

## Study on the Effect of Cyanide Concentration on Gold Leaching Recovery in Ore at PT Indo Muro Kencana

Frideni Yushandiana Putri G.F<sup>a\*</sup>, Armitha Lisanul Karimah<sup>a</sup>, Sulaeman<sup>b</sup>

<sup>a</sup>Program Studi Teknik Metalurgi, Fakultas Teknologi Mineral, UPN "Veteran" Yogyakarta, Yogyakarta, Indonesia 55283

<sup>b</sup>PT Indo Muro Kencana, Camp-Muro Site, Dirung, Dirung Lingkin, Tanah Siang Sel., Kabupaten Murung Raya, Kalimantan Tengah, Indonesia 73971

\*Corresponding author: [armithalisanul@gmail.com](mailto:armithalisanul@gmail.com)

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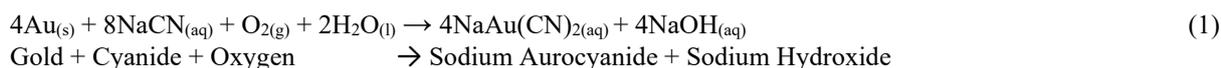
Cyanidation, Gold, Leaching, Extraction.

**ABSTRACT.** Indonesia is a country that has abundant natural resources, including non-renewable natural resources such as various types of metals, natural gas, petroleum and others. Besides that, Indonesia also has an important role in supplying the world's gold raw materials. Therefore, it is necessary to develop technology and science in the mining industry, especially gold to increase process optimization and increase the added value of the mining products themselves. One of the gold extraction processes can be carried out hydrometallurgically using the cyanidation method using agitator leach, as was done at PT Indo Muro Kencana. Process optimization is carried out with various test work, such as leaching tests, by varying the operating parameters of the leaching. The variations of parameters used in this study are the cyanide concentrations at 600 ppm, 700 ppm, and 800 ppm. The results of the analysis show that the optimal cyanide concentration for leaching of PT Indo Muro Kencana's gold ore is 600 ppm by controlling the Rate rate control.

## 1. INTRODUCTION

Indonesia is an archipelagic country rich in natural resources, including in the field of mining. According to the Investment Opportunities in Gold-Silver in Indonesia booklet by the Ministry of Energy and Mineral Resources (2020), Indonesia's gold reserves reach 5% or 2,600 tons of Au out of the world's total gold reserves of 50,300 tons of Au. It can be concluded that Indonesia plays an important role in the supply of global gold raw materials [1]. The potential for gold deposits is found in several regions of Indonesia, such as Sumatra, Papua, Kalimantan, Nusa Tenggara, Riau Islands, Java, Sulawesi, and Maluku. [1]

Gold is a highly valued metal and is widely used for investment, jewellery, electronics, and more. This increases the demand for gold, which in turn drives the gold and silver mining industry to continue developing. Gold extraction through hydrometallurgy is a process that involves purification and recycling of the metal using aqueous solutions at temperatures <200°C. This technique is economically applied to low-grade gold ore due to its selectivity for precious metals. When combined with advanced pyrometallurgical and electrometallurgical processes, the metal can achieve higher purity levels up to 999.9 or 24 karats. One example of a hydrometallurgical process is the cyanidation method. Cyanide is a reagent commonly used for gold processing and purification. The cyanidation method with agitation leaching has been widely applied in the industry, such as at PT Indo Muro Kencana (IMK).



Common solvents used in the cyanidation process include NaCN, Ca(CN), and KCN. The most frequently used solvent is NaCN, as it is more stable in the leaching process and is available in higher-purity forms [2]. In the leaching process, the following reaction occurs (1).

The mechanism of gold ore leaching can be observed in Figure 1. Oxygen will oxidize the solid gold present in the ore into its ions. These gold ions will then bind with dissolved cyanide ions, culminating in the reaction as described in equation (1)

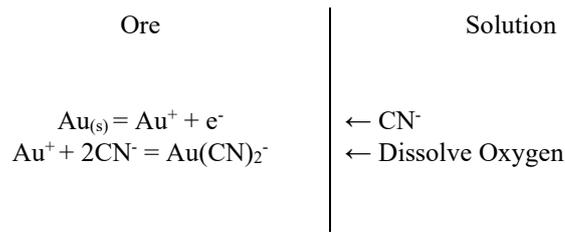


Figure 1. Mechanism of Gold Extraction from Ore in Leaching Process [2]

The concentration of cyanide greatly influences the gold cyanidation process. An increase in cyanide concentration drives the reaction to the right by consuming reactants, forming  $\text{Au}(\text{CN})_2^-$  complexes in the solution [3]. Furthermore, cyanide consumption is also influenced by the characteristics of the ore itself. The effect of cyanide concentration on the dissolution rate of gold and silver can be observed in Figure 2.

