Wastewater afterpurification of chromium compounds production by the ultrafiltration and reverse osmosis

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Abstract. Most often, reagent methods are used to treat wastewater from Cr (VI) compounds. This treatment technology allows reducing the concentration of Cr (VI) in wastewater only. Comparing the composition of wastewater after reagent treatment of chromium compounds using Ca(OH)₂ with established standards, it can be concluded that it is necessary to purify a number of pollutants. In this study, wastewater afterpurification of chromium compounds production by the ultrafiltration and reverse osmosis was considered. Modelling processes using WAVE 1.72 software confirmed that the proposed post-treatment scheme was highly efficient and that wastewater could be discharged into a water body without harming it.

1. Introduction
Enterprises specializing in the production of chromium compounds are a dangerous source of pollutants in wastewater that can have a negative impact on the environment. The wastewater of these enterprises contains extremely toxic substance – chromium (VI).

To prevent pollution of water reservoirs, wastewater is required to be treated. Various methods are used to remove chromium (VI) from wastewater [1-5]. A comparative analysis of various methods of wastewater treatment from chromium compounds is carried out in [6]. Most often, reagent methods are used to treat wastewater from Cr (VI) compounds. Figure 1 shows a reagent wastewater treatment scheme [7].

Figure 1. Structural diagram of reagent wastewater treatment and disposal.
The reagent methods are based on the reduction of dissolved Cr (VI) with FeSO$_4$ to less toxic Cr (III), which in base conditions precipitates as sparingly insoluble hydroxides and is removed from water. After purification, the mass concentration of Cr (VI) is not more than 0.06 mg/dm$^3$, and the pH is 6.5-8.3 [6]. These values satisfy regulatory requirements. This treatment technology allows reducing the concentration of Cr (VI) in wastewater only. The contents of other pollutants during the cleaning process do not change remaining their initial values. In addition, using reagents in purified water increases the content of sulphates and iron [7].

Table 1 shows the average seasonal composition of contaminants in the wastewater of AO “Russian Chrome 1915” after their purification by the reagent method [2]. When wastewater is discharged into water bodies, their quality should satisfy the requirements. The most stringent requirements are the standards for fishery water reservoirs – MPC$_{rh}$. Comparing the composition of wastewater after reagent treatment of chromium compounds using Ca(OH)$_2$ with established standards, it can be concluded that it is necessary to purify a number of pollutants.

### Table 1. The composition of wastewater after reagent treatment of chromium compounds and standard for effluents composition.

| Wastewater composition indicators | The wastewater composition of AO “Russian Chromium 1915”, mg/l | Standard for effluents composition of fishery water body (MPC), mg/l |
|----------------------------------|-------------------------------------------------------------|---------------------------------------------------------------|
| Iron (general)                   | 0.7-1.0                                                    | 0.10                                                          |
| Chloride ion                     | 150.0-200.0                                               | 300.00                                                        |
| Sulphate ion                     | 2000.0-4000.0                                             | 100.00                                                        |
| Suspended solids                 | 5.0-30.0                                                  | 14.95                                                         |
| Nitrate ion                      | 20.0-40.0                                                 | 40.00                                                         |
| Ammonium ion                     | 20.0-40.0                                                 | 0.50                                                          |

One of the most effective methods for removing various ions from water is membrane technology. Membrane systems are used to remove bacteria, protozoa, and viruses, prepare high-quality drinking water, and partially or deeply desalinate the water [8]. Ultrafiltration and reverse osmosis allow concentrating and separating the pollutants dissolved in wastewater.

Thus, the aim of this work is to develop wastewater afterpurification of chromium compounds production by the ultrafiltration and reverse osmosis.

### 2. Methods
In the work, a calculation of a wastewater treatment plant including the stage of ultrafiltration and reverse osmosis was made. Ultrafiltration and reverse osmosis processes were simulated using the WAVE 1.72 software [9].

### 3. Results
The proposed flow chart of wastewater afterpurification of chromium compounds production wastewater treatment is presented in Figure 2.

After the reagent removal of Cr (VI), the wastewater containing pollutants is pumped (item 1) to the ultrafiltration unit (item 3), where it is purified from iron and suspended substances. The obtained filtrate is sent to an intermediate collector (item 10), and the concentrate enters the sewage regulator (item 4), from where it is pumped to mix with the initial wastewater. Most of the filtrate is then sent for purification to the reverse osmosis unit (item 11), and the rest is periodically used for backwashing the membranes of the ultrafiltration unit. Wash water containing impurities of iron and suspensions trapped on the membranes is received in the averaging tank (item 6).
**Figure 2.** Flow chart of wastewater treatment. I – wastewater for treatment, II – purified water, III – for evaporation plant. 1 – pump; 2 – valve; 3 – ultrafiltration unit; 4 – tank with concentrate; 5 – neutralizing tank; 6 – sewage regulator 7 – dosage block of NaOH; 8 – dosage block of HCl; 9 – dosage block of NaOCl; 10 – an intermediate tank; 11 – reverse osmosis plant; 12 – capacity with purified wastewater; 13 – tank with a concentrate for reverse osmosis; 14 – tank-neutralizer for reverse osmosis; 15 – sewage regulator of reverse osmosis plant.

The ultrafiltration filtrate from the intermediate collector (item 10) is pumped to the reverse osmosis membrane system (item 11) for wastewater treatment from residual iron, suspended solids, sulphate, nitrate, ammonium, and chloride ions. The obtained permeate is taken to the collection of purified water (item 12), from where it is sent to the consumer (to circulating water supply systems or to the technological process).

