

Optimization of tungsten recovery from tungsten-bearing raw materials by roasting and alkaline leaching

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Abstract: This study investigates an integrated technological approach for the extraction and recovery of tungsten from tungsten-bearing raw materials, with particular emphasis on roasting, alkaline leaching, purification, and crystallization processes. Scheelite and wolframite are considered as the principal mineral sources of tungsten. The proposed methodology involves the conversion of tungsten-bearing phases into soluble sodium tungstate, followed by leaching and purification to remove major impurities. Sodium nitrate (NaNO_3) was considered as an oxidizing agent, while sodium hydroxide (NaOH) served as an alkaline reagent. The experimental results obtained from eight batches demonstrated consistently high tungsten recovery, ranging from 98.1% to 98.9%, with an average recovery of approximately 98.5%. The variation in reagent consumption showed that high tungsten recovery could be maintained under different NaNO_3 and NaOH ratios. The obtained results indicate that the proposed technological scheme provides stable and efficient tungsten recovery and can be considered a suitable basis for processing primary and secondary tungsten-bearing resources. Further optimization of reagent consumption and operating parameters may improve process efficiency and reduce processing costs.

Keywords: Tungsten, scheelite, wolframite, roasting, alkaline leaching, sodium tungstate, tungsten recovery.

INTRODUCTION

Tungsten is one of the strategically important metals for modern industry due to its exceptional physical and mechanical properties, particularly its ability to retain structural stability under high-temperature conditions. As a refractory metal, tungsten is characterized by an extremely high melting point of approximately 3410 °C, high strength, low vapor pressure, and excellent thermal stability. These properties have resulted in its extensive application in electrical engineering, electronics, mechanical engineering, and other high-technology industries [8]. Tungsten is widely used in the manufacture of incandescent lamp filaments, electrodes for electronic devices, components of X-ray equipment, heating elements, and structural materials designed for operation under elevated temperatures [11].

The technological significance of tungsten is further enhanced by its ability to form alloys with various metallic elements. Alloying with nickel, tantalum, molybdenum, and rhenium can improve the mechanical strength, thermal stability, wear resistance, and service performance of tungsten-based materials. Consequently, tungsten-containing alloys and cemented carbides are extensively utilized in cutting and drilling tools, mining equipment, wear-resistant components, and other applications where high mechanical strength and resistance to elevated temperatures are required [2].

The primary objective of tungsten ore beneficiation is to separate valuable tungsten-bearing minerals from gangue materials and produce a concentrate suitable for subsequent metallurgical

treatment. Depending on the characteristics of the ore, gravity separation, flotation, and other physical and physicochemical beneficiation methods can be applied [5]. The selection and optimization of a particular processing route depend on the initial tungsten content, mineralogical composition, particle-size distribution, liberation characteristics, and presence of associated valuable or undesirable components.

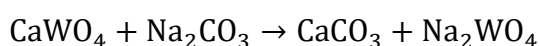
Although tungsten deposits are distributed across different regions of the world, economically significant resources are concentrated in a relatively limited number of countries. This circumstance increases the importance of efficient utilization of existing tungsten resources, comprehensive processing of ores, and maximization of valuable component recovery. In particular, the development of effective technologies for recovering tungsten from low-grade ores, secondary raw materials, and technogenic waste represents an important scientific and practical challenge [1]. Such approaches can contribute to improving resource efficiency, reducing material losses, and decreasing the environmental impact associated with conventional mining and processing operations.

Therefore, the development and optimization of technological approaches for the comprehensive processing of tungsten-bearing raw materials, taking into account their mineralogical and chemical characteristics, is of considerable scientific and practical importance. Particular attention should be given to improving beneficiation efficiency and establishing optimal technological conditions that ensure a high degree of tungsten recovery from primary and secondary raw materials [12].

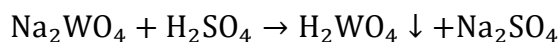
RESEARCH METHODOLOGY

The research methodology was based on the hydrometallurgical and pyrometallurgical processing of tungsten-bearing ores, primarily scheelite (CaWO_4) and wolframite ($(\text{Fe,Mn})\text{WO}_4$). The proposed approach includes ore preparation, alkaline decomposition or roasting, leaching, purification of the tungsten-bearing solution, crystallization of ammonium paratungstate, and subsequent production of tungsten oxide and metallic tungsten [10].

