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TECHNOLOGICAL ASSESSMENT OF TUNGSTEN TAILINGS REPROCESSING FOR FINE AND ULTRAFINE MINERAL RECOVERY

Boymurodov Najmiddin Abduqodirovich
Karshi State Technical University, PhD, Karshi, Uzbekistan
E-mail: najmiddinboy-94@mail.ru
Bo‘riyev Sardor Sayfullayevich
Karshi State Technical University, Assistant, Karshi, Uzbekistan
Mamadaliyeva Intizor Muxamedovna
University of Information Technologies and Management, Karshi, Uzbekistan

Abstract

Tungsten is a critical strategic metal widely used in high-technology and industrial applications due to its exceptional hardness, density, and thermal stability. The present study evaluates the technological potential of tungsten tailings as a secondary resource and analyzes advanced reprocessing methods for fine and ultrafine tungsten recovery. Comparative assessment of gravity separation, wet high-intensity magnetic separation, flotation, chemical leaching, and bioleaching was conducted. The results indicate that integrated processing schemes combining enhanced physical and physicochemical methods provide the highest recovery efficiency. The study highlights the importance of technological optimization for sustainable resource utilization and environmentally responsible mine waste management.

Keywords

tungsten tailings, reprocessing technology, fine particle recovery, magnetic separation, flotation, sustainable mining

Introduction

Tungsten remains a strategic and critical metal in 2025 due to its exceptional physical and chemical properties, including high hardness, elevated density, excellent wear resistance, and stability at high temperatures. These characteristics make tungsten indispensable across a wide range of industrial sectors such as mining, machining, aerospace, electronics, and defense. Tungsten carbide continues to dominate as the primary industrial product, used widely in cutting tools, drilling apparatus, wear-resistant parts, and high-temperature applications. Additionally, recent advancements have highlighted the potential of tungsten and its alloys in advanced energy technologies, including plasma-facing components for future nuclear fusion systems.

Despite its industrial importance, the global supply of tungsten remains geographically concentrated and subject to market instability. In 2025, primary tungsten production and reserves continue to be dominated by a few countries, and global market dynamics reflect ongoing challenges in supply security and pricing. As global demand has steadily increased, especially in high-technology and defense applications, the industry’s focus has shifted toward optimizing both primary and secondary sources of tungsten.

Secondary resources, particularly industrial scrap, currently constitute the principal source of recycled tungsten. However, mine tailings generated in the beneficiation of tungsten ores represent a large and underexploited secondary reserve. Due to the typically low grades of many tungsten deposits, beneficiation processes produce significant volumes of tailings relative to the amount of tungsten recovered. On a global scale, tungsten tailings are estimated to exceed 100 million tonnes, containing approximately 96 thousand tonnes of WO_3; however, the residual tungsten in these tailings is predominantly present in fine and ultrafine particles that are not efficiently recoverable using conventional gravity and magnetic separation techniques.

Although tungsten itself is generally regarded as having low environmental toxicity under typical exposure conditions, tungsten-bearing tailings often contain associated heavy metals and sulfide minerals, which pose environmental risks if not properly managed. Therefore, the

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reprocessing of tungsten tailings is of growing economic and environmental importance, offering the potential to improve resource efficiency while reducing the environmental footprint of mining operations.

In this context, the present study examines tungsten resources as of 2025, including primary and secondary sources, the characteristics of tungsten tailings, and current and emerging technological approaches for their reprocessing, with emphasis on both economic feasibility and environmental sustainability.

Methodology

The methodological framework of this study is primarily focused on the technological aspects of tungsten tailings reprocessing. The research design integrates systematic literature analysis, comparative technological evaluation, and process efficiency assessment in order to determine the most effective approaches for recovering tungsten from fine and ultrafine fractions.

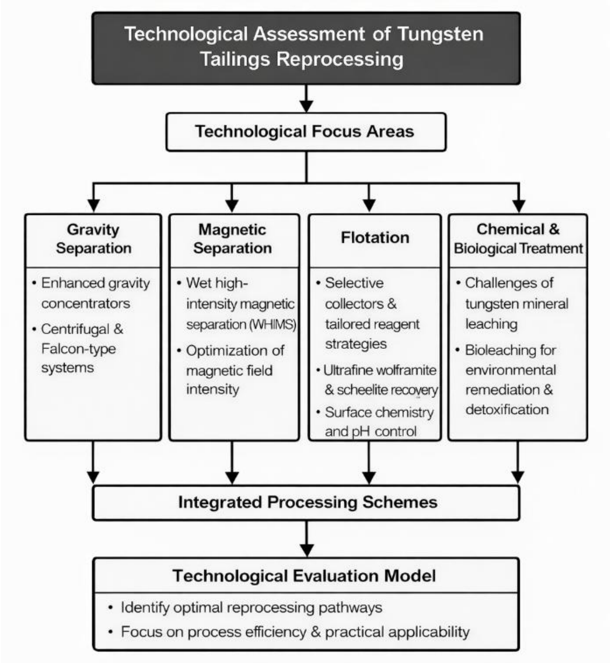

Figure 1. Block diagram of technological approaches for tungsten tailings reprocessing

First, a structured review of scientific publications, technical reports, and industrial case studies was conducted with emphasis on mineral processing technologies applied to tungsten ores and tailings. The selection criteria included relevance to tungsten beneficiation, recovery of fine particles, process innovation, and demonstrated industrial applicability. Particular attention was given to gravity separation, high-intensity magnetic separation, flotation, chemical treatment, and bioleaching technologies.

Second, the technological characteristics of tungsten tailings were analyzed. This included evaluation of particle size distribution, mineralogical composition, and liberation characteristics of wolframite and scheelite. Since residual tungsten in tailings is predominantly present in fine and ultrafine particles, the study focused on technologies capable of effectively treating particle sizes below conventional gravity and magnetic separation limits.

