



Extraction of tellurium from lead and copper bearing feed materials and interim metallurgical products – A short review



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ARTICLE INFO

Keywords:

Tellurium
Extraction
Pyro-hydrometallurgy
Lead/copper minerals

ABSTRACT

Tellurium is a rare metalloid with relatively low abundance in the earth's crust (0.001–0.005 g/t) compared to the crustal abundance of gold (0.0031 g/t) and platinum (0.0037 g/t). It is mainly used as an additive to an assortment of compounds and alloys in various industries. It is primarily produced from intermediates or by-products of metallurgical processes. About 90% of tellurium is produced from copper anode slimes generated during electrolytic refining of blister copper and the remainder from processing of bismuth, lead and gold ores. The production of CdTe solar cells photovoltaic (PV) modules for generation of low-cost solar electricity consumes 40% of global tellurium output. This review summarises the current knowledge on distribution of tellurium species in processing of tellurium bearing minerals and identifies some metallurgical process streams and interim products from lead and copper bearing feed materials which could be valuable sources for extraction of tellurium.

1. Introduction

The chemical properties of tellurium are similar to those of selenium and sulphur as they belong to column 16 (O, S, Te, Se, Po) in the periodic table of elements. It exhibits semi-conducting and amphoteric properties (Awad and Issa, 1953). Tellurium was first discovered in a gold ore from Transylvania (Romania) where it was originally thought to be a compound of antimony or bismuth (Sindeeva, 1964; Chizhikov and Shchastlivyi, 1970; Cooper, 1971). It is the general belief that tellurium originates in the exploding stars where it is produced through rapid neutron capture process or “r-process” (Kavlak and Graedel, 2013). It is a rare metalloid with relatively low abundance in the earth's crust estimated at 0.001–0.005 g/t compared to the crustal abundance of gold and platinum of 0.0031 and 0.0037 g/t, respectively (Cooper, 1971; Kavlak and Graedel, 2013).

Tellurium metal or compounds are used in many applications from being pigments in ceramics, an additive in steel, to improving reflectance in glass optical fiber, to being a catalyst in chemical manufacturing. But its most renowned use is in production of cadmium telluride semiconductors in solar panels. Tellurium alloys give the greatest solar cell electrical generation efficiencies allowing for effective and low cost power generation (First Solar, 2013). The price of tellurium metal has increased over the years and peaked in 2011 when tellurium price was at about 350 USD/kg before a falling back to traditional pricing of less than 50 USD/kg (Fig. 1). The change in the price of tellurium has been

driven by increasing market demand particularly from China for its end uses and growing demand for photovoltaic (PV) solar cell manufacturing (Candelise et al., 2012). Amorphous silicon and copper indium gallium selenide were the two principal competitors of CdTe in thin-film photovoltaic solar cells (US Geological Survey, 2017).

Despite the fluctuation in price of tellurium metal and its relative rarity, the economic potential and increasing demand due its growing applications has continued the research interest in extraction of tellurium from tellurium bearing ores or metallurgical byproducts. Currently, more than 90% of tellurium is produced from a by-product of copper smelting and electrolytic refining of crude copper metal (US Geological Survey, 2008; Wang, 2011). The remaining 10% of tellurium production is from (i) skimming during smelting and refining of lead, (ii) gold ores and (iii) flue dusts generated during smelting of bismuth, nickel and copper ores (Chizhikov and Shchastlivyi, 1970).

The extraction processes of tellurium from tellurium bearing-materials have been reported as a challenging and complicated process (Chizhikov and Shchastlivyi, 1970; Cooper, 1971). The methods and the degree of treatment of tellurium-bearing ores affect the efficiency of concentration and distribution of tellurium species as well as extraction of tellurium from metallurgical intermediate products or byproducts. This short review describes the extraction and distribution of tellurium in various byproducts in the treatment processes of tellurium bearing copper-lead ores.

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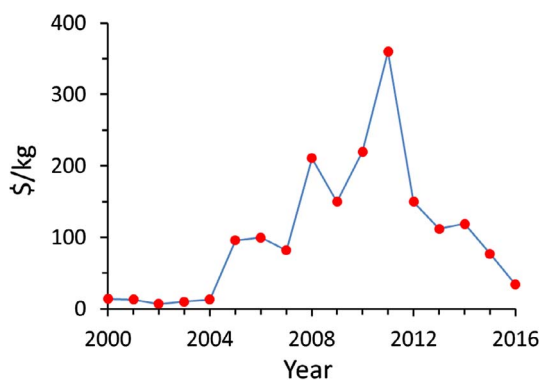


Fig. 1. Tellurium price (purity 99.95%); Ref. Selenium and tellurium mineral yearbook, 2013; U.S Geological Survey (2003, 2010, 2011, 2012, 2017).

2. Minerals

Tellurium minerals listed in Table 1 have been reported to occur mainly with sulphides of heavy non-ferrous and noble metals. The most common pyritic deposits associated with tellurium minerals are pentlandite ((FeNi)₉S₈), chalcopyrite (CuFeS₂), pyrite (FeS₂), sphalerite (ZnS) and pyrrhotite (FeS) (Cooper, 1971; Mohammad, 2009). Tellurium occurs as divalent anions in primary indigenous minerals and interacts with metal and hydrogen ions to form telluride compounds (Sindeeva, 1964). The commonly encountered tellurides are those of silver and gold such as calaverite (AuTe₂), petzite (Ag₃AuTe₂), hessite (Ag₂Te), krennrite ((Au, Ag)Te₂) and malonite (NiTe₂). An example of these ore deposits are found in Cripple Creek in Colorado (USA), Emperor and Tavatu in Fiji, Kalgoorlie in Western Australia and in Golden Sunlight, Montana (USA) where tellurium mineralization occurs in veins, fissures and breccias pipes in tertiary rocks (Sindeeva, 1964; Chizhikov and Shchastlivyi, 1970; Cooper, 1971; Marsden and House, 2006; Zhang et al., 2010). Tellurium also interacts with other elements in the same group where an isomorphic substitution occurs (Chizhikov and Shchastlivyi, 1970). In this respect, tellurium forms mixed or single minerals with oxygen, selenium and sulphur as well as in association with other elements.

