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Processing double refractory gold-arsenic-bearing concentrates by direct reductive melting

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ABSTRACT

Iron arsenides may be the key to extraction of gold from existing refractory ores such as that at Bakyrchik, Kazakhstan, an ore body containing an estimated £8.5 billion reserve of gold. Gold is not extractable without significant ecological contamination from the associate arsenopyrite mineralisation. A new method for gold recovery from refractory gold-arsenic-bearing materials, based on direct reductive melting (DRM) of the concentrate has been developed, which locks As into relatively benign iron arsenide phases, whilst gold is extracted into lead alloy. The method has been filed as a patent with the Patent Office of the Republic of Kazakhstan.

1. Introduction

Mining metallurgists classify gold ores into two categories according to their amenability to a conventional "cyanidation-carbon adsorption" gold extraction technology: "free milling" and "refractory" (La Brooy et al., 1994). The former are those ores from which more than 90% of the gold can be extracted by simple gravity techniques or direct conventional cyanide leaching, whilst under the same treatment the latter ores give much lower recovery and require more complex methods to release gold (Vaughan, 2004). The term double refractory is applied when refractoriness of the gold ore is exacerbated by the presence of preg-robbing carbonaceous material. The problem of double refractory ores is not well understood. It is a current topic of investigation by a few mining companies and research groups in terms of processing. Several pre-cyanidation treatment methods have been developed for double refractory gold ores, such as flotation and depression, blanking, the use of activated carbon or resin in the leach, roasting, chemical oxidation and bioleaching. These technologies are reviewed in details by Afenya (1991). However, in most cases they do not guarantee high gold recovery upon cyanidation (Fridman et al., 1980; Lodeischikov, 1999). Double refractory ores are found across the globe (Hausen, 1989; Guay and Gross, 1981; Osseo-Asare et al., 1984; Zhuchkov, 1970; Nice, 1971; Radtke and Scheiner, 1970; Leaver et al., 1930; Adamson, 1972). For example, Nevada, Mother Lode, Gold Quarry, Gold Acres, Getchell Mine, Maggie Creek, and Jerritt Canyon in the United States of America; McIntrye Porcupine, Kerr Anderson, and Gold Strike in Canada; Prestea, Ashanti, and Bogosu Mine in Ghana; Natalkinck in Russia; Witwatersrand in South Africa; Bakyrchik in Kazakhstan, Morro Velho and Queiroz Mine in Brazil, Cosmo Howley and Fortnum in Australia; Waihi/Paeroa in New Zealand; Laizhou and Neilanggou in China.

Of all nations, the Republic of Kazakhstan has the sixth largest reserves of gold (Official Site of the President of the Republic of Kazakhstan, 2016). With the depletion of the oxide lode deposits, gold extraction is moving towards the mining of increasingly technologically difficult ores in Kazakhstan and generally throughout the world (Vaughan, 2004). We have focussed on Bakyrchik ore as an accessible example of a generic type of refractory ore that is now being considered for exploitation across the globe. The Bakyrchik ore deposit is the largest native gold deposit in Kazakhstan and one of the largest gold deposits in the world. It is a part of Kyzyl Gold Project, which also includes Bolshevik gold deposit (Fig. 1). According to a feasibility study carried out by the international mining consultants Roscoe Postle Associates, based on drill hole data available on 31 July 2013, the Bakyrchik deposit contains approximately 10.5 Moz of gold (300 t) (Polymetal International Plc, 2016), with an equivalent value of more than £8.5 billion. The deposit is located in the Auezov village in north-eastern Kazakhstan, about 75 km south-west of East Kazakhstan's centre, the city Oskemen (previously known as Ust-Kamenogorsk), which

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Fig. 1. Kyzyl Gold Project (Turquoise Hill Resources, 2016).

is built on the non-ferrous metals industry. The mine has road and railway connections to Europe, Russia, and China.

Bakyrchik is a hydrothermal gold-ore deposit within the Kalba gold belt (Poltorikhin, 1974). It consists of a series of mineralised lenses lying within the 11.5 km long Kyzyl Shear Zone, defined in the early 1950s by surface trenching. Gold mineralisation is hosted within sheared carbonaceous sediments in the fault zones, and is principally contained within sulphide mineralisation. The geology and mineralisation of Bakyrchik has been previously described (Narseev et al., 2001). The mineralogical composition of the ore is represented by three main mineral associations (Poltorikhin, 1974): (1) pyrrhotite, globular pyrite, marcasite, gregite, pyrite, and carbonates (the so-called "barren stage"); (2) quartz, pyrite, arsenopyrite, and gold (known as the "first productive stage"); and (3) pyrite, sphalerite, galena, chalcopyrite, tennantite and tetrahedrite, bismuthinite, and aikinite (the "second productive stage"). The total sulphide content of the ore varies from 0.5% to 10%. Throughout, gold is dispersed in pyrite and arsenopyrite in the form of microscopic and submicroscopic inclusions. Larger gold particles (up to 1 mm in size) are found along microfractures in pyrite and arsenopyrite, and occur in association with galena, sphalerite, chalcopyrite, quartz, and carbonate. Gold can also be found as inclusions in quartz-sericite-carbonate assemblages, surrounding sulphides. Free gold of 900 fineness (90% in the alloy) constitutes no more than 10% of the recovered amount and has a positive correlation with arsenic. The quartz in shear zones does not contain gold (Levitan, 2008).

1.1. Refractoriness of Bakyrchik ore

Mineralogical studies indicate that the majority of the gold is encapsulated by arsenopyrite and, to a lesser extent, pyrite (Table 1). Cyanides are unable to access the locked gold. Hence it is necessary to induce decomposition of iron sulphide minerals in order to release the gold particles. All pre-treatment processes are based on the oxidative destruction of sulphides: thermal, chemical or biological (Haque, 1987).

The refractoriness of the Bakyrchik ore is also exacerbated by the presence of carbonaceous matter (up to 4%), which has high sorption capacity with respect to gold-cyanide complexes or pregnant leach solution, and further excludes the use of conventional cyanide leaching methods. Carbon removal at the enrichment step usually significantly reduces subsequent gold recovery. Direct cyanide leaching of the Bakyrchik concentrates allows recovery of only 26–28% of the gold.

Further difficulties arise from the presence of arsenic in the ore - up to 1.4%. This complicates recovery because, although roasting can potentially liberate gold, in air this would be accompanied by arsenic release into the atmosphere in the form of As_2O_3. The significant quantity of arsenic in the concentrate during roasting raises serious environmental concerns. The condensation of As_2O_3 remains the principal problem in roasting, in terms of its hazardous nature in both air and water contamination. Furthermore, safe disposal of the arsenic compounds in the mine waste, in adherence with environmental legislative norms, is problematic.

Table 1
Gold and other admixture elemental concentrations in the monomineralic fractions of pyrite and arsenopyrite of the Bakyrchik ore, ppm Poltorikhin (1974).

Mineral	Pb	Cu	Zn	Ni	Co	Ga	Sb	As	Ag	Au
Pyrite	1100	300	2500	1500	950	–	1000	60,000	–	25
Arsenopyrite	50	400	1300	300	250	2	300	60,000	8	400