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Treatment of wastewater resulting from iron ore beneficiation

Очистка сточных вод обогащения железных руд

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Key words: wastewater; iron ore; beneficiation; magnetic separation; suspended solids; hydraulic size; sedimentation; coagulants; flocculants

Ключевые слова: сточные воды; железная руда; обогащение; магнитная сепарация; взвешенные вещества; гидравлическая крупность; отстаивание; коагулянты; флокулянты

Abstract. The overall objective of this article is to study the potential of the reagent treatment of wastewater resulting from the iron ore beneficiation process, as well as preventing the discharge of the wastewater into the open waters. The wastewater at the Mikhailovskii iron ore beneficiation plant (Kursk Region, Russia) discharged into a tailings pond has become an object of the research. This article looks at the sedimentation kinetics of the wastewater resulting from the wet magnetic separation of iron ores. The results of the kinetic studies allow one to predict the efficiency of water clarification and the necessary duration of sedimentation of the recycled water of the iron ore processing plant in sedimentation facilities. It has been experimentally shown that the wastewater resulting from iron ore beneficiation plants contains kinetically stable suspended substances with a hydraulic size of less than 0.013 mm/s. The efficiency and time of wastewater clarification through the reagentless sedimentation depends on the hydraulic size of the suspended solids and the depth of the settling zone. The analysis proves the efficiency of an advanced wastewater treatment, which entails reagent sedimentation with the use of aluminum polyoxychloride Aqua-Aurat 18 and flocculant Praestol 853. This approach helps to obtain the required quality of water for discharge into open reservoirs and to reduce the concentration of suspended solids by 99.6 % and total dissolved solids by 30 %. The preferable reagents dose, their ratio, as well as the method of the advanced wastewater treatment are determined.

Аннотация. Цель работы – исследование возможности реагентной очистки сточных вод обогащения железных руд, исключение сбросов сточных вод в открытые водоемы. В качестве объекта исследований применялись сточные воды Михайловского горно-обогатительного комбината (ГОК) (Курская область, Россия), направляемые в хвостохранилище. Изучена кинетика отстаивания сточных вод мокрой магнитной сепарации железных руд. Результаты кинетических исследований позволяют прогнозировать эффективность осветления и необходимую продолжительность отстаивания оборотной сточной воды ГОК в отстойных сооружениях. Экспериментально показано, что сточная вода ГОК содержит кинетически устойчивые взвешенные вещества с гидравлической крупностью менее 0.013 мм/с. Эффективность и продолжительность осветления сточной воды безрегентным отстаиванием зависит от гидравлической крупности выделяемых взвешенных веществ и глубины зоны отстаивания. Показана эффективность глубокой доочистки воды реагентным отстаиванием с применением полиоксихлорида алюминия марки Аква-Аурат18 и флокулянта Праестол 853, позволяющая получать требуемое качество воды для сброса в открытые водоемы и снизить содержание взвешенных веществ на 99.6 %, солесодержание на 30 %. Определена оптимальная доза реагентов, их соотношение, технология доочистки воды.

1. Introduction

The improvement of the recycled water supply at iron ore processing plants is important, as there is no universal technological solution for the acceleration of suspended solids sedimentation that is equally effective for different types of wastewater with different composition.

The extensive water use at iron ore beneficiation plants is accompanied by the formation of tens of thousands cubic meters of wastewater per day (tailings wastewater) resulting from the processes of wet iron ore beneficiation and the thickening of the iron ore concentrate. Tailings are a concentrated slurry which contains some particles of gangue (sand, clay…), as well as some quantity of small particles of iron ore, that haven't been extracted in the beneficiation process. Apart from the fine grit (up to 9 %) with an average size of the particles 0.04 millimeter (75 %) the wastewater could also contain dissolved inorganic salts (sulfates, chlorides, silicates) as well as reagents used in the flotation method of iron ore beneficiation. Total dissolved solids (TDS) varies from 500 to 3000 ppm.

