

Research Article

Process and Impact of Combustion on Cement Oxide Minerals: An Experimental Study

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Abstract: The main stages of the primary materials are that feed the furnaces to form the mineral compounds of cement, which are the stage of drying the materials from water at a temperature of 100 degree Celsius and moving to the crystallization area at a temperature of 550 degree Celsius. Thus, the free lime begins to break down the calcium carbonate by interacting with silica and clay compounds to form (C₂S) at a temperature 900 degree Celsius. In the transition region at a temperature of 1260 degree Celsius begins the formation of liquid compounds (C₃A, C₄AF), where the formation of a compound (C₂S) continues and begins to form a compound (C₃S). When the temperature rises at 1450 degree Celsius, the formation of the clinker is complete, and this depends on the quality of the blended raw materials that affect the life of the firing blocks and the fuel consumption. As for the silica coefficient, it has a major role in determining the clinker quality, as the best silica coefficient (2.7) was obtained, as well as the best coefficient of alumina (1.38), as well as obtaining the best lime saturation coefficient (0.96) and the percentage of magnesium oxide not exceeding 5 percent, thus stabilizing the ratio Magnesium oxide to form the best burning plants (108). The difference in the concentration of substances leads to an incomplete chemical reaction and this affects the size of the resulting crystals.

Keywords: Alite (C₃S), Belite (C₂S), Clinker Compounds, Free Lime, Metal Compounds.

1. Introduction

The cement industry depends primarily on burning primary materials, which are calcium oxides that interact with silica, alumina, and iron oxides with a temperature of 1450°C to produce clinker in ovens. This industry has evolved over time from the wet method to the semi-wet, semi-dry, dry method and the dry method with preheating. Therefore, the parts should line with materials that resist high temperatures to ensure the stability of the furnace ignition.

In industrial processes, high-temperature strong granules are common intermediate products (e.g., steel sinters, carbon coke, ceramic granules, and cement clinkers), which should cool down for further processing or

transportation. To improve the energy utilization efficiency, the thermal strength saved in high-temperature granules should be recovered effectively; shifting packed beds are commonly used for this motive [1]. Cement is a manufactured product made by using mixing a range of raw materials, such as lime, silica, alumina, and iron. In the remedy process, the usage of high temperatures to reap the proper product. The product is known as clinker cement.

The temperature was once influenced by means of the system of making cement clinker [2]. As the main components of cement consist of calcium aluminate with a mixture of calcium silicate [3]. Clinker is a semi-finished "cement" material by burning alumina, limestone, and clay [4], [5]. The materials that uses in the cement industry

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consist of a main part represented by limestone (calcium carbonate) as well as silica, clay, and iron sand. For the secondary part represented by basalt stone or primary and secondary gypsum as the main compounds for the cement industry are calcium oxide, silica oxide, aluminum oxide and iron oxide [6], [7]. In order to improve the quality of cement, raw materials must be selected within the required specifications for the quality of the cement used in building construction [8]. When the water is mixed with cement, the reaction is formed, thus forming multiple chemical compounds (C_3S , C_2S , C_3A , and C_4AF) [9]–[11]. Whereas the clinker reaction temperatures are within different levels [12].

Clinker reaction temperatures are within the following levels: 100-500°C: At this point the water evaporated and the clinker is dried, 500-600°C: dihydroxylation of clay $2SiO_2Al_2O_3 \cdot 2H_2O \rightarrow 2SiO_2 + Al_2O_3 + 2H_2O \uparrow$, 700°C: At this point the water evaporates and silicates are activated, 700-900°C: At this stage the main mixture consisting of alumina and ferric oxide removes calcium carbonate, 900-1200°C: The composition of the mixture is according to the chemical equation $2CaCO_3 + SiO_2 \rightarrow C_2S + CO_2 \uparrow$, >1250°C: The liquid phase (aluminate and ferrite) is formed, 1300 °C: In the liquid phase, C_2S is reacted with CaO to form C_3S at 1450°C: The reaction completes, alite (Ca_3SiO_5) and belite (dicalcium silicate Ca_2SiO_4) are scattered in several sizes-small limestones. The main materials needed for the manufacture of cement are those that contain a lot of silica (40-55%) and alumina (12-17%) [13].

