Cement Production Optimization Modeling: A Case Study BUA Plant (Primary Fuel and Agricultural waste). Using Particle Swarm Optimization, and Comparing with Genetic Algorithm and Pattern Search.

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Abstract: This paper deals with cement production optimization modeling using Particle Swarm Optimization (PSO) and the results was compared with Genetic Algorithm (GA) and Pattern Search (PS). This optimization modeling took into account mixtures of primary fuel (mineral coal, pet-coke and heavy oil) and its alternative fuel which is agricultural waste (rice husk, sugar waste and ground shell). The optimization simulation models predict the cost benefit to the manufacturer using alternative fuel, environmental impact to world at large and finally the quality of the cement produced to the end user. Production cost for one (1) ton of cement using PSO is ($23 =4945naira), GA ($33= 7095naira), PS (38.2 = 8170naira). The oxides in this research work met standard cement specification: Silica Modulus (M.S-2.9), Alumina Modulus (M.A- 1.3), Lime Saturation factor (LSF-93.3%). The results show that the cost of cement production can be reduced by 30-70% with the use of alternative fuel (Rice husk, Sugar cane waste, ground nut shell) and without greatly affecting the final product.

Keywords: Fuel mixture, Energy Consumption, Cement cost.

INTRODUCTION

In cement production energy consumption takes the largest bulk of production cost. 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.

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

Primary fuels used in cement industry are mineral coal, petroleum coal, gas oil and natural gas. These provide most of the energy needs of the World today. Coal and natural gas are used in their natural forms, but petroleum and other fossil fuels such as shale and bituminous sands require distillation and refinement to produce consumable fuels. These fuels exist in the following forms: gaseous, liquid, and solid. The high cost of fossil fuels and most importantly, their damaging effect on the environment underscore the need to develop alternative fuel mixture for many industrial systems that rely on fossil fuels. Increased use of renewable and alternative fuels can extend life cycle of fossil fuel supplies and help resolve the present world global warming (Green House Gases) which is associated with the use of conventional fuels. Joseph S.O and Obodeh .O (2014).

Material and Methodology

The methodology of research is to use the Particle Swarm Optimization, Genetic Algorithm and Pattern Search simulation modeling. This will be generated from MATLAB software. Data used for this research will be obtained from BUA cement plant laboratory and other foreign major cement group laboratory, such as Lafarge Group and Holcim Group, which are the largest cement manufacture in the world, while Flsmidth are the designer and manufacturer of cement equipment. The research results obtained (through optimization) will be compared with standard cement result.

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	Rice husk % weight	Sugar cane % weight	Ground nut shell % weight
Notation	X_8	X_9	X_{10}
C	37.48	41.16	45.9
H	4.41	5.08	5.34
O	33.27	37.42	36
N	0.17	0.14	1.09
S	0.04	0.02	0.01
Cl	0.09	0.01	
LHV(kJ/kg)	13,517	15,479	17.8

Data Processing

The method of analysis was the use of Particle Swarm Optimization, Genetic Algorithm and Pattern Search simulation model. This was generated from MATLAB software.

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 (%) and Alternative Fuel percentage (%).

The following training procedures were used:

- ✓ A training set used in determining the Particle Swarm Optimization, Genetic Algorithm and Pattern Search simulation.
- ✓ A validation set, used in estimating the Particle Swarm Optimization Genetic Algorithm and Pattern Search and decide when to start training.
- ✓ Testing of the Particle swarm optimization Genetic Algorithm and Pattern Search 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). (Carpio 2004 and 2005).

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

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).

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:

$$MIN Cost_1 X_1 + Cost_2 X_2 + Cost_3 X_3 + Cost_4 X_4 + Cost_5 X_5 + Cost_6 X_6 + Cost_7 X_7 + Cost_8 X_8 + Cost_9 X_9 + Cost_{10} X_{10} + Cost_{EE*} \{(5.76(MS) - 5.82) * e^{(-0.2(MS)+0.98)*S}\} \quad 2)$$

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

The Constraints

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

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

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

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

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

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

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

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

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

$$28.2X_5 + 33.7X_6 + 43X_7 + 13.517X_8 + 15.479X_9 + 17.8X_{10} = 3.60 \quad (13)$$

$$1.30X_5 + 4.00X_6 + 1.54X_7 + 0.04X_8 + 0.17X_9 + 0.02X_{10} \leq 5.0 \quad (14)$$

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

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

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

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

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

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

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 Obedeh O. (2014).

RESULTS AND DISCUSSION

Optimization simulation runs results at 20 using Matlab software (Matlab 7.13). The grinding process of the cement a specific surface area S = 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 parameters of PSO, GE and PS used a population of 100 particles; $C_1 = C_2 = 2.0$; initial weighted (theta) 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.

