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MODELLING OF LIMESTONE CALCINATION FOR OPTIMIS ATION OF PARALLEL FLOW REGENERATIVE SHAFT KILN (PFR), CASE STUDY: IRAN ALUMINA PLANT

To produce the lime required for the Bayer process, two parallel flow regenerative shaft kilns (PFR) were used in the Iran Alumina plant located in Jajarm, North Khorasan Province, Iran. In this study, the calcination conditions of limestone were modelled in a laboratory furnace by considering three factors of limestone size, temperature and calcination time using the Box-Behnken method. The calcination model of limestone was obtained using a quadratic equation. Due to the importance of limestone dust in the performance of industrial kilns, conditions of calcification and its reactivity with water were examined at three temperature ranges of 800, 1000, and 1200°C, by two methods of titration and standard ASTM C110. The results indicated a decrease in reactivity of lime relative to the increased temperature of calcination and the lack of forming the burnt lime particles that stick together (blocking). Finally, the ratio of input limestone (kg) to fuel (m^3) was reduced from 16.4 to 15.3 to increase the average temperature of the burning zone to 1000°C. Also, excess air was reduced from 40 to 20%. In this condition, the lime quality was increased by about 6% in the kilns.

Keywords: Calcination; PFR kiln; Limestone Dust; Blocking; ASTM C110 Standard Method

1. Introduction

Accumulation of impurities in the recycled solution of the Bayer process leads to an increase in the consumption of fresh materials and eventually decreased quality of the product. These impurities are divided into two general types of organic and inorganic impurities, which can cause changes in the physical properties (density and viscosity) and chemical properties (adsorption on seeds surfaces or interference with sodium aluminate ions interactions in precipitation process).

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Both of these impurities directly affect the recycling of the precipitation process [1-3]. Using lime in the Bayer method has a lot of useful effects. Some of them include increasing the alumina extraction, controlling the impurities (silica, carbonate, and in some cases phosphate), helping to remove impurities from the pregnant liquor during the filtration stage, and reducing the loss of the sodium hydroxide in red mud [4]. The usage of combined processes such as pre-sintering with lime and Bayer-Lime process has been developed in the processing of low-grade bauxites, especially diasporic bauxite [5]. In these processes, lime is presented in three forms: hydrated lime or lime milk ($Ca(OH)_2$), quicklime (CaO), and Tricalcium Aluminate (TCA, $Ca_3Al_2(OH)_{12}$). TCA is usually the result of the presence of lime milk in the aluminate solution [6]. Endothermic decomposition of the limestone takes place in the following form:

$$CaCO_3 \leftrightarrow CaO + CO_2 \qquad \Delta rH^\circ = +177.8 \text{ kJ/mol} \tag{1}$$

The calcination process of the limestone is controlled by CO_2 partial pressure. If the CO_2 partial pressure in the kiln is lower than the partial decomposition pressure inside the material, this process can occur at a lower temperature. For example, calcination of calcium carbonate takes place at the pressure of one atmosphere at temperatures of 800 to 850°C [7]. Hydration of the lime with water is an exothermic reaction, which will produce $Ca(OH)_2$. The hydration reaction of quicklime in water is according to the following equation:

$$CaO + H_2O \leftrightarrow Ca(OH)_2 + 15300 \text{ cal/grmol} \tag{2}$$

This process is affected by the temperature of limestone calcination and by the specifications of the lime crystals [8,9].

In the Iran alumina plant, Diasporic bauxite with sodium hydroxide and about 8 to 12% of lime (relative to the amount of bauxite) were inserted into tubular ball mills, and the produced slurry enters the pre-desilication stage. Mahmoudian et al. (2015) mentioned two impurities of carbonate and oxalate as the main impurities in the process of this plant. They recommended using chemical methods by Ba2Al4(OH)16 and heating as effective methods for removing carbonate and oxalate impurities, respectively [10]. The lime for this process is produced in two parallel flow regenerative shaft kilns (PFR). In standard PFR kilns, the volume of the burning area is designed so that limestone gets completely calcined at an average temperature of 950 to 1050°C. The calcination time in these kilns is considered averagely as 8 hours, according to the boundary conditions and the calcination cycle time [9]. Several studies have been conducted to determine the optimal conditions for the calcination of limestone in a laboratory furnace or an industrial furnace. Most of these studies have optimised the conditions by examining the factors affecting the calcination of limestone by single-factor analysis (OFAT, one factor at a time). For example, in a study, the reduction of excess air during the limestone calcination process was examined by modelling and returning hot gases as combustion air to reduce energy loss in an annular shaft kiln [11]. The experiments proved that temperatures of 850 to 1200°C could be selected for producing natural hydraulic lime (NHL). They suggested the optimal temperature for the calcination process as about 100 to 1100°C [12].

