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# Techno-economical and Environmental Study of Utilizing Alternative Fuel and Waste Heat Reuse in a Cement Plant

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## Abstracts

In this work, a cement plant was simulated to estimate heat losses and pollution emission in the process. Also, a waste heat recovery system was introduced to use two main sources of heat losses, i.e. flue gas and hot air streams and produce steam and power. Moreover, the use of natural gas as an alternative to the current energy source, fuel oil, was studied in two cases, associated with and without waste heat recovery system. Results showed that 34.28% of initial energy was lost in the base case, 48% of which is from flue gas and hot vent air streams. Also, changing the fuel source from fuel oil to natural gas results in $CO_2$ emission rate to decrease from 118,693 to 115,367 kg/hr, and emission of $NO_2$ and $SO_2$ was reduced to nearly 100%. In addition to environmental benefits, economical analyses suggest the use of waste heat recovery system as well as change of fuel for this plant.

**Key words:** Cement plant; Waste heat recovery; Alternative fuel; HYSYS simulation; Air pollution reduction

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## NOMENCLATURE

| | |
|---|---|
| GHG | Greenhouse Gases |
| UNFCCC | United Nations Framework Convention on Climate Change |
| ppm | Part per million |
| Tg $CO_2$ Eq | Teragrams of $CO_2$ Equivalent |
| WHRSG | Waste Heat Recovery Steam Generator |
| VOC | Volatile Organic Compound |
| TDF | Tyre-Derived Fuel |
| XRD | X-Ray Diffraction |
| XRF | X-Ray Fluorescence |
| PAHs | Polycyclic Aromatic Hydrocarbons |
| GA | Genetic Algorithm |
| ORC | Organic Rankine Cycle |
| PCDD/Fs | Poly Chlorinated Dibenzo-p-Dioxins and Dibenzo Furans |
| $\beta$-$C_2S$ | Beta-Dicalcium Silicate |
| $C_3S$ | Tricalcium Silicate |
| $C_3A$ | Tricalcium Aluminate |
| $C_4AF$ | Tetracalcium Alumino ferrite |
| HHV | Higher Heating Value |
| MW | Molecular Weight |
| PFD | Process Flow Diagram |
| L.O.I | Loss of Ignition |

## INTRODUCTION

Since two past decades and due to dramatic increase of environmental threats, societies have pressured their governments to discuss environmental issues, and the accumulation of greenhouse gases (GHG) emissions in the atmosphere is one of these controversial debates. The Kyoto Protocol and Copenhagen Conference are two agreements made under the United Nations Framework Convention on Climate Change (UNFCCC). Under these agreements some countries committed to reduce their Greenhouse Gas (GHG) emissions to the certain levels.

Carbon dioxide as the most important and abundant gas among greenhouse gases is generated and emitted by human related activities. The concentration of this gas in the atmosphere during preindustrial time was about 290 part per million (ppm). Since the beginning of the industrial revolution and due to dramatic increase of industrial activities as well as public and individual transportation this concentration was increased and today has reached to 360 ppm and is being increased by the rate of 0.3-0.4 % per year (Nazmul, 2005).

Industrial activities due to combusting huge quantity of fossil fuels in order to generate required energy for their process are the most important factors of carbon dioxide emission in the world. In addition to carbon dioxide generated via fuel combustion, in some processes such as production of ammonia, petrochemicals, titanium dioxide and cement plenty of carbon dioxide is generated by the inherent chemical reaction during the process.

Cement production is one of the most energy intensive and carbon dioxide emitter industrial processes in the world. It contributes approximately five percent of the total $CO_2$ emitted worldwide, emitting nearly 810 kg of $CO_2$ for every 1000 kg of cement produced (Hendriks et al., 1999).

In view to the latest ranking of the most carbon dioxide emitter industrial processes in U.S, cement industry has been ranked in the second place which has emitted almost 41.1 Tg $CO_2$ Eq (teragrams of $CO_2$ equivalent) in 2008 (U.S.A, Environmental Protection Agency, 2010). This huge quantity of emission is generated through 4 major sources, including fossil fuel combustion (about 40% of the industry's emissions), transport of raw materials (about 5%), and generation of electricity consumed by the cement manufacturing operations (about 5%). The remaining cement-related emissions (about 50%) originate from the process that converts limestone to carbonate oxide (Nazmul, 2005).

In addition to intensive fuel consumption and inherent reaction, the presence of some problems in conventional plant can also indirectly increase the quantity of carbon dioxide emission in the process. These problems which can increase fuel consumption and result in $CO_2$ emission are classified as follow:

- losses of large quantity of thermal heat through flue gas and hot air streams
- heat losses through cooler stack, kiln, calciner, cyclones and ducts' shell
- utilizing high carbon content fuels as the major source of thermal energy

Therefore and in order to solve these problems and mitigate energy requirement as well as carbon dioxide emission in cement production process, it is necessary to explore, find and implement proper methods such as process optimization, heat losses reduction and using alternative fuels.

