In-Processing Plant Recovery of Gold from Waste Activated Carbon Using a Novel Reactor Designed at the University of Mines and Technology, Tarkwa, Ghana

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Abstract
A novel reactor for plant-site preparation/ashing of gold loaded Waste Activated Carbon (WAC) for recovery of gold by cyanidation has been designed. Test Trials on combustion of various samples of WAC were carried out using the reactor and assessment of leachability of the oxidized WAC obtained from the reactor was also carried out. Combustion of the carbon fractions of WAC from various companies produced ash with gold enrichment ratio of 8.5 - 9.6 (>730%) in relation to the carbon fraction feed. Gold recoveries from the ash products are about 96% @ 1000 ppm cyanide and 64% @ 200 ppm cyanide. It is proposed that plant-site treatment of WAC shall comprise separation of the carbon fraction from the WAC, ashing of the carbon fraction, leaching at 1000 ppm and sending the leach solution for electrowinning and smelting to obtain bullion. This reactor can be integrated into the operations of gold processing plants to treat WAC for in-plant gold recovery. This technology has the potential to generate US$57,153.11 from a tonne of ashed WAC at operational cost of about US$9,000.00. Material cost of fabrication of the reactor is about US$10,000.00.

Keywords: Waste Activated Carbon (WAC), Combustion, Gold Recovery.

1 Introduction

Most gold processing plants in Ghana and worldwide use activated carbon (AC) adsorption processes for recovery of gold. The AC may be applied in carbon-in leach (CIL) or carbon-in-pulp (CIP) (Wadnerkar *et al*., 2015; Schmitz, *et al*., 2001, Gönen, *et al*., 2001). During CIL, the AC is added to the cyanided pulp in the course of leaching so that there is simultaneous leaching and adsorption (Fleming, *et al*., 2011; Edahbi, *et al*., 2019). In the case of CIP, the AC is introduced after leaching to adsorb the dissolved gold (Snyders *et al*., 2017; Wadnerkar *et al*., 2015. During application, brittle portions of the AC break into fine particles. These fine carbons, referred to as waste activated carbon (WAC), are very active and contain a substantial amount of gold but are not retained in the leach tanks by inter-tank screens for gold recovery. The gold contained in the WAC may be lost to the process tailings through the openings in the inter-tank screens, a problem which causes gold processing companies to lose substantial amount of gold through the WAC. Rowe and McKnight (2009) also reported that the attrition of activated carbon, and the loss of gold associated with it, is of significant economic importance to the operation of a CIP/CIL circuit. Gold assays of WAC may range between 50 g/t and 2,350 g/t (Amankwah and Buah, 2007). A recent survey revealed up to 4.0 tons of WAC produced per month at an average gold grade of 65 – 80 g/t by a mine in Ghana. In another mine, 5.0 tons of the WAC at an average head grade of 150.0 g/t per month is produced.

Currently, gold processing companies are not recovering gold from the WAC in their plants because there is no technology to treat the WAC in their processing plants. Currently some companies in Ghana discharge the WAC into their tailing dams. Others do stockpile the WAC and sell them to offsite treatment facilities to recover the gold. In all cases the mining companies do not get the full benefit of the gold they have mined. Researcher have carried out laboratory investigations on recovery of gold from WAC (Amankwah *et al*., 2005; Lin *et al*., 2002; Amankwah and Asiam 1996). This paper presents a technology for treatment of the WAC in the processing plants, where they are produced. This research, therefore, provides a technology for on-site treatment of the WAC to make them cyanide leachable to recover gold contained in them on the processing plants. In this research samples of WAC were obtained from three gold processing plants in Ghana which produce WAC. Investigations on the combustion behavior of the WAC Samples were carried out. A Reactor, which could allow continuous combustion of the WAC was conceptualized and fabricated. Test Trials on combustion of various samples of WAC were

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carried out using the reactor and finally, assessment of leachability of the oxidized WAC obtained from the reactor was carried out.

The outcome of the research is that a novel reactor for plant-site preparation of gold loaded waste activated carbon (WAC) for recovery of gold by cyanidation has been designed. This reactor can be integrated into the operations of gold processing plants to treat WAC for in-plant gold recovery by cyanidation.