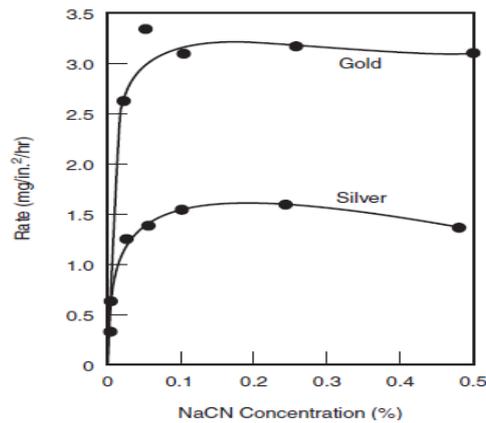


Figure 2. The Influence of Cyanide Concentration on the Dissolution Rate of Gold and Silver [2]

pH plays a significant role in the gold cyanidation process. The leaching pH is maintained at 10.20 – 10.50 to prevent cyanide from hydrolyzing and forming HCN. The gold dissolution rate decreases as the pH increases due to the adsorption of  $\text{OH}^-$  ions on the gold surface, inhibiting the reaction of cyanide with the gold surface [2]. pH is adjusted by adding lime ( $\text{CaO}$  and  $\text{CaCO}_3$ ).

Dissolved oxygen is one of the factors influencing the gold cyanidation process. The addition of oxygen drives the reaction to the right [4]. Oxygen functions as an oxidizer for Au, converting it into its cation form ( $\text{Au}^+$ ), allowing Au to bind with cyanide to form an Aurocyanide or  $\text{Au}(\text{CN})_2^-$  complex [2]. Required dissolved oxygen can be sourced from air or pure oxygen [5].

Residence time is also a crucial process parameter for gold cyanidation. Residence time is the duration slurry needs to flow through tanks and the contact time between metal particles and reagents. Residence time is influenced by slurry flow rate, solid percentage, and leaching tank efficiency [2].

Particle size is a factor affecting the gold cyanidation process. The process is more effective for particle sizes smaller than 200 microns, as it facilitates gold dissolution [6]. The standard particle size for cyanidation is  $P_{80}$  75  $\mu\text{m}$ , which serves as a reference for liberated ore and increased surface area exposure, optimizing gold recovery. Gold dissolution rate increases with smaller particle sizes as the contact area between solid and liquid phases becomes larger [5].

Temperature significantly influences gold dissolution and oxygen solubility. Typically, higher temperatures increase metal solubility in the solvent while reducing the viscosity of the aqueous phase and increasing diffusivity. Higher temperatures increase dissolved metal but decrease dissolved oxygen. Additionally, elevated temperatures lead to higher impurity dissolution, so cyanidation is typically performed at room temperature [2]. Moreover, the level of HCN volatilization from the cyanide solution increases with temperature [2].

Agitation rate is a crucial factor in the gold leaching process, and the gold dissolution rate depends on the diffusion layer thickness and mixing characteristics, affecting particle diffusion. Increasing the agitation rate enhances the gold dissolution rate as mixing reduces the diffusion layer thickness. Therefore, the mass transfer rate of cyanide and oxygen, as well as the accessibility of dissolved oxygen, can be improved. Agitation rate can

enhance the rate of external mass transfer control.

Optimizing the leaching process affects gold and silver recovery. To determine the recovery percentage, it can be calculated using formulas (2) and (3).

Actual Head Recovery

$$\frac{\text{Au in Solution}}{\text{Total Au from Ore Grade}} \times 100\% \quad (2)$$

Calculated Head Recovery

$$\frac{\text{Au in Solution}}{\text{Au in Solution and Residue}} \times 100\% \quad (3)$$

## 2. MATERIAL AND METHODS

The gold ore used in this study is of the low sulfidation type originating from Murung Raya Regency, specifically from PT Indo Muro Kencana (IMK). The samples used in this experiment were analyzed for their chemical composition using Atomic Absorption Spectrophotometry (AAS). The AAS analysis results provide the concentration of each metal element in the sample, such as gold, silver, and copper.

