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The optimum operating conditions in rotary kilns in cement industries Case study: Lebda cement Plant – Ahlia Cement Company

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الظروف التشغيلية المثلى للأفران الدوارة في صناعة الأسمنت دراسة حالة: مصنع أسمنت لبدة – الشركة الأهلية للأسمنت

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Abstract:

The chemical and mineralogical properties of the raw materials used in the kiln feed have a significant impact on the performance of a rotary kiln in the production of cement. Important factors like burnability, heat consumption, clinker formation, and overall kiln stability are directly impacted by changes in the ratios of limestone, clay, silica, alumina, and iron-bearing components. The impact of altering the raw material composition on the rotary kiln's output rate will be the main topic of this study. This research paper will focus on the effect of changing the composition of raw materials on the production rate of the rotary kiln. Samples for six-month period will be studied and analyzed to find out the optimum operating conditions lead to higher production rate, low fuel consumption, and high-quality level for produced clinker.

Keywords: Cement Industry, Rotary kilns, Optimum conditions, Raw materials, Clinker.

الملخص

تؤثر الخصائص الكيميائية والمعدنية للمواد الخام المستخدمة في تغذية الفرن بشكل جوهري على أداء الفرن الدوار في عملية إنتاج الأسمنت. وتتأثر عوامل بالغة الأهمية -مثل قابلية الحرق، واستهلاك الحرارة، وتكوّن الكلنكر، واستقرار أداء الفرن بشكل عام- بالتغيرات في نسب الحجر الجيري، والطين، والسيليكا، والألومينا، والمكونات المحتوية على الحديد. وسيكون المحور الرئيسي لهذه الدراسة هو بحث تأثير تغيير تركيبة المواد الخام على معدل إنتاج الفرن الدوار. كما سيركز هذا البحث على دراسة وتحليل عينات جُمعت

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على مدى ستة أشهر، وذلك بهدف التوصل إلى ظروف التشغيل المثلى التي تحقق أعلى معدل إنتاج، وأقل استهلاك للوقود، وأفضل جودة ممكنة للكلنكر المُنتج.

الكلمات المفتاحية: صناعة الأسمنت، الأفران الدوارة، الظروف المثلى، المواد الخام، الكلنكر.

Introduction:

The efficiency and stability of the rotary kiln feed in the cement industry are largely dependent on the quality and composition of the raw materials. The core of the cement production process is the rotary kiln, which uses heat to turn raw mill into clinker. As a result, kiln performance, product quality, and energy consumption are all directly impacted by the properties of the input materials [1]. To get the right chemical composition, raw materials including limestone, clay, shale, iron ore, and sand must be properly chosen and balanced. The ratios of calcium oxide (CaO), silica (SiO_2), alumina (Al_2O_3), and iron oxide (Fe_2O_3) are important factors [2]. Any difference in these elements may interfere with the clinker production process, resulting in subpar cement or kiln operational problems. The chemical diversity of source materials has a significant impact on kiln feed. Variations in the kiln feed chemistry brought on by inconsistent raw material composition can lead to unstable burning conditions, higher fuel consumption, and the development of unwanted phases in clinker. In order to assure a consistent raw mill before feeding it into the kiln, cement companies employ blending and homogenization procedures [3]. Kiln performance is also greatly impacted by the physical characteristics of raw materials. The raw mill behavior during preheating and calcination is determined by variables such particle size, moisture content, and grindability [1, 2, 3]. For instance, while excessive moisture raises energy requirements and therefore lower kiln efficiency, finer particles enhance heat transfer and reaction speeds. Additionally, operating difficulties may arise from the presence of contaminants including sulfur, chlorides, and alkalis. These factors may impede airflow, create buildups or rings inside the kiln, and obstruct preheater cyclones. These problems not only lower kiln efficiency but also raise maintenance needs and downtime [4].

Finally, it can be say that the raw materials have a significant impact on the feed of rotary kilns in the cement industry. To guarantee consistent kiln operation, high-quality clinker production, and optimal energy utilization, both chemical composition and physical properties must be strictly regulated. To achieve effective and sustainable cement manufacturing, raw material management including selection, preparation, and homogenization is crucial [3].

