

Flotation of antimony ores with high arsenic content

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Abstract: Efficient evaluation of antimony ores, which are on the critical raw materials list due to the supply risk by the European Union, is an important necessity. In this context, ore preparation and enrichment processes are very important during the process from ore to metal. Especially for sulfide antimony ores, the most common beneficiation method is flotation. Therefore, antimony ore consisting of stibnite mineral obtained from Tokat-Turkey region was used in this study. Due to the low antimony (5.06%Sb) and the high Arsenic (1.38%As) content, it is an important requirement to increase the Sb content of this ore by flotation, as well as to reduce the As content to certain levels. Stibnite as an antimony mineral and arsenopyrite as arsenic mineral, are minerals that have a sulphurous structure in mineralization and their flotation properties are quite close to each other. Therefore, in this study, it is aimed to selectively separate the bulk concentrate taken from rougher flotation by cleaning steps. A bulk sulfur concentrate with 24.54% Sb and 3.69% As content obtained as a result of the rougher flotation was obtained with a recovery of 98.9%. This product was subjected to 6 stages of cleaning flotation and a concentrate with a content of 63.8% Sb and 0.31% As was produced with an antimony recovery of 83% Sb.

Keywords: antimony, arsenic, flotation, rougher, cleaning

1. Introduction

Today, in metal and oxide form of antimony is an important source of raw materials with its use in flame-retardants, lead-acid batteries, chemicals, ceramics, glasses, heat stabilizers and plastics. The factors that increase the importance of this valuable resource in geopolitical, economic, social, environmental and technological aspects in the future can be expressed as follows:

- China is the world's largest supplier of antimony and has a production rate of 60-70%. This situation makes this raw material to a strategic point for other world countries.
- The use of micro capacitors as anode materials for the semiconductor industry, thin-film photography and sodium ion storage batteries and the increasing usage rate in some high technologies indicate that the demand for antimony will be high in the future.
- Significant interest in this raw material is increasing with the use of antimony trioxide in order to achieve higher performance.
- Recycling rates are very low (under 30%) and are limited to used lead-acid batteries only as a secondary source (European Commission, 2017a; Grund et al, 2011; Sundqvist Okvist et al, 2018; USGS, 2020a)

Especially the European Union countries remain in a vulnerable position against the supply risks of antimony ores due to their limited reserves and China's dominance over this sector, and therefore they have to deal with this issue seriously. In this context, the European Commission publishes a list in which a selected raw material group is considered "critical" and the stibnite mineral has been included in this critical raw materials list, for 2020 (European Commission, 2020, 2017b, 2014, 2010).

Although more than 100 types of antimony minerals are known, the most important mineral is stibnite (Sb_2S_3). In addition, scenarmonthite (Sb_2O_3), valentinite (Sb_2O_3), servantite (Sb_2O_4) and crayfish ($2Sb_2S_3 \cdot Sb_2O_3$) stand out as other important Sb minerals. As in the process of obtaining metals such as copper, zinc and lead, the method to be applied in the production of antimony is determined depending

on the structure and metal content of the ore. If the antimony content of the most widely found and produced stibnite ore is low, the gangue minerals in the ore composition should be removed by an enrichment process to produce a concentrate with high antimony content. Such ores are usually upgraded by froth-flotation process while high-grade ores can be utilized directly for metal recovery due to decrease in gangue content.

The beneficiation process of sulfide ores includes size reduction-size classification, physical beneficiation processes and/or flotation steps. Anderson (2012) described a typical Chinese stibnite operation treating an ore containing about 2.7 wt. % Sb. The ore was crushed to -150 mm and a high-grade concentrate and low-grade tailing were obtained from the $-150 + 35$ mm fraction by hand sorting. A heavy media separation was used to reject gangue from the $-35 + 10$ mm fraction and then the resulting concentrate, and the low-grade tailing from hand sorting, were ground to 60% -74 μm for flotation. Overall, 33 wt. % of the ore was treated by hand sorting, 7 wt. % by heavy media separation and 60 wt. % by flotation. Generally, for stibnite ores where the gangue minerals are quartz and feldspars, gravity concentration is often used because of the differences in density (Gülcan et al., 2019; Lager and Forssberg 1989b). Flotation is one of the most important methods used in the enrichment of sulfide ores and enrichment of minerals is carried out according to their buoyancy properties. It is based on the principle that the hydrophobic minerals in the composition of the ore are floated by attachment to an air bubble, while the hydrophilic minerals remain at the liquid-solid interface instead of the air-solid interface. Only a few minerals such as graphite, coal, sulfur, talc ($\text{Mg}_3\text{Si}_4\text{O}_{10}(\text{OH})_2$) and molybdenite (MoS_2), stibnite are not easily wetted by water. These minerals are composed of covalent molecules held together by van der Waals (non-polar) forces that produce special crystal lattice structures with nonpolar surfaces. Examples of special crystal lattice structures include the layered structure in graphite and molybdenite, the open layer structure in talc with van der Waals bonding between the oxygen atoms of adjacent layers, and fracture without interatomic bonds (stibnite, Sb_2S_3 , or sulfur) and/or cleavage surfaces. Non-polar surfaces do not readily bond to water dipoles, are consequently hydrophobic, and have high natural buoyancy with contact angles between 60 and 90°. While it is possible to float these minerals without the use of chemical reagents, it is universal to increase their hydrophobicity by adding hydrocarbon oils or some agents (Selura-Salazar, Brito-Parada, 2021).