Since past decade enormous worthwhile studies have been conducted on energy saving and alternative fuel utilization in cement plant aimed to operate the process energy efficiently and environmental friendly. For example, Khurana et al. (2002) investigated heat recovery from two main sources of thermal heat losses, i.e. flue gas and hot air streams and producing steam using Waste Heat Recovery Steam Generator (WHRSG). Implementing WHRSG indicated that it was possible to save up to 10% of initial energy consumption in the process. Prisciandaro et al. (2003) analyzed the experimental results of the emission of alternative fuels replaced with conventional fuel in two different cement plants in Italy using Statistical Student's t-tests, stepwise linear regression models and factor analysis. Results indicated that if less than 20% of regular fuel is replaced with tyre, stack emissions (mainly $NO_x$, $SO_2$ and $C_O$) were slightly increased, but remaining almost always below the law imposed limits. In contrast, if waste oils were used polluted gas emissions were significantly decreased. Mokrzycki et al. (2003) studied ecological and economical features of utilizing alternative fuels made from waste, called PASi and PASr in the Lafarge Cement Polska S.A. group in Poland. They showed that combusting these fuels would result on permissible values of emissions. The results also confirmed that utilizing these alternative fuels is both environmentally-friendly and profitable to cement industry and society. Gabel & Tillman (2005) simulated nine scenarios of using 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% due to use of recovered material and alternative fuel. Rasul et al. (2005) used data obtained from industry in Indonesia to estimate heat losses through the kiln system and Cooler. Furthermore, he identified thermal energy conservation opportunities which showed that about 1.264 × 105 US dollars per year could be saved by replacing industrial diesel oil with waste heat recovery from kiln and cooler exhaust for drying of raw meal and fuel and preheating of combustion air. Engin & Ari (2005) found that 40% of initial energy was lost through hot streams (19.15%), cooler stack (5.61%) and the kiln's shell (15.11%) in a cement plant in turkey. In order to reduce heat losses and run the process in optimized form, they utilized (WHRSG) to produce steam by hot air stream, hot flue gas to preheat raw material and also secondary shell as insulation layer for the kiln to decrease thermal energy losses through kiln surface. By applying these proposals they achieved 15.6% reduction in energy losses in the process. Pipilikaki et al. (2005) investigated the possibility of using tyre-derived fuel (TDF) as supplemental alternative fuel in cement plant. Quality measurements were carried out by 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 the use of TDF. In this specific study, TDF was used as the 6% of the total fuel. It was found that there was no apparent problem associated with utilizing TDF as a supplemental fuel in the clinker burning. Zabaniotou & Theofilou (2008) studied possibility of utilization 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 that not only produces energy, but reduces pollutants emissions as well. In their work, environmental gaseous emission with emphasis on heavy metal concentrations, specially mercury (Hg) were measured. They reported that heavy metal concentrations in gas amounted to only 16% of the allowable levels and dioxin/furans amounted to only 6% of the allowable levels. It was also estimated that the saving out of using 7.5% wet sludge in this plant as supplementary fuel can reach to 8.0 euro/h. Conesa et al. (2008) analyzed the emission of different pollutants when partially substitute the typical fuel with tyre and two types of sewage sludge. In their experiments, different fuel samples containing sludge and/or tyres were tested and emission of Dioxins and furans, polycyclic aromatic hydrocarbons (PAHs) and other hydrocarbons, heavy metals, HCl, HF, CO, $CO_2$, $NO_x$ and other parameters of the stack were analyzed for more than 1 year. It was found that the emission of PAHs and dioxins seems to increase with the amount of tyres fed to the kiln, probably due to the fed point used for this waste. Wang et al. (2009) conducted exergy analysis and optimization approach using genetic algorithm (GA) to find the most efficient case among different cogeneration systems including single flash steam cycle, dual-pressure steam cycle, organic Rankine cycle (ORC) and the Kalina cycle aimed to reuse waste heat from the exhaust gas and air vent streams in cement plant. The results of exergy analysis showed that thermal heat losses in turbine, condenser, and heat recovery vapor generator are relatively large and optimization strategy indicated that the Kalina cycle could achieve the best performance in cement plant. Sögüt et al. (2010) applied exergy analysis in a cement plant in Turkey. Analysis showed that 51% of the initial energy of the process was lost. Moreover a mathematical model was developed in order to assess the possibility of using heat losses to supply thermal energy for dwellings in the vicinity. They proved that by using thermal energy losses instead of coal and natural gas it was possible to decrease domestic coal and natural gas consumption by 51.55% and 62.62% respectively and also to reduce CO2 emissions by 5901.94 kg/hr and 1816.90 kg/hr. Kabir et al. (2010) conducted thermal energy audit analysis on the pyroprocessing unit of the cement plant, and found that flue gases and kiln shell lost 27.9% and 11.97% of initial thermal energy respectively. In order to enhance the energy performance and to reduce heat losses, (WHRSG) and Secondary kiln shell were considered. It was indicated that 5.30 MW of thermal energy losses and also 14.10% of Greenhouse Gases can be reduced by applying (WHRSG) and Secondary kiln shell. Rovira et al. (2011) evaluated human health risks for the population living around the cement plant in Spain. The objective of their study was to compare temporal trend of the environmental levels of polychlorinated dibenzo-p-dioxins and dibenzofurans (PCDD/Fs) and a number of metals (As, Cd, Co, Cr, Cu, Hg, Mn, Ni, Pb, Sn, Tl, V, and Zn). After 1 year utilizing sewage sludge and those obtained in previous studies performed when petroleum coke was exclusively used as source of required energy. Results showed an acceptable range according to international standards which support and encourage the option of using sewage sludge as fuel in processes without apparent additional health risks for the population living in the vicinity.

