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Minimization of variation in clinker quality

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Abstract: Cement quality is typically assessed by its compressive strength development in mortar and concrete. The basis for this property is a well-burned clinker with consistent chemical composition and free lime. The main reason for the clinker free lime to change in situation with stable kiln operation is variation in the chemical composition of the kiln feed. This variation in chemical composition is related to raw mix control and the homogenization process. To ensure a constant quality of the product and maintain a stable and continuous operation of the kiln, the attention must be paid to storage and homogenization of raw materials and kiln feed. Due to variations in the kiln feed chemical compositions that affect its burnability and the fuel consumption. The raw materials for Portland cement production are the mixture (as fine powder in the 'Dry process') of minerals containing calcium oxide, silicon oxide, aluminum oxide, ferric oxide, and magnesium oxide. The homogeneity of feed chemical composition has an important relationship to fuel consumption, kiln operation, clinker formation and cement performance. In this regard an attempt made to deals with the mixing of raw materials process and estimation of composition of raw mill feed, kiln feed, as well as formed clinker, which were done successfully through various results obtained experimentally and various steps have been taken to reduce these variations in clinker quality.

Keywords: Lime Saturation Factor, Silica Ratio, Alumina Ratio

1. Introduction

Portland cement (often referred to as OPC, from Ordinary Portland Cement) is the most common type of cement in general use around the world because it is a basic ingredient of concrete, mortar, stucco and most non-specialty grout. It is a fine powder produced by grinding Portland cement clinker. Portland cement clinker is a hydraulic material which shall consist of at least two-thirds by mass of calcium silicates (3CaO.SiO2 and 2CaO.SiO2), the remainder consisting of aluminium- and iron-containing clinker phases and other compounds. There are three fundamental stages in the production of Portland cement [1]: (a) Preparation of the raw mixture, (b) Production of the clinker, (c) Preparation of the cement

The raw materials for Portland cement production are the mixture (as fine powder in the 'Dry process') of minerals containing calcium oxide, silicon oxide, aluminum oxide, ferric oxide, and magnesium oxide. The raw materials are usually quarried from local rocks, which in some places is already practically the desired composition and in other places require addition of the clay and limestone, as well as iron ore, bauxite or recycled materials [2, 3]. The cement clinker is a coarse agglomerate of synthetic materials that is produced by burning a raw meal consisting of a selected mixture of raw materials at very high temperature in a specialized kiln system. The clinker mostly appears as a dusty granular mixture of dark grey/black particles up to 40mm in size. The cement is prepared by grinding the clinker in a coal mill. Recent studies have shown that the cement clinker variations have a greater effect on the workability and strength of cement. The unexpected variations may lead to serious disturbances in production in the form of poor compaction, too low early strength and strand slippages. This is causing increased waste in production of cement and considerable economical losses [4].

The homogeneity of feed chemical composition has an important relationship to fuel consumption, kiln operation, clinker formation and cement performance. Cement quality is typically assessed by its compressive strength development in mortar and concrete [5, 6]. The basis for this property is well-burned clinker with consistent chemical composition and free lime. There are only two reasons for the clinker free lime to change in a situation with stable kiln operation: variation in the chemical composition of the kiln feed or variations in its fineness [7]. Variations in fineness depend on possible changes in raw materials or in operation of the raw mill. Variation in chemical composition is related to raw mix control and the homogenization process. To ensure a constant quality of the product and maintain stable and continuous operation of the kiln, attention must be paid to storage and homogenization of raw materials and kiln feed [8].

Cement quality is typically assessed by its compressive strength development in mortar and concrete. The basis for this property is well-burned clinker with consistent chemical composition and free lime [9]. There are only two reasons for the clinker free lime to change in a situation with stable kiln operation: variation in the chemical composition of the kiln feed or variations in its fineness. Variations in fineness depend on possible changes in raw materials or in operation of the raw mill [10]. Variation in chemical composition is related to raw mix control and the homogenization process. To ensure a constant quality of the product and maintain stable and continuous operation of the kiln, attention must be paid to storage and homogenization of raw materials and kiln feed [11, 12]. It focuses on to study the role of raw mix composition control and the homogenization process. Variations in the kiln feed chemical compositions affect its burnability and eventually the fuel consumption [13]. So the calculations done to give a good raw feed composition to the kiln to allow soft burning inside kiln [14-17]. This article is focused on the minimization of variation of clinker quality by cement modulus.