Mcpheil (1995) studied thermodynamics of aqueous tellurium species at higher temperature and established that, a vapor-phase transport of tellurium is important in the formation of telluride-bearing

epithermal ore deposits. The redox conditions during ore formation and pH of the medium have been reported to have a profound effect on behavior of tellurium during mineral formation. Chizhikov and Shchastlivyi (1970) reported that tellurium concentrates itself in low temperature ores of hydrothermal mineralization where it occurs as sulphosalt. In the secondary minerals formation, tellurium is known to occur as the native element and as ions of bismuth and mercury salts of tetravalent tellurous and hexavalent telluric acids: Te(IV)O₃²⁻, Te(VI)O₄²⁻, Te(VI)O₆⁶⁻ (Chizhikov and Shchastlivyi, 1970). In the most oxidizing environment, tellurium becomes tetravalent and hexavalent with ease and forms tellurites and tellurates. The best known tellurite and tellurate minerals are those of iron, bismuth and mercury (Table 1).

3. Tellurium distribution during metallurgical unit operations

3.1. Lead smelting

The main sources of tellurium in the lead smelting process are copper dross (mass of solid impurities floating on a molten metal), alkaline skimming and rich sliver dross intermediate products (Chizhikov and Shchastlivyi, 1970; Smirnov, 1977; Davey, 1980; Margulis and Zaitsev, 1985). Tellurium accumulates in these byproducts during refining of crude lead bullion to high purity lead metal. Table 2 lists concentrations of tellurium in some copper-nickel ore deposits in Russia (Sindeeva, 1964; Chizhikov and Shchastlivyi, 1970). Table 3 presents the tellurium content in various minerals. Galena is one of the minerals with high tellurium content (0.37% Te); however, not all galena concentrates contain tellurium. Chizhikov and Shchastlivyi (1970) reported the distribution of tellurium during flotation of polymetallic ores, where Te reported to lead concentrates (32%), copper concentrates (8–10%) and pyrite concentrates (18%). Although the tellurium content is higher in lead concentrates, a component of processing polymetallic tellurium bearing ores, only a small percentage of that tellurium is recovered from smelting of lead sulphide ores (Chizhikov and Shchastlivyi, 1970).

Chizhikov and Shchastlivyi (1970) described the agglomeration roasting of lead sulphide concentrate where 92–98% of tellurium is reported to remain in the sinter while 3–7% reported to metallurgical dust. In the blast furnace operation, 30–40% of tellurium in the sinter reported to lead bullion, 8–10% to matte, 25% to waste slag and 25% to furnace dust (Fig. 2). The tellurium fraction that reported to lead

Table 1
Minerals of tellurium as tellurides or other chalcogens.

Mineral type	Mineral	Formulae	Mineral	Formulae	
Tellurium as tellurides	Native tellurium	Te	Antamokite	(Au, Ag)Te	
	Hessite	Ag ₂ Te	Krennerite	(Au, Ag)Te ₂	
	Calaverite	AuTe ₂	Goldschmidtite	(Au, Ag) ₂ Te	
	Sylvanite	AuAgTe ₄	Niggliite	PtTe ₃	
	Montbrayite	Au ₂ Te ₃	Melonite	NiTe ₂	
	Muthmannite	(Ag, Au)Te	Stutzite	Ag ₄ Te	
	Speculite	(Au, Ag)Te	Piccardite	Cu ₄ Te ₃	
	Coloradoite	HgTe	Weissite	Cu ₅ Te ₃	
	Frohbergite	FeTe ₂	Wehrlite	Bi ₃ Te ₂	
	Tellurobismuthite	Bi ₂ Te ₃	Hedleyite	Bi ₇ Te ₃	
	Altaite	PbTe	Empressite	Ag _{5-x} Te ₃	
	Tellurium as other chalcogens	Tetradymite	Bi ₂ Te ₂ S	Grunlingite	Bi ₄ S ₃ Te
		Nagyagite	Au ₂ Pb ₁₀ Te ₆ Sb ₂ S ₁₅	Oruette	Bi ₃ S ₄ Te
Joseite		Bi ₃ Te(S, Se)	Arseniotellurite	Te ₂ As ₂ O ₇	
Colusite		(Cu, Fe, Mo, Sn) ₄ (S, As, Te) ₃₋₄	Selenotellurium	Se ₂ Te ₃	
Goldfieldite		Cu ₆ Sb ₂ (S, Te) ₃	Dunhamite	PbTeO ₃	
Tellurium Silver		Ag ₂ Bi ₂ Te ₂ S	Csiklovaite	Bi ₂ TeS ₂	
Tellurite		TeO ₂	Emmonsite	Fe ₂ O ₃ ·TeO ₂	
Ferrotellurite		FeTeO ₄	Magnolite	HgTeO ₄	
Durdenite		Fe ₂ (TeO ₃) ₃ ·4H ₂ O	Montanite	BiTeO ₆ ·2H ₂ O	

References: Sindeeva (1964), Chizhikov and Shchastlivyi (1970), Cooper (1971), and Zhang et al. (2010).

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