In the flotation of a stibnite ore, stibnite has been declared as naturally hydrophobic in the presence of air or as partially hydrophobic on the basis of the critical surface tension of wetting (Ozcan, 1992, Popov et al., 1987, Herrera-Urbina et al., 1990, Fuerstenau et al., 2007). In addition, in practice, the particle shape, roughness and particle size, heterogeneous structure of the minerals to be flotation affect their surface properties and thus their buoyancy. In that sense, it has been a frequent practice to add collectors in order to improve the flotation rate of those minerals (Fuerstenau et al., 2007).

The most common collectors for stibnite flotation have been alkyl xanthates, preferably those of long chain (4 or more carbon atoms). These kinds of collectors improve stibnite recovery compared to those whose hydrocarbon chains are shorter, even when the dosage is increased in the latter. This has experimentally revealed by Oberbillig (1964), Lager and Forssberg, 1989a, Richards, 1977 at bench and micro flotation scale, respectively. These studies may have established a reference for the selection of xanthates in later stibnite flotation studies, where a clear preference is observed towards long chain xanthates (Table 3), such as potassium amyl xanthate, potassium or sodium butyl xanthate, among others. Moreover, there seems to be a consistency in the superior performance of long-chain xanthates over short-chain xanthates for different pH values, at least in terms of antimony grade in the concentrate (Ealedona and Fujita, 2006, Richards, 1977). Stibnite generally can be found with different minerals such as pyrite, arsenopyrite, jamesonite, copper, lead and silver, and the main gangue minerals (quartz, chlorite, calcite and plagioclase etc.) can be composed of minerals. Especially the presence of stibnite mineral together with arsenic minerals is very important for the flotation process. Because the movement of the arsenopyrite mineral, which has very high flotation properties, with the stibnite mineral, which has natural buoyancy, causes to the high As contents in the obtained antimony concentrates. Arsenic (As) is one of the hazardous substances. It is a penalty element in the sale of metal concentrates, in terms of both human health and the environment, and because of the negativities, it creates in its use in subsequent processes (rusting and damaging the melting furnaces and shortening the furnace life, etc.). In addition, the import and export of ores containing more than 0.5% arsenic are

currently restricted. Arsenopyrite, which is one of the most common arsenic minerals, is especially found together with sulfide minerals and the removal of these sulfide minerals from its composition is a very important issue in both environmental and economic terms. In a process to be created for enriching sulfide minerals containing metals such as lead, zinc, copper, molybdenum, nickel and antimony, arsenic contents should be taken into consideration as well as the contents of these metals. Suppressing the flotation properties of arsenopyrite, which is an arsenic source, is one of the most important study subjects in flotation. In this study, it was aimed to produce an antimony concentrate with high Sb and low As content by flotation.

2. Materials and methods

This study was carried out to produce a high-quality antimony concentrate (>60% Sb and <0.5% As) from high As content antimony ore taken from the field with the most important antimony reserve in Turkey. For this purpose, by revealing the characterisation of the ore, flotation experiments were conducted to determine the conditions to obtain the highest Sb and lowest As contents in the flotation process. Antimony ore used in this study was taken from a region called Turhal located in the central and inner regions of Northern Anatolia (Fig. 1). Before the experimental studies, size reduction and sample preparation processes were performed and physical, chemical and mineralogical analyses were carried out on the representative samples, which ground under 100 microns, by Retsch brand ring Mill.

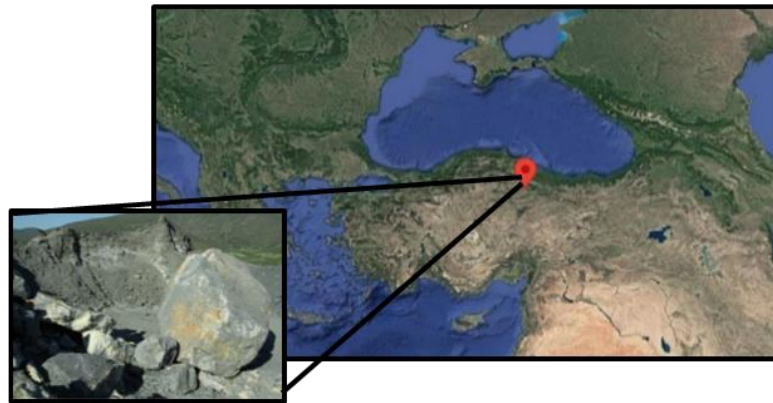


Fig. 1. Location map of the region where the ore used in the study was taken

Chemical analysis of the tested antimony ore and its products obtained from experiments was performed using the Perkin Elmer-OPTIMA8300 Inductively Coupled Plasma (ICP). X-ray Diffraction (XRD) analysis method was also performed to determine the mineralogical composition of the samples using Rigadu D Max III device with Cu X-ray tube.

In the As analysis carried out within the scope of the studies carried out, a mixture of 2.5 M H_2SO_4 (50 ml), Potassium Antimonitartarate (5 ml) at 0.45%, Ammonium molybdate (15 ml) at 5% and Ascorbic Acid (30 ml) at 2.5% content was prepared. Analysis solutions were created with certain arsenic content and added to this mixture, and absorption readings were made in the Shimadzu UV 1208 device at a wavelength of 880 nm. The colors of the created solution change depending on the amount of arsenic, and it progresses from transparency to dark blue as the arsenic concentration increases. The colors of the solutions prepared at 0, 0.2, 0.5, 1, 2, 4 ppm are shown in Fig. 2, respectively. The variation of As content depending on the absorbance values read in these solutions prepared with different contents is also given in Fig. 2. By using the inequality resulting from this curve, the As contents of other products can be calculated. As a result, the As contents of all the product solutions obtained were calculated by using this uniqueness of the absorbance values read in the Shimadzu UV 1208 device. Here, the detection limit is 4 ppm, but the solutions with higher content are diluted and the absorbance value is read in UV. Then, the actual As concentrations are calculated by considering the dilution rate. (Kocabaş et al., 2012).

