Industrial Engineering Letters
ISSN 2224-6096 (Paper) ISSN 2225-0581 (online)
Vol.5, No.3, 2015 

# Effect of Fuel Mixture on Cement Production: A Case Study of BUA Plant. Cement Production Optimization with change in Specific surface area (0.35cm$^2$/g and 0.38cm$^2$/g). Using Particle Swarm Optimization model.

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**Abstract**

Ordinary Portland cement industries have been using co-processing from industrial waste. These paper present opportunities of using both Conventional fuel and Agricultural waste for cement production optimization an in-depth analysis on effect of using conventional fuel (mineral coal, pet-coke, Heavy oil and Natural gas) and Agricultural waste (sugar waste and ground nut shell). This mixture is intended for use in a rotary kiln of clinker production, dry process. The optimization model used was Particle Swarm Optimization (PSO). The change in the specific surface area(S) from 0.35cm$^2$/g to 0.38cm$^2$/g of the final product (cement), this resulted into slight increased the energy consumption, more retention time, reduction in production output, increased wear rate on mill liners.

**Keywords:** Fuel mixture, Cement quality, Environmental effect.

## Introduction

Production of Ordinary Portland Cement, environmental pollution and energy consumption is very high. Due to this impact the cement manufacturers are always concerned about using alternative fuel mixture with low production cost without losing the quality of the final product and less environmental impact to the society. The process consists basically the replacement of the primary fuels by residues generated by other industries such as used tires, waste oils and other industrial wastes, agricultural waste, municipality waste, among others.

Cement production is an energy-intensive process, consuming thermal energy in the order of 3.3-3.6 GJ/ton of clinker produced. Electrical energy consumption is about 90 – 120 kWh/ton of cement (Giddings, et al., 2000). The primary fuel used in cement industry is coal. A wide range of other fuels such as heavy oil, natural gas, liquid waste materials, solid waste materials and petroleum coke have all been successfully used as sources of energy for kilns firing, either on their own or in various combinations.

This research work presents the possibility of using the mixture of mineral coal, petroleum coke, heavy oil and natural gas, with an agricultural waste (sugar cane waste and ground nut shell), etc. as fuel feed stock. This mixture is intended for a rotary kiln, clinker production; mainly dry process with a pre-heater. The optimization procedure will take into account process restrictions such as specific heat consumption, cement quality and environmental impact. Joseph S. O. and Obodeh O. (2014).

## Material and Data Collection

Raw materials used for this research were obtained from BUA cement plant laboratory analysis.

Table 1 Data of Raw meal material Preparation Used.

| Material | Limestone | Clay | Laterite | Iron |
|---|---|---|---|---|
| Notation | $X_1$ | $X_2$ | $X_3$ | $X_4$ |
| Cao | 52.18 | 1.03 | 1.0 | 0.11 |
| $SiO_2$ | 6.20 | 63.62 | 94.70 | 3.60 |
| $Al_2O_3$ | 1.12 | 17.19 | 3.67 | 0.98 |
| $Fe_2O_3$ | 0.47 | 9.65 | 1.43 | 92.97 |
| MgO | 0.80 | - | 0.17 | - |
| $SO_3$ | 0.05 | 3.00 | 0.78 | - |
| $Na_2O$ | 0.07 | 0.30 | 0.50 | - |
| $K_2O$ | 0.20 | 3.00 | 1.28 | - |

Table 2 Data of Fuel composition employed as primary fuels

| Component | Mineral Coal % weight | Pet coke % weight | Heavy oil uses % weight |
|---|---|---|---|
| Notation | $X_5$ | $X_6$ | $X_7$ |
| C | 70.60 | 89.50 | 84 |
| H | 4.30 | 3.08 | 12 |
| N | 1.20 | 1.71 | Trace |
| O | 11.8 | 1.11 | 1 |
| S | 1.30 | 4.00 | 3.00 |
| Cl | 0.07 | | |
| $P_2O$(In ash) | 0.02 | | |
| $Na_2O$(In ash) | 0.05 | | |
| $K_2O$(In ash) | 0.12 | | |
| CaO(In ash) | 0.18 | | |
| $Fe_2O$(In ash) | 0.31 | | |
| $Al_2O$(In ash) | 1.07 | | |
| $SiO_2$(In ash) | 2.00 | | |