In addition to the properties of raw materials, which is the focus of this research, numerous other factors considerably affect the quality and performance of rotary kiln feed in the cement industry. These elements mostly pertain to process regulation, equipment efficacy, and operating circumstances. Consequently, these factors can be succinctly elucidated as follows:

1- **Homogenous Silos**: Even with well-proportioned raw materials, inadequate mixing in silos might result in variations in feed chemistry. This irregularity directly impacts clinker formation and kiln stability, frequently resulting in fluctuations in free lime concentration and product quality [5].
2- **Preheating system**: These units condition raw material prior to its entry into the rotary kiln by eliminating moisture and commencing calcination. Inefficient heat exchange or uneven airflow may result in the feed entering the kiln at variable temperatures or levels of calcination, hence escalating fuel consumption and diminishing throughput [5].
3- **Fuel of combustion:** Differences in fuel type influence flame temperature, heat distribution, and conditions within the combustion zone. Suboptimal combustion may result in insufficient clinker production or the emergence of coating and ring formations within the kiln [6].

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4- **Kiln operating conditions:** The residence period of the material and the effectiveness of heat transfer are influenced by factors like kiln rotation speed, inclination, and internal temperature profile. Inadequate settings may lead to insufficient or excessive combustion of clinker.
5- **Kiln Feed stability:** Changes in feed rate disturb the thermal equilibrium within the kiln, resulting in temperature variations and operational instability. Consistent and regulated feeding is crucial for sustaining steady-state conditions [7].
6- **Atmospheric conditions**: The environmental temperature and humidity can also affect feeding behavior. Elevated humidity in the ambient air might influence the storage and management of raw mill, hence indirectly affecting the uniformity of kiln feed.
7- **Recirculation system:** Dust accumulated from preheater cyclones or electrostatic precipitators is frequently reintroduced into the system. This dust may possess elevated levels of alkalis, sulfates, and chlorides, thereby modify feed chemistry and lead to operational complications such as accumulations [7].

The feed of rotary kilns in cement industries is determined by raw materials, process efficiency, equipment performance, fuel characteristics, and operational control. Ensuring stability among all these elements is crucial for optimal kiln operation and uniform clinker quality.

Why Lebda Cement Plant?

The most important point of selecting Lebda cement Plant as case study for this research that the factory was designed to produce one million ton per year of cement where the actual percentage of production does not exceed 50 – 70% of the design percentage since established on 1981 for many reasons. Some of these reasons related to the design itself and others related to operation and maintenance procedures. The rotary kiln in this factory was designed to accept feed flow rate more than 200 ton/hr, but in fact the actual feed rate was about 170 ton/hr and in some conditions goes below to about 140 ton/hr or less. Controlling the factors mentioned above is much easier than controlling the compositions of raw materials entering the rotary kiln. This research will focus on the quality of raw materials and how can affecting on the feed of rotary kiln.

The mechanism of reactions:

To understand the effecting of changing the composition of the raw materials entering the rotary kiln on the production rate, it is crucial to understand what happen inside the kiln during the period and stages of the formation of clinker. There are many reactions occur progressively as the material moves through different temperature zones inside the kiln.

- The first reaction happen in the calcination zone where the temperature in the range 800 ~ 1000 ◦C therefore, most the calcium carbonate $CaCO_3$ breaks down to calcium oxide CaO as a result large amount of CO_2 released and the free lime CaO is ready for clinker formation:

$$CaCO_3 \longrightarrow CaO + CO_2$$

- The second reaction occur in the transition zone where the temperature not more than 1250 ◦C where the CaO reacts with silica, alumina, and iron oxides from the raw materials and as a result of this reaction initial clinker compounds begin forming which called dicalcium silicates (Belite C_2S).

$$2CaO + SiO_2 \longrightarrow 2CaO.SiO_2$$

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In cement industry some abbreviations are considered as follow:

$C - CaO$, $A - Al_2O_3$, $F - Fe_2O_3$, $S - SiO_2$

Therefore,

$$C_2S = 2CaO.SiO_2$$

- The last reaction to form the most important compound in the clinker composition which known as tricalcium silicates (Alite, C_3S) that gives the cement the early strength:

$$2CaO.SiO_2 + CaO \longrightarrow 3CaO.SiO_2$$

- Other clinker compounds also forming in this zone:
  Tricalcium aluminate

$$3CaO + Al_2O_3 \longrightarrow C_3A$$

And Tetracalcium aluminoferrite

$$4CaO + Al_2O_3 + Fe_2O_3 \longrightarrow C_4AF$$

Table (1) below summarize the percentage of clinker compounds and their functions:

Table (1): The percentage of clinker compounds

Phase name	Clinker Compounds	Percentage	Function
Alite	C_2S	45 – 60 %	Early strength
Belite	C_3S	15 – 30 %	Later strength
Tricalcium aluminate	C_3A	5 – 12 %	Fast reaction with water
Tetracalcium aluminoferrite	C_4AF	6 – 10 %	Flux phase, color

The methodology:

This study depended on collecting the operating data of the rotary kiln in Lebda cement plant which took about more than six months. To find out the optimum operating conditions that lead to maximum production rate of clinker, it is very important to focus on the factors that have a direct effect on that. The raw materials entering the kiln come from the homogenous silos which should have a total carbonate (T.C) percentage in the range of 76 – 77 %. The raw mill working in continuous process and correct the percentage must happen immediately depending on the addition process system control. But due to some conditions the mixing in the homogenous silo does not happen well which lead to these unmixed materials to enter the kiln where the percentage of carbonate goes out of the rage where it can be more than 77 % up to 78% or less than 76 % down to 75% or less.

In this research will collect all these data and study them to find out firstly the effect on the production rate, and secondly, side by side the quality of production, and the fuel consumption.

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Data Collected:

The process of collecting the data focused on three ranges of total carbonates content which are listed in tables 2, 3, and 4 below. For each single value of total carbonate (TC), three other values were recorded and monitored include fuel consumption, kiln feed, and burning zone temperature. The value of lime saturation factor (LSF) was in the acceptable range for all data collected (96.13 ~ 99.66) therefore no need to study the effect of changing the value of LSF on kiln feed as it is in the same way of studying the changing of total carbonates itself.

Table (2): Kiln operating data for total carbonate of kiln feed (76 ≤ **TC** ≤ 77%)

Sample No.	TC	LSF	Fuel Consumption m^3/hr	Kiln Feed Ton/hr	Burning zone Temperature ◦C
1	76.11	97.92	8805	163	1496
2	76.34	97.25	8517	162	1447
3	76.01	97.85	8300	170	1464
4	76.39	98.11	8431	167	1477
5	76.82	98.54	8743	160	1447
6	76.81	97.15	8912	164	1417
7	76.62	97.92	8865	163	1474
8	76.86	97.84	9015	167	1420
9	76.69	97.51	9100	175	1461
10	76.45	96.13	9100	172	1521
11	76.95	99.32	9722	172	1503
12	76.45	97.16	8496	168	1500
13	76.81	97.86	8492	166	1447
Average			**8808**	**167**	**1467**

Table (3): Kiln operating data for total carbonate of kiln feed (77 ≤ **TC** ≤ 78%)

Sample No.	TC	LSF	Fuel Consumption m^3/hr	Kiln Feed Ton/hr	Burning zone Temperature ◦C
1	77.48	98.42	8600	150	1500
2	77.72	97.91	8464	150	1500
3	77.27	97.21	8123	142	1464
4	77.01	97.01	8112	150	1479
5	77.94	97.99	8227	141	1469
6	77.77	98.12	8457	140	1456
7	77.17	97.89	7840	141	1440
8	77.91	98.51	7500	120	1122
9	77.61	99.09	7500	128	1170
10	77.81	97.65	7495	122	1270
11	77.92	98.28	7580	122	1130
12	77.77	97.97	9095	162	1496
13	77.91	97.98	7600	134	1390
14	77.56	98.36	9187	165	1350
15	77.04	98.52	8500	158	1450