2. Material and Methods

2.1. Calculation

For a long time cement was manufactured on the basis of practical experience collected from the process of production. When comparing chemical analyses of Portland cement (Feed raw materials and/or clinker) it was found that certain relations exist between the percentage of lime on the one hand and the combination of silica, alumina and iron oxide on the other. These moduli are [18];

2.1.1. Lime Saturation Factor (LSF)

It is the ratio of the actual amount of lime to the theoretical lime required by the other major oxides in the raw mix or clinker. When LSF>100% the ordinary clinker will always contain some free lime. When firing a kiln with coal containing ash the LSF of the raw meal can be higher than 100%. The incorporation of ash into the clinker lowers the LSF because of silica, alumina &iron content of the ash. To monitor the burning process the amount of unreacted CaO free in the clinker is analyzed. The lower the free lime the closer the reactions are to completion, however too low free lime can also indicate too hard & uneconomic burning. The free lime target is normally about 0.5-1.5%CaO free.

LSF is calculation and range is follow:

$$LSF = \frac{100(CaO + 0.75MgO)}{2.85SiO_2 + 1.18Al_2O_3 + 0.65Fe_2O_3}$$

Range = 92±1

2.1.2. Silica Moduli(SM)

The amount of melt phase in the burning zone is a function of SM. When SM is high the amount of melt is low & vice versa. Therefore, when the SM is too high the formation of nodules & the chemical reactions may be too slow making it difficult to operate. The higher the SM the harder it is to burn. When SM is too low there may be too much melt phase & the sulphur coating can become too thick.

SM can calculate as:

$$SR = \frac{SiO_2}{Al_2O_3 + Fe_2O_3}$$

Range = 2.1±0.1

2.1.3. Alumina Moduli (AM)

The temperature by which the melt form depends on the AM. The lowest temperature is obtained when the AM is approximately 1.6 which is the optimum regarding formation of clinker minerals & nodulisation. The AM also affects the colour of clinker & cement. The higher the AM the lighter the colour of the cement.

Alumina Moduli are calculated as:

$$AR = \frac{Al_2O_3}{Fe_2O_3}$$

Range = 1.2±0.2

2.2. Process

The moduli are control by two process (a) Raw mill (b) Kiln

2.2.1. Raw Mill Process

Raw mill is used for grinding and drying of raw material. It contains rotating table on which four rollers are pressed by hydraulic pressure with a certain clearance required for grinding. The ground product is called raw meal. The purpose of this equipment is drying and grinding of cement raw material. Material is transported to constant feed weigh from hopper and to vertical roller mill through belt conveyors, triple gate and ground and dried with exhaust gas from the rotary kiln. Ground material is conducted to separator located in the upper part of the mill, grinding on the ventilating current generated by exhaust fan and classified by the centrifugal force of a rotor into fines and coarse. In addition coarse material is fallen on the table and ground again.

2.2.2. Kiln Process

Kiln is used for further increase in temperature of the material which comes from the preheated to increase the temperature of raw meal from 300ºC-400ºC to 1400ºC-1500ºC. At kiln outlet there is flame of fire, continuously increasing the temperature of the kiln or it maintains the inner temperature of the kiln. It consists of a one coal burner and air burner for firing of coal, here firing of coal is made by diesel. Successive chemical reactions take place in kiln as the temperature of raw meal rises. On the left-hand is the feedstock comprising, in this case, calcite (CaCO3), quartz (SiO2), clay minerals (SiO2-Al2O3-H2O) and iron oxide (Fe2O3). Up to a temperature of about 700°C, activation through the removal of water and crystal structure changes take place. Within the temperature range 700-900°C, decarbonation of the calcium carbonate occurs, together with the initial combination of the alumina, ferric oxide and of activated silica with lime. From 900 to 1200°C, Belite forms. Above 1250°C and more particularly above 1300°C, the liquid phase appears and this promotes the reaction between Belite and free lime to form Alite. During the cooling stage on the right-hand side of the diagram, the molten phase goes to a glass or, if cooling is slow, the C3A crystallizes out and in extreme cases the Alite dissolves back into the liquid phase and reappears as secondary Belite. Alkali sulfates condense out as a separate phase during the cooling process

