

Ion-exchange recovery and sorption behavior of molybdenum from hydrometallurgical solutions

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Abstract: This study investigates the recovery and purification of molybdenum from hydrometallurgical solutions using ion-exchange methods. The research focuses on the influence of molybdenum ionic forms, solution acidity, acid concentration, initial molybdenum concentration, contact time, and physicochemical properties of anion exchangers on the sorption process. A comparative analysis of molybdenum behavior in hydrochloric, sulfuric, nitric, phosphoric, and perchloric acid media was carried out. The results demonstrate that molybdenum sorption is strongly dependent on the acidity of the solution and its ionic state. Sorption isotherms indicate an increase in molybdenum uptake with increasing equilibrium concentration, followed by gradual saturation of the active exchange sites. Kinetic investigations show rapid molybdenum sorption during the initial stage and subsequent attainment of equilibrium. The obtained results confirm the potential of ion-exchange technology for selective molybdenum recovery and purification and provide a basis for optimizing the main technological parameters of the process.

Keywords: molybdenum, ion exchange, sorption, anion exchanger, hydrometallurgy.

INTRODUCTION

Molybdenum is an important strategic metal widely used in metallurgy, chemical engineering, energy production, electronics, and other high-technology industries. Its unique physical and chemical properties, including high melting point, thermal stability, corrosion resistance, and ability to form stable alloys, determine its significance in the production of special steels, superalloys, catalysts, lubricants, and various chemical compounds. The main mineral sources of molybdenum are molybdenite-containing ores, copper–molybdenum ores, oxidized molybdenum ores, and secondary raw materials generated during industrial processing.

Historically, the extraction and processing of molybdenum have involved pyrometallurgical and hydrometallurgical approaches. Earlier pyrometallurgical processes were mainly applied to sulfide ores and concentrates; however, their application is associated with high energy consumption, environmental emissions, and difficulties in achieving selective recovery of valuable components. The development of chemical and hydrometallurgical technologies subsequently provided new opportunities for the selective extraction, concentration, and purification of molybdenum from both primary ores and secondary resources.

In recent decades, increasing attention has been focused on the development of efficient and environmentally sustainable methods for molybdenum recovery. Leaching, solvent extraction, ion exchange, precipitation, adsorption, and sorption processes have demonstrated significant potential

for the selective separation and purification of molybdenum compounds. These technologies are particularly relevant for low-grade ores, complex mineral raw materials, industrial wastes, and secondary resources, where conventional processing methods may be economically or technologically inefficient.

The growing demand for high-purity molybdenum and its compounds necessitates the development of integrated technological approaches that combine high recovery rates, selective separation, reduced reagent consumption, and minimum environmental impact. Therefore, investigation of the physicochemical characteristics of molybdenum-bearing raw materials and optimization of the parameters of extraction and purification processes remain important scientific and technological objectives. The present study is aimed at improving the efficiency of molybdenum recovery through the development and optimization of appropriate processing conditions for molybdenum-containing raw materials.

RESEARCH METHODOLOGY

The research methodology was based on a comparative analysis of pyrometallurgical and hydrometallurgical methods for processing molybdenum-containing raw materials. Molybdenite concentrates, oxidized molybdenum ores, copper–molybdenum ores, and secondary raw materials were considered as the main objects of investigation. The evaluation focused on the chemical composition of the raw materials and the technological parameters affecting molybdenum recovery.

The main process parameters considered were temperature (T), pressure (P), reaction time (τ), reagent concentration (C), solid-to-liquid ratio (S:L), and molybdenum recovery (R_{Mo}). Particular attention was paid to oxidative roasting, autoclave leaching, alkaline decomposition, nitric-acid leaching, ion exchange, and precipitation. The transition of molybdenum from sulfide minerals into soluble molybdate compounds was considered as the principal technological stage.

The efficiency of molybdenum extraction was calculated using:

$$R_{Mo} = \frac{m_{Mo}^p}{m_{Mo}^0} \cdot 100\%$$

where R_{Mo} is molybdenum recovery (%), m_{Mo}^p is the amount of molybdenum in the obtained product, and m_{Mo}^0 is its initial amount in the raw material.

