CSCanada
Energy Science and Technology
Vol. 4, No. 1, 2012, pp. 10-18
DOI:10.3968/j.est.1923847920120401.356

ISSN 1923-8460[PRINT]
ISSN 1923-8479[ONLINE]
www.cscanada.net
www.cscanada.org

Overview of Process Modeling Software: Utilizing Alternative Fuels in Cement Plant for Air Pollution Reduction

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Received 9 April 2012; accepted 27 August 2012

Abstract

The use of process systems engineering tools, such as process modeling software enable the alternative generation of more efficient and sustainable processes. This paper presents the simulation of cement process using alternative fuels to replace coal. The process modeling is performed using Aspen HYSYS. Simulation results revealed that the substitution of fuel oil, natural gas and palm kernel shell for coal had a significant contribution for emission reduction in cement industry. The emissions for the base case scenario found to be 40,317 kg/h CO_2, 806 kg/h NO_2 and 146.8 kg/h SO_2. Utilizing fuel oil mitigated 22% of CO_2 and 92% of NO_2 but increased 232% of SO_2 emissions. Altering coal to palm kernel shell resulted in 46.16% of CO_2, 73% of NO_2 and 68% of SO_2 emission reduction. In the best case 45.64 % reduction of CO_2 emissions was achieved by replacing coal to natural gas and neither NO_2 nor SO_2 was generated.

Key words: Cement plant; Process simulation; Aspen HYSYS; Alternative fuels; Air pollution reduction

Benhelal, E., & Rafiei, A. (2012). Overview of Process Modeling Software: Utilizing Alternative Fuels in Cement Plant for Air Pollution Reduction. *Energy Science and Technology*, *4*(1), 10-18. Available from: URL: http://www.cscanada.net/index.php/est/article/view/10.3968/j.est.1923847920120401.356
DOI: http://dx.doi.org/10.3968/j.est.1923847920120401.356

INTRODUCTION

In the recent years, efficient and sustainable use of fossil fuels and renewable energy has attracted much attention worldwide. It is mainly due to high energy costs dictated by oil prices and the strong environmental concerns associated with carbon dioxide (CO_2) emissions. The use of process systems engineering tools, such as process modeling i.e., (1) Aspen HYSYS; (2) CHEMCAD; (3) GAMS; (4) gPROMS; (5) HEXTRAN; (6) Open Modelica; (7) PNS Solutions and S-Graph Studio; (8) PRO/II; (9) SPRINT, STAR, WORK and WATER; (10) Super Target and (11) UniSim Design, enable the alternative generation of more efficient and sustainable processes. Software tools have been widely used for process simulation, integration and optimization, which help process industry companies to achieve their operational excellence goals. The main functions of process software are to:

(1) Model process plant, which is especially important in modeling systems that do not yet exist;
(2) Design or retrofit complex process facilities;
(3) Determine the overall effects of potential process changes in one area;
(4) Predict capital cost expenditures;
(5) Track/predict emissions; and
(6) Evaluate optimization and integration options.

This paper evaluates the emission reduction particularly CO_2 for cement manufacturing process that used fuel oil, natural gas and palm kernel shell to replace coal. Carbon dioxide is one of the most important and abundant air pollutant components having the highest contribution in global warming phenomenon. Concentration of this gas in atmosphere during preindustrial time was about 290 part per million (ppm). However due to extension of industrial activities this concentration was rapidly increased and in May 2011 reached to 394.35 ppm (Scripps CO_2 Program UCSD, 2011). Among industries, cement plant is considered as one of the most air pollution emitter processes. Regarding to the latest ranking of industrial sources of CO_2 emission in US, cement industry is the second largest source, emitting almost 41.1 Tg CO_2 Eq (Teragrams of CO_2 equivalent) in 2008 (U.S.A, Environmental Protection Agency, 2010).

This large amount of carbon dioxide has been released from four main sources including:

(1) Fossil fuel combustion which emits 40% of total emission;
(2) Raw material and cement transportation produce 5% of emission;
(3) Electricity generation contributes 5% of total emission; and
(4) Decomposition of limestone that generates almost 50% of emission (Nazmul, 2005).

In typical cement process, more emission has been released due to:

(1) Utilizing high carbon, nitrogen and sulphur content fuels;
(2) Energy losses through exhaust gas streams;
(3) Heat losses through facilities, instruments and unit operations;
(4) Employing non-efficient processes such as wet or semi wet.

Numerous studies have been conducted on alternative fuel utilization in cement plant.