After the mineralogical and chemical properties of the ore were determined, flotation enrichment experiments were carried out for the selective recovery of stibnite minerals. However, the most important and critical step for a beneficiation process is to determine the liberation grain size of the precious mineral that forms this ore. For this purpose, flotation experiments were conducted with the

materials obtained at the end of the grinding process to different sizes, and the size that gave the best enrichment and antimony recovery was determined. Flotation studies were carried out using a Denver type laboratory scale flotation machine at 1500 rpm using a 2 dm³ flotation cell. In the flotation experiments, some factors such as particle size of flotation feed, the pH value of the flotation pulp, the amount of KAX as collector reagent, the amount of Pb(NO₃)₂ as activator and the number of cleaner flotation steps were examined and the results were revealed. The all-flotation parameters are given in Table 1.

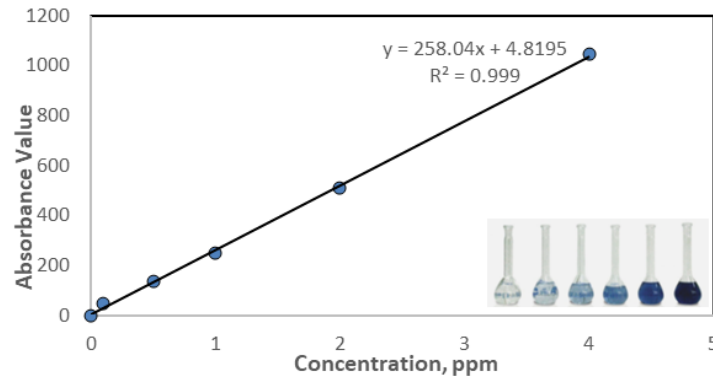


Fig. 2. Variation of the amount of concentration corresponding to absorbance

Table 1. The all flotation parameters in the experiments

Particle size d ₁₀₀ (micron)	300, 212, 106 micron
pH	6,5 (Natural pH)
Pulp Density (%)	%20 constant
AEROFROTH 65 Amount (g/t)-frother	100 constant
Pb(NO ₃) ₂ Amount (g/t)-activator	50,100, 150, 200
KAX Amount (g/t)-collector	50,100,150,200,250
Gradual KAX addition (g/t)-collector	3*50, 3*100, 3*150, 3*200, 3*250
Cleaning Stages, times	1,2,3,4,5 and 6
KAX Condition Time (min.)	10 constant
Pb(NO ₃) ₂ Condition Time (min.)	30 constant
Flotation Time (min.)	4 constant

3. Results and discussion

Chemical analysis results of antimony ore within the scope of ore characterization studies are given in Fig. 3. According to these results, it was determined that the Sb content of the ore was 5.84% and it contained 1.38% As. In addition, from the XRD analysis results given in Fig. 4, the antimony in the structure of the ore originates from the sulphide mineral Stibnite. Stibnite, an antimony mineral, is dispersed in the main rock quartz. In addition, the low content of arsenic element originates from arsenopyrite and could not be displayed in the XRD analysis due to its low content.

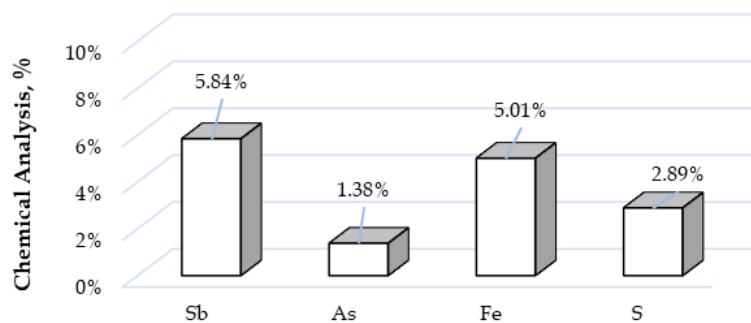


Fig. 3. Chemical analysis results of antimony ore

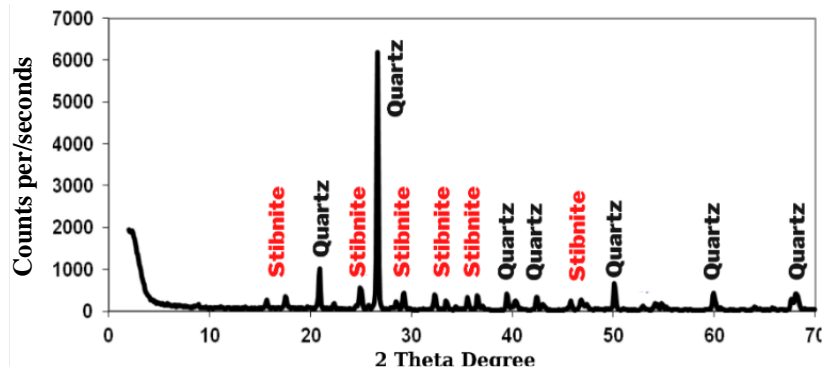


Fig. 4. XRD analysis result of antimony ore

Flotation experiments were conducted to concentrate stibnite minerals. In the experiments, the flotation conditions which given high grade concentrates and high recovery were investigated and the results of these experiments were discussed

3.1. The effect of particle size

In a beneficiation process, the liberation particle size is one of the most important parameters for the separation recovery. Therefore, it is important to determine the liberation size. In addition to grinding to fine sizes due to both the grinding costs and the negative effect of slimes in the flotation process, considering the negative effects in terms of separation selectivity in the flotation process to be performed on particles larger than the liberation size, it is very important to carry out enrichment experiments in optimal particle sizes.