In order to reduce water consumption and wastewater disposal at iron ore beneficiation plants the systems of water reclamation are used, which enable the reuse of wastewater after the separation of the suspended solids from the liquid in slurry ponds (clarification ponds, tailings dams), sand separators, hydrocyclones, separators and thickeners [1].

In Russia, the following two methods of water reclamation in the process of iron ore beneficiation [2, 3] are primarily employed:

1) Clarification of tailings slurry in tailings ponds, where also accumulation, dewatering and storage of the slurry take place. The clarified water contains from 27 to 1000 ppm of suspended solids depending on the sedimentation time;

2) A combined scheme – the clarification of tailings slurry in thickeners, which is later discharged in a concentrated form into a tailings pond.

The first method provides a natural (non-reagent) clarification of the slurry and is applied for example, at the Mikhailovskii mining and beneficiation plant. Tailings dams are considered to be one of the cheapest and technically simplest ways to generate clarified water [1].

However, this method of wastewater treatment has certain limitations such as poor quality of the clarified water, large areas needed for sedimentation (up to 2.000 ha), a necessity to build protecting fences around tailings impoundments and to relay the slurry piping system, as well as a negative impact on the environment (submergence of the nearby areas due to filtration processes, dust dispersion of open beaches).

The second approach entails the use of flocculants to accelerate the process of grit sedimentation in thickeners. This method of water reclamation with the use of polyacrylamide (from 0.5 to 1 g/m^3) is applied at the Lebedinskii iron ore beneficiation plant: at first the thickening of the tailings containing 5 to 8 % of solids in the initial slurry takes place in hydrocyclones and then in thickeners. The effluent from the thickening process with 700-900 ppm of solids in suspension is used as reclaimed water, while the sand from the thickeners is discharged to a tailings pond.

The experience of the mining and beneficiation plant shows that the use of the recycled water, which contains up to 1000 ppm of suspended solids after clarification with or without PAM, does not interfere with the beneficiation technology und gives an opportunity to generate high grade concentrates (at more than 68 % iron). However, the discharge of the reclaimed water from tailings pounds into water basins without an additional treatment is impossible due to high levels of suspended solids (up to 1000 ppm) and dissolved salts (up to 5 ppt) [1].

The closed-loop water recycling systems, which treat wastewater locally, are currently employed. This reduces specific water consumption, decreases and sometimes even rules out wastewater discharge into open waters as well as achieves quality targets for treated water.

Aside from conventional methods such as sedimentation and flocculation the professional literature looks at various approaches to water clarification and wastewater treatment at mining and processing plants: use of chemical methods (neutralization with the milk of lime [2–4], magnesite-bentonite clay composite [5] or with Portland cement concrete (slurry) with 30 % of fly ash or without it [6]), electrochemical (membrane filtration [7–9]), electrophysical (pulse treatment in order to intensify wastewater clarification [10]), biological [11], bioelectrochemical methods [12], as well as the sorption method [13–17] and other approaches [18, 19] which aim at recovering and reusing valuable components.

However, the use of neutralizing reagents [2–6] for the treatment of the iron ore process wastewater is associated not only with significant costs of the reagents and the need for the maintaining of a reagent dosing system, but also with the formation of large volumes of sediment, which is considered a secondary pollutant of the environment. The use of membrane filtration [7–9], as well as electrophysical methods [10] is highly efficient, but is at the same time cost-intensive and thus inexpedient for the industrial-scale wastewater treatment, because a comprehensive preliminary removal of suspended substances from tens of thousands cubic meters of water per day is therefore needed. Biological methods [11] are employed at the Mikhailovskii iron ore processing plant (tailings dam), yet they have a low efficiency of removing heavy metal ions from water and are accompanied by the degradation of large fertile areas. Sorption and recovery methods [13–19] are of relevance, have a great ecological potential, but their application is at the time being unrealistic due to significant volumes of water requiring treatment.