The researchers provided the structure and main functions of a supervisory-level simulated mathematic model and a holographic monitoring system for the lime production process. They also provided a holographic monitoring system for industrial-scale lime production at an aluminium production plant in China. They achieved an instantaneous expert diagnostic system by collecting and analys ing different fault types and corresponding corrective responses, which can be used for an advanced high-level control system based on fuzzy logic principles and a novel linguistic equation approach [13].

Gutierrez et al. (2013) examined the exergy and energy consumption of the calcination process in vertical shaft kilns, and in the end, they mentioned the improvement of control of operating parameters as the best method to increase the efficiency of kilns. The most important operating parameters consist of the ratio of stone to fuel, excess air, the size and size distribution of the limestone fed to the kiln, and the temperature of the quicklime flow [14].

Krause et al. (2015) simulated limestone's bed movement and gas flow in a kiln with a vertical shaft by combining the two methods of discrete element method (DEM) and computational fluid dynamics (CFD) for the careful examination of thermal-chemical processes of a component [15].

In another study, a regenerative shaft kiln (PFR) with a height of 18 meters and a diameter of 1.6 meters was simulated with a time cycle of 15 minutes with a combination of CFD-DEM methods [16].

Comparison of calcination process of limestone in the traditional furnace with the industrial furnace has shown that the quicklime produced in traditional furnaces usually has larger particle size and pores and also a larger volume of mesopores, and due to the increased speed of water passing through the material, this condition causes less exothermic [17].

A simple schematic of one of the PFR kilns of the Iran Alumina Plant has been presented in Fig. 1. These kilns have two vertical shafts with a connection channel in their middle section, and the burning takes 680 seconds during operation on one of these shafts. The production of

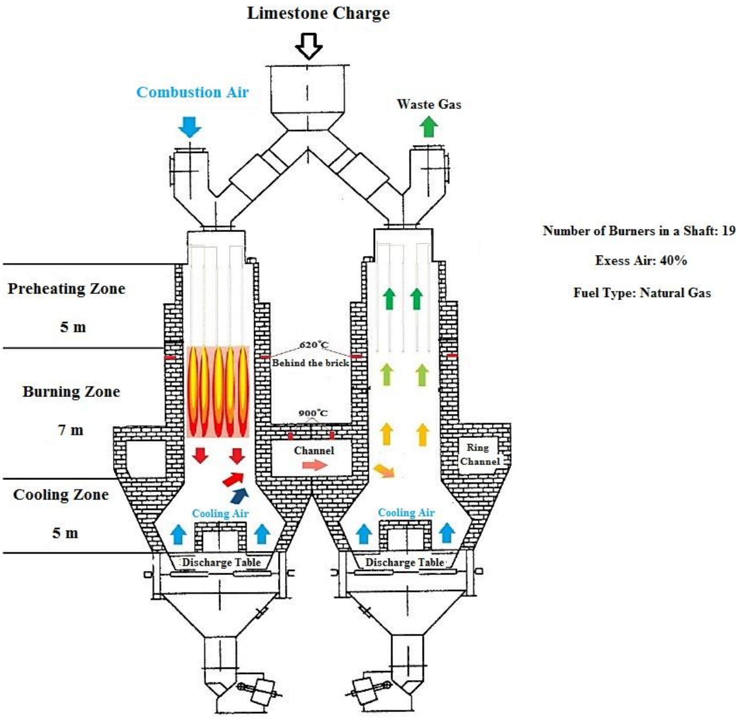

Fig. 1. Schematic of PFR Kilns of Iran Alumina Plant

hot gases resulted from the burning pass through the connection channel to the other shaft, and it exits the kiln after preheating the limestone in the preheating section and passing the filters. At the end of the burning in the first shaft, after adjusting the required conditions, the combustion begins in the other shaft, and the hot gases come out of the adjacent shaft, and in this way, the calcination process of limestone continues within the shafts steadily. The time required for burning in a shaft and its shift between the two shafts is known as the time cycle which lasts about 770 seconds. Limestone is entered into these kilns with a tonnage of 315 to 500 tons per day in two size fractions of 30-70 mm and 70-140 mm, and it exits the kiln in the form of quicklime after the process of calcination. The fuel used by the kilns at the time of initial design was fuel oil with a thermal value of 10,000 kcal/kg. It was later changed to natural gas with a thermal value of about 8100 kcal/m^3. In terms of structure (length, layout, and diameter of the burners) and kiln conditions, no changes had occurred. In recent years, the decline in the quality of lime produced in these kilns has directly led to an increase in the carbonate impurity and has indirectly increased the number of other impurities (decrease in the amount of active CaO) in obtained liquor of this process.

