UDC 502.7.719:628.5

A. N. KORCHEVSKYI [1], *Head of the Department of Mineral Processing, Professor, Candidate of Engineering Sciences, korcheval737@gmail.com*
L. I. NAZIMKO [2], *Head of the Department of Marine Ecology, Professor, Doctor of Engineering Sciences*
O. K. MAZHAN [3], *Post-Graduate Student*
K. A.KHOLODOV [1], *Post-Graduate Student*

[1] *Donetsk National Technical University, Donetsk, Donetsk People's Republic/Ukraine*
[2] *Kerch State Maritime Technological University, Kerch, Russia*
[3] *Donetsk National University, Donetsk, Donetsk People's Republic/Ukraine*

IMPROVING EFFICIENCY OF RETURN WATER CLARIFICATION IN GAS-CLEANING SYSTEM CYCLE AT OXYGEN-CONVERTER PLANT OF ARCELORMITTAL TEMIRTAU IRON & STEEL WORKS

The article presents the industrial tests results on clarification of return water in gas cleaning system cycle at the oxygen-converter plant of ArcelorMittal Temirtau Iron & Steel Works. The authors show that the use of organic reagents of the series Flopam SNF provides high efficiency of sedimentation of suspended solids by enlarging the size of floccules, which accelerates their deposition as a result. At the same time, the quality of return water significantly improves, and return water is suitable for multi-use in industrial closed-loop water cycle.

The settled solid phase in the form of fine dispersed particles represents the iron-containing material with total iron content of up to 45%. This material can be returned to the production cycle provided that efficient technologies for its capture and enrichment are used.

Reconstruction and modernization of wet gas cleaning sites at blast furnace and oxygen-converter plants will allow on-site production of to 20 million m3/year of industrial water without treatment and clarification in external settling pond. At the same time, the captured solid phase in the amount up to 35 thousand tons of the iron-containing material will have characteristics acceptable for the agglomeration cycle. The same volume will be withdrawn from the total solid phase storage in currently operating external sedimentation tanks.

The introduction of the modifications will lead to essential decrease in volume of slime pumped to external settlers, which will cut down energy consumption and operational expenses of the gas cleaning site. Termination of the polluted water discharge will contribute to saving of water resources, efficient use of iron-containing raw material and enhancement of environmental protection in the region.

Keywords: *gas cleaning plants, return water, clarification, reagent, efficiency, water resources, conservation, environmental protection.*
DOI: *10.17580/em.2019.02.12*

Introduction

In recent decades, mankind has finally come to understand the negative consequences of man-made impact on the environment as at a certain stage of interaction between man and the biosphere, renewable natural resources become non-renewable [5]. At the same time, there are profound changes in the environment as well as significant overexploitation reaching the extreme exhaustion. The man-made changes activate the law of internal dynamic equilibrium; there is a significant increase in energy costs due to the replacement of energy-intensive natural processes with technogenic. Energy efficiency of nature management is constantly decreasing: to obtain useful products from natural systems, it is necessary to increase energy costs per unit [2]. Global resource potential is continuously exhausted in the course of the societal development, which demands scientific and technical improvement from mankind. The more prudent the approach to natural resources and habitat, the less investment is needed for successful development. Preservation of resources as a result is favorable in the social and economic relation.

Researchers in the different countries study the level of pollution and destruction of components of the atmosphere, the World Ocean, internal waters, lithospheres and biospheres. On the basis of such studies, the assessment, forecast and modeling of the effects of anthropogenic impacts is carried out, as well as the recommendations are developed for preserving the integrity of the natural environment. The main ways are optimization of economic activity of the society and regulation of consumption of resources [9].

Scientists develop theories of relations between population and consumption of resources, as well as problems of limited resources. The law of the exhaustibility of natural resources emphasizes that all natural resources are finite. Completely waste-free production is impossible. The first stage in the development of technology should be the low resource intensity, and then it is necessary to create "cyclical" production in which the waste of some industries can be raw materials for other branches, or can be used within the same technological cycle [4].

