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# Gold extraction via cyanide leaching using alkaline-based empty fruit bunch activated carbon

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**Abstract.** This research is carried out to extend the knowledge on the modernized method of modifying the physical and structural properties of empty fruit bunches (EFB), a low-cost, highly accessible and abundant agricultural waste in Malaysia, for gold adsorption process. To complete this aim, EFB was modified by using an alkaline-based chemical to improve the surface area, porosity volume and surface chemistry of sorbents. The structure of the empty fruit bunch is characterized by using characterization techniques such as Thermogravimetric analysis (TGA) and Energy-Dispersive X-ray spectroscopy. The gold solution was prepared by mixing gold with a sodium cyanide solution to undergo a leaching process for 24 hours. The solution was then used for the adsorption experiment. The performance of the alkaline-based EFB-AC to separate gold from the cyanide leaching solution was further studied on the effect of contact time, pH and agitation rate. The gold adsorption capacity achieved by the alkaline-based EFB-AC was measured by calculating the difference between the initial and final gold concentrations using Atomic Absorption Spectrometry (AAS). The maximum gold adsorption capacity findings of contact time, pH, and agitation rate were found to be 2.5 hours, pH of 10 and 60 rpm, respectively. This study reveals that the alkaline-based EFB-AC has the potential to extract gold as an alternative activated carbon in the gold adsorption process.

## 1. Introduction

Gold is a valuable metal that has been commonly used in various fields such as the electrical and electronic industries, jewellery, and medicine, as well as a catalyst in many chemical processes [1]. Gold is an asset that has several attractive properties such as chemical stability, high redox potential and a good conductor for heat and electricity [2]. According to an executive at the Malaysian Chamber of Mines, the gold industry in Malaysia has grown by three-fold in the past decade from RM221 million in 2006 to RM780 million in 2015. Gold mining in Malaysia can be found in several regions including Pahang, Johor, Sabah, Terengganu, and Kelantan [3]. Malaysia exports around 50 tonnes of gold jewellery annually to Middle Eastern countries like the United Arab Emirates and Turkey, an amount which is worth RM6 to RM7 billion [4].

There are several techniques and processes for gold extraction from the mineral mixture. The techniques include amalgamation, sluicing, magnetic, centrifuge and hydrometallurgy [5]. Cyanide leaching treats gold in a hydrometallurgical process from its ores where the processes rely on the recovery of gold from the enriched gold leach pulp by a suitable activated carbon [6]. This process has high sensitivity, a high percentage of gold extraction and low operational cost [7]. There are three types



of carbon adsorption which are carbon-in-pulp (CIP), carbon-in-leach (CIL) and carbon-in-column (CIC).

Activated carbon derived from the coconut shell has been the preferred adsorbent due to its selectivity for gold [8]. However, an alternative activated carbon should be explored from other abundantly available and cost-effective materials that can be found in Malaysia. The Malaysian palm oil industry is one of the largest in the world and produces large amounts of by-products, mainly empty fruit bunches [9]. The empty fruit bunch has a high carbon content and hydroxyl groups which can be modified to improve its adsorption potential. In this study, gold adsorption is done using empty fruit bunches to analyse whether they can be used to be an alternative activated carbon for gold adsorption in the gold mining industry.

## 2. Materials and methods

### 2.1. Materials

An empty fruit bunch was selected as a precursor in this study and this material underwent physical modifications via carbonization and activation steps as previously reported [10]. Potassium hydroxide (KOH) was used to impregnate the empty fruit bunch to produce alkaline-based EFB-AC. Sodium cyanide (NaCN), AR, 97%, was purchased from Evergreen Engineering & Resources and was used for cyanide leaching. Gold samples were collected from a gold mine in Pahang.

### 2.2. Experimental procedures

Gold was mixed with sodium hydroxide (NaOH) to adjust the pH, then sodium cyanide with a concentration of 1 g/L was prepared before being added to the mixture. The solution was left to undergo the leaching process for 24 hours and filtered to obtain a gold cyanide solution. Then, the gold concentration was analyzed by using Atomic Absorption Spectrometry (AAS).

