Treatment of industrial effluents using evaporation installations

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Abstract. The purpose of the paper is to present the structure of the needs of industrial enterprises in the treatment of industrial effluents using evaporation installations and to analyse parameters of these effluents using the example of Russia. These parameters are the volume flow of wastewater that is supposed to feed the plant, their composition, the origin of the runoff, the type of production, where the runoff was formed. The obtained results of the analysis of data on the effluents of enterprises will help to find out whether the technological schemes and the evaporation installations included in them will be the most popular and efficient from the point of view of environmental safety of production. In addition, based on this work, it becomes clear what conditions require increased attention when developing hardware design of industrial wastewater treatment processes. Main problems of thermal desalination of industrial effluents by evaporation were considered in this paper.

1. Introduction
A liquid is required for carrying out technological processes at industrial enterprises. Liquid comes into contact with chemicals, solids, and gases. At the same time, it may lose its properties necessary for repeated usage and disposal. That is how industrial effluents are formed – they are processed, used in the technology liquids, the use of which is impossible in the future due to technical conditions or impractical because of technical and economic indicators. Uncontrolled discharge of containing harmful impurities wastewater into sewers and reservoirs without proper treatment is unacceptable because it causes irreparable harm to the environment and human health.

As the analysis of the work of industrial treatment facilities [1] shows, most of them use reagent methods. These allow to purify wastewater from heavy metals and to neutralize partially defused effluents in the best case. All easily soluble salts (chlorides, sulphates, fluorides, nitrates, carbonates, ammonia, and phosphates) remain in wastewater. This makes it impossible to reuse these liquids in the main technology of enterprises. One of the techniques that can solve the problem of wastewater treatment from easily soluble impurities is thermal desalination. Exploitation of evaporation installations makes it possible to effectively purify wastewater from the compounds contained in it and obtain desalinated water of required quality and a wet salt deposit [1]. This paper analyses the structure of the needs of Russian industrial enterprises in evaporation equipment. The analysis was carried out in order to determine the required parameters of evaporation plants of enterprises of different industries: high, medium, or low capacity of raw materials, the composition of industrial effluents and their origin, and industry branches requiring processing of the residue.
2. Methods
On the example of one of Russian research and production enterprises, documents containing 145 applications for the design of evaporation installations (questionnaires, technical tasks, and official requests) from 2009 to 2020 were collected. A table was compiled that reflected required capacity of initial solution for evaporation installation from each request, composition of the solution, its origin and field of the customer enterprise. Then enterprises were ranked by listed parameters into categories, and shares of enterprises belonging to different categories from total number of requests were calculated. The structure based on calculated data is presented in this paper.

3. Results
The type of manufactured products determines technology of enterprises and, therefore, pollution factors that contacted with source resources. Analysis of requests shows that waste disposal by evaporation is required for a wide range of industries – light and heavy, chemical and petrochemical, fuel, pulp and paper, glass, food, metallurgy, and metalworking. The structure of demand for evaporation equipment is presented in diagrams depending on the attribute of ranking the requests from enterprises. The structure of needs depending on the customer's belonging to a particular industry branch is shown in Figure 1.

![Figure 1](image-url)

**Figure 1.** The structure of the needs of enterprises in evaporation equipment, depending on the branch of industry.

The overwhelming number of requests (19 %) came from machine-building enterprises, mainly chemical ones, which ensured functioning of the fuel and energy complex of the country. The second place in terms of the number of applications is occupied by ferrous metallurgy – 12 %, as well as companies that design evaporation plants for the water treatment sites of their customers. Energy producers – thermal power plants and CHP – occupy the third place, 10 % of requests. They require
evaporation equipment to produce pure desalinated condensate to create steam and feed it to the steam turbine when high corrosion activity of used water is unacceptable. Dewatered sludge can be used for regeneration and washing of materials of the company's treatment facilities – ion exchange resins, sorbents, and solutions, or in some cases these can be sold if it is valuable. 9 % of applications were received from the most expected category of enterprises – producers of mineral fertilizers and pure chemical reagents. This category of enterprises requires evaporation plants primarily for obtaining the salt crystal of target substance of the technology – a pure reagent or mineral fertilizer, as well as for the disposal of by-products formed in the technology. Slightly less applications were received from non-ferrous metallurgy enterprises (8 %). Non-ferrous metallurgy enterprises use evaporation not only for wastewater treatment, but also as a stage for obtaining the target product and intermediate products, for example, sodium aluminate powder in aluminium production. Next, in terms of the number of applications are oil and gas processing and coking chemical enterprises (7 %), food processing enterprises (4 %), organic synthesis and catalyst production enterprises (3 %), and nuclear industry enterprises (2.5 %). 2 % each were received from mining and hydrometallurgy, microelectronic production, metalworking, and textile industries. 1 % of application came from enterprises operating boilers. As for origin of wastewater, evaporation is the most popular treatment method for reverse osmosis wastewater (33 % of applications) (Fig. 2).

