Evaluation of the possibility of using underground salts for the regeneration of Na-cationite filters of WTP TPP and NPP in the territory of the CFD

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Abstract. When studying groundwater in the Central Federal District (CFD), it was found that the mineralization of groundwater, including brines, increases "from top to bottom" - as the depth of the aquifer complex. The possibility of using underground natural chloride sodium brines for the regeneration of Na-cationite exchange filters is determined by two boundaries - upper and lower. The upper limit of applicability of the brines is controlled by the salinity of the brines of 165 g/dm³, that is, you can use brines with a salinity of at least 165 g/dm³. The lower limit of applicability of the brines is determined by the ratio of the content of sodium ion (in mEq/dm³) to the total hardness of the brine (in mEq/dm³), which should be at least 3.5. In addition to these requirements, the ability to use underground natural chloride sodium brines as a regeneration solution for Na-cation exchange filters is influenced by the total hardness of the brine depending on the total salinity of the brine: to prevent an increase in the counterionic effect, the total hardness of the brine should not exceed 500 mEq/dm³ with a total mineralization of 100–150 g/dm³, and should not exceed a value of 1,500 mEq/dm³ with a total mineralization of 250–300 g/dm³. The regionalization of the territory of the CFD, taking into account these requirements, revealed 41 thermal power plants and one nuclear power station as potential consumers of underground sodium chloride brines. In addition, on the basis of regionalization, aquifer complexes containing underground brines of conditional quality, depths of aquifer complexes, and approximate depths of design salt-producing wells, on which the cost of well construction largely depend, were determined.
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The electric power industry of the CFD is represented by three types of electricity production: thermal, nuclear and hydraulic. The installed capacity of thermal power plants is 71% of the total installed capacity of the entire electric power industry of the CFD, nuclear power plants - 26% and hydroelectric power plants - 3%. Thus, the production of electricity in the CFD is based mainly on the operation of thermal power plants. In total, there are 67 thermal power plants and four nuclear power plants in the CFD (Figure 1). Thermal power plants belong to the following enterprises: PJSC «Quadra - Power Generation» - 19 thermal power plants, PJSC «Mosenergo» - 15, PJSC «TGK-2» - 5, PJSC «T Plus» - 3, JSC «Inter RAO-Electric Power Generation» - 3, PJSC «NLMK» - 2, LLC «Tvverskaya Generation» - 2, JSC «Test bench of Ivanovo State District Power Station» - 1, OJSC «Kaluga Turbine Plant» - 1, JSC «GT Energo» - 1, LLC «Senergo» - 1, LLC «Rosmix» - 1, LLC «VTK-invest» - 1, KP «MEDO» - 1, PJSC «Unipro» - 1, JSC «Voskresensk Mineral Fertilizers» - 1, LLC «Novo-Ryazan Thermal Power Plant» - 1, PJSC «OGK-2» - 1, LLC «Dorogobuzhskaya Thermal Power Plant» - 1, PJSC Enel Russia - 1, LLC OHC Shchekinoazot - 1, PJSC Tulachemert - 1, LLC Shchekinskaya TPP - 1, LLC Huadyan-Teninskaya TPP - 1. Nuclear power plants of the Central Federal District are owned by Rosenergoatom Concern JSC: Kalinin NPP, Kursk NPP, Smolensk NPP and Novovoronezh NPP.

For the purpose of regeneration of Na-cation exchange filters in the water treatment cycle, dry technical sodium chloride salt is used for the preparation of brines in chemical shops of power plants. Beginning in 1979, at «Mosenergo» thermal power plants for the regeneration of Na-cation exchange filters, natural underground brines of sodium chloride composition have been used instead of preparing brines from dry salt [2 - 5]. Here, great experience has been gained both in the use of natural sodium chloride brines in the process of regeneration of Na-cation exchange filters and in the operation of brine-producing wells. As a result of many years of research by employees of Mosenergo PJSC, ORGRES Firm OJSC, MEI National Research University, conditions were established for underground natural sodium chloride brines, if possible they can be used as regeneration brines, which are as follows: the total brine mineralization should be not less than 165 g/dm³; the ratio of the sodium content in brine (in mEq/dm³) to the value of the total hardness of the brine (in mEq/dm³) should be at least 3.5; to exclude an increase in the counterionic effect, the value of the total brine stiffness should not exceed 500 mEq/dm³ with a total mineralization of 100-150 g/dm³, and should not exceed 1500 mEq/dm³ with a total mineralization of 250-300 g/dm³.