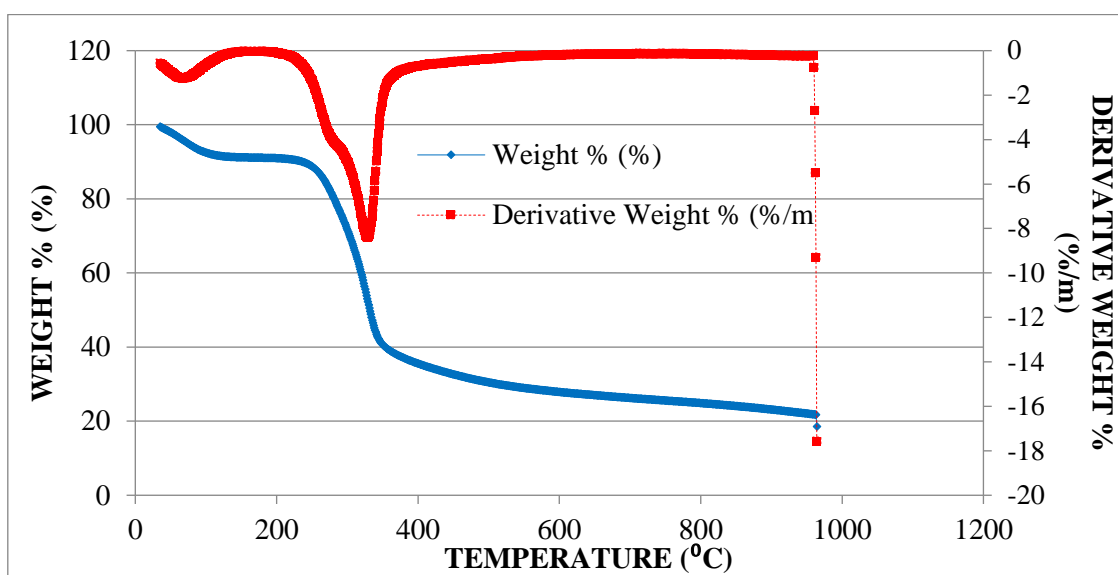
The empty fruit bunch was characterized structurally by using a thermogravimetric analyzer (TGA), and electron dispersive x-ray (EDX). Thermogravimetric analysis (TGA) is an analysis technique used to determine the changes in the weight of each component of the sample as the temperature is increased. The electron dispersive x-ray (EDX) is used by detecting the x-ray reflected from the sample during the injection of an electron beam to determine the elemental compositions.

Afterwards, the adsorption experiments were performed by placing the prepared alkaline-based EFB-AC in 50mL of the gold cyanide solution for two hours. The effects of pH, agitation rate and adsorption time were studied and evaluated in this experiment. The solution was then filtered, and AAS was used to analyze the gold concentration.

## 3. Results and discussion

### 3.1. Thermogravimetric analysis (TGA)

Thermogravimetric analysis (TGA) was used to determine the changes in the weight of the samples with respect to the increasing temperature [11]. The x-axis indicates the temperature (°C), while the y-axis represents the percentage of weight loss. The temperature range for this analysis was between 20 to 1000°C. Figure 1 shows the TGA curve of the unmodified empty fruit bunch (EFB).



**Figure 1.** TGA curve for unmodified empty fruit bunch.

Three degradation steps are observed which signify the weight loss due to the removal of moisture content, removal of cellulose and hemicellulose contents, and the formation of char, respectively [12]. The first degradation observed at a temperature range between 20 to 100°C is smooth and slightly bent downward. This TGA result indicates the removal process of moisture and extractives. The second degradation range for the empty fruit bunch occurs at 250 to 350°C where the weight loss can be explained by the degradation of hemicelluloses, lignin, and celluloses. The production of char empty fruit bunch takes place in the third stage which occurs at a temperature range of 390 to 1000°C.

### 3.2. Energy dispersive X-ray spectroscopy (EDX)

Energy Dispersive X-Ray Spectroscopy (EDX) serves to detect the elemental compositions of the prepared sample [13]. Table 1 shows the elemental compositions of an empty fruit bunch in different states which are raw, carbonized, and activated carbon.