Table 1. Main parameters used for evaluating molybdenum-processing technologies

Processing method	Main parameters	Target process	Evaluation indicator
Roasting	T, τ , O ₂	Oxidation of MoS ₂	R _{Mo} , sulfur removal
Autoclave leaching	T, P, τ , O ₂	Oxidative dissolution	R _{Mo} , Mo dissolution
Alkaline decomposition	T, C, S:L, τ	Formation of molybdate	R _{Mo} , selectivity

Nitric-acid leaching	C(HNO ₃), T, τ	MoS ₂ oxidation and dissolution	RMo, impurity removal
Ion exchange	pH, C, τ	Mo separation and purification	Mo concentration, purity
Precipitation	pH, T, reagent C	Recovery of Mo compound	Product yield and purity

**Note: T – temperature; P – pressure; τ – reaction time; C – reagent concentration; S:L – solid-to-liquid ratio; RMo – molybdenum recovery.*

The comparative analysis was used to determine the relationship between technological parameters and molybdenum recovery. The obtained results were evaluated in terms of recovery, selectivity, reagent consumption, product purity, and process efficiency, providing a basis for selecting suitable conditions for the processing of molybdenum-containing raw materials.

RESULTS

The obtained results demonstrate that the efficiency of molybdenum recovery by ion-exchange methods is strongly influenced by the ionic state of molybdenum, acidity of the solution, and physicochemical properties of the anion exchangers. The investigated technological scheme includes beneficiation of molybdenum-containing ores, oxidative and hydrometallurgical treatment, leaching, ion exchange, and subsequent production of purified molybdenum compounds.

The distribution of molybdenum species in aqueous solutions depends strongly on the acidity of the medium. Changes in pH lead to the formation of different molybdate and polymolybdate species, which directly affects their interaction with anion-exchange resins. Under suitable acidic conditions, molybdenum is predominantly present in anionic forms that can be selectively sorbed by strongly and weakly basic anion exchangers.

The effect of mineral acid concentration on molybdenum sorption is particularly important for the selection of optimum ion-exchange conditions. The investigated results show that the distribution coefficient of molybdenum changes with increasing acid concentration and differs depending on the type of mineral acid. This behavior is associated with changes in the ionic state of molybdenum and competition between molybdenum-containing species and other ions in solution.

The results indicate that the sorption behavior of molybdenum is not identical in hydrochloric, sulfuric, nitric, and phosphoric acid media. The decrease in the distribution coefficient at higher acid concentrations indicates that the formation and stability of sorbable molybdenum anions are strongly dependent on the acidity of the solution. Therefore, acid concentration represents an important parameter for controlling the selectivity of molybdenum sorption.