To determine the optimal particle size for froth flotation of the stibnite, three samples with particle size ranging from 300 μm , 212 μm and 106 μm respectively were prepared by two stage grindings (7+7, 10+10 and 15+15 minutes for -300-, 200- and 106-micron products respectively). The size distributions of the test samples were given in Fig. 5. Experiments were carried out with samples ground to three different particle sizes under standard flotation conditions (Table2) and the test results are demonstrated in Table 3.

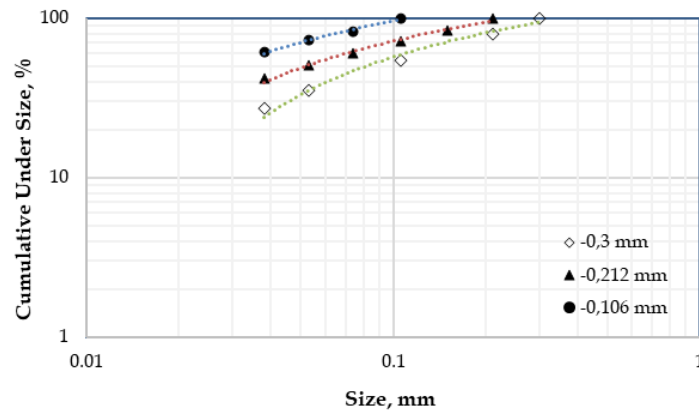


Fig. 5. Size distributions of samples ground to different particle sizes

Table 2. The conditions of flotation carried out to determine the effect of particle size

Pulp Density (%)	20
KAX Amount (g/t)	100
Pb(NO ₃) ₂ Amount (g/t)	100
AEROFROTH 65 Amount (g/t)	100
KAX Condition Time (min.)	10
Pb(NO ₃) ₂ Condition Time (min.)	30
Flotation Time (min.)	4

Table 3. Flotation results in different particle sizes

Particle Size	Products	Weight, %	Sb, %		As, %	
			Content	Yield	Content	Yield
d₁₀₀ 300 Micron	Concentrate	4.2	16.17	14.0	5.21	19.6
	Tailings	95.8	5.34	86.0	1.15	80.4
	Feed	100.0	5.89	100.0	1.36	100.0
d₁₀₀ 212 Micron	Concentrate	5.3	29.12	26.3	5.57	21.3
	Tailings	94.7	4.57	73.7	1.15	78.7
	Feed	100.0	5.87	100.0	1.38	100.0
d₁₀₀ 106 Micron	Concentrate	8.9	17.9	36.3	5.09	35.2
	Tailings	90.1	4.21	63.7	0.90	64.8
	Feed	100.0	5.83	100.0	1.39	100.0

As can be seen from the results given in Table 2; the flotation performed with which is ground under 212 microns (d_{80} : 142 microns), gives the best results in terms of both the grade and recovery. In the flotation test performed at a larger size (d_{100} : 300 micron and d_{80} : 215 micron), there are antimony losses in the tailings. In addition, it is seen that the fine size reduces the concentrate selectivity in the flotation process performed in smaller particle sizes (d_{100} : 106 micron and d_{80} : 65 micron).

3.2. The effect of pH

The pH of the pulp, which determines the surface charge of the minerals and the adsorption of the reagents on the minerals, plays a crucial role in froth flotation. Therefore, pH can also be used to act as a simple and economical depressant to achieve higher selectivity. In order to determine the appropriate pH of pulp in the flotation experiments, a series of tests were carried out by considering the Sb and As content of products. In these tests, different pH values were taken as 6.0, 6.5, 7.1, 7.5 and 8.0. All the flotation tests were conducted single stage rougher flotation. During these tests, 100 g/t KAX and 100 g/t AeroFroth 65 were used as collector and frother, respectively. Furthermore, 100 g/t $Pb(NO_3)_2$ was also used as depressant in this group of tests.

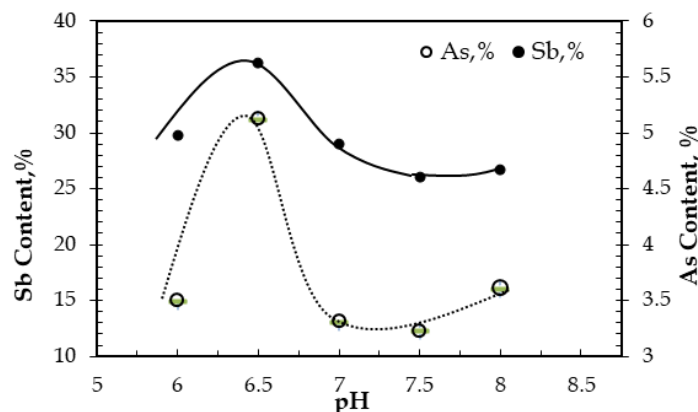


Fig. 6. The result of flotation experiments conducted to determine optimum pH (natural pH: 7.1)

According to the results given in Fig. 6, pH: 6.5 were found as an optimum pH value, considering the antimony and arsenic content of the concentrate and tailings. These results also indicated that increase on pH value resulted in an increasing oxidation on the Sulphur mineral surfaces and it can be also thought that a competition between collector and hydroxyl ion occurring for absorption on the surface of the mineral.