 

| | | | |
|---|---|---|---|
| MgO(In ash) | 0.08 | | |
| NiO(In ash) | - | 0.04 | |
| LHV(kJ/kg) | 28,800 | 33,700 | 43,000 |

Table 3 Data of Fuel composition employed as Alternative fuels

| Component | Natural gas % weight | Sugar cane waste% weight | Rice husk % weight |
|---|---|---|---|
| Notation | $X_8$ | $X_9$ | $X_{10}$ |
| C | 74 | 41.16 | 45.9 |
| H | 25 | 5.08 | 5.34 |
| O | 5.5 | 37.42 | 36 |
| N | 0.00 | 0.14 | 1.09 |
| S | 0.0 | 0.02 | 0.01 |
| Cl | 0.0 | 0.01 | |
| LHV(kJ/kg) | 50.67 | 15,479 | 17.8 |

**Data Processing**

The method of analysis was the use of Particle Swarm Optimization simulation. This was generated from MATLAB software. The method of analysis was intended to predict the personal best (pbest) and global (gbest) alternative fuel low Calorific Value (LCV).

The concept of Particle Swarm Optimization consists of changing the velocity of each particle towards the *pbest* (personal best) and *gbest* (global best) locations. The velocity of the search procedure is pondered through a generated term in a random way linked in a separate way of the *pbest* and of the *gbest* locations. The development of this model involved its training, validation and testing. Different sets of data were used at each stage. Thus the data were used at each simulation stage are based on the Raw material percentage (%), Primary Fuels percentage and Alternative (%).

The following training procedures were used:

- ✓ A training set used in determining the Particle Swarm Optimization simulation.
- ✓ A validation set, used in estimating the Particle Swarm Optimization and decide when to start training.
- ✓ Testing of the Particle swarm optimization tool with other optimization tools
- ✓ Inputting the result of the simulations and also checking that all the constraint $X_1$, $X_2$, $X_3$ …$X_{10}$ are satisfied.

**Raw Materials and Fuel mixture model**

The material and fuel mixture optimization, was consider for the stable operation of the rotary kiln, the quality of the clinker produced, the minimum cost of the composition used and the electric power; all these variables are considered in the nonlinear model proposed through the following objective function, Eq.(1).

$$C = \sum Pic * Xi + Pe * A * \exp^{(B.S)} \quad (1)$$

The first term (linear) represents the raw materials and fuels (primary and alternative) costs used in the clinker production ($p_i$, is the raw materials and fuels costs i = 1,2....... 10, that participate in the burning, with their respective percentages $X_1$, $X_2$,......$X_{10}$). The objective function (C) of the model tried to obtain a minimum cost in the clinker production, considering the raw materials costs as well as the consumption of the energy required for grinding.

The second term (nonlinear) represents electricity cost ($p_e$) and the energy consumption required in kWh/t for the grinding process of a certain specific surface (S is the specific surface area in $cm^2/g$, A and B are constants that depend on the clinker composition). (Carpio 2004 and 2005).

Based on raw material, fuels chemical composition values and on the Eq. (1), an objective function was set up, which represents costs minimization problem, considering the operational and environmental costs presented as it follows:

$$MINCost_1X_1 + Cost_2X_2 + Cost_3X_3 + Cost_4X_4 + Cost_5X_5 + Cost_6X_6 + Cost_7X_7 + Cost_8X_8 + Cost_9X_9 + Cost_{10} + Cost_{EE*}\{(5.76(MS) - 5.82) * e^{(-0.2(MS)+0.98)*S}\} \quad (2)$$

$$M.S = \frac{(6.20X_1 + 63.62X_2 + 94.70X_3 + 3.6X_4 + 2.0X_5)}{(1.59X_1 + 26.84X_2 + 5.1X_3 + 93.95X_4 + 1.38X_5)} \quad (3)$$