Prisciandaro *et al*. (2003) employed statistical methods such as Statistical Student's t-tests, stepwise linear regression models and factor analysis to analyze experimental results of replacing alternative fuels with conventional fuel in two different cement plants in Italy. Results indicated that if less than 20% of regular fuel was replaced with tire, stack emissions (NO_x, SO_2 and CO mainly) would be slightly increased, but remaining almost always below the law imposed limit. However, for the case of waste oils, significant emissions reduction was achieved.

Gabel and Tillman (2005) considered nine different scenarios of utilizing recovered materials and alternative fuels. Simulations results showed that emissions of CO_2, NO_x, SO_2, CO, VOC, CH_4 and dust could be mitigated up to 80% depend on the type of recovered materials and alternative fuels.

Pipilikaki *et al*. (2005) investigated practicality and advantages of using tire derived fuel (TDF) as supplemental alternative fuel in cement plant. Quality measurements were carried out using different qualitative analytical techniques such as X-ray diffraction (XRD), X-ray fluorescence (XRF) and optical microscopy in two series of raw mill, clinker and fuel samples with and without using TDF. In this study TDF was replaced by 6% of current fuel and it was found that there was no apparent problem in result of utilizing TDF as supplemental fuel in the clinker burning.

Zabaniotou & Theofilou (2008) explored the utilization of municipal sewage sludge as a partial alternative fuel at a cement plant in Cyprus in order to consume unused wastes (traditionally considered an environmental problem) as renewable fuel not to only produce energy, but to reduce pollutants emissions as well. In this work environmental gaseous emission with emphasis on heavy metal concentrations especially mercury (Hg) were measured and it was indicated that concentration of heavy metal in gas amounted to 16 % of the allowable levels and dioxin/furans amounted to only 6% of the allowable levels. It was also estimated that economic income of utilizing 7.5% wet sludge as supplementary fuel could reach to 8.0 euro/h.

Conesa *et al*. (2008) analyzed the emission of different pollutants when typical fuel was partially substituted with tire and two types of sewage sludge. In this experimental work, six scenarios including one blank (no sewage sludge) and five different scenarios with increasing amount of sludge and/or tires were considered. In each case during 1 year, emission of Dioxins and Furans, polycyclic aromatic hydrocarbons (PAHs) and other hydrocarbons, heavy metals, HCl and HF, CO, CO_2, NO_x and other parameters of the stack were analyzed. It was found that emission of PAHs and dioxins were increased with the amount of tires fed to the kiln, probably due to the fed point used for this waste.

In this study, Aspen HYSYS software is used to simulate cement process and evaluate the air pollution reduction through fuel substitution of coal with fuel oil, natural gas and palm kernel shell.

1. CEMENT PROCESS DESCRIPTION

Cement making process as shown in Figure 1 consists of 3 major stages; raw material crushing & grinding, pyro-processing and clinker grinding & blending stage. Among all, pyro-processing (preheater, calciner, kiln and coolers) is the most important and essential stage since it consumes more than 90% of input energy and leads to more than 90% of air pollution emission in cement process (Holderbank, 1993).

As shown in Figure 1 feed stream composed of limestone and clay is entered to the preheater stage. Properties and composition of the feed stream is shown in Table 1 (Perry & Green, 1999; Boateng, 2008). Preheater stage consists of 5 separators and mixers which are used to transfer heat from the hot gas stream originated by calciner to raw materials. In this part hot gas stream coming from calciner, is counter currently mixed with feed stream and is then separated and sent to the upper mixer to supply enough energy for preheating raw materials. Feed stream then leaves the preheater when the temperature is reached to 700˚C and is then fed to the calciner chamber.

Table 1
Properties and Composition of Feed

Component	Composition in feed (%wt)	MW	Specific gravity	Heat capacity (cal/ mol K)	Heat of formation (kcal/mol)	Free energy of formation (kcal/mol)
$CaCO_3$ (aragonite)	79.14	100.09	2.93	19.68+0.0118T	-289.5	-270.8
SiO_2	15	60.06	2.32	10.87+0.0055T	-202	-190.4
Fe_2O_3	1.3	159.7	5.12	24.72+0.016T	-198.5	-179.1
Al_2O_3	4.56	101.94	4	22.08+0.0089T	-399.09	-376.87

3 main energy sources for decalcination reaction in calciner are supplied by energy released from combustion of coal, hot gas from the kiln and hot air from the coolers. In calciner, decomposition of $CaCO_3$ takes place at high temperature, around 700-900˚C (Khurana *et al*., 2002), therefore raw materials should be entered to the calciner at 700˚C and calciner's temperature should remained at 950˚C. By calcination reaction

$CaCO_3 \longrightarrow CaO + CO_2$, (1)

CaO and CO_2 are generated and then leave the calciner to be used in other parts. The solid product from calciner which composed of CaO, SiO_2, Al_2O_3 and Fe_2O_3 at 950˚C is then fed to the kiln. In the kiln, heat is supplied from combustion of coal as well as hot air stream from the cooler stage. This energy is required for several chemical and physical reactions to produce clinker in a liquid form. All reactions, temperature range, heat and the location of the reactions in simulation are tabulated in Table 2 (Kaantee *et al*., 2004; Mintus *et al*., 2006; Mujumdar & Ranade, 2006).

