



Improving Gold Recovery from Artificial Preg-Robbing Ore by Pre-treatment using Blinding Agent and Resin-in-Leach

Mohammad Zaki Mubarak^{1,*} & Prasetyo Sandha Irianto²

¹Department of Metallurgical Engineering,
Faculty of Mining and Petroleum Engineering,
Institute Technology of Bandung, JalanGanesha, 10, Bandung 40132, Indonesia

²PT. Antam, Tbk., UBPP Logam Mulia, JalanRaya Bekasi Km. 18, Pulogadung
Jakarta, 13010, Indonesia

*E-mail: zaki@mining.itb.ac.id

Abstract. In the present paper, the effectiveness of the use of blinding agents, ionic exchanger resins and the combination of them in improving gold extraction from simulated preg-robbing ore is discussed. The blinding agents used were kerosene, diesel oil and pine oil, while the ion exchange resins used were Lewatit Monoplus MP 800, Lewatit AF 5 and guanidine. Preg-robbing conditions were simulated by blending fine activated carbon with ore sample. The investigation results show that the presence of artificial carbonaceous materials at 2% (w/w) in the gold ore significantly reduces gold recovery. Pretreatment of artificial preg-robbing ore prior to cyanidation by mixing with kerosene, diesel oil and pine oil for 0.5h improved gold recovery up to 25.4%. A combination of pre-treatment using blinding agent and a resin in leach (RIL) test using Lewatit MP 800 resin demonstrated a synergistic effect that improves gold recovery up to a level of 99.5%, which is significantly higher than using activated carbon and without pretreatment.

Keywords: *blinding agent; gold; preg-rob ore; recovery; resin.*

1 Introduction

Minimizing gold loss in the final tails is one of the most important tasks in gold cyanidation plants. In order to achieve and maintain a high level of gold recovery, problems in the processing plant that can cause gold loss during cyanidation and recovery from pregnant leach solutions must be identified and managed carefully. Gold loss in final tails can be due to several reasons; one of the most prominent reasons is a phenomenon commonly called preg-robbing. This phenomenon is associated with the adsorption of dissolved gold onto carbonaceous materials and/or other preg-robbing materials contained in the ore. In carbonaceous preg-robbing ore, the carbonaceous materials behave like activated carbon that adsorbs dissolved gold and silver. Due to the fine size of the ore, gold and silver being adsorbed by the carbonaceous materials in the ore

Received October, 27th, 2015, 1st Revision December 16th, 2015, 2nd Revision June 14th, 2016, Accepted for publication July 15th, 2016.

Copyright ©2016 Published by ITB Journal Publisher, ISSN: 2337-5779, DOI: 10.5614/j.eng.technol.sci.2016.48.3.3

pass through the interstage screen and are lost in the tails. Carbonaceous materials that have preg-robbing properties include amorphous and graphitic carbon, carbonate minerals, as well as hydrocarbons with high molecular weight[1]. Non-carbonaceous preg-robbing materials are clay minerals present in ores such as pyrophyllite, kaolinite and montmorillonite, as well as sulphide minerals such as pyrite, sphalerite, chalcopyrite, arsenopyrite and pyrrhotite[2,3].

The level of preg-robbing ores is classified as high, medium and low. For the low to medium levels of preg-robbing activity, gold losses can be minimized by selecting the carbon in leach (CIL) route or