In this study, in the next step, after designing the test based on the Box- Behnken method, the calcination conditions of the limestone were modelled in different size fractions in a laboratory kiln. Three parameters of limestone size fraction, temperature, and time were selected as important factors in the calcination of limestone. In the second step, limestone dust calcination conditions were evaluated as an intruder in industrial kilns. In the third step, two methods of laboratory and standard ASTM C110 were used for more accurate recognition of the reactivity of lime produced from limestone dust at different temperatures and its comparison with lime produced in an industrial kiln. Finally, after examining and analysing the obtained results, the optimal condition was applied to improve the quality of lime produced in existing industrial kilns. In this paper, for the first time, a numerical model is presented for limestone calcination (based on three factors: limestone size, temperature, and calcination time). Also, using slaking test method and lime reactivity, the average temperature of the burning zone in an industrial furnace has been estimated.

2. Materials and methods

2.1. Sample and characteris ation studies

Illustrations of the limestone utilised in this research were prepared from a limestone mine in Jajarm located 7 kilometres away from the Iran Alumina Plant located in North Khorasan Province of Iran. XRF and XRD analyses of limestone are presented in Tab. 1 and Fig. 2, respectively. The XRD analysis shows that calcite and dolomite with hexagonal crystals are the dominant minerals in the sample.

TABLE 1

The XRF analysis of limestone

CaO (%)	MgO (%)	Al_2O_3 (%)	SiO_2 (%)	Fe_2O_3 (%)	LOI (%)
55.18	0.47	0.22	0.46	0.19	43.48

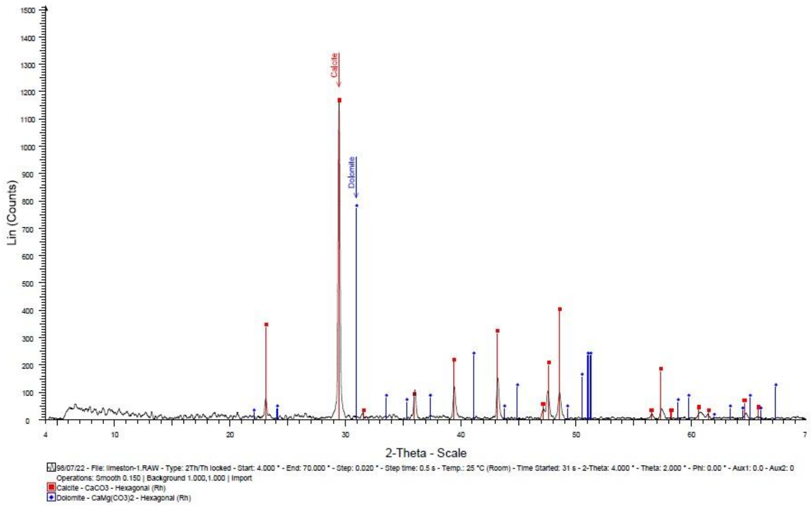

Fig. 2. The XRD analysis of limestone

2.2. Modeling of limestone calcination on a laboratory scale

For the modelling of conditions of limestone calcination in different size fractions, three parameters of inlet limestone size fraction, calcination temperature, and time were investigated as the main factors in calcination of limestone (since there were not many variations in the quality of the limestone that was entered into the plant, the factor of limestone quality was not considered as one of the main factors). By taking the operating conditions and previous research into account, two levels with one central point were considered for each parameter to evaluate the effect of parameters on the process efficiency (Table 2).

TABLE 2

Factors affecting limestone calcination and their levels

Factor	**Name**	**Units**	**Low Actual**	**High Actual**
A	Limestone Size fraction	mm	30	140
B	Calcination Time	hour	2	8
C	Calcination Temperature	°C	800	1200

Considering the type of the process and existing parameters, the Box-Benken method was implemented to model the calcification process. As a result, 13 experiments were designed and the relevant experiments were carried out with the help of a laboratory furnace and at the same temperature conditions occurred. The procedure took place by adjusting the temperature and time requirements for calcination after placing the sample in the kiln. After the time required for calculations was passed, depending on the design conditions (2 to 8 hours), the sample was kept in the oven kiln the following day to cool down. After preparation of the samples obtained and grinding them up to size fractions below one millimetre, the CaO_{act} amount in the produced lime was measured by titration method.