The cost used for this simulation are local market cost based in Nigeria where one (1) dollar $ = 215 naira.

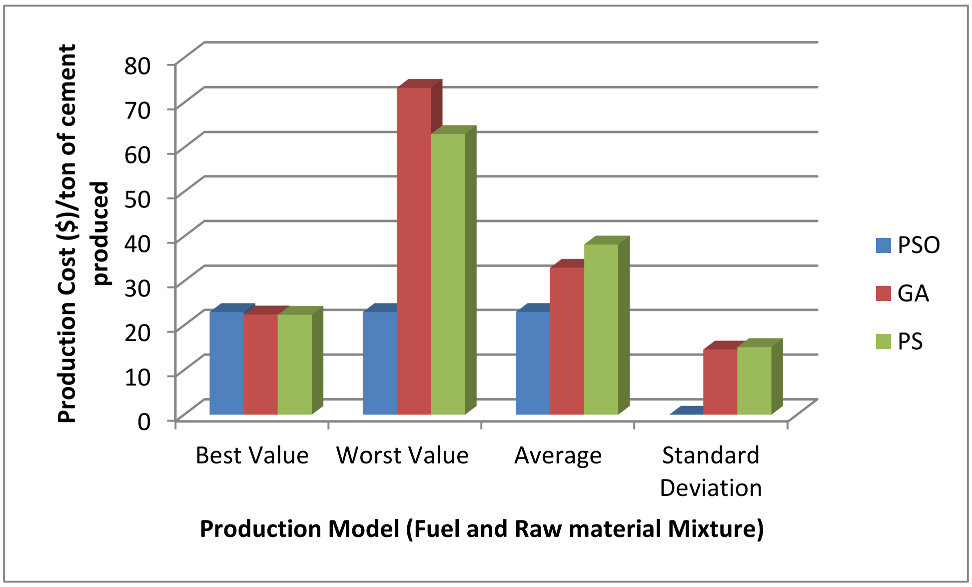


Fig.1 Bar chart for cost analysis for 20 runs simulation result.

The PSO has the lowest standard deviation and best average cost of producing one (1) ton of cement. All the constraints in the equation (1) to (20) are all satisfied for PSO, GA and PS. To produce one (1) ton of cement using PSO, GA, PS model, it is expected that an average cost of $ 23 = 4945 naira, GA=$33.0 = 7095 naira and PS = $38.2 =8170 naira respectively are needed to produce one ton of cement. PS has the highest cost of producing one ton of cement.

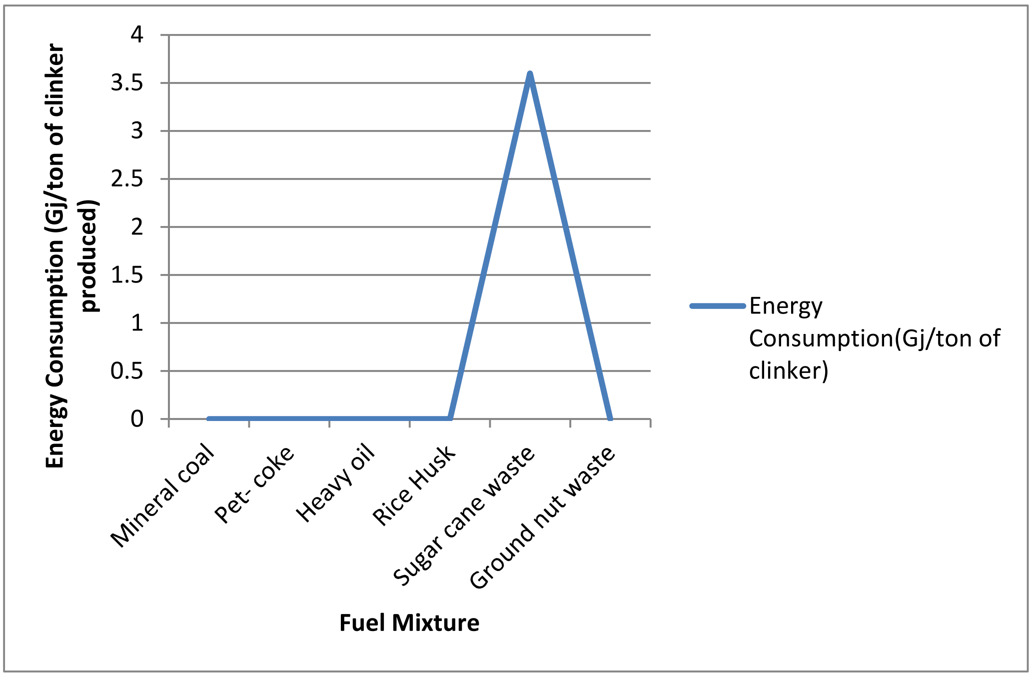
Table 4. 50 Runs Simulation result for Restriction, using $S = 0.38cm^2/g$