Table 2
Chemical and Physical Reactions in the Process

Reaction name	Reaction	Temperature range (°C)	Heat of reaction (ΔH_R)	Location
Decalcination	$CaCO_3 \longrightarrow CaO + CO_2$	700 - 900	+179.4 kj mol^{-1}	Calciner
β-C_2S formation	$2CaO + SiO_2 \longrightarrow \beta\text{-}C_2S$	900 - 1200	-127.6 kj mol^{-1}	Calciner+Kiln
C_3S formation	$\beta\text{-}C_2S + CaO \longrightarrow C_3S$	1200 - 1280	+16 kj mol^{-1}	Kiln
C_3A formation	$3CaO + Al_2O_3 \longrightarrow C_3A$	1200 - 1280	+21.8 kj mol^{-1}	Kiln
C_4AF formation	$4CaO + Al_2O_3 + Fe_2O_3 \longrightarrow C_4AF$	1200 -1280	- 41.3 kj mol^{-1}	Kiln
Liquid clinker formation	$Clinker_{Sol} \longrightarrow Clinker_{Liq}$	>1280	+ 600 kj kg^{-1} clinker	Kiln

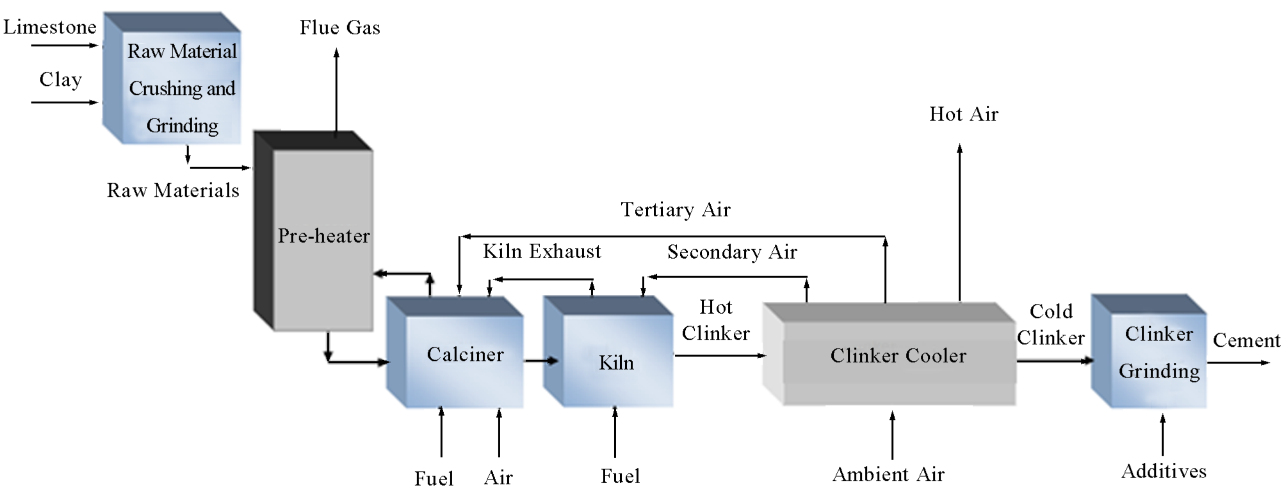

Figure 1
Cement Manufacturing Process Block Diagram

Since final required temperature for reactions as well as forming liquid and nodular clinker is 1450˚C (Kaantee *et al*., 2004), Kiln's temperature should be remained at 1500˚C. Clinker having composition and properties shown in Table 3 (Bogue, 1955; Taylor, 1990; Ghosh, 2002; Mujumdar & Ranade, 2006) in liquid form is then fed to the coolers before transfer for further processing such as grinding and blending. In cooler stage, ambient air is blown to cool down the hot clinker. Clinker cooler recovers heat from the clinker and returns the excess heat to the pyro-processing process, thus reducing fuel consumption as well as emission. Clinker leaves the coolers when the temperature dropped to 50˚C. Hot air is then sent to the kiln and calciner to provide a required energy and sufficient air for combustion. A small part of hot air at 1100˚C is also vented to the surrounding. On the other section kiln exhaust is utilized in calciner and hot gas stream produced in calciner is sent to the preheater stage to preheat raw materials and eventually is emitted to atmosphere as the major source of air pollution in the process (Kaantee *et al*., 2004; Mujumdar *et al*., 2007; Rodriguez *et al*., 2009).

