Process Solutions to Improve Sintering Kiln Performance

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Abstract

Kamensk-Uralsky Alumina Refinery uses thermal causticization to compensate for the caustic soda losses. The thermal causticization process implies sintering of soda ash and Middle Timan Bauxites (STBR) in a rotary kiln producing sodium aluminate to feed to the Bayer process. The high recirculation load of fine dust from the external gas treatment system to the cold end of the kiln leads to significant dust losses including alumina and soda. The paper proposes a solution to reduce the circulating dust load by binding dust from the external gas treatment system in the forms of briquettes. During the studies, physical and chemical parameters of sintering dust were determined and laboratory tests on dust briquetting were carried out with/without the use of binding agents. An effective dust briquetting process was developed. At the laboratory scale the tests on briquette baking with subsequent sinter leaching were performed.

Keywords: Sintering, Bauxites, Briquetting.

1. Introduction

Production of alumina from low-grade bauxites requires an additional process area, i.e. sintering of alumina-containing mixtures. The sintering area is one of the most energy consuming areas in alumina production [1].

It should be noted that to be competitive in the global market, the alumina and aluminium industries must reduce power consumption and cash cost of the products. Therefore, reducing fuel consumption is an important line of research of alumina production processes.

Process solutions, which promote the enhancement of the sintering process and are associated with changing the process flow diagram, mixture preparation processes [2], generation of the optimal phase composition of nepheline sinter [3] are well under development and require significant capital investments. The sintering process for bauxite mixtures requires that the process dust captured in the external gas treatment system is returned to the cold end of the kiln [4]. This results in the circulation of a high dust load in the "sintering kiln – external gas treatment" circuit. The process dust, which is directed to the cold end of the kiln, is heated by the kiln exhaust gases, then it gets into the external gas treatment system, cools down and is supplied to the cold end of the kiln again, thus consuming the heat required for mixture heat treatment.

The authors determined the properties of the gas-and-dust flows at the outlet from the kiln, thus demonstrating that depending on the kiln performance and specifics of the kiln shell shape, dust circulation amounts to 17 % - 45 % of kiln capacity.

The assessment of the sintering heat balance [1] shows that approximately 30 % of the heat is lost with off-gases and circulating dust.

There are various solutions to reduce the unwanted circulating dust load in the kilns [5, 6]. One solution is to granulate dust from the gas treatment system with drum, disk or other type of granulators with further supply of granules to the kiln. Thus, cement industry uses granulation of the dust from the clinker furnaces [7, 8] with further returning the dust granules to the process.

Raw granules need to shall be roasted to improve the strength properties of the granules [9]. Unroasted granules lack the mechanical strength required to transfer them to the cold end of the kiln. Moreover, to ensure the required mechanical properties of the granules, the binding agent should be added in most cases. However, owing to the properties of the dust in the external gas treatment system, the binding agent, which is added to the process, cause blockages of the granulator leading to the disruption of the production process.

An alternative to the granulating would be briquetting of the circulating dust.

This pelletizing method proves to have at least two advantages as compared with granulation, i.e. briquettes have an identical regular shape and demonstrate better transportation properties; additionally, they do not need to be roasted [10, 11].

So far, briquetting the dust from the sintering kiln gas treatment systems of alumina production has received almost no attention. One more objective of this research is to evaluate the prospects of using the briquettes as a raw material for sintering kilns of alumina refineries.

Thus, this paper presents the results of laboratory tests to develop the briquetting technology as well as to evaluate the properties of the sintered material obtained from the briquettes.

2. Laboratory Research of Briquetting Process

2.1 Properties of the Materials

The bauxite mixture sintering area is arranged so that the dust from the kiln is supplied to the stage-wise dry scrubbing around the “dust chamber – cyclones – electrostatic precipitator” circuit [12]. All dust captured at different gas treatment stages is directed to the screw feed of the dust collector. Thus, this circulating dust consists of coarse particles from the dust chamber, finer fraction from the cyclones and fine dust captured from the electrostatic precipitator.