In this work, a cement plant is selected for study. The purpose of this study is to investigate the environmental and economic benefits of replacement of fuel oil with natural gas in DASHTESTAN cement plant, and also feasibility of using stack gas waste heat for steam generation. The process is briefly described first. Then, the process is simulated through commercial process simulator. After that, several scenarios will be proposed and discussed to make the process more efficient in terms of energy saving and pollutant reduction.

## 1. PROCESS DESCRIPTION

DASHTESTAN cement plant is located in the south of Iran, near the north-western Persian Gulf bank. It produces 150 ton/hr clinker and is consisted of three major stages. The first stage is mixing and crushing stage which is responsible to mix certain proportion of clay and limestone and to crush them to powder form. The second and the most important stage is pyroprocessing which consumes more than 90% of total energy (Kabir et al., 2010) and in consequence generates more that 90% of $CO_2$ emitted in the process. This stage includes preheater, calciner, kiln and cooler. Clinker as nodular and well mixed form is the main production of this stage which then is sent to final grinding and crushing stage. During third stage, clinker is crushed and grinded to tiny grinds in powder form, mixed with additives and then is sent to packaging stage. Schematic of DASHTESTAN cement plant is shown in Figure 1.

 

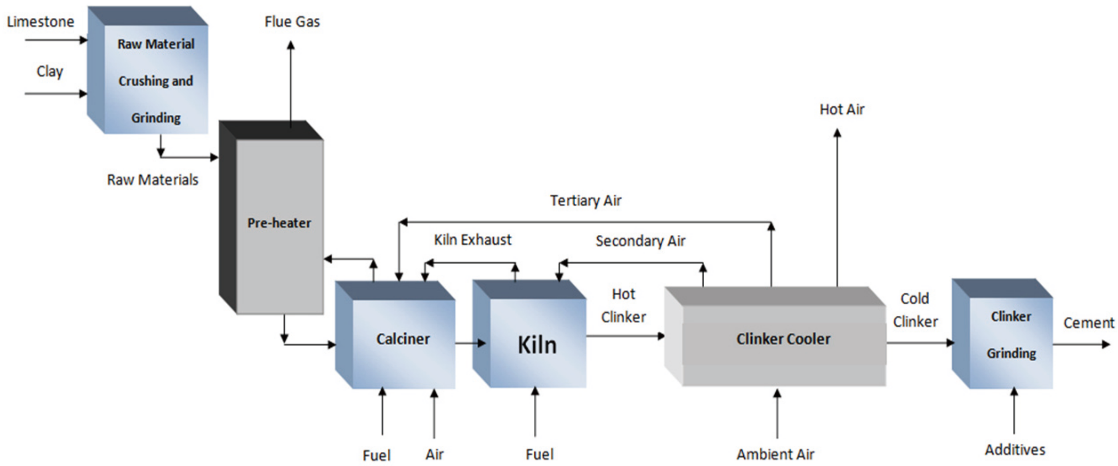


**Figure 1**
**DASHTESTAN Cement Plant Block Diagram**

As mentioned before, pyroprocessing is the most important stage in terms of energy and pollution management in cement plant. In this stage, raw materials mixture of clay and limestone with composition mentioned in Table 1 is crushed and mixed in the first crushing stage reaches to 50µm grain size. This solid mixture is entered to the preheater at 50°C. The preheater step is consisted of five cyclones which are used to preheat raw materials and separate them from the preheater gas. In this stage, feed stream with 50°C is heated up to 760°C by heat exchange with flue gases entering at 850°C from calciner. Flue gases then leave the preheater stage at 315°C and discharged to the environment. Such a high temperature is a valuable source of thermal heat. Solid stream at 760°C leaves preheater stage and is preceded to claciner where two reactions occur to convert 95% of $CaCO_3$ and all amount of $MgCO_3$ to CaO and MgO respectively. These endothermic reactions which are the major source of $CO_2$ production in cement plant require too much thermal energy. This thermal heat is provided through 3 different sources including combustion of fuel (fuel oil), hot gases produced in the kiln as well as hot air discharged from the coolers.

