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Development Of A Model For Optimal Utilization Of Raw Material In Cement Production Planning Process

Engr. Ogbeide, S.O (Ph.D)
Ambrose Alli University,
Faculty of Engineering and Engineering Technology,
Department of Mechanical Engineering,
Ekpoma, Edo State, Nigeria

Omorodion, I. I.
Department of Production Engineering
Faculty of Engineering and Engineering Technology,
Ambrose Alli University,
Ekpoma, Edo State.

***Abstract*—This study introduces the development of a model and its optimal application in the utilization of raw material in cement production planning process, and the goal is to develop a model for raw material determination in cement production process in order to meet optimum production. The developed model will be particularly of great assistance to new comers who are not familiar with the field and will facilitate them in gaining a better understanding of the type, quality and quantity of raw material for cement production process and in making decisions about any necessary actions. The developed model is versatile in the sense that it quickly generates results which hasten decision making process, and the quantity of the raw material is also projected accurately, bearing in mind the type of cement to produce at any giving period.**

Keywords—cement, optimal utilization, raw material, planning process

INTRODUCTION

The use of cementing materials is very old. The ancient Egyptians used calcined impure gypsum. The Romans made use of volcanic ash and burnt marble and later learned to add lime and water, sand and crushed stones to produce cement for their roads, bridges and buildings. The active silica and alumina in the ash combined with the lime to produce “pozzolanic cement”, extorted from the name of the village of ‘pozzuoli’, near vesuvius, where the volcanic ash was first found. The name pozzolanic cement is used till this day to describe cements obtained simply by grinding of natural materials at normal temperature (1).

The Middle Ages brought a general decline in the quality and use of cement, and it is only in the 18th century that an advance in the knowledge of cement came to limelight. John Smeaton, commissioned in 1756 to rebuild the Eddystone light-house, off the Cornish coast, found that the best mortal was produced when pozzolana was mixed with limestone containing a high proportion of clayey matter. By recognizing the role of the clay, hitherto considered undesirable, Smeaton was the first to understand the chemical properties of hydraulic lime (2).

There followed a development of other hydraulic cement, a material that hardens under water. This property and the related property of not undergoing chemical change by water in later life are most important and have contributed to the widespread use of cement as a building material.

The manufacturing scene today is undergoing a revolution. Infact the technology that had the greatest impact on the production system over the last decades is computer modeling. Modeling have important role to play in job shop and batch production manufacturing plants, which constitute an important portion of the total manufacturing activity. It may be remembered that traditional batch manufacturing suffers from drawbacks like low equipment utilization, long lead times, inflexibility to market needs, increased indirect cost and high manufacture cost. It is estimated that in conventional batch production methods, only 5 to 10% time is utilized on machines and the rest is spent on moving and waiting. Out of the total time on machine, only 30% is on machining, rest being on positioning, loading, gauging and idling (3).

Consequently, a need exists for adequate modeling cement production process in the manufacturing sector using feedback control, process control, planning and decision making to support manufacturing activities (4). Market demands have changed towards higher quality, shorter delivery times and lower product cost. To be competitive, it is necessary to reduce or completely eliminate material wastage in order to keep the manufacture cost as low as possible, hence the need to model the production process of cement.

The objectives of this research are to;

(i) ascertain the relevant raw material related to the planning of cement production process.
(ii) develop a mathematical model for optimal raw material utilisation in the cement production process.
(iii) Validate the developed model.

JUSTIFICATION OF STUDY

Cement manufacturing consists of many complex, capital and energy intensive processes including mechanical activities and chemical reaction on raw materials, yet, a vital industry for the modern society, where cement is used in almost all construction applications, such as homes, public buildings, roads, industrial plants, dams, bridges, and many other structures. Considering the rising costs of cement, and the failures of constructed roads and collapse of bridges and structures, thereby constituting health hazard, a study was carried out on cement and it is indisputable that the applications of a developed model in the cement manufacturing industry is a win-win situation where manufacturing costs is reduced, material waste are reduced, energy is conserved and human lives are saved from failures associated in the low quality cement produced using the conventional approach.

Developing a model for optimal utilization of raw material in cement production process has both economic and technological merit. The system will assist knowledge engineers to programme and make decision concerning the production process in the entire department so as to determine the production level, cost, and production constraint. In a country like Nigeria, where the shortage of cement is prominent coupled with the high cost of its importation, inflation, trade restriction and cash flow problems, the use of a model in the cement production process is justified that will provide a system devoid of wastage of raw materials, production capability and human resources. The model will effectively determine exact quantities of raw materials needed for optimal production processes through proactive process planning.

