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COAGULATION TREATMENT OF FOUNDRY AND THERMAL POWER PLANT WASTEWATER IN THE NAVOI REGION USING AN IRON(III) CHLORIDE COAGULANT FROM LOCAL RAW MATERIAL

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Abstract:
Machine-building and power-generation enterprises in the Navoi region discharge wastewater that exceeds permissible concentrations for suspended solids, mineral salts and trace metals while relying mainly on mechanical settling ponds. This work evaluated a liquid iron(III) chloride coagulant (32.81 % $FeCl_3$) obtained from a local iron-bearing ore for four wastewater streams: the foundry shop of the Navoi Machine-Building Plant (NMZ) and three streams of Navoi Thermal Power Plant JSC (TPP). In the foundry wastewater, coagulation reduced solids from 10,557.8 to 1,372.5 mg/dm³ (87.0 %), Mn from 8.53 to 1.33 mg/dm³ (84.4 %) and Cu from 0.066 to 0.010 mg/dm³ (84.8 %), whereas Ni decreased by only 31.7 % and dissolved iron increased from 8.3 to 10.5 mg/dm³, indicating an excessive dose for this stream. In the TPP stream entering mechanical treatment, all parameters exceeded the maximum permissible concentrations (MPC) by 1.26–1.53 times; after coagulation, non-settleable solids fell from 460 to 278 mg/L, chloride from 1,360 to 960 mg/L and sulfate from 630 to 465 mg/L, and all parameters except BOD_5 (32 vs 30 mg/L) met the MPC. In the production-shop and 450 MW-unit streams, sulfate decreased from 4,383 to 3,132 and from 4,112.4 to 3,234 mg/L, bringing all exceeding parameters below the MPC. For the TPP annual discharge of 2,182 thousand m³, the treatment would keep about 397 t of suspended solids, 873 t of chloride and 360 t of sulfate out of the receiving water per year. A coagulation stage added to the existing three-pond mechanical treatment is proposed.

Keywords: Ferric chloride, coagulation, foundry wastewater, thermal power plant, suspended solids, manganese, Navoi.

Introduction

The Navoi region combines large mining, metallurgical, machine-building and energy enterprises with acute water scarcity, which makes the quality of industrial discharges a regional environmental issue [1], [2]. Navoi Thermal Power Plant JSC (TPP) discharged 2,182 thousand m³ of treated wastewater in 2018 according to the environmental impact statement disclosed for its switchyard expansion project [3]. At the enterprises studied here, wastewater passes through local facilities consisting of three settling ponds in series with a screen and a sand filter, a scheme that provides only mechanical treatment and cannot remove dissolved or colloidal pollutants.

Chemical coagulation is the simplest way to upgrade such facilities. Coagulation with hydrolysing iron(III) salts removes colloids by charge neutralisation and by sweep flocculation in precipitating hydroxide [4], [5]. It has been applied to tannery [6], petrochemical [7], beverage [8] and electroplating [9] wastewaters, and coagulant dose also controls nutrient removal and sludge production [10]. Floc strength and sludge properties determine the performance of the subsequent settling and dewatering steps [11], [12]. For metallurgical circulating and waste waters, complex coagulants have been proposed [13].

Uzbekistan imports iron(III) chloride. The authors developed a process to obtain a liquid coagulant with 32.81 % $FeCl_3$ by leaching a local iron-bearing ore with 28 % hydrochloric acid, in line with recent work on iron coagulants from ore tailings [14] and acid mine drainage [15]. The aim of this study was to evaluate this coagulant on wastewater of the Navoi Machine-Building Plant foundry and Navoi TPP, compare the results with maximum permissible concentrations (MPC), and estimate the reduction in pollutant discharge.

Materials and Methods

Coagulant. The liquid phase obtained by treating the ore (41.4 % Fe_2O_3 on average) with 28 % HCl at a 1 : 2.0 mass ratio for 120 min was used; it contained 32.81 % $FeCl_3$ and had a density of 1.349 g/cm³.

Wastewater. Four streams were sampled: (1) wastewater of the foundry shop of the Navoi Machine-Building Plant (NMZ); (2) TPP wastewater entering mechanical treatment; (3) TPP production-shop wastewater; and (4) TPP 450 MW unit-shop wastewater.

Coagulation tests. The coagulant was dosed into a wastewater sample, rapidly mixed, slowly mixed for flocculation, and settled; the clarified water was analysed. The starting dose was taken from published alum dose tables based on suspended solids and permanganate oxidisability and was refined in jar tests.