To ensure the quality of cement, it depends on burning the clinker completely, by coordinating the chemical composition of the raw materials, and thus operating the oven in more stable conditions, depending on the homogeneity of the chemical composition of the burning raw materials, thus reducing the fuel consumption of the furnaces. Clinker is produced within the specifications required for the basic standards in the cement industry [14]. Clinker is formed through the formation of coarse raw materials and burned at very high temperatures. The granular clinker shape is often dark gray (black) and 4 cm in diameter, after which the clinker is ground. Figure 1 show the initial phases of clinker formation (Alite (C_3S) at (50-70%) in ordinary cement, as well as the formation of (Belite (C_2S) at (15-30%) for ordinary cement and aluminum formation (C_3A) at (5-10%) as well as forming iron at a rate (5-15%) [15]. Typically, fuel consumption depends on the homogeneity of the chemical composition of the materials involved in the formation of clinker, and consequently, the quality and performance of the produced cement, which are evaluated by the compressive strength of the concrete [12,13]. As the main characteristic of clinker is the burning of chemicals

(raw materials) in the oven with very high temperatures [18]. Therefore it is necessary to control and calculate the proportions of the raw materials feeding the furnaces, and thus the materials are burned smoothly [15, 16].

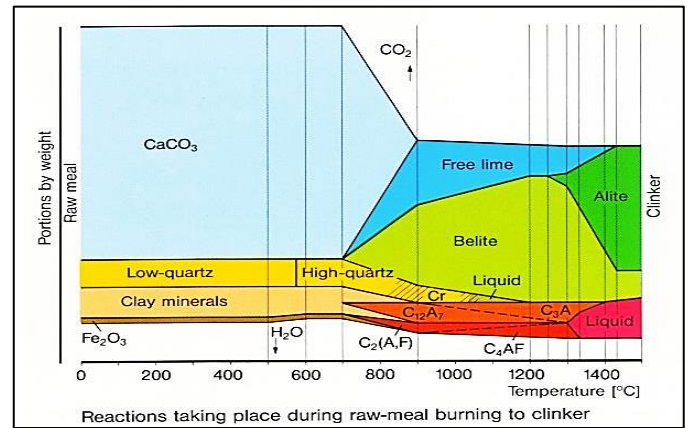


Figure 1. A schematic view of the clinker formation reactions

Therefore, this current work is done to shed light on the main elements of clinker production are silica, alumina, iron and calcium as well as the chemical reactions that occur for materials in different regions inside the furnace to form mineral compounds for cement (Kufa Cement Factory) from the oxides which are (C_2S , C_3S , C_3A , C_4AF) to benefit researchers who work in developing this field.

2. Research Methods

The burning process is known as the ease or difficulty in forming clinker pellets, which must be in accordance with known specifications, whereby the burning process plays an important role in the quality of cement in addition to the economic cost, as the geometrical shape of the burner has a major role in the stability of the flame of the burner [17,18]. As changing flame has an effect on the burning process, it must be taken into account the length of the flame, the shape, shape, color and direction of the flame, which are accurately described as the point of combustion [19,20]. We can summarize that the process depends on the chemical composition of the mixture of the raw materials, the chemical and physical specifications of the raw materials, the temperature, and the burning period. The main elements of clinker production are silica, alumina, iron, and calcium.

A practical study was conducted using a jet burner equipped with two types of fuel (liquid fuel + gaseous fuel) that burns the raw materials feeding the furnace according to specific temperatures and a suitable time to form a clinker dough, as inside the burning body contains side holes to supply the secondary air and also contains in the middle The body of the burner on a metal tube prepares the primary air to help abrade the fuel supplied from the

nozzle and also helps to mix air with natural gas to form a homogeneous mixture that helps to complete the burning homogeneously as shown in Figure 2 (a and b).