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16	77.07	97.88	8895	163	1449
17	77.17	97.71	9106	170	1420
18	77.58	99.62	9700	176	1450
19	77.67	99.55	9800	172	1490
20	77.51	99.43	9418	176	1511
21	77.02	99.35	9700	161	1437
Average			**8507**	**149**	**1394**

Table (4): Kiln operating data for total carbonate of kiln feed (TC ≥ 78%)

Sample No.	TC	LSF	Fuel Consumption m^3/hr	Kiln Feed Ton/hr	Burning zone Temperature ◦C
1	78.02	98.12	8800	136	1325
2	78.15	98.11	7982	120	1443
3	78.24	98.25	8000	121	1421
4	78.12	98.14	9200	163	1492
5	78.12	97.25	7600	130	1360
6	78.18	98.99	8104	152	1257
7	78.38	99.12	8098	143	1400
8	78.39	99.66	9843	180	1490
9	78.89	99.72	9500	168	1450
10	78.99	99.34	9670	171	1423
11	78.12	98.97	9500	172	1480
12	78.02	99.55	9763	163	1489
Average			**9088**	**152**	**1419**

Results and Analysis:

To find out the optimum operating conditions that lead to the best production rate of the rotary kiln, three factors were studied all together which are: total carbonate percentage , fuel consumption and burning zone temperature.

1- **Total Carbonate Content (TC):**

Putting all data together to find out the effect of increasing the TC on the kiln feed can be clear in figure (1) which shows increasing the total carbonate content can lead to decrease the kiln feed from 175 ton/hr (TC =76.69) to approximately 120 ton/hr (TC = 78.15). On the other hand, working in a very small range of total carbonate for example the data presented in table 2 where 76.11 ≤ TC ≤ 76.80 the kiln feed can be stable for the same fuel consumption and can be clear in figure (2) below. To increase the production rate for this small range of total carbonate we need to increase the fuel consumptions which as a results increase the burning zone temperature for an effective calcination process where this can be clear in figure (3). In this case the production rate increased for about 15 ton/hr by increasing the fuel for about 800 m^3/hr.

Using the all data collected to test the effect of increasing the percentage of total carbonate on the fuel consumption can give a clear picture. Figure (4) shows a clear increase of the fuel consumption with increasing the carbonate content for example at TC = 76.69 the fuel consumption was 7540 m^3/hr but when the TC = 78.39 the fuel

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consumption was 9843 m^3/hr. as a results taking these point to see the effect on production will find the kiln feed increased from 175 to 180 ton/hr by increasing the fuel consumption by approximately 1300 m^3/hr which economically bad.