2.3. Major Steps in Operation

(a) If the pyroprocessing time is too short or the temperature too low, combination of the raw material components may be less complete and some free unreacted lime will be present. The process is shown in Fig. 1.

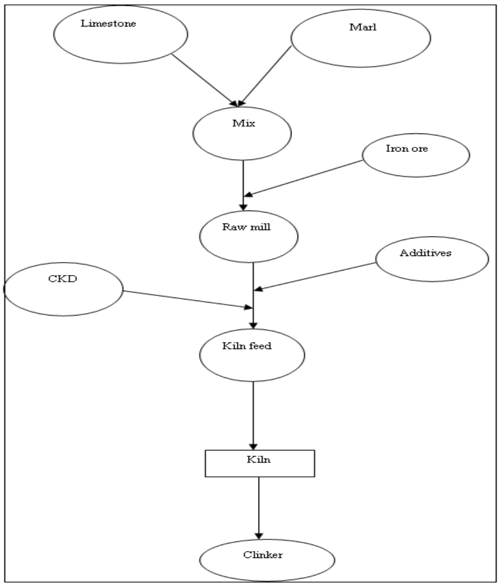

Fig 1. *Simplified process schematic for mixing process of raw materials*

(b) Insufficient control of the raw mixture and its blending will cause large variations in the chemical composition of the kiln feed.

(c) If the kiln is operated at constant material residence time and temperature, that will cause variations in clinker composition, including free lime. This is important because the free lime is usually used as the process parameter to indicate how well the clinker is burned.

(d) Assuming changes when operators are not available at that particular time.

(e) When the kiln is operated on the hot side, alkalis and sulfate become more volatile. This, in turn, might increase the possibility for build-ups in the cooler parts of the kiln system.

(f) Hard burning tends to cause low clinker porosity, large crystals of Alite, and often contributes to generation of dust instead of good, nodular clinker. It also slows down the cooling process, both because the maximum temperature is higher, and because the low-porosity clinker is more difficult to cool.

(g) Reduced clinker porosity can make the clinker harder to grind, increasing finish mill power consumption or reducing mill production.

3. Results and Discussion

3.1. Effect of Raw Mill Mixing

Purpose of calculating the composition of the raw mix is to determine the quantitative proportions of the raw components, in order to give the clinker the desired chemical and mineralogical composition. For this, there are many methods of calculations. The basis of calculation is the chemical composition of the raw materials. So, the built program done based on (Alligation alternate method), this method allows the determination of the proportion of two raw material components [19]. In this case, LSF should be in the range of 92±1, but minimum value obtained is 91.43 and it goes to a maximum of 106.74, average it remains 99.81. Hence deviation observed in LSF value for raw mill is 3.00, which is shown in Fig. 2. To determine the silica and alumina ratio reading was take for 24 hours, which is shown in Fig. 3. It was observed from the fig. that S/R minimum value obtained is 2.29 and it goes to a maximum value of 2.75, on average it remains 2.47. Hence deviation observed in S/R value is 0.17. The minimum AR value obtained is 1.00 and it goes to a maximum value of 1.36, average it remains 1.27. Hence deviation observed in A/R value is 0.07. The importance of the calculation is preparation a kiln feed mixture with a suitable content of calcium carbonate (76-76.5%) to avoid hard burning process at high content of calcium carbonate content, as well as to avoid friction resulting from the silica on the formed coat on the internal kiln wall when calcium carbonate content is low.