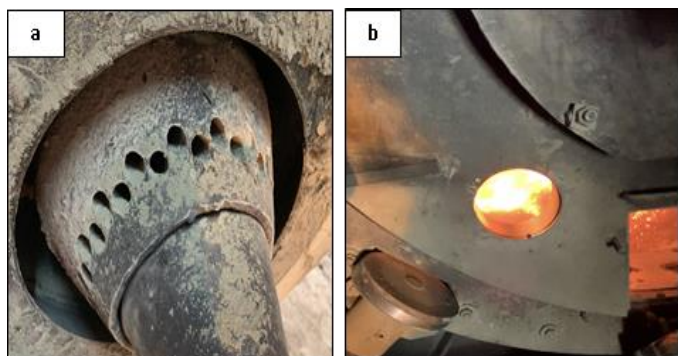


Figure 2. A practical picture show (a) the shape of the burner and (b) the burning process.

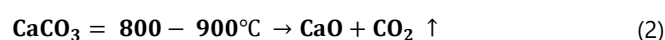
The steps to be taken when warming up the oven are running all the oven equipment for a period of time (2 hours) without rotation with the back fan gate closed to the oven and then the burner is fed with preheated black oil at a temperature (100-110°C) to break the carbon bonds and reduce the viscosity and thus the nozzle burner helps spread the fuel spray in a homogeneous manner with the air and thus homogeneous combustion, since igniting the oven for the first time requires a small amount of black oil, that is, less than 1 m³ and operating the front fan, while noting that oil does not fall on the bricks and then the oven is rotated 1/3 A cycle every 30 minutes, after which the oven rotates 1/3 cycle during 15 minutes after completing the warm-up process, after which the oil is gradually increased so that the difference in temperature per hour does not exceed (50°C) because the unexplained increase causes cracking or breaking in the walls of the oven. When the temperatures reach the required degrees, the rear fans run with the gates closed and then open gradually, then the oven is fed with a quantity of water (wet method) and then the rotation of the oven is shifted to the main motor where the position of the flame direction is set with respect to the raw materials feeding the oven with the oven speed control to ensure Raw materials remain inside the oven for a longer period of time, according to the required time. Then the processes of water drying are carried out by chains, preheating, slugging, combustion in a firehouse, and clinker cooling.

The amount of feeding should be constant and not fluctuating, as any fluctuation in nutrition leads to instability and lack of control over the burning process, as all the above steps are controlled by high-quality control systems equipped with sensors to know the problems during the work and complete maintenance for them quickly and periodically. The practical study was carried out at the Kufa Cement Factory in Iraq in cooperation with

the AL-Furat Al-Awsat Technical University, Najaf Technical engineering college, Najaf, Iraq, to reduce the excessive fuel consumption as well as the quality of the produced cement.

3. Result and Discussions

The practical results show that the effects of the chemical reactions that occur to the materials in different regions inside the furnace to form the mineral compounds of cement go through several important stages. Whereas, the stage of drying the materials, especially in the wet way by chains, where the water evaporates at a temperature of 100°C, and when the temperature rises to 500°C, the crystallization water evaporates. In the calcination stage, the calcium and magnesium carbonate are decomposed, as in the following chemical treatments:



In this stage, the free lime resulting from the decomposition of calcium carbonate begins by interacting with the clay and free silica compounds to form the first of the cement compounds, which is (C2S). Then the transitional phase begins with the formation of the compounds of the liquid (C3A) and (C4AF). Also, the formation of a compound (C2S) continues and the formation of a compound (C3S) begins at a temperature of 1260 ° C. The burning zone is the final region in which the formation of compounds (C2S, C3S) is completed at a temperature of 1450 ° C. The following graph shows the type of heat during reactions inside the oven, as shown in Figure (3).