The source [20] presents the results of the studies and outlines the high efficiency of the new coagulant CYH, synthesized by the researchers from China, which was applied together with sodium hypochlorite to treat water discharged into a tailings pond. It was however of interest to look into the possibility of using the recently introduced coagulant - aluminum polyoxychloride Aqua-Aurat 18 (AA 18), which proved to be effective in various industries, for the treatment of wastewater resulting from iron ore beneficiation.

The overall objective of this article is to study the potential of the reagent treatment of wastewater resulting from the iron ore beneficiation process, as well as preventing the discharge of the wastewater into the open waters.

The grade of the clarification of iron ore process wastewater at primary treatment facilities depends on the initial concentration and the size of the particles left over after a solid phase of tailings treatment, on sedimentation time, concentration of TDS and is usually measured by experiment based on the findings of kinetics studies.

This article looks at kinetics of wastewater sedimentation resulting from the wet magnetic separation at the iron ore beneficiation plants and its influence on the parameters of water clarification as well as advanced treatment of clarified water with application of chemical reagents.

2. Methods

The wastewater at the Mikhailovskii iron ore beneficiation plant (Kursk Region, Russia) discharged into a tailings pond has become an object of the research.

The concentration of suspended solids in the wastewater has been measured by its turbidity. The turbidity of the wastewater before (M_{orig}) and after (M_{fin}) treatment was estimated with the help of a colorimeter KFK-2 at wavelength λ = 540 nm by grade of absorbance.

The dispersity of suspended solids present in the wastewater was measured by the size of the hydraulic size, U_0 – the rate of clarification of a layer of water of height H equal to 50 mm during the settling time T, which was determined by the formula: $U_0 = H/T$, mm/s.

Specific electrical conductivity of water X was measured on the Anion conductivity meter 7020.

During the reagent sedimentation of wastewater, aluminium polyoxychloride of the brand Aqua-Aurat 18 (AA 18) and cationic flocculant Praestol 853 (Pr 853) were used in the form of 0.1 % aqueous solutions with which the wastewater was mixed for 1 minute before sedimentation and then 5 minutes slowly. Settling for 5 min. provided separation from the waste water of suspended solids with a hydraulic size of more than 0.07 mm/s.

3. Results and Discussion

In appearance, the wastewater in question is a suspension of red-brown color with a suspended solids concentration of 10855 ppm, pH = 7.6 and a specific electrical conductivity of 1.7 mS/cm, which corresponds to a TDS of 854 ppm (sodium chloride). Suspended solids in the wastewater are mainly represented by iron oxides (35.7 %) and silicon dioxide (55 %) [21].

Kinetic studies have shown (Figure 1) that the wastewater contains 85 % of suspended solids with the hydraulic size of less than 0.013 mm/s, of which 31 % has a hydraulic size ranging from 0.0044-0.013 mm/s, 46.4 % in the range from 0.0022 to 0.0044 mm/s and 7.6 % of the suspended solids – less than 0.0022 mm/s.

The high content of kinetically stable, finely dispersed suspended solids in the waste water (Figure 2) with a low hydraulic size, which is many times lower than U_0 of the slurry removed in a conventional settling tank (0.2-0.8 mm/s), confirms the necessity of its long non-reagent settling using tailings ponds [1].

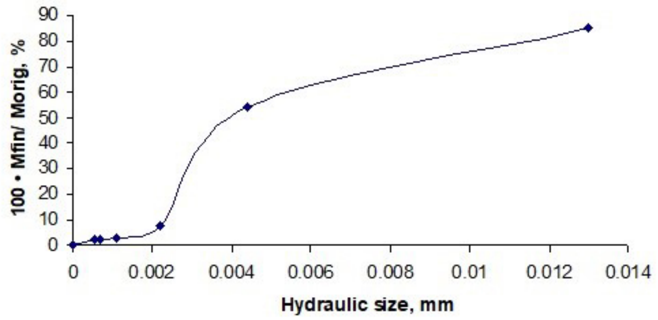

Figure 1. Sedimentation kinetics of wastewater resulting from an iron ore beneficiation plant