Scheelite and wolframite concentrates were considered as the main raw materials. Depending on their mineralogical composition, sodium carbonate Na_2CO_3 , sodium hydroxide NaOH , and hydrochloric or sulfuric acid were used for decomposition and leaching. The main transformation of scheelite during alkaline treatment can be expressed as:



The obtained sodium tungstate solution was purified from impurities such as iron, manganese, silicon, phosphorus, arsenic, and molybdenum. After purification, acidification was applied to obtain tungstic acid:



The purified tungsten compound was subsequently converted into ammonium paratungstate, followed by thermal decomposition to tungsten oxide and hydrogen reduction to metallic tungsten.

Table 1. Main stages of tungsten processing

Stage	Main process	Main product
1	Ore preparation and grinding	Prepared concentrate
2	Alkaline decomposition/roasting	Sodium tungstate
3	Leaching and purification	Purified tungsten solution
4	Acidification	Tungstic acid
5	Ammonium treatment and crystallization	Ammonium paratungstate (APT)
6	Thermal decomposition and reduction	Metallic tungsten

Table 2. Main raw materials and reagents

Material-Reagent	Purpose
CaWO_4	Tungsten-bearing raw material
$(\text{Fe}, \text{Mn})\text{WO}_4$	Tungsten-bearing raw material
Na_2CO_3	Alkaline decomposition
NaOH	Caustic leaching
$\text{HCl} - \text{H}_2\text{SO}_4$	Acid decomposition and acidification
NH_4OH	Formation of ammonium tungstate
H_2	Reduction of tungsten oxide

The overall processing route can therefore be represented as:

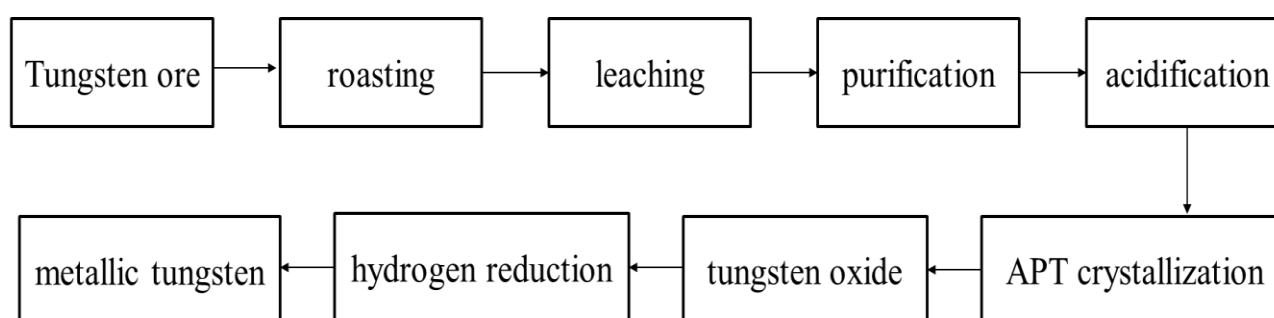


Figure 1. General technological flow diagram for tungsten extraction and recovery

RESULTS AND DISCUSSION

The results demonstrate that tungsten can be efficiently recovered from tungsten-bearing materials through a combined thermal, leaching, purification, and crystallization route. The investigated process converts tungsten-containing phases into soluble sodium tungstate, followed by purification and further conversion into valuable tungsten products. The experimental data reported

for the trial batches show consistently high tungsten recovery, indicating that the selected processing scheme provides stable extraction performance [9].

As presented in Table 1, the tungsten yield varied from 98.1 to 98.9% across the eight trial batches, with an average value of 98.50%. The relatively narrow range of recovery indicates good reproducibility of the process. The highest yield was obtained in Batch 1, while the lowest value was observed in Batch 4. The differences between the batches are comparatively small, suggesting that changes in the proportions of oxidant and alkaline moderator affected the process but did not cause a substantial loss of tungsten.

The main technological stages responsible for the observed recovery are roasting or alkaline decomposition, leaching, purification, and crystallization. During alkaline treatment, tungsten is transferred into sodium tungstate, while a significant part of the accompanying matrix remains in the solid phase. Subsequent leaching increases tungsten transfer into the liquid phase, whereas purification reduces the concentration of impurities before the formation of ammonium paratungstate. This sequence is consistent with the general hydrometallurgical route for tungsten recovery [14].