Restriction	PSO	GA	PS
X_1	1.2547	1.2383	1.2339
X_2	0.1687	0.1942	0.1317
X_3	0.0468	0.0038	0.0419
X_4	3.9357e-04	1.3710e-04	0
X_5	9.3586e-07	7.9050e-05	0
X_6	4.6072e-05	4.1912e-04	1.3878e-17
X_7	4.6108e-06	2.3625e-04	6.9389e-17
X_8	4.3800e-11	0.03616	5.5511e-17
X_9	0.2326	7.7721e-06	0
X_{10}	6.7502e-07	0.1995	0.2022

Using the above results on 50 runs simulation model using $0.38cm^2/g$, the restriction in equation (4) to (20) are all satisfied. PSO uses sugar cane waste (X_9) 100% as a major source of fuel in kiln firing for clinker production, PS uses 100% Ground nut shell (X_{10}) in the kiln firing. GA uses 0.062% Mineral coal(X_5), 0.4% Pet coal(X_6), 0.3% Heavy oil, 13.5% Rice husk(X_8), 85.8% Ground nut shell (X_{10}) in the kiln firing. Results are substituted into equation (1) to (20). The results are summarized in table 4

Table 5 Summary of Result.

Objective Function Cost (C) = 22.9646 US$ = 4945(naira)	Oxides composition in clinker (%)	Modulus	Specific heat consumption = 3.6Gj/ton of clinker
X_1= 1.2495 X_2 = 0.1687 X_3 = 0.0436 X_4 = 0.0120 X_5 = 7.4977e-06 X_6 = 4.197e-08 X_7 = 3.898e-7 X_8 = 5.4881e-07 X_9 = 0.2326 X_{10} = 5.64749e-06	CaO =65.42 SiO = 22.65 Al_2O_3 = 4.5 Fe_2O_3 = 3.4 MgO = 1.01	M.S = $((SiO_2/(Fe_2O_3 + Al_2O_3)) = 2.9$ M.A=$(Al_2O_3/Fe_2O3) = 1.3$ LSF = $(((CaO+0.75)/((2.8SiO +(1.18Al_2O_3 *0.68Fe_2O_3)) *100\% = 93.3\%$ S.R = $(SiO_2/((Fe_2O_3+ Al_2O_3)) = 2.87$ A.R = $(Al_2O_3/Fe_2O_3) = 1.3$	Mineral Coal X_5 =0.00021 Pet Coke X_6 = 0.000014 Heavy oil X_7 = 0.000017 Rice Husk X_8 = 0.0000074 Sugar cane waste X_9 = 3.6 Ground nut shell X_{10} = 0.0001



Results on Quality of Cement

The research results met the following requirement for a good Ordinary Portland Cement as these quality ranges for C_3S (35-70%), C_2S(20-45%),C_3A(3-18%),C_4AF(1-15%), CaO (0.5-2%)), low cost of clinker production.

$$C_3S = 4.07\ CaO - 7.6\ SiO_2 - 6.72\ Al_2O_3 - 1.43\ Fe_2O_3 = 59 \quad (21)$$

$$C_2S = 8.6\ SiO_2 + 5.07\ Al2O_3 + 1.08\ Fe_2O_3 - 3.07\ CaO = 20.4 \quad (22)$$

$$\text{Or } 2.87\ SiO_2 - 0.754\ C_3S$$

$$C_3A = 2.65\ Al_2O_3 - 1.69\ Fe_2O_3 = 6.2 \quad (23)$$

$$C_4AF = 3.04\ Fe_2O_3 = 10.336 \quad (24)$$

The results in the above solution correspond to a final clinker composition, satisfying all objective function, constraint and restriction in the equation, with all parameters within their allowable range. The solution for the optimization model is a function of the specific heat consumption and of the operational and environmental restrictions.

Conclusion

In cement production equipment optimization, the operating rate is different from design rate of the equipment. The design rate gives room for increasing or decreasing the feeding phase for the raw meal and the fuel usage in a rotary kiln, it also allows some freedom for change in the composition of raw meal (raw mix and corrective materials) and fuel consumption. The aim is to minimize cost of production without losing the quality of the final production, prolong the life of the equipment, while satisfying the environmental and operational restriction. The alternative fuel used is an agricultural waste (sugar cane waste, ground nut shell and rice husks) and primary fuel are mineral coal, pet-coke and heavy oil. These Agricultural wastes present a great potential use in the production of cement via rotary kilns.

The solution to this optimization problem finds composition values for the production constraints. Which will result is a cement production with low free lime (CaO) 0.5-1.5, less environmental pollutants and good quality cement production.

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