Table 3
Composition and Properties of the Clinker

Components	Composition in clinker (wt%)	MW	Density (kg/m^3)	Specific heat capacity (KJ/kmol)	Heat of reaction (KJ/mol)	Components ingredients
C_2S	34.266	172.25	3300	151.7	-127.6	65.1% CaO + 34.9% SiO_2
C_3S	50.54	228.33	3150	267.9	+16	73.7% CaO + 26.3% SiO_2
C_3A	9.25	270.2	3060	260.7	+21.8	62.3% CaO + 37.7% Al_2O_3
C_4AF	5.95	485.98	3570	374.6	-41.3	46.15% CaO + 21% Al_2O_3+ 32.85 Fe_2O_3

2. PROCESS SIMULATION AND TECHNICAL CHALLENGES

In this study, all scenarios were simulated by Aspen HYSYS. Following are technical challenges faced during simulation and solutions performed in order to obtain accurate and reliable results.

2.1 Define New Components to Software Database

Since Aspen HYSYS is created to mainly simulate chemical and petrochemical processes, its solid database has various limitations. Cement process is a semi-chemical process and most of the components presented in this process are minerals which are not available in software database. However, Aspen HYSYS allows the users to create new components and add to its databank. Although new components are created by just adding two physical properties such as density and molecular weight, however accuracy of simulation results are highly depend on these hypothetical components and their properties. Therefore these components should be as accurate as possible and in order to create them variety of physical and chemical properties such as molecular weight, density, particle diameter, element analysis (for fuels), heat of formation, heat of combustion, specific heat coefficients and so on should be introduced to the software.

In current simulation various components created and required properties were added to define them. Table 1 and 3 demonstrated hypothetical components and their properties defined to the software.

2.2 Determine the Appropriate Equation of State (EOS)

Another critical stage in simulation is selection of equation of state. Since equation of state is responsible to calculate all other physical and chemical properties and also is involved in estimating transfer phenomena and chemical reactions, choosing the appropriate equation is a basic prerequisite. Using all equations of state available in software such as Kabadi Danner, Peng Robinson, Lee-Kesler Ploker, Modified Benedict Webb Rubin (MBWR), Sour PR, Peng Robin Stryjek Vera (PRSV), Soave Redlich Kwong (SRK) and Sour SRK and compare simulation results with published data indicated that except for the case of MBWR which is not incompatible with solid substances, all equations of state led to almost same results with tolerable errors.

2.3 Mixing and Separating Solid and Gas Streams in Cyclones

Preheater stage of cement process includes numbers of cyclones which are charged to firstly heat up and then separate raw materials from flue gases. Usually cyclones in industry are used to separate a mixture of solid particles and gas stream. Therefore they have one input which is mixture of gas and solid particles and two output streams which are highly pure solid stream from downside and gas stream from upside. Based on this fact in Aspen HYSYS cyclones include one input and two output streams as well. However in cement process special kind of cyclones having two input and two output streams are used to fulfill both heating and separating raw materials from hot gas stream. To solve this problem and to model cement cyclones in Aspen HYSYS a couple of one mixer and one normal cyclone was used to perform both heating (in mixer) and separating (in normal cyclone) process. Figure 2 illustrates the modeling.