**The Constraints**

$$52.18X_1 + 1.03X_2 + 1.01X_3 + 0.11X_4 + 0.18X_5 \geq 64 \quad (4)$$

$$52.18X_1 + 1.03X_2 + 1.01X_3 + 0.11X_4 + 0.18X_5 \leq 71.2 \quad (5)$$

$$6.20X_1 + 63.62X_2 + 94.70X_3 + 3.60X_4 + 2.0X_5 \geq 20.0 \quad (6)$$

$$6.20X_1 + 63.62X_2 + 94.70X_3 + 3.60X_4 + 2.0X_5 \leq 24.50 \quad (7)$$

$$1.12X_1 + 17.19X_2 + 3.67X_3 + 0.98X_4 + 1.07X_5 \geq 3.80 \quad (8)$$

$$1.12X_1 + 17.19X_2 + 3.67X_3 + 0.98X_4 + 1.07X_5 \geq 6.83 \quad (9)$$

$$0.47X_1 + 9.65X_2 + 1.43X_3 + 92.97X_4 + 0.31X_5 \geq 1.32 \quad (10)$$

$$0.47X_1 + 9.65X_2 + 1.43X_3 + 92.97X_4 + 0.31X_5 \leq 5.40 \quad (11)$$

$$0.80X_1 + 0.17X_3 + 0.08X_5 \leq 6.5 \quad (12)$$

$$28.2X_5 + 33.7X_6 + 43X_7 + 50.2X_8 + 15.5X_9 + 17.8X_{10} = 3.6 \quad (13)$$

$$1.30X_5 + 4.00X_6 + 1.54X_7 + \leq 5.0 \quad (14)$$

$$0.05X_1 + 3X_2 + 0.78X_3 \geq 0.20 \quad (15)$$

$$0.05X_1 + 3.0X_2 + 0.78X_3 \leq 2.07 \quad (16)$$

$$0.07X_1 + 0.3X_2 + 0.5X_3 \geq 0.03 \quad (17)$$

$$0.07X_1 + 0.3X_2 + 0.5X_3 \leq 0.33 \quad (18)$$

$$0.2X_1 + 3X_2 + 1.28X_3 \geq 0.31 \quad (19)$$

$$0.2X_1 + 3X_2 + 1.28X_3 \leq 1.82 \quad (20)$$

Equation (4) and (5) show the percentage of calcium oxide (CaO) contained in raw meal (clinker) 1 ton should be between 64% - 71.2 %, equation (6) and (7) show the percentage of silicon oxide ($SiO_2$) is contained in calcareous granules 1ton should be between 20 % - 25 %, equation (8) and (9) show the percentage of aluminum trioxide ($Al_2O_3$) is contained in the calcareous grains per 1ton should be between 4 % - 7 % equation (10) and (11) show the percentage ferrous trioxide ($Fe_2O_3$) is contained in calcareous granules 1ton should be between 2 % - 5 %, equation (12) represents the percentage of magnesium should be less than or 6.50% . Equation (13) represents the heat value (Heating Value) used in the production of clinker , which requires an amount of heat equal to 3.6 GJ per ton of clinker Equation (14) represents the percentage of sulfur (Sulphur) should be less than or equal to 5 % of the sulfur from the fuel type, equations (15) to (16) is the equation of an acid and a base of clinker, which comes from the ingredients used in the production of each species which is between 0.2 % - 2.07%, equation (17) to (18) is the best of sodium oxide ($Na_2O$) should be between 0.03% - 0.33%, equation (18) to (19) values . Best of potassium oxide ($K_2O$) should be between 0.31% - 1.76 %. Joseph S.O and Obodeh (2014)

**RESULTS AND DISCUSSION**

Matlab software (Matlab 7.13) was used. The grinding process of the cement with a specific surface area S = 0.35 and 0.38 $cm^2/g$ were used. The laptop used was Intel(R) Core™ i5-2540M CPU@ 2.60Hz RAM 4.00GB, system type 32-bit operating system. In this case, the required chemical composition is sought for a cement type produced in a rotary kiln, dry process with heat specific consumption of 3600 clinker kJ/kg.

The cost used for this simulation are local market cost based in Nigeria where one (1) dollar $ = 215naira. The parameters of PSO used are population of 100 particles; $C_1 = C_2 = 2.0$; initial weighted of 0.9 with linear decline up to 0.3; search space of the variables to be optimized in the interval $0 < X_n < 3$, where n=1,..,10.

