Analysis of parameters technological gas emissions neutralization during the sintering process of phosphorite agglomerate

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Abstract. This study analyzes the specific properties and technological parameters of gas emissions from chemical-energy processes [1], considering the volume and content of toxic components, as well as the operating experience of gas emission purification systems at existing phosphate plants. A three-stage system of apparatuses is studied for gas purification: an ensemble of single cyclones, foam aggregates irrigated with aqueous caustic soda solution. It is established that cyclones are the most suitable apparatus for dry gas cleaning, and that their diameter should be no more than one meter to increase the efficiency of cleaning. It has been demonstrated through scientific research that when cleaning phosphorite sintering gases, which have a volume exceeding the capacity of a single cyclone, it is necessary to use group cyclones. These are several cyclones combined into one group with a common hopper. It is recommended that the cyclone speed be increased by approximately 50% in comparison to the standard speed, which contributes to an increase in the efficiency of the separation of impurities in the purified gas.

1 Introduction

The production of yellow phosphorus is associated with the generation of a considerable quantity of gas emissions containing toxic components [2-3]. These gases originate from the sintering and sinter cooling processes, as well as from the aspiration of gases from the slag discharge unit and ferro-phosphorus discharge unit. Additionally, aspiration air from the crushing, screening, transportation, and other processing units of phosphate rock, sinter, coke, and quartzite contributes to the emission of these gases.

The parameters of gas emissions from the sintering process of ore phosphate raw materials at the inlet to the purification system are provided for a capacity of 270K t/year of commercial phosphorus. The volume is 525K m^3/h, the temperature is 120 ºC, and the rarefaction is 9 kPa. The content of toxic components, in nanomoles per cubic meter (nmol/m^3), is as follows: dust (total) - 4.3, sulphur dioxide - 1.2, sulphur trioxide - 0.05, total fluorine (total) - 0.12, including in the form of silica fluoride (total) - 0.015,

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phosphorus pentoxide - 0.4, sodium chloride - 0.2. The elevated dust content can be attributed to the utilization of dry rather than wet dust removal from beneath the vacuum chambers. Furthermore, the absence of cottrel milk in the charge results in a P_2O_5 content of 0.06–0.1 g/nm³.

2 Materials and methods

The specific properties of the gases to be purified (in terms of volume and content of toxic components) and the experience of operating gas emission purification systems at existing phosphate plants have led to the adoption of a three-stage system for gas purification. The first stage involves single cyclones, the second and third stages utilize foam devices irrigated with aqueous caustic soda solution.

Cyclones are the simplest and most reliable apparatuses for dry gas purification [4-5]. In order to ensure high efficiency of purification, the diameter of cyclones should be, as a rule, not more than 1 m. The exception to this rule is highly efficient conical cyclones, which diameter can be up to 2.5 m. Therefore, when cleaning gases, the volume of which exceeds the capacity of a single cyclone, group cyclones are used. This involves several cyclones being combined into one group with a common hopper. However, as demonstrated by operational experience, the number of cyclones in a group is limited to eight to ten. Otherwise, there is a significant decline in efficiency due to gas flow between cyclones within the hopper. The use of conventional cyclones in this case is inadvisable due to the large volume of gases to be purified, as the number of cyclones would be approximately sixty [6]. High-efficiency conical cyclones are only operated with separate hoppers. A cleaning system consisting of a large quantity of cyclones with separate hoppers is rather complicated in operation. The use of single cyclones of large diameter significantly simplifies the purification system and reduces its resource intensity. However, high efficiency of gas cleaning is not achieved. To eliminate this disadvantage, a technical solution is proposed.

Firstly, to increase the speed in the cyclone by more than x1.5 in comparison with the regulation speed, which contributes to the increase of the separation factor.

Secondly, to prevent the entrainment of secondary dust, the concentrated dust gases from the cyclone hopper are extracted by a smoke pump. The quantity of these gases is approximately 6% of the total purified gases. Their purification is conducted in a single high-efficiency conical cyclone. The gases exiting both cyclones are combined in a common gas duct and subsequently undergo wet cleaning [7]. The combination of these two measures allows for the achievement of dry gas cleaning efficiency of up to 85%. Additionally, the use of large-diameter cyclones, in comparison to small-diameter cyclones, is advantageous due to their reduced abrasive wear. Furthermore, foam apparatuses with foam layer stabilizers have been successfully implemented in numerous mineral fertilizer production facilities. These devices are distinguished by their high efficiency, relatively low hydraulic resistance, and high reliability in operation. Furthermore, they are stable in various media and relatively resistant to clogging by salt deposits and dust. The operational principle of foamers is based on the creation of a highly developed gas-liquid foam layer on a gas-distributing perforated grid arranged horizontally [8]. Liquid is fed to the grate from above, while gas is fed underneath from below. To create fine-cell foam, eliminate its longitudinal oscillation and reduce splash drift, a honeycomb foam stabilizer made of vertical plates is installed above the grid [9-10]. A centrifugal stabilizer, constructed of inclined radial plates, is positioned above the honeycomb stabilizer. The aqueous solution of caustic soda is selected as the absorption solution. In the Russian industrial context, soda solution is commonly utilized for the purification of analogous gases. The purification process and its primary indicators exhibit minimal variation when employing soda or caustic soda. The principal advantage of caustic soda or soda over other types of absorbents, such as lime, is the formation of soluble products because of chemisorption of fluorine, sulphur, and phosphorus compounds present in the gases [11]. This increases the reliability of the gas cleaning equipment. Gases from the sintering process initially enter the first stage of the purification system - four single parallel positioned cyclones position 1, shown in Figure 1.