The equipment used in this experiment includes sample preparation tools, including a mill, leaching reactor, agitator, pH meter, dissolved oxygen (DO) meter, burette, beaker glass, Erlenmeyer flask, measuring tube, syringe, spatula, scale, and sample bottles. The materials used in this experiment include pulverized ore samples with a size of P<sub>80</sub> 75 μm, water, oxygen, lime, rhodanine, AgNO<sub>3</sub>, and NaCN.

The gold leaching process begins with sample preparation. The ore is initially comminuted with a crusher to a size of 2 mm. It is then pulverized for 2 minutes and 16 seconds to achieve a P<sub>80</sub> 75 μm particle size. The pulverization time is determined based on the previous grind establishment analysis. The sample is further homogenized using a mill. After homogenization, three samples of head grade, each weighing 50 grams, are taken for analysis of Au and Ag content using AAS.

The next step involves leaching preparation by preparing three samples weighing 1 kg and 1500 ml of water in three measuring tubes. Subsequently, the oxygen supply lines for each reactor are checked to ensure proper functioning before the leaching process is carried out.



Figure 3. Leach Reactor



Figure 4. Vacuum Filter

The leaching process begins by adding 1000 ml of water to each reactor, followed by gradually introducing the ore into the reactor to minimize clumping. As the slurry thickens, 500 ml of water is added to each reactor. Periodic pH checks are performed until the range of 10.20 - 10.50 is achieved. Maintenance is carried out by adding lime to the slurry. Dissolved oxygen levels are monitored and adjusted to the 15-20 ppm range. Once the leaching parameters are met, NaCN is added to each reactor at concentrations of 600 ppm, 700 ppm, and 800 ppm. Sampling is conducted at hours 2, 4, 6, 8, 24, 32, and 48, where 200 ml slurry is collected from each reactor. The collected samples undergo solid-liquid separation using a vacuum filter, as shown in Figures 3 and 4. The extracted solution is titrated, and a portion is used to check the Au and Ag content. Maintenance is performed at each designated time interval by topping up cyanide along with solids and solutions collected during sampling. The samples to be tested for their content using AAS include leach tail and solution samples at each time interval.

### 3. RESULT AND DISCUSSION

The gold leaching process was carried out using variations of NaCN dosages at 600 ppm, 700 ppm, and 800 ppm. This experiment was conducted over a period of 48 hours, with sampling intervals at hours 2, 4, 8, 24, 32, and 48. Other parameters were maintained constant under the following conditions: pH 10.20 - 10.50, solid percentage of 40%, and dissolved oxygen of 25-20 ppm. The pH, dissolved oxygen (DO), and cyanide concentration were maintained through maintenance at each time interval. If a decrease in cyanide concentration occurred, cyanide was replenished to match the initial cyanide concentration.

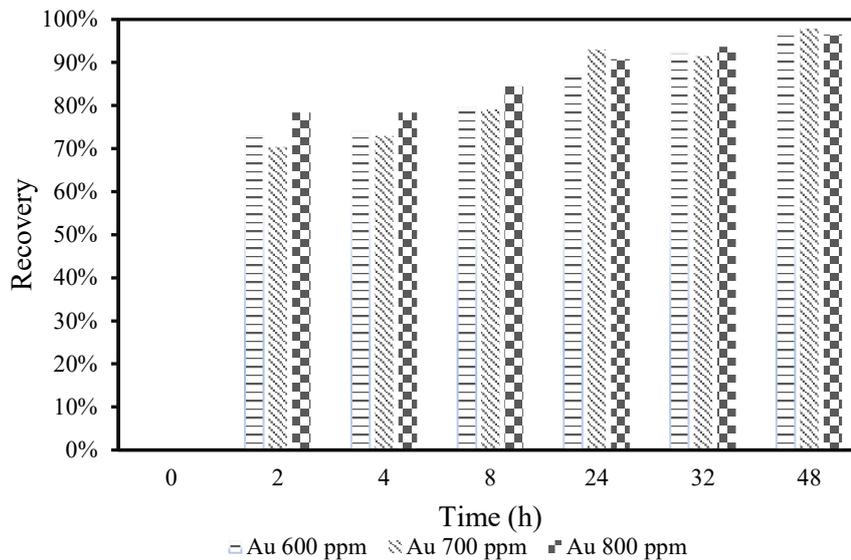


Figure 5. Gold Extraction Percentage Over Leaching Time for Each Cyanide Concentration Variation

Based on Figure 5, it can be observed that the gold recovery percentage at a concentration of 700 ppm is 97.9%. The concentration of 700 ppm yields the highest value compared to 600 ppm and 800 ppm, which are valued at 96.5%. The recoveries obtained for each cyanide concentration variation are relatively similar.