The concentrate enters the tank (item 13) for co-recycling with ultrafiltration wastewater. Part of the permeate from the collection (item 12) is used for periodic washing of reverse osmosis membranes, which is carried out by the pump. The wash water is sent to the averaging tank of the ultrafiltration unit (item 6).

Once a day, chemical washing of the reverse osmosis membranes with solutions of NaOH, HCl and NaOCl (for disinfection) is carried out by feeding them from dosing units (items 7-9). Water from chemical washing is supplied to the neutralization tank (item 5), where it is treated together with similar waters of the ultrafiltration unit and then transferred to the evaporation unit to reduce the volume of wastewater.

Based on the wastewater flow rate equal to 160 m$^3$/h, it is proposed to use two PVO-UF-80 ultrafiltration units (capacity 80 m$^3$/h), including 16 ultrafiltration modules each. For selected ultrafiltration units, it is proposed to use IntegraPac IP-51XP modules equipped with PVDF (polyvinyl difluoride) membranes. The specifications of the membrane elements are presented in Table 2 [10].

As a result of ultrafiltration purification, part of the water is spent on the plant’s own needs, while other part is left with concentrate, so the permeate volume was 135.8 m$^3$/h. The calculation of the reverse osmosis was carried out by this value.

To conduct reverse osmosis, it is proposed to use three reverse osmosis plants MA-50 (the productivity of each installation is 50 m$^3$/h). As membranes, high-performance low-pressure roll membrane elements FORTILIFE XC80 are used, the specifications of which are given in Table 3 [11]. The permeate output from the reverse osmosis unit will be 94.54 m$^3$/h.
Table 2. Main specifications of the module type IntegraPac IP-51XP.

| Specifications                   | Unit | Value |
|----------------------------------|------|-------|
| Membrane surface area            | m²   | 51    |
| Module outer diameter            | mm   | 225   |
| Case material                    | –    | PVC-U |
| Maximum pressure                 | bar  | 6.25  |
| Temperature range                | °C   | 1-40  |
| Capillaries in fibre             | pc.  | 7     |
| Inner diameter of the capillaries| mm   | 1.5   |
| Outer diameter of the capillaries| mm   | 6.0   |
| Pore size                        | mkm  | 0.02  |
| Material                         | –    | PVDF  |

Table 3. Main specifications of the membrane type FORTILIFE XC80.

| Specifications                   | Unit | Value |
|----------------------------------|------|-------|
| Membrane surface area membrane   | m²   | 41    |
| Module outer diameter            | m    | 201   |
| Configuration                    | –    | roll  |
| Maximum pressure                 | MPA  | 8.3   |
| Temperature range                | °C   | 1-45  |
| Pore size                        | mkm  | 0.001 |
| Material                         | –    | Polyamide |
| Selectivity                      | %    | 99.5  |

Table 4 presents the calculation results of the proposed wastewater treatment plant obtained using the WAVE 1.72 software. Comparison of the obtained results of the quality of treated wastewater with standards (MPC) shows that the proposed post-treatment scheme is highly efficient, and wastewater can be discharged into a water reservoir without harming it.

Table 4. Efficiency of wastewater treatment by ultrafiltration and reverse osmosis obtained using WAVE 1.72 software.

| Wastewater composition indicators | Concentration of pollutants, mg/l | Standard for effluents composition of fishery water body (MPC), mg/l |
|----------------------------------|-----------------------------------|------------------------------------------------------------------|
|                                  | Wastewater                        | Permeate                                                                 |
|                                  | After ultrafiltration              | After reverse osmosis                                               |                                                                           |
| Suspended solids                 | 30.00                             | 0                                                                   | 0                                                                           | 14.95                                                                     |
| Sulphate ion                     | 2000.00                           | 2000.00                                                             | 0.58                                                                       | 100.00                                                                    |
| Nitrate ion                      | 40.00                             | 40.00                                                               | 1.13                                                                       | 40.00                                                                     |
| Ammonium ion                     | 20.00                             | 20.00                                                               | 0.39                                                                       | 0.50                                                                      |
| Chloride ion                     | 200.00                            | 200.00                                                              | 0.77                                                                       | 300.00                                                                    |
4. Conclusion
Wastewater treatment is an important stage in the work of the enterprise, since the state of the environment, in particular water bodies, depends on the quality of the wastewater discharged.

The work has developed a flow chart for the wastewater treatment of enterprises producing chrome compounds. Wastewater after the reagent method is sent to the proposed scheme including ultrafiltration and reverse osmosis treatment unit.

Based on the wastewater flow rate equal to 160 m$^3$/h, it is proposed to use two PVO-UF-80 ultrafiltration units (capacity 80 m$^3$/h), including 16 ultrafiltration modules each. For selected ultrafiltration units, it is proposed to use IntegraPacIP-51XP modules equipped with PVDF (polyvinyl difluoride) membranes. As a result of ultrafiltration purification, part of the water is spent on the plant’s own needs, while other part is left with concentrate, so the permeate volume was 135.8 m$^3$/h.

To conduct reverse osmosis, it is proposed to use three reverse osmosis plants MA-50 (the productivity of each installation is 50 m$^3$/h). As membranes, high-performance low-pressure roll membrane elements FORTILIFE XC80 are used. The permeate output from the reverse osmosis unit is 94.54 m$^3$/h.

Modelling processes using WAVE 1.72 software has confirmed that the proposed post-treatment scheme is highly efficient, and wastewater can be discharged into a water body without harming it.

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