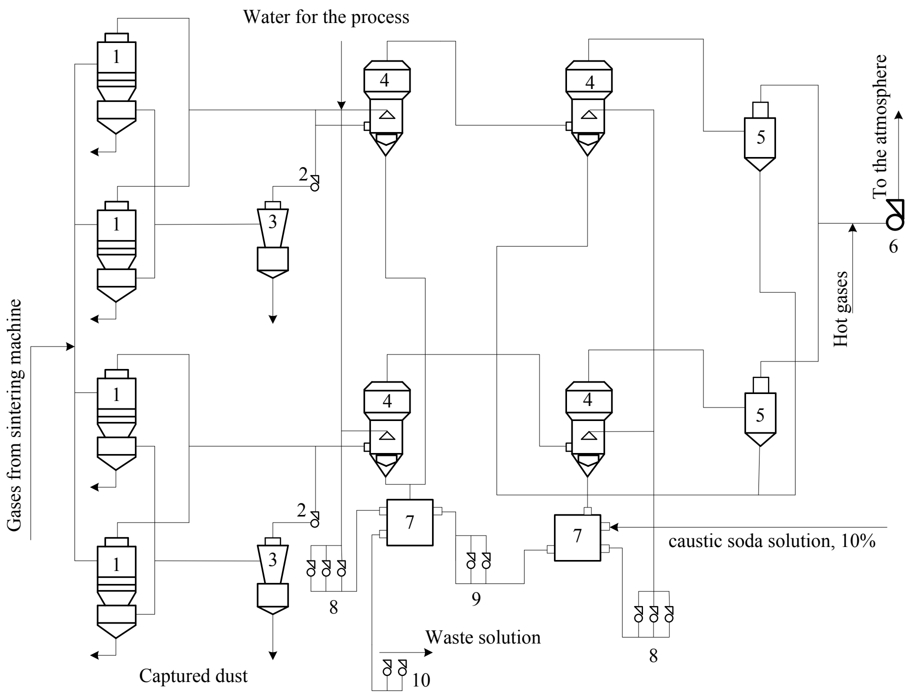

Fig. 1. The following diagram illustrates the purification process of gas from the sintering process. The apparatus is comprised of the following components: 1-cyclone, 2-smoke pump, 3-conical cyclone, 4-foam apparatus with foam layer stabilizer, 5-centrifugal splash catcher, 6-exhauster, 7-circulation tank, 8-circulation pump, 9 and 10-slurry pumps.

From the hoppers of these cyclones a part of the gases is passed by the smoke pump, position 2, through two parallel conical cyclones, position 3. The captured dust in cyclones, position 1 and 3, is returned to the sintering process. After passing through the dry-cleaning stage, the gases enter the wet cleaning stage, which consists of two stages. In each stage there are two foamers with foam stabilizer, position 4. The gases cleaned in the foam apparatuses enter the centrifugal type of splash collectors, position 5. After being freed from splashing gases by an exhausted, item 6, through a chimney are discharged into the atmosphere.

To prevent condensation of moisture from the gases inside the exhauster, hot gases from the cooling zone in the amount of 30K nm^3/h with a temperature of 300 ºC are introduced into the section of the gas duct located between the splash collectors and the exhauster. To reduce the dust content in the gases, their intake is carried out from the section of the gas duct, located after the dry stage of gas cleaning of the sinter cooling zone. In addition, these gases are cleaned in two single, parallel cyclones. The apparatus, item 4, is irrigated with a fresh caustic soda solution, which is continuously fed into the circulation tank, item 7. From this, a portion of the spent solution is conveyed to the circulation tank by pumps, item 9. This solution is used to irrigate the foam apparatus, item 4. The level of the solution in the tanks, item 7, is kept constant. The spent solution is removed from the tank by pumps, item 10, and directed to the evaporation basin. Circulation of solutions in the foamers is accomplished by pumps, item 8. Fresh solution is fed continuously into the circulation tank, item 7.