Table 4 50 Runs for Particle Swarm Optimization Simulation with Specific surface area (S)- 0.35$cm^2/g$ and 0.38$cm^2/g$

| Restriction | Specific Surface area(S)= 0.38$cm^2/g$ | Specific Surface area(S)= 0.35$cm^2/g$ |
|---|---|---|
| $X_1$ | 1.2229 | 1.2550 |
| $X_2$ | 0.1682 | 0.1688 |
| $X_3$ | 0.0469 | 0.0468 |
| $X_4$ | 0.0110 | 0.0065 |
| $X_5$ | 1.4e-04 | 3.0201e-04 |
| $X_6$ | 9.4e-04 | 0.002 |
| $X_7$ | 5.0e-04 | 3.3e-04 |
| $X_8$ | 4.7e-5 | 3.5e-05 |
| $X_9$ | 0.2274 | 0.2274 |
| $X_{10}$ | 8.9e-04 | 5.0e-04 |

 

The above result on 50 runs simulation model using 0.35cm$^2$/g and 0.38cm$^2$/g, the constraints and restriction in equation (4) to (20) are all satisfied. . PSO uses sugar cane waste ($X_9$) about 99.9% as a major source of fuel in kiln firing for clinker production and 0.1% of other source fuels.

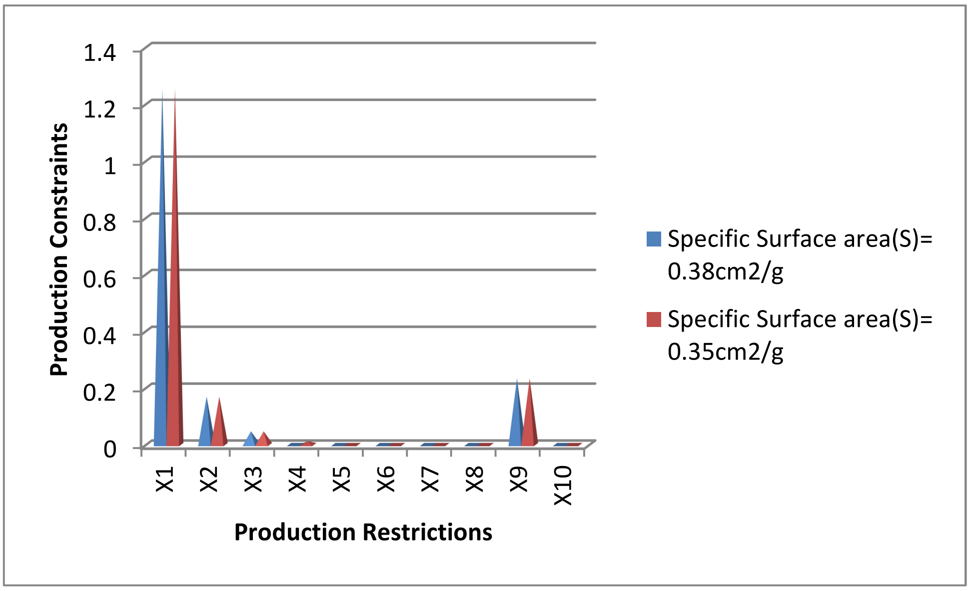


Fig. 1 50 Runs for Particle Swarm Optimization Simulation with Specific surface area (S) - 0.35cm$^2$/g and 0.38cm$^2$/g.

Comparing the simulation results of the specific surface area for 0.35cm$^2$/g and 0.38cm$^2$/g of the final product (cement), there are slight increases in the cost of production. These increase in cost of production was as the result of change in the specific surface area from 0.35cm$^2$/g to 0.38cm$^2$/g in the clinker and gypsum grinding. The increase in specific surface area resulted into the e following:

- ✓ More grinding takes place in the grinding mill (Vertical roller mill or ball mill), that is more retention time, reduction in residue (%), more recirculation, particle sizes distribution and increase in fineness.
- ✓ More energy consumption
- ✓ Finally increase in cost of production.