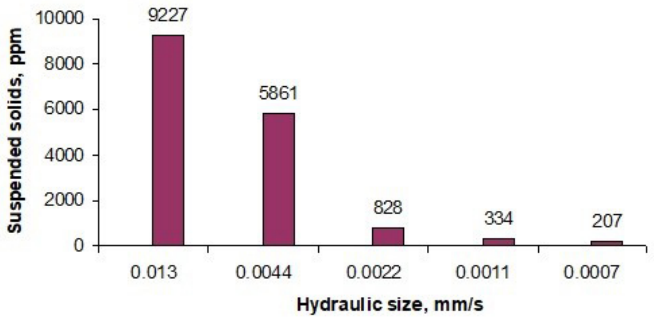

Figure 2. Particle size distribution of suspended solids in wastewater from an iron ore beneficiation plant

The sedimentation time of wastewater in these facilities increases with the increasing depth of the settling zone (Figure 3). Thus, to obtain a wastewater treatment effect of 92.4 % and a residual content of suspended solids of 830 ppm, the calculated settling time will be $T = H/U_0$ = 500 / 0.0022 · 60 = 63 hours with a clarification zone depth of 0.5 meters and 126 hours – at a depth of 1 m.

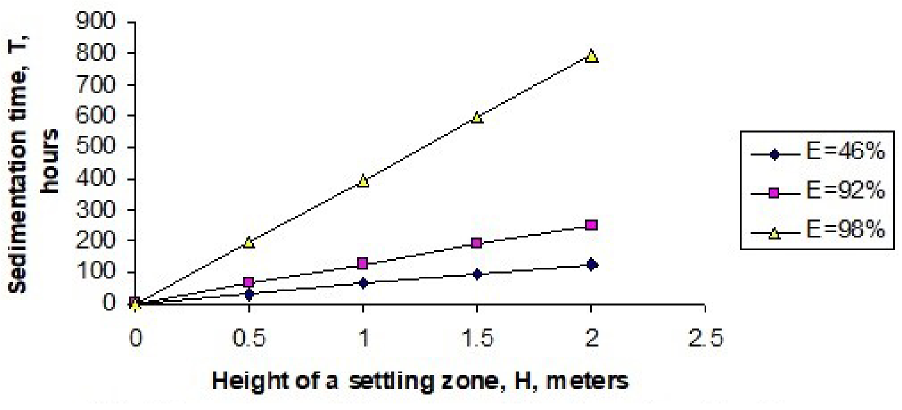

Figure 3. Dependence of the sedimentation time of wastewater from an iron ore processing plant on the height of the settling zone with different clarification effects

The maximum effect of water treatment, equal to 98 %, at which suspended solids with U_0 of more than 0.0007 mm/s are removed, is achieved in 198 hours with the depth of the settling zone H = 0.5 m (Figure 3). The clarified water contains 200 ppm of suspended solids in the form of a pinkish turbidity. The relatively high concentration and, consequently, the low U_0 of suspended solids in the clarified water of an iron ore processing plant is, in all probability, determined by the presence of practically non-settling colloidal silicon compounds. Compounds of silicon in the form of numerous hydrates, various silicic acids, iron silicates are formed in water as a result of different kinds of interactions from contact of fine silica and iron oxides with water and with an aqueous solution and are not extracted from water upon settling [22].

It follows *from the foregoing* that the results of kinetic studies allow one to predict the efficiency of clarification and the necessary duration of sedimentation of the recycled water of the iron ore processing plant in sedimentation facilities.

If it is necessary to discharge excess wastewater from the recycling system into open waters, the reduction of the suspended matter content is achieved by the advanced treatment of the wastewater by sedimentation with preliminary treatment of water with coagulants separately [23, 24] or together with flocculants [25]. The results of the coagulation treatment of the preliminarily settled water from an iron ore beneficiation plant with the initial content of suspended solids of 670 ppm and the hydraulic size of less than 0.0018 mm/s are shown in Figures 4 and 5.