Water is one of the most important resources on the planets; with the development of the industry its consumption is constantly growing. Water consumption in mining

and metallurgy per ton of production is from 1 to 6–8 m^3, fresh water— 0.3 m^3, including 0.01–0.04 m^3 of drinking water. Industry uses clarification systems for removal of suspended particles from reusable water. These systems represent an integrated package of activities, including classification of particles, clarification of slime waters, condensation and dehydration of slimes, dehydration and warehousing of products [11–13].

Despite the technical advance of the clarification systems in the direction of abandonment of external treatment facilities and treatment of circulating water within the technological scheme of a plant, until now slime storage facilities continue to be used, contributing to environmental pollution. These facilities occupy large areas, and considerable funds are spent for their operation and maintenance, which adversely affects the economy of industrial projects. Therefore, it is necessary to minimize consumption of water from external sources down to a technologically possible inferior limit and to exclude the release of contaminated water and slime outside the external treatment facilities. In this regard, the problem of purification of process wastewater is of great importance since it is closely related to the protection of water resources, which is of particular importance for Kazakhstan.

Storage of wastes of metallurgical industry is accompanied by their large-scale impact on the environment, expressed in the alienation of land and in pollution of air, groundwater and surface water [1].

Effective operation of the process water clarification (regeneration) system should provide the necessary content of solid in it. Multiple circulation of contaminated water causes unwanted accumulation of the solid phase, which leads to the change in its rheological indexes and the need to add fresh water to the system [12]. At the same time, it is economically inexpedient to extract all solid phase from industrial water.

The main processes in the system of service water clarification are accompanied by the phase interaction and are reduced to the separation of the particle size *d* and density *r* (if considered generally). Even the fact that addition of flocculants initiates complex physicochemical processes does not fundamentally change the final result since the most expedient way to increase the deposition rate is to enlarge the particle size by forming their aggregates during coagulation or flocculation [7]. In general, flocculants are anionic or cationic reagents that are derived from a well-known polyacrylamide. Investigations are aimed at reducing the cost of compounds and their consumption based on various methods being developed [6, 8, 10, 14].

Industrial tests of polymer flocculant

Technological cycles the large industrial company ArcelorMittal Temirtau (hereinafter AMT) include production of coke in the cake and by-product process using coal produced by AMT, agglomerate in agglomeration, pig iron in blast furnace shop, steel in oxygen-converter plant, steel casting on slab and blooming machines for continuous casting of blanks, production of rolled products in rolling shops of AMT.

Contaminated water used in the technological cycles, after wet scrubbers of converter production and deposition of large particles, is sent to five radial thickeners with a diameter of 30 m (**Figs. 1** and **2**).

The pulp temperature at the inlet is 45–60 °C. The concentration of suspended matter in the clarified water from the thickeners is 150–200 mg/dm^3. The radial thickeners in turn discharge thickened slime. The discharge of thickeners is returned to the process cycle, and the thickened product is pumped to the ash-collecting slime pit.

The total current flow rate of the pulp after the gas treatment plants is 3500 m^3/h, the average content of trapped solid particles in the pulp is 6 g/dm^3; the total rate of solid waste generation is 21 t/h.

Characteristics of the solid phase in the oxygen-converter plant waste (OCP slime)

Weight of waste, t/year	61100
Waste volume, m^3/year	2892150
Gross storage volume, m^3/year	4627430
The density of the solid phase (averaged), g/cm^3	4
Density of pulp, g/cm^3	1.6
The average size of slime particles, mm	0.2
Quantity of particles fineness less than 0.1 mm, %	17.2
pH medium	11.5
Agents in use	IOMS

The analysis of the material composition of slimes shows that it is dominated by the iron compounds. The maximum content of iron oxide FeO 83.3% and total iron Fe 68% concentrates in the size class 0.16–0.315 mm, silica SiO_2 6.5%—in class 0.315–0.63 mm. Size 0.63–1.0 mm is characterized by the highest content of CaO 28.2%, MgO 7.25%, MnO 1.5%, P 0.65% and Zn 1.2%. The maximum content of Pb 0.068% and Al_2O_3 0.86% is recorded in the class larger than 1 mm, the iron content here is 42–43%.

To improve the efficiency of solid phase capture, the authors of this article together with the representatives of AMT conducted industrial tests on clarification of circulating process water in the water cycle of gas cleaning devices (GCD) at the oxygen-converter plant (OCP) of the metallurgical company. The proposed technological solutions provide treatment of the pulp with flocculants based on polyacrylamide.