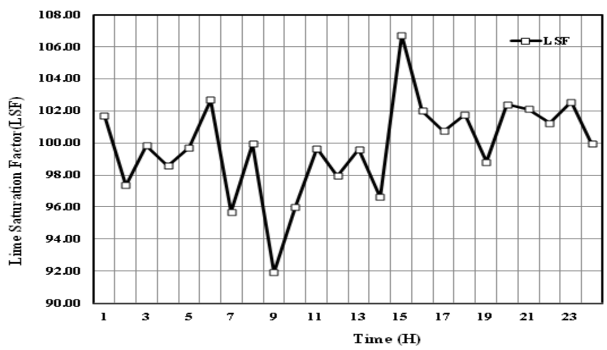

Fig 2. *Effect of raw mill on LSF with time*

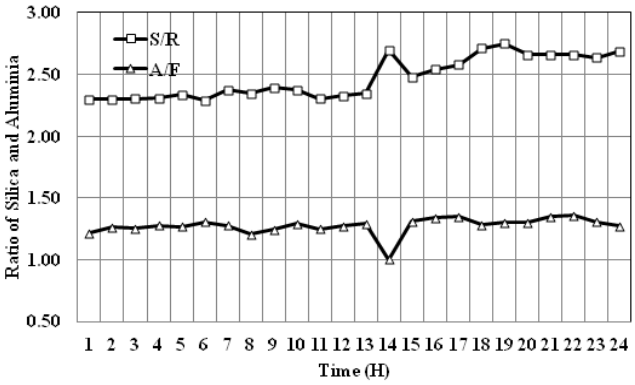

Fig 3. Effect of raw mill in silica and alumina ratio

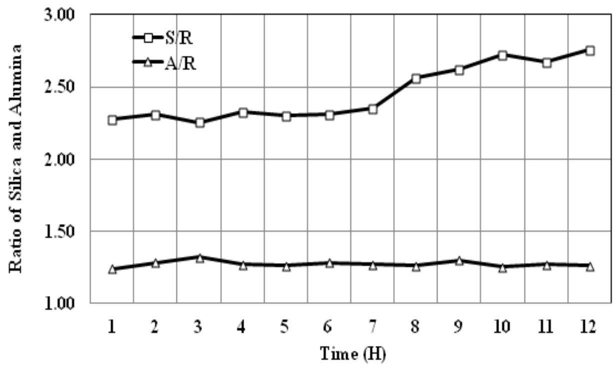

Fig 5. Effect of kiln feed on Silica and Alumina ratio

3.2. Effect of Kiln Feed

Variations in the kiln feed chemical composition affect its burnability and eventually the fuel consumption. To determine the effect of kiln on the formation LSF and SR and AR are shown in Fig. 4 and 5. From the fig.4 it was seen that minimum value of LSF is 98.68 and maximum value is 105.37 with an average of 101.50 so deviation was 2.17 is respectively. From fig. 6 it was observed that minimum silica ratio is 2.25 and maximum value is 1.32 with an average of 1.27 so deviation was 0.19. The minimum alumina ratio value is 1.24 and maximum value is 1.32 with an average of 1.27 so deviation of 0.02 was observed. It might be due fuel penalty for burning to an average of 0.8% free lime because of large variability instead of an average of 1% can easily be on the order of 4% [12]. When the kiln is operated on the hot side, alkalis and sulfate become more volatile. This, in turn, might increase the possibility for build-ups in the cooler parts of the kiln system. In severe cases, controlling the kiln may become difficult because of surges of the material through the kiln. Hard burning tends to cause low clinker porosity, large crystals of Alite, and often contributes to generation of dust instead of good, nodular clinker [16, 17]. It also slows down the cooling process, both because the maximum temperature is higher, and because the low-porosity clinker is more difficult to cool [11].