The main reactions of each section are given in Table 2, along with other data as operating temperature and heat of reaction (Mintus et al., 2006; Kaantee et al., 2004; Mujumdar & Ranade, 2006). The reaction products are solid materials which consist of remained $CaCO_3$, CaO, MgO, and the other materials. This solid stream is entered to the kiln at 890°C, where $C_2S$, $C_3S$, $C_3A$ and $C_4AF$ are produced as four major components of clinker under several chemical and physical (phase change) reactions presented in Table 2. The required thermal heat is provided by combustion of fuel oil and hot air sent from coolers. The composition of produced clinker is given in Table 3. The clinker enters the cooler with 12 fans at 1500°C and cooled down to 80°C. Ambient air which is sent to hot clinker is separated to three streams and different temperatures by ducts. One stream at 980°C is sent to the kiln, another one at 900°C is launched to calciner and the last one at 230°C is discharged to the environment as the second major source of thermal heat in cement plant.

**Table 1**
**Raw Material Composition in DASHTESTAN Cement Plant**

| Component | Composition (%wt) |
|---|---|
| CaO | 41.51 |
| MgO | 2.59 |
| $Al_2O_3$ | 3.39 |
| $Fe_2O_3$ | 2.54 |
| $SiO_2$ | 14.03 |
| $SO_3$ | 0.30 |
| $K_2O$ | 0.57 |
| $Na_2O$ | 0.24 |
| L.O.I | 34.83 |

**Table 2**
**Chemical and Physical Reactions in DASHTESTAN Cement Plant**

| Reaction name | Reaction | Temperature range (°C) | Heat of reaction (ΔHR) |
|---|---|---|---|
| Decalcination | $CaCO_3 \longrightarrow CaO + CO_2$ | 700 - 900 | +179.4 kJ $mol^{-1}$ |
| $MgCO_3$ dissociationMg | $CO_3 \longrightarrow MgO + CO_2$ | 700 - 900 | +117.61 kJ $mol^{-1}$ |
| β-$C_2S$ formation | $2CaO + SiO_2 \longrightarrow$ β-$C_2S$ | 900 - 1200 | −127.6 kJ $mol^{-1}$ |
| $C_3S$ formation | β-$C_2S$ + CaO $\longrightarrow C_3S$ | 1200 - 1280 | +16 kJ $mol^{-1}$ |
| $C_3A$ formation | $3CaO+Al_2O_3 \longrightarrow C_3A$ | 1200 - 1280 | +21.8 kJ $mol^{-1}$ |
| $C_4AF$ formation | $4CaO + Al_2O_3 + Fe_2O_3 \longrightarrow C_4AF$ | 1200 -1280 | −41.3 kJ $mol^{-1}$ |
| Liquid clinker formation | Clinkersol $\longrightarrow$ $Clinker_{liq}$ | >1280 | +600 kJ $kg^{-1}$ clinker |

 

**Table 3**
**Clinker Composition Produced in DASHTESTAN Cement Plant**

| Component | Composition (wt %) |
|---|---|
| $C_2S$ | 22.42 |
| $C_3S$ | 52.62 |
| $C_3A$ | 7.34 |
| $C_4AF$ | 11.88 |
| $SO_3$ | 0.66 |
| $K_2O$ | 0.87 |
| $Na_2O$ | 0.47 |
| MgO | 3.74 |

## 2. PROCESS SIMULATION

Process simulation is the best approach in order to assess the possibility of a new proposed process or proposed changes in a current process. On the other hand, it is time and budget consuming to test a new process or any proposed changes experimentally in the laboratory or in the pilot plant. Therefore, in order to assess possibility of fuel substitution from fuel oil to natural gas in DASHTESTAN cement plant and evaluate the use of waste heat for steam generation, simulation scenarios were proposed. The simulation of process and scenarios were conducted in the following manner. First, the existing plant was simulated by HYSYS, version 3.0.1. To do this, details of raw materials and kinetic reactions information were added to the component data bank. Also, the fuel was defined for simulator by adding different laboratory analysis reports. Then, the existing cement production process was simulated as base case. The simulation results were then validated by available plant operating data. Then, a scenario was defined to alter the plant fuel from fuel oil to natural gas. In this step, modifications were made to the plant to meet change of fuel, and analysis of stack gas was compared to the base case which applies fuel oil. Another scenario was proposed to use the waste heat of stack gas as a heat source to produce steam. The feasibility of altering fuel to natural gas and steam generation in conjunction with cement production is proposed as energy efficient, less pollutant process. The main assumptions are as follow:

1. Process is operated at atmospheric pressure and pressure drop is negligible;
2. Heat losses through pipes and heat exchangers are ignored;
3. Adiabatic conversion reactors have been used as calciner and the kiln;
4. Heat exchangers are used as clinker cooler and steam generator;
5. Preheater stage is a complex of five counter-current flow separators and mixers;

The composition and heating value of fuels used in this study are shown in Table 4 (Iran, Ripi, 2010)

**Table 4**
**Properties of Fuels Used in Process Simulation**

| Fuel | C(%wt) | H(%wt) | N(%wt) | S(%wt) | Methane(%mol) | Ethane(%mol) | MW | HHV (MJ/kg) |
|---|---|---|---|---|---|---|---|---|
| Fuel Oil | 85.25 | 11.8 | 0.2 | 2.75 | ------- | ------- | 211.6 | 43.5 |
| Natural Gas | ------ | ------ | ------- | ------- | 98.65 | 1.35 | 16.23 | 51 |

## 3. RESULTS AND DISCUSSION

The details of different scenarios to investigate change of fuel and reuse of waste heat for steam generation are summarized in Table 5.