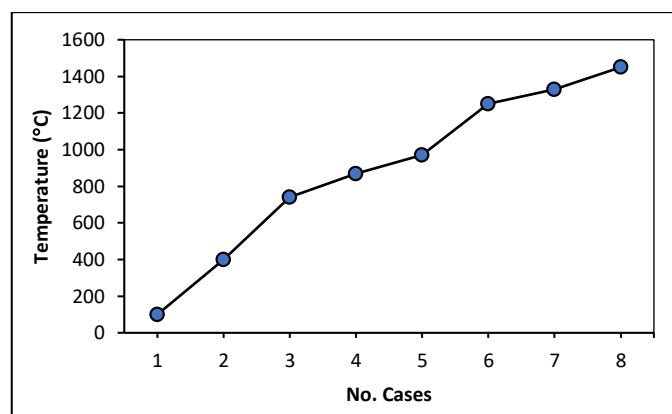


Figure 3. The reaction temperatures of the compounds

The reaction speed for cases from 1 to 5 in the decomposition of raw material compounds and the analysis of compounds in the form of oxide depends on

the transfer of heat to the solid materials, while the reaction speed for cases 6 and 7 depends on the reactions that occur between the compounds in the solid state, either in the last case number 8 it is the spread of the reactants in the liquid matter, as the Table 1 shows the reactions that take place inside the oven and are considered to be heat acquired.

Table 1. The quantities of heat gained

Reaction Temperature	Kilo Kcal/ kg clinker
Evaporating water combined with raw materials	20
Disintegration of dirt compounds	35
Carbon dissociation	475
Heat to produce clinker compounds	-130
Heat cooling raw materials combustion	-15
Total reaction temperature	385

These heaters depend on the chemical and mineral composition of the feedstock compounds. There is heat loss due to increased air in clinker coolers, radiation in the oven wall, clinker cooler and heaters. The percentages of results obtained for clinker mineral compounds were (C3S (Alite) 35 – 60 %), (C2S (Belite) 20 – 45 %), (C3A (Aluminate phase) 5 – 18 %) and (C4AF (Ferrite phase) 0 – 15 %). Therefore, the silica coefficient plays an important role in the economics of clinker production, as its height leads to the difficulty of burning, whereas its decrease causes obstruction to the movement of raw materials inside the furnace, and thus through the results that we have found that the best silica coefficient is 2.7, depending primarily on the nature of the raw materials from the chemical side And synthetic.

As for the alumina factor, it has an important role in the mineral compounds of clinker in the case of its decrease, the burning is simpler and therefore the temperature of the clinker decreases and increases the liquid material and vice versa leads to the difficulty of burning, and through the practical results show that the best factor for alumina is 1.38 to produce a good clinker and the highest percentage of liquid sins at the lowest temperature of production. The following diagrams illustrate the effect of silica and alumina coefficient on the temperatures inside the furnace to produce clinker compounds based on the chemical reactions of the raw materials. As for the lime saturation factor, it has an important role in burning operations. When it is above 1%, the burning process is very difficult, as the best coefficient was 0.96% to produce good quality.

With regard to magnesia, it helps to facilitate clotting in the fire house (furnace), and there is a change of 1% alkali or magnesia in the burning process, an increase or

decrease that has an effect of 3% of a change in the lime saturation coefficient, or 0.3%, a change in the silica factor for the same raw materials and the percentage should not increase MgO About 5%. Regard to the proportion of the liquid formed at the temperature of clinker formation, where the proportion of the formed liquid was calculated so that the ratio is 23 - 28% at a temperature of 1450°C according to the following Liquid phase (LP) formula:

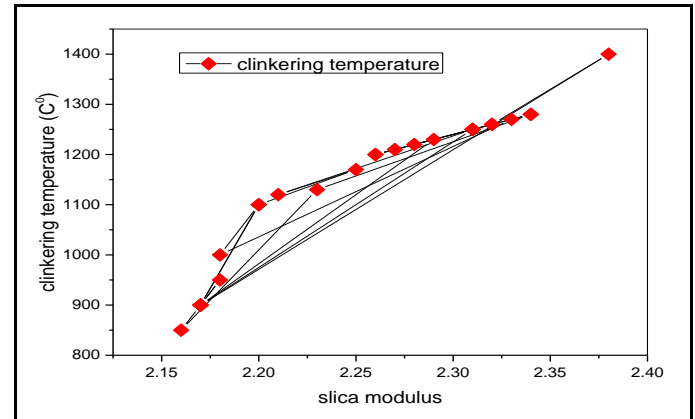
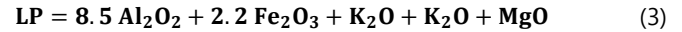