3.3. The effect of collector (KAX) amount

On the other hand, to reach to higher selectivity and recovery, reagent dosage plays a crucial role in flotation. Therefore, reagents especially collectors should be accurately balanced to obtain optimum

grade and recovery. Xanthate collectors are one of the most broadly used collectors for sulphide minerals flotation, especially for easy- to-treat ores where selectivity against penalty elements is not a critical problem. He noted that short chain xanthates such as sodium ethyl xanthate require much higher amounts to achieve the performance achieved with long chain xanthates at acidic pH. Popov et al. (1987) analyzed the infrared spectra of stibnite surface products and concluded that potassium amyl xanthate alone improves the buoyancy of stibnite at acidic pH due to the formation of antimony xanthate on the mineral surface. For this reason, Potassium Amil Xanthate (KAX) was used as the collecting reagent in the flotation experiments. In the flotation of the ore milled to -200 Micron in size, the conditions given in the Table 4 were kept constant, and experiments were carried out with 1% concentration KAX solution in different amounts (50 g/t, 100 g/t, 150 g/t, 200 g/t). The evaluation was made according to the Sb and As contents of the concentrates and residues obtained as a result of the flotation experiments with different collector amounts are given in Figs. 7 and 8, respectively.

According to the test results obtained; the highest Sb content (approximately 29%) was obtained using 100 g/t KAX. Besides the much lower Sb contents obtained at lower amount of KAX, higher

Table 4. The conditions of flotation carried out to determine the effect of collector (KAX) amount

Particle size d_{100} (micron)	212
Pulp Density (%)	20
Pb(NO ₃) ₂ Amount (g/t)	100
AEROFROTH 65 Amount (g/t)	100
KAX Condition Time (min.)	10
Pb(NO ₃) ₂ Condition Time (min.)	30
Flotation Time (min.)	4

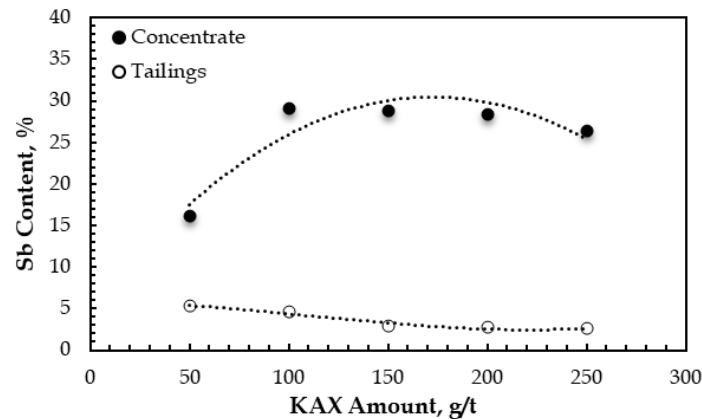


Fig. 7. The effect of KAX amount on Sb content of flotation products (concentrate and tailing)

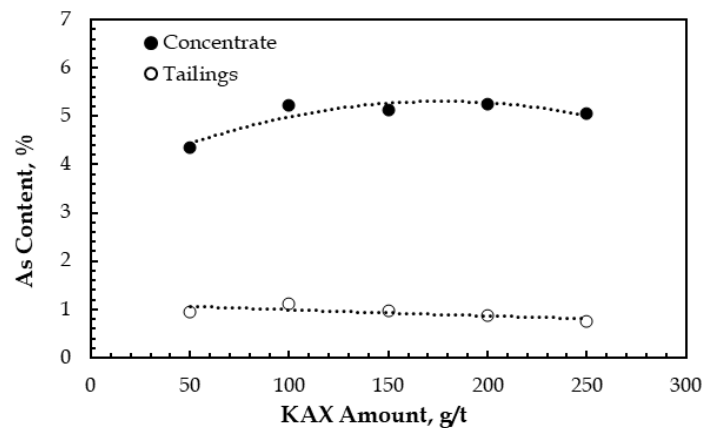


Fig. 8. The effect of KAX amount on As content of flotation products (concentrate and tailing)

contents could not be obtained at amounts higher than 100 g/t of KAX. When an evaluation was made in terms of arsenic, the change in KAX dosage and the change in the As content showed the same behavior. The reason for this is that arsenic mineral, arsenopyrite, has a sulfide structure and the flotation behavior of these minerals is similar. On the other hand, Zeta potential measurements of stibnite and arsenopyrite (Fig. 9) indicated that their surface are negatively charged within a wide pH range, allowing positive ions in solution to be attracted to the surface (Ealedona and Fujita, 2006).