The comparison of reagent quantities in the trial batches indicates that the oxidant and alkaline moderator were varied over a relatively broad range. Nevertheless, tungsten recovery remained above 98% in all reported experiments [7]. This result suggests that the process has a relatively wide operational range, although the exact optimum should be established experimentally for a particular feed composition, particle size, and impurity content.

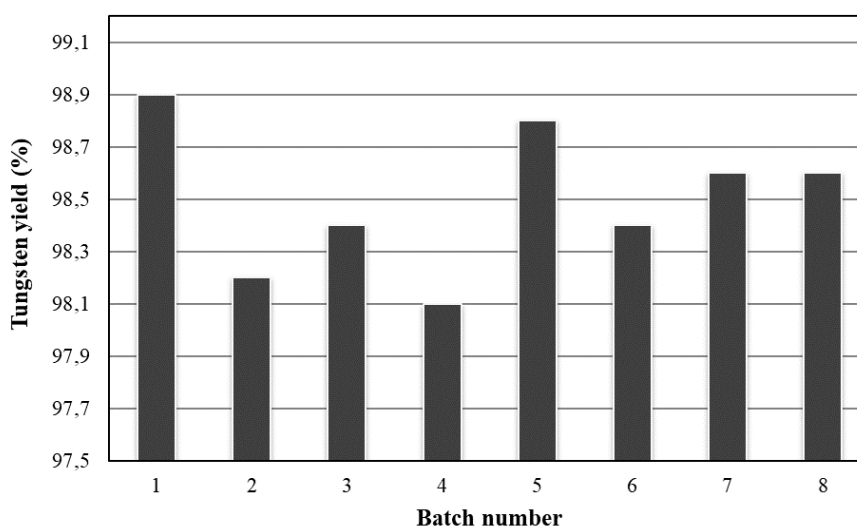
From a technological perspective, the process can be implemented as a continuous equipment chain consisting of feed preparation, grinding, thermal or alkaline treatment, quenching and leaching, solid–liquid separation, purification, acidification or APT crystallization, and final product recovery. The proposed equipment sequence is shown in Figure 1. Such a configuration allows the main unit operations to be integrated into a single processing scheme and provides opportunities for controlling reagent consumption, temperature, residence time, and tungsten recovery.

Table 3. Results of trial batches for tungsten recovery

Batch	Scrap carbide (kg)	NaNO ₃ , kg	NaOH, kg	WO ₃ , g/L	Na ₂ CO ₃ , g/L	NaOH, g/L	NaNO g/L	W-yield (%)
1	55	75	25	268	58	4	30	98.9
2	50	75	25	219	39	4	33	98.2
3	37	50	20	231	39	3	37	98.4
4	37	50	20	234	46	2	27	98.1
5	37	42	20	258	56	20	25	98.8
6	37	33	33	232	62	44	9	98.4
7	37	33	33	243	57	43	8	98.6
8	37	33	33	240	65	45	3	98.6

Table 4. Interpretation of the principal processing stages

Stage	Main function	Principal product
Roasting	Conversion of tungsten-bearing phases	Sodium tungstate-bearing material
Leaching	Transfer of soluble tungsten to liquid phase	Tungstate solution
Purification	Removal of Fe, Mn, Si, P, As, Mo and other impurities	Purified tungsten solution
Acidification	Conversion of tungstate to tungstic acid or related intermediate	Purified tungsten compound
APT crystallization	Controlled precipitation	Ammonium paratungstate (APT)
Thermal decomposition	Conversion to oxide and metallic tungsten	Tungsten oxide - metallic W

**Figure 2. Oxidant and moderator quantities in trial batches.**

The results presented in Figure 2 show the tungsten recovery yield obtained for the eight experimental batches. The tungsten recovery remained consistently high, ranging from 98.1% to 98.9%. The highest recovery of 98.9% was achieved in Batch 1, whereas the lowest value of 98.1% was observed in Batch 4. Batches 5–8 demonstrated relatively stable recovery values between 98.4% and 98.8%.