Onsite treatment of WAC can help gold processing plants gain all the revenue from the additional gold recoverable from the WAC and save on cost due to transportation of the WAC to off-site treatment facilities. The overall effect is increased revenue and profitability of the gold processing companies.

2 Resources and Methods Used

2.1 Sampling of WAC and its Characterisation

Samples of WAC were obtained from three gold processing plants in Ghana which produce the WAC. The sample were subjected to particle size distribution (PSD) analysis.

2.2 Investigation on Oxidation Behavior of the WAC Samples

Different representative samples of the WAC were placed in crucibles and they were combusted (oxidized/ashed) in a muffle furnace to determine the suitable conditions for oxidation of the WAC. The oxidized WAC samples were leached with cyanide, using conditions similar to what pertains in most CIL/CIP gold processing plants. Samples of the leach solution were taken at regular time intervals and tested for gold. This provided information on the gold leachability of the oxidized WAC.

2.3 Design of a Reactor for Oxidation of the WAC

Conceptual design and detail drawings of the reactor were developed using a Computer Aided Design system as shown in Figure 2.

2.4 Fabrication of the Designed Reactor

Fabrication and assembling of the parts of the designed reactor were done in the UMaT Mechanical Workshop. Installation of the Reactor was done at Government Hill as shown in Figure 3.

2.5 Test Trial Oxidation of WAC Using the Reactor

The suitable samples of the WAC, and the conditions for oxidation of the WAC, determined in 2.2, were used as basis for oxidation of the WAC in the designed reactor. The process conditions were then optimized.

2.6 Assessment of Leachability of the Oxidized WAC Obtained from the Reactor

Oxidized WAC samples obtained from the reactor were leached with cyanide, using conditions typical of most CIL/CIP gold processing plants. Leach solution samples were taken at regular time intervals and tested for gold. This provided information on the gold leachability of the oxidized WAC obtained from the reactor.

3 Results and Discussion

3.1 Characteristics of the WAC

Table 1 shows the cumulative percent passing of three WAC samples against particle size. 100% of WAC 1 samples were found to be retained on the 3.35 mm screen while 100% of the WAC 2 and WAC 3 samples were retained on the 4.0 mm screen. About 90% of the WAC samples were retained on the 2.80 mm screen whiles about 96% of the WAC samples were retained on the 3.35 mm screen. The average particle size of the WAC samples is assumed to be 3.35 mm.

Table 1 Characteristics of the WAC – PSD

Seive Sizes (mm)	Cumulative % Passing		
	WAC 1	WAC 2	WAC 3
5.60	100.00	100.00	100.00
4.00	100.00	100.00	100.00
3.35	100.00	98.50	95.68
2.80	94.45	90.63	89.76
2.36	80.10	71.66	71.83
2.00	65.67	54.33	54.50
1.40	43.35	27.12	28.30
1.18	37.29	17.78	17.96
0.60	14.84	3.57	3.85
0.00	0.00	0.00	0.00
Cut-off Size, mm	**3.35**	**4.00**	**4.00**

Table 2 shows the Bulk Weight and Bulk Denisty of the carbon and non-carbon fractions of the WAC samples against particle size. 1406.03 g of WAC were retained on the 4 mm screen with 1.39 g/cm^3 bulk densities of the non-carbon fractions. The +4 mm contained no carbon. 24093.97 g of WAC passed the 4 mm screen but were retained on the 1.4 mm screen with 0.67 and 1.45 g/cm^3 bulk densities of the carbon and non-carbon fractions respectively. 3703.61 g of the WAC passed through the 1.4 mm screen with 0.68 and 1.50 g/cm^3 bulk density of carbon and non-carbon fractions respectively.