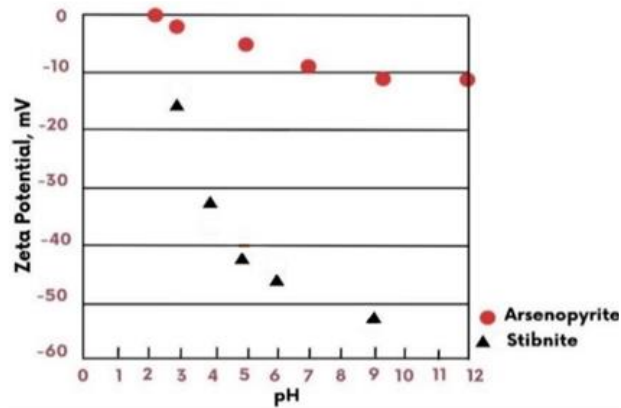


Fig. 9. Zeta potential measurements of stibnite and arsenopyrite

3.4. The effect of addition of KAX in stages on flotation

In the series of experiments carried out to determine the effect of the number of stages on flotation, the effect of the change in the amount of KAX added gradually, by keeping the amount of activator, the conditioning time and the pH constant. In these studies, experiments were carried out in 4 stages (at 150, 300, 450, 600, 750 g/t) by using 1% concentrated KAX solution. Flotation test conditions are shown in Table 5. Experiment results on the effect of gradually added KAX amount on concentrated Sb – As contents and yield is shown in Fig. 10 and Fig. 11, respectively.

Table 5. The Conditions of flotation to determine the effect of addition of KAX in stages on flotation

Particle size d_{100} (micron)	212
Pulp Density (%)	20
$Pb(NO_3)_2$ Amount (g/t)	100
AEROFROTH 65 Amount (g/t)	100
KAX Condition Time (min.)	10
$Pb(NO_3)_2$ Condition Time (min.)	30
Flotation Time (min.)	4

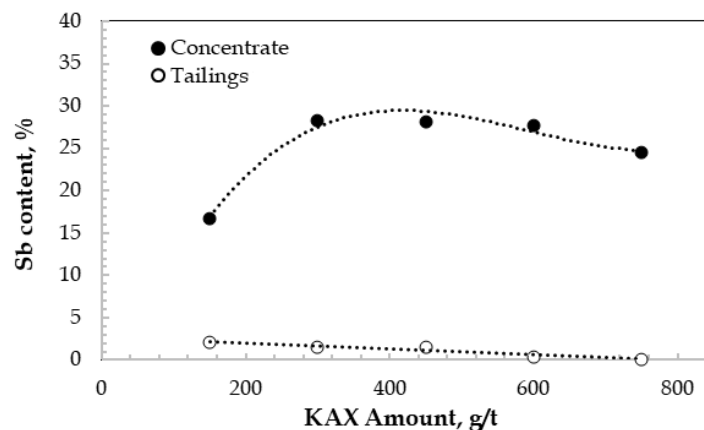


Fig. 10. The effect of gradual KAX addition on Sb content of flotation products (concentrate and tailing)

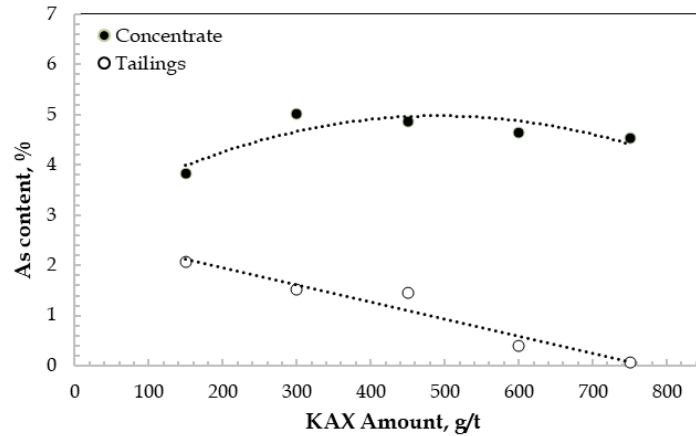


Fig. 11. The effect of gradual KAX addition on As Content of flotation products (concentrate and tailing)

In this series of experiments, the best results were obtained in three-stage experiments using 250 g/t of KAX. The bulk concentrate obtained was approximately 24.54% Sb, 4.54% As content, and the % Sb content in the discarded residue was determined as 0.08%. Although the experimental condition with the highest content in terms of bulk concentrate was 100 g/t KAX addition at each stage, it was not accepted as the optimum amount of KAX due to the high Sb content in the residue and accordingly higher Sb losses. As a result of an evaluation made in terms of recovery (Fig. 12); It has been determined that a bulk concentrate with 24.54% Sb content is obtained with 99% recovery and the experimental conditions where Sb losses are at minimum level are 250+250+250 g KAX amount.

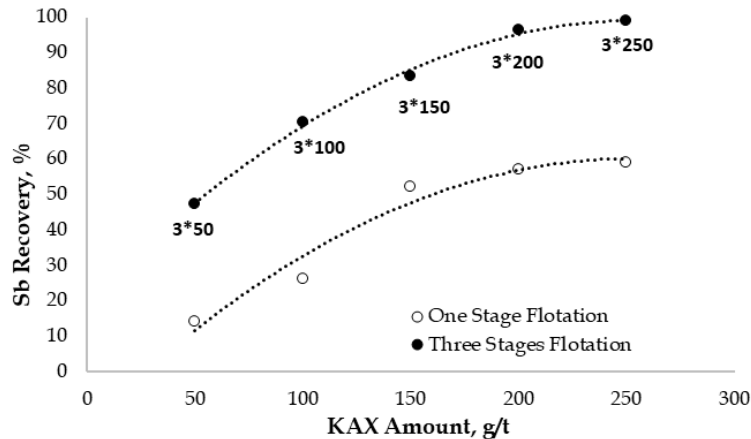


Fig. 12. The effect of gradual KAX addition on Sb recovery [3 (stages) * (dosages for every stage)]

3.5. The effect of $Pb(NO_3)_2$ amount

As known from the literature, the addition of lead nitrate in the flotation of stibnite with KAX improves the flotation conditions at 6.5 pH and more than 89% of the added lead is adsorbed on the stibnite surface as Pb^{2+} ions. Pb^{2+} adsorption on the negatively charged stibnite surface causes an increase in the zeta potential of stibnite. Studies have shown that this effect depends on the amount of added $Pb(NO_3)_2$ and is an optimum value. For this reason, experiments were carried out to determine the optimum amount of Pb Nitrate. Experimental conditions are given in the Table 6.

