Sorption of scandium from hydrofluoric acid solutions in the integrated processing of uranium ores by in situ leaching

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The relevance of the dissertation topic is determined by the need to enhance the comprehensive utilization of Russian uranium-bearing raw materials processed by in situ leaching (ISL). ISL solutions contain valuable associated components, including scandium, rhenium, and rare-earth elements, whose by-product recovery can increase the overall efficiency of mineral resource utilization.

The economic feasibility of recovering these components is largely due to the fact that the major share of mining and processing costs is attributed to uranium production, while the recovery of rare and high-value elements requires comparatively limited additional expenditures.

Scandium is of particular interest because of its application in aluminum–scandium master alloys used in the aerospace, automotive, and other high-technology industries. However, its by-product recovery from uranium ISL processing streams is complicated by its low concentration and the presence of impurities that adversely affect sorption, resulting in a multistage process for producing marketable scandium compounds, primarily scandium oxide and scandium fluoride.

A promising approach is sorption-based purification of scandium followed by direct precipitation of the target product from the resulting eluate. This approach can simplify the technological flowsheet, reduce the number of processing stages, and improve the efficiency of comprehensive uranium raw-material utilization.

Objective of the work – development of an efficient sorption technology for scandium recovery from hydrofluoric acid solutions generated during the integrated processing of uranium ores by in situ leaching.

Work objectives:

1. To determine the sorption characteristics of weak-base anion-exchange resins for the recovery of scandium from hydrofluoric acid solutions (hydrofluoric

acid eluates) generated during the integrated processing of uranium in-situ leaching solutions.

2. To establish the main regularities governing the sorption of scandium and impurity elements from hydrofluoric acid solutions on a weak-base anion-exchange resin containing primary amine functional groups.

3. To determine the conditions for washing the loaded anion-exchange resin to remove impurity elements, as well as the conditions for scandium desorption from the loaded weak-base anion-exchange resin containing primary amine groups.

4. To determine the conditions for scandium recovery from the product carbonate eluate obtained by desorption of the scandium-loaded weak-base anion-exchange resin.

5. Based on the established regularities, to develop a process flow diagram for the sorption recovery of scandium from hydrofluoric acid solutions with the production of scandium oxide and scandium fluoride.

6. To conduct semi-industrial tests on scandium recovery from hydrofluoric acid solutions generated during scandium extraction from uranium in-situ leaching solutions, with the production of scandium oxide and scandium fluoride meeting the required quality specifications.

Scientific novelty:

1. For the first time, the sorption–desorption characteristics of a weak-base anion-exchange resin containing primary amine functional groups were studied for scandium recovery from hydrofluoric acid solutions generated during scandium extraction from uranium in-situ leaching solutions.

2. The kinetic characteristics of scandium sorption from hydrofluoric acid solutions generated during scandium extraction from uranium in-situ leaching solutions on a weak-base anion-exchange resin containing primary amine groups were determined: the half-sorption time was 62.3 min and the rate constant was $3.4 \cdot 10^{-2}$ g·mg^{-1}·min^{-1}.

3. The dynamic characteristics of scandium sorption from hydrofluoric acid solutions generated during scandium extraction from uranium in-situ leaching

solutions on a weak-base anion-exchange resin containing primary amine groups were determined: the sorption kinetic coefficient was 0.14 h, the concentration factor was 70.3, and the total dynamic exchange capacity was 34.7 g/dm^3.

4. The optimal parameters of acid washing and carbonate desorption were determined. Acid washing was performed using a 4 N sulfuric acid solution at a volume of 3–4 bed volumes (BV) and a flow rate of 1 BV/h. For the production of ScF_3, scandium desorption was carried out using a 150 g/dm^3 ammonium carbonate solution at a solution-to-resin ratio of 3–4:1. For the production of Sc_2O_3, a 300 g/dm^3 potassium carbonate solution was used at a solution-to-resin ratio of 5–6:1. In both cases, the flow rate was 1 BV/h. The selected conditions provide efficient removal of impurity elements and enable the direct production of scandium compounds meeting the required quality specifications.

Theoretical and practical significance of the work:

1. The regularities governing the sorption of scandium and impurity elements from hydrofluoric acid solutions on a weak-base anion-exchange resin containing primary amine groups were established, and the corresponding sorption parameters were determined.

2. The regularities governing the desorption of scandium and impurity elements from the loaded weak-base anion-exchange resin containing primary amine groups were established, and the corresponding desorption parameters were determined.

3. The conditions for scandium recovery from the carbonate eluate obtained by desorption of the loaded weak-base anion-exchange resin were determined.

4. A process flow diagram for the sorption recovery of scandium from hydrofluoric acid solutions with the production of scandium oxide and scandium fluoride was developed.

5. Semi-industrial tests on scandium recovery from hydrofluoric acid solutions generated during scandium extraction from uranium in-situ leaching solutions were carried out, resulting in the production of scandium oxide and

scandium fluoride meeting the required quality specifications. The possibility of repeated recycling of the hydrofluoric acid solution without critical accumulation of impurity elements was demonstrated.

The novelty of the technical solution involving the use of a sorption material containing specific functional amine groups was confirmed by Russian Federation Patent No. 2854951 with a priority date of June 26, 2024.

Provisions submitted for defense:

1. Sorption characteristics of ion-exchange resins with respect to scandium and impurity elements during scandium recovery from hydrofluoric acid solutions generated in the integrated processing of uranium in-situ leaching solutions.

2. Results of the mathematical treatment of equilibrium, kinetic, and dynamic data on scandium sorption from hydrofluoric acid solutions generated during the integrated processing of uranium ores by in-situ leaching using a weak-base anion-exchange resin containing primary amine groups.

3. Results of semi-industrial tests and the developed process flow diagrams for scandium recovery from hydrofluoric acid solutions with the production of scandium oxide and scandium fluoride meeting the required quality specifications.