MAJOR RAW MATERIALS FOR CEMENT PRODUCTION

The major raw materials that are required for cement production are enumerated below. These materials are mixed in a proper proportion and burnt in a rotary kiln at a regulated temperature.

(i) Blasted Limestone

This is the first major raw material needed in cement production. The blasted limestone is obtained or produced in the quarry through blasting of the natural limestone on earth with the help or use of explosives.

(ii) Crushed Limestone

This is also likened to the blasted limestone, but the only different is that, it has been crushed to a recognizable size by a machine known as crusher. The crushed limestone is a reduced size of the blasted limestone.

(iii) Raw Meal

The raw meal is the dry powder obtained from the crushed limestone after raw milling.

(iv) Gypsum

This is another principal raw material for cement production. Gypsum can either be imported or obtained locally mainly from the Northern parts of Nigeria. Gypsum is added to cement production process so as to prevent the flash setting of cement when mixing.

(v) Red Alluvium

This is another featured raw material used by the Ewekoro Cement factory. It is lightly red in colour, and dried sand-like that is added for cement production in order to improve the fineness to touch and quality of the cement.

(vi) Clinker

The clinker is what is obtained when the raw meal is passed through the kiln at high temperature. Afterwards, a chemical reaction takes place and the raw meal fuses into hardball - like substance known as clinker. Other raw materials needed for the cement production of cement are:

- Coal for firming the kiln.

MODELS

Models are representation of abstract or reality. It is a basis for experimental investigation at lower cost and in less time than trying changes in actual systems and it has become widely accepted as a means for studying complex phenomena especially in the manufacturing process.

A model is the process of converting the verbal description and numerical data into mathematical expression, which capture the relevant relationships, goals and restriction (5). Models can be referred to as constructing a suitable representation of the problem specified, obtaining a solution for that representation and interpreting the solution in terms of the real situation (6). A task in modeling phase of a simulation study is the estimation of the system variable and parameter. This is commonly done by collecting data over some period of time and then computing a frequency distribution for the desired variable (7). A number of pitfalls await the un-suspecting researcher in the collection and interpretation of data. The cost in term of time, money and personnel can become prohibitive, the data may be incomplete or inaccurate, the data may contain unsuspected interdependencies, periodicities or complexities in the method of collection may introduce an inadvertent bias into the data.

This study carried out expose the major reasons for using or implementing a model

- Easy to use and less expensive.
- Require the user to organize for quality information
- Increase understanding of the problem
- Provision of systematic approach to problem solving
- Serves as a consistent tool for evaluation
- Increase decision making process
- Provide a standardized form for analyzing a problem.

Model may also imply some sort or idealization often embodying a simplification of details. In short, model is a ‘vehicle’ for arriving at a well-structured view of reality.

Modeling Cement Production Processes

The identified critical elements of cement production includes: the proportion of materials used for cement production; proportion of energy used for the production; capacity of the machines used for cement production and manpower required for the operations. But for the purpose of this study, effort will be concentrated on raw material development using a mathematical model.

Proportion of Materials for Cement Production

The proportion of material used per ton of the output cement is related as

$$M_i = \gamma_i^m C_e \qquad (1)$$

Where;

M_i, is the material of type i used per ton of the output cement

γ_i^m, is the material proportional factor per ton of output cement, and

C_e, is the quantity of cement output (ton)

Total quantity of materials needed per ton of processed cement is determined from

$$M_T = \sum_{i=1}^{\theta} M_i \qquad (2)$$

Where;

$i, \ldots, \theta$ is the counter for material type

Major Combination for Cement Production

Table 1 Input-Output Ratios in the Production Process

Parameter	Value
Gypsum (T)/(T) of cement	0.063
Cake (T)/(T) of cement	0.917
Red Alluvium (T)/(T) of cement	0.02
Clinker (T)/(T) of raw meal	0.7186
Cake (T)/(T) of raw meal	0.7186
Crushed limestone (T)/(T) of raw meal	1.15
Blasted limestone (T)/(T) of crushed limestone	1
Blasted limestone (kg)/(T) of Ammonium nitrate	9.285
Blasted limestone (kg)/(T) of Higher explosive	21.65
Coal (T)/(T) of Clinker	0.134
No of bags/ton of cement	20

The major raw material combinations for cement production process are clinker, gypsum and red alluvium, and their percentages are stated as follows: Clinker 91.7%, Gypsum 6.3% and Red Alluvium 2%

Table 1 shows the summary of input-output ratios in the cement production process. The input-output ratio is an extreme parameters of the process, and relates the input of the raw materials to the processed cement obtained from the designed production planning process. Data on raw materials was also collected from the cement industry.