Flocculants contribute to the formation of floccules, the size of which is ten times the size of the primary particles. This effect enhances the action of the vector component of the gravitational force and accelerates deposition on the gutter bottom. This effect is utilized also in the technology of capture and dewatering of solid particles with the simultaneous yield of up to 80% clarified return water. The remaining part—20% of the pulp—is subjected to thickening according to the classical schemes adapted to the real conditions of ArcelorMittal Temirtau based on the production procedures.

It is topic to increase the clarification efficiency of gas cleaning plant return water in oxygen-converter production with the purpose of the repeated close-loop water use since treatment of slime waters requires high energy, material and labor inputs. The volume of pulp with a density

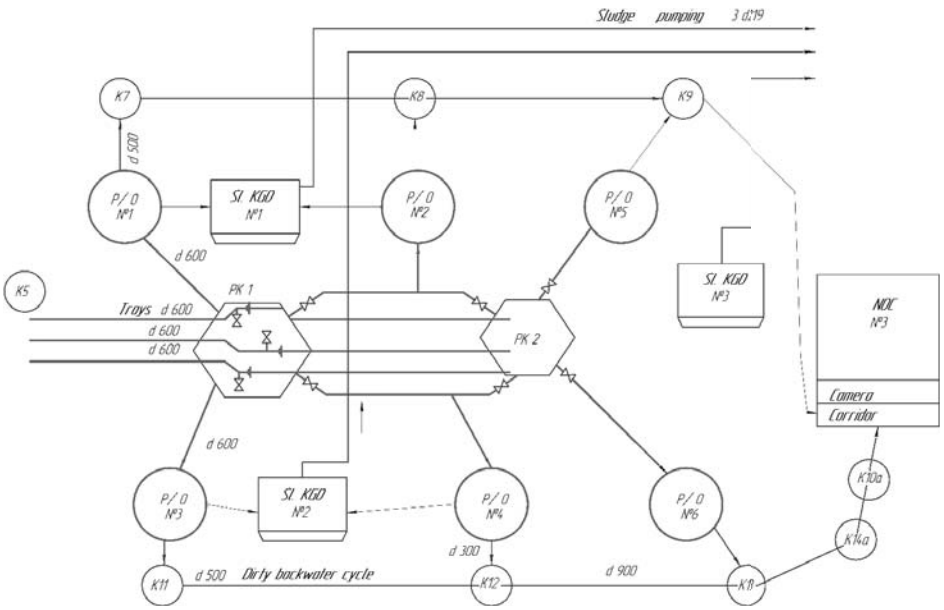

Fig. 1. Water circulation diagram

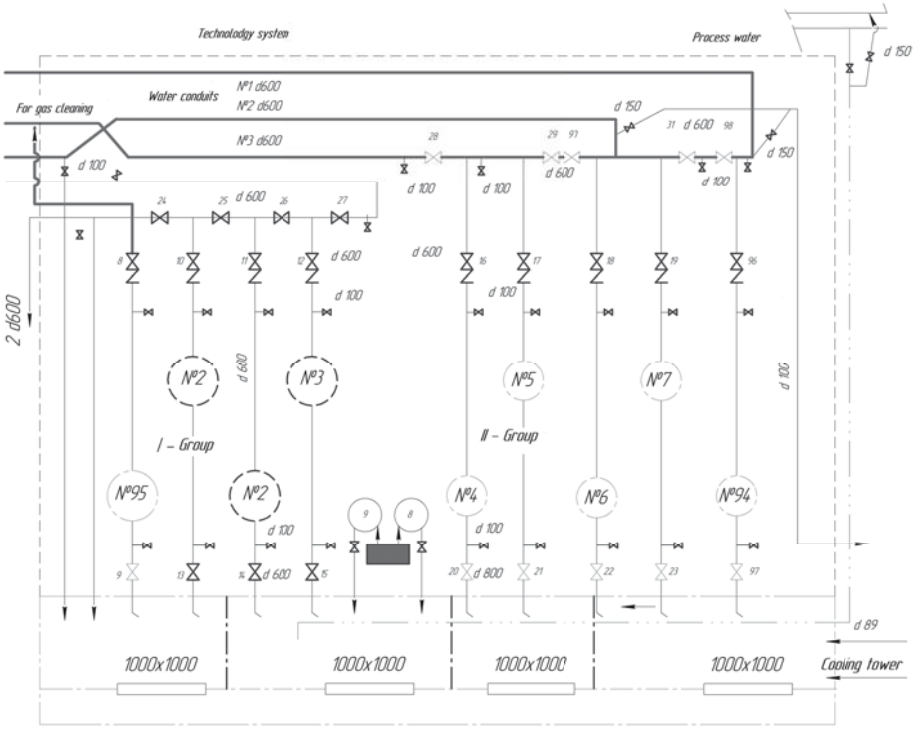

Fig. 2. Process flowsheet

of 1.6 g/cm^3 in the discharge and waste of the total gas cleaning system is greater than 2.9 million m^3/year.

Maintenance of a gas cleaning system assumes operability assurance radial thickeners, pumping facilities, pipelines, etc. Availability is even more complicated due to a wide range of ambient temperatures from +40 °C to –40 °C. A significant problem of the general scheme is the technical state and operability of the group of external settlers and their pipelines. Considering the high losses and low efficiency of the clarification system in the external settling tanks, increasingly larger volumes of water are required to supply gas cleaning cycle. Among other things, considerable amount of iron-containing material is carried away with slime—more than 61100 t/year with total iron content of up to 45%, which can be returned to the production cycle with the use of effective capture and enrichment technologies.

Organic coagulants and flocculants are synthetic polymers (polyelectrolytes) used for the mechanical purification of water from suspended and colloidal particles. Coagulants destabilize the colloidal system by neutralizing the charges on the surface of the particles and by preventing them from combining into flakes. Flocculants increase the size of flakes formed during coagulation and agglomeration of suspended particles, which increases the speed and, accordingly, the efficiency of their mechanical removal.