As follows from Fig. 4, the optimal dose of AA 18 is 12 ppm (for aluminum oxide), which reduces the suspended matter content in the settled water to 37 ppm. The hydraulic size of the released coagulated impurities increased 39-fold, to the level of 0.07 mm/s. The joint application of AA18 coagulant and flocculant Pr 853 at a mass ratio of coagulant: flocculant 10 : 1 leads to a decrease in the coagulant dose to 8 ppm. An additional water filtration allows to reduce the content of suspended solids to 3.3 ppm.

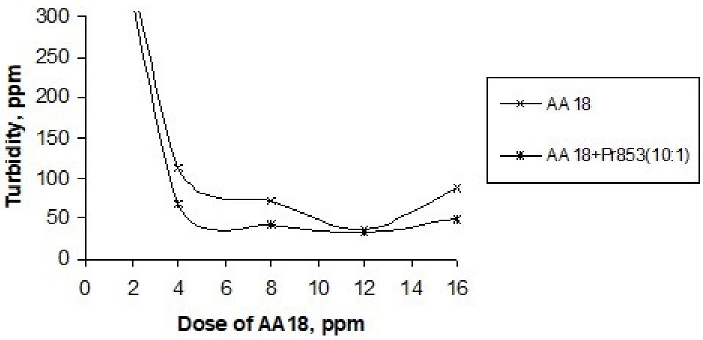

Figure 4. Dependence of turbidity of the settled wastewater on the dose of AA1 8 without and with the flocculant

The effect of the dose of the flocculant Pr 853 on the residual turbidity of the settled and filtered water is shown in Figure 5, from which it can be seen that the ratio of coagulant: flocculant of 10 : 1 is optimal and provides minimum turbidity of both settled and filtered water.

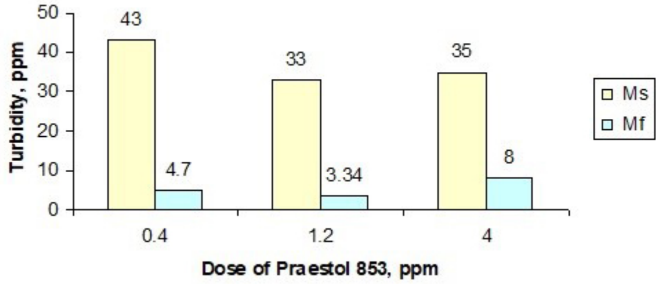

Figure 5. Dependence of turbidity of the settled and filtered water on the dose of Praestol 853/ The dose of AA 18 equals 12 ppm

Thus, an advanced treatment of the reused wastewater of the iron ore processing plant according to the scheme: coagulation using AA 18 together with flocculant Praestol 853, followed by sedimentation and filtration, allows to reduce the content of suspended solids after settling – by 95 %, after filtration – by 99.5 %, from 670 ppm to 3 ppm.

At the same time, the specific electrical conductivity (TDS) of wastewater decreases by 30 %, from 1.7 to 1.19 mS/cm, which is probably the result of the settling of silicates and phosphates in the form of insoluble aluminum salts.

4. Conclusions

1. It has been experimentally shown that the wastewater resulting from iron ore beneficiation plants contains kinetically stable suspended substances with a hydraulic size of less than 0.013 mm/s.

2. The efficiency and time of wastewater clarification through the non-reagent sedimentation depends on the hydraulic size of the suspended solids and the depth of the settling zone.

3. The use of the aluminium polyoxychloride Aqua-Aurat 18 with the flocculant Praestol 853 at the stage of the advanced treatment of the reclaimed water from an iron ore processing plant by sedimentation and filtration allows to reduce the content of suspended solids by 99.6 %, TDS by 30 %.

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