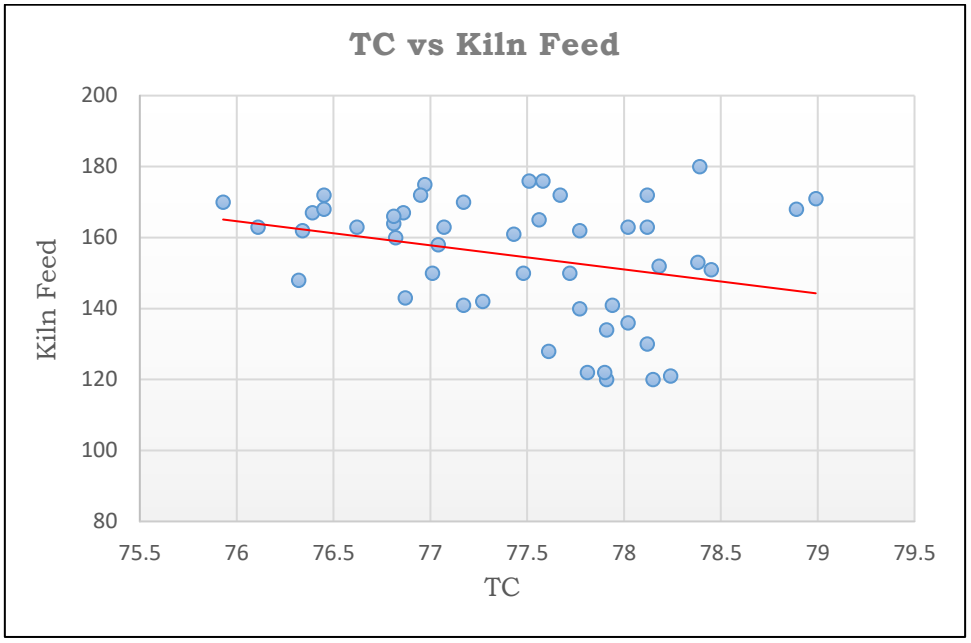

Figure (1): The effect of increasing the total carbonate content on kiln feed

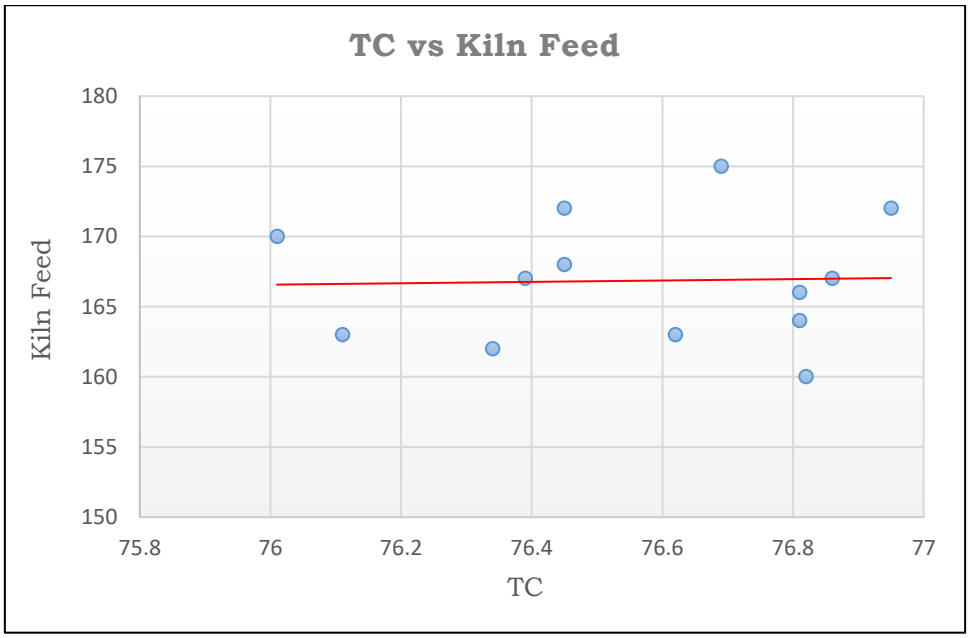

Figure (2): The effect of small range of total carbonate content on kiln feed

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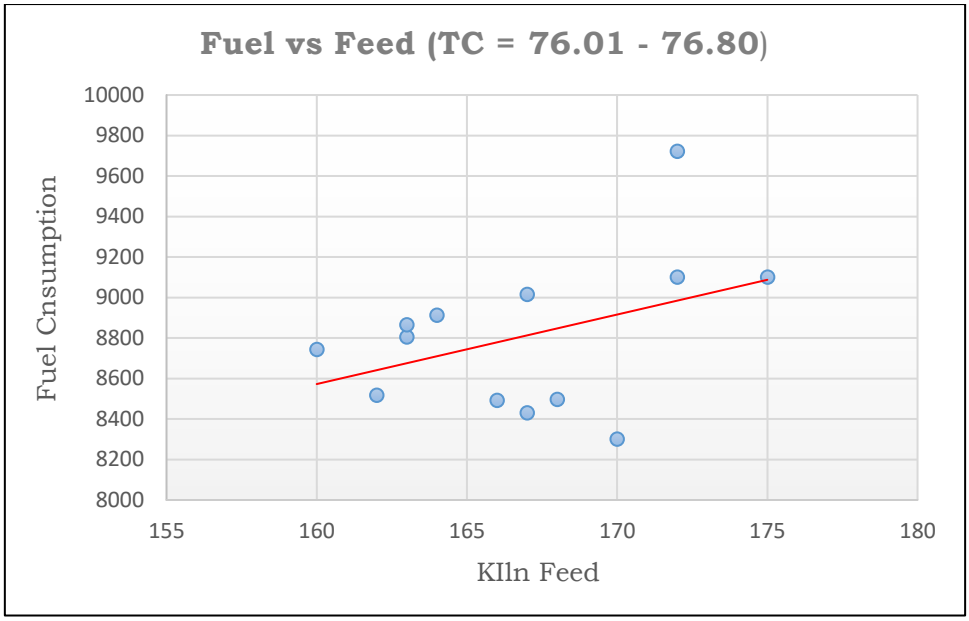

