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**Research Article**

# SCANDIUM EXTRACTION TECHNOLOGY AND ENVIRONMENTAL IMPACT ANALYSIS OF TAILINGS FROM BAYAN OBO MINE IN CHINA

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**A R T I C L E I N F O**

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**A B S T R A C T**

Bayan Obo mine is a world-famous polymetallic deposit characterized by rare-earth resources, with extremely comprehensive utilization value. After exploitation over a half century, it produces many industrial solid wastes such as tailings. The so called "waste" is also secondary resource, still contains multiple valuable elements, especially scandium. Extracting scandium from tailings in Bayan Obo not only can reduce many social problems which brought by tailings storage, but also can create extremely high economic value. This study mainly explores some methods that extracting and recycling scandium from Bayan Obo tailings, analyzes its advantages and disadvantages, and gives a direction of technology improvement, which provides a basis for the green, comprehensive and high-value utilization of the Bayan Obo mine.



## INTRODUCTION

In a broad sense, scandium is a rare earth element and extremely dispersed in nature, but it isn't rare. It can be found in many deposits（Wang *et al*., 2014; Li *et al*., 2013a; Li *et al*., 2013b; Mao *et al*., 2013; Shen *et al*., 2012). Scandium is associated with many minerals, but independent minerals are few (Hou *et al*., 2018; Zhang *et al*., 2016; Kong *et al*., 2015; Qiu *et al*., 2015; Wang *et al*., 2015). The known minerals which contain scandium have complicated component with low content of scandium. Its enrichment, separation, and extraction processes are pretty complicated (Qiu *et al*., 2019). Nevertheless, scandium and its compound have been widely applied to many important fields due to their multiple good qualities (Pyrzynska *et al*., 2019). Scandium reserves around the world are around 2 million tons, among which, China has about 0.6 million tons, ranking the first place (Luan, 2015).

Bayan Obo mine, the largest rare earth deposit in the world, is located 149 km north of Baotou city, Inner Mongolia Autonomous region, China (Wang *et al*., 2018) (Figure 1). The average content of scandium oxide in raw ore is about $50\times10^{-6}$ ppm, while the scandium grade in tailings is as high as about $300\times10^{-6}$ to $500\times10^{-6}$ ppm. The total reserves are 140,000 tons (Li and Li, 2014).

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This study based on comprehensive utilization technology of Bayan Obo tailings designed by Baotou Iron and Steel Group Mining Research Institute, provides a basis for the green, comprehensive and high-value utilization of the Bayan Obo mine.

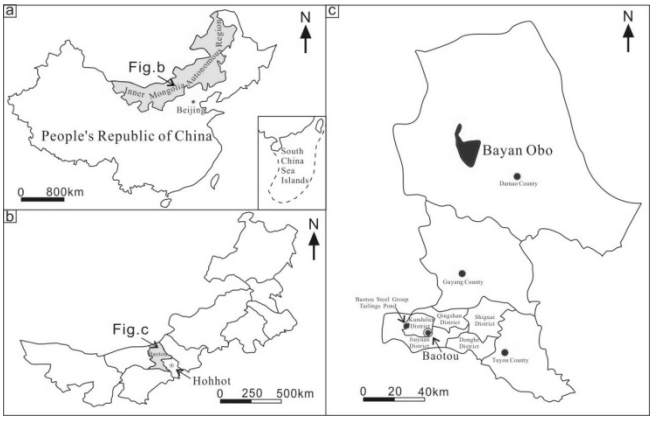


**Figure 1** Location of Bayan Obo mine (Modified from Wang *et al*., 2019)
a. Inner Mongolia Autonomous Region; b. Baotou city; c. Bayan Obo mine

### *Recovery and Extraction technology of Scandium*

Bayan Obo tailings include many valuable elements such as iron, niobium, scandium, fluorite, sulphur and potassium, etc. In order to realize the maximum comprehensive utilization of tailings, improve the comprehensive utilization rate of the mine, reduce tailings emissions, and achieve higher economic

and social benefits, the comprehensive utilization process designs for extracting valuable elements in tailings successively, and finally extracts scandium from the remaining tailings.First, using flotation selection to recycle rare earth for tailings completely due to good flotability; second, applying mixed flotation selection technology to divide rare earth tailings into two parts: mixed foam and mixed grit, achieving grouping and sorting of easy flotation mineral and Iron - niobium- silicon mineral, mixed foam mainly contains fluorites; Mixed grit mainly contains Iron oxide and niobium oxide, etc. For these raw materials, first, recycling sulfur by flotation selection, second, recycling iron, and then re-using gravity selection for discarding tailings to improve scandium grade in raw materials. Later, recycling sulfur and iron of flotation selection for gravity selection concentrate mine, recycling scandium by flotation selection finally; Therefore, adopting strong magnetic technology to recycle Silicate mineral such as pyroxene and amphibole, etc in order to acquire scandium concentrate mine because of scandium exited in Silicate mineral (Figure 2).