2.3. Calcination of limestone dust at different temperatures

The limestones with smaller size fractions are converted into lime at lower temperatures and shorter times. Also, this part of the limestone in an industrial kiln leads to a disruption in the movement of fuel and air needed for it, because of the reduced pore size. On the other hand, by increasing the calcination temperature of the limestone up to 1200°C, over time, the crystals of lime get larger, and their reactivity with water decreases. The lime which is produced at different temperatures has different applications depending on the properties of particles and reactivity. Burnt lime is produced at temperatures above 1200°C with a retention time of fewer than 8 hours or at 800°C and a retention time of more than 20 hours. Overall, this lime has a larger crystal size and less reactivity compared to quicklime with water. Burnt lime has various uses, including construction, hygienic, industrial uses and, etc. Burning lime is considered as one of the main problems in the industrial kilns for quicklime production [9,18,19]. In the operating conditions of the Iran Alumina Plant, some limestone dust enters the kiln with limestone despite the split screens that are placed at the entrance of the stones into the kiln. Particularly in the kiln with limestone with a size fraction of 30-70 mm, this is considered to be one of the factors that stop temperature rise in the burning zone. Given the concerns regarding the ticking or blocking of limestone particles in high-temperature in industrial kilns, some samples were prepared from limestone dust in the plant so that the calcination conditions of this dust at different temperatures can be evaluated. The Particle size distribution of limestone dust is presented in Table 3.

TABLE 3

The particle size distribution of Limestone dust

–5 μm (%)	–10 μm (%)	–20 μm (%)	–44 μm (%)	–45 μm (%)	–63 μm (%)	–105 μm (%)
37.07	56.98	76.42	95.33	95.7	99.44	100

The sample of 200 g of the limestone dust was placed in a laboratory kiln at three temperatures of 800, 1000, and 1200°C for 8 hours (Fig. 3). After calcination of the samples, 0.5 g of the lime was poured into about 50 ml of distilled water and 5 g of sugar was added to it. The obtained solution was stirred at different times (15, 30, 60, and 1200 seconds before the start of titration) and a few drops of phenolphthalein were added to it. The solution was then titrated with hydrochloric acid (0.5 normal) to reach the phenolphthalein colorless phase. Finally, the lime quality or $\mathrm{CaO_{act}}$ amount was obtained from formula (3).

$$\mathrm{CaO_{active}}\ (\%) = 1.402 \times \mathrm{V_{HCl}} / \mathrm{m} \tag{3}$$

Where:

$\mathrm{V_{HCl}}$ — Volume of hydrochloric acid consumed (ml).
m — Amount of the lime (gr).

Also, to evaluate the reactivity of the lime calcined at different temperatures more accurately, ASTM C110 standard method called „Slaking Test“ was used. In this method, 100 grams of calcined sample was added to 400 grams of water, and the produced temperature was recorded relative to the time (with stirring conditions of 400 rpm).

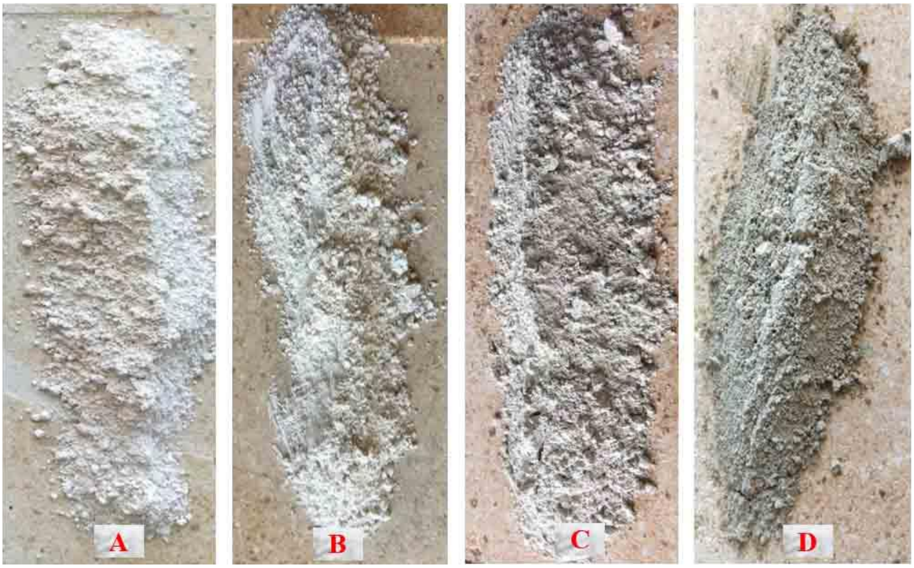

Fig. 3. A) limestone dust before calcination, B) sample calcined at a temperature of 800°C and calcination time of 8 hours, C) sample calcined at a temperature of 1000°C and calcination time 8 hours, and D) sample calcined at a temperature of 1200°C and calcination time of 8 hours

Based on the F values in Table 5, it is clear that temperature is the most effective factor that affects the quality of the produced lime. After, the size fraction of limestone and calcination time of limestone are effective factors, respectively. The presented model also shows the interactions between the parameters.