Based on the Figure 6, it can be observed that the silver recovery percentage at a concentration of 800 ppm reaches the highest value of 91.8%, compared to 600 ppm and 700 ppm, which are valued at 91.4% and 91.1% respectively. The recoveries obtained for each cyanide concentration are relatively close as well.

From the above analysis, it is evident that cyanide concentration variation affects leaching recovery. Higher cyanide concentrations lead to higher leaching recovery percentages, but this increase may taper off once a maximum point is reached. According to Marsden (2006), the gold extraction rate increases with higher free cyanide concentrations. Free cyanide in the solution exists as HCN and CN<sup>-</sup> ions [2].

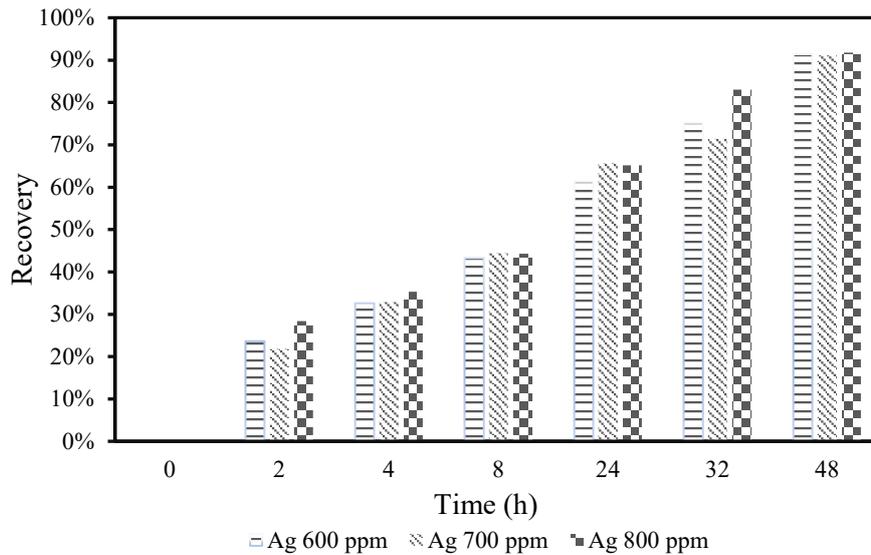


Figure 6. Silver Extraction Percentage Over Leaching Time for Each Cyanide Concentration Variation

Based on the analysis of the graph depicting gold and silver recovery over leaching time, it can be observed that the increase in recovery during the initial time intervals (0-4 hours) is rapid. However, over time, the rate of recovery increase slows down, forming a gradual curve as seen in the later time intervals (8-48 hours). This is because during the initial time intervals, the concentration of gold and silver cations in the solution is high, but as time progresses, more of them react with free cyanide ( $\text{CN}^-$ ), leading to a smaller incremental increase in recovery.

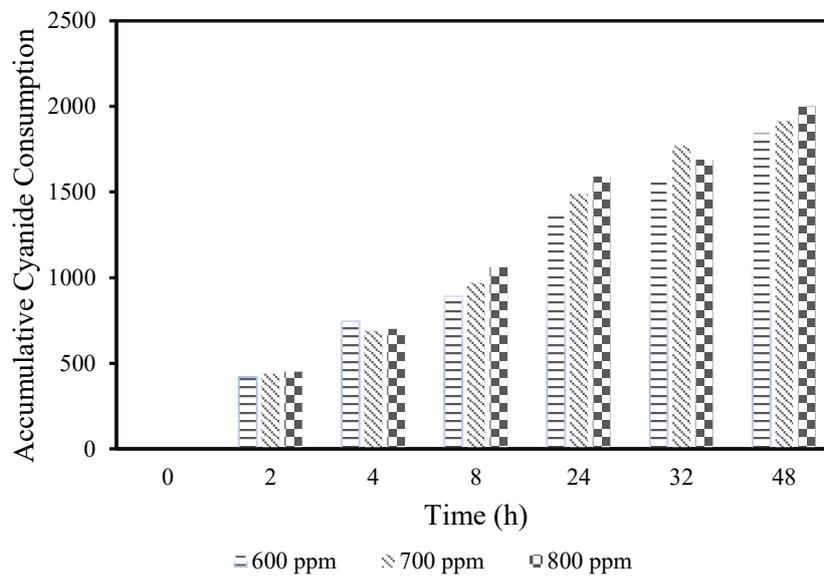


Figure 7. Accumulated Cyanide Consumption Over Leaching Time for Each Cyanide Concentration Variation

