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DROPLET FLOTATION IN METALLURGICAL MELTS

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Abstract
The paper considers one of the main mechanisms of transition of precious and non-ferrous metals into slag. This happens during the melting of sulfide materials. Sulfide droplets together with their associated precious metal particles are carried into the slag by gas bubbles. The size of metal particles reaches up to 25 microns. The high values of the calculated adhesion values for gold – matte and platinum – matte systems indicate the strength of metal adhesion to sulfide droplets. Analytical expressions describing flotation are obtained.

Keywords*: sulfide droplet, particle, matte, slag, bubble, flotation, gold, platinum, silver*

1. INTRODUCTION

Liquid droplet flotation is often used to purify industrial and wastewater from oil [1-3], mercury [4]. Geologists consider flotation as a method of transporting metal and sulfide droplets to the upper layers of magma [5].

Most of the world's production of copper, nickel, and platinum group metals is carried out by melting sulfide ores and concentrates into matte [6-7]. In the settling chambers of the furnaces, the melt is separated into slag and matte. Sulfide droplets are deposited in the slag into the matte layer. Losses of non-ferrous and precious metals are largely since some of the sulfide droplets do not reach the matte boundary and are removed together with the slag into landfills. It was previously shown that these droplets are retained in the slag due to flotation by gas bubbles [8]. However, if conditions are created that increase the flotation rate, this will lead to the accumulation of sulfide droplets due to coagulation. Further, the rate of droplet deposition will increase, and the "mechanical" losses of valuable components will decrease [9-11].

Thus, the study of the droplet flotation process in metallurgical melts is an actual problem.

The purpose of the study is to consider the conditions of flotation of liquid sulfide droplets in oxide melts.

2. EXPERIMENTAL

The samples are represented by platinum-containing copper-nickel sulfide ore, gold-containing copper-pyrite ore and silver-containing sulfide material from landfills of host rocks. In order to determine the forms of existence of precious metals in sulfide melts using microscopes, their content was increased by adding dispersed metals (platinum to 1000 ppm, gold to 1300 ppm and silver to 100 ppm). The concentrations of chemical elements in the starting material and in the melting products were determined on Spectroflame Modula S atomic emission spectrometer with inductively coupled plasma. The melting products were analyzed on a Vega LMS scanning electron microscope equipped with an Xplore30 energy dispersive attachment. The materials were heated and melted in corundum crucibles in a resistance furnace at temperatures of 1300-1350 °C.

3. RESULTS AND DISCUSSION

Metallic gold, alloy (Au, Cu), aurostibite $AuSb_2$, alloy (Pt, Fe), and silver-containing particles were found during the study of matte samples after melting sulfide materials. The matte consists mainly of troilite (FeS), with small amounts of copper sulfides, Fe-Ni alloys, and iron oxides. Slags are represented by a porous brownish glassy mass. They contain many sulfide droplets (up to 15 vol.%). Droplet size reach 4 mm. The composition of the droplets is like that of the matte. The droplets contain teardrop-shaped gold particles (up to 17 μm, Fig. 1a), crystals (Pt, Fe) of predominantly needle shape and their aggregates (up to 25 μm, Fig. 1b), particles containing silver of irregular shape (up to 10 μm, Fig. 1c).

