RECOVERY OF TUNGSTEN FROM LOW-GRADE SCHEELITE CONCENTRATE BY SODA ASH ROAST – LEACH METHOD

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Abstract

In this work, the possibility of obtaining tungsten compounds from a poor scheelite concentrate (13.26% WO₃) produced from the Blagojev Kamen mine tailings was investigated. The method was used for laboratory test is the scheelite roast with soda ash along with subsequent leaching of the roasting products with water. Scheelite concentrate was homogenized with a corresponding quantity of Na₂CO₃ (1.7 times the stoichiometrically required) and SiO₂ and roasted for a period of 1 hour at a temperature of 810°C. Roasted mass was subjected to a three-stage leaching with hot water (80°C), with a duration stages of 30, 10 and 10 min, accompanied with intense stirring. Tungsten conversions (calculated on the basis of WO₃) were 11.75%, 12.70% and 12.74% for the first, second and third leaching, respectively. The solution of Na₂WO₄ was, without purification, treated with hydrochloric acid with the aim of producing H₂WO₄. The obtained a technical H₂WO₄ contained about 3% of impurities and therefore it had to be purified. To this end, H₂WO₄ was dissolved by ammonium hydroxide and the obtained solution was evaporated and then cooled. In this way, white (transparent) flaky crystals of ammonium paratungstate (APT) were produced. Crystals of APT was roasting on temperature of 700-800°C and was obtained yellow powder of tungsten trioxides which has purity than 99.9%.

Keywords: scheelite, roasting, leaching, APT, tungsten trioxide
1. Introduction

Tungsten is included into a group of rare metals that is not present in nature in a native form, but it is exclusively presents in a form of its minerals represented by tungstate acid salts. It is very little spreaded in the earth crust, only $1 \cdot 10^{-4}\%$. General, that is economical important tungsten minerals are scheelite ($\text{CaWO}_4$) and wolframite ($\text{Fe-Mn WO}_4$). Tungsten ores are characterized by complex chemical content and mainly low-grade $\text{WO}_3$, from 0.1-0.2%, until the ores with tungsten content of 0.5-2.0% $\text{WO}_3$ are considered as high-grade ores. Tungsten ores are undertaken to the dressing techniques as well as gravity concentration, froth flotation, magnetic and electrostatic separation for the aim of obtaining higher grade commercial concentrates (60-70% $\text{WO}_3$). Besides a fact that the mentioned dressing techniques are usually very efficient, due to mineralization of tungsten in a fine dissiminated form, low-grade concentrates with tungsten content from 5-20% $\text{WO}_3$ are still in production. It is necessary to treat additionally such concentrates to increase tungsten recovery [1-3].

Depending on chemical and mineralogical content of concentrate, the procedures of their treatment are various mainly at first stage, i.e. stage of decomposition, until further treatment in the majority of cases is unique. Four procedures and their sub-variants are used nowadays in practice for tungsten concentrates treatment. It is usual that high-grade scheelite concentrates are undertaken to acid leaching with hydrochloric acid, until wolframite concentrates of similar quality are undertaken to alkaline leaching ($\text{NaOH, Na}_2\text{CO}_3$). Leaching method with sodium carbonate under pressure in autoclave is used for low-grade scheelite concentrates, until smelting method with sodium carbonate and leaching with water of the obtained product is used for low-grade wolframite concentrates [1,4].

Tungsten is strategically important metal that has various industrial use. As pure metal, it is used in production of electrical bulbs and electrical heaters for high temperature furnaces as well as in X-ray technics. Tungsten alloys with niobium, tantalum and/or molybdenum are used in space industry, until hard alloys, based on tungsten carbide, are used in the cutting tool industry. The important part of tungsten concentrates is treated and used in production of special steel and ferrotungsten. Besides that, tungsten is also used in a from of
its chemical compounds in production of some lacquers and pigments resistant to light, for painting and production of thermo and water-proof fabrics as well as catalyst in production of high-octane petrol and others [5].

Having in mind the above mentioned facts and also the importance of tungsten as a strategic raw material for each country, this work also presents the results of tungsten valorization from low-grade scheelite concentrate, obtained from tailings of the Blagojev Kamen mine. The aim of this work was to establish, that is to check, the technological parameters and possibilities for obtaining the commercial products based on tungsten at laboratory level. The investigations were, first of all, outlined based on Russian literature from the beginning of the seventies in the last century, since the Russians has the leading role in the fifties and sixties in technology of tungsten treatment, primarily with the help of Maslenicki, Zelikman and others.

