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TREATMENT OF HYDROMETALLURGICAL PROCESS WATERS OF THE NAVOI MINING AND METALLURGICAL COMPANY WITH AN IRON(III) CHLORIDE COAGULANT PRODUCED FROM LOCAL ORE

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Abstract:

Hydrometallurgical plants in the arid Navoi region recirculate large volumes of process water that accumulate sulfate, chloride, suspended solids and dissolved metals. This study evaluated a liquid iron(III) chloride coagulant obtained by hydrochloric acid processing of a local iron-bearing ore (32.81 % $FeCl_3$) for treating three process streams of the Navoi Mining and Metallurgical Company: the circulating water of Hydrometallurgical Plant No. 4 (GMZ-4), the water of its tailings ponds 1–2, and the recycled technical water of the BIOX shop of Hydrometallurgical Plant No. 3 (GMZ-3). Each stream was analysed before and after laboratory coagulation and compared with the plant regulation targets or maximum permissible concentrations (MPC). In GMZ-4 circulating water sulfate decreased from 816.8 to 380.4 mg/dm³ (53.4 %) and suspended solids from 31.2 to 13.3 mg/dm³ (57.4 %); in the tailings-pond water sulfate fell from 1645 to 403 mg/dm³ (75.5 %) and chloride from 226.4 to 57.8 mg/dm³ (74.5 %), meeting the regulation targets. In the BIOX water Mn and Cu were removed by 85 % and Pb by 80 %, but As (20.0 → 10.0 mg/dm³), Ni (5.0 → 2.0) and Co (2.4 → 1.3) remained far above the MPC. Per 1000 m³ of treated water, 1242 kg of sulfate and 168.6 kg of chloride (pond water) and 10.0 kg of arsenic and 3.0 kg of nickel (BIOX water) are kept out of the receiving environment. Pre-oxidation and pH adjustment to 8–9 are recommended for arsenic- and nickel-rich streams.

Keywords: ferric chloride, coagulation, hydrometallurgy, mine water, sulfate, arsenic, Navoi.

Introduction

Water scarcity makes the treatment and reuse of industrial process water a priority for the Navoi region of Uzbekistan, where irrigation, mining and energy compete for limited resources [1]. Water quality monitoring of the transboundary Zarafshan River has shown the cumulative pressure of agricultural and industrial discharges on the basin [2]. The Navoi Mining and Metallurgical Company (NMMC) reported a water intake of 122,550 thousand m³ and a wastewater discharge of 5,157.1 thousand m³ for 2022 and acknowledged that all its water sources are located in water-stressed areas [3].

Hydrometallurgical process waters differ from acid mine drainage, but share some of its problems: high sulfate, dissolved metals and metalloids, and suspended solids [4], [5], [6]. Tailings storage facilities concentrate these contaminants and pose long-term environmental risks if seepage or overflow occurs [7]. Among treatment options, chemical coagulation with iron(III) salts is attractive because it is simple, inexpensive and also removes arsenic: Qiao et al. studied the effects of pH, As/Fe ratio and co-existing solutes on arsenate and arsenite removal by $FeCl_3$ [8], and Ge et al. highlighted the difficulty of removing arsenic from wastewater by $FeCl_3$ and alum coagulation [9]. Applied research in the mining industry continues to optimise clarification and treatment schemes [10], and sorbent systems have been tested for sulfate and metal removal from mining wastewater [11].

Uzbekistan does not produce iron(III) chloride, although local iron-bearing ores are available. The authors have developed a process in which an ore from the Tebinbulak deposit is leached with 28 % hydrochloric acid at a 1 : 2.0 mass ratio for 120 min to obtain a liquid product containing 32.81 % $FeCl_3$. Similar routes to iron coagulants from secondary iron sources have been reported [12], [13]. The aim of this work was to test the locally produced coagulant on real process waters of NMMC hydrometallurgical plants and to quantify the treatment effect against plant regulation targets and MPC values.

Materials and Methods

Coagulant. The coagulant was the liquid phase obtained by treating the ore (41.4 % Fe_2O_3 on average; hematite as the main iron mineral) with 28 % HCl at a 1 : 2.0 ore-to-acid mass ratio for 120 min. It contained 32.81 % $FeCl_3$ and had a density of 1.349 g/cm³.