Table 2 Bulk Weight and Density of Carbon and Non-Carbon Fractions

Size (mm)	Bulk Weight (g)	Bulk Density of Carbons Fraction (g/cm3)	Bulk Density of Non-carbons Fraction (g/cm3)
+4	1406.03	-	1.39
-4 +1.4	24093.97	0.67	1.45
-1.4	3703.61	0.68	1.50

The carbon and silica fractions of WAC are essential components that influence its characteristics. Understanding these fractions is crucial for the proper management of WAC. From Table 3, Carbon fractions of sample 1 and 2 were >93% with silica content of <7%. Sample 3 had silica content of 58.49% with 41.51% carbon content. Silica is abrasive, and its presence in WAC can impact the wear and tear of processing equipment during handling and processing. This abrasive nature may affect the physical integrity of the activated carbon particles. Silica should be separated from WAC using various physical separation methods to enhance the quality of the carbon fraction and decrease its effect on plant-site treatement of WAC. Figure 1 shows physical separation of WAC.

Table 3 Carbon and Silica Fractions of WAC Samples

Components of WAC	Percentage Composition, %		
	Sample 1	Sample 2	Sample 3
Carbon fraction	93.03	93.52	41.51
Silica Fraction	6.97	6.48	58.49
Total	100	100	100

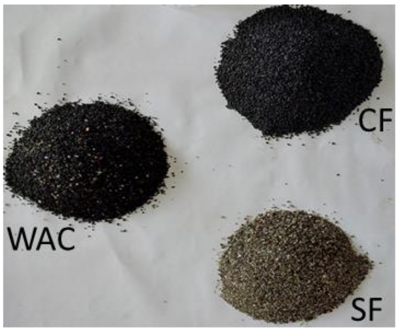

Fig. 1 Products of Physical Separation of the WAC (CF- *carbon fraction*; SF- *Silica Fraction*)

3.2 Reactor Performance Indicators

The reactor performance indicators are shown in Table 4. It is observed that there was an increase in ash content with respect to increase in residence time for all samples. Increase in residence time enhances the decomposition of complex organic structures, leading to the production of volatile gases and leaving behind a char residue that may contain an increased concentration of ash. It is also observed that there was in increase in ash content with respective to increase in combustion temperature from 700 to 800 °C. Temperature increases led to complete breakdown of organic components, resulting in higher ash content in the remaining char. However, excessive temperatures can sometimes lead to the volatilization of certain ash components, reducing the overall ash content.

3.3 Economic Performance Indicators

In Table 5, the rate of feeding the WAC samples into the reactor, the ash content of the WAC samples and the grade of gold in the WAC samples have been presented. Again, the rate of production of ash from combustion of the corresponding quantities of the WAC in the reactor and the grade of gold in the ash are also presented.

It can be deduced that the combustion of the WAC led to concentration of gold in the produced ash. The carbon fraction of WAC received from Company A with ash content of 10% and gold grade 105.91 g/t was fed at 500 g/min into the reactor at 800 °C. the combustion product was 98% ash and had a gold grade 1018.37 g/t gold enrichment ratio of 8.5 – 9.6 (>730%) in relation to the carbon fraction feed. Gold recoveries from the ash product was about 96% @ 1000 ppm cyanide and 64% @ 200 ppm cyanide.

It was estimated that about US$57,153.11 worth of gold could be recovered from a tonne of ashed WAC at operational cost of about US$9,000.00. Materials cost of fabrication of the reactor is about US$10,000.00.

Table 4 Reactor Performance Indicators

Samples	Speed of Motor Frequency (Hz)	Rotation (rev/min)	Feed Rate (g/min)	Furnace Temperature °C	Residence Time hr	Ash Content %
As Received	2.1	0.33	500	700	0	45
					3	55
					6	70
Carbon Fraction	2.1	0.33	500	700	0	10
					3	65
					6	87
Carbon Fraction	2.1	0.33	500	800	0	10
					3	76
					6	98

Table 5 Economic Indicators

		WAC Feed			Ash Yield			
Company	Samples	Feed Rate g/min	Ash Content %	Au g/t	g/min	Ash content %	Au g/t	Recovery %
A	As Received	500	45	43.91	310	70	60.40	72.70
	Carbon Fraction	500	10	105.91	56	83	945.63	84.30
	*Carbon Fraction	500	10	105.91	52	98	1018.37	96.10
B	Carbon Fraction	500	12	132.00	60	79	1100.00	80.60
C	Carbon Fraction	500	11	65.97	59	81	559.07	82.40
	*Ashing @ 800 °C; all others @750 °C							