2. Experimental

In 1949, the tungsten ores were discovered in East Serbia, at the area between Majdanpek and Kučevo, then in Železnik, Blagojev Kamen and on the mountain Deli Jovan. The reserves of tungsten ore were evaluated as enough for the needs of our tungsten metallurgy (that means former SFRY). In a period from 1953 to 1964, the previous exploitation of gold and silver stoped in the Blagojev Kamen mine and tungsten ore – scheelite exploitation was carried out due to favourable price of tungsten and low price of gold on the world market. In this period approximately 640 tones of concentrate with average content of 60% WO₃ was produced. Scheelite ore reserves are present in Blagojev Kamen. However, ther exact amount of ore reserves as well as the real reasons of scheelite exploitation stoppage are unknown.

The old flotation tailing dump of the Blagojev Kamen mine represented a solid raw material for preliminary investigations connected to a possibility of tungsten valorization from scheelite. Namely, the assumptions that this tailings contain scheelite were justified and it was established that content of WO₃ in it varies in a wide range from 0.05 – 2%, where average content is 0.2-0.3% WO₃. In the world ratios, the tungsten ores with this content have economic interest since the same ones are exploited. In this case, a special
advantage was a fact that this tailings are prepared for tungsten valorization due to a fact that the ore was mined, crushed, ground and purified from sulphides (flotated sulphides).

Low grade scheelite concentrate with content of 13.26% WO₃ was used as investigation material. Concentrate was obtained by gravity concentration of the highest grade sample, selected from nine bore holes from the old flotation tailing dump of the Blagojev Kamen mine. Chemical content of concentrate is shown in Table 1, and X-ray analysis in Fig. 1.

Table 1. Chemical content of scheelite concentrate, %

<table>
<thead>
<tr>
<th></th>
<th>SiO₂</th>
<th>Al₂O₃</th>
<th>Fe</th>
<th>Pb</th>
<th>MgO</th>
<th>WO₃</th>
<th>Ti</th>
<th>Na</th>
<th>CaO</th>
<th>Mn</th>
<th>Zn</th>
<th>Cu</th>
</tr>
</thead>
<tbody>
<tr>
<td>%</td>
<td>20.36</td>
<td>7.20</td>
<td>2.77</td>
<td>0.10</td>
<td>42.86</td>
<td>13.26</td>
<td>0.11</td>
<td>0.082</td>
<td>15.60</td>
<td>2.47</td>
<td>0.023</td>
<td>0.023</td>
</tr>
</tbody>
</table>

Decomposition of scheelite concentrate was carried out by calcination, that is roasting with sodium carbonate and quartz sand. Smelting products were leached with water for the aim of obtaining the sodium tungstate, and then Na₂WO₄ solution was treated with hydrochloric acid. Technical tungstic acid was obtained that is further purified by ammonium procedure and ammonium paratungstate was obtained, that is further annealed to tungsten trioxide, what
represented the final product.

X-ray analysis, OES, AAS, ICP-AES, gravimetry, volumetry and optical microscopy were used for determination of scheelite in concentrate as well as quantitative analyses of the obtained products.

3. Results and discussion

3.1. Roasting of scheelite concentrate with sodium carbonate

It is generally known that scheelite roasting with soda ash does not result into satisfied tungsten conversion into solution, even at considerable surplus of Na₂CO₃ in charge. At smelting temperatures from 800-900°C, the reaction is moved into direction of Na₂WO₄ formation (reaction 1), although a reversible reaction could be also developed in calcine leaching with water.

\[
\text{CaWO}_4 + \text{Na}_2\text{CO}_3 \rightarrow \text{Na}_2\text{WO}_4 + \text{CaCO}_3
\] (1)

Namely, at temperature higher than 825°C, the obtained CaCO₃ is partly decomposed with formation of CaO per reaction:

\[
\text{CaCO}_3 \rightarrow \text{CaO} + \text{CO}_2
\] (2)

This calcium oxide hydrolyzes in leaching of roasting products and reacts with a part of sodium tungstate, where CaWO₄ is again formed and drops as a sediment (reaction 3). It is also confirmed by increased content of tungsten in a solid residue with increased leaching time of calcine.