We analyzed the possibility of using underground sodium chloride brines in the CFD, the results of which are presented in Figure 1. The figure shows the red line, which is the southern boundary of the distribution of conditioned underground sodium chloride brines. To the north of this line, in the territory of the city of Moscow, Moscow, Kostroma, Yaroslavl, Ivanovo, Tver, Vladimir, Ryazan, as well as partially Smolensk, Kaluga, Tula and Tambov regions of the Central Federal District, underground sodium chloride brines can be used as conditioners. There are 41 TPP and one NPP in this territory. South of the red line, in the Bryansk, Oryol, Lipetsk, Kursk, Voronezh and Belgorod regions, where 26 thermal power plants and four nuclear power plants are located, in which the regeneration of Na-cation exchange filters can be carried out mainly by the traditional method - by preparing brines from imported dry technical salt. However, in this territory it is possible to distinguish a district, for the most part of which, in the Tula, Kaluga and Smolensk regions, there are no conditioned natural brines, but in the Middle Devonian rocks there are deposits of rock salt of the Moscow salt-bearing basin. This area will be discussed below.

The territory under consideration belongs to the East European system of formation water basins - to the Central Russian complex basin of non-pressure and pressure water — to the Moscow
The alternation in the geological section of water-permeable and poorly permeable rocks of various lithological composition and age led to a complex system of aquifers and complexes on the territory of the Moscow artesian basin. Pore and fissure waters are confined to sediments of the upper part of the Archean, Proterozoic, Devonian, Carboniferous, Permian, Jurassic, Cretaceous, Paleogene, Neogene, and Quaternary systems that form the crystalline basement and sedimentary cover of the platform. The total thickness of the sedimentary cover of the platform reaches 5 km. The sedimentary cover lies on an uneven, complexly located surface of the crystalline basement. In the considered territory of the Moscow artesian basin, aquifers naturally subside in the northeast direction. As
aquifers dive, the chemical composition and mineralization of groundwater changes from calcium hydrocarbonate, through calcium sulfate and sodium to sodium chloride and calcium-sodium. Accordingly, the salinity of groundwater increases. As aquifer complexes sink in chloride sodium waters, the content of calcium and magnesium ions gradually increases, i.e. the magnitude of the total rigidity increases. Brines, groundwater - whose mineralization exceeds 50 g/dm³, are widespread at depths of more than 700 m, but conditioned brines are confined only to certain aquifers in certain areas.

According to geological and hydrogeological conditions, as well as location in the CFD, power plants located north of the red line in Figure 1 can be divided into eight groups.

**The first group** includes Ivanovo TPP-2, Ivanovo TPP-3, Ivanovo CCGT, Test bench of Ivanovo TPP, Kostroma TPP, Kostroma TPP-1, Kostroma TPP-2, Yaroslavl TPP-1, Yaroslavl TPP-2, Yaroslavl TPP-3, Huadian -Teninskaya CHPP, which are compactly located in the eastern part of the Yaroslavl region, the southwestern part of the Kostroma region and the western part of the Ivanovo region. Thermal power plants are located in the central part of the Moscow artesian basin [6, 7].

As the target aquifer complex containing underground natural sodium chloride brines suitable for the regeneration of Na-cation exchange filters, the aquifer Old Oskol-Timan terrigenous complex can be used.