Figure 4. The relationship of silica coefficient to temperature

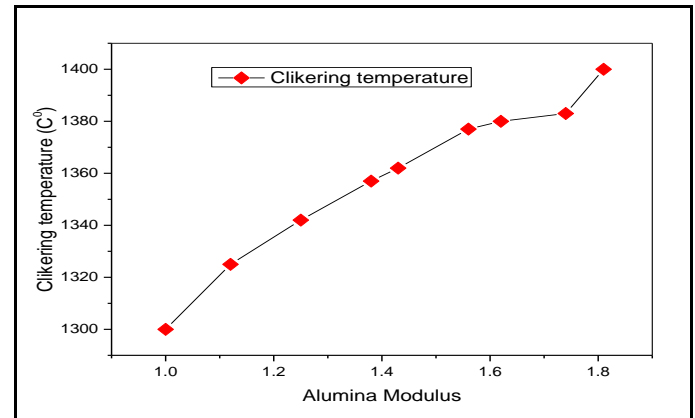


Figure 5. The relationship of alumina coefficient to temperature

To control the burning processes, the stages of heat transfer inside the oven are monitored by following the temperatures, and the simplest way to control the burning is to follow the results of a liter's weight of clinker and the percentage of free lime as measures are taken on the results that appear in these two variables during working hours in addition to chemical analysis.

The obtained practical results are a relationship between the mineral compounds of cement with (SM and AM). The relationship between the alumina coefficient and the belite clinker compounds (C₂S), and thus shows that the relationship is inverse and in the case of insufficient alumina, the production of the belite compounds increases, which causes ease in burning the primary materials involved in clinker formation.

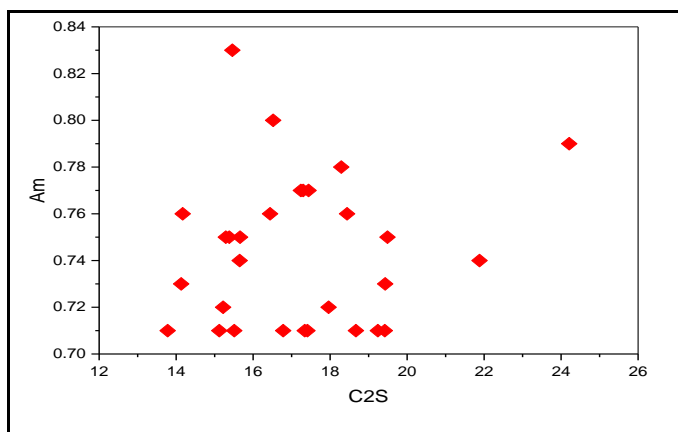


Figure 6. The relationship between belite and alumina coefficient.

As for Figure it shows the relationship between the alumina coefficient and the alite (C_3S) compounds of clinker, where we observe the inverse relationship also, but with a longer period, and therefore in the case of insufficient alumina the formation of the alite compounds increases and thus the clinker temperature decreases and the liquid materials increase and thus the furnace increases its productivity and the clinker is adherent and highly reactive.

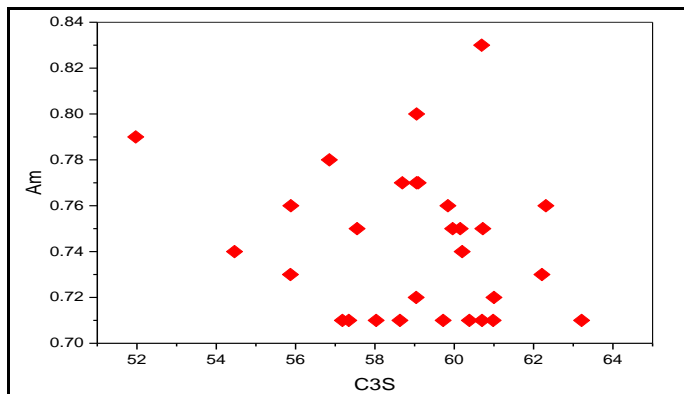


Figure 7. The relationship between alite and alumina coefficient.