\[
\text{Na}_2\text{WO}_4 + \text{Ca(OH)}_2 \rightarrow \text{CaWO}_4 \downarrow + 2\text{NaOH}
\] (3)

For reaction (1) development in a direction of sodium tungstate formation and supply of process irreversibility, according to Zelikman et al. [6], minimum required soda ash surplus is at least 3.17 times higher than stoichiometrical required quantity. In practice, the required soda quantitity is much more higher. To reduce the soda consumption and disable formation of free
sodium oxide, quartz sand (SiO₂) is added into charge in a required quantity for calcium binding in hard dissolvable silicate (reaction 4).

\[
\text{CaWO}_4 + \text{Na}_2\text{CO}_3 + \text{SiO}_2 = \text{Na}_2\text{WO}_4 + \text{CaSiO}_3 + \text{CO}_2
\]  

The most likely, first of all quartz sand and sodium carbonate react where sodium silicate is formed (reaction 5). Sodium silicate reacts with calcium tungstate giving water dissolvable calcium tungstate and hard dissolvable calcium silicate (reaction 6).

\[
\text{Na}_2\text{CO}_3 + \text{SiO}_2 = \text{Na}_2\text{SiO}_3 + \text{CO}_2
\]  

\[
\text{CaWO}_4 + \text{Na}_2\text{SiO}_3 = \text{CaSiO}_3 + \text{Na}_2\text{WO}_4
\]

However, it is necessary to add a surplus of sodium carbonate from 50 to 100% of stoichiometrical required quantity into charge to increase, in this case, a degree of tungsten transformation into solution. According to literature data at temperatures from 800-900°C, at soda ash surplus of 100% from theoretical required quantity and at ratio CaO/SiO₂ of 2.5, reaction is finished for 20 minutes. Besides presented reactions, secondary reactions are also developed with mineral ingredients what also results into consumption of sodium carbonate and silicon dioxide with formation of dissolvable salts of sodium and release of CO₂ [1-3, 6,7].

For alkaline decomposition of scheelite concentrate, first of all the charge was formed by homogenization of concentrate, sodium carbonate and quartz. During this, the literature data were adopted, so sodium carbonate was added more than 70% of stoichiometrical required quantity [1,3] until SiO₂ was added 20% less than stoichiometrical required quantity per reaction (4) due to its content in input concentrate. Homogenization was manually carried out and into laboratory ceramic ball mill during 10 minutes. As it was seen in the next stages of investigation, the homogenization method in charge formation had a great influence on production and quality of the required products. Charge was roasted in shallow steel dishes in a stationary layer of 1 cm depth at temperatures ≥800°C in chamber furnace and in various roasting times of 25, 30, 60 and 180 minutes. Larger sample masses, from one to two kilograms,
were used. The obtained results are presented in Table 2. Probably, due to a favourable chemical content and relatively pure concentrate, high recoveries of WO$_3$ were obtained, especially in roasting time of 60 minutes because such recoveries were found in literature only during longer roasting times (3, 4 hours) [1,5]. Further laboratory investigations were mainly carried out with calcine No.3.

Table 2. Influence of time and temperature of roasting on tungsten recovery

<table>
<thead>
<tr>
<th>Order No.</th>
<th>Roasting time (min)</th>
<th>Roasting temperature (°C)</th>
<th>Recovery of WO$_3$ (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>25</td>
<td>850</td>
<td>75.9</td>
</tr>
<tr>
<td>2</td>
<td>30</td>
<td>800</td>
<td>71.4</td>
</tr>
<tr>
<td>3</td>
<td>60</td>
<td>810</td>
<td>96.1</td>
</tr>
<tr>
<td>4</td>
<td>60$^*$</td>
<td>810$^*$</td>
<td>95.8$^*$</td>
</tr>
<tr>
<td>5</td>
<td>180</td>
<td>810</td>
<td>96.3</td>
</tr>
</tbody>
</table>

$^*$sample formed by homogenization in ceramic ball mill

3.2. Calcine leaching with water

Cooled calcine was first of all fragmented in mortar with pestle and leached with hot water (~80°C) such as it was added partially into warm water with stirring. Leaching was carried out in three stages in time of 30, 10 and 10 minutes. It was carried out in a glass of 5 l, in ratio of solid:liquid=1:1.5 and intensive stirring that was carried out by the use of impeller of laboratory flotation machine of Denver type. By this way, tungsten transformation into solution was provided in a form of sodium tungstate. Degree of tungsten transfer into solution per leaching stages is given in Table 3.