Water samples. Three NMMC process streams were studied: (i) the circulating water of GMZ-4, an alkaline stream (pH 10) carrying sulfate, nitrite and nitrate; (ii) the water of GMZ-4 tailings ponds 1–2, a more mineralised stream (dry residue 2750 mg/dm³); and (iii) the recycled technical water of the BIOX (bio-oxidation) shop of GMZ-3, the stream most contaminated with metals and arsenic.

Coagulation tests. Laboratory coagulation followed the conventional sequence: the coagulant solution was added at the calculated dose, the sample was mixed rapidly, then slowly to form flocs, and allowed to settle; the clarified water was analysed. The initial dose was selected from published alum dose tables according to suspended solids and permanganate oxidisability and refined in preliminary jar tests.

Analyses and calculations. pH, dry residue, suspended (non-settleable) solids, chloride, sulfate, nitrite, nitrate and metals (Ni, Zn, Mn, Cu, Pb, Co, As) were determined. The treatment efficiency for each parameter was calculated as

$$\eta = \frac{C_{\text{in}} - C_{\text{out}}}{C_{\text{in}}} \cdot 100\ \% \qquad (1)$$

where C_{in} and C_{out} are the values before and after treatment. The mass of a pollutant kept out of the environment per 1000 m³ of treated water was calculated as

$$M_{\text{i}} = V \cdot (C_{\text{in}} - C_{\text{out}}) \cdot 10^{-3} \qquad (2)$$

where V = 1000 m³ and concentrations are in mg/dm³ (g/m³), giving M_i in kg.

Results and Discussion

1. GMZ-4 circulating water and tailings-pond water. The main results are summarised in Table 1 and Fig. 1. The circulating water of GMZ-4 was alkaline (pH 10) and contained 816.8 mg/dm³ sulfate, 31.2 mg/dm³ suspended solids, 18.6 mg/dm³ chloride, 19.4 mg/dm³ nitrite and 28.4 mg/dm³ nitrate. After treatment with the coagulant, sulfate decreased to 380.4 mg/dm³ (53.4 %), suspended solids to 13.3 mg/dm³ (57.4 %), chloride to 7.4 mg/dm³ (60.2 %), nitrite to 9.3 mg/dm³ (52.1 %) and nitrate to 18.2 mg/dm³ (35.9 %), while pH fell to 8.4. All parameters reached the plant regulation targets (sulfate 604.5, suspended solids 30, chloride 10 mg/dm³), and the treated water was better than the regulation for every listed parameter.

Table 1. Composition of NMMC process waters before and after treatment with the local $FeCl_3$ coagulant

Parameter, mg/dm³	Before	Target / MPC	After	Efficiency, %
		GMZ-4 circulating water		
pH	10	10.9	8.4	–
Dry residue	614	1628	518	15.6
Suspended solids	31.2	30	13.3	57.4
Chloride	18.6	10	7.4	60.2
Sulfate	816.8	604.5	380.4	53.4
		GMZ-4 tailings ponds 1–2		
pH	9.4	8.0	7.7	–
Dry residue	2750	1980	1974	28.2
Suspended solids	69.4	37.6	31.4	54.8
Chloride	226.4	156	57.8	74.5
Nitrate	21.4	9.7	7.3	65.9
Sulfate	1645	1528	403	75.5
		GMZ-3 BIOX technical water		
Arsenic	20.0	0.05	10.0	50.0
Nickel	5.0	0.1	2.0	60.0
Cobalt	2.4	0.1	1.3	45.8
Lead	1.0	0.03	0.2	80.0
Manganese	0.4	0.1 (0.5)	0.06	85.0
Copper	0.2	1.0	0.03	85.0
Zinc	4.0	5.0	3.0	25.0

Note: for GMZ-4 streams the comparison value is the plant regulation target; for GMZ-3 BIOX water it is the MPC.