According to the results obtained; Addition of 100 g/t $PbNO_3$ as an activator gives the best results in terms of both concentrate content and Sb recovery. The Sb content of the bulk concentrate obtained by adding lower and higher amounts of $PbNO_3$ decreases. Accordingly, antimony losses increase in the obtained residue. The optimum flotation conditions in the bulk flotation circuit in the stibnite flotation study carried out were determined as follows, and the properties of the obtained products are given in the Table 7.

The most obvious result obtained at the end of the flotation process; the flotation abilities of antimony and arsenic minerals are similar to each other. The graph in the Fig. clearly shows that there

Table 6. The Conditions of flotation carried out to determine the effect of $\text{Pb}(\text{NO}_3)_2$ amount

Particle size d_{100} (micron)	212
Pulp Density (%)	20
KAX Amount (g/t)	250+250+250
AEROFROTH 65 Amount (g/t)	100
KAX Condition Time (min.)	10
$\text{Pb}(\text{NO}_3)_2$ Condition Time (min.)	30
Flotation Time (min.)	4

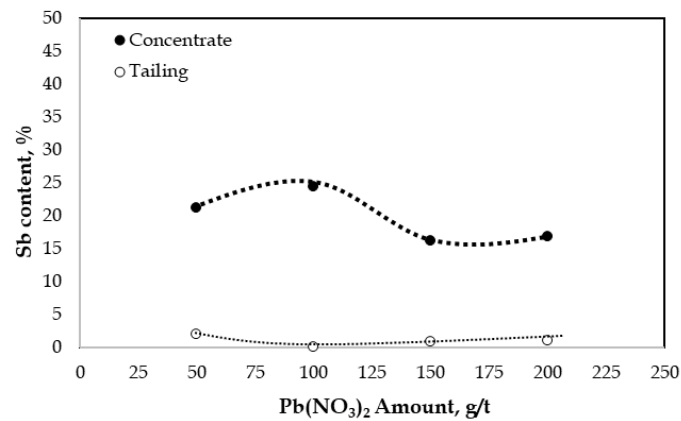


Fig. 13. The effect of $\text{Pb}(\text{NO}_3)_2$ amount on Sb content of flotation products (concentrate and tailing)

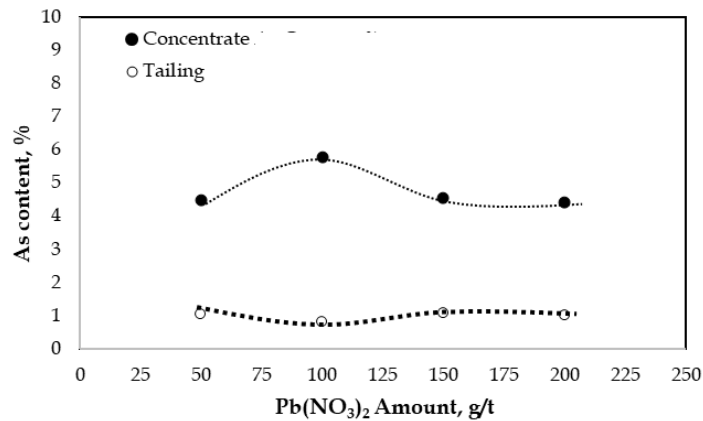


Fig. 14. The effect of $\text{Pb}(\text{NO}_3)_2$ amount on As content of flotation products (concentrate and tailing)

Table 7. Flotation conditions in rougher flotation circuits

Particle size d_{100} (micron)	-0,200
Pulp Density (%)	20
pH	6,5
AEROFROTH 65 Amount (g/t)	100
KAX (g/ton)	250+250+250
$\text{Pb}(\text{NO}_3)_2$ Amount (g/t)	100
Flotation Time (min.)	4
KAX Condition Time (min.)	10+10+10
$\text{Pb}(\text{NO}_3)_2$ Condition Time (min.)	30

Table 8. Rougher flotation results conducted optimum conditions

Products	Weight, %	Sb, %		As, %	
		Content	Recovery	Content	Recovery
Concentrate	23.5	24.54	98.9	3.69	62.6
Tailing	76.5	0.08	1.1	0.68	37.4
Feed	100.0	5.84	100.0	1.39	100.0

is a correlation between the Sb and As contents for all the flotation products obtained. This is because, as mentioned before, the surface properties and flotation behaviors of these sulfide minerals are quite close. However, considering the prices, conditions of sale, and environmental restrictions of antimony concentrate; An arsenic content of less than 0.5% is a technical and economic necessity. For this reason, in addition to increasing the Sb content in the cleaning stages, the As content should also be reduced to appropriate values.