Upon first leaching stage, filtration was carried out on Buchner’s funnel on warm under vacuum where filtrate was separated for further investigations, and undisolved part is gone to next leaching stage. During leaching experiments of many calcines, it was noticed that stirring rate of suspensions (800, 1000, 1200 min$^{-1}$) as well as temperature of hot water (40-100°C) have no important influence on leaching degree of tungsten. It is seen from Table 3 that two-stage leaching gives satisfied results such as filtrates from I and II stage are combined for further work. Filtrate from III stage of leaching only
increase volume and makes complex further operation until tungsten content in it is negligible.

**Table 3. Multistage calcine leaching with water**

<table>
<thead>
<tr>
<th>Leaching stage</th>
<th>Leaching time (min)</th>
<th>Degree of tungsten transfer into solution (%)</th>
<th>Cumulative content of WO$_3$ in solution (%)</th>
<th>Cumulative degree of calcine leaching (% WO$_3$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>I$^{st}$</td>
<td>30</td>
<td>88.61</td>
<td>11.75</td>
<td>88.61</td>
</tr>
<tr>
<td>II$^{nd}$</td>
<td>10</td>
<td>62.91</td>
<td>12.70 (I+II)</td>
<td>95.78 (I+II)</td>
</tr>
<tr>
<td>III$^{rd}$</td>
<td>10</td>
<td>7.69</td>
<td>12.74 (I+II+III)</td>
<td>96.10 (I+II+III)</td>
</tr>
</tbody>
</table>

3.3. **Obtaining of technical tungstic acid**

Precipitation of tungstic acid from sodium tungstate is carried out by hydrochloric acid per equation (7):

\[
\text{Na}_2\text{WO}_4 + 2\text{HCl} = \text{H}_2\text{WO}_4 + 2\text{NaCl}
\]  

(7)

For that purpose, filtrates from I and II stage of leaching were combined and newly-formed solution, that contains sodium tungstate, is concentrated by evaporation to 1/5 from starting volume. Upon this, hot concentrated solution of Na$_2$WO$_4$ was slowly added drop by drop into two times larger volume of boiling hydrochloric acid with stirring [8]. Suspension of lemon yellow colour was obtained by this way, that is kept at temperature between 60 and 70°C another 60 minutes with intensive stirring. The obtained suspension is then precipitated, clear part is decanted and filtered with multistage rinsing of deposit by hot water (6 to 8 times) with repeating the previous operations. 1% of HCl is added into final rinsing water to preven tungsten transfer into colloidal state. Filtration was carried out at the beginning by free fall to formation of «cake», and then vacuum was included. Low-grain size sediment of lemon yellow colour of tungstic acid was obtained. A part of sediment of H$_2$WO$_4$ was taken out and dried into laboratory dryer at 110°C and given to
X-ray analysis (Fig. 3A). Nevertheless to a way of obtaining and appearance of tungstic acid, it adsorbs one part of present ingredients from solution so is requires further purification. Spectrographic and X-ray analysis have shown that the obtained acid is of technical quality with ingredients content about 3% with predominant content of silicates (Si>1% and Ca>1%).

An attempt of addition the solution of sodium tungstate in large portions very fast into boiling hydrochloric acid with the aim of obtaining the coarse-grain crystals of tungstic acid, which are easy filterable, was not successful. Hot solution of Na2WO4 could be added in a thin stream and into hot mixture of two acids, HCl i HNO3, in a volume ratio 50:1 [9]. This way should be used on samples with higher content of iron because nitric acid oxidizes ingredients of iron(II) to iron (III) what prevents partial reduction of tungstic acid by ions of iron(II) to lower compounds. No difference was noticed during those investigations in quality of the obtained tungstic acid nevertheless on neutralization way.