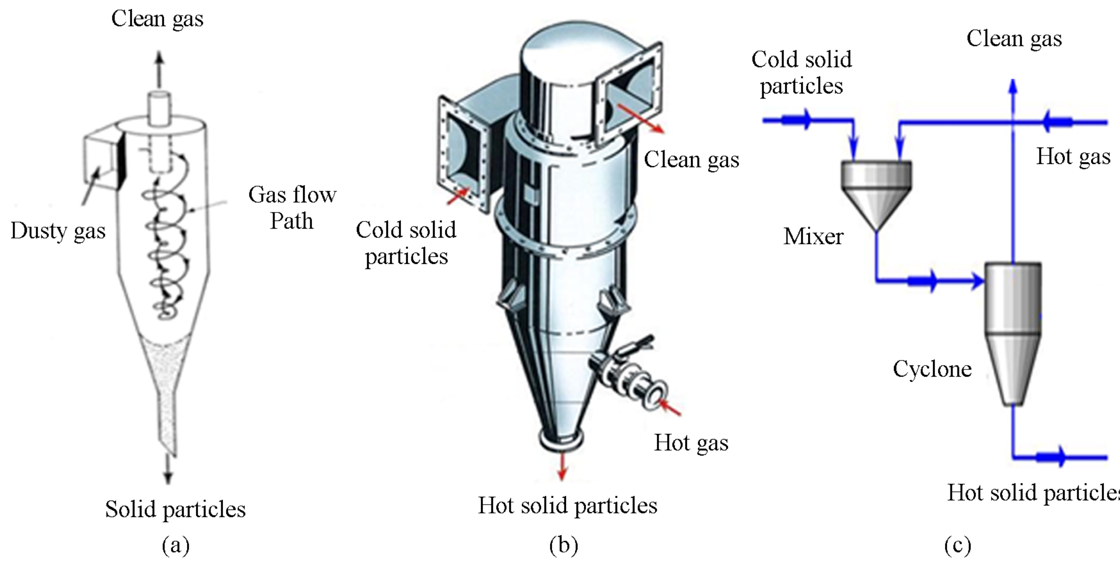

Figure 2
Normal Cyclone (a), Cement Process Cyclone (b) Cement Cyclone Model in Aspen HYSYS (c)

2.4 Estimate Conversion Rate of Chemical Reactions

According to published data of raw material and clinker's composition, chemical reactions leading to produce clinker should be controlled accordingly. In simulation it is essential to put correct conversion rate of different reactions. These conversion rates are estimated using mass balance on different reactions by considering feed flow rate and composition, clinker composition and flow rate and stochiometry of reactions. Table 4 summarizes the results of these calculations.

2.5 Other Assumptions

In addition to these calculations and techniques in order to simplify process simulation and ignore irrelevant items following assumptions have been also considered in simulation.

(1) Process is operated in atmospheric pressure and pressure drop is considered to be negligible.
(2) Heat losses through instruments, facilities and piping system are not taken into account.
(3) Both calciner and the kiln are adiabatic conversion reactors.

Table 4
Base Components and Conversion Rates Considered in Simulation

Chemical reaction	Base component*	Quantity of base component		Quantity of product		Conversion rate (%)*
		Mole	Mass (kg)	Mole	Mass (kg)	
			In Calciner			
$CaCO_3 \rightarrow CaO + CO_2$	$CaCO_3$	1,415.33	141,660.60	1,415.33	70,879.83	100
			In the Kiln			
$2CaO + SiO_2 \rightarrow \beta\text{-}C_2S$	SiO_2	447.05	26,850	447.05	77,004.36	100
$\beta\text{-}C_2S + CaO \rightarrow C_3S$	$\beta\text{-}C_2S$	263.40	45,370.65	263.40	60,142.60	58.91
$3CaO + Al_2O_3 \rightarrow C_3A$	Al_2O_3	40.74	4,153.03	40.74	11,007.50	50.88
$4CaO + Al_2O_3 + Fe_2O_3 \rightarrow C_4AF$	Fe_2O_3	14.57	2,327.00	14.57	7,080.72	100

*Conversion rate is the percentage of the base component which should be consume to produce desired amount of product

(4) Heat exchanger is used as clinker cooler.
(5) Fuels have been utilized in dry and ash free form.
(6) 3.23 GJ energy is required to produce each ton clinker (Khurana *et al*., 2002).

By considering these assumptions, pyro-processing stage of the conventional cement manufacturing process has been simulated by Aspen HYSYS to determine quantity of air pollution emission in result of producing 3000 ton/day cement (2856 ton/day clinker and 144 ton/day additives). Simulation results have been then validated by reliable published data (Khurana *et al*., 2002; Rodriguez *et al*., 2009). Eventually three different scenarios have been defined to alter process fuel from coal to fuel oil, natural gas and palm kernel shell separately in each scenario and to find the most sustainable and environmental friendly fuel.

3. ALTERNATIVE FUELS

Various alternative fuels have been used in cement plant instead of coal depend on possibility, availability and economy of process. These fuels are generally included petroleum coke, fuel oil, natural gas, industrial wastes and biomass fuels.

Following are briefly description of alternative fuels considered in this work.

3.1 Fuel Oil

Fuel oil is defined as any liquid hydrocarbon chain originated from petroleum products. It is mostly combusted to generate thermal heat in boiler or furnace or used to generate power in automobile engines. It can be either production of distillation process or a residue. In term of structure it is made of various long hydrocarbon chains, particularly alkanes, cycloalkanes and aromatics.