Using data collected from control room and chemical laboratories, the base case process was simulated with its process flow diagram shown in Figure 2. The pyroprocessing stage of this cement plant consists of four main parts, including:

1. Preheater, a complex of 5 mixers and separators to preheat raw material and separate them from hot gas;
2. Calciner, which is a conversion reactor to calcinate 95% of $CaCO_3$ and also to decompose all amount of $MgCO_3$;
3. Kiln, which is a conversion reactor to provide a suitable space for all the reactions to produce nodular and well mixed clinker;
4. Coolers, which are heat exchangers to cool hot clinker down and prepare it for final grinding stage

The simulation results were used to estimate pollutants emission, heat losses and fresh air used in different parts of the process.

**Table 5**
**Summary of Studied Scenarios**

| Case | Fuel type | Waste heat recovery | Additional facilities used |
|---|---|---|---|
| I | Fuel Oil | − | Base Case |
| II | Fuel Oil | + | 1. Two boilers for steam generation<br>2. Two pumps to increase water pressure from 1bar to 11.35 bar |
| III | Natural Gas | − | 1. One heat exchanger with 157,230 kg/hr air capacity<br>2. One fan with the same capacity |
| IV | Natural Gas | + | 1. Two boilers for steam generation<br>2. Two pumps to increase water pressure from 1bar to 11.35 bar<br>3. One heat exchanger with 157,230 kg/hr fresh air capacity<br>4. One fan with the same capacity of fresh air |

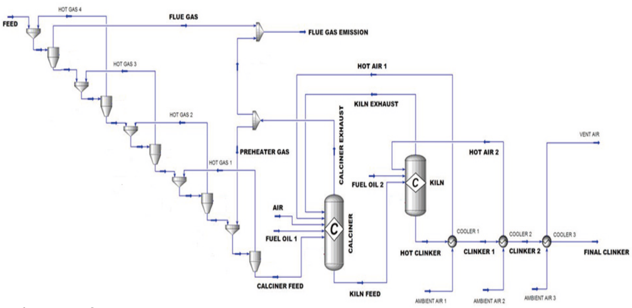


**Figure 2**
**DASHTESTAN Cement Manufacturing Process Flow Sheet**

### 3.1 Steam Generation Unit

As mentioned earlier vent air and flue gas streams are two significant sources of heat losses in cement plant. In order to recover heat from these two streams and reuse a part of energy, Waste Heat Recovery Steam Generator (WHRSG) is proposed. This process is sometimes referred as economizer, as it can make use of waste heat more efficiently. Block diagram of this option is shown in Figure 3. The produced steam can be used directly in the process; alternatively, it may be used as a source for electricity generation through steam power plant.

Simulation results show that if temperature of exhaust streams from WHRSG be set in 100°C, the vent air and flue gas streams will generate 7,528 and 25,114 kg/hr steam (180.7°C, 11.35 bar), respectively.