For laboratory testing two different samples of circulating dust were used, i.e. circulating dust from the cyclones and electrostatic precipitator (Sample 1) and total circulating dust from sintering kilns comprising the dust from the dust chamber (Sample 2). Prior to the laboratory tests dust samples were analyzed to determine chemical properties by X Ray Fluorescence (XRF) and particle size distribution (PSD) by sieving. Table 1 presents the PDS of the dust samples.

Table 1. PSD of the dust samples.

	Fraction content, %			
Sample	**+ 630 µm**	**+ 100 µm**	**+ 50 µm**	**- 50 µm**
1	1.61	34.53	43.64	20.22
2	0.86	91.26	6.24	1.64

As the data in Table 1 show the size distribution in Sample 1 significantly differs from the one in Sample 2.

As Sample 1 comprises dust from the cyclones and electrostatic precipitator, therefore, it contains finer fractions. For example, Sample 1 contains twelve times more - 50 µm fraction as compared with Sample 2. However, + 100 µm fraction content in Sample 1 is almost one third of that in Sample 2.

The higher content of the + 630 µm fraction in Sample 1 is attributed to the formation of clusters of ultrafine fractions (- 5 µm, - 1 µm), which are apt to agglomerate during the tests.

Table 2 presents the chemical composition of the dust samples by XRF.

Table 2. Chemical composition of the dust samples by XRF.

Sample	**Content, %**										
	SiO_2	**Al_2O_3**	**Fe_2O_3**	**TiO_2**	**CaO**	**MgO**	**Na_2O**	**K_2O**	**MnO**	**SO_3**	**LOI**
1	3.5	23.6	10.6	1.3	3.3	0.28	31.5	5.1	0.07	0.65	23.8
2	3.09	27.52	13.37	1.58	3.40	0.43	28.7	0.71	0.09	0.50	17.25
Initial mixture	3.92	26.64	12.87	1.27	3.33	0.2	25.18	0.3	-	0.92	25.37

As the test results show, the Al_2O_3 content in the dust samples differs from that in the initial mixture. The Al_2O_3 content in Sample 2 is slightly higher (3.3 $\%_{rel}$) due to lower moisture and presence of coarse particles from the dust chamber, and Al_2O_3 content in Sample 1 is 11 $\%_{rel}$ lower as compared with the initial mixture. It can be attributed to a higher LOI value or higher content of alkaline oxides. Na_2O + K_2O content in Sample 1 is ~ 43 $\%_{rel}$ higher as compared with the initial mixture.

The high content of alkaline oxides (Na_2O + K_2O) in Sample 1 promotes better plasticizing properties of the dust in further industrial briquetting that is confirmed by the data of the particle size distribution test.

2.2 Laboratory Simulation of the Briquetting Process

For briquetting of the sintering dust Nordberg N365OF laboratory hydraulic press (maximum force of 40 tf) and press moulds (diameters of 30.0 mm, 36.1 mm and 51.6 mm) were used. The resulting briquettes were of a pellet shape.

One of the main control parameters of the briquetting process with the use of a roll press is the force applied to the briquetted material [10]. For this reason, tests were carries out under different pressing forces.

The following pressing forces were used in the briquetting tests: 100 kgf/cm^2 (10.2 MPa), 200 kgf/cm^2 (20.4 MPa), 350 kgf/cm^2 (35.7 MPa), 500 kgf/cm^2 (51.0 MPa), 1000 kgf/cm^2 (102.0 MPa), 1500 kgf/cm^2 (153.0 MPa) and 2000 kgf/cm^2 (204.0 MPa).

Several series of the tests were carried out with addition of the binding agent (3 % of the sample weight) depending on the dust type; the process evaporated sodium carbonate solution was used as a binding agent.

Following the pressing, the briquettes were tested for strength by a breaking and dropping methods. Upright breaking tests of the briquettes were performed twice, i.e. immediately after the pressing and four minutes after the pressing. The force (kfg), which was sufficient to break the upright briquette, was recorded.