Analyses. pH, dry residue, mineralisation, suspended and non-settleable solids, chloride, sulfate, bisulfite, nitrite, nitrate, ammonium nitrogen, sulfides, BOD_5, cyanide, fluoride, Ca, Mg and metals (Fe, Mn, Ni, Cr, Cu, Co, Zn, Pb, As, Al) were determined. Treatment efficiency was calculated as

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

and the exceedance factor as C/MPC. The mass of each pollutant kept out of the receiving water was calculated per 1000 m³ as

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

with V in m³ and concentrations in g/m³, giving M_i in kg.

Results and Discussion

Foundry wastewater of the Navoi Machine-Building Plant. The foundry stream was weakly acidic (pH 5.85) and contained an extremely high load of solids (10,557.8 mg/dm³) and dry residue (3,864.4 mg/dm³), with Mn 8.53, Fe 8.3, Ni 0.322 and Cu 0.066 mg/dm³. After coagulation, solids decreased to 1,372.5 mg/dm³ (87.0 %), Mn to 1.33 mg/dm³ (84.4 %), Cu to 0.010 mg/dm³ (84.8 %), Cr to 0.00032 mg/dm³ (84.0 %) and Co to 0.022 mg/dm³ (73.5 %), whereas Ni decreased only to 0.22 mg/dm³ (31.7 %) and dry residue by 20.0 % (Fig. 1). The pH rose to 8.65. Compared with the plant regulation (treatment) values, the coagulant gave lower residuals for solids (1,372.5 vs 9,483.7 mg/dm³), Mn (1.33 vs 5.26), Cu (0.010 vs 0.042) and Co (0.022 vs 0.059 mg/dm³).

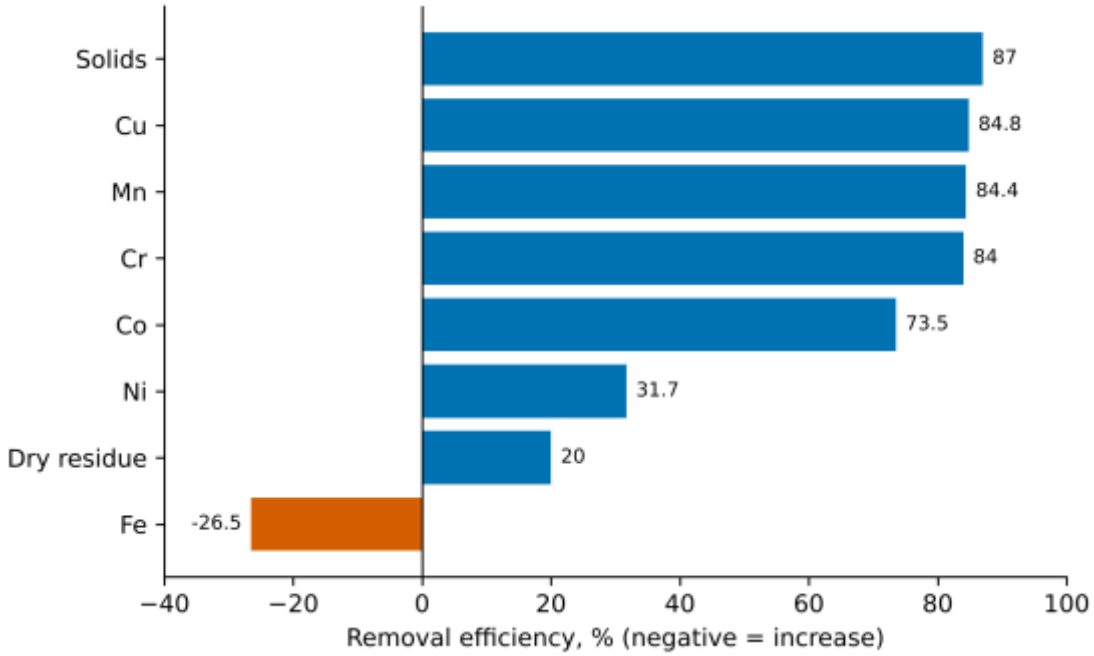


Figure 1. Removal efficiency of pollutants from Navoi Machine-Building Plant foundry wastewater with the local $FeCl_3$ coagulant (negative value: increase after treatment)

The high removal of solids reflects sweep flocculation by iron(III) hydroxide, which enmeshes fine particles in the growing flocs. Nickel removal remained low because nickel hydroxide is soluble at near-neutral pH and its effective precipitation requires a considerably higher pH; Johnson et al. reported the same limitation for nickel in coagulation-enhanced primary treatment [16]. The final pH of 8.65 was therefore insufficient. Dissolved iron increased from 8.3 to 10.5 mg/dm³ (−26.5 %), which shows that part of the coagulant remained in the treated water as dissolved or colloidal iron. This can occur when the dose is too high for the stream or when flocculation and settling time are insufficient; in the TPP streams iron decreased, which confirms that the dose must be selected for each stream. Per 1000 m³, the treatment removes 9,185 kg of solids, 773 kg of dry residue and 7.2 kg of manganese.