In order to produce a salable antimony concentrate, 6 stages of cleaning flotation were applied to the pre-concentrate obtained after rougher flotation. In these flotation experiments, the pH was taken as 6.5 and the froth was scraped for 4 minutes without the addition of any reagents. Sb and As analyzes were made by taking samples from the foam drawn at each stage. The change in the Sb and As contents of the concentrates obtained after this process, which was repeated 6 times in total, is given in Fig. 16.

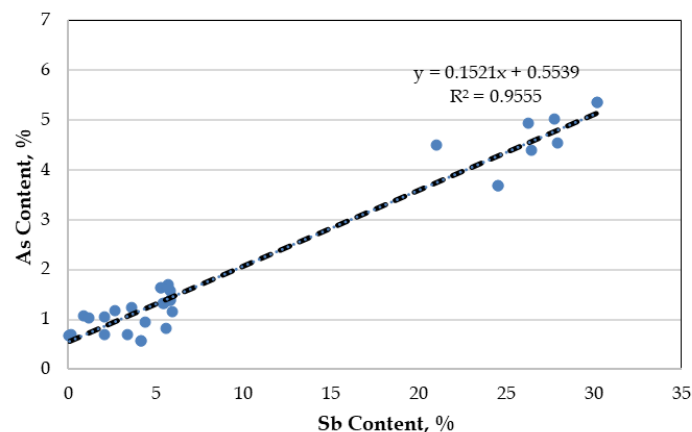


Fig. 15. The relationship between Sb and As contents in flotation products

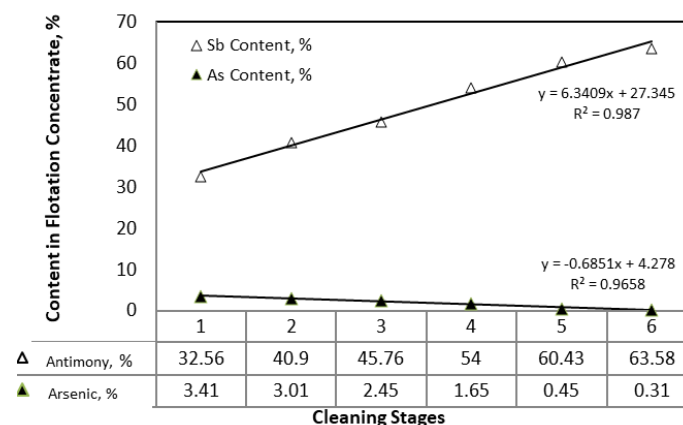


Fig. 16. The relationship between Sb and As contents in flotation products

In Rougher flotation, Sb mineral and As mineral move together and are concentrated in the floating product. Because there is no selective flotation potential in thermodynamics for Sb-As bulk concentrate with KAX as collector. For this reason, in order to achieve a selective separation, cleaning flotations were carried out on the rougher concentrate in this context. In the concentrate obtained in the single-stage

cleaning process, the increase in the Sb content and the decrease in the As content were determined and it was observed that it was not at sufficient levels. The results of the flotation experiments carried out to determine the number of steps that will allow the production of a concentrate with >60% Sb and <0.5% As content with a sufficient separation can be seen from the Fig.; It is seen that the Sb content increases and the As content decreases with the increase in the number of cleaning steps. This shows that reaching the desired levels of Sb and As contents is related to the number of cleaning steps. At the end of the experiments, a concentrate containing 63.58% Sb and 0.31% As can be obtained after a 6-stage cleaning flotation.

No reagents were added in the cleaning steps of the rougher flotation concentrate. After the Cleaning Flotation process, with the additional water, the reagent concentration decreases in the next cleaning process and the efficiency of the collector reagent becomes less. As a result, the selective separation of stibnite and arsenopyrite minerals, which have very close flotation properties, is facilitated. The selectivity in this separation process reaches maximum levels with the increase of the cleaning step, and in this study, it was possible to produce concentrate with the desired properties at the end of 6 steps.

4. Conclusions

Since the flotation properties of As and Sb minerals are very close to each other, there is no potential for Sb and As minerals to be taken as separate products in a bulk concentrate to be obtained in the flotation process using KAX as the collecting reagent. In this study, no selectivity was achieved in terms of Sb and As in the experiments carried out to find the optimum Rougher flotation conditions. In the flotation process, both Sb and As minerals float together, increasing the As and Sb contents in the Rougher Concentrate. Rougher concentrate obtained with 24.54% Sb and 3.69% As content and 98.9% Sb recovery was obtained under the following conditions;

- a) Particle size(d_{100}): 212 μm , b) pH:6.5, c) three stages 250+250+250 g/t KAX amount, d) 100 g/t $\text{Pb}(\text{NO}_3)_2$, e) 20% solids in pulp ratio, f) 100 g/t frother (AEROFROTH 65).

In the next step, it is aimed to obtain selective products in terms of As and Sb by applying cleaning flotation to the rougher concentrate produced. With the experiments in this scope, the flotation abilities of As minerals, which float together with the Sb mineral, are weakened and remain in the residue with each cleaning step. As a result, the content of Sb concentrate increases. Within the scope of this study, Sb content greater than 60% (63.8%) and 83% Sb recovery were obtained with 6 stages of cleaning.

Consequently, an antimony concentrate should be evaluated together for both its Sb content and its As content, which may prevent from its sale. Since the surface properties are close to each other in the flotation of this existing mineral, it is necessary to be a property difference for a selective separation. This is usually achieved by controlling with the flotation conditions or by the amount and types of reagents used. This study shows that without applying these transactions on this type of ore, a surface property difference can be achieved with the number of cleaning process steps and suitable concentrates with Sb and As content can be obtained.

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