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Review Article

Review of barriers to reduce mercury use in artisanal gold mining

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ABSTRACT

This article reviews the use of amalgamation in artisanal gold mining (AGM) and the barriers to reducing mercury use and emissions from the sector. In 2012, AGM accounted for approximately 12% of all the gold produced in the world. The main method of extraction used is gold amalgamation, a process which accounts for the release of between 1000 and 1600 tonnes of metallic mercury every year. The availability of mercury is expected to decline since the international market is shrinking as a result of international policies. Major producers and traders are discontinuing efforts to market the metal. Unfortunately, gold amalgamation is still in wide use around the world, despite its elevated price in a restricted market. Alternative gold extraction methods for artisanal miners have been attempted, but with limited success. This paper brings to light the perceptions of different stakeholders, including governments, communities, academics, and the artisanal gold miners themselves, all of whom have impeded progress towards improved gold processing practices. Capacity building, education, and the presence of trainers prior to introducing a new approach are keys to facilitating change.

Contents

1. Introduction and background

Approximately 30 million individuals spread over virtually all developing countries are involved in extracting over 30 different minerals using rudimentary techniques (Veiga and Baker, 2004). Gold is the predominant product being worked since the price of the metal has increased three fold over the past 10 years. Its extraction on a small scale, however, induces extremely high levels of river siltation, mercury pollution, and many other environmental and social problems (Velasquez-Lopez et al., 2010).

In 2004, annual gold production from Artisanal Gold Mining (AGM) was estimated at 20–30% (500–800 tonnes) of total global production (Swain et al., 2007). A more recent study (Seccatore, 2012) placed production from AGM at about 392 tonnes/a or 12.2% of total output (2828 from organized mines (WGC, 2013) + 392 tonnes from AGM = 3220 tonnes).

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Annual mercury releases to the environment from AGM operations based on UNEP (2013) and Swain et al. (2007) is 1400 tonnes and 1000 tonnes, respectively giving a global range of average ratio of tonnes of Hg_{lost} to tonnes of $Au_{produced}$ between 2.5 and 3.5. Recently, Koekkoek (2013) projected the annual amount of mercury released by AGM in 70 countries to be 1608 tonnes. This estimate represents 93% of the countries that use mercury in AGM.

The environmental and health impacts of mercury pollution from AGM have been well-documented in different parts of the world (Pfeiffer et al., 1989; Malm et al., 1990, 1995; Ikingura and Akagi, 1996; Veiga, 1997; Lacerda, 1997; Olivero and Solano, 1998; Malm, 1998; Harada et al., 1999; Akagi et al., 2000; Drake et al., 2001; Wasserman et al., 2003; Eisler, 2004; Castilhos et al., 2006; Böse-O'Reilly et al., 2008; Cordy et al., 2011, 2013). It seems that the health effects of mercury vapour emissions in workers and families living in mining towns is much more evident and dramatic than the effects of methylmercury by fish ingestion in mining communities (van Straaten, 2000; Drasch et al., 2001; Ogola et al., 2002; Feng et al., 2006; WHO, 2013; Sieber and Brain, 2014). The main cause of environmental problems related to mercury releases is amalgamation of the whole ore (Spiegel and Veiga, 2010) whereas the main health problem is caused by inhalation of metallic mercury vapours when amalgams are thermally decomposed without using a condenser or filter (Veiga and Baker, 2004).

The objective of this paper is to provide a review of mercury use in AGM identifying perceptions from different stakeholders (governments, NGOs, academics and artisanal gold miners) around the world that may have created barriers to introducing Hg-free practices or to reduce mercury pollution from artisanal gold miners. The data and comments presented in this article are the result of over 35 years of practical experience of the authors in the field of mercury and artisanal mining.

2. Gold amalgamation: an overview

Amalgamation is one of the oldest gold extraction methods. When mercury is added to gold and silver ores, it forms an amalgam (or paste) following contact with these metals. Mercury amalgamates all metals except iron and platinum. The heavy mass of liquid mercury with the solid amalgam inside can be separated from other minerals through panning. The amalgam is then squeezed by hand in a piece of fabric to eliminate the excess liquid mercury not bound to gold. The resulting amalgam consisting of 40–50% mercury can be separated from the gold by decomposition using a propane or gasoline torch at temperatures around 460 °C. This process produces a gold *doré* containing about 2–5% residual mercury, depending on the effectiveness of the evaporation process (Veiga and Hinton, 2002). In some cases, such as those observed in some African countries, when amalgams are burned in low-temperature bonfires, the *doré* will contain as much as 20% mercury (Veiga et al., 2006).