3. Results and Discussion

3.1. Modeling of limestone calcination on a laboratory scale

Designed experiments and their results are presented in Table 4. After fitting different models to the obtained data, the quadratic model was selected as the best fit by converting the natural logarithm. Depending on the selected model, data analysis of variance (ANOVA) is shown in Table 5. Given P-Value (less than 0.05), it is clear that the selected model and parameters are significant with a very high level of confidence.

Data on model validation is presented in Table 6, which clearly shows a very good fit of the model to the data.

The model obtained for calcination of limestone with the conditions of coded and actual factors is presented as follows:

- The final equation with the condition of coded factors:

$$\mathrm{Ln}\,(\mathrm{CaO_{act}}) = +4.19 - 0.40 * A + 0.37 * B + 1.04 * C + 0.37 * A * B + 0.40 * A * C - 0.35 * B * C - 0.67 * C^2$$

TABLE 4

Results obtained from the designed experiments

Std.	Factor 1	Factor 2	Factor 3	Response 1
	A: Lime Stone Size (mm)	B: Calcination Time (hour)	C: Calcination Temperature (°C)	CaO_{act} (%)
1	30.00	2.00	1000.00	96.3
2	140.00	2.00	1000.00	21.0
3	30.00	8.00	1000.00	93.9
4	140.00	8.00	1000.00	88.4
5	30.00	5.00	800.00	27.2
6	140.00	5.00	800.00	5.4
7	30.00	5.00	1200.00	96.0
8	140.00	5.00	1200.00	96.1
9	85.00	2.00	800.00	5.6
10	85.00	8.00	800.00	24.2
11	85.00	2.00	1200.00	91.2
12	85.00	8.00	1200.00	96.4
13	85.00	5.00	1000.00	73.7

TABLE 5

Analysis of variance (ANOVA) for the selected model

Source	Sum of Squares	df	Mean Square	F Value	p-value	
Model	14.07	7	2.01	508.41	< 0.0001	Significant
A-Lime Stone Size Fraction	1.28	1	1.28	323.66	< 0.0001	
B-Calcination Time	1.07	1	1.07	271.60	< 0.0001	
C-Calcination Temperature	8.64	1	8.64	2184.58	< 0.0001	
AB	0.53	1	0.53	135.18	< 0.0001	
AC	0.65	1	0.65	165.51	< 0.0001	
BC	0.50	1	0.50	125.34	< 0.0001	
C^2	1.40	1	1.40	352.98	< 0.0001	
Residual	0.020	5	3.95E-003			
Cor Total	14.09	12				

- The final equation with the condition of actual factors:

$$\begin{gathered}\mathrm{Ln}\,(CaO_{act}) = -16.70317 - 0.055118 * \text{Lime Stone Size} + 0.52045 * \\ \text{Calcination Time} + 0.038676 * \text{Calcination Temperature} + 2.21536\text{E-}003 * \\ \text{Lime Stone Size} * \text{Calcination Time} + 3.67695\text{E-}005 * \text{Lime Stone Size} * \\ \text{Calcination Temperature} - 5.86631\text{E-}004 * \text{Calcination Time} * \text{Calcination} \\ \text{Temperature} - 1.68364\text{E-}005 * \text{Calcination Temperature}^2\end{gathered}$$

In Fig. 4, the individual effect of each factor on the response is demonstrated. Fig. 5 shows the graph of the interaction effect of the parameters.

According to the effect diagrams of the parameters in Fig. 4, it can be seen that increasing the size of limestone particles reduces the CaO_{act} percentage or decreases the quality of the produced lime (Fig. 4-A). Also, increasing the time and calcination temperature of the limestone increases its quality (Fig. 4-B and C). In the meantime, according to the slope of the graph and the F value in the table of analysis of variance (Table 5), it can be stated that the parameter of calcination temperature had the highest effect on the response. Thus an increase in the calcination temperature from 900 to 1000°C leads to the lime quality from 33% to 66% (limestone size fraction of 85mm and calcination time of 5 hours). Based on the graph of the interaction effect of the parameter of the size of limestone particles on calcination of limestone in Fig. 5-A, it is evident that more calcination time is needed to produce quality lime at a constant temperature by increasing the size of the limestone particles. So, at a temperature of 1000°C (intermediate value for calcination temperature parameter) and calcination time of 2 hours, limestone analysis with a size fraction of 30 mm, increases by more than 90% (about 98%). But lime analysis with a limestone size fraction of 85 mm is about 45%, and lime analysis with limestone size fraction of 140 mm is about 20% after calcination. As a result, more than 7 hours 36 minutes, and 8 hours are required for limestone size fractions of 70 and 140 mm to increase their quality to over 90%. Based on the graph of the interaction effect of the parameters of calcination time and temperature in Fig. 5B (The parameter size fraction is at its middle value of 85 mm), it is evident that a higher temperature is needed to get good quality lime with a constant size fraction from limestone at a shorter calcination time. Thus, for the calcination of limestone of 85 mm, quality higher than 90% occurs at a calcination time of 2 hours and temperatures above 1160°C. However, at the calcination time of 5 hours, the temperature can be reduced to 1085°C. Also, at a calcination time of 8 hours, a temperature of 986°C can produce lime with a quality higher than 90% (for limestone size fraction of 85 mm). According to the graph of the interaction effect of the parameters of the limestone size fraction and calcination temperature in Fig. 5C, it can be postulated that, at a constant time of calcination, (calcination time parameter is in its middle value of 5 hours), a higher temperature is needed to produce high-quality lime with increasing