The tailings-pond water was considerably more mineralised: dry residue 2750 mg/dm³, sulfate 1645 mg/dm³, chloride 226.4 mg/dm³ and suspended solids 69.4 mg/dm³. After treatment sulfate fell to 403 mg/dm³ (75.5 %), chloride to 57.8 mg/dm³ (74.5 %), suspended solids to 31.4 mg/dm³ (54.8 %), nitrate to 7.3 mg/dm³ (65.9 %) and nitrite to 0.6 mg/dm³ (60.0 %); dry residue decreased to 1974 mg/dm³ (28.2 %). The difference from the regulation target was largest for sulfate: 403 mg/dm³ against the target of 1528 mg/dm³, i.e. the treated water was 3.8 times below the target.

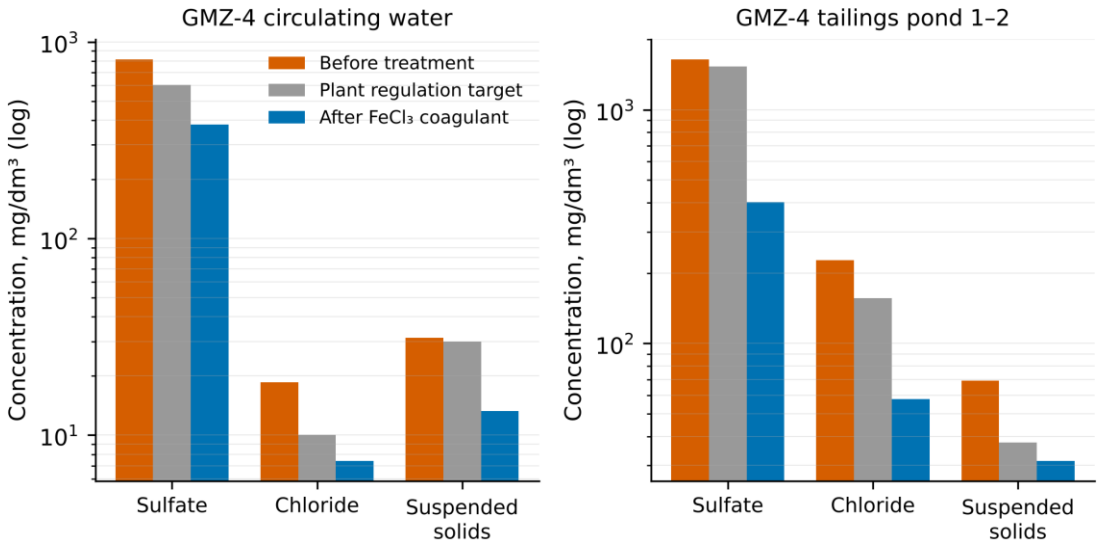


Figure 1. Sulfate, chloride and suspended solids in GMZ-4 circulating water and tailings-pond water before treatment, according to the plant regulation and after treatment with the local $FeCl_3$ coagulant (logarithmic scale)

The reductions in suspended solids (54.8–57.4 %) are consistent with sweep coagulation by precipitating iron(III) hydroxide, which is the dominant mechanism of hydrolysing metal coagulants at neutral to alkaline pH [14]. The large decreases in sulfate and chloride, however, require careful interpretation. Coagulation with $FeCl_3$ adds chloride to the water: by our calculation, 1 kg of the 32.81 % solution introduces 328 g $FeCl_3$ and 215 g chloride, i.e. 215 mg/L when dosed at 1 kg/m³. That chloride nevertheless decreased in both streams indicates that the dose used was much smaller than 1 kg/m³ and that part of the anions was removed with the sludge. Uptake of sulfate by freshly formed iron hydroxide flocs is a plausible contribution, but the observed sulfate removal of 53–76 % is high for coagulation alone; it should be confirmed by replicate tests with a closed mass balance (sulfate in sludge) before it is used for design.

2. GMZ-3 BIOX technical water. The BIOX water was the most contaminated stream: arsenic 20.0 mg/dm³ (400 times the MPC of 0.05 mg/dm³), nickel 5.0 mg/dm³ (50 times), cobalt 2.4 mg/dm³ (24 times) and lead 1.0 mg/dm³ (33 times), together with zinc 4.0, manganese 0.4 and copper 0.2 mg/dm³ (Table 1, Fig. 2). Treatment reduced manganese to 0.06 mg/dm³ (85.0 %), copper to 0.03 mg/dm³ (85.0 %) and lead to 0.2 mg/dm³ (80.0 %); nickel decreased to 2.0 mg/dm³ (60.0 %), arsenic to 10.0 mg/dm³ (50.0 %), cobalt to 1.3 mg/dm³ (45.8 %) and zinc to 3.0 mg/dm³ (25.0 %). Copper and zinc met their MPC values (1.0 and 5.0 mg/dm³); manganese met the 0.5 mg/dm³ limit but not 0.1 mg/dm³, while Pb, Ni, Co and As remained above the MPC.