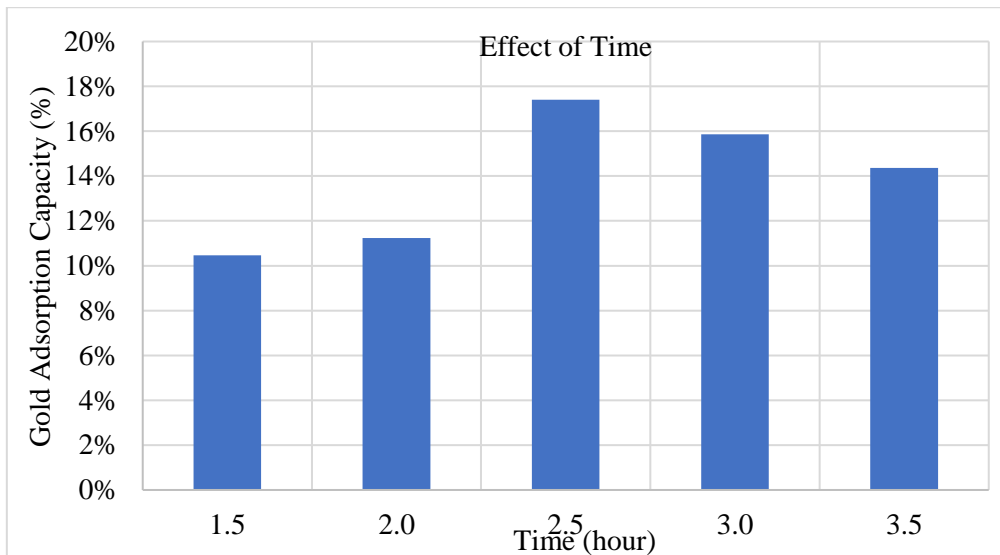
**Table 1.** Elemental compositions of empty fruit bunch.

Sample	Empty Fruit Bunch (EFB)		
	Raw	Char	Activated Carbon
Elemental Composition (%)			
Carbon (C)	54.85	51.03	63.88
Oxygen (O)	41.27	9.78	10.24
Sodium (Na)	-	2.54	0.85
Magnesium (Mg)	0.94	1.91	2.46
Potassium (K)	2.40	32.21	18.45
Calcium (Ca)	0.54	2.54	2.02

Table 1 indicates that an empty fruit bunch is categorized as a natural material as the elemental composition results indicates the presence of cellulose, hemicellulose and lignin. Table 1 shows that the elemental composition for carbon (C) and oxygen (O) for the raw empty fruit bunch are 54.855 and 41.27%, respectively. The increment of carbon content in the empty fruit bunch activated carbon correlates with the presence of inert gas which improves the carbon composition [13]. The high composition of carbon affects the adsorption of gold as it is influenced by the exchange with the charged groups that exist in the surface of activated carbon [14].

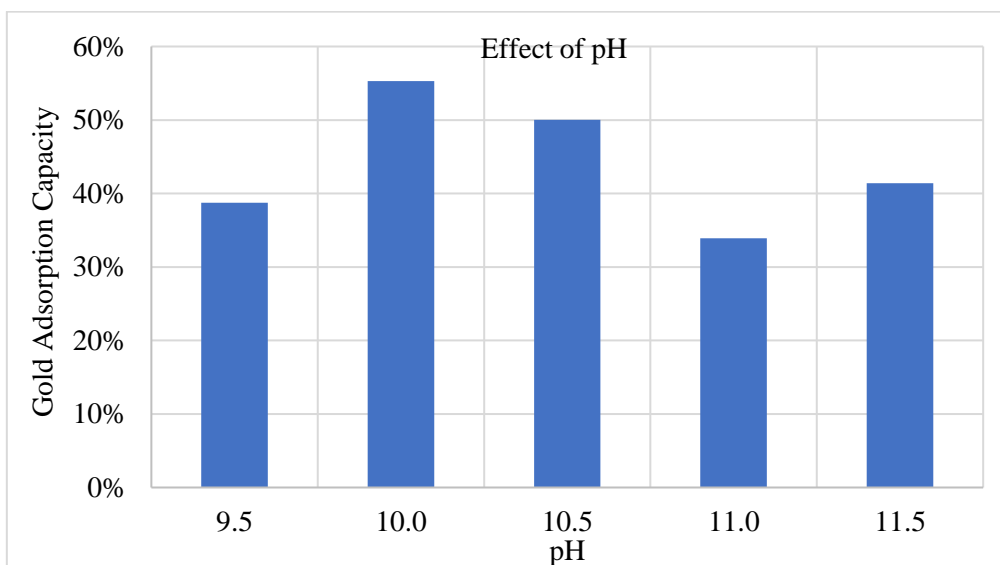
### 3.3 Gold adsorption study

Gold adsorption via the cyanide leaching process was determined through the sorption of gold onto alkaline-based EFB-AC. Figure 2, Figure 3 and Figure 4 show the percentage of gold adsorption capacity in terms of the effect of time adsorption, effect of pH and effect of agitation rate, respectively.