Table 2: Data on Raw Materials for Cement Production between the Month of January to June, 2013.

Raw Materials	January (Period 1)	Febuary (Period 2)	March (Period 3)	April (Period 4)	May (Period 5)	June (Period 6)
Limestone (Tons)	106,312	109,536	120,660	112,420	113,818	102,212
Red alluvium (Tons)	2,142	2,177	2,391	2,265	2,274	2,056
Gypsum (Tons)	4,004	4,121	4,542	4,232	4,291	3841
Coal (Tons)	552,954	569,751	626,730	584,896	591,109	531,761

Source: (8)

Table 3: Data on Raw Materials for Cement Production between the Month of July to December, 2013

Raw Materials	July (Period 7)	August (Period 8)	September (Period 9)	October (Period 10)	November (Period 11)	December (Period 12)
Limestone (Tons)	114,089	110,469	110,389	114,069	110,389	114,069
Red alluvium (Tons)	2,096	1,803	1,885	2,095	2,027	1,818
Gypsum (Tons)	4,347	3,740	3,907	4,348	4,107	3,770
Coal (Tons)	558,114	564,651	619,770	555,489	601,109	631,761

Source: (8)

Analysis of the Data Collected

The data collected was analysed using the mathematical model developed in the study. From the data obtained from Ewekoro cement company, the input-output ratio parameters of the raw materials for cement production process including gypsum (G), cake (K), red alluvium (R), clinker (C), raw mill (RM), crushed limestone (CL), blasted limestone(BL), ammonium nitrate(AN), limestone blasting explosive (ER), coal (CO) and number of bags per ton cement (NB) are related using data on Table 1

RESULTS

Input Material and Processed Cement Ratio Analysis

Based on mathematical model developed, the fraction of gypsum G required per tonnage of processed cement C_e is expressed as Eqn. 3

$$G = 0.063C_e \quad (3)$$

While the fraction of cake K required per tonnage of processed cement C_e is expressed as Eqn. 4

$$K = 0.917C_e \quad (4)$$

Similar expression is obtained for red alluvium R as

$$R = 0.02C_e \quad (5)$$

Since cake K, and clinker C are similar, then

$$K = C \quad (6)$$

From which

$$C = 0.917C_e \quad (7)$$

Similarly tonnage of blasted limestone BL required for cement production process is equal to crushed limestone CL. This is expressed as in Eqn. 8

$$BL = CL \quad (8)$$

However, the relationship between crushed limestone and raw mill tonnage for cement production process is expressed as in Eqn. 9

$$CL = 1.15\ RM \quad (9)$$

Similar expression is gotten for the blasted limestone, Therefore

$$BL = 1.15\ RM \quad (10)$$

But ammonium nitrate AN required in the cement production process is a fraction of blasted limestone and expressed as in Eqn. 11

$$BL = 9.285\ AN \quad (11)$$

Crushed limestone required for production process is similar to the one in Eqn. 11

$$CL = 9.285\ AN \quad (12)$$

The heat energy from coal Co is also required for the heating of the mixed material in the kiln to formed cake or clinker. The quantity (tons) of coal C_o required depends on the clinker C tonnage expected and is expressed as:

$$C_o = 0.134C \quad (13)$$

By substituting for C in Eqn. 13 with Eqn. 12, expression in Eqn. 14 based on per ton of processed cement C_e is obtained as

$$C_o = 0.134 \times 0.197\ C_e \quad (14)$$

That is, $C_o = 0.1229C_e$ (15)

Number of bags of cement NB produced per ton of processed cement C_e is expressed as

$$NB = 20\ C_e \quad (16)$$

The system's material relationship between raw mill quantity (ton) and the clinker quantity in the production process is mathematically formulated as

$$C = 0.7186\ RM \quad (17)$$

Since clinker C and cake K are similar, then the same expression holds for both.