Two methods are used by operators to extract gold with mercury:

(1) amalgamation of a gravity concentrate;
(2) amalgamation of the whole ore.

The first method dramatically reduces mercury releases (losses) to the environment since only a small amount of material (concentrate) is amalgamated. The second method is responsible for the largest losses of mercury to the environment (Veiga and Hinton, 2002).

Most operators have the wrong perception that amalgamation is very efficient at extracting gold and that no mercury is lost in the process. When a miner is asked how much mercury he or she lost in the amalgamation process, they virtually all answer, "almost nothing". However, when they are asked how much mercury they buy every month, they reveal the real mercury losses, since they would not buy mercury if they did not need it (Veiga and Baker, 2004).

Amalgamation is not complicated, but gold must be liberated from the gangue for the process to be effective. Mercury combines with gold to form a wide range of compounds, from $AuHg_2$ to Au_8Hg (Taggart, 1945). When amalgamating a concentrate, mercury losses occur mainly because of "mercury sickening" and loss of coalescence (or "flouring"). "Sickening" is caused by mercury oxidation or impurities such as oil, grease, clay minerals, sulfates, and sulfides on the mercury surface while "flouring" is the dispersion of mercury into small drops caused by "sickening" or by mechanical forces such as grinding (Beard, 1987). It is believed by the miners in most AGM regions of the world that addition of "amalgamation-aiding reagents" avoids complete mercury sickening and flouring, therefore eliminating mercury losses. In many parts of the world, miners add lemon juice, brown sugar, caustic soda, quicklime, tooth paste, baking powder, guava leaves, urea, cyanide, urine, or detergent to reduce "flouring" (Veiga et al., 2006). There is no study proving that such reagents increase the capacity of mercury to hold together and avoid formation of droplets. Neither are there studies about how these reagents work, although some do appear to be effective. Alteration of mercury's surface tension or adsorption of such reagents to act as a surfactant is a possible way of enhancing mercury coalescence.

An experiment conducted by Veiga et al. (2009) demonstrated to Ecuadorian miners that amalgamation extracted only 26% of the gold from a gravity concentrate, whereas cyanidation extracted more than 90%. The low efficiency of gold extraction was attributed to the oxidation of the mercury. Pantoja and Alvarez (2000) recommended using an electrolytic process to remove mercury oxidation layers and form sodium-amalgam, which is more efficient in gold amalgamation than mercury alone. Their results were impressive, showing an increase of recovery of around 60% (using regular mercury) to 92% (using "activated" mercury). Mercury is activated in an electrolytic process with a 10% NaCl solution. Metallic mercury is connected via a copper wire to the negative pole of a 12-V motorbike battery and a rod of graphite that can be obtained from an old radio battery connected to the positive pole for 15 min (Fig. 1). "Activated" mercury is much more coalescent than "sick" mercury. As mercury salts are soluble at high pH values (Meech et al., 1998) and sodium-amalgam forms sodium hydroxide in water, this is likely the mechanism by which the surface of metallic mercury is cleaned from oils and mercury oxide. This process is similar to the industrial process used to manufacture caustic soda. Actually, the use of "charged mercury", as this process is popularly known, is recommended by the Nevada Prospectors Association (Ralph, 2013).

Whole ore amalgamation is the oldest technique, culminating in the greatest environmental damage in gold processing. Mercury is introduced into a sluice box directly, the ore pulp is allowed to flow over copper-plates or the mercury is poured into small ball mills prior to grinding. This latter technique results in the greatest Hg loss since mercury droplets are formed during grinding, and are then dragged into the tailings that end up in the environment or are sent for cyanide leaching and then to the environment.

There is a general perception in the public domain that the main source of mercury pollution from AGM is amalgam burning (Veiga and Hinton, 2002). Amalgams usually contain 40–50% of Hg and 40–60% of gold and silver. Thus, the emission level from amalgam burning is restricted to the amount of gold produced. In contrast, amalgamation of the entire ore requires the addition of much more mercury. Based on mass balances of 15 artisanal mining plants, Cordy et al. (2011) demonstrated that mercury losses when the

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