Drop tests of the briquettes were conducted at a height of 600 mm and repeated in triplicate. The strength parameter used was the amount of coarse fraction (> 5.0 mm) as a percent to the initial weight of the briquettes.

2.3 Results of the Laboratory Simulation of the Briquetting Process

As discussed above, the laboratory simulation was carried out using circulating dust from the external gas treatment system (cyclones, electrostatic precipitator) of the sintering kiln (Sample 1) and "common" circulating dust from the external gas treatment system of the sintering kiln (Sample 2).

Figure 1 and Figure 2 show the changes in the volume and density of Sample 1 briquettes depending on the specific pressing pressure with press moulds of different diameters.

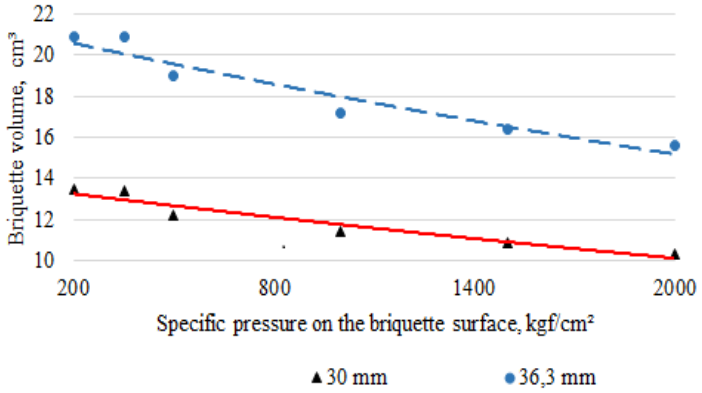

Figure 1. Changes in the volume of the briquettes depending on the specific pressing pressure.

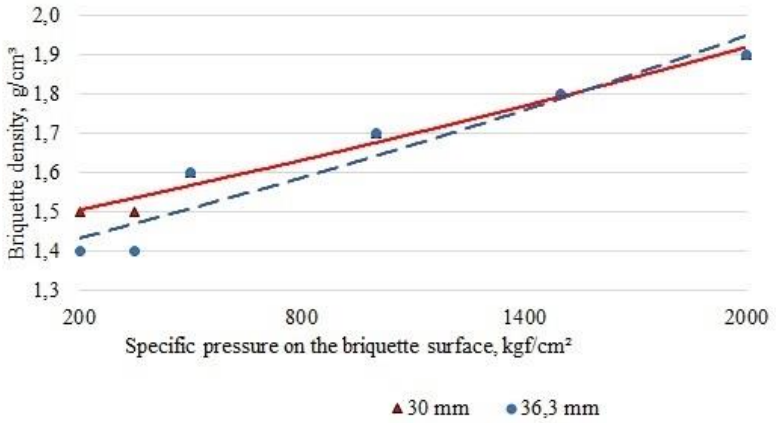

Figure 2. Changes in the density of the briquettes depending on the specific pressing pressure.

As the data show, the maximum decrease of briquette volume of 1.2 cm^3 for the 30 mm mould is observed under the force of 500 kgf/cm^2. Under 2000 kgf/cm^2 the briquette volume decreased by 0.6 cm^3.

Data for the 36.6 mm mould demonstrates a similar behaviour. A pressing force of 200 kgf/cm^2 and 300 kgf/cm^2 caused no dynamic changes on the sample volume, whereas, under 500 kgf/cm^2 force, the sample volume changes by 1.9 cm^3. Further increasing the pressing force within the range of 1000–2000 kgf/cm^2 resulted in changes of the volume by 0.8–1.8 cm^3. Maximum dynamic change of the sample volume was achieved under the pressing force of 500 kgf/cm^2.

The density of the briquettes also increases from 1.4 g/cm^3 under the pressing force of 200 kgf/cm^2 to 1.9 g/cm^3 under the briquetting pressure of 2000 kgf/cm^2. Notably, it is true for both 30 mm press mould and 36.3 mm press mould. Figure 2 shows that density increases smoothly by 0.1 g/cm^3.