Based on the recovery analysis for the cyanide concentration variations, it can be observed that the incremental recovery for each cyanide concentration is not significantly different. In Figure 7, the accumulated cyanide consumption is obtained to be 2.88 g at a concentration of 600 ppm, which is slightly lower than the consumption at 700 ppm and 800 ppm, which are valued at 2.97 g and 3.11 g, respectively. Therefore, it can be concluded that

the optimal cyanide concentration for gold leaching at PT Indo Muro Kencana is 600 ppm. This conclusion is based on both recovery and cyanide consumption.

A reaction rate control analysis was conducted using linear regression curves for the experimental results of each cyanide concentration, considering three kinetic models as depicted in Figure 8, 9 and 10. The linearity of the linear regression was assessed by evaluating the coefficient of determination ( $R^2$ ) that approaches one [7]. Below are the results of the reaction rate control analysis for the three cyanide concentration variations. Based on the  $R^2$  values of the three Shrinking Core Model kinetic models, the rate-controlling mechanism is determined to be product diffusion layer.

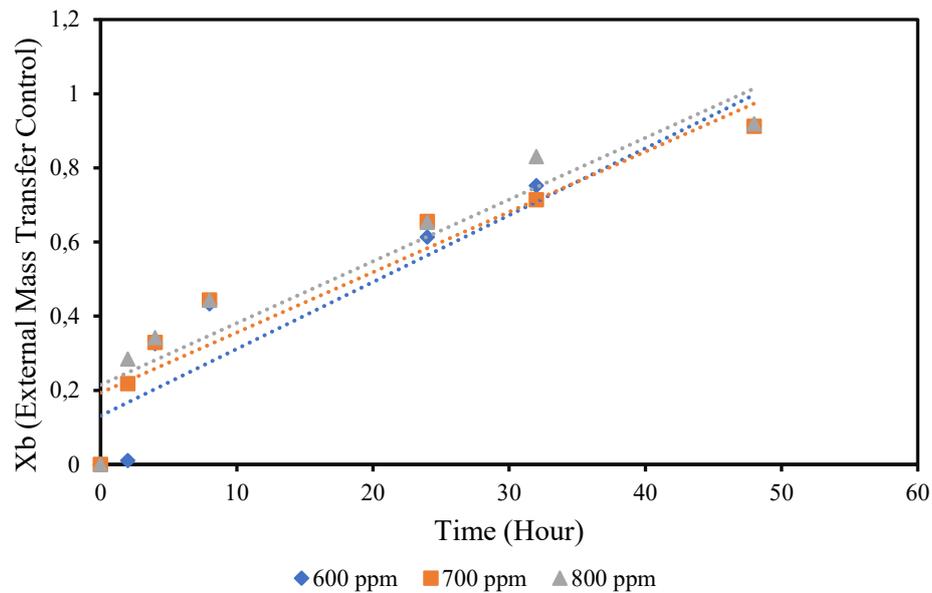


Figure 8. The Experimental Results Channeling for Cyanide Concentration of 600 ppm into the 3 Shrinking Core Model Kinetic Models