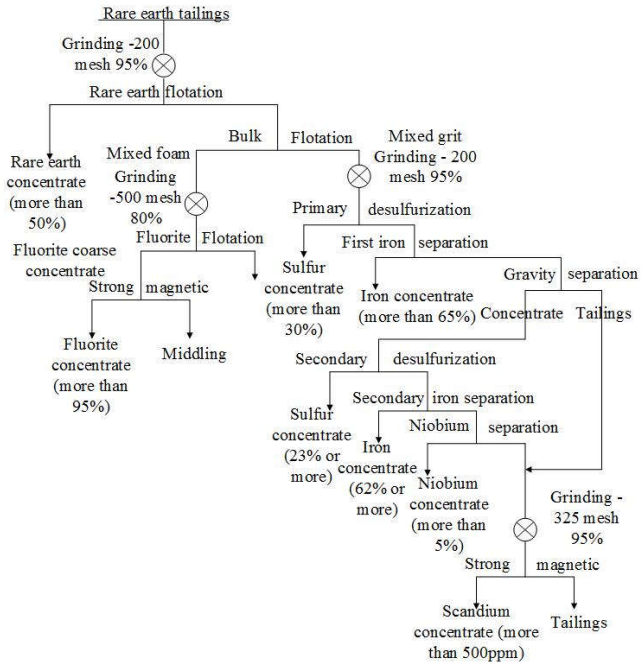


**Figure 2** Comprehensive utilization technology of Bayan Obo tailings (Baotou Iron and Steel Group Mining Research Institute, 2014; 2015)

Scandium extraction technology for this study is mainly scandium concentrate mine as raw material from Bayan Obo tailings after mine selection to extract high-pure scandium oxide. High pure oxide scandium extracted from scandium concentrate mine is mainly composed by acid leaching process and leaching liquid treatment process. Acid leaching process uses two-step acid leaching process. First, size mixing acid leaching with normal pressure is conducted and acid leaching under added pressure done. Under exited technology, this method can extract scandium products with higher purity in lower, acidity and pressure so as to get high pure scandium oxide over 99.9 % (Figure 3).

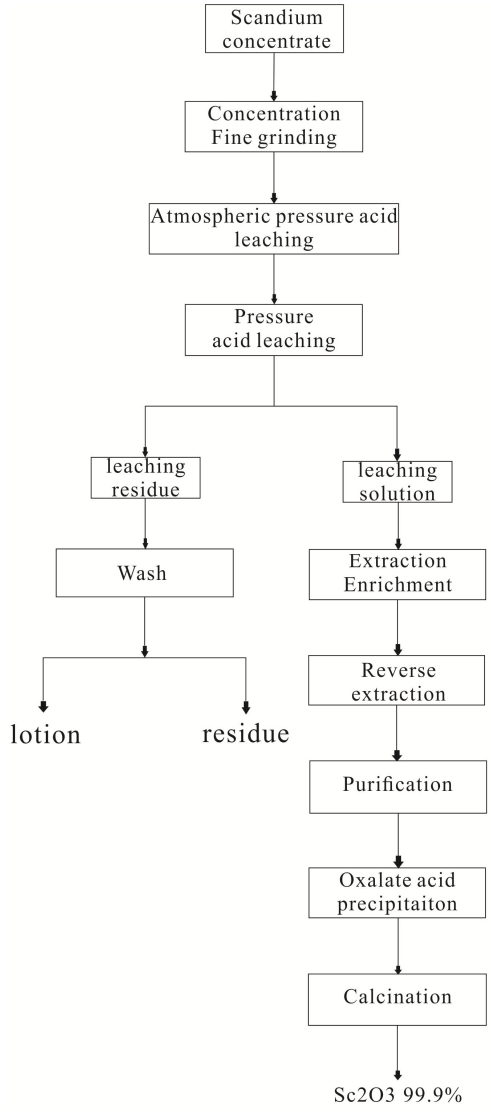


**Figure 3** Scandium extraction technology of Bayan Obo tailings (Baotou Iron and Steel Group Mining Research Institute, 2014; 2015)

Scandium concentrate mine may contain silicon, iron, magnesium, aluminum, calcium, manganese, and rare earth, etc. In this case, scandium in the solution needs to be gathered and refined after size mixing acid leaching with normal pressure and acid leaching under added pressure. Currently, the extraction method is basically used to enrich and refine scandium oxide in China. The extraction method widely used is $P_{204}$ and TBP.