Figure 3 shows the changes in the breaking force applied to the upright briquette depending on the pressing specific pressure.

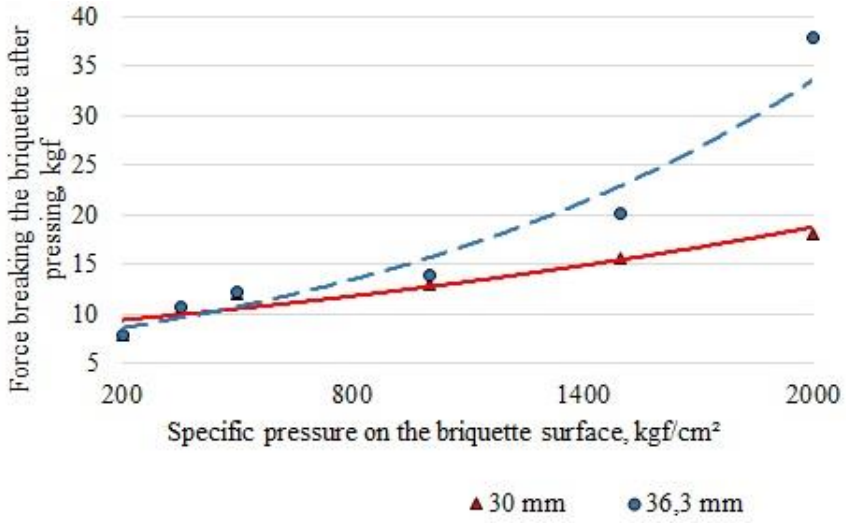

Figure 3. Changes of the breaking force applied to the upright briquette depending on the briquetting specific pressure.

As the given dependencies show breaking force for 30 mm press mould increases from 7.8 kgf under briquetting pressure of 200 kgf/cm^2 to 18 kgf under briquetting pressure of 2000 kgf/cm^2 respectively. The maximum increase of breaking force (by 2.7 kgf) is recorded under 300 kgf/cm^2. Further increase of briquetting pressure results in increase of breaking force within 1.0–2.6 kgf.

Sample 2 demonstrates a similar behaviour. Though as the briquetting pressure increases from 300 kgf/cm^2 to 2000 kgf/cm^2 the volume of the briquettes decreases from 12.2 cm^3 to 1.9 cm^3, the maximum dynamic change of the volume (1.1 cm^3) is observed under pressure of 500 kgf/cm^2.

The density of the briquettes for both 30 mm press mould and 36.3 mm press mould increases from 1.5 g/cm^3 to 1.9 g/cm^3 along with increasing briquetting pressure.

The briquette breaking force also increases from 5.3–7.9 kgf to 31.8–38.0 kgf under briquetting pressure increase from 200 kgf/cm^2 to 2000 kgf/cm^2.

Additionally, Sample 2 was briquetted using a 36.1 mm press mould with the addition of the binding agent in the amount of 3 % of the total weight of the sample. Specific pressure on the briquette surface is 500 kgf/cm^2. For the tests, the period of mixing the dust sample with the binding agent changed from 15 s to 150 s. Besides the samples were analyzed immediately after the testing and after 4 minutes residence time.

Test results show that after mixing for 15 s, the breaking force of the briquette immediately after the pressing amounted to 0.3 kgf, while after 4 min residence it amounted to 29.1 kgf. The best briquette strength is achieved under mixing the sample for 90 s and 4 min residence of the briquette. To break such briquette a force of 58.0 kgf must be applied.

It should be noted that 30 mm briquettes break under lower breaking force. Thus, when briquetting pressure increases from 200 kgf/cm^2 to 2000 kgf/cm^2 breaking force for 30 mm briquettes increases by 2.3 times while for 36 mm briquettes said force increases by 4.8 times.