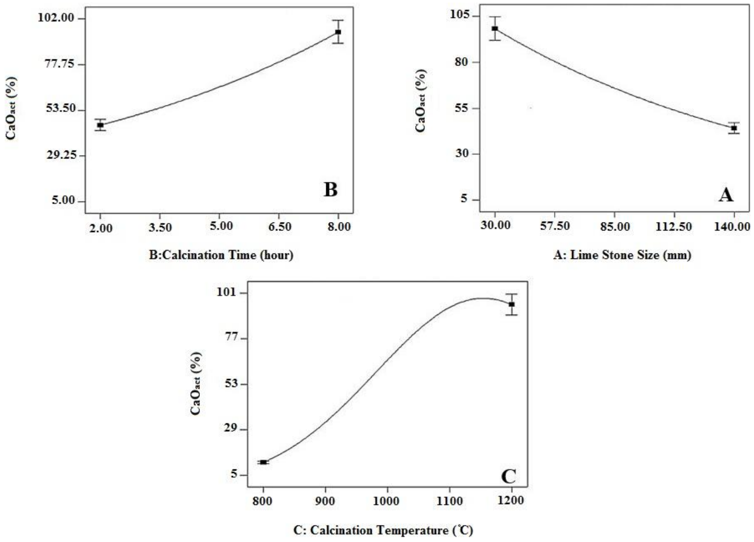

Fig. 4. Graph of the effect of calcination factors on the quality of produced lime
(in each graph, two other parameters were in the middle value)

limestone size fraction. So, at a calcination time of 5 hours, the lime analysis made of 30 mm limestone with a temperature of 980°C reached over 90%. But temperatures higher than 1085 and 1155°C are required for limestone with the size fractions of 85 mm and 140 mm.

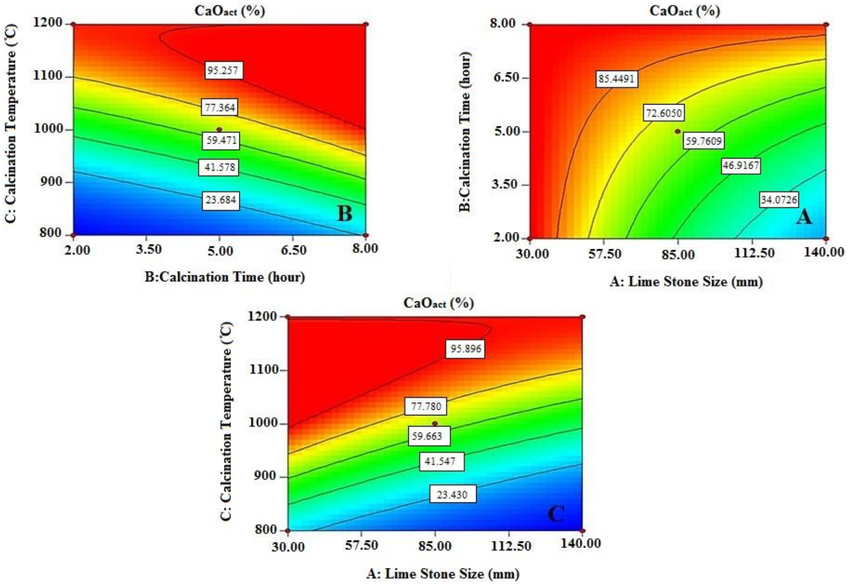

Fig. 5. Graph of the interaction effect of parameters on calcination of limestone (in each graph, the other parameter was in the middle

To determine the optimal conditions in the obtained model, and considering the conditions of existing industrial kilns, the following conditions were considered:

- Considering that two limestone size fraction ranges (30-70 mm and 70-140 mm) were used in two separate kilns, to produce lime in the plant in each kiln, the parameter of limestone size fraction was considered as the maximum amount. Therefore, the optimal condition for calcination of the limestone with the size fraction of 70 mm was considered in one kiln, and the limestone with the size fraction of 140 mm was considered in the adjacent kiln.
- The objective of optimisation was considered to provide a minimum of 90% analysis for the output lime from the kilns.
- The useful calcination time was selected as an average of 8 hours by considering the length of the burning zone in existing kilns, time of change in the burning shaft per cycle, and the speed of stone movement based on the tonnage of the input limestone. It should be noted, when lowering the tonnage of the consumed stone, the amount of this time may be increased up to 10 hours.
- The minimum temperature required to produce high-quality lime was considered to be 90%, based on the cost of gas consumed, construction conditions of the kiln, and controlling the operating conditions. The optimal calcination conditions of the limestone in the kilns were determined as follows (Table 7).