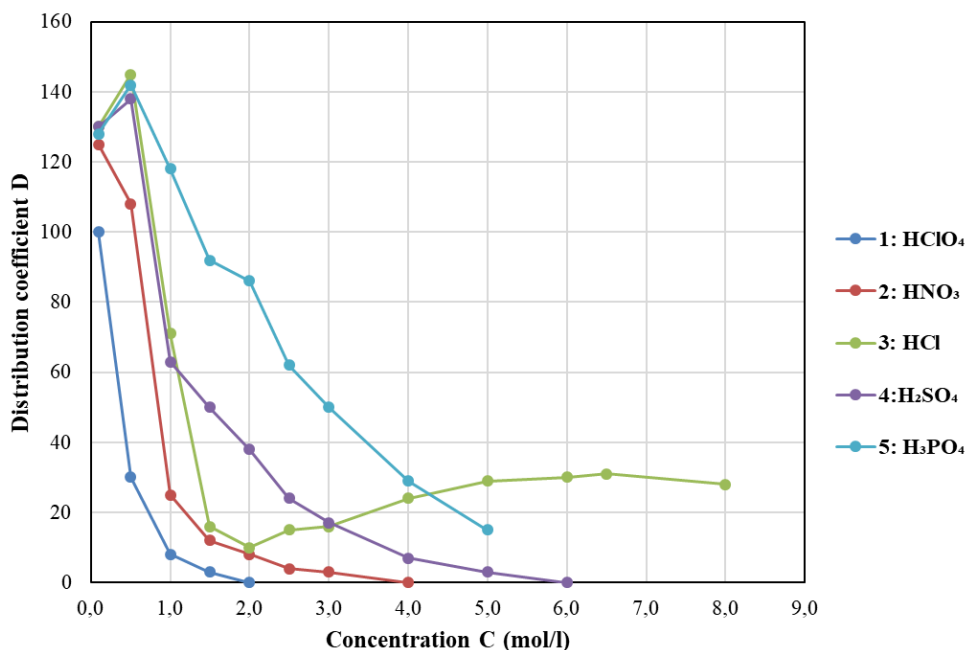


Figure 1. Effect of mineral acid concentration on the distribution coefficient of molybdenum on anion exchanger AN-85P.

The sorption capacity of anion exchangers also depends on the equilibrium concentration of molybdenum in solution. As the molybdenum concentration increases, the amount of sorbed molybdenum increases rapidly at the initial stage and subsequently approaches a nearly constant value. This behavior indicates gradual occupation of the available active exchange sites and the approach of the resin to saturation.

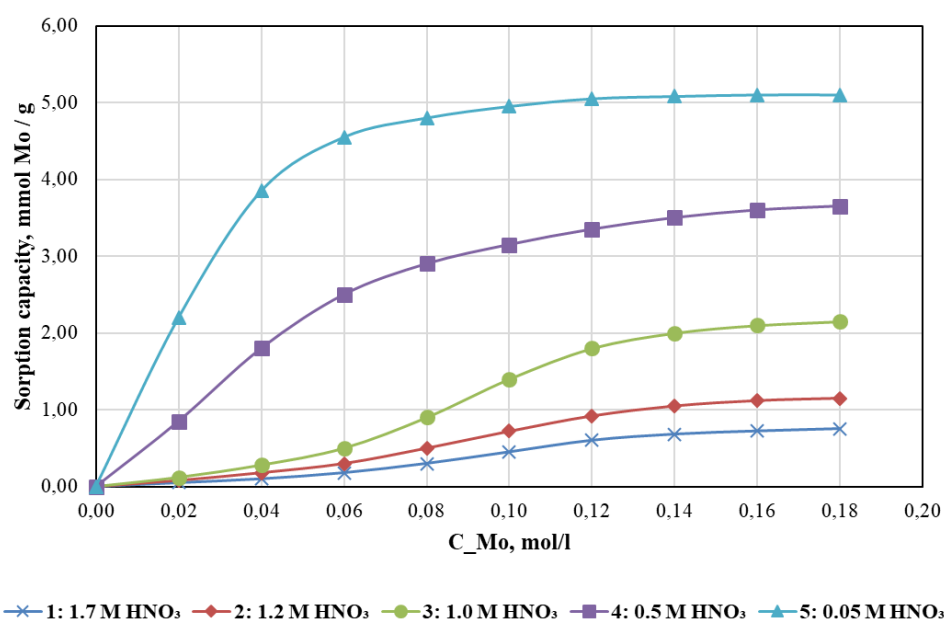


Figure 3. Isotherms of molybdenum sorption on anion exchanger AN-85-10P at different nitric acid concentrations.

The isotherms demonstrate that the concentration of nitric acid considerably affects the sorption capacity of the anion exchanger. Higher molybdenum concentrations result in greater resin loading until the available exchange sites become progressively occupied. These results confirm that both the initial molybdenum concentration and the acidity of the solution should be considered when designing an ion-exchange process.

The kinetic behavior of molybdenum sorption was also evaluated. The experimental curves show a relatively rapid sorption during the initial contact period, followed by a gradual approach to equilibrium. The initial high sorption rate can be associated with the availability of free active exchange sites and a high concentration gradient between the solution and the resin. With increasing contact time, the number of available sites decreases and the sorption rate becomes lower.