The Sample 1 briquettes were also subject to the drop test. The test results proved that increase of the briquetting pressure from 200 kgf/cm^2 to 350 kgf/cm^2 results in increase of + 5 μm by 5.5 %. Further increasing briquetting pressure does not produce any significant effect on the content of + 5 μm.

3. Laboratory Study of Processing Properties of Dust Briquettes

Laboratory tests showed the technological possibility of producing briquettes from the sinter dust of the sintering kilns.

However, the main objective of the present research was not obtaining the briquettes as a final product but to use said briquettes in the existing sintering process, i.e. develop a new technology for sinter dust processing. Therefore, in addition to the quality assessment, the processing properties of the briquettes were tested.

3.1 Method of Studying the Processing Properties of the Briquettes

To evaluate the processing properties, new briquettes using Sample 1 and Sample 2 were prepared. Table 3 presents the preparation conditions and main properties of the Sample 1 briquettes.

Table 3. Properties of the Sample 1 briquettes.

Briquette	Binding agent, %	Pressure, kgf/cm^2	Weight, g
1	0	1000	20
2			25
3	3		20
4			25
5	0	500	20
6			25
7	3		20
8			25

As dust from electric precipitators and cyclones (Sample 1) is intended for industrial processing, this sample was tested with addition of the binding agent and without it. Briquettes 1, 2, 5, and 6 were prepared without any binding agents. Briquettes 3, 4, 7, and 8 were pressed using the binding agent, i.e. evaporated sodium carbonate solution.

For the sake of comparison, new briquettes were also prepared from Sample 2 material. Table 4 shows the preparation conditions and main properties of the Sample 2 briquettes.

Table 4. Properties of the Sample 2 briquettes.

Briquette	Binding agent, %	Pressure, kgf/cm^2	Weight, g
1	-	500	30.7 ÷ 31.1
2	-	500	20.6 ÷ 20.8
3	-	500	19.7 ÷ 20.6

The obtained briquettes were sintered under the laboratory conditions to evaluate the processing properties of the briquettes and their sintering and digestion efficiencies.
All briquettes were sintered under similar conditions. The briquettes were placed on the trays and sintered in SNOL 6.7/1300 laboratory furnace at a heating rate of 11 °C/min up to the temperature of 1200 °C and then held for a residence time of 1 hour. The sintered material was left in the furnace for cooling.

Digestion under normal conditions was carried out to evaluate the processing properties of the sintered material obtained from the dust samples. Briquettes were digested with 0.25 N NaOH solution at a temperature of 100 °C and residence time of 15 minutes. The digested sample was filtered using Buchner funnel and washed with a fixed amount of distilled water. The precipitate obtained was dried in the drying oven at a temperature of 110–120 °C for two hours and the sample prepared as previously.

3.2 Results of Laboratory Tests on Sintering the Briquettes from Sintering Kiln Dust

The chemical composition of the briquettes after the sintering was analyzed by XRF.

Table 5 presents the chemical composition of the sinters obtained from Sample 1 briquettes after laboratory sintering.

Table 5. Chemical composition by XRF of the sinters obtained from Sample 1 briquettes.

Briquette	LOI	Al_2O_3	Fe_2O_3	SiO_2	TiO_2	CaO	MgO	$\sum Na_2O$	K_2O	MnO	SO_3	C\A	μ_{Si}
1	9.6	29.1	14.2	4.4	1.5	3.2	0.39	33.8	3.6	0.1	2.1	1.15	6.61
2	11.4	28.4	13.2	4.4	1.4	3.1	0.38	33.5	4.2	0.1	2.0	1.18	6.45
3	10.1	28.4	13.4	4.1	1.4	3.1	0.34	34.4	4.1	0.1	2.1	1.21	6.93
4	10.4	28.6	13.4	4.0	1.4	3.2	0.35	34.8	3.9	0.1	2.1	1.23	7.15
5	10.5	27.8	13.1	4.6	1.4	3.1	0.35	34.6	4.3	0.1	2.1	1.22	6.04
6	11.2	27.7	13.0	4.3	1.4	3.1	0.35	34.8	4.3	0.1	2.0	1.25	6.44
7	7.3	29.0	13.7	4.3	1.4	3.2	0.34	35.5	3.8	0.1	2.3	1.22	6.74
8	7.5	29.0	13.7	3.9	1.4	3.2	0.31	36.0	3.8	0.1	2.2	1.26	7.44