TABLE 7

The optimal conditions were obtained for the calcination of limestone

Limes tone Size (mm)	Calcination Time (hour)	Calcination Temperature (°C)	CaO_{act} (%)
140	8	996.50	90.00
70	8	980.36	89.99

For validation of the obtained optimal conditions, two samples of limestone with the size fractions of 70 and 140 mm, were placed in the laboratory kiln at optimal temperature and calcination time. The obtained results are presented in Table 8.

According to the data presented in Table 8, it is evident that the calcination model of limestone was able to estimate the quality of the produced lime with an accurate approximation. The quality of lime produced from a limestone size fraction of 140 mm at 996°C and calcination time of 8 hours, was predicted as 90%, and after the test with real conditions, it was obtained as 88.36%. Likewise, the predicted quality by the model for the produced lime of limestone size fraction of 70 mm at 980°C and calcination time of 8 hours, was determined as 89.99%, measured as 92.65%. According to the results obtained from this section, it was found that the most important factor in the calcination of limestone is the calcination temperature. The fluctuations in the quality of the lime produced in the kilns of the Iran Alumina Plant were caused by the lack of proper calcination conditions for the input limestone to the kilns in different size fractions. Calcination time of 8 to 10 hours in the kiln (by taking into account the burning zone length and different tonnage), the calcination temperature of the limestone has not been enough for the calcination of limestone to take place completely. It should be mentioned that in recent years, the temperature of the connection channel has been below 900°C and even 850°C, and the ratio of stone (kg) relative to fuel (m^3) had many fluctuations (which in most cases was more than 16.4). Based on the quality of the output lime and the results of this study, limestone had not gone through the average temperature of 1000°C in the kiln. Also, some of the other functional factors include several changes in the size of the limestone particles, different leakage on the kiln structure and gas lines, and a large amount of excess air (40%).

TABLE 8

Validation of optimal conditions obtained in laboratory kiln

Limes tone Size (mm)	Calcination Time (hour)	Calcination Temperature (°C)	CaO_{act} (%)
140	8	996	88.36
70	8	980	92.65

3.2. Calcination of limestone dust at different temperatures

The results of titration and standard ASTM C110 methods for lime samples obtained by calcination of limestone dust at different temperatures are presented in Figures 6 and 7, respectively. The reactivity graph in Fig. 6 shows that by increasing calcination temperature the reactivity and quality of the produced lime are reduced. Analysis obtained for lime produced at 1200°C is about 70% at a time duration of 15 seconds of stirring (until titration begins). The amount of lime produced at 1000 and 800°C was 82.8% and 84.1%, respectively.

Fig. 7 also clearly shows the reactivity of lime produced at higher temperatures. Thus, the lime sample produced at 800°C, the temperature of the solution reached higher than 70°C, after about 20 seconds. This occurred after about 160 seconds for the sample produced at 1000°C. The sample produced at 1200°C, the solution temperature did not reach 70°C even after 1000 seconds. The temperature graph of the operating sample was also placed between the two samples and was produced at temperatures of 800 and 1000°C (and close to the graph of 800°C). Also, the maximum temperature produced from the operating sample, given the analysis (less CaOact),

