by Iran's energy efficiency and the conversion coefficients existing in the energy balance sheet in the year 2006, the amount of CO_2 production in the thermal section is about 11582424.7 ton. It should be pointed out that international average of such index, in the thermal section is 650 kcal/kg of clinker.

The total amount of CO_2 released from cement production process in the year 2008, regarding the production statistics and in two forms of thermal and electrical energy consumption has been 37064495.7 tons (Table 2). Thus it can be concluded that, per each ton of cement being produced, about 830 kgs of CO_2 is released. This figure in the world is 0.65 to 0.92 tons per each ton of cement.

Estimation of released SO_2

A great portion of SO_2 released in the process, is absorbed during alkaline clinker production. Fuel emissions are considered as energy section emissions, whereas SO_2 released from clay should be measured as non-combustive emissions.

The emission factor will be variable depending on sulfur percentage in raw materials and the absorption degree. But according to PCC guideline, in case of lack of information about sulfur contents and absorption degree, non – combustive emission factor equivalent to 0.3 kg/SO_2/t cement, is recommended.

Considering this figure and the amount of cement produced in year 1387 equals 44456000 tons and the amount of SO_2 released will be 13336800 kg (Table 3).

Discussion

As the results show, the amount of CO_2 released in cement production process (calcination) is much more than its amount released from electrical or thermal energy consumption. 61%, 31.2% and 7.6% of CO_2 emission is respectively due to cement production process, thermal section and electrical energy (Table 4).

As a result, mitigation measures to reduce the amount of CO_2 produced in cement production process can be very effective. In the following paper corrective strategies have been recommended. In this regard, energy consumption is also under corrective functions done by fuel optimization organization and other relative organs which will be further discussed.

Cement is one of the most important sections in producing carbon dioxide which has major environmental impacts on ecosystem [6]. On the other hand energy consumption in cement industry has played an important role in environmental pollutions since it first consumes a large amount of energy and second due to its transportation as a major good in Iran. Increase in energy efficiency is an economical option to decrease greenhouse gases with a potential of about 31% in the year 2020. Optimization of energy carriers such as utilization of more natural gas can lower the emission of greenhouse gases.

Another noticeable result of this research was that, regarding the amount of CO_2 measured for one ton of cement which is about 830 kg, the amount of CO_2 has been measured according to previous years which have been shown in Tables 2-4. Table 5 shows an escalating amount of greenhouse gases related to cement production. Regarding the importance of cement and Iran's general feature to increase the cement production capacity, observing the emission of greenhouse gases will be very important and will be taken under consideration more and more.

Taking into consideration that in the year 2008 the total amount of greenhouse gases in Iran had been 500 million tons, it can be conclude that cement industries has a share of about 7.4 percent of total greenhouse gases released in Iran. Since the industrial section of the country has produced about 187 million tons of greenhouse gases in 2008, so cement industries' share among other industries is about %18.6.

Saving potentials in cement industry

Regarding the international and economical criteria, cement saving potential in electrical part is about 41 million dollars per year and in thermal section about 59 million dollars per year that sums up to US$ 100 million a year. If one considers 80 liters of Mazut consumption per

Tons of CO_2 produced In calcination process	*Tons of CO_2 produced By using electricity*	*Tons of CO_2 produced By using thermal energy*	*Total*
22644000	2838071.04	11582424.7	37064495.74

Table 2: Total tons of CO_2 produced per cement production in Iran in 2008.

Emission Factor of SO_2		*Tons of cement product*		*The amount of SO 2 released (kg)*
0.3	×	44456000	=	13336800

Table 3: Calculation of the amount of released SO_2.

Parameter	*The amount of CO_2 production (ton)*	*CO_2 production percentage*
Cement production process calcination	22644000	61%
Thermal energy consumption	11582424.7	31.2%
Electrical energy consumption	2838071	**7.6%**

Table 4: The amount and percentage of CO_2 production in different sections of cement industry.

CO_2 production (million Tons)	*Cement production (million Tons)*	*Year*
19.95	26.6	2001
21.34	28.45	2002
22.33	29.78	2003
24	32	2004
24.49	32.65	2005
26.47	35.3	2006
30.21	40	2007
37.06	44	2008

Table 5: The amount of cement and CO_2 production in previous years in Iran.

each ton of clinker and 80 Kwh per one ton cement as a base, in such conditions, we can reach a 30% of electric saving and 20% of thermal potential saving in cement industry. This calculation leads up to US$ 100 million dollars. Through such great saving one can build up a cement factory with a capacity of a million ton per year. The following factors influence the specific consumption in cement production;

- Factory capacity and capability of using higher potentials.
- Process type.
- Quality and fuel type.
- Raw material quality and the designing type of raw materials.
- Transferring system type.
- Encouraging workers by compromising them with shown and other benefits of energy saving.
- System maintenance.