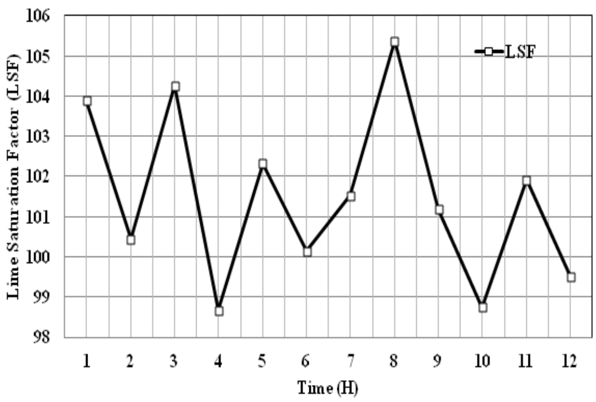

Fig 4. Effect of kiln feed on lime saturations factor

4. Effect of Burning Property on Clinker

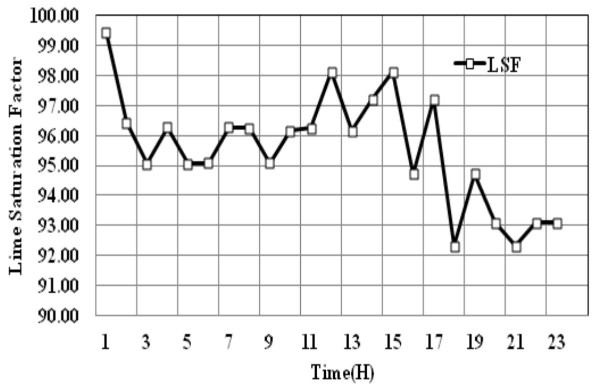

Fig 6. Effect of clinker formation on lime saturations factor

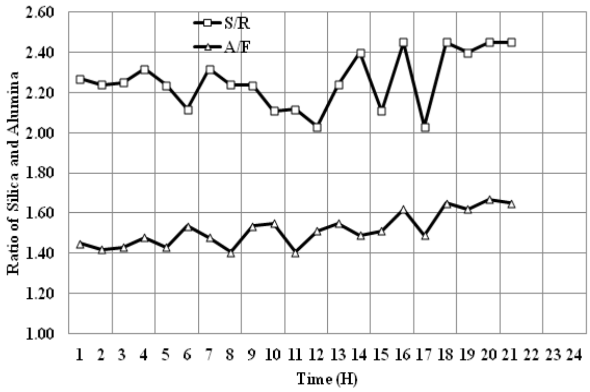

Fig 7. Effect clinker formation of on Silica and Alumina ratio

Cement quality is typically assessed by its compressive strength development in mortar and concrete. The basis for this property is well-burned clinker with consistent chemical composition and free lime. There are only two reasons for the clinker free lime to change in a situation with stable kiln operation: variation in the chemical composition of the kiln feed or variations in its fineness. Variations in fineness depend on possible changes in raw materials or in operation of the raw mill. Variation in chemical composition is related to raw mix control and the homogenization process. To ensure a constant quality of the product and maintain stable and continuous operation of the kiln, attention must be paid to storage and homogenization of raw materials and kiln feed. It focuses on to study the role of raw mix composition control and the homogenization process. Variations in the kiln feed chemical compositions affect its burnability and eventually the fuel consumption [20]. To studied the effect of clinker quality on LSF, silica and alumina ratio was done at different interval of time are shown in fig. 6and 7. I t was observed from fig. 6 the minimum value of LSF goes to 92.32 and maximum value observed is 99.5 with an average of 95.85 so deviation observed in is 1.99 respectively. It seen that from fig. 7 minimum value of silica ratio reach to 2.03 and maximum was observed 2.45 with an average of 2.26 so deviation observed is 0.13. The minimum alumina ratio value was 1.41 and maximum value observed was 1.67 with an average value of 1.52 so deviation observed in the value of A/R is 0.09. So the calculations done to give a good raw feed composition to the kiln to allow soft burning inside kiln.