3.4. Recovery of ammonium paratungstate

Tungstic acid, precipitated from sodium tungstate solution, according to the literature data, very often contains from 0.1-0.3% NaCl, until total content of ingredients could be from 0.2-3.0%. The most often ingredients are sodium, calcium and silicon salts [10]. General usable, and for silicious ingredients the most sophisticated purification method of H2WO4, is the ammonium method. H2WO4 is easy dissolvable by ammonium solution where ammonium tungstate (reaction 8) is obtained.

\[
\text{H}_2\text{WO}_4 + 2\text{NH}_4\text{OH} \rightarrow (\text{NH}_4)_2\text{WO}_4 + 2\text{H}_2\text{O} \quad (8)
\]

The obtained solution is mainly without basic mass of ingredients. The most often present ingredients (SiO2, H2SiO3, sulphides and others) do not react with ammonium and remain as undissolved sediment, until some other ingredients (FeCl3) react with ammonium and precipitate in a form of hydroxide. However, one part of present ingredients reacts with ammonium and gives watersoluble salts type [Me(NH3)4]2+X [11]. Upon filtration of ammonium solution, ammonium paratungstate is obtained from it by crystal-
lization or $\text{H}_2\text{WO}_4$ could be again precipitated and retreated by ammonium procedure.

Fig. 2. X-ray analysis of products obtained from scheelite concentrate

**Fig. 2. X-ray analysis of products obtained from scheelite concentrate**
In this work, the obtained technical H$_2$WO$_4$ was prepared in a form of thick suspension with water (1 H$_2$WO$_4$: 1 H$_2$O) that is first of all heated up to 80°C, and then slowly with continuous stirring added into NH$_4$OH solution. By this way, so called ammonium purification is carried out. The formed suspension was left to standing i.e. clarifying of 18 hours. Literature time of clarifying is in a range from 8 to 24 hours, however, it was shown out, in carried out investigations, that there are no important differences in quality of the obtaine paratungstate at various clarifying times (12, 18, 24h). Due to a fact that H$_2$WO$_4$ is easy dissoluble in NH$_4$OH, upon many hours clarifying in a glass, a clear solution and sediment on the bottom could be noticed. Clear part presents solution of ammonium tungstate that is separated from deposit by filtration. Solution was evaporated to ~1/3 from starting volume, at temperature of ~70°C, and then the first crystals started to drop down. Upon this, the evaporation was interrupted and the system was left to crystallize out by slow natural cooling at room temperature. Small crystals of white (transparent) color were crystallized out, washed with cold distilled water and dried at temperature of 110°C during one hour. By the use of X-ray analysis (Figure 3B), the presence of shelly form of crystal, i.e. 5(NH$_4$)$_2$O·12WO$_3$·5H$_2$O, was established.

Depending on precipitation conditions, ammonium paratungstate (APT) could be crystallized with various quantity of crystal water. Due to this, general formula of APT is 5(NH$_4$)$_2$O·12WO$_3$·xH$_2$O. Hydratation degree and crystal form depend on crystallization temperature. If APT is crystallized from solution at room temperature, small, needles, white crystals with 11 molecules of water are formed. If crystallization is carried out by sudden evaporation, transparent and shelly crystals with 5 molecules of water are formed [10]. Figure 3 presents a view of obtained crystals. It should be pointed out that the clearest crystals were obtained during first hour of crystallization, and those primary crystals make 40% of total obtained mass of crystal.

It was previously mentioned that method of charge homogenization for roasting could have a large influence on further tungsten valorization from scheelite. It could be well seen from Table 4. According to this, the input concentrate should not be over-size reduced because it results into losses that could be avoided in later operations, what further means that it was thought about this in a grinding stage of scheelite ore.
Fig. 3. Optical microscopy of crystals obtained in this investigation (left photograph – increased 5X, right photograph – increased 20X)

Table 4. Influence of homogenization method of charge for roasting on valorization operations and recovery of tungsten from scheelite

<table>
<thead>
<tr>
<th>Method of homogenization</th>
<th>Upper size limit of sample</th>
<th>Appearance of calcine</th>
<th>Observations upon leaching with water</th>
<th>Observations in obtaining H₂WO₄</th>
<th>Observations in obtaining APT</th>
<th>Total losses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manual</td>
<td>-0.200 +0.0 mm (~70% sample with size range between 0.100 and 0.200 mm)</td>
<td>Kompakt, easy separable from dish and easy fragmented, dark brown colour</td>
<td>Suspension is easy filterable, filtrate is clear</td>
<td>Filtration is successful but slow, sediment is yellow, small grain-size, filtrate is clear</td>
<td>Successful clarifying, relatively pure crystals of APT</td>
<td>10 - 12%</td>
</tr>
<tr>
<td>In ceramic ball mill</td>
<td>-0.074 +0.0 mm (~60% sample with size range between 0.040 and 0.074 mm)</td>
<td>Same as above but hard size reduction</td>
<td>Suspension if hard filterable, filtrate is gentle muddy</td>
<td>Filtration is slow, a part of deposit transfers into filtrate, deposit is yellow in a form of paste, filtrate is muddy yellow</td>
<td>Partly clarifying, strong small-grain crystals with a lot of ingredients</td>
<td>35 - 40%</td>
</tr>
</tbody>
</table>
3.5. Obtaining of tungsten trioxide