Figure (3): effect of increasing fuel consumption on kiln feed for small range of TC

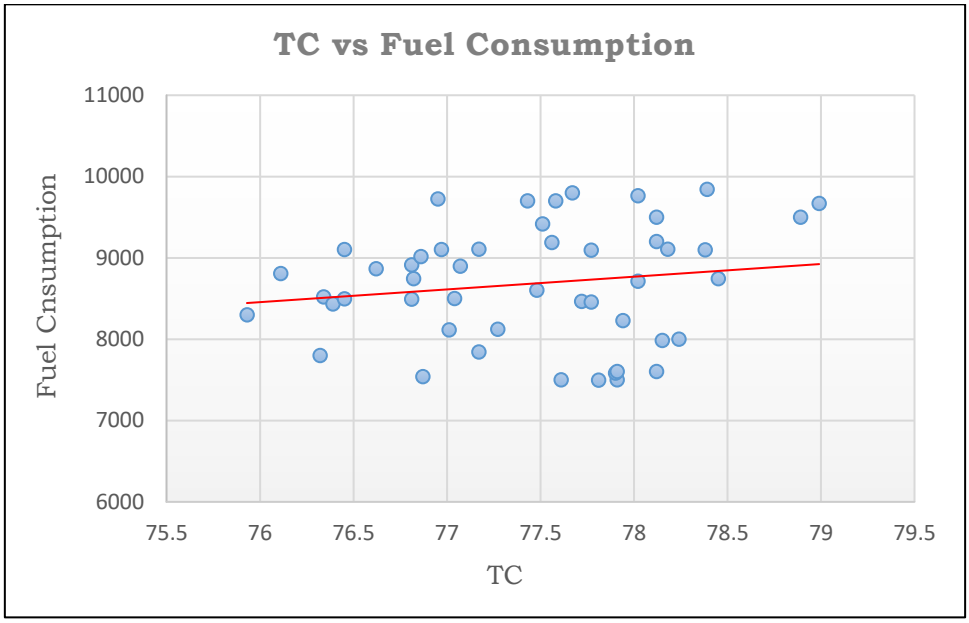

Figure (4): The effect of increasing the total carbonate content on fuel consumption

2- Fuel Consumption & Burning zone temperature

There is no doubt that increasing consumption will lead to increase the burning zone temperature which as a result the driving force of calcination process and that is clear in figures (5) and (6) by using the wide range of data collected. Looking for samples 8,9,10, and 11 in table (3) where the total carbonate is about 77 % decreasing burning zone temperature down to about 1122 – 1270 ◦C led to decrease the kiln feed to about 120 ton/hr. why this happen? The answer is when the burning zone temperature goes down this will lead to uncomplete reaction and the kiln will produce a dust (unburned materials) includes bad quality clinker with high percentage of free lime (unreacted

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Cao). Therefore, the action of the operator is to decrease the amount of raw materials in the burning zone for complete reaction.

Using a fixed rate of fuel consumption and increasing the carbonate content will lead to decrease the burning zone temperature and this can be shown in figure (7). The explanation of this situation comes from that more carbonate content means we need more heat for reaction zone to allow all the calcium oxide Cao produced to react with silicon oxide (SiO_2) to produce clinker compounds mentioned before in this research.