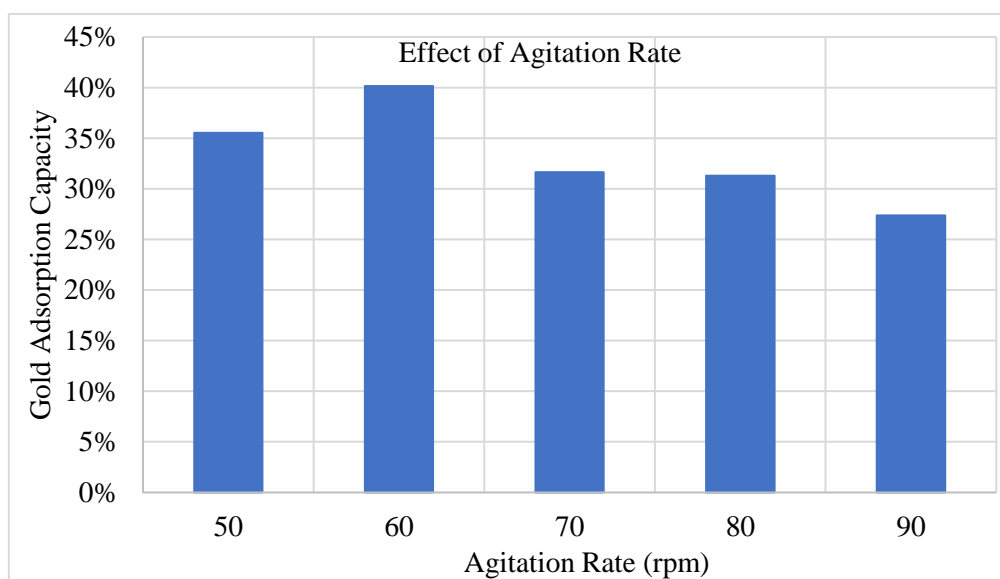
**Figure 2.** Gold adsorption capacity from effect of time.

Figure 2 presents the effect of contact time on the gold adsorption capacity between the range of 1.5 to 3.5 hours. It can be observed that the activated carbon empty fruit bunch adsorbent has a much higher adsorption capacity at 2.5 hours. The percentage of adsorption increases from 1.5 to 2.5 hours then decreases slightly. This is due to the vacant adsorption sites on the sorbents at the beginning and as the sites are filled, the sorption decreases. As the adsorption sites become filled after a while, there are repulsive forces between the solute molecules on the solid and bulk phases which makes the sorption decreases [15]. 2.5 hours is the highest gold adsorption capacity recorded, which is why the time for study on the effect of pH and the effect of agitation rate conducted for 2.5 hours.



**Figure 3.** Gold adsorption capacity from effect of pH.

In this study, the performance of the alkaline-based EFB-AC was studied in the pH between 9.5 to 11.5 to prevent hydrogen cyanide gas formation. The gold adsorption capacity of the alkaline-based EFB-AC affects the surface charges of the adsorbent and the speciation of the metal adsorbate is significantly affected by the pH as can be seen in Figure 3. The results suggest that gold adsorption is optimal at pH 10 and decreased from pH of 10.5. Based on the pH analysis, the gold adsorption capacity of the alkaline-based EFB-AC was affected greatly due to the surface charges of the adsorbent and the speciation of the metal adsorbate [16]. At a very basic pH solution, gold cyanide ion may be deprotonated, which can cause repulsive interaction between the charge of alkaline-based EFB-AC and gold cyanide.



**Figure 4.** Gold adsorption capacity from effect of agitation rate.

Figure 4 shows the effect of agitation rate of 50 to 90 rpm towards gold sorption onto alkaline-based EFB-AC. The maximum gold adsorption is achieved at 60 rpm. The percentage capacity of gold adsorption increases until 60 rpm and decreases from 70 to 90 rpm. This is due to the bond breaking between the gold trapped onto the alkaline-based EFB-AC as there is a decrease in the boundary layer thickness around the adsorbent particle as a higher agitation rate is used [17]. Besides, it is possible that with less of the CN<sup>-</sup> being available for reactions with the activated carbon surface groups ultimately resulted in a decrease of gold adsorption.

#### 4. Conclusions

The empty fruit bunch was chosen as a precursor for this research due to its high potential. Through carbonization, the empty fruit bunch was physically modified which enhanced the adsorption process. Structural analysis was used to characterize the samples through energy dispersive x-ray spectroscopy (EDX) and thermogravimetric analysis (TGA). Based on the TGA and EDX results, the transformation of carbonized samples to activated carbon is proven. The percentage of gold adsorption towards the empty fruit bunch activated carbon in terms of the effect of pH, agitation rate and adsorption time has been studied. The maximum gold adsorption capacity for effect of pH, agitation rate and adsorption time were found to be 10, 60 rpm and 2.5 hours, respectively.

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