For example to increase the production capacity non – energy related share can be decreased. The new technology is to reduce energy consumption and to recycle more energy.

The mechanical air comment material transferring systems are better at energy consumption since they interrupt the extra air volume in systems and baking system vacuums [7,8]. Energy saving strategies in raw material will is replacing roller mills with ball mills which reduce energy consumption up to 30%., or using roller process reduces energy saving up to 10% to 30% . By using high efficiency separators electrical energy can be saved up to 8 percent.

In cement raw material mills and by stopping accessory devices in case of mill stopping if it isn't an inter luck , their energy consumption will be more than interlock type and once the mill stops all accessory devices will as well stop.

Saving strategies in raw materials mill

- Adjusting aggregation mill feed on a desire range.
- Regular shot charge control.
- Controlling material's humidity during wet seasons.
- Using high efficiency separators.
- Appropriate duct insulation which carry hot gas to the mill to supply thermal energy for ripping the materials.
- Pre-installed chopper to increase the Capacity and decrease the specific Consumption.
- Replacing roller mills with ball mills.

Energy consumption saving strategies in cooling and baking systems

Using alterative turning drives to control the amount of air, instead of using dampers , will reduce the energy up to 60% to change wet process to dry one, 25 kcal of thermal energy will be saved. Installing emersion tube (which is a new device to exchange gas and dust) in pre-heater systems will help dusting process efficiency and its heating exchange in packing system and thus saves energy. Cement superior energy consumption is shown in Table 6.

Energy saving strategies in the furnace section

- Controlling the uniformity of physical and chemical composition of furnace feed.
- Complete classification of cooking system.
- Using variable rate control system instead of mechanical transmission Dampers (elevator) to control the amount of air.
- Using low pressure drop cycles.
- Controlling the additional amount of air to improve combustion efficiency and increase the baking region temperature.
- Using melting catalysts to decrease two baking temperature.
- Converting the wet process to dry process by using per-calciner adding pre-calciner and pre-heater tries by using ducts.
- Floating the silicones by using new designs.
- Optimizing cooling performance.

Strategies for saving energy in cement mill

In the mill section of cement factory, electrical energy is used.

- Continuous control of short circuits.
- Continuous control of uniformity and clinker aggregation.
- Converting the open circuit system to close circuit system.
- Producing blended cements and using additive materials.
- Using high efficiency separators.
- Using pre – wearing machineries.
- By using roller presses we can double the capacity of the system.

Use of new (modern) Technologies

- Using alternative fuels to reduce energy costs.
- Using high efficiency equipments.
- Using variable rate drives instead of dampers and valves in wells and pumps.
- using pre – aggregating systems before raw material and cement mill.

Specific thermal energy (kcal/K clinker	*Specific Electrical energy(Kwh/$_{ton}$ cement)*	*Pre-calciner*	*Pre-heater*	*Raw materials & cement mill*	*Process type*
715 - 730	80-85	Includes	5 storey	Roller	Dry
700-715	80-85	Includes	6 storey	Roller	Dry

Table 6: Cement superior energy consumption.

- Using vertical roller mills with roller press for the final rubbing.
- Using new pipe designs which float in silicones to reduce pressure drop and increase the efficiency of thermal exchange and separation.
- Using high efficiency torches.
- Using high efficiency coolers.
- Producing electrical energy by recycling external (output) heat from the pre-heater and dryer.
- Using oxygen injection technology in cement furnaces [9].

The technology process is followed by energy consumption, selecting machineries wit optimized capacity is important. The latest technology used by the dry system is roller mill the number of the plates for silicon pre-heater should be 5-6 and owns a pre-calciner system. In this situation we can reduce about 80-85 Kwh/h ton of specific electrical energy and also about 700-715 kcal/kg of specific thermal energy.

Considering the above mentioned factors, it can be suggested that cement industries should use new and modern technologies. Several energy saving strategies in different levels have been proposed in similar studies all around the world [10-15] which indicate the necessity of implementing such instructions.

The Government of Iran should provide more financial help through Note 13. Since Iran has joined climate change convention it will be suitable to compute the greenhouse gases from different sectors for allocation of carbon quota [16-21] Exchange of such quota amongst industries can lead to more energy efficiency measures. Such measure will eventually reduce the local air pollutants. It is recommended that all cement industries in Iran participate in the CDM (Clean Development Mechanism).

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Citation: Hoveidi H, Pazoki M, Hadizadeh H, Nasri A (2013) Appropriate Measures to Reduce Greenhouse Gases` Emissions from Iran's Cement Industry. J Earth Sci Clim Change 4: 147. doi:10.4172/2157-7617.1000147