As Table 5 shows, the Al_2O_3 content in the sintered material varies: in the samples prepared with the binding agent, the Al_2O_3 content changes from 27.7 % to 29.1 % and averages to 28.3 %. In the samples prepared without the binding agent, the Al_2O_3 content ranges from 28.4 % to 29.0 % and averages to 28.8 %. The difference of alumina content in the sinters prepared with and without the binding agent is 0.5 % (1.8 $\%_{rel}$). The average content of total alkali (Na), expressed as total Na_2O, in the samples with the binding agent amounts to 34.18 % and ranges from 33.5 % to

34.8 %. While the average content of total alkali (Na), expressed as total Na_2O, in the samples without the binding agent amounts to 35.2 % and ranges from 34.4 % to 36.0 %.

Table 6 presents the chemical composition by XRF of the sinters obtained from Sample 2 briquettes after laboratory sintering.

Table 6. Chemical composition by XRF of the sinters obtained from Sample 2.

Briquette	LOI	Al_2O_3	Fe_2O_3	SiO_2	TiO_2	CaO	MgO	$\sum Na_2O$	K_2O	MnO	SO_3	C\A	μ_{Si}
1	2.10	35.00	18.80	3.90	1.50	3.80	0.47	32.50	0.50	0.11	1.10	0.97	8.97
2	2.50	34.70	18.00	4.00	1.60	3.80	0.47	32.60	0.50	0.11	1.20	0.98	8.68
3	2.50	34.90	17.40	4.10	1.60	3.90	0.47	33.10	0.53	0.10	1.20	1.00	8.51

In this case, the difference in the Al_2O_3 content is lower and does not exceed 0.3 % (0.9 $\%_{rel}$). The Al_2O_3 content in the sinters ranges from 34.7 % to 35.0 % and on average amounts to 34.9 %.

The average content of total alkali (Na), expressed as total Na_2O, in the samples on average amounts to 32.7 % and ranges from 33.1 % to 32.5 %. The difference of alumina content in the sinters is 0.6 % (1.8 $\%_{rel}$).

Figure 4 shows the results of measuring soluble alumina and alkali in the sinters from Sample 1 briquettes obtained under normal digestion conditions.

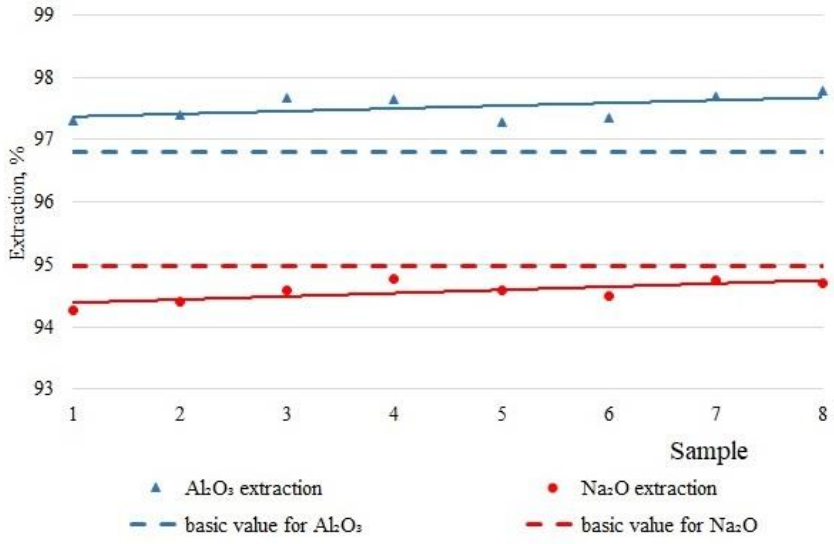

Figure 4. Al_2O_3 and Na_2O extraction from the Sample 1 briquettes.

