The solution to the problems of gas treatment in alumina production with application of ecological engineering

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Abstract. In this paper, the analysis of the modern situation of the environment in the process of sintering alumina production is carried out. The data on the technology of preparation of sinter and the situation of environmental equipment are given. Ecological assessment of implemented technological decisions in the sintering department and alumina plant was carried out. There is substantiation for the introduction of additional stages of gases at furnace sintering with the direction of the waste gases of the furnace for the carbonization of aluminate solution. The technical decision in the direction of the gases in the wet treatment in a scrubber-electrofilters and their subsequent use in the alumina production was developed and implemented in the framework of the implementation of ecological engineering in gas treatment of furnaces sintering.

1. Introduction
The aluminum industry occupies a leading place in Russia and abroad. The raw material for aluminum is alumina. Almost 98% of alumina for the aluminum industry in the world is produced from bauxite and only about 2% from nepheline [1,2]. In Russia, for the first time in the world, a method for producing alumina from nepheline by sintering is proposed and mastered [3].

At the same time, it is known that the production of 1 ton of aluminum produces about 1.5 tons of gaseous and solid pollutants, of which only about 90% is captured in gas treatment systems [4]. Gas treatment systems used in alumina production are not always effective. They cannot be used in alumina production, given the high temperature of the process [5-7]. One of the plants of alumina and soda production in Russia is Achinsk alumina plant (JSC "RUSAL Achinsk"), introducing new technologies of gas treatment and improving the situation of atmospheric air in the zone of the production area. The main production determining the productivity of the entire technological process is the conversion of sintering. The gas treatment system of sintering furnaces used at the plant with the use of multi-field electric filters requires constant replacement of their structural elements due to their rapid wear [8]. Therefore, the solution to the problems of gas treatment from sintering furnaces is currently relevant.

2. Purpose of research
The aim of this work was implementation of technological solutions, providing increase of efficiency of atmospheric air treatment and reduces pollutant emissions from the furnaces of sintering alumina production.

3. Obtained result
Processing of nepheline ore is carried out by the method of sintering in the alumina plant. As a raw material, limestone-nepheline-soda charge is used, which is subjected to heat treatment in sintering furnaces to obtain a sinter containing aluminum oxide up to 15-16%. Since nepheline ore contains a significant amount of silicon dioxide (up to 42%), which can form insoluble compounds with aluminum oxide and lead to its losses, silicon dioxide must be removed from the process. This is done by binding it to a two-calc silicate, which is slightly soluble in alkaline solutions.

All physical and chemical transformations are carried out in sintering furnaces at a temperature of 1200 to 1280°C and the presence of a liquid phase that activates the diffusion of the charge components. With a subsequent decrease in the temperature of the material to (1100-900) °C, the crystallization of the formed compounds and the formation of the physical structure of the sinter in which the above compounds are located finishes.

Furnace gases are subjected to sequential treatment in dust removal installations to ensure sanitary and hygienic standards of atmospheric air quality. For this purpose, a dust chamber, cyclones and electric filters are provided.

The dust chamber acts as a connecting link between the sintering furnace and the gas treatment system of the furnace (cyclones, electric filters) and is provided for the coarse treatment of the gases of the sintering furnaces from large dust fractions (more than 50 microns). Further treatment is carried out in cyclone batteries, where particles larger than 20 microns are deposited. The next stage of treatment is electrofilters with a higher degree of treatment. Each furnace is equipped with two electrofilters running at the same time. Smaller particles are captured in the electrofilters. But at present, there are furnaces at the sintering redistribution, where the established standard of maximum permissible emissions of solid pollutants is not reached. The degree of gas treatment after electrofilters in this case was 98-99%. The regular dust level at the outlet of the emission source is exceeded.

One of the options for reducing the planned emissions from the sintering furnace No. 1 can be the direction of the gases for their use in the technological process of carbonization of aluminate solutions and the production of aluminum hydroxide (figure 1).

But the use of gases from the sintering furnace No. 1 in the technology of producing aluminum hydroxide makes demands for a higher degree of treatment them from dust and the presence of the necessary concentrations of carbon dioxide in them. Therefore, it was necessary to develop an additional technical measure to ensure the treatment of the gases from the sintering furnace No. 1 to the required degree of treatment. This technical measure is the decision to send the gases of the sintering furnace No. 1 for additional treatment to the wet scrubber-electrofilters KM-21 and then to transfer the gas treatment from dust to the carbonization of the aluminate solutions by the superchargers H-1200-26-1.
Figure 1. The transfer of gases from the sintering furnace No. 1 to the carbonation.