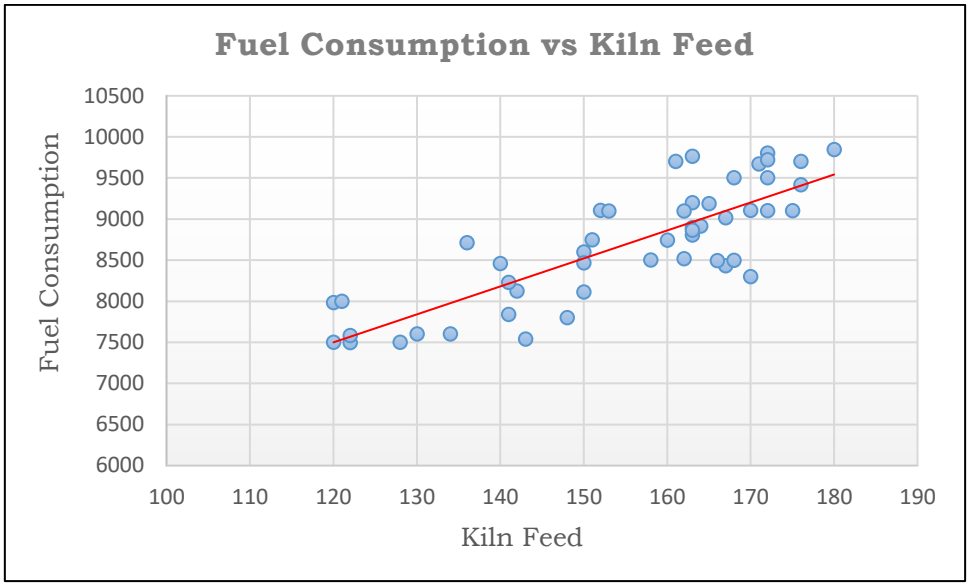

Figure (5): Effect of increasing fuel consumption on kiln feed

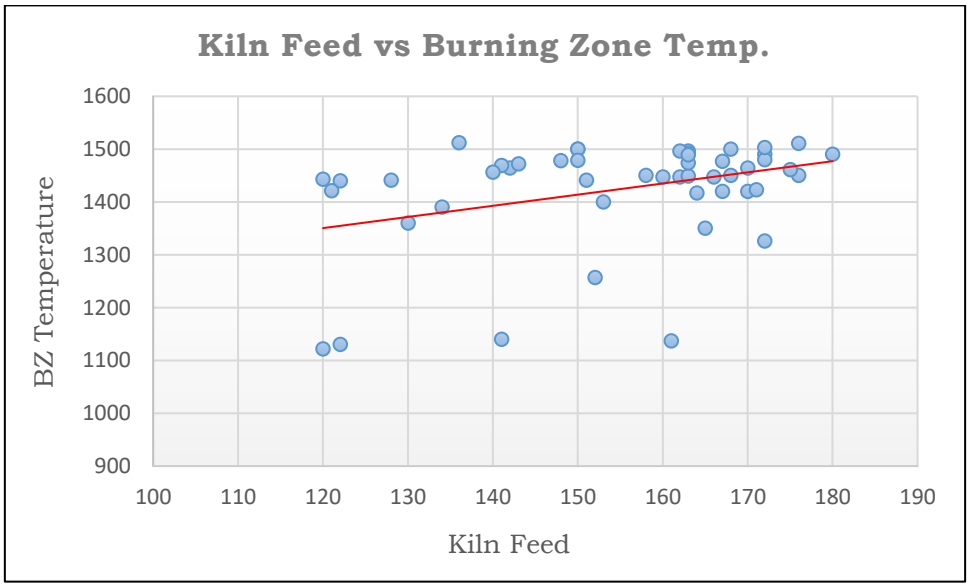

Figure (6): effect of burning zone temperature on kiln feed

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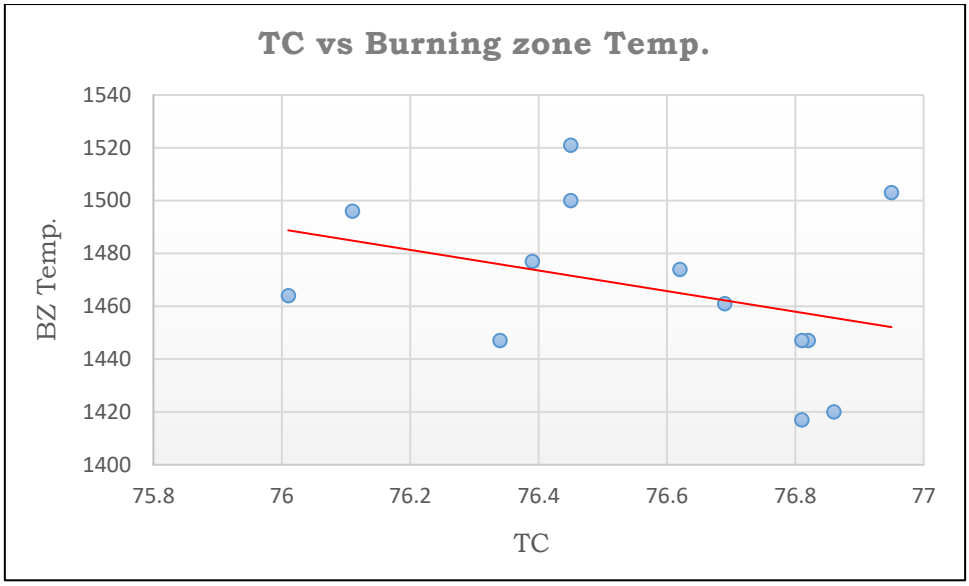

Figure (6): Effect of increasing total carbonate content on burning zone temperature

Conclusion:

High carbonate content in the raw mix promotes efficient calcination and supports the formation of alite-rich clinker, whereas low carbonate levels can lead to reduced lime availability, poorer burnability, and the need for higher sintering temperatures. Looking for our results in tables 2, 3 and 4 combined with the figures presented it can be said that the highest values for kiln feed were when the three factors the total carbonates content, fuel consumption and burning zone temperature at its acceptable values as following:

Total carbonates contents (TC) = 76.50 – 77.50 %

Burning zone temperature (BZ) = 1400 – 1500 ◦C

Fuel Consumption = 8000 – 9000 m^3/hr (based on operation conditions required for kiln feed)

For total carbonate content (TC) values less than 76.50 can increase the kiln feed but as a results will produce clinker with low quality regarding the function of its compounds. On the other hand for values of total carbonates more than 77.50 up to 78 or more this can cause more fuel consumption and less production. In addition, high content of carbonate will put the product at the risk of uncomplete reaction therefore, free lime (Cao) will be produced with clinker which very bad. Finally, controlling the three factors mentioned above with their ranges is very important to ensure steady state operation with high production rate.