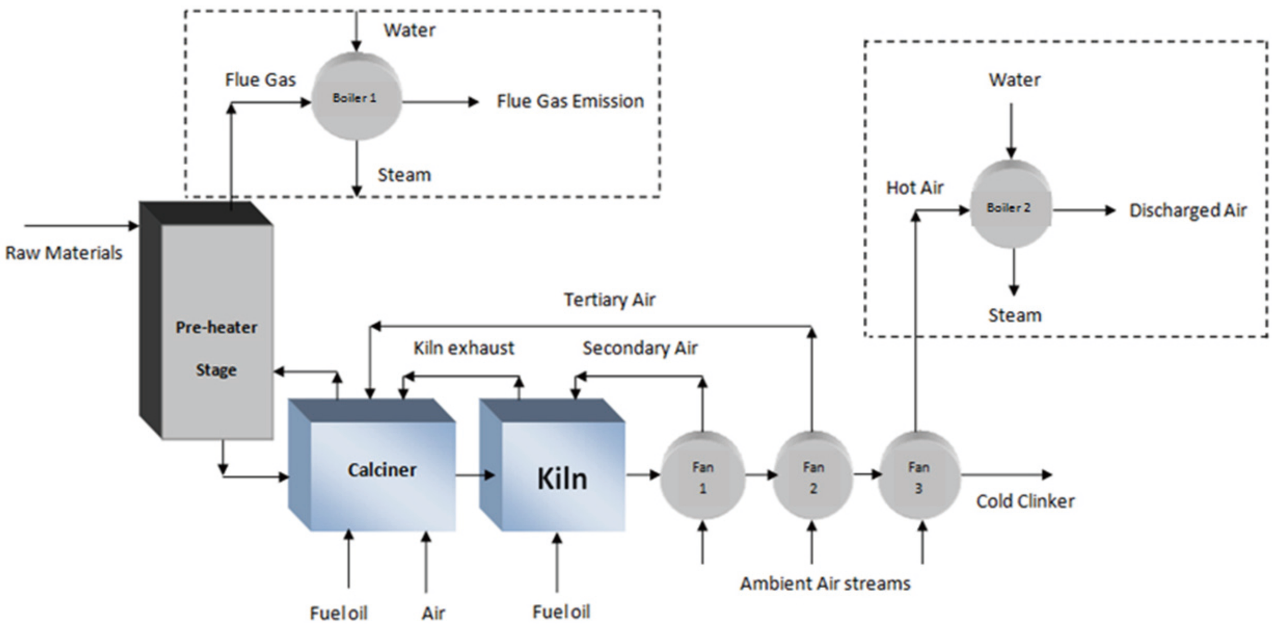


**Figure 3**
**Block Diagram of Base Process Including Steam Generation**

### 3.2 Utilizing Natural Gas as an Alternative Fuel and Steam Generation Unit

The objective of this scenario is to study the feasibility of using sweet natural gas as an abundant source of energy available in the area. Natural gas is a low-carbon fuel with high hydrogen-to-carbon (H/C) ratio, and has many advantages against fuel oil from environmental aspects, and produces less pollutant when burnt. The sweet natural gas contains neither sulfur nor nitrogen-containing compounds. Therefore, emission of $SO_x$ and $NO_x$ pollutants is diminished.

The PFD of plant utilizing natural gas as fuel is shown in Fig. 4. The process is similar to the case with fuel oil, except for an additional heat exchanger used to preheat combustion air sent to calciner chamber. Moreover simulation shows that from vent air and flue gas streams 5,326 and 44,156 kg/hr steam (180.7°C, 11.35 bar) can respectively be generated if temperature of exhaust streams from WHRSG be set in 100° C.

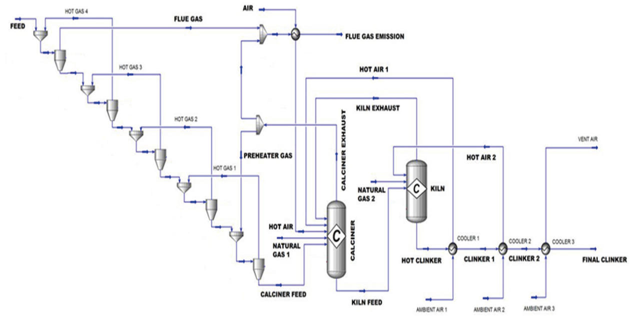


**Figure 4**
**Proposed Process Flow Diagram Utilizing Natural Gas**

Table 6 summarizes flow rate and temperature of the main streams in the both base and proposed process. Composition of pollutants, as well as rate of fuel consumption in processes is given in Table 7 and Fig.5. The heat loss through major parts of plants is also shown in Table 8.

**Table 6**
**Flow Rate and Temperature of the Main Streams in both Base and Proposed Process**

| | Base case process simulation | | Natural gas process simulation | |
|---|---|---|---|---|
| Stream | Flow rate (kg/hr) | Temperature (˚C) | Flow rate (kg/hr) | Temperature (˚C) |
| Feed | 232,360 | 50 | 232,360 | 50 |
| Calciner Feed | 231,200 | 760 | 231,200 | 760 |
| Fuel oil 1 | 7,500 | 120 | -------- | ----------- |
| Natural gas 1 | -------- | -------- | 7,727 | 50 |
| Air | 35,000 | 50 | 157,230 | 30 |
| Hot air | --------- | --------- | 157,230 | 500 |
| Calciner exhaust | 313,970 | 850 | 447,740 | 850 |
| Kiln Feed | 153,770 | 890 | 153,770 | 890 |
| Natural gas 2 | ------- | ------ | 4,854 | 50 |
| Fuel oil 2 | 5,300 | 120 | ---------- | -------- |
| Hot Clinker | 150,000 | 1500 | 150,000 | 1500 |
| Final Clinker | 150,000 | 80 | 150,000 | 80 |
| Total Ambient Air | 341,000 | 26.8 | 307,571 | 26.8 |
| Hot Air 1 | 80,000 | 900 | 110,210 | 900 |
| Hot Air 2 | 105,000 | 980 | 86,551 | 980 |
| Vent Air | 156,610 | 230 | 110,810 | 230 |
| Kiln exhaust | 114,060 | 1,150 | 95,164 | 1,150 |
| Preheater gas | 233,600 | 850 | 223,500 | 850 |
| Flue Gas emission | 315,130 | 315 | 448,900 | 350 |