The ferrite iron compounds (C_4AF) used in the manufacture of clinker do not differ much from the alite compounds because they depend on them completely as they start forming after the completion of the following compounds and therefore that the lack of alumina causes a decrease in the clinker temperature and the liquid increases and reduces free lime as shown in Figure (8). Silica coefficient has an important role in the formation of clinker compounds as Figure 7 shows that an increase in the silica coefficient accelerates the formation of belite compounds, but its height causes difficulty in burning raw materials and consumption in fire blocks, which causes problems in cooling clinker.

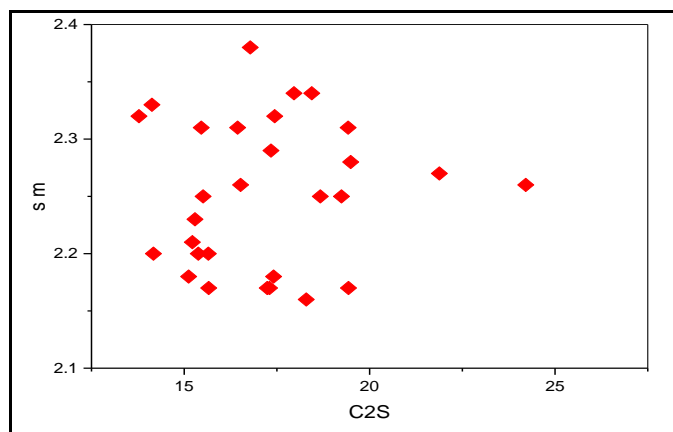


Figure 8. The relationship between Belite and silica coefficient.

As for Figure 8 it shows the relationship between silica coefficient and the alite compounds, as the increase in silica also causes an increase in the composition of the alite compounds and thus this increase causes fuel consumption, smooth clinker production and problems in the walls of the furnace.

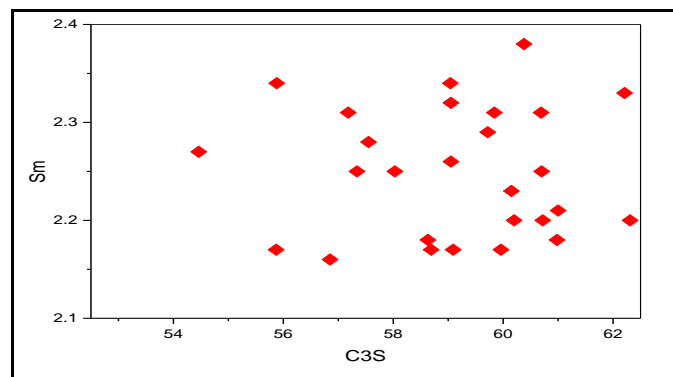


Figure 9. The relationship between alite and silica coefficient

Clay is a mineral particle with a silica base frame with a diameter of less than $4 \mu m$. Clay is formed from the weathering process of silica rock by carbonic acid and partly produced from geothermal activity. One characteristic of clay particles is that they have a charge of positive ions which can move. Clay material has good absorption ability to change moisture content because clay has a very large surface area.

Clay is the basic material used in making ceramics, its use is very beneficial for humans because the material is easy to obtain and its use is very broad [25]. About 70% or 80% of the earth's crust consists of rock which is a source of clay. Clay found in agriculture, especially rice fields. Viewed from the standpoint of chemistry, clay including alumina hydro silicate and in its pure state has the formula: $Al_2O_3, 2SiO_2, 2H_2O$. Clay has unique characteristics, that is when it is wet it will have plastic properties but when it is dry it will become hard, whereas if it burned it will become solid and strong [26], [27]. Usually people use clay or clay as raw material for making ceramics, brick, and

earthenware. In general, clay contains silica compounds, but with different levels of silica in each soil and each location. Silica contained in clay can generally be used as a rubber filler and cement making material. By using an X-Ray Fluorescence tool, it can analyze the chemical composition and concentration of the elements contained in a sample by spectrometry method [28]. The analysis used is quantitative and qualitative analysis.