Scrubber-electrofilter KM-21 is projected for gas treatment from solid pollutants to 0.02 g/nm³ and pre-cooling to 45-55°C gases containing carbon dioxide going to the supercharger H-1200-26-1 for their subsequent transfer to the carbonation redistribution. The scrubber-electrofilter is a wet dust removal device, consisting of two parts: a scrubber and an electrofilter.

The scrubber collects coarse dust with a particle diameter of more than 10 microns. Dust capture with a diameter of less than 10 microns occurs in the electrofilter. The supercharger is made in the form of a single-cylinder two-stage one-way suction machine. The air entering the supercharger must be treated of solid mineral particles and impurities that can cause mechanical wear. The amount of solid particles in the air entering the superchargers should not be more than 0.02 g/nm³.

Gas treatment of furnaces sintering after treatment in the scrubber – electrofilters blowers directed at the redistribution of carbonized alumina plant. The chemical interaction of carbon dioxide contained in the gases of sintering furnaces with the aluminate solution takes place at the carbonation redistribution of the alumina plant.

Carbonation of aluminate solutions is carried out by bubbling through a solution of a mixture of gases containing CO₂. The essence of the process is to neutralize the caustic alkali to form soda:

\[ 2NaOH + CO_2 = Na_2CO_3 + H_2O \]  
(1)

In the interaction of the aluminate solution with carbon dioxide, the content of caustic alkali is reduced, which leads to the decrease of the resistance of the aluminate solution and the separation of aluminum hydroxide in the sludge:

\[ NaAl(OH)_4 + CO_2 = Al(OH)_3 \downarrow + NaHCO_3 \]  
(2)

With a deep carbonization carried out at the second stage (in the presence of carbonate and bicarbonate bases), there is decomposition of the remaining sodium aluminate with the formation of sodium hydroaluminate \((Na_2O \times Al_2O_3 \times 2CO_2 \times 4H_2O)\):

\[ 2Na(Al(OH))_4 + 2NaHCO_3 \rightarrow Na_2O \times Al_2O_3 \times 2CO_2 \times 4H_2O \downarrow + 2NaOH \]  
(3)

The formation of bicarbonate occurs according to the reaction:

\[ Na_2CO_3 + CO_2 + H_2O = 2NaHCO_3 \]  
(4)

The separation of aluminium hydroxide occurs according to the reaction:

\[ NaAl(OH)_4 \rightarrow Al(OH)_3 \downarrow + NaOH \]  
(5)

Gases containing carbon monoxide are fed into the bubblers to a depth of 5 m from the solution level in each device. The feed is carried out through the cover of the carbonizer. Gases that have been carbonized are released into the atmosphere. They limit the content of pollutants. Maximum permissible concentration of pollutants in the air-alkali aerosols (in terms of NaOH) is 0.5 mg/m³. The analysis of the actual performance of the gas treatment system of the sintering furnace No. 1 showed that the dust content at the outlet of the electrofilters of the furnace did not exceed 0.7 g/nm³. The average volume flow rate of the gas treatment of the sintering furnace No. 1 is 688680 pm³/h or 396909 nm³/h. The distribution of dust contained in the furnace gas by fractions is given in table 1.
Table 1. The distribution of dust contained in the furnace gas by fractions.

| Particle size (µm) | 20   | 20-15 | 15-8 | 8-5.5 | 5.5-3.5 | less than 3.5 |
|-------------------|------|-------|------|-------|---------|--------------|
| Dust weight fraction (%) | 44.2 | 10.5  | 18.8 | 10.0  | 6.2      | 10.3         |

The analysis of experimental data obtained during industrial tests of the proposed gas treatment technology showed that these gases can be directed to wet post-treatment scrubber-electrofilters and fed to carbonation. Based on the data in table 2, it follows that the gas treatment technology for the carbonization, the structural elements of wet scrubber-electrofilters, blowers and carbonization provide stable work of the redistribution of carbonation. They also show the principal possibility of using the gases of the sintering furnace No. 1 in the technological process of decomposition of aluminate solutions and the release of aluminum hydroxide in the proposed project of the gas supply for treatment in the KM-21 device. The calculated hydrodynamic performance and instrumental measurements on scrubber-electrofilter No. 7 are given in table 2.