The aquifer of the Stary Oskol-Timan terrigenous complex (D2:3st-tm) is confined to the thickness of fine-grained sands and sandstones with interlayers of clays of the Stary Oskol horizon of the Zhivsky layer of the middle section and the Timan horizon of the lower stage of the French layer of the upper section of the Devonian systemic thickness from 200 to 250 m of depth. complex 1350-1400 m. The flow rate of the wells is 0.20-0.95 l/s. The chemical composition of the aquifer contains strong sodium chloride brines with a salinity of 200-230 g/dm³. The estimated depth of the wells is 1600 m.

**The second group** includes one Tver NPP, which is located in the northern part of the Tver region and is confined to the eastern side of the Valdai aulacogen, in the northwestern part of the Moscow artesian basin [6, 7]. The geological structure of the region includes deposits of the Archean system, Riphean and Vendian of the upper part of the Proterozoic system, the lower and middle sections of the Cambrian system, the Ordovician system, the middle and upper sections of the Devonian system, the lower and middle sections of the coal system and the Quaternary system. An aquiferous Cambrian terrigenous complex can be used as the target aquifer complex containing underground natural sodium chloride brines suitable for the regeneration of Na-cation exchange filters.

The aquifer Cambrian terrigenous complex is confined to the thickness of fine-grained sands and sandstones with intercalations of clays of the Izhora horizon and eophyton horizon of the Baltic series of the middle section of the Cambrian system with a thickness of 120 to 130 m. The depth of the roof of the aquifer is 1272.5-1281.7 m. The absolute level of groundwater is -2.62 - 2.93 m. The flow rate of wells is 0.22-0.88 l/s. The chemical composition of the aquifer contains strong sodium chloride brines with a salinity of 219-221 g/dm³. The approximate depth of the wells is 1450 m.

**The third group** includes Konakovskaya TPP, Tverskaya TPP-3 and Tver TPP-4, which are located in the south of the Tver region, Vladimir TPP-2 - in the central part of Vladimir region, in the south-eastern part of the city of Vladimir, Diagilev TPP - in the north-western part Ryazan region in the city of Ryazan, Novo-Ryazan CHP - in the western part of the Ryazan region, in the city of Novomichurinsk, CHP-26, CHP-21, CHP-23, CHP-25, CHP-20, CHP-16, CHP-12, CHP -8, TPP-11, TPP-9, TPP Mezhduarodnaya, TPP Tereshkovo, TPP Kolomenskoye, TPP Vnukovo, TPP-1, Kashirskaya TPP, Shaturskaya TPP, TPP-22, TPP-27, TPP -3 them. R.E. Klassona, TPP-17, TPP JSC "Resurrection Mineral Fertilizers" - in the city of Moscow and the Moscow Region [1, 6, 7].

As the target aquifer complex containing underground natural sodium chloride brines suitable for the regeneration of Na-cation exchange filters, the Ryazh aquiferous terrigenous complex can be used. The aquifer Ryazhsky terrigenous complex (D2:3rz) is represented by sands and sandstones with interbeds of clay. The total thickness of the rocks of the complex varies from 8 to 97 m, usually 50-60 m. The roof of the aquifer Ryazhsky complex lies in the Moscow region at absolute elevations from -850 to -1200 m. The sulfate-terrigenous sediments of the Dorogobuzh horizon of the Eiffel layer serve as the upper confinement of the complex under consideration. middle section of the Devonian system.
On the territory of TPP-21, experimental pumping was carried out in wells equipped for the Ryazhsky aquifer complex. The pumping rate reached 9.5 l/s with decreases to 28 m. The absolute level of the piezometric level is + 8.2 m. Mineralization of sodium chloride brines 244 g/dm³. During the study of the Ryazhsky aquifer, a large amount of hydrogeological work was carried out at the CHPP-26 site, including solitary and cluster pumping. The absolute mark of the piezometric level is +6.2 m. The flow rate of the wells during pumping varied from 8.5 to 10.0 l/s, with decreases not exceeding 7.2 m. The mineralization of sodium chloride brines of the Ryazhsky aquifer in the territory of TPP-26 reaches 275 g/dm³. In the city of Moscow and the Moscow Region, 53 salt-producing wells, one injection well and seven observation wells are currently in operation. The water mobility of the complex is uneven, the specific flow rates of the wells vary from 0.016 to 0.52 l/s.