Qualitative analysis is used to identify the elements contained in the material while quantitative analysis serves to determine the concentration of elements. Previous research stated that the main raw material for making cement is limestone as a source of CaO and clay as a

source of Al₂O₃. The selected limestone is limestone with a relatively high CaCO₃ content of 97-99%. Meanwhile, clay has the largest components of SiO₂ and Al₂O₃. Generally, clays have alumina silica compounds with a maximum H₂O content of 25% and a minimum Al₂O₃ content of 14%. Clay functions as a source of alumina, iron, and silica oxides [25], [29]. The feasibility level of clay used as raw material for making cement can be seen from the value of Silica Modulus (SM) and Alumina Modulus (AM). The value of Silica Modulus (SM) and Alumina Modulus (AM) determined by the company is 2.0-2.6 for BC, while 1.5-2.5 for AM. Through laboratory results obtained laboratory for silica, alumina and iron trioxide as shown in the next figures.

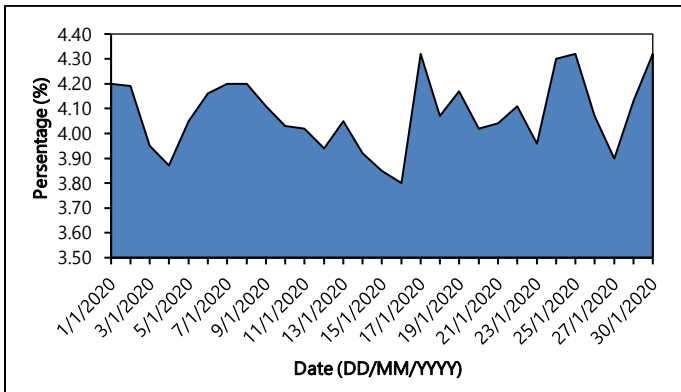


Figure 10. The amount of alumina (Al₂O₃) present in a month.

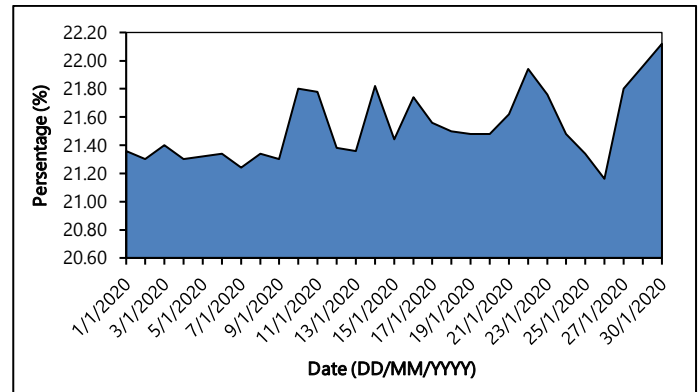


Figure 11. The amount of silica (SiO₂) present in a month.

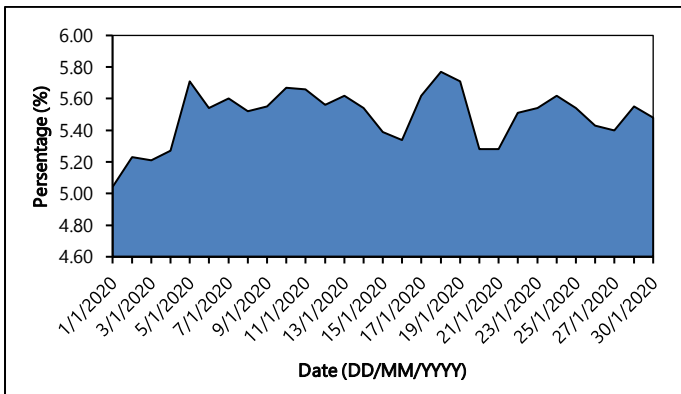


Figure 12. The amount of iron trioxide (Fe₂O₃) present in a month.