It is also classified in to six classes, numbered 1 to 6, according to its boiling point, composition and purpose, having boiling point from 175 to 600°C and carbon chain length from 9 to 70 atoms (Wikipedia, 2012).

Depend on (H/C) ratio, nitrate and sulphur composition and also heating value of each type of fuel oil, it can be considered as environmental friendly or environmental polluter fuel. By utilizing proper type of fuel oil having high (H/C) ratio and low nitrate and sulphur content, this type of alternative fuel can satisfy both economic and environmental concerns in cement process.

3.2 Natural Gas

Sweet natural gas is an abundant and relatively cheap source of energy available in the world. Natural gas which is composed of mainly methane is a low-carbon fuel with high hydrogen-to-carbon (H/C) ratio. It has many advantages against conventional fuels from environmental aspects and produces less pollutant when burnt. The sweet natural gas contains neither sulphur nor nitrogen-containing compounds. Therefore, emissions of SO_x and NO_x pollutants are eliminated.

3.3 Biomass Fuels and Palm Kernel Shell (PKS)

Among all alternative sources of energy, biomass fuels are becoming interesting options since they bring fascinating environmental and economic advantages, such as low greenhouse and acidic gas emissions as well as low production cost. Although burning biomass fuels produce CO_2 but it is equal to the CO_2 that was absorbed as the plants grew. On the other hand there is "no net release of CO_2" if the cycle of growth and harvest is sustained.

Numerous studies have proved that biomass fuels have significantly less impact on environment than fossil fuels. U.S Department of Energy Laboratory operated by Midwest Research Institute Biomass Power and Conventional Fossil Systems with and without CO_2 Sequestration Comparing the Energy Balance, Greenhouse Gas Emissions and Economics Study indicated that combusting biomass instead of coal resulted in 148% reduction in Global Warming Potential (Wikipedia, 2012).

In Malaysia and among all types of biomass fuels, PKS outruns the others. It is the production of palm oil mills and was usually left unused in the factory or disposed to the land-fills. However, recently many palm oil mills have installed co-generation plants to generate heat and electricity from this valuable and cheap source of energy. By utilizing PKS which previously was considered as an environmental problem, factories can achieve both environmental and economic benefits. Table 5 (Harimi *et al*., 2005; Taniguchi, 2008; Ripi, 2010) classifies all fuels and their properties considered in this study.

Table 5
Properties and Compositions of Fuels

Fuel	C %wt	O %wt	H %wt	S %wt	N %wt	Methane %mol	Ethane %mol	Heat value MJ/kg
Coal (Bituminous)	81.33	11.4	4.83	0.6	1.84	----	----	30.56
Fuel Oil	85.25	----	11.8	2.75	0.2	----	----	41.15
Natural Gas	----	----	----	----	----	95	5	51
Palm Kernel Shell (PKS)	54.12	38.5	6.55	0.22	0.61	----	----	24.52

4. RESULTS AND DISCUSSIONS

4.1 Base Case Process Simulation

In this work, process described by Mujumdar *et al.* (2007) and industrial data published in reliable literatures were taken as the base case. Simulation data was then validated and indicated that there was a very good agreement between simulation and published data. For example energy consumption in base case was 3.26 MJ/kg clinker while it was 3.23MJ/kg clinker and 3.29MJ/kg clinker in study conducted by khurana *et al.* (2002) and Rodriguez *et al.* (2009) respectively. Figure 3 demonstrates process simulation flow sheet and Table 6 shows flow rate and temperature of the main streams in conventional process.

In term of emission as shown in Table 7 and Figure 4 due to combusting coal in the process 40,317 kg/h CO_2, 806 kg/h NO_2 and 146.8 kg/h SO_2 were generated. Note that this amount of pollutants is only due to fuel combustion. Since chemical reactions (limestone decomposition and clinker making reactions) and air pollution generated by these reactions are independent of the type fuel utilized, pollution produced by these chemical reactions are not taken in account.