Therefore for equal RM

$$K = 0.7186\ RM \quad (18)$$

By making RM the subject of the formula in Eqn. 18

$$RM = \frac{C}{0.7186} \quad (19)$$

The substituting the value of C in Eqn. 17 into Eqn. 19, the expression in Eqn 20 is obtained as raw mill required per tonne of processed cement.

$$RM = \frac{0917\ C_e}{0.7186} \quad (20)$$

By appropriate substitution, the relationship between the crushed limestone per ton of the processed cement is expressed as

$$CL = 1.15\left[\frac{0.917\ C_e}{0.7186}\right] \quad (21)$$

$$Similarly\ BL = 1.15\left[\frac{0.917\ C_e}{0.7186}\right] \quad (22)$$

The expressions, Eqns. 20 and 21, shows that the same quantities (tons) of blasted and crushed limestone are required for the production of one ton of cement. The quantity of ammonium nitrate (tons) AN required in cement production process is obtained by making AN the subject of the formulae in Eqns. 9 and 11. These are expressed as Eqns. 22 and 24, respectively. Eqns. 22 and 26 are gotten respectively for the two scenarios through appropriate substitution for process parameters BL and CL, which expressed quantity of ammonium nitrate required per ton of the processed cement.

$$AN = \frac{BL}{9.285} \quad (23)$$

$$= \frac{1.15 \times 0.197\ C_e}{9.285 \times .7816} \quad (24)$$

$$Similarly\ AN = \frac{CL}{9.285} \quad (25)$$

$$AN = \frac{1.15 \times 0.197\ C_e}{9.285 \times .7816} \quad (26)$$

The summary of the analysis of raw materials input-output ratios per ton output of the processed cement is presented in Table 4

Table 4: Results of Ratios of Raw Material Input to Processed Cement

Process parameter ratios	Value
G/C_e	0.0630
K/C_e	0.9170
R/C_e	0.0200
C/C_e	0.9170
C_o/C_e	0.1229
NB/C_e	20.0000
RM/C_e	1.2761
CL/C_e	1.4675
BL/C_e	1.4675
AN/C_e	1.5806

Table 5: Developed Model on Raw Materials for Producing 1 Million Bags of Cement

Raw Materials	Quantity Available (Tons) (WAPCO)	Quantity Required (Tons) (Developed CPPES)	Remark
Limestone	50,000	73,421	23,421 more tons needed
Red aluvium	10,000	1,350	Excess of material (Wastage)
Gypsum	2,000	2,799	799 more tons needed

Table 6: Developed Model on Raw Materials for Producing 2 Million Bags of Cement

Raw Materials	Quantity Available (Tons) (WAPCO)	Quantity Required (Tons) (Developed CPPES)	Remark
limestone	50,000	146,842	96,842 more tons needed
Red alluvium	10,000	2,701	Excess of material (Wastage)
gypsum	2,000	3598	1,598 more tons needed

Verification by Test Cases

Apart from various test carried out during the development of the CPPES modules, there were also some test cases carried for verification of the obtained result from the model. The test cases were performed throughout the development cycle to check for any system errors in the developed model, in order to enhance the system performance. Examples of some of the test cases are as follows.

(i)**"<u>RC-RAW MATERIAL MODULE" Test Case 1</u>**

Significant input:

If targeted number of cement to produce is 500,000 bags

And available quantity of limestone is 20,000 tons

And available quantity of red aluvium is 15,000 tons

And available quantity of gypsum is 5,000 tons

And available quantity of coal is 20,000 tons

<u>Output by "RC-RAW MATERIAL":</u>

The available limestone is 20,000 tons
Required limestone should be 367,107 tons
167,107 tons of limestone will be needed to be added to the available limestone
The available red aluvium is 15,000 tons
Required red aluvium should be 67,543 tons

Hence the available red aluvium will be sufficient for the production process and it is advised that the excess be kept for future use.

The available gypsum is 5,000 tons
Required gypsum should be 13,995 tons
8,995 tons of gypsum will be needed to be added to the available gypsum

The available coal is 20,000 tons
Required coal should be 1,893,939 tons
1,873,939 tons of coal will be needed to be added to the available coal
Output correct? Yes.

Summary on Quantity and Quality Control of Raw Material

A summary of quantity and quality of result are highlighted;
Coal – the requirement for coal was met
Red Aluvium – the requirement for red alluvium was in excess in the production process
Limestone – there was a deficit of between 758 and 952 tons of limestone
Gypsum - there was a deficit of between 77 and 90 tons of Gypsum
Explosive - there was a deficit of between 39 and 48 tons of explosives

Note that the developed model generate and send an alert signal report through machine sensors to the control room each time there is deficit of raw material at any point in the production process.

CONCLUSIONS

The developed model for determining the quality and quantity of raw material has shown to be generally successful and have performed well in meeting the purpose and objectives of the study. The developed model is effective and accurate as it was able to determine the accurate quality and quantity of raw material needed for producing a desired quantity of cement.

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