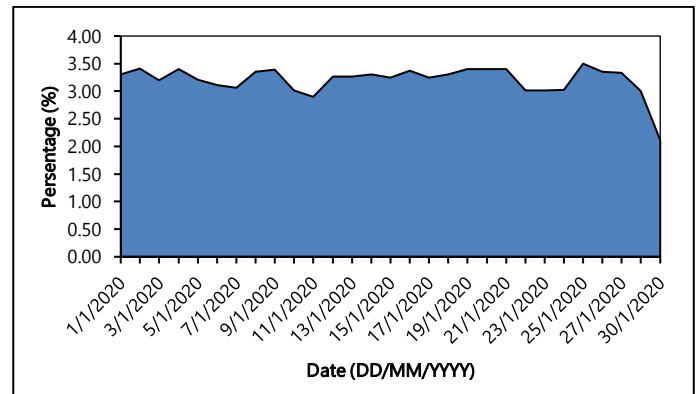


Figure 13. The amount of magnesium oxide (MgO) present in a month.

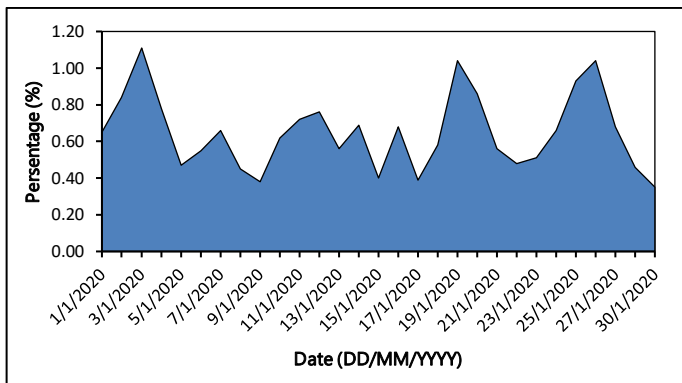


Figure 14. The amount of sulfur trioxide (SO₃) present in a month.

Through laboratory results, the impurities present in the raw materials and their effect on the production process, as the magnesium oxide (MgO) present in the soil constitutes magnesium carbonate and at a constant rate, almost in the limestone, is variable and depends on how it is deposited. Through the laboratory results obtained for a month, it was found that the impurities (sulfur oxide) that come from soil and limestone and that are in the form of calcium, sodium and potassium sulfate at a rate of no more than 1%, due to its negative impact on the consumption of the grinding bodies in the mills of the raw materials and on the consumption of Iron chains and backlit fans for

furnaces and thus affect fuel combustion, as shown by the red points obtained during the laboratory examination within a month.

4. Conclusions

The main conclusions that could be concluded from this paper are:

- Increasing carbonates, silica, less iron, alumina, magnesium, and alkalis lead to consumption of fire bricks and an increase in the amount of fuel, and thus higher production in addition to operational problems.
- The high silica coefficient leads to the production of a soft clinker, which leads to problems in the clinker coolers and is apparent (snow man) and consequently, the higher load on the clinker pullers is refrigerated, and in its low state it leads to obstruction of the movement of materials inside the furnace and thus reducing the production and the production of hard clinker which will affect the efficiency of the cement mills.
- In the event of a lack of alumina, the burning is simpler, and vice versa leads to the difficulty of burning in addition to the fuel exchange, and consequently the resulting clinker is hardened.
- The high lime saturation factor leads to the difficulty of burning, which leads to fuel exchange, an increase in the percentage of free lime and good quality production.
- The heterogeneity of raw materials and their size leads to lack of control over the burning process and consequently to lack of control over the oven.
- The increase in the fuel rate does not always cause increase in the flame temperature as the flame temperature depends on other factors, the most important of which amount of air used (increasing the secondary air temperature, reducing the front air ratio) as well as obtaining the fastest mixing of fuel and air by designing the burning air tube.
- Improve the ablation process (atomization) of the liquid fuel by increasing the temperature of the fuel entering the oven.
- Maintaining the percentage of oxygen 0.7 – 3.5 %.
- In case of difficulty burning the raw materials, it is necessary to reduce the speed of the oven to control the quality of production and consequently to reduce clinker production.

Acknowledgments

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laboratories to check the raw materials chemically and accomplish what required to complete the work.

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