The reaction of interaction of toxic components contained in gases with caustic soda solution is described by the following equations:

$$NaOH{+}HF \rightarrow NaF{+}H_2O$$
$$4NaOH{+}\ 3SiF_4 \rightarrow 2Na_2SiF_6{+}SiO_2\downarrow + 2H_2O$$
$$2NaOH + SO_2 \rightarrow Na_2SO_3 + H_2O$$
$$2Na_2SO_3 + O_2 \rightarrow 2Na_2SO_4$$
$$4NaOH + P_2O_5 \rightarrow 2Na_2HPO_4 + H_2O$$

In order to compensate for the evaporated water, the calculated amount of water is continuously fed to the upper stage of the foamers, position 4. The cyclone operation parameters are as follows:

Position 1: conditional gas velocity in the cross-section = 5.2 m/s, hydraulic resistance = 3500 Pa, dust collection efficiency = 85%.

Position 3: conditional gas velocity in the cross-section = 2 m/s, hydraulic resistance = 3000 Pa, dust collection efficiency = 95%.

Parameters of operation of foam devices, position 4: circulating irrigation with a 10% caustic soda solution, gas velocity in the free cross-section (average) - 3m/s, irrigation density – 20 m^3/m^2/hour, flow rate of the circulating irrigation solution – 400 m^3/hour, amount The quantity of water required for makeup (for the entire cleaning system) is 40 m^3/h, while the amount of waste solution (from the entire system) is 8 m^3/h. The consumption of caustic soda (for the entire system) is 0.8 t/h, and the hydraulic resistance is 3 kPa. The operational parameters of the splash catcher are as follows: gas velocity in the free section is 3 m/s, hydraulic resistance is 1 kPa, and splash capture efficiency is 98%. The content of toxic components in the gases at the outlet from the splash catcher (before the hot gases are introduced into the gas duct), in nanomoles per cubic meter (nmol/m^3): dust, 0.02; sulphur dioxide, 0.05; sulphur trioxide, 0.007; total fluorine. The concentration of these components is as follows:

- 0.01, including in the form of silicofluoride.
- 0.014, phosphorus pentoxide.
- 0.06 (without the introduction of cottrel milk, the content of P_2O_5 is 0.012).
- sodium chloride - 0.02.

The parameters of the gases at the outlet of splash catchers (prior to the introduction of the hot gases into the gas duct) were as follows: volume, 118 nm/s; temperature, 55 ºC; and splash content, 0.1 g/nm^3. The content of toxic components in gases at atmospheric emission, in grams per cubic nanometer: dust, 0.02; sulph ur dioxide, 0.06; sulphur trioxide, 0.008; total fluorine, 0.01. Including the form of silicofluoride, the concentration is 0.0015, while the concentration of phosphorus pentoxide is 0.07 (without the introduction of cottrel milk into the charge, the concentration of P_2O_5 is 0.013). The parameters of the gases at the inlet to the exhauster (after the introduction of hot gases into the gas duct) are as follows: volume = 125.2 nm^3/s, temperature = 70 ºC.

The total efficiency of the purification process for toxic components is as follows: 99.5% for dust, 95% for sulphur dioxide, 84% for sulphur trioxide, 91.6% for total fluorine, including silica fluoride (90%), phosphorus pentoxide (85%), and sodium chloride (85%).

The content of components in the treated solution, g/l: dust - 34.8, sodium sulphate - 70.5, sodium sulphite - 60.5, sodium fluoride - 7.1, sodium silicon fluoride 5.5, sodium chloride - 10.2, sodium phosphate - 40.5 (without introduction of cottrel milk into the charge the content of sodium phosphate is 9.2 g/l).

3 Results and Discussion

To reduce the amount of wastewater (spent solutions), it is necessary to use a caustic soda absorption solution with the highest concentration, and the degree of its utilization should be close to 100%. However, to ensure stable operation of the treatment equipment, the concentration of the solution should not exceed 10%. The degree of caustic soda utilization can be monitored by an indirect indicator, namely the acidity of the spent solution. At a pH of 5, the degree of utilization is close to 100%. An alkaline environment of the spent solution indicates incomplete utilization of caustic soda. However, at a neutral environment and even more acidic environment, the efficiency of gas cleaning decreases and corrosion of equipment increases. The optimum value of the pH of the spent solution is 7-8.

4 Conclusion

A multistage system of phosphorus production of gas emissions and wastewater treatment is proposed for implementation. This system will significantly reduce harmful emissions into the atmosphere and hydrosphere of the planet, which is a highly relevant area of scientific research for engineers around the world. Consequently, the studies were conducted, resulting in scientifically based recommendations that can be employed to reduce the amount of wastewater, ensure the sustainable operation of gas cleaning equipment with high efficiency of gas purification, and reduce corrosion of equipment. It was demonstrated that to achieve the optimal parameters of the purification process, the concentration of the irrigating absorption solution of caustic soda should be equal to 10%, and the acidity of the discharged waste solution should be pH = 7-8. It can be demonstrated that the most effective process of purifying liquid fractions of phosphorus production waste in industry is that which is ecologically safe.

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