Compliance with ethical standards

Disclosure of conflict of interest

The authors declare that they have no conflict of interest.

References

[1] Samariddin Eshkoraev, “Portland Cement Compositions, Properties, and Applications” The Multidiscilinary Journal of Science and Technology, Vol.4, Issue-1, 2024.

[2] Q. Yin, Q. Chen, W. J. Du, X. L. Ji, and L. Cheng, “Design requirements and performance optimization of waste heat recovery systems for rotary kilns,” International Journal of Heat and Mass Transfer, vol. 93, pp. 1–8, feb 2016.

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[3] P. John John “Parametric Studies of Cement Production Processes”, Journal of Energy Volume 2020, Article ID 4289043, Indawi
[4] Hendar W, and Nazzaruddin S. “ Exergy Analysis of Rotary Kiln in Cement Production Process” SJME KINEMATIKA, Vol.6, No.1, 2021, pp65-84.
[5] A. Atmaca and R. Yumrutaş, “Analysis of the parameters affecting energy consumption of a rotary kiln in cement industry,” Applied Thermal Engineering, vol. 66, pp. 435–444, may 2014.
[6] N. A. Madlool, R. Saidur, M. S. Hossain, and N. A. Rahim, “A critical review on energy use and savings in the cement industries,” Renewable and Sustainable Energy Reviews, vol. 15, pp. 2042–2060, may 2011.
[7] M. Mirhosseini, A. Rezania, and L. Rosendahl, Power optimization and economic evaluation of thermoelectric waste heat recovery system around a rotary cement kiln,” Journal of Cleaner Production, vol. 232, pp. 1321–1334, 2019.

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