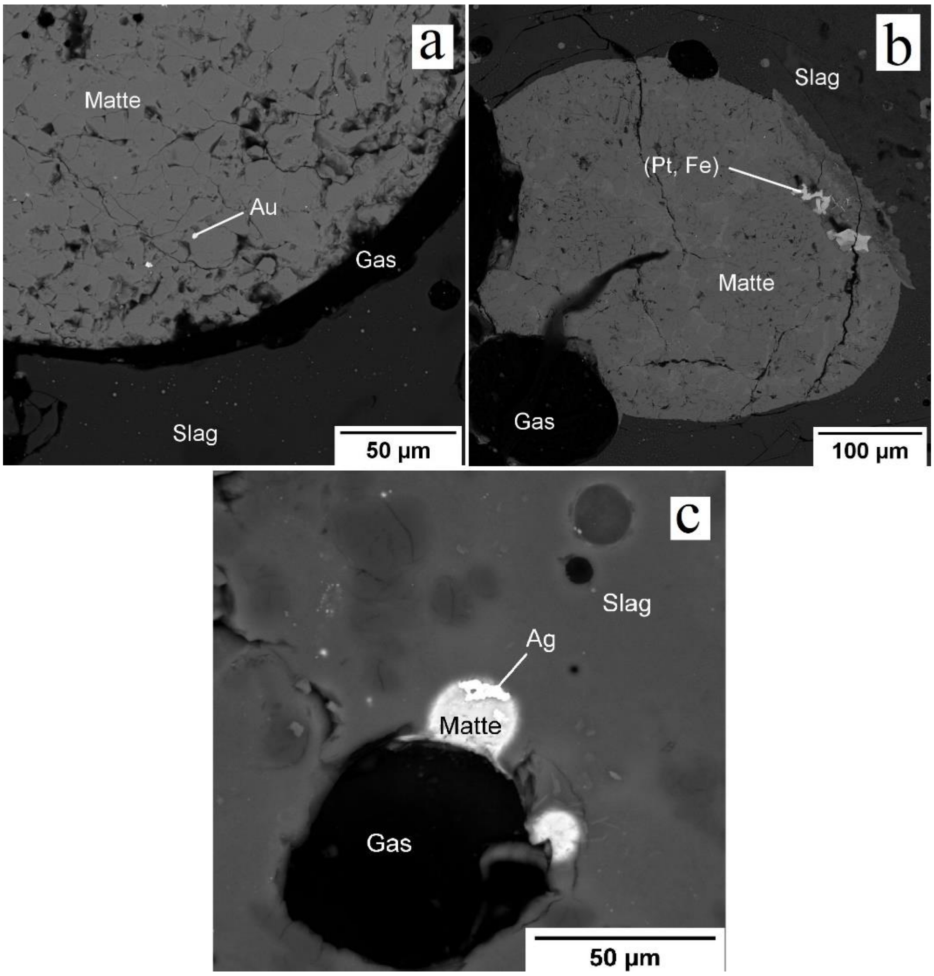

Figure 1 Sulfide droplets (Matte) attached to gas bubbles in slags after melting sulfide materials. The shooting was done in BSE mode. Sulfide droplets contain a – gold (Au), b – alloy (Pt, Fe), c – silver (Ag)

Chemical analysis of copper-nickel sulfide ore smelting products (Table 1) shows that the slag contains from 0.4 to 15% of precious metals. In industrial conditions, after smelting sulfide materials in ore-thermal and depleted electric furnaces, up to 1-2% of these metals pass into slag [12-13].

Table 1 The content of precious metals in matte and slag after smelting of copper-nickel sulfide ore, ppm

Materials	Metal content						
	Ru	Rh	Pd	Ir	Pt	Au	Ag
Matte	0.21	2.08	5.36	0.02	1.26	1.77	5.9
Slag	0.004	0.07	1.66	0.013	0.13	0.42	0.67

The most likely reason for the transition of dispersed sulfide droplets from matte to slag is their flotation by gas bubbles. Bubbles appear due to the decomposition of sulfides [8-11]. During the passage of the boundary of two immiscible liquids (matte and slag), the bubble can capture and float a drop of heavier liquid (matte). The conditions of flotation [10, 14] are as follows. The force of the drop's adhesion to the bubble must be greater than its gravity. The buoyant force applied to the bubble must be greater than the gravity of the drop:

$$\begin{cases} 2\pi r\sigma_{m-s}\sin\theta > c\frac{4}{3}\pi r^3\rho_m g, \\ \frac{4}{3}\pi R^3(\rho_s-\rho_g)g \geq c\frac{4}{3}\pi r^3(\rho_m-\rho_s)g \end{cases}, \quad (1)$$

where r is the radius of the sulfide droplet;

R is the radius of the gas bubble;

σ_{m-s} is the interfacial tension at the matte – slag boundary;

θ is the angle between the tensions at the matte – slag and matte – gas boundary;

c is the volume fraction of the whole droplet;

p_m, p_s, p_g are the densities of the matte, slag and gas accordingly;

g is the acceleration of gravity.

For experimentally studied slag and matte, the maximum possible radius of floated sulfide droplet is about 4.2 mm. Sulfide droplets with a radius of up to 2 mm were found in the slags. The size of the bubble may be smaller than the size of the sulfide droplet that this bubble floats. This is confirmed experimentally [14].

For ultrafine particles and sulfide droplets, flotation is possible not only due to the formation of a three-phase wetting perimeter, but also due to the action of wedging pressure [15].

Since gold droplets and platinum solid particles are deposited in the slag together with sulfide droplets, their adhesion W_A to matte was evaluated. These metals interact with the components of the matte. Therefore, we are talking about dynamic wetting angles and dynamic (non-equilibrium) adhesion. As for the gold droplets, it does not matter whether the dynamic or equilibrium tension values act on it. Only the magnitude of these tensions is important. The adhesion for the gold – matte – slag and platinum – matte –slag systems was calculated using the Dupree equation:

$$W_A = \sigma_{Me-m}(1+\cos\theta), \quad (2)$$

where σ_{Me-m} is the interfacial tension of the metal–matte;

θ is the wetting angle.

The wetting angles included in equation (2) were determined from images of the gold – matte – slag and platinum – matte – slag boundaries. The images were taken with an electron microscope. The adhesion work for the gold – matte system is ~ 1600 mJ/m^2, for platinum – matte system is ~ 3000 mJ/m^2 [14]. The values obtained are very significant and comparable to the work of cohesion for gold and platinum. Consequently, these metals are firmly bonded to the matte droplets and move with them in the slag. The adhesion values are also consistent in order of magnitude with those calculated based on the theory of dielectric formalism in the absence of a gap between metal surfaces: Cu/Al – 3100, Fe/Cu – 4200 mJ/m^2.

4. CONCLUSION

The paper considers one of the main mechanisms of transition of precious and non-ferrous metals into slag. This happens during the melting of sulfide materials. Sulfide droplets together with their associated precious metal particles are carried into the slag by gas bubbles. The size of metal particles reaches up to 25 microns. The high values of the calculated adhesion values for gold–matte and platinum–matte systems indicate the strength of metal adhesion to sulfide droplets. Analytical expressions describing flotation are obtained.

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