Tungsten trioxide is the most important compound obtained by processing of tungsten ores. It could be observed as a final product, that is sold like this or as a basic mineral raw material for production of tungsten powder and metal tungsten. Depending on needs for purity, form and particle size as well as the other physico-chemical characteristics, tungsten trioxide could be obtained from $\text{H}_2\text{WO}_4$ per reaction (9) and from APT per reaction (10). P.a. tungsten compounds are most often obtained from APT.

$$\text{H}_2\text{WO}_4 \rightarrow \text{WO}_3 + \text{H}_2\text{O} \quad (9)$$

$$5(\text{NH}_4)_2 \cdot 12\text{WO}_3 \cdot x\text{H}_2\text{O} \rightarrow 12\text{WO}_3 + 10\text{NH}_3 + (n+5)\text{H}_2\text{O} \quad (10)$$

In this work, the obtained APT crystals were annealed in a tube furnace at temperature of 700°C for an hour, and then temperature was increased and annealing was carried out another an hour. Tungsten trioxide with excellent physico-mechanical characteristics was obtained (flows as sand, coarse-grain size, yellow color). With content of impurities lower than 0.095%. X-ray analysis of the obtained $\text{WO}_3$ is presented in Figure 3C, and chemical content of impurities is given in Table 5. In Table 5, due to a comparison, the chemical content of impurities in commercial $\text{WO}_3$ from the Austrian company Bergbau und Huttengesellschaft m.b.H. is also presented.

<table>
<thead>
<tr>
<th>Element (%)</th>
<th>$\text{WO}_3$ obtained in this investigation</th>
<th>Element (%)</th>
<th>Commercial $\text{WO}_3$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cu</td>
<td>&lt;0.0020</td>
<td>K</td>
<td>max. 0.0010</td>
</tr>
<tr>
<td>Pb</td>
<td>&lt;0.0010</td>
<td>Ni</td>
<td>max. 0.0010</td>
</tr>
<tr>
<td>Sn</td>
<td>&lt;0.0010</td>
<td>S</td>
<td>max. 0.0015</td>
</tr>
<tr>
<td>Al</td>
<td>&lt;0.0010</td>
<td>Al</td>
<td>max. 0.0015</td>
</tr>
<tr>
<td>Ag</td>
<td>&lt;0.0010</td>
<td>Mo</td>
<td>max. 0.0080</td>
</tr>
<tr>
<td>Mn</td>
<td>&lt;0.0010</td>
<td>Na</td>
<td>max. 0.0020</td>
</tr>
<tr>
<td>Fe</td>
<td>0.0027</td>
<td>Fe</td>
<td>max. 0.0010</td>
</tr>
<tr>
<td>Si</td>
<td>&lt;0.0050</td>
<td>Si</td>
<td>max. 0.0025</td>
</tr>
<tr>
<td>Ca</td>
<td>0.0800</td>
<td>Ca</td>
<td>max. 0.0015</td>
</tr>
</tbody>
</table>
4. Conclusion

Based on the presented results, it could be seen that recovery of tungsten (WO$_3$) from low-grade scheelite concentrate is very complex method that includes a large number of operations. It could be also seen from presented technological layout in Fig. 6.

It was necessary to establish experimentally a lot of parameters to obtain the satisfied recovery of tungsten and product quality because there are no literature data or they are general. One of the most important factors in those investigations was also particle size range of starting sample. Namely, it was proved experimentaly that input raw material could not be over fragmentated and not of small grain-size because it results into formation of colloidal hard filterable deposits what has a negative influence on recovery and quality of the obtained products.

Although it was law-grade scheelite concentrate, it was proved by this laboratory investigation that relatively pure compounds of tungsten (APT, WO$_3$) could be obtained from such raw material. The established content of impurities in WO$_3$ was unde 0.095% what present a very good result. It should be said that an exemption in this work was absence of some ingredients in concentrate (Mo, sulphides) that additionaly makes this method of WO$_3$ recovery more complex.

References

Recovery of tungsten from low-grade scheelite concentrate by soda ash roast ...