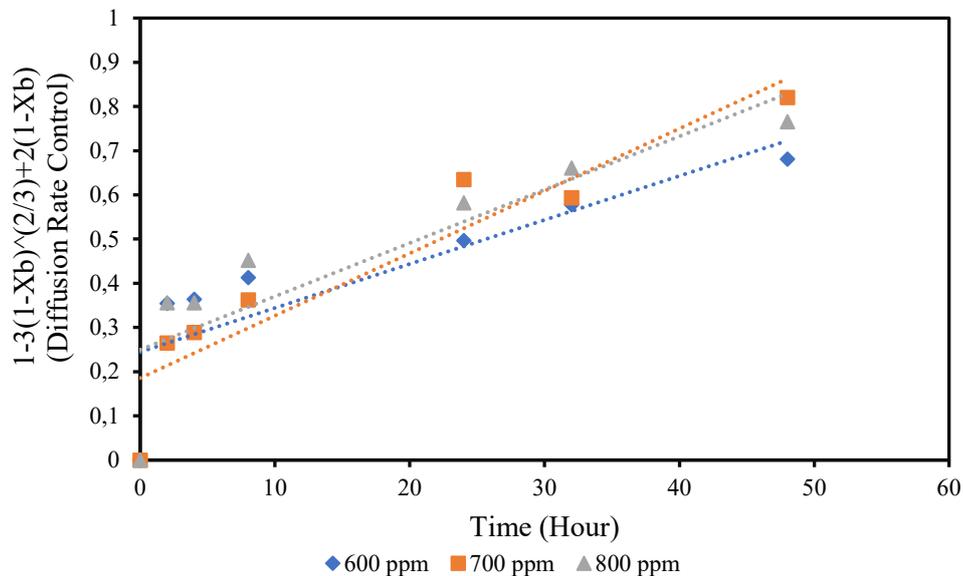


Figure 9. The Experimental Results Channeling for Cyanide Concentration of 700 ppm into the 3 Shrinking Core Model Kinetic Models

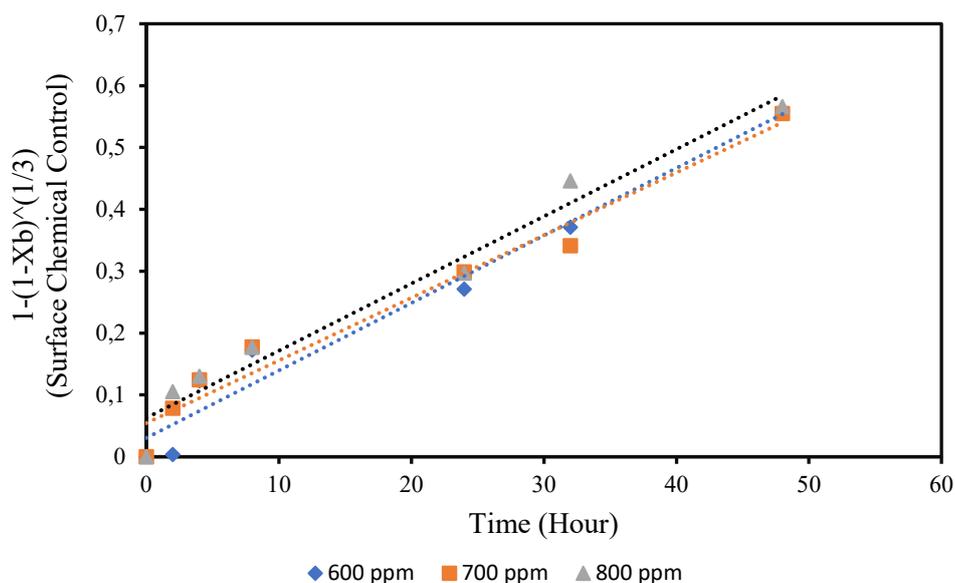


Figure 10. The Experimental Results Channeling for Cyanide Concentration of 800 ppm into the 3 Shrinking Core Model Kinetic Models

**Table 1.** Linear Regression Values for Each Cyanide Concentration

Cyanide Concentration	R <sup>2</sup> Values for Each Reaction Rate Control Model		
	External Mass Transfer Control	Diffusion Rate Control	Surface Chemical Control
600 ppm	0,4024	0,8556	0,7071
700 ppm	0,4307	0,8705	0,7462
800 ppm	0,3402	0,7636	0,6185
Average	<b>0,3911</b>	<b>0,8299</b>	<b>0,6906</b>

Based on the R<sup>2</sup> analysis above, the rate-controlling mechanism determined is Diffusion Rate Control. The solid product layer forms due to the presence of insoluble minerals or reprecipitation of reaction products [7]. To optimize leaching, particle size reduction can be employed to increase liberation and enhance surface area. Finer particle sizes accelerate reaction rates, thus optimizing the leaching process [2].

#### 4. CONCLUSION

Based on the results and discussions above, by varying the NaCN concentration in the gold cyanidation process, the following conclusions can be drawn:

1. The optimal condition in the experiment with variations in cyanide concentration, based on gold and silver recovery results as well as NaCN reagent consumption, is 600 ppm.
2. Based on data analysis, it is concluded that the gold recovery percentage at a NaCN concentration of 600 ppm is 96.5%, while for silver it is 91.4%.
3. From the leach test data, the NaCN consumption at a concentration of 600 ppm is found to be 2.88 grams.
4. The rate-controlling mechanism in this experimental process is Diffusion Rate Control.

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