Before the appearance of synthetic organic polymers in the 1960s, coagulation was carried out using inorganic coagulants such as aluminum sulfate and ferric chloride. Polymers were used as an additive to inorganic coagulant for more intensive flakes formation. Currently, these polymers serve as basic coagulants, completely or partially replacing inorganic. They are more economical in a wide range of processes, including sedimentation, flotation and filtration, and have proven their ability to stably ensure the purified water quality corresponding to established standards with optimum reliability and efficiency. Organic reagents of the Flopam SNF series (France) possess:

- high cationic charge necessary to destabilize negatively charged colloidal particles and ensure rapid flocculation;
- relatively low molecular weight and viscosity, which contributes to good spread of the polymer in the treated water and cationic charges around the colloidal particles.

Compared with inorganic coagulants, polymer coagulants are advantageous for:

Table 1. Preliminary test results of the reagent Flopam SNF

Ingredients	Without flocculant					With flocculant Flopam SNF			
Sampling point No.	1	4	5	6	9	2	3	7	8
Suspended solids, mg/dm^3	38	5722	1789	174	5120	14	12	32	61
Carbonates, mg-eqv/dm^3	1.6	0.3	0.6	0.6	1.6	2.6	0.4	0.6	1.0
Hydrocarbonates, mg-eqv/dm^3	0	5.7	0	0	0	0	0	2.2	0
Hydrates, mg-eqv/dm^3	15.6	0	14.6	11	34.6	43.5	15.4	0	15.7
Total alkalinity, mg-eqv/dm^3	7.2	6.3	15.8	12.2	37.8	46.1	15.8	3.4	17.7
Calcium, mg-eqv/dm^3	16.0	5.8	17.7	11.2	43.3	42.8	17.7	4.4	14.0
Magnesium, mg-eqv/dm^3	0.4	2.5	0	3.5	0	0	0.8	3.0	5.0
Overall stiffness, mg-eqv/dm^3	16.4	8.3	17.7	14.7	43.3	42.8	18.5	7.4	19.0
Chlorides, mg/dm^3	349	346	346	328	269	357	347	232	315
Sulfates, mg/dm^3	277	273	270	316	219	238	294	338	298

Table 2. Return water test results at ArcellorMittal Temirtau

Description	Slime pipe (feed)	Clarified water discharge (pumping slurry pipe	Settler No 3		Settler No. 4	
Sampling conditions	without flocculant	without flocculant	after the action of the flocculant		after the action of the flocculant, through	
Suspended solids, mg/dm^3		3 h	in 2 h	in 3 h	in 2 h	in 3 h
		184	62	53	44	50