Using kerosene as the extraction solvent, the scandium in liquid is extracted with two extracting agents, namely P204 and TBP, and the scandium oxide is obtained by repeated extraction and purification. The main reaction steps are as follows:

***Extraction***

$$Sc^{3+} + 3(HA)_2 + \chi H_2O \rightarrow Sc(HA_2)_3 \cdot \chi H_2O + 3H^+$$

(Formula 1)

$$Sc(HA_2)_3 \cdot \chi H_2O + \chi TBP \rightarrow Sc(HA_2)_3 \cdot \chi TBP + \chi H_2O$$

(Formula 2)

Reextraction:

$$Sc(HA_2)_3 \cdot \chi TBP + NaOH \rightarrow Sc(OH)_3 \downarrow + 3Na(HA)_2 + \chi TBP$$

(Formula 3)

Purification:

$$Sc(OH)_3 + 3HCl \rightarrow ScCl_3 + 3H_2O$$

(Formula 4)

$$ScCl_3 + 3H_2C_2O_4 \rightarrow Sc_2(C_2O_4)_3 + 6HCl$$

(Formula 5)

$$Sc_2(C_2O_4)_3 \rightarrow Sc_2O_3 + 3CO\uparrow + 3CO_2\uparrow$$

(Formula 6)

Note: $(HA)_2$ represents $P_{204}$

***Analysis of recycle and extraction technology for scandium***

The ultimate product of comprehensive utilization technology in Bayan Obo mine is high-purified scandium oxide. Scandium oxide and other valuable elements from tailings are extracted at the same time, among which, the influences of operation cycles of various processes on the environment need to be evaluated.

***Technology process***

For comprehensive utilization technology in Bayan Obo mine, first, recycling rare earth, so to eliminate its influences on the following technologies. In the stage of rare earth recycle, the flotation agent mainly uses water glass and a rare earth collector. The usage amount of water glass increases, rare earth grade improves but the recycle rate decreases. Collector amount increases, grade decreases but recycle rate improves, so ensuring that the rare earth concentrate REO grade is above 50% by proper adding according the corresponding conditions. Mixed flotation selection stage is the key for separation between easy floating mineral (exited in mixed foam) and Iron, bismuth, and silicate minerals (exited in mixed sands) and important cycle of this technology. Mixed foam is used for recycling fluorite and not necessary in the production of scandium oxide. But it needs to conduct so as to share cost and final environmental load. Mixed flotation selection is performed followed by recycle of sulfur concentrate and iron concentrate, because if the iron and sulfur are not cleaned in advance, the flotation will be seriously affected. Flotation selection of niobium agent is to select ammonium fluorosilicate. The mineral hardly floats when the amount of the agent is small, the grade of niobium is low, and the amount is large. The collector amount and production increase while the grade decreases. So how to collocate the pharmacy is the key. Since scandium is mainly found in pyroxene and amphibole, both of which are weak magnetic minerals, the scandium grade can be improved by strong magnetic separation. At this stage, the gravity selection of tailings and niobium tailings selection are adopted and combined as the raw materials for scandium selection, and finally scandium concentrate over 500 ppm is obtained.

***Environmental Influences***

Presently, scandium is mainly extracted from wastes including titanium white waste liquid, red mud, tungsten slag, chlorinated soot, rare earth tailings, etc. Scandium is extracted from different materials with similar core technology and equal environmental discharge of unit product due to scandium oxide extraction by acid leaching method. Only the more by-products that can share the environmental load, the smaller the environmental impact (Wang *et al*., 2019). The first four extraction methods have fewer types of products that can be allocated. The environmental load sharing contains iron concentrate, rare earth concentrate, fluorite concentrate, sulfur concentrate, niobium concentrate and high-purified scandium oxide when scandium extracted from rare earth tailings. Therefore, the extraction of high-purified scandium oxide from rare earth tailings has little influence on the environment.

In the previous study, the influences of the comprehensive utilization process in Bayan Obo mine on the environment (Wang *et al*., 2018; Wang *et al*., 2019) shows that, the human health non-carcinogenicity is the main type, followed by human health carcinogenicity, indicating the impact of main environment on human health in the application process of this technology. Among them, the most important impact on human health non-carcinogenicity is the iron flotation selection stage. Steam input is the main factor affecting this indicator; the most important impact on human health carcinogenicity is the rare earth flotation selection stage. Water glass input is the main factor affecting human health carcinogenicity, which shows pollution brought by raw materials is much higher than that caused by pollutant in the actual production.

In the various technology processes, the flotation selection stage causes the greatest pollution on the environment. Some flotation selection cycles have greatest pollution caused by the production of flotation selection agents, such as rare earth flotation selection, and some cycles have great pollution caused by the energy consumed by flotation selection, such as iron flotation selection. The comprehensive environmental impacts in rare earth flotation and iron flotation selection stages account for the largest impact on the entire technology life cycle environment, accounting for almost half of all environmental impacts.

## CONCLUSIONS AND RECOMMENDATIONS

Existed extraction methods are usually operated under conditions of high acid, high temperature and high pressure, with high production cost and high requirements for equipment, so which is difficult to meet large-scale and long-term industrial production demands, while comprehensive utilization technology of Bayan Obo mine uses leaching high-purified scandium oxide method under conditions of low acid, low temperature and low pressure.

Mixed flotation selection is the most critical in this process, and the allocation of flotation selection agents in each process plays a key role in the grade and recycling rate of scandium concentrate. In current case of equivalent environmental discharge, the environmental influences produced by scandium oxide extracted from rare earth tailings is small, and the influences of raw material production on the environment is much higher than pollutant discharge during production.

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