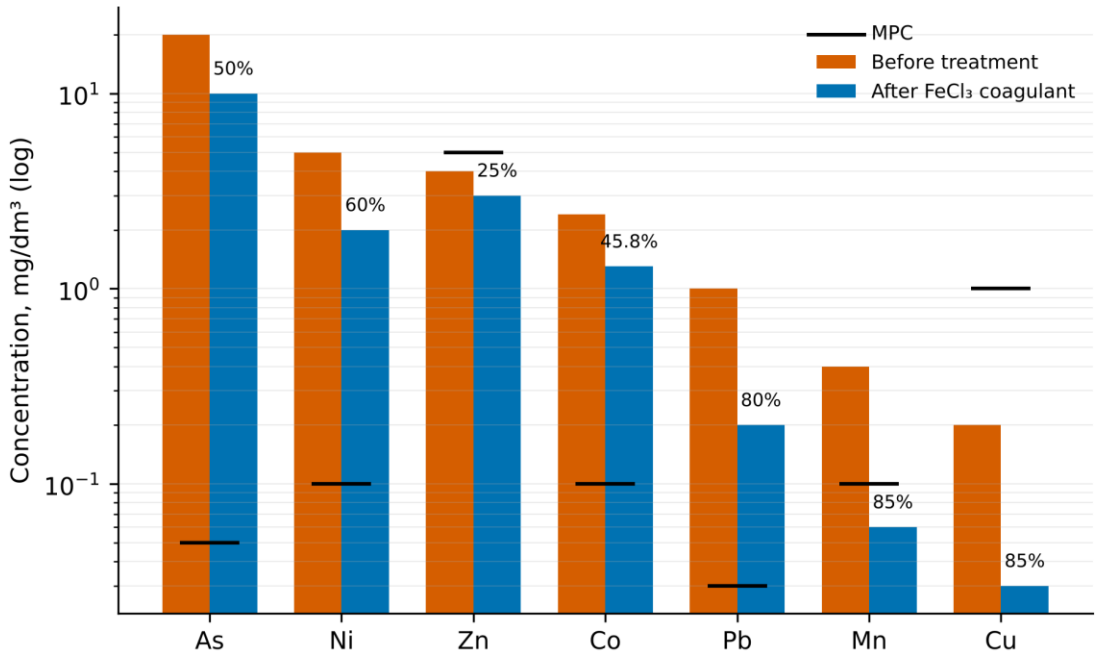


Figure 2. Metals and arsenic in GMZ-3 BIOX technical water before and after treatment with the local $FeCl_3$ coagulant; horizontal bars show the MPC, labels show the removal efficiency (logarithmic scale)

The selectivity pattern agrees with the chemistry of iron(III) hydroxide. Lead and copper are strongly bound by hydrous ferric oxide; on ferrihydrite the affinity sequence Pb > Cu > Zn > Cd > Ni has been reported [15], whereas nickel, cobalt and zinc require higher pH for hydroxide precipitation or adsorption; in coagulation-based primary treatment nickel removal is generally limited at neutral pH [16]. Only 50 % of arsenic was removed. Iron(III) chloride removes arsenate much more effectively than arsenite, and the outcome depends strongly on pH and the As/Fe ratio [17]; in the BIOX circuit, where sulfide minerals are oxidised biologically, the arsenic speciation and pH of the recycled water determine the result. Moreover, Ge et al. showed that achieving low residual arsenic in wastewater by coagulation is difficult even with optimised $FeCl_3$ doses. For this stream we therefore recommend (a) a pre-oxidation step to convert As(III) to As(V), (b) a higher Fe/As molar ratio, and (c) pH adjustment to 8–9 to improve Ni, Co and Zn removal.