Table 2. Hydrodynamic performance of the scrubber-electrofilter.

| Name of indicators | Calculated data | Performance of measurements on the scrubber-electrofilter No. 7 |
|--------------------|-----------------|---------------------------------------------------------------|
| The performance of the scrubber-electrofilter: | | |
| P (m³/h) | 105200 | 80976 |
| H (m³/h) | 74520 | 50846 |
| Gas velocity in the core of the electrofilter (m/s) | 1.2 | 0.88 |
| Maximum gas temperature at the inlet of the electrofilter (°C) | 140-150 | 138 |
| Maximum gas temperature at the outlet of the electrofilter (°C) | 40-45 | 46 |
| A valid discharge gas in the electrostatic electrofilter (mm of water. St./kPa) | 500/4.9 | 498/4.9 |
| Hydraulic resistance of scrubber-electrostatic electrofilter (kPa) | 2.7 | 2.27 |
| The total water consumption of the scrubber-electrofilter (m³/h) | 675 | 506 |
| The consumption of water for periodic flushing of the collecting electrodes (m³/h) | 50 | 50 |
| Water consumption for irrigation of the scrubber part (m³/h) | 625 | 456 |
| Dust content in the gas at the inlet to the scrubber-electrofilter, (g/nm³) | to 0.7 | 0.683 |
| Dust content in the gas at the outlet to the scrubber-electrofilter (g/nm³) | 0.020 | 0.019 |

The data obtained experimentally on the volume flow of gases sent to the wet gas treatment in scrubber-electrofilters confirm the calculated data. The measured volume flow rate of gas treatment after scrubber-electrofilters is 365134 m³/h. A slight deviation of 0.4% is within the limits of the gas measurement method. The calculated volume flow rate of the furnace gas should provide the required completeness of the deposition of aluminum hydroxide on carbonation. The results of the measurements protocols of alkali aerosols emissions, performed by the sanitary-industrial laboratory of JSC "RUSAL Achinsk", at the outlet of the carbonized battery No. 1 showed the following: the actual number of aerosols of NaOH alkali at the outlet of the carbonized battery No. 1 was 1.623 g/s, which did not exceed the established standard of maximum permissible emissions for this source
1.627 g/s. Analysis of gas phase emissions from carbonizers into the atmosphere for the content of nitrogen dioxide, carbon monoxide, sulfur dioxide showed their complete absence.

4. Conclusion

Thus, the carried out industrial tests practically confirmed the results of calculations of pollutants dispersion from the source of emission and showed that the direction of the gases in the sintering furnace No. 1, on the redistribution of carbonation provides the necessary requirements of the technological regime. Emissions of inorganic dust into the atmosphere through the chimney from sintering furnaces do not exceed the established standard. The expected reduction in dust emissions from furnace No. 1 is achieved when the direction of the gases of the furnace after a treatment in an existing 2-step system, in the amount of not less than 67% of the total on a wet post-treatment in the scrubber-electrofilter and, further, for use in the technology allocation of aluminum hydroxide on the redistribution of carbonized alumina plant.

The calculated aerohydrodynamic parameters of scrubber-electrofilters confirm the technical possibility of effective wet treatment of furnace gases for their subsequent direction in the technological process of decomposition of the aluminate solution. Taking into account the annual productivity of the plant, the total consumption of furnace gas necessary for the technological process of aluminum hydroxide extraction was determined.

Technological calculations determined the optimal region of the gas fraction of the sintering furnace No. 1 for carbonation from 60 to 80%, providing them with the necessary concentration of carbon dioxide at least 16.5%. In this interval, the calculated values of the gas volume of the sintering furnace No. 1 directed to the wet post-treatment in the scrubber-electrofilters and their subsequent supply to the carbonization redistribution are placed. The tests showed that the use of even 100% of the gas volume of the sintering furnace No. 1 on carbonation does not worsen the quality of the seed, production aluminum hydroxide and commercial alumina.

References

[1] Sizyakov V M, Vlasov A A and Bazhin V Yu 2006 Strategic objectives of the metallurgical complex of Russia Non-ferrous metals 1 32-8
[2] Wang X L 2010 Alumina production theory and technology (Changsha:Central South University) p 411
[3] Arlyuk B I and Liner Yu A 1994 Complex processing of alkaline aluminum-containing raw materials (Moscow: metallurgy) p 384
[4] Xiang D, Weining L, Xun L, Qiyi D and Xiaobing 2016 The study and applications of modern potline fume treatment plant (FTP) Minerals, Metals and Materials 210869 775-80
[5] Neate M and Currell B 2016 Latest filter developments increasing existing aluminium smelter gas treatment centre capacity and reducing emissions Minerals, Metals and Materials Series 210869 799-804
[6] Martineau P, Maltais J-N, Vérin M and Frainais M 2015 Start-up of the ozeos gas treatment center (GTC) for RTA AP60 Light Metalls 2015 pp 623–5
[7] Fraser P, Steele P and Cooksey M 2016 PFC and carbon dioxide emissions from an Australian aluminium smelter using time-integrated stack sampling and GC-MS, GC-FID analysis Minerals, Metals and Materials Series 210869 871-6
[8] Gusaev V A and Troitskiy A A 2011 Technical solutions to improve the efficiency and reliability of electrostatic precipitators FINGO Moscow collection of reports of the IV International Intersectoral conference “Dust and gas treatment” pp 16-8