Table 3. Return water test data

Description	Settler No. 3						Settler No. 4	
	Without flocculant				With flocculant		Without flocculant	With flocculant
Sampling point No.	1	2	3	4	5	6	7	8
Suspended solids, mg/dm^3	2142	241	1848	6610	23	11	206	43

• the same or better result at significantly lower consumption;

• applicability in a wide pH range of the medium;

• unfaltering of the purified water pH;

• insensitiveness to chlorination;

• nonletting of metal ions (aluminum or iron) to the purified water);

• increasing the separation rate of liquid and solid phase;

• extending of the service life of direct filtration filters;

• removal of unicellular algae;

• minimization of the residuum amount;

• generation of easier dewatered residuum;

• reduction in the cost of the residuum treatment and disposal;

• better convenience in preparation and use.

The SNF Floerger company is the leading producer of organic cationic coagulants. Flopam SNF (France) is produced as a white granular powder, used together with coagulants, has a high molecular weight, and possesses weak cationic character of up to 15%, or anionic character from 0 to 50%. The use of Flopam allows reducing the load on the sewage treatment plant, which greatly improves clarification of effluents discharge in water bodies. Furthermore, flocculants of the Flopam series are used in the chemical and petrochemical industry for separating oil sludge and for cleaning areas occupied by fuel oil and oil sludge.

Table 4. Return water test results

Description	Settler № 3		
Sampling time, h	18.00	20.00	22.00
Suspended solids, mg/dm^3	18	401	101

Due to the large molecular weight, these polymeric flocculants effectively form bridges between the microclusters that appeared during coagulation and create larger macro-flocs. Using very small quantities of these flocculants (0.01-0.5 mg/dm^3) after the coagulation maximizes the capture of particles, accelerates the formation of flakes and makes the flocs denser and readily precipitable. In this case, the dosage of coagulants is minimized to an amount necessary to destabilize the colloidal suspension, and no extra coagulants are required to form a suspension capable of precipitating.

During the tests, the most effective flocculants and their specific costs were selected and determined for operation of gas cleaning systems. The pilot test data on Flopam SNF agent are compiled in Table 1.

The test results on the return water of the production units at ArcellorMittal Temirtau are presented in Table 2.

Due to the fact that radial thickeners are highly inertial devices [13], it was of some interest to obtain information about the content of suspended matter in their flows with

time after addition of the test polymer agent Flopam SNF. These results are shown in Table 3 and 4.

Discussion

The clarification tests of return water of the oxygen-converter plant with Flopam SNF flocculant on two radial thickeners Nos. 3 and 4 at the synchronous combination of pulp and flocculant consumption showed the following:

1. The content of suspended matter was 734 mg/dm^3 in the feed and 184 mg/dm^3 in the discharge. The latter exceeded the standard (80 mg/dm^3) more than twice. (The data in Table 3, the samples were taken by the employees of AMT).

2. After inertial delay in reaching working volumetric working concentration by the flocculant in the radial thickener (after transient process for two hours), the content of suspended solids in the feed was 44, 52, 62 and 53 mg/dm^3, which was a low level as per the norms. (Samples were taken by the employees of AMT).

3. The content of suspended solids was 2142 mg/dm^3 in the feed and 241 mg/dm^3 in the discharge, which exceeded the standard (80 mg/dm^3) more than three times.

4. After inertial delay in reaching working volumetric working concentration by the flocculant in the radial thickener (after transient process for two hours), the content of suspended solids in the feed was 23, 11 and 43 mg/dm^3, which was quite low relative to the norms—from two to eight times.

5. The looseness of the bottom sediment of gas cleaning slime in the thickener increased with the use of flocculant. At the same time, the coefficient of friction of rest of the bottom sediment in the conical part of the radial thickener decreased. The turnaround time of the carriage has decreased by 18%, and the power consumption of the electric motor drive of the carriage in radial thickener (peripheral drive) lowered by 20%.