The results under normal digestion conditions show that the Al_2O_3 extracted from the Sample 1 sinters (without adding the binding agent) on average amounts to 97.33 % and ranges from 97.19 % to 97.42 % (or by 0.23 %). Alkali extraction ranges from 94.0 % to 94.7 % and averages to 94.33 %.

The presence of the binding agent improves alumina extraction by 0.37 % to 97.71 % and increases alkali extraction up to 94.70 %.

Analysis of the samples prepared with the binding agent shows the increase of the alumina and alkali extraction that is one of the main indicators of the sinter quality. However, applying this

technology in the actual process might prove to be complicated. The addition of the binding agent might lead to issues, such as: steaming, condensation, congealing and, consequently, hardening of the dust that can disrupt the briquetting process, hinder the supply of the material to the kiln, reduce the service life of the equipment, and compromise the entire sintering process.

However, increasing the briquetting pressure up to 1000 kgf/cm^2 does not produce any significant negative effect on the extraction. Thus, alumina extraction from the briquettes prepared without binding agent amounted to 97.32 % under the pressure of 500 kgf/cm^2 and 97.34 % under the pressure of 1000 kgf/cm^2. These results show the difference of 0.02 %. The difference in the alkali extraction is even lower, i.e. 0.01 %.

Adding a binding agent to the briquettes does not affect the extraction parameters under different pressures. Under the pressure of 500 kgf/cm^2 – the average alumina extraction amounted to 97.74 % and under the pressure of 1000 kgf/cm^2 average alumina extraction amounted to 97.67 %.

Alkali extraction shows a similar trend. Under the pressure of 500 kgf/cm^2, the average alkali extraction amounted to 97.72 % and under the pressure of 1000 kgf/cm^2, average alumina extraction amounted to 94.68 %.

Sample 2 sinter digestion showed average alumina extraction of 96.57 % and average total alkali (Na) extraction of 95.35 %.

Alumina extraction from Sample 1 briquettes is 0.75 % higher as compared with Sample 2 briquettes, while with alkali the situation is different. Alkali extraction from Sample 2 is 0.98 % higher as compared with Sample 1.

The digestion results show that alumina extraction from all samples is higher as compared with the sinters with similar silica ratios obtained under the same (laboratory) conditions.

Alkali extraction is lower, most likely because of a high silica ratio caused by formation of double silicates $mNa_2O \times pCaO \times nSiO_2$.

4. Conclusions

The results of the laboratory tests show the possibility of developing an acceptable technology for processing the dust from the sintering kilns by briquetting.

The briquetting pressure for the dust from the external gas treatment system has been determined to obtain a hard briquette. The tests conducted, demonstrated that increasing the specific briquetting pressure above 500 kgf/cm^2, up to 2000 kgf/cm^2, does not significantly affect the strength of the briquettes produced. In this case, a briquette is not a final product, therefore, the strength properties obtained should be sufficient to transfer said briquettes to the sintering kilns.

Digestion tests under the normal conditions showed that alumina extraction from all briquettes increased from 97.32 to 97.74 %, and alkali extraction changed from 94.32 to 94.72 %. These values are somewhat better than the extraction from similar sinters, so it proves the better efficiency of the sintering process.

Though adding the binding agent improves alumina and alkali extraction from sintered briquettes to a certain degree, use of additional binders in the briquettes can hinder the operation of the briquetting unit or disrupt the entire sintering process and therefore not recommended.

Laboratory tests show that the process for briquetting the circulating dust from the sintering kilns can be introduced on an industrial scale to improve the performance of the sintering kilns and external gas treatment system. and thereby maximise fuel efficiency and reduce alumina and soda losses.

5. References

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