Increasing the number of runs in the optimization simulation model, gives a better and satisfying optimization (maximum and minimum) results in the raw material and fuel mixing ratio.

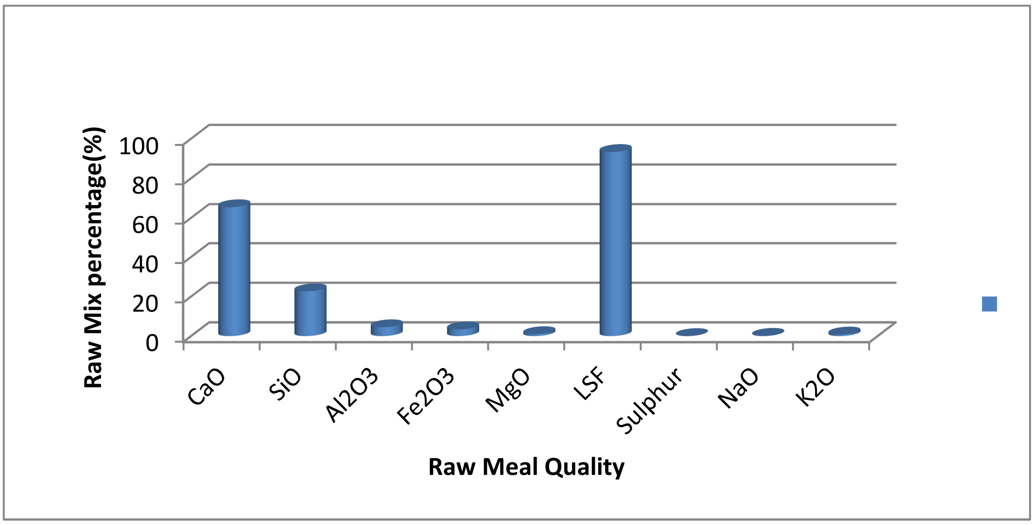


Fig.2 Raw mix percentage (%) vs Raw meal quality

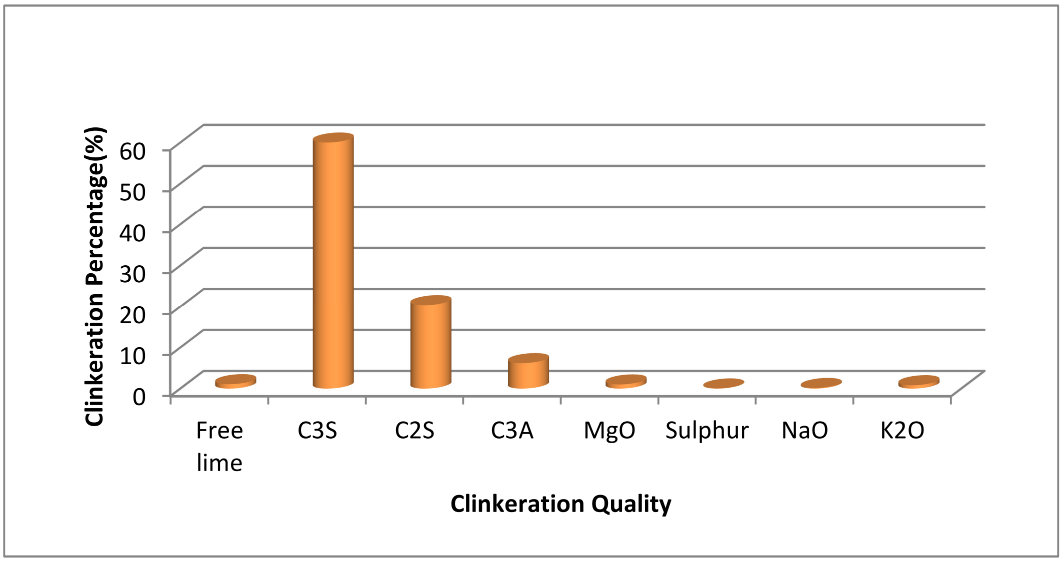


Fig.3 Clinker quality after firing the raw meal.