TPP wastewater entering mechanical treatment. All seven measured parameters of this stream exceeded the MPC by 1.26–1.53 times (Table 1). The largest exceedances were for non-settleable solids (460 mg/L; 1.53×), sulfides (2.2 mg/L; 1.47×) and BOD_5 (42 mg/L; 1.40×). After coagulation, non-settleable solids fell to 278 mg/L (39.6 %), chloride to 960 mg/L (29.4 %), mineralisation to 970 mg/L (27.6 %), sulfate to 465 mg/L (26.2 %), sulfides to 1.16 mg/L (47.3 %) and ammonium nitrogen to 1.68 mg/L (35.4 %), all below the MPC. BOD_5 decreased from 42 to 32 mg/L (23.8 %) but remained slightly above the MPC of 30 mg/L, which is expected because coagulation removes mainly particulate and colloidal organic matter.

Table 1. Navoi TPP wastewater entering mechanical treatment before and after coagulation with the local $FeCl_3$ coagulant

Parameter	Unit	Before	MPC	After	Before/MPC	Efficiency, %
pH	–	7.32	6–9	7.14	–	–
Mineralisation	mg/L	1340	1000	970	1.34	27.6
Non-settleable solids	mg/L	460	300	278	1.53	39.6
Chloride	mg/L	1360	1000	960	1.36	29.4
Ammonium nitrogen	mg/L	2.6	2.0	1.68	1.30	35.4
BOD_5	mg/L	42	30	32	1.40	23.8
Sulfides	mg/L	2.2	1.5	1.16	1.47	47.3
Sulfate	mg/L	630	500	465	1.26	26.2

TPP production-shop and 450 MW unit-shop wastewater. These streams were dominated by sulfate (4,383.0 and 4,112.4 mg/L) with mineralisation of 1,360 and 1,220 mg/L, and contained Ca, Mg, bisulfite, nitrate and trace metals slightly above the MPC (Fig. 2). In the production-shop stream, coagulation reduced mineralisation to 840 mg/L (38.2 %), sulfate to 3,132.0 mg/L (28.5 %), Mg to 35.3 mg/L (44.9 %), Fe^{3+} to 0.42 mg/L (40.8 %), Ca to 167.8 mg/L (27.8 %) and Pb from 0.013 to 0.0087 mg/L (33.1 %). In the 450 MW stream the reductions were smaller: sulfate to 3,234.0 mg/L (21.4 %), chloride to 283.6 mg/L (23.1 %), Ca to 179.4 mg/L (22.7 %) and mineralisation to 910 mg/L (25.4 %); Pb decreased by 25.2 %, Mn by 17.4 %, As by only 4.2 %, while Co and Cr were unchanged and cyanide changed within measurement error (0.045 → 0.046 mg/L). In both streams, every parameter with an established MPC that exceeded it before treatment was below it afterwards, although several (Ca 179.4 vs 180 mg/L, NO_3^- 43.7 vs 45 mg/L, Fe^{3+} 0.47 vs 0.50 mg/L in the 450 MW stream) were close to the limit.