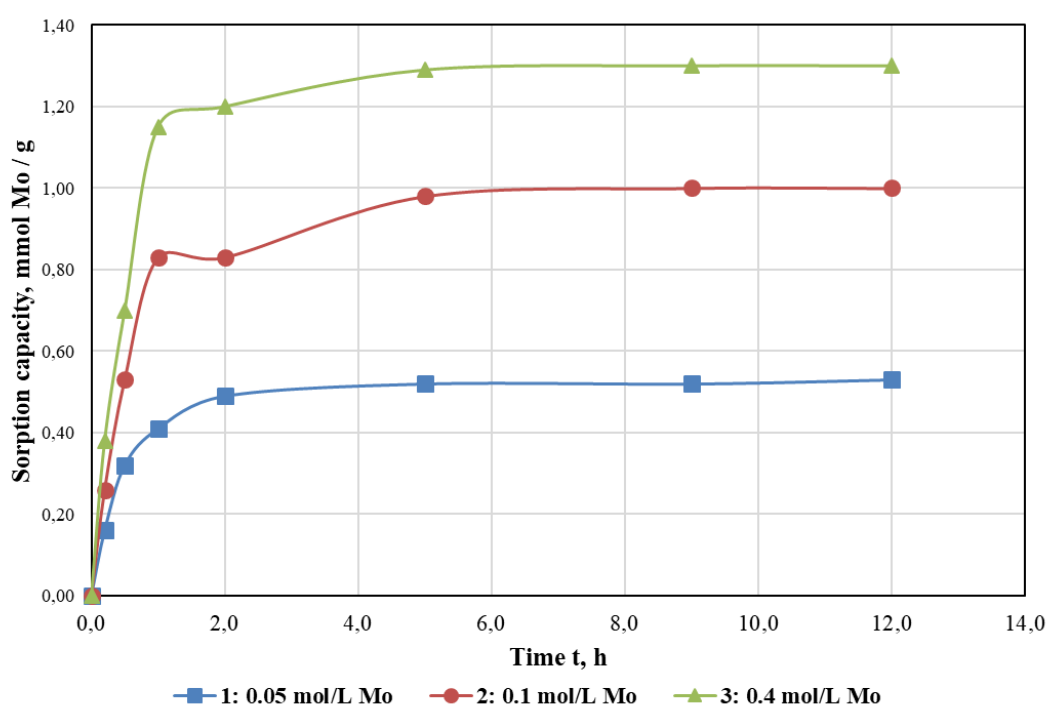


Figure 4. Kinetic curves of molybdenum sorption on anion exchanger AN-85-10P from nitric acid solutions at different initial molybdenum concentrations.

The kinetic results demonstrate that increasing the initial molybdenum concentration leads to a higher equilibrium sorption capacity of the anion exchanger. At prolonged contact times, the sorption curves approach a plateau, indicating that equilibrium between the solution and ion exchanger has been reached. Thus, contact time and initial molybdenum concentration are important parameters for controlling the productivity of the ion-exchange stage.

The IR-spectroscopic data further confirm changes in the chemical state of the ion exchanger after interaction with molybdenum-containing solutions. Differences between the initial resin

spectrum and the spectra obtained after molybdenum sorption at different pH values indicate changes in the functional groups involved in the ion-exchange process.

CONCLUSION

The results demonstrate that ion-exchange methods provide an effective approach for the recovery and purification of molybdenum from hydrometallurgical solutions. The efficiency of the process is mainly controlled by the ionic state of molybdenum, solution pH, mineral acid concentration, initial molybdenum concentration, contact time, and the physicochemical characteristics of the anion exchanger. The analysis of sorption isotherms and distribution coefficients confirms that changes in the acidity of the medium significantly affect molybdenum sorption, while the investigated anion exchangers show different capacities depending on their polymer structure and functional groups.

The kinetic results indicate rapid molybdenum uptake during the initial stage of sorption, followed by gradual attainment of equilibrium. Increasing the initial molybdenum concentration increases the amount of molybdenum retained by the ion exchanger, while prolonged contact leads to saturation of active exchange sites. Overall, the obtained results provide a methodological basis for selecting suitable ion exchangers and optimizing acid concentration, pH, contact time, and molybdenum concentration for the selective recovery and purification of molybdenum from technological solutions.

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