**Table 7**
**Fuel Consumption and Pollutant Emission in Two Processes**

| | Item (Kg/hr) | | | | |
|---|---|---|---|---|---|
| Process | $CO_2$ emission | $NO_2$ emission | $SO_2$ emission | Dust | Fuel |
| Base case | 118,693 | 39.39 | 329.94 | 1,160 | 12,800 |
| Process utilizing natural gas | 115,367 | 0 | 0 | 1,160 | 12,581 |

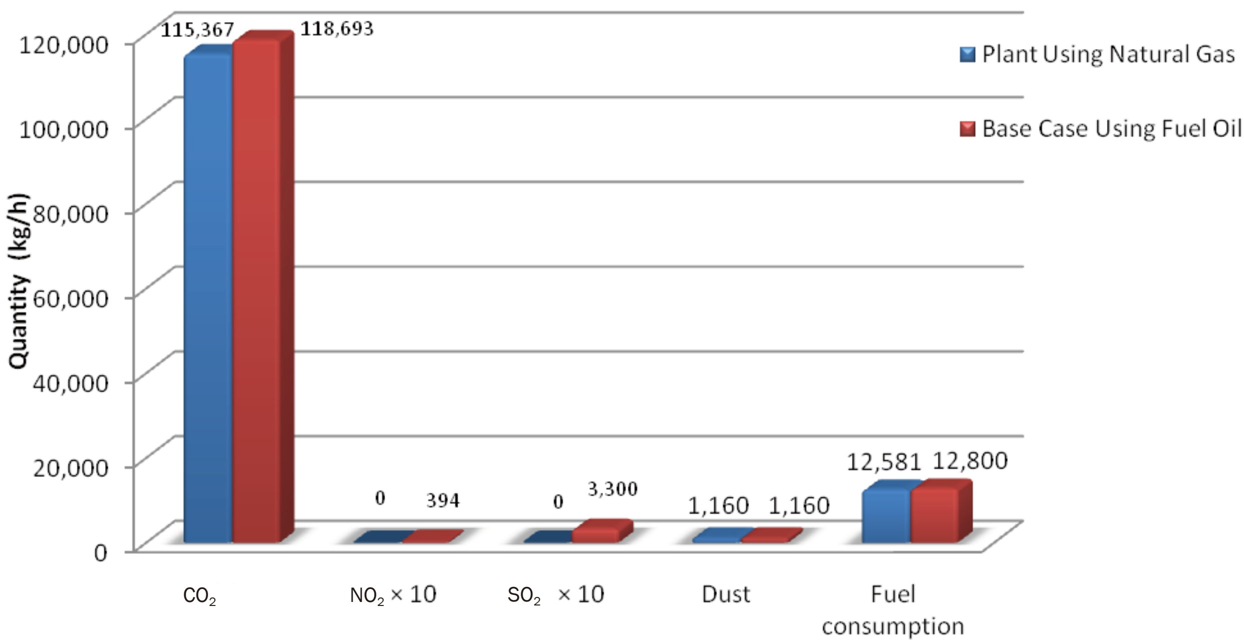


**Figure 5**
**Comparison of Fuel Consumption and Pollutants Emission for Two Fuels**

As Table 7 and Fig.5 clearly demonstrate using natural gas instead of fuel oil in this cement process can reduce 3,326 kg carbon dioxide per hour. Although this amount of reduction seems to be small quantity but when annual mitigation is taken to account, 26,342 ton carbon dioxide reduction will be resulted in a year which is significant approach to mitigate greenhouse gases emission and to subside impact of global warming.

Moreover since sweet natural gas contains neither sulfur nor nitrogen-containing compounds. Therefore, emission of $SO_2$ and $NO_2$ pollutants is eliminated as compare to fuel oil.

As far as dust emission is concerned and by considering the nature of dust in cement process which is tiny particles of minerals carried by hot gases starting from coolers and emitting with flue gases, therefore and in result of the same quantity of raw materials and cement production in both processes, it can concluded that dust emission is independent of type of fuel and it is same in two processes.

**Table 6**
**Flow Rate and Temperature of the Main Streams in both Base and Proposed Process**

| Major parts | Base case process | | Natural gas process | |
|---|---|---|---|---|
| | Heat Loss (MJ/hr) | Losses of Initial Energy (%) | Heat Loss (MJ/hr) | Losses of Initial Energy (%) |
| Heat losses through vent air | 21,180 | 3.82 % | 15,000 | 2.32% |
| Heat losses through flue gas emission | 70,660 | 12.71% | 124,200 | 19.35% |
| Heat losses through the kiln | 52,751 | 9.43% | 50,078 | 7.82% |
| Heat losses through calciner and preheater | 46,313 | 8.32% | 47,661 | 7.43% |
| Total heat losses | 190,904 | 34.28 % | 236,939 | 36.92% |

### 3.3 Economic Investigation

Although economic investigation of a process is one of the most complex, detailed and time consuming part of the research, it is essential to perform economic analysis to get a perspective whether or not a feasible engineering modification is economically attractive. Therefore, to assure the economic advantages of proposed scenarios in addition to their environmental benefits, economic comparison between proposed cases and base case in term of fuel consumption, additional facilities used and producing steam has been done. This comprehensive investigation requiers estimating capital cost, operating cost as well as variable cost of the fuel, raw material, addetives, salries and so on. In this work, we have applied engineering cost estimation techniques (Peters et al., 2003) to prepare construction and production costs for each scenario. Marshall & Swift Equipment Cost Index (2010) was used in all cases. In short the purpose of this evaluation is to prove that in addition to environmental friendly features of the scenarios they are capable to bring remarkable economic benefits which encourage industries to implement them.