3. Pollutant load reduction and dosing. Equation (2) gives the pollutant mass kept out of the environment per 1000 m^3 of treated water. For the GMZ-4 circulating water this is 436.4 kg sulfate, 17.9 kg suspended solids, 11.2 kg chloride, 10.1 kg nitrite and 10.2 kg nitrate; for the tailings-pond water 1242 kg sulfate, 168.6 kg chloride, 38.0 kg suspended solids and 14.1 kg nitrate; and for the BIOX water 10.0 kg arsenic, 3.0 kg nickel, 1.1 kg cobalt, 1.0 kg zinc, 0.8 kg lead, 0.34 kg manganese and 0.17 kg copper. Since arsenic- and nickel-bearing sludge is generated, its leaching behaviour must be tested before disposal.

Based on these tests and on the model-solution experiments, a dose of 1.0–2.0 kg of 32.8 % coagulant per m^3 (328–656 g $FeCl_3/m^3$; 113–226 mg/L Fe; 215–430 mg/L Cl^- added) is proposed for streams with heavy metals above 10 mg/L, such as the BIOX water, and 0.1–0.3 kg/m^3 (33–98 g $FeCl_3/m^3$) for weakly polluted sulfate–chloride streams such as GMZ-4 waters. The chloride introduced with the reagent is a design constraint for streams that are recirculated; the dose should therefore be set for each stream by jar testing [18].

4. Limitations. The results were obtained in laboratory coagulation tests, and seasonal variability of the stream composition was not studied. Sludge composition and settling characteristics were not determined.

Conclusion

A liquid iron(III) chloride coagulant (32.81 % $FeCl_3$) produced from a local iron-bearing ore was tested on three hydrometallurgical process streams of the Navoi Mining and Metallurgical Company.

In GMZ-4 circulating water and tailings-pond water, the coagulant reduced suspended solids by 54.8–57.4 %, sulfate by 53.4–75.5 % and chloride by 60.2–74.5 %, bringing all monitored parameters within the plant regulation targets; the high sulfate removal requires confirmation by mass balance.

In GMZ-3 BIOX water, Mn and Cu were removed by 85 % and Pb by 80 %, whereas As, Ni and Co removal was 45.8–60.0 % and their residual concentrations remained above the MPC; pre-oxidation, a higher Fe/As ratio and pH adjustment to 8–9 are recommended.

Per 1000 m^3 of treated water, 1242 kg sulfate and 168.6 kg chloride (tailings-pond water) and 10.0 kg arsenic and 3.0 kg nickel (BIOX water) are kept out of the environment. Doses of 1.0–2.0 kg/m^3 for metal-rich streams and 0.1–0.3 kg/m^3 for weakly polluted streams are proposed for pilot testing.

Author Contributions, Conflict of Interest and Funding

D. Olzhaev: investigation, data curation, writing – original draft. U. Temirov: conceptualization, methodology, supervision, writing – review and editing. The authors declare no conflict of interest. This research received no external funding. The AI tool Claude (Anthropic) was used to structure and edit the manuscript text; all experimental data were obtained by the authors.

References

[1] R. Kulmatov, M. Groll, A. Rasulov, I. Soliev, and M. Romic, “Status quo and present challenges of the sustainable use and management of water and land resources in Central Asian irrigation zones – The example of the Navoi region (Uzbekistan),” Quaternary International, vol. 464, pp. 396–410, 2018, doi: 10.1016/j.quaint.2017.11.043.

[2] R. Kulmatov, C. Opp, M. Groll, and D. Kulmatova, “Assessment of water quality of the trans-boundary Zarafshan River in the territory of Uzbekistan,” Journal of Water Resource and Protection, vol. 5, no. 1, pp. 17–26, 2013, doi: 10.4236/jwarp.2013.51003.

[3] NMMC JSC, “Sustainability Report 2022,” Navoi Mining and Metallurgical Company, Navoi, 2023. [Online]. Available: https://www.ngmk.uz/wp-content/uploads/2023/11/sr-2022-en.pdf

[4] A. Akcil and S. Koldas, “Acid mine drainage (AMD): causes, treatment and case studies,” Journal of Cleaner Production, vol. 14, pp. 1139–1145, 2006, doi: 10.1016/j.jclepro.2004.09.006.