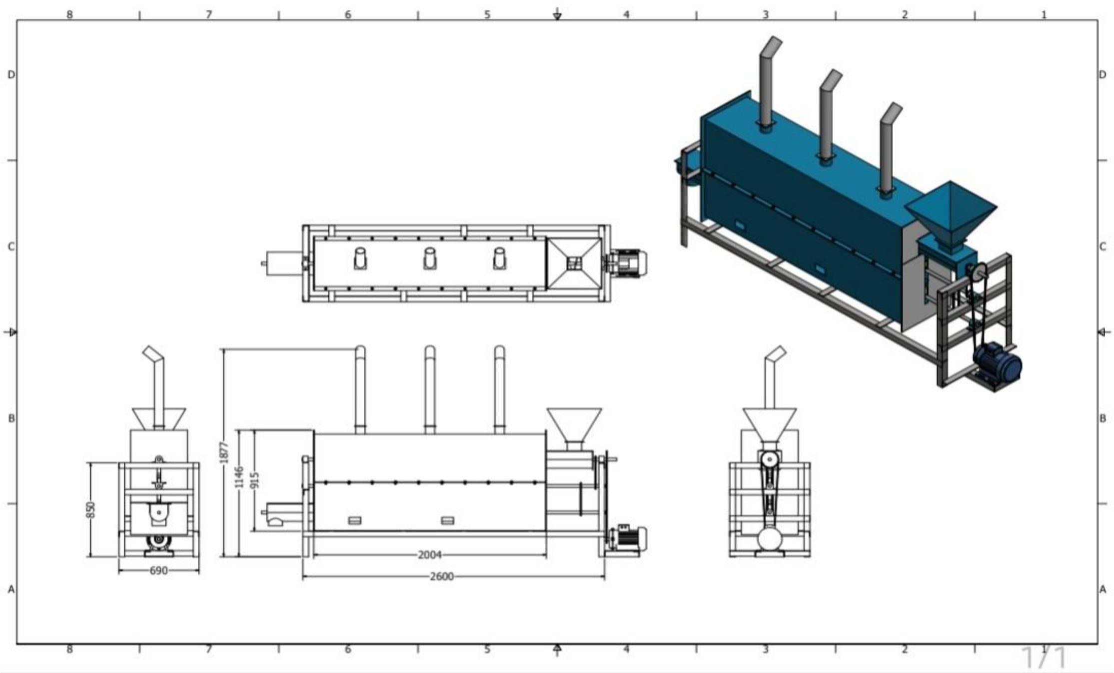

Fig. 2 Design of the Proposed WAC Combustion Reactor

Fig. 3 Picture of the Waste Activated Carbon Combustion Reactor

4.0 Conclusions

A novel Reactor for Plant-Site Preparation of Gold Loaded Waste Activated Carbon (WAC) for Recovery of Gold by Cyanidation has been designed. This reactor can be integrated into the operations of gold processing plants to treat WAC for in-plant gold recovery by cyanidation. Combustion of the carbon fractions of WAC from various companies produces Ash with gold enrichment ratio of 8.5 – 9.6 (>730%) in relation to the carbon fraction feed. Gold recoveries from the Ash products is about 96% @ 1000 ppm Cyanide and 64% @ 200 ppm cyanide.

4.1 Recommendations

It is recommended that treatment of WAC shall comprise separation of the carbon fraction from the WAC, ashing of the carbon fraction, leaching of the ashed WAC at 1000 ppm and sending the leach solution for electrowinning and smelting to obtain bullion. This technology has the potential to generate US$57,153.11 from a tonne of ashed WAC at operational cost of about US$9,000.00. Materials cost of fabrication of the reactor is about US$10,000.00.

It is also recommended that optimisation studies continue to enhance performance and economic indices of the reactor.

Again, this collaborative research with industry shall continue to increase confidence in the proposed treatment technology and ultimately ensure adoption of this technology in gold cyanidation/activated carbon adsorption plants.

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