Such a spread in the values of the specific flow rates of the wells is explained not only by the variability of the filtration parameters, but also by the quality of drilling, the designs and methods of well development. In the territory under consideration, the salinity of brines varies from 196 to 293 g/dm³. The estimated depth of the wells is 1200-1400 m.

**The fourth group** includes the Smolensk State District Power Station, located in the village of Ozerny, Dukhovschinsky District, in the northern part of the Smolensk Region, in the western part of the Moscow artesian basin [6, 7].

An aquiferous Vendian terrigenous complex can be used as a target aquifer containing underground natural sodium chloride brines suitable for the regeneration of Na-cation exchange filters.

The aquiferic Cambrian terrigenous complex (V) is confined to the intercalation of fine-grained sandstones, siltstones, and argillites of the Vendian sub-tier of the Riphean tier of the upper part of the Proterozoic system with a thickness of 400 to 450 m. The depth of the roof of the aquifer is 850–900 m. The flow rate of wells is 0.1–0, 0, 8 l/s. The chemical composition of the aquifer contains strong sodium chloride brines with a salinity of 170-180 g/dm³. The estimated depth of the wells is 1350 m.

The fifth group includes the Dorogobuzh TPP, located east of the village of Verkhnedneprovsky in the Dorogobuzh district of the Smolensk region, in the western part of the Moscow artesian basin [6, 7].

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The aquiferic Cambrian terrigenous complex (V) is confined to the intercalation of fine-grained sandstones, siltstones, and argillites of the Vendian sub-tier of the Riphean tier of the upper part of the Proterozoic system with a thickness of 350 to 400 m. The depth of the roof of the aquifer is 1000-1100 m. The flow rate of wells is 0.2-0, 0, 7 l/s. The chemical composition of the aquifer contains strong sodium chloride brines with a salinity of 165-175 g/dm³. The estimated depth of the wells is 1400 m.

**The sixth group** is distinguished separately and includes thermal power plants located south of the red line in Figure 1, where there are no conditioned brines, but there are deposits of rock salt in the Dorogobuzh horizon of the Eiffel layer of the middle section of the Devonian system [1, 6, 7]. On the territory of the Tula region under consideration are Aleksinskaya TPP - in the city of Aleksin, Novomoskovskaya TPP - in the city of Novomoskovsk, Pervomayskaya TPP - in the working village of Pervomaisky Shchekinsky district, TPP-PVS PJSC Tulachermet - in the southern part of the city of Tula, Shchekinskaya TPP - in the city of Sovetsk Shchekinsky district. Rock salts are developed by leaching using wells in the city of Novomoskovsk. The thickness of rock salt deposits is 40-60 m. The roof of the deposits lies at a depth of 800-850 m. The estimated well depth is 850-900 m. The extraction of brines is carried out as follows. Two columns of pipes are lowered into the well. Fresh water is supplied through one of them, which dissolves rock salt, and on the other, brines are pumped out. The salinity of the brines is about 300 g/dm³. The content of calcium and magnesium ions is minimal. The estimated well depth is 850-900 m. The extraction of brines is carried out as follows. Two columns of pipes are lowered into the well. Fresh water is supplied through one of them, which dissolves rock salt, and on the other, brines are pumped out. The salinity of the brines is about 300 g/dm³. The content of calcium and magnesium ions is minimal.
Conclusions

The regionalization of the territory of the CFD, taking into account the geological and hydrogeological conditions and the territorial location of energy facilities, made it possible to assess the possibility of using underground natural chloride sodium brines for the regeneration of Na-cation exchange filters.

Determine the target aquifers for five groups of power plants, the depths of aquifers and the estimated depths of the design brine-producing wells, on which the cost of constructing these wells depends to a large extent. Select a group of power plants for which it is possible to use rock salt deposits for the preparation of regeneration brines.

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