Mineralogical Characterization and Determination of Refractoriness of Malaysian Gold Ore

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Abstract. This study aims to conduct mineralogical characterization and determine the refractoriness of gold ore from Eastern Coast of Peninsular Malaysia. Elements presence in the sample were investigated using X-ray fluorescence (XRF) analysis while X-ray diffraction (XRD) method was used for the identification of mineral phases. Polished sections samples were studied by optical microscopy (OM), scanning electron microscopy and energy-dispersive X-ray (SEM/EDX). XRD phase analysis showed the presence of mineral phases of quartz, iron sulphide and silicate minerals, which were confirmed by XRF with the elements detected as Si, O, Al, Fe, As and S. From SEM/EDX analysis, gold was found mostly interlocked in sulphide minerals such as arsenopyrite, galena and others. Fire assay and cyanide bottle roll test were employed on the bulk samples to assay the gold content and free gold, respectively. Atomic Absorption Spectrometry (AAS) revealed the gold content to be 31 gram per tonne in the sample. The cyanide bottle roll test determined the free gold assay of 16 gram per tonne. These findings imply that the samples contained free gold of about 52% along with gold present interlocked with minerals unfavourable to cyanidation, which further provide valuable information in terms of the refractoriness of the gold for further processing.

1. Introduction

Gold has been mined for centuries for its unique properties and abundant applications. From jewellery to electronic applications [1], gold has been utilized worldwide. Its price is relatively higher compared to other metals since it requires more complex and tedious processing methods. However, this depends on the type of ore that bears the gold. In general, gold ore can be divided into two types, namely “free milling” ore and “refractory” ore [2]. Free milling ore refers to ore in which gold can be liberated easily from other minerals by physical means (crushing and grinding) and then by direct cyanidation. This type of ore requires less investment to be processed. As for refractory ore, it refers to ore which requires pre-treatment, usually by chemical means and it cannot be processed by direct cyanidation. Cyanide is used mainly to liberate free gold particles. Refractory gold usually co-exist with preg-robbing minerals or “preg-robbers” such as sulphide minerals which are very difficult to be processed [3].

In comparison to the previous decades, free milling gold ores are currently found to be less abundant in nature. This is due to their easy accessibility and simple processing route which led to their maximum utilization and in return brought them to the verge of depletion. Thus, currently most gold processing plants took the initiative to process refractory gold ores. However, there is no established processing
routes for treating and processing refractory gold since the refractoriness of the ores are dependent largely on their mineralogical and geological data, which are variable from place to place. In Malaysia, almost all gold processing plants are using cyanide leaching as their method for gold recovery and this situation is quite irrelevant to the processing of refractory gold ores. This is because the ores contained preg-robbers which tend to deplete cyanide and resulted in the inefficient consumption of cyanide for gold leaching purposes. Therefore, the purposes of this research are to characterize the gold ore obtained from the Eastern Coast of Peninsular Malaysia and to determine the refractoriness of the ore. These information are very crucial and important for geologists and engineers to upgrade the processing routes of Malaysian refractory gold ores, since cyanide utilization alone is not efficient in treating this type of ores. Some physical or chemical processing stages can be added into the established cyanidation processes to treat the preg-robbers before being treated with cyanide.

2. Experimental study

Rock sample from the Eastern Coast of Peninsular Malaysia was crushed by using laboratory scale jaw crusher and cone crusher to produce rock sample of size ≤4 mm. The crushed rock sample was then ground to particle size of 80% passing -75 μm by using ring mill. Cone and quartering sampling method was used on the ground rock sample to produce two well-distributed sample portions [4][5].

For mineralogical characterization, one sample portion from the cone and quartering method was used. The sample was analyzed qualitatively using X-ray fluorescence (XRF; Rigaku Rix-3000) and the mineral phase identification was analyzed by X-ray diffraction (XRD; Bruker D8-advance). Besides powdered sample, some selected fresh rock samples were also used in studying the phases and morphology of the ore. Polished sections of the rock sample were prepared by using mixture of resin and epoxy [5]. Morphology of the rock sample was identified using optical microscopy (OM; Olympus BX51M), scanning electron microscopy and energy-dispersive X-ray analysis (SEM/EDX; Leo Supra 35VP).

Fire assay and cyanide bottle roll test were employed on the other portion from the cone and quartering method. Fire assay aims to determine the grade or assay of gold in the ore by using Carbolite HTF 1800 furnace. Fire assay is the most effective digestion technique in determining the quantitative grade of gold in an ore [4][6]. Cyanide bottle roll test, on the other hand determines the free gold content in the ore [4]. Sodium cyanide (NaCN) solution was used as the lixiviant in leaching the free gold from the ore into the solution. 24 hour cyanide leaching test was conducted on the sample to determine its free gold content [1][7]. For both fire assay and cyanide bottle roll test, the gold content was determined quantitatively using the Atomic Absorption Spectrometry (AAS; AAnalyst 700, Perkin Elmer). The fire assay and cyanide bottle roll test were repeated three times and the average gold content were obtained for each method.