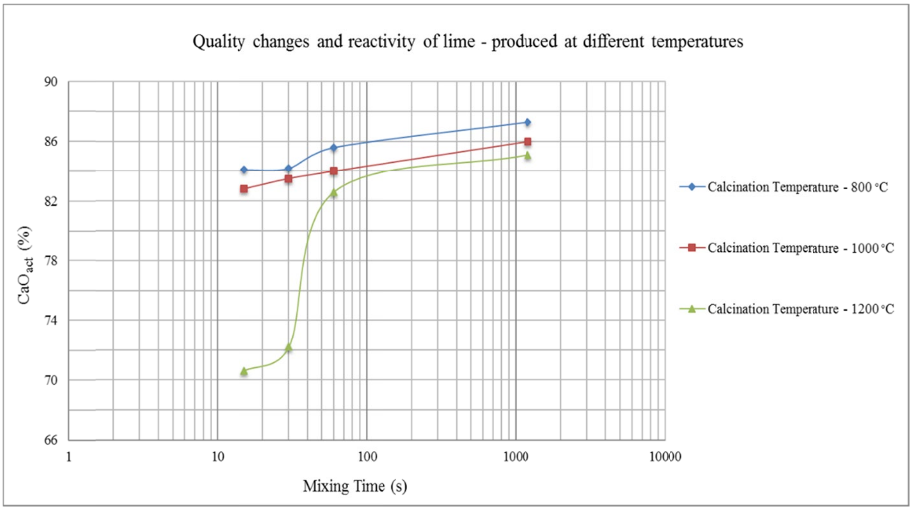

Fig. 6. Graph of the reactivity of lime produced from limestone dust at different temperatures

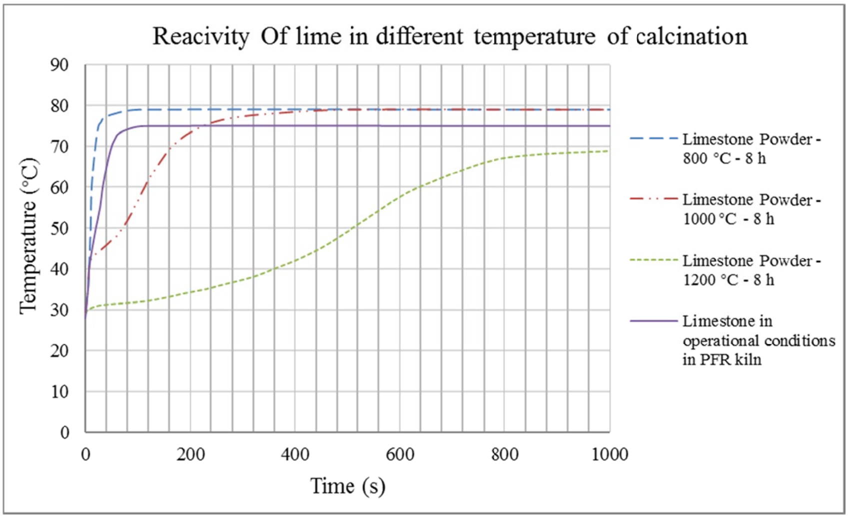

Fig. 7. Reactivity of lime produced from limestone dust at different temperatures and its comparison with the lime sample produced in PFR kiln with analysis of 80.8%

was less than two samples produced at temperatures of 800 and 1000°C. Observations from the tests performed in this section also indicated no sticking particles or in operational terms, no blocking occurred in the samples calcined at temperatures of 800 and 1000°C (Fig. 3a, b). Some sticking was observed in particles of samples calcined at 1200°C (Fig. 3c), but since it was weak, it cannot be considered as a blocking factor in the kiln. The formation of the blocking may occur in these kilns at temperatures above 1200°C or at a longer calcination time, making it possible to reduce the amount of stone to fuel ratio and increase the average temperature of the calcination section to 1000°C. According to the lime reactivity graph in Figures 6 and 7, it can be seen that by increasing the calcination temperature, the reactivity of lime is reduced. This is evident at the calcination temperature of 1200°C. The cause for reduced reactivity of lime produced at high temperature and its partial quality decline can be due to the lime particles sticking together and sintered at high temperatures and also the reduction of the specific surface area.

4. Conclusions

The objective of conducting this study was to model the calcination conditions of limestone with different size fractions to optimis e limestone calcination in two PFR kilns of the Iran Alumina Plant. For this purpose, three parameters of limestone size fraction, temperature, and calcination time were selected as important factors in the calcination of limestone, and 13 experiments were designed by using the Box-Benken method. The results indicated that the parameter of calcination temperature was the most effective factor in the calcination of limestone. Considering the obtained results and operating conditions of existing industrial kilns, increasing the temperature of the burning zone to 1000°C was considered for the study. To reduce excess air from 40 to 20%, the ratio of stone (kg) relative to fuel (m^3) was decreased to 15.3. Also, the kilns were monitored and a diagnosis was performed, and the leakage of gas and air pipes were fixed to control the conditions and prevent the loss of energy and fuel. The results obtained after one month showed an increase in the output lime analysis of the kiln. So that in both of the kilns, the average amount of lime analysis was increased from 80.72% (average analysis of lime in the last 5 years) to 86.54%. It seems that the amount of analysis of lime might become even higher after applying the required repairs for the kilns.

Acknowledgements

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Abbreviations

Parallel Flow Regenerative shaft kiln	PFR kiln
Natural Hydraulic Lime	NHL
Discrete element method	DEM
Computational Fluid Dynamics	CFD
Active lime (%)	CaO_{act}
Loss On Ignition	LOI

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