Table 6
Flow Rate and Temperature of the Main Streams in Conventional Process

Stream	Flow rate (kg/h)	Temperature (°C)
Feed	179,000*	50*
Calciner Feed	179,000*	700*
Fuel 1 (coal)	7,500	30*
Kiln Feed	119,000*	950*
Fuel 2 (coal)	5,205	30*
Clinker	119,000*	1500*
Cold Clinker	119,000*	50*
Ambient Air	150,120*	30*
Hot Air	150,120*	1100*
Hot Air 1	53,000	1100*
Hot Air 2	94,987	1100*
Air Vent to Env	2,132	1100*
Kiln Exhaust	57,538	1500
Hot Gas	224,200	950
Preheater	127,950	950
Flue Gas	224,200	485*

* (Engin & Ari, 2005; Kabir *et al.*, 2009; Rodriguez *et al.*, 2009; Khurana *et al.*, 2002)

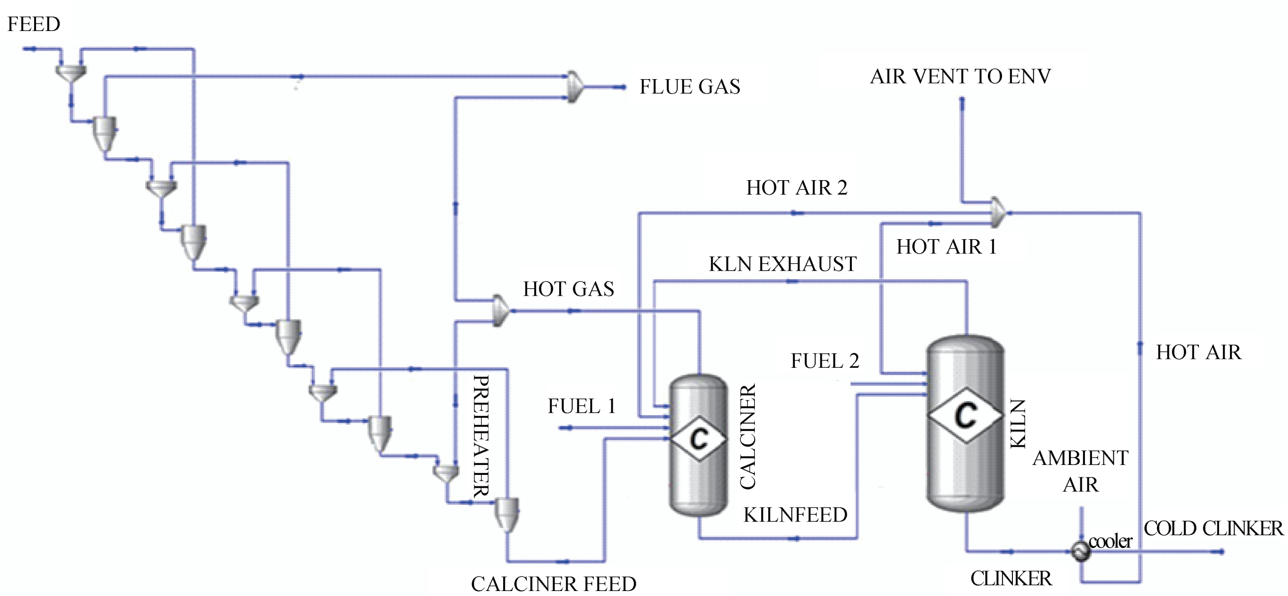

Figure 3
Conventional Cement Process Flow Sheet

4.2 Utilization of Fuel Oil

Fuel oil as representative of liquid hydrocarbon fuels was utilized in process to compare its flue gas emissions with coal. Results indicated that 31,400 kg/h CO_2, 64.7 kg/h NO_2 and 489 kg/h SO_2 were generated in result of burning fuel oil in both calciner and the kiln.

4.3 Utilization of Natural Gas

Natural gas as a low carbon content, free ash and almost free nitrate and sulphur fuel is considered as the best alternative fuel. Running process by natural gas showed that 21,915 kg/h CO_2 was produced. Furthermore since natural gas in considered to be free of nitrate and sulphur, no NO_2 and SO_2 were generated.

4.4 Utilization of Palm Kernel Shell (PKS)

Palm kernel shell was also expected to be an environmental friendly alternative fuel. Using this fuel in simulation showed that 21,705 kg/h CO_2, 217.6 kg/h NO_2 and 46.5 kg/h SO_2 were produced when palm kernel shell was burnt.

4.5 Comparing Air Pollution Emissions in Different Scenarios

As illustrated in Figure 4, coal is the worst fuel in term of CO_2 and NO_2 production. Although this chosen type of coal produces fewer amount of SO_2 as compare to fuel oil but since it produces plenty of carbon dioxide and nitrogen dioxide, it can be resulted that coal is the worst fuel among all.

The second large pollution emitter in this study is fuel oil. As it was expected and in result of heavy components which compose fuel oil, utilizing this fuel produces 31,400 kg/h CO_2. Therefore it is ranked as the second CO_2 and the first SO_2 emitter. However fuel oil is still better than coal since reduces 22% of CO_2 emission.