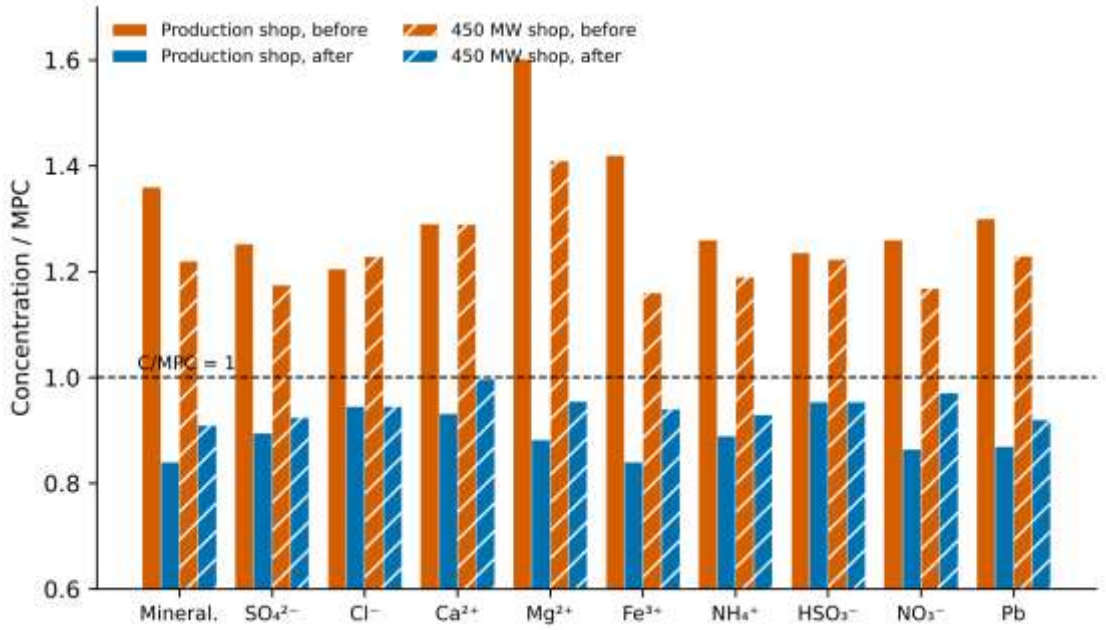


Figure 2. Ratio of concentration to MPC for the main parameters of Navoi TPP production-shop and 450 MW unit-shop wastewater before and after coagulation

The removal of dissolved ions such as sulfate, chloride, Ca and Mg by 21–45 % is higher than usually expected from coagulation alone, because $FeCl_3$ does not form insoluble compounds with these ions and itself introduces chloride (215 mg/L per 1 kg/m³ of the 32.81 % solution, by our calculation). The decreases imply that the doses used were small and that part of the ions was incorporated into the sludge or associated with the removed solids. These results should be confirmed by replicate tests and a sludge mass balance before full-scale design.

Environmental effect and proposed scheme. Using Eq. (2), the treatment of the TPP stream entering mechanical treatment keeps 182 kg suspended solids, 400 kg chloride, 165 kg sulfate and 370 kg of mineral salts per 1000 m³ out of the receiving water; for the production-shop stream these values are 1,251 kg sulfate and 78 kg chloride, and for the 450 MW stream 878 kg sulfate and 85 kg chloride. For the annual TPP discharge of 2,182 thousand m³, the effect for the mechanical-treatment stream corresponds to about 397 t of suspended solids, 873 t of chloride and 360 t of sulfate per year. Under Cabinet of Ministers Resolution No. 202 of 12 April 2021, discharges above the established standards are subject to compensation payments with increased multiplying coefficients [17]; bringing the stream within the MPC therefore also has a direct economic effect. An assessment using the coefficients of the 1999 Russian methodology for prevented environmental damage [18] gives 121.3 conditional tonnes per year, which we use only to compare sites, because the monetary coefficients of that methodology are not directly transferable to Uzbekistan.

We propose to add a coagulation stage (solution tank, dosing pump, rapid mixer, flocculation chamber and clarifier) upstream of the existing three-pond system. Doses of 0.1–0.3 kg of 32.8 % coagulant per m³ (33–98 g $FeCl_3$/m³) are recommended for weakly polluted sulfate–chloride streams such as the TPP streams, and 1.0–2.0 kg/m³ for streams with heavy metals above 10 mg/L; for the foundry stream the dose should be reduced and flocculation time increased to avoid residual iron, and pH adjustment is needed for nickel. Settled sludge must be dewatered and its metal content assessed before disposal.

Limitations. The results were obtained in laboratory coagulation tests, and seasonal variability of the wastewater composition was not studied. Sludge volume and composition were not measured.

Conclusion

A locally produced liquid iron(III) chloride coagulant (32.81 % $FeCl_3$) was tested on foundry wastewater of the Navoi Machine-Building Plant and three wastewater streams of Navoi TPP.

For the foundry wastewater, coagulation removed 87.0 % of solids and 84–85 % of Mn, Cu and Cr, but only 31.7 % of Ni, and increased dissolved iron from 8.3 to 10.5 mg/dm³, indicating the need for a lower dose, longer flocculation and pH adjustment.

For the TPP stream entering mechanical treatment, parameters that exceeded the MPC by 1.26–1.53 times were brought within the MPC, except BOD_5 (32 vs 30 mg/L); in the production-shop and 450 MW streams all exceeding parameters were brought below the MPC.

For the TPP annual discharge of 2,182 thousand m³, the treatment would keep about 397 t of suspended solids, 873 t of chloride and 360 t of sulfate per year out of the receiving water. A coagulation stage upstream of the existing ponds with a dose of 0.1–0.3 kg/m³ is 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.

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