6. Circumstantial evidence identified improvements in the unloading and transportation of bottom slime of the carriage.

7. The change in the viscous characteristics of the bottom sediments made it possible to reconfigure the schemes for pumping the thickened product from two radial thickeners with a single pump. At the same time, no significant increase in power consumption was observed. The performance of the electric motor improved by 25%.

Conclusion

During the pilot tests conducted in 2016 and 2017, the most effective flocculants and their specific costs were selected and determined to ensure rational operation of the gas cleaning system. The flocculants were selected from standard samples from suppliers at a warehouse in Karaganda and from analogues of the efficiency.

Kaztransprodukt company is sufficiently qualified in return water treatment using modern technological solutions and is ready to undertake management of the wet gas cleaning site of blast furnace and oxygen-converter plants with their subsequent reconstruction and upgrading. This will ensure that on-site production of up to 20 million m^3/year of industrial water without the need for its clarification in external sedimentation basins, as well as on-site production of up to 35000 tons of iron-containing material with characteristics acceptable for the sinter plant. The same amount will be withdrawn from the total storage of the solid phase in the external sedimentation tanks. The introduction of these modifications will lead to a significant decrease in the amount of slime pumped to external sedimentation tanks, which will cut down in energy and operational expenses of the gas cleaning site. At the same time, efficient use of natural resources is ensured together with reduction in the environmental load.

Acknowledgments

The authors are grateful to the personnel of the workshops and of the Water Body Protection Laboratory of the Environmental Department of ArcelorMittal Temirtau for their assistance, advice and participation in the testing.

References

1. Bolshina E. P. Ecology of metallurgical production Available at**:** http://nmetau.edu.ua/file/ktemp_15502.pdf (accessed: 9.08.2018).
2. Danilov-Danilyan V. I. Ecological problems: what happens, who is guilty and what to do? Moscow : MNEPU, 1997. 332 p.
3. Karmanov A. P., Polina I. N. Technology of sewage treatment. Education guidance. Syktyvkar, 2015. 208 p.
4. Korchevskyi A. N., Gumenyuk K. V., Nazimko L. I. Waste of metallurgical production. *New technology solutions on complex processing : Materials of a Scientific and Practical Conference of Russia "Current problems of a biodiversity and environmental management"*. 2017. pp. 227–233.
5. Fridman V. S. Global ecological crisis. Moscow, 2017. 444 p.
6. Banaś M. Development of the flocs' structure during coagulation of the fine-grained suspensions. *Polish Journal of Environmental Studies*. 2012. pp. 45–49.
7. Brostow W., Pal S., Singh R. P. A model of flocculation. *Materials Letters.* 2007. No. 61. pp. 4381–4384.
8. Castellini E., Berthold C., Malferrari D., Bernini F. Sodium hexametaphosphate interaction with 2:1 clay minerals illite and montmorillonite. *Applied Clay Science*. 2012. No. 83-84. pp. 162–170.
9. Cehlàr M. Evaluation and risk estimation by business with the earth's resources. *Proceedings of XVIII ICPC, Saint-Petersburg, Russia*. Ed. V. Litvinenko. Switzerland : Springer Int. Publishing, 2016. pp. 463–468.
10. Kisielevska E., Surowiak A. Reseach Over bio-flocculation application in sedimentation of mineral suspension. *Journal of the Polish Mineral Engineering Society*. 2015 Vol. 16, No. 1(35). pp. 189–195.
11. Kowalski W. P., Banaś M., Kołodziejczyk K., Mięso R., Malcher T., Hilger B., Turlej T. Modern sedimentation techniques in environmental protection. WIMIR AGH Publisher. 2015. pp. 21–29.
12. Nazimko L. I., Garkovenko E. E., Korchevskyi A. N., Druts I. N. Kinetics of phases interaction during mineral processing simulation. *Proceedings of XV ICPC*. China, Beijing, 2006. pp. 785–798.
13. Nazimko L. I., Korchevskyi A. N., Rozanov Yu. A., Martianov S. V. Simulation of coal separation and dehydration processes. *Proceedings of XVII ICPC*. Turkey, Istanbul, 2013. pp. 495–501.
14. Ozkan A., Duzyol S. Gamma processes of shear flocculation, oil agglomeration and liquid liquid extraction. *Separation and Purification and Technology*. 2014. No. 132. pp. 446–451. EM