The simulation results shown in Fig.2 and Fig.3 proved that the mixture of primary fuel (mineral coal, pet-coke, heavy oil and natural gas) and agricultural waste (sugar cane waste and ground nut shell), do not affect the quality of the clinker produced greatly.

The major challenge is the high free lime present in the final product (clinker). To produce Ordinary Portland Cement free lime will need to be minimized.

**Conclusion**

Effect of Fuel Mixture on Cement Production: A Case Study of BUA Plant. Cement Production Optimization with change in Specific surface area ($0.35cm^2/g$ and $0.38cm^2/g$).The Particle Swarm Optimization model presented the possibility to foresee effect of the fuel mixture on raw material composition when it is decided to burn agricultural waste as secondary fuel in cement industries via rotary kiln. It is also possible to calculate the substitution ratio of the primary fuel to alternative fuel derived from the agricultural waste.

The quality result shows clearly that fuel mixture and the raw material used can produce quality cement with proper control of the free-lime (CaO un-burnt), alkaline material and improve $C_3S$ (early strength).

 

Finally increasing the specific surface area of the final product from $0.35cm^2/g$ to $0.38cm^2/g$. Has some cost implications on production cost and it will also have effect on the wear and tear on the equipment.

This model show satisfactory based on the presented results, either for keeping the values of the chemical composition inside the quality parameter and finding smaller production costs.

**References:**

Carpio, R.C.; Silva, R.J.; and Jorge, A.B. (2004). Heavy Metals Influence in the Mixture Optimization of Industrial Waste Fuels in Cement Industry, XXV Iberian Latin-American Congress on Computational Methods in Engineering, Recife, PE, Brazil.

Carpio, R.C.; Coelho, L.S.; Silva, R.J.; and Jorge, A.B. (2005).Case Study in Cement Kilns Alternative Secondary Fuels Mixing Using Sequential Quadratic Programming, Genetic Algorithms, and Differential Evolution, Proceedings of 6th World Congress on Structural and Multidisciplinary Optimization, Rio de Janeiro, RJ, Brazil.

CEMBUREAU. (1999), Environmental Benefits of Using Alternative Fuels in Cement Production, 19: 25-39

Davidor,Y. and Schwefel, H.P.(1992). An Introduction to Adaptive Optimization Algorithm based on principles of Natural Evolution Dynamic, Genetic and chaotic programming, 6th Generation 183-202

Diez, C.; Martinez,O.; Calvo, L.F. and Cara, J. (2004). Pyrolysis of tyres. Influence of the final temperature of the process on emissions and the calorific value of the products recovered. Waste Management. 24: 463 – 469.

Eberhart, R.C.; Kennedy, J.F. and Shi, Y. (2001). Fuzzy Adaptive Particle Swarm Optimization. Evolutionary computation, proceeding of the 2001 congress 1: 101-106.

F.L Smidth and Co. (2000). Dry process kiln systems, technical brochure.

Gabbard, W. D. and Gossman, D. (1990). Hazardous waste fuels and the cement kilns – The Incineration Alternative. ASTM Standardization News, September 1990 and March 2011, August 2014.

Ghosh, S.N. (1991). Cement and Concrete Science and Technology, 1: 1

Giddings, D.; Eastwick, C.N.; Pickering, S.J. and Simmons, K. (2000). Computational fluid dynamics applied to a cement precalciner. Proc. Instn. Mech. Engrs, 214:A.

Goeran, O.; Wang, W.; Ye, Z.; Bjerle, I. and Anderson, A. (2002). Repressing NOx and $N_2O$ emissions in fluidized bed biomass combustor. Energy Fuels, 4: 915 – 919.

Gulyurtlu, I.; Boavida, D.; Abelha, P.; Lopes, M.H, and Cabrita, I. (2005). Co-combustion of coal and meat and bone meal. Fuel, 84: 2137 – 2148.

Joseph S. O and Obedeh O. (2014). Optimizing Alternative Fuel mixtures in Cement Plant (BUA Cement Plant), Using Particle Swarm Optimization Method.

Kääntee, U.; Zevenhoven, R.; Backman, R. and Hupa, M. (2004). Cement Manufacturing Using Alternative Fuels and the Advantages of Process Modeling. Fuel Processing Technology; 85: 293-301.