Slightly less of requests are for secondary industrial wastewater – 22 %. 10 % of enterprises require evaporation to obtain the target product from the salt crystal, 9 % – regenerative and washing water from ion exchange filters, 7 % – for obtaining by-products of the technology, 4 % each – for evaporation of technological solutions, 3 % each – of galvanic effluents, storm water, and wash water. 2 % of enterprises need to evaporate acid pickling solutions and 1 % – solutions from electric desalting plants of oil refineries.
Figure 3. The structure of the need of enterprises in evaporation equipment, depending on the capacity of supplied raw materials.

Figure 4. The structure of the needs of enterprises in evaporation equipment, depending on the composition of wastewater.
The largest number of applications were received for installations with low raw material productivity (Fig. 3): 2-3 m³/h – 24 %, 4-5 m³/h – 16 %. Installations with a high capacity of more than 17 m³/h are required in 20 % of requests. Average productivity at 8-10 m³/h is required for 15 %, 11-16 m³/h – for 10 %, 6-7 m³/h – for 6 %. A minimum capacity of 0,1-1 m³/h is required for 10 % of applications.

Regarding a composition of wastewater (Fig. 4), the mixture of sodium sulphate and chloride most often occupies main share in a composition – 24 % of such requests. Solutions of sulphates and chlorides of various metals, except sodium-alkaline, alkaline-earth, heavy-ore at the second place in terms of occurrence, which is 11 % of requests. Solutions of NaCl are at the third place, and this is 8 % of requests.

Next, the main wastewater substances in descending order: 7 % each – NH₄NO₃ with presence of HNO₃, a mixture of rare earth metal nitrates with HNO₃, 6 % – calcium chlorides, sulphates, carbonates, and bicarbonates, 6 % – a mixture of (NH₄)₂SO₄ and NH₄Cl, 5 % – only Na₂SO₄, 4 % – lithium compounds. CaCl₂ sometimes mixed with Ca(ClO)₂ is the main compound in 3 % of applications, as well as NaOH and mix of FeSO₄, HCl, and H₂SO₄ jointly. 2 % of applications belong to each: NaNO₃ sometimes with impurity of NaNO₂, mix of NaNO₃, Na₂SO₄, Ca(NO₃)₂, and Mg(NO₃)₂ are major in composition for 1.5 % of requests, mix of alkali and alkaline earth metals oxides is for 1 %, as well as Na₂S₂O₄.

4. Conclusion

Obtained results can be taken into account by the developers of evaporation installations when the direction of scientific development is chosen and possibility of adapting existing technologies to a specific origin of wastewater is implemented. They are also useful when forming a proposal for wastewater treatment for enterprises of machine building, ferrous metallurgy, and power plants, primarily. It is possible that these enterprises should also provide for introduction of evaporation plants in advance in their production at the design stage of industrial units, especially if reverse osmosis effluents are expected to form or if there is no equipment for treating wastewater from the enterprise. The result of the study shows that popular installations in Russia for the evaporation of sulphate effluents of reverse osmosis, containing mainly sodium sulphate, and the design of the installation for the treatment of these effluents productivity 2 m³/hour will be cost-effective. As it was confirmed during the analysis of applications, reverse osmosis wastewater and other wastewater usually contained a large number of various components. It complicates the hardware design of their evaporation processes, and this requires an individual approach to its development. The main problem is the complexity of obtaining pure powdered products, which leads to the accumulation of non-recyclable waste-salt mixtures. Obtaining clean condensate to create a closed water cycle at enterprises can be complicated by the presence of volatile gases in effluents – ammonia, nitrogen oxides, and fluorine-containing compounds, which pollute condensate of secondary steam, that requires equipping an evaporation unit with additional devices scrubbers, distillation columns, absorbers, and adsorbers. Most effluents contain hard salts, which was confirmed by the analysis of applications. This requires inclusion of reactors for softening and solid separation to the technology, since these salts lead to formation of scale on heat exchange surfaces of equipment, which sharply reduces heat engineering characteristics [1]. The high demand for high performance of evaporators, showed by analysis of requests, is associated with the problem of their large dimensions.

References
[1] Linnikov O, Kovzel V, Malyshev A, Molostova L, Shaburov V and Rodina I 2015 Water Magazine 99 18