✓ Third, a comparative technological assessment was carried out. Each reprocessing method was evaluated according to the following criteria:

- ✓ recovery efficiency for fine and ultrafine tungsten minerals;
- ✓ adaptability to different mineralogical compositions;
- ✓ energy and reagent consumption;
- ✓ operational complexity;
- ✓ scalability for industrial application.

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Gravity separation technologies were assessed with emphasis on enhanced gravity concentrators such as Falcon and centrifugal systems. Magnetic separation analysis focused on wet high-intensity magnetic separation and its performance under varying magnetic field intensities. Flotation technologies were evaluated based on collector selectivity, surface chemistry control, and the effectiveness of reagents for ultrafine wolframite and scheelite recovery. Chemical leaching methods were examined in terms of thermodynamic feasibility and reaction conditions required for tungsten mineral decomposition. Bioleaching approaches were analyzed as emerging technologies, particularly for combined metal recovery and tailings detoxification.

Fourth, process integration strategies were examined. The potential combination of physical separation methods with flotation or biological treatment was analyzed to determine whether hybrid processing routes could enhance overall recovery while maintaining economic feasibility.

Finally, a technological evaluation model was developed to identify optimal reprocessing pathways depending on tailings characteristics. The methodology emphasizes process efficiency, technological innovation, and practical applicability, providing a structured basis for selecting advanced tungsten tailings reprocessing technologies.

Results

The technological assessment demonstrated that conventional gravity and magnetic separation methods show limited efficiency in the recovery of tungsten from tailings, particularly when tungsten minerals are present in fine and ultrafine fractions. Traditional gravity concentration methods exhibit reduced performance when particle sizes fall below 20–25 µm, resulting in significant tungsten losses to tailings. However, enhanced gravity concentrators such as centrifugal and Falcon-type systems significantly improve recovery for fine particles in the range of 10–75 µm. Experimental data from previous studies indicate that recovery rates exceeding 75–80% can be achieved for fine fractions under optimized operational parameters.

Table 1. Comparative technological performance of tungsten tailings reprocessing methods

Technology Method	**Particle Size Range (µm)**	**Concentrate Grade WO_3, %**	**Recovery Rate (%)**	**Main Limitation**
Conventional Gravity Separation	>25	45–55	40–60	Low efficiency for fine particles
Enhanced Gravity (Falcon/Centrifugal)	10–75	50–60	75–83	Reduced recovery below 10 µm
Conventional Magnetic Separation	>20	50–65	60–85	Strongly size-dependent
WHIMS	10–50	55–65	80–90 (>10 µm)	Limited efficiency for <10 µm particles
Flotation (Hydroxamate collectors)	<20	35–55	60–80	Reagent consumption and selectivity issues
Integrated Scheme (Enhanced	0–75	55–65	85–92 (overall)	Higher operational

Gravity + WHIMS + Flotation)				complexity
Chemical Leaching	Fine fraction	-	<40 (direct W recovery)	High temperature/pressure required
Bioleaching	Fine fraction	-	<30 (W recovery)	More suitable for contaminant removal

Magnetic separation analysis revealed that recovery efficiency strongly depends on particle size and magnetic field intensity. Wet high-intensity magnetic separation (WHIMS) demonstrates improved performance compared to conventional magnetic systems. For particles larger than 10 μm, recovery rates can approach 85–90% under high magnetic field intensity conditions. However, recovery decreases substantially for ultrafine particles (<10 μm), indicating that magnetic separation alone is insufficient for complete tungsten recovery from slimes.

Flotation results show higher technological potential for ultrafine tungsten recovery compared to purely physical separation methods. The application of selective collectors and surface chemistry control significantly enhances wolframite and scheelite floatability. Studies demonstrate that flotation can produce concentrates with WO_3 grades above 35–50% from low-grade slimes, with recovery rates ranging from 60% to 80%, depending on reagent schemes and mineralogical characteristics. The use of hydroxamate-based collectors and optimized pH conditions improves selectivity and recovery, particularly for fine wolframite.

Chemical leaching was found to be technologically constrained due to the stability of tungsten minerals under ambient conditions. Effective decomposition of scheelite and wolframite requires elevated temperature and pressure, which limits the feasibility of heap leaching for tailings reprocessing. As a result, hydrometallurgical approaches are more suitable as complementary treatment methods rather than primary recovery technologies.

Bioleaching results indicate promising potential for selective removal of associated contaminants such as arsenic and manganese from tungsten tailings. While direct tungsten extraction via bioleaching remains limited in efficiency, microbial treatment significantly enhances environmental stabilization and may serve as a supportive process in integrated tailings management systems.

The comparative technological analysis demonstrates that integrated processing schemes provide the highest recovery potential. A combined approach involving enhanced gravity separation, high-intensity magnetic separation, and flotation yields substantially higher overall recovery compared to single-stage processing. Hybrid technological routes allow more effective treatment of different particle size fractions and mineralogical associations.

Conclusion

The conducted technological analysis confirms that tungsten tailings represent a promising secondary resource, particularly when advanced fine-particle processing methods are applied. Conventional gravity and magnetic separation alone are insufficient for efficient recovery of ultrafine tungsten minerals; however, enhanced gravity concentrators, wet high-intensity magnetic separation, and selective flotation significantly improve recovery performance. Chemical leaching is limited by thermodynamic constraints, while bioleaching demonstrates greater potential for environmental stabilization than direct tungsten extraction. The highest recovery efficiency is achieved through integrated processing schemes that combine physical and physicochemical methods. Therefore, the technological optimization of hybrid reprocessing

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routes provides a practical pathway for improving resource efficiency, reducing tungsten losses, and supporting sustainable mine waste management.

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