#### 3.3.1 Plant Utilizing Fuel Oil Including Steam Generation

• Fixed extra costs

Since producing steam in this case requires some facilities such as two heat exchangers with 7,528 and 25,114 kg/hr steam generation capacity and two pumps to increase water pressure from 1bar to 11.35 bar with capacity of 7,528 and 25,114 kg/hr, these additional charges should also be considered. This additional charge to provide these facilities is about $536,630.

• Income

As mentioned before, utilizing waste heat provided by vent air and flue gas streams 32,642 kg/hr steam at 180.7° C, 11.35 bar can be generated. The value of produced steam is 32,642 kg/hr × 4.5×10-3 $/kg = $146.89 /hr which annually comes to 146.89 $/hr × 24 hr/day × 330 day/year = $1,163,369 /year

Taking 5 years as the service life for new facilities and applying linear depreciation method, the net income for this scenario is estimated to be $1,056,043/year.

#### 3.3.2 Plant Utilizing Natural Gas

• Fixed extra costs

Since this plant needs facilities such as one heat exchanger with 157,230 kg/hr hot air production and a fan with the same capacity, their costs should also be included in the estimation of fixed cost. In this way, by estimating $4000 as the cost of air fan and $1,013,040 for heat exchanger, the fixed cost is estimated to be $1,017,040.

• Income

Natural gas price in 2010 in Iran was $ 0.1/kg. Therefore, the net yearly cost of natural gas for this plant is estimated to be $9,946,152 /year. On the other hand, 12,800 kg/hr fuel oil is consumed in base case, with its price estimated to be $0.262/kg. Therefore, total yearly cost of fuel is estimated to be $26,560,512/year. As a result, the net income from changing the fuel is $16,614,360/year. Taking 5 years as the service life for new facilities and applying linear depreciation method, the net income for this scenario is estimated to be $16,410,952/year.

#### 3.3.3 Plant Utilizing Natural Gas Including Steam Generation

• Fixed extra costs

This case is similar to previous one except for adding two steam generators and two pumps to generate 49,482 kg/hr steam from flue gas emission and vent air streams. By considering two steam generators, two pumps, one heat exchanger and a fan, extra fixed cost is estimated to be $2,105,940.

• Income

Steam generated in this case is 49,482 kg/hr which has an estimated value of $1,763,538/year. Adding this value to the net income from changing the fuel, total income for this case is estimated as $18,377,898 /year. Taking 5 years as the service life for new facilities and applying linear depreciation method, the net income for this scenario is estimated to be $17,956,710/year.

Table 9 summarizes extra fixed costs, gross and net income, and payback period of all proposed cases as compared to base case. Calculations show that all modifications are attractive from economic point of view.

**Table 9**
**Economic Comparison of Proposed Processes and Case Study**

| Scenario | Extra Fixed Cost (over existing plant), ($) | Gross income, ($/year) | Net Income (Subtracting Depreciation), ($/year) | Payback Period, (months) |
|---|---|---|---|---|
| Adding waste heat recovery to Base Case | 536,630 | 1,163,369 | 1,056,043 | 5.5 |
| Changing fuel for Base Case without waste heat recovery | 1,017,040 | 16,614,360 | 16,410,952 | 0.75 |
| Adding waste heat recovery as well as changing fuel for Base Case | 2,105,940 | 18,377,898 | 17,956,710 | 1.4 |

## CONCLUSION

In this work, a cement plant located in the south west of Iran, northern bank of Persian Gulf was selected for analysis. The main objectives of the study were to find quantity and the sources of thermal heat loss in the process, evaluate the feasibility of alternating fuel from fuel oil to natural gas and add a waste heat recovery for energy reuse.

It was shown that adding waste heat recovery systems will lower the temperature of stack gases from 315°C and 350°C to 100°C in base case and process utilizing natural gas, respectively. This temperature gradient is capable to generate 32,642 and 49,482 kg/hr of steam in two processes. The best economic case in term of annual net income was estimated to be case III which is process utilizing natural gas including steam generation. The fixed extra costs in this process and payback period were estimated to be $2,105,940 and 1.4 months, respectively.

As conclusion it is justified that alternating process fuel from fuel oil to natural gas is advantageous from both environmental and economical points of view.

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