As far as finding the best fuel in term of low carbon dioxide production is concerned, there is a close competition between PKS and natural gas. While using PKS reduces 46.16% of carbon emission as compare to burning coal, utilizing natural gas mitigates 45.64% of this emission. Although in term of carbon emission PKS is seem to be the most promising case but by considering and taking in account emission of NO_2 and SO_2 it can be concluded that natural gas is the most environmental friendly fuel among subjected fuels.

Table 7
Quantity of Air Pollution Components due to Fuel Combustion

Fuel type \ Emission (kg/h)	CO_2	NO_2	SO_2
Coal	40,317	806	146.8
Fuel Oil	31,400	64.7	489
Natural Gas	21,915	0	0
Palm Kernel Shell (PKS)	21,705	217.6	46.5

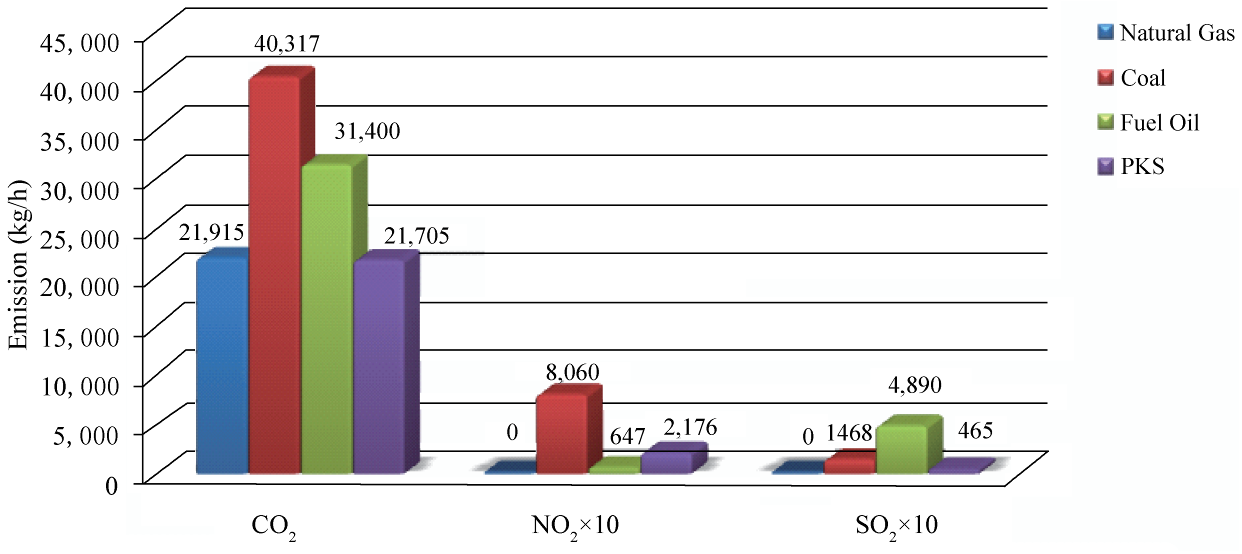

Figure 4
Air Pollution Emissions in Various Scenarios

CONCLUSION

Cement plant is considered as one of the most air pollution emitter industries in the world. The significant air pollution emission released imposes an immeasurable impact on environment if not treated properly. Although there have already been state of the art technologies available to solve the problems caused by the emissions from cement plant, however the solutions are still neither environmental nor economic satisfactory. Utilizing alternative fuels is among effective solutions in order to operate cement process environmentally clean and is a promising strategy to reduce the impact of air pollutants on both human health and environment.

In this study based on typical clinker making process described by Mujumdar *et al*. (2007) and also reliable published data, pyro-processing stage of the conventional cement manufacturing process was simulated by Aspen HYSYS. Fuel substitution scenarios by replacing coal with fuel oil, natural gas and palm kernel shell separately was carried out to evaluate the pollution reduction. Simulations results showed that fuel oil was the second largest pollution emitter after coal since produces 31,400 kg/h CO_2 and was the first SO_2 producer. It was also found that while using PKS reduced 46.16 % of CO_2, 73% of NO_2 and 68% of SO_2 emissions as compare to burning coal, utilizing natural gas mitigated 45.64 % of carbon emissions and produced neither NO_2 nor SO_2.

Therefore it is concluded that natural gas is the most environmental friendly fuel among subjected fuels which could significantly reduce emission of carbon dioxide, NO_2 and SO_2.

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