[5] D. B. Johnson and K. B. Hallberg, “Acid mine drainage remediation options: a review,” Science of the Total Environment, vol. 338, no. 1–2, pp. 3–14, 2005, doi: 10.1016/j.scitotenv.2004.09.002.

[6] K. K. Kefeni, T. A. M. Msagati, and B. B. Mamba, “Acid mine drainage: Prevention, treatment options, and resource recovery: A review,” Journal of Cleaner Production, vol. 151, pp. 475–493, 2017, doi: 10.1016/j.jclepro.2017.03.082.

[7] D. Kossoff, W. E. Dubbin, M. Alfredsson, S. J. Edwards, M. G. Macklin, and K. A. Hudson-Edwards, “Mine tailings dams: Characteristics, failure, environmental impacts, and remediation,” Applied Geochemistry, vol. 51, pp. 229–245, 2014, doi: 10.1016/j.apgeochem.2014.09.010.

[8] J. Qiao, Z. Jiang, B. Sun, Y. Sun, Q. Wang, and X. Guan, “Arsenate and arsenite removal by FeCl3: Effects of pH, As/Fe ratio, initial As concentration and co-existing solutes,” Separation and Purification Technology, vol. 92, pp. 106–114, 2012, doi: 10.1016/j.seppur.2012.03.023.

[9] J. Ge, B. Guha, L. Lippincott, S. Cach, J. Wei, T.-L. Su, and X. Meng, “Challenges of arsenic removal from municipal wastewater by coagulation with ferric chloride and alum,” Science of the Total Environment, vol. 725, Art. no. 138351, 2020, doi: 10.1016/j.scitotenv.2020.138351.

[10] K. V. Raevich, V. N. Vokin, E. V. Kiryushina, and Yu. A. Maglinets, “Applied research and

process solutions in waste water clarification and treatment in mining industry: Review," Eurasian Mining, no. 1, pp. 66–70, 2024, doi: 10.17580/em.2024.01.16.
[11] E. A. Krasavtseva, H. Gogoi, A. V. Svetlov, T. Leiviskä, and D. Makarov, "Removal of sulfate and metals from wastewater of a mining enterprise by a dual sorbent system: A case study," Mine Water and the Environment, vol. 42, no. 1, pp. 200–208, 2023, doi: 10.1007/s10230-023-00923-9.
[12] V. O. Almeida and I. A. H. Schneider, "Production of a ferric chloride coagulant by leaching an iron ore tailing," Minerals Engineering, vol. 156, Art. no. 106511, 2020, doi: 10.1016/j.mineng.2020.106511.
[13] M. B. Mahlohla, V. Masindi, M. Tekere, and S. Foteinis, "Treatment of wastewater using ferric chloride synthesized from Fe(III) recovered from acid mine drainage," Water Resources and Industry, vol. 35, Art. no. 100358, 2026, doi: 10.1016/j.wri.2026.100358.
[14] J. Duan and J. Gregory, "Coagulation by hydrolysing metal salts," Advances in Colloid and Interface Science, vol. 100–102, pp. 475–502, 2003, doi: 10.1016/S0001-8686(02)00067-2.
[15] B. He, W. Zhang, Y. Diao, S. Sun, Y. Zhang, W. Zhao, F. Wen, and G. Yang, "Mechanistic study of the adsorption capabilities of heavy metals on the surface of ferrihydrite: batch sorption, modeling, and density functional theory," RSC Advances, vol. 15, 2025, doi: 10.1039/d4ra07426b.
[16] P. D. Johnson, P. Girinathannair, K. N. Ohlinger, S. Ritchie, L. Teuber, and J. Kirby, "Enhanced removal of heavy metals in primary treatment using coagulation and flocculation," Water Environment Research, vol. 80, no. 5, pp. 472–479, 2008, doi: 10.2175/106143007X221490.
[17] D. A. Dzombak and F. M. M. Morel, Surface Complexation Modeling: Hydrous Ferric Oxide. New York, NY, USA: John Wiley & Sons, 1990.
[18] J.-Q. Jiang, "The role of coagulation in water treatment," Current Opinion in Chemical Engineering, vol. 8, pp. 36–44, 2015, doi: 10.1016/j.coche.2015.01.008.