5. Formation of C3S and Cao

The cement clinker is composed of four main phases: C3S, C2S, C3A and C4AF where in the standard cement chemistry the notation C stands for CaO, S for SiO2, A for Al2O3 and F for Fe2O3. The setting and hardening of the cement paste are the results of complex reactions, called hydration reactions, between clinker phases and water. In a simplified view, the main phases of the microstructure of the cement paste are calcium silicate-hydrate (C-S-H), Portlandite (CH), Aluminates (AL), anhydrate clinkers (CK) and macro-porosity (V). More details about the microstructure of cement paste are presented in [16]. The homogenization method needs the evaluation of the volume fractions of different constituents of the microstructure of cement paste. These volume fractions can be evaluated by knowing cement composition, water-to-cement ratio and degree of hydration, using the method presented by Bernard et al. [21] which is explained in details in [6]. This method assumes simple stoichiometric reactions for the hydration of the four dominant compounds in Portland cement. The complete set of chemical reactions is presented in [22]. The following relations are studied on fig. 8 and 9, It was observed that percentage of C3S should be in the range of 50-65%. The minimum value 44.72 and maximum value goes to 62.94 with an average of 54.94 and deviation of 5.58 respectively. Percentage C3S is known as Alite contributes to early strength of cement. It is resistant to sulphur attack. High content of C3S will increase strength of clinker and cement at all ages. For percentage of CaO it seen that the minimum value 0.89, maximum 3.08, average 1.77, and the deviation was 0.68 respectively. So it can be concluded that percentage of free lime should be very small in order to achieve good burnability of coal in kiln.

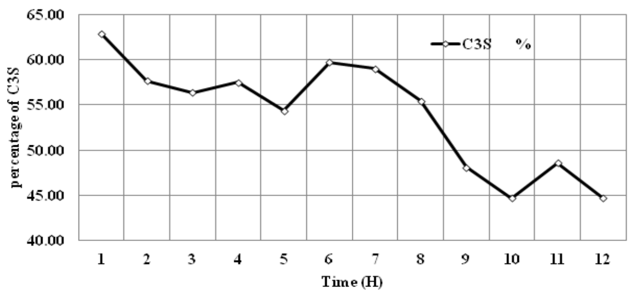

Fig 8. *Formation of C3S(%) with respect to time*

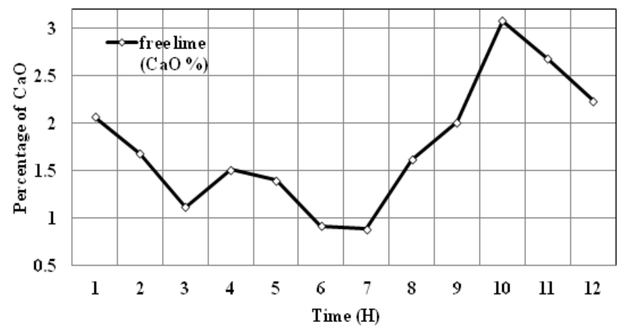

Fig 9. *Formation of Cao (%) with respect to time*

6. Conclusion

From all the above study it was concluded that cement module Lime saturations factor (LSF), Silica ratio (SR) and Alumina ratio (AR) and variations in clinker quality on the limit. It can be decreased by carrying out various steps at different level which reduces the deviations of blending efficiency, raw mill feed, kiln feed and clinker compositions and its minerals.

Following are results are obtained clinker quality variations:

- Higher amount of sandstone is hard to burn in kiln because it consumes large amount of coal and it even increases % ash content and free lime. So % age of sandstone initially was 5-6% in raw mix which is now reduced to a negligible amount.
- Percentage of quartz in sandstone is about 92%. Quartz is hard to burn. So % of quartz is decreased automatically in reducing % age of sandstone.
- Raw mill residue of 90µ sieve was initially 24% which is now reduced to 10-11% and residue on 212µ sieve is negligible.
- Percentage of C3S content in clinker in increased. Alite hardens the cement faster and contributes to early strength formation. It resistant to sulfur attack hence high strength of C3S will increase the strength at all ages.
- Free lime content i.e. free CaO % to feed is decreased because free lime is hard to burn and high % of CaO causes increased % of ash content.
- In silo blending system of raw mill all 4 gates are kept open in fully working conditions.

- Alpine sieve method is applied. Alpine sieve is an automatic sieve analyzer which gives amount of residue obtained in a given product. It gives information about materials retained and materials obtained as residue. Previously this sieve analysis was done manually.

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