The relatively small variation in the results indicates that the investigated processing conditions provided stable tungsten recovery. The average recovery was approximately 98.5%, confirming the high efficiency of the applied roasting, leaching, and purification processes. These results suggest that variations in reagent ratios and operating conditions within the investigated range had a limited effect on the overall tungsten recovery.

The influence of reagent consumption on the tungsten recovery process was also evaluated by comparing the amounts of sodium nitrate NaNO_3 and sodium hydroxide NaOH used in the experimental batches. These reagents play important roles in the oxidative and alkaline stages of tungsten recovery. The quantities of the two reagents used in each batch are presented in Figure 3.

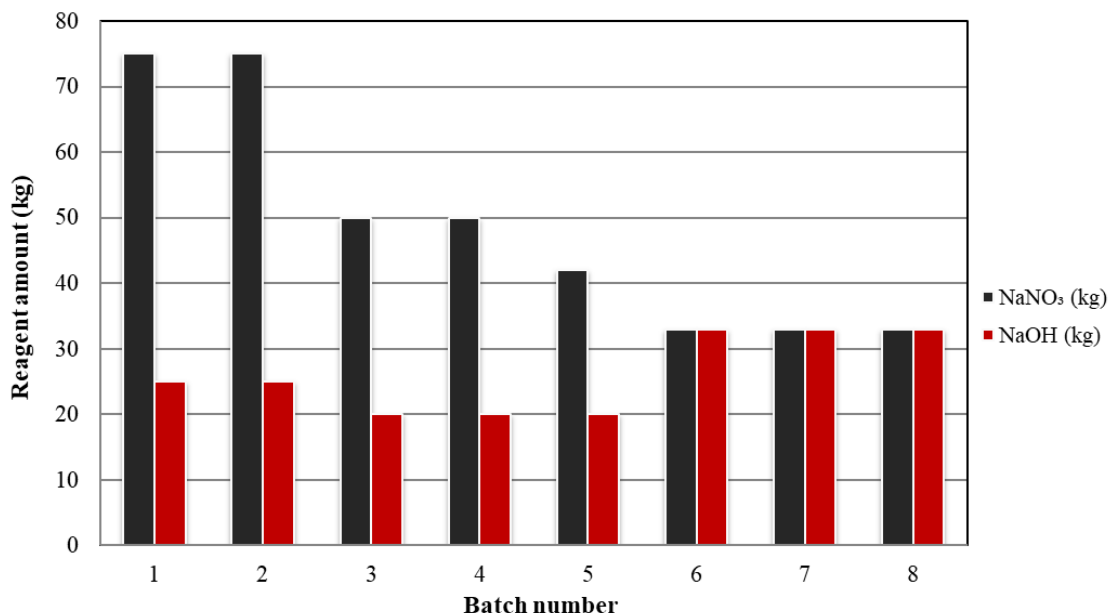


Figure 3. Variation in NaNO_3 and NaOH consumption during the experimental batches.

Overall, the obtained results indicate that the investigated technological route provides a high and relatively stable tungsten recovery. The combination of thermal/alkaline treatment, leaching, purification, and APT crystallization is therefore suitable as a general process scheme for tungsten-bearing raw materials. Further optimization should focus on reagent ratios, temperature, residence time, particle size, and impurity control in order to reduce reagent consumption while maintaining high tungsten recovery.

CONCLUSION

The results demonstrate that the investigated technological approach provides effective recovery of tungsten from tungsten-bearing raw materials through a combination of roasting, alkaline leaching, purification, and subsequent conversion of tungsten compounds. The experimental results obtained from eight batches showed a consistently high tungsten recovery of 98.1–98.9%, with an average value of approximately 98.5%. The relatively small variation in recovery confirms the stability of the proposed processing route under the investigated conditions. The use of NaNO_3 as an oxidizing agent and NaOH as an alkaline reagent enabled efficient conversion of tungsten into a soluble tungstate form.

The obtained results also indicate that optimization of reagent consumption can be carried out without significant deterioration in tungsten recovery. In particular, the reduction of NaNO_3 consumption accompanied by an increase in NaOH content maintained tungsten recovery above 98%. Therefore, the proposed process can be considered a suitable technological basis for the efficient recovery of tungsten, while further optimization of reagent ratios, temperature, leaching time, and solid–liquid ratio may contribute to reducing operating costs and improving the overall efficiency of the process.

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