3. Results and discussion

3.1 Mineralogical Characterization of Gold Ore Sample

The mineral characterization of the gold ore sample was conducted by using X-ray fluorescence (XRF), X-ray diffraction (XRD), optical microscopy (OM), scanning electron microscopy (SEM) and energy dispersive X-ray (EDX). The XRF result is presented in Table 1. As shown in Table 1, the most abundant compound in the sample are silica and feldspar, due to the significant amount of Al₂O₃ and K₂O. The amount of iron oxide in the sample is also quite significant, which is about 2.17%.
Table 1. Mineral composition of ground ore sample from XRF analysis

| Compound | wt%  | Compound | wt%  | Compound | wt%  |
|----------|------|----------|------|----------|------|
| SiO₂     | 81.14| MgO      | 0.21 | ZnO      | 0.01 |
| Al₂O₃    | 11.18| Na₂O     | 0.03 | Ga₂O₃    | 0.01 |
| Fe₂O₃    | 2.17 | P₂O₅     | 0.02 | Rb₂O₃    | 0.01 |
| K₂O      | 2.10 | CaO      | 0.01 | SrO      | 0.01 |
| SO₃      | 0.78 | MnO      | 0.01 | ZrO₂     | 0.01 |
| As₂O₃    | 0.59 | NiO      | 0.01 | Au₂O     | 0.01 |
| TiO₂     | 0.21 | CuO      | 0.01 | PbO      | 0.01 |

Loss on Ignition (LOI) = 1.50 %

In determining the main and trace minerals and their interlocking in the sample, X-ray diffraction (XRD) studies were performed [5]. The major phases of minerals identified were quartz, iron sulphide and silicate minerals as shown in Figure 1. This findings were then further confirmed by microscopic analysis. From the optical microscope (OM) studies of the rock sample, it was found that the sample contained gold (Au), pyrite (FeS₂), silica (SiO₂) and arsenopyrite (FeAsS) [8]. Pyrite and arsenopyrite were not detected in the XRD analysis due to their low amount within the sample. Images of the OM were shown in Figure 2. Gold has a distinct bright yellow colour and its shape is irregular with soft edges. Pyrite on the other hand has hard edges with euhedral cubes and triangles shapes, while arsenopyrite has euhedral rhombs shape. It was shown that gold occurred both free and as inclusions in arsenopyrite [9].

Figure 1. XRD diffractogram showing the major phases of minerals identification in the ground ore sample.
For further identification of sample characterization, scanning electron microscopy (SEM) and electron dispersive X-ray (EDX) methods were used and the results were presented in Figure 3. As it can be seen, gold was found interlocking in the sulphide mineral with major components presence such as As, Pb, Fe and S [8]. This shows that the refractoriness of the gold ore sample could be due to the presence of gold associated with sulphide minerals [10]. These findings complimented with analysis results from XRD, XRF and OM. Besides, from SEM micrographs, the average liberation size of gold is 20 µm.
3.2 Gold Content Determination and Refractoriness Identification

Fire assay and cyanide bottle roll test were performed on the ground ore samples. Based on the atomic absorption spectrometry (AAS) analysis, gold content of the ore sample were determined. Fire assay method gave an average gold content of 31 gram per tonne. This result shows the total gold in the ore sample, since almost all impurities were removed as slag during fire assay [6].

Cyanide bottle roll test is a method in which cyanide solution was used to recover free gold in ore [1][11]. From this test, it was found that the amount of free gold in the sample to be of average 16 gram per tonne. This finding shows that there are about 15 gram per tonne of gold interlocked within the ore, as compared to the amount of total gold obtained by fire assay method. As discussed from the mineralogical characterization, gold in this ore were found mainly interlocked in sulphide minerals.

Therefore, we can say that gold recovery using direct cyanidation method will not provide high gold recovery due to unliberated gold [3]. The ore sample contained gold associated with other components such as sulphide minerals and silicate minerals which reduced the effectiveness of gold cyanidation process. Thus, it is concluded that the ore sample is a refractory gold ore type and this information is very useful in determining the next step in gold recovery process.

4. Conclusion

Several major findings were obtained from this research. It can be concluded that the gold ore sample contain the mineral phases of quartz, iron sulphides and silicate minerals based on the XRD analysis, which were also confirmed by XRF, OM and SEM/EDX analysis. Other minerals to be found associated with gold were galena, pyrite and arsenopyrite. From the mineralogical characterization of the ore sample, it was found that gold was interlocked in the sulphide and silicate minerals. Fire assay of the ground sample gave an average total gold of 31 gram per tonne. For cyanide bottle roll test, the amount of free gold within the sample was found to be of average 16 gram per tonne. These findings imply that the samples contained free gold of about 52%, leaving the remaining unliberated gold still interlocked in the sulphide and silicate minerals. Thus this ore sample can be classified as a refractory gold ore type, as proven by the mineralogical characterization, fire assay and cyanide bottle roll test. This information will be very useful in gold recovery since it will provide the possible processing route for this type of gold ore. However, the selection of processes will also depend on the cost of operating rather than only high percentage of gold recovery. From the mineralogical characterization of the gold ore sample, a diagnostic leaching approach could be used as an analytical tool to determine gold deportment in gold ore sample.

Acknowledgement

The authors would like to express their gratitude and appreciation to the ASEAN University Network/Southeast Asia Engineering Education Development Network (AUN/SEED-Net) for the financial support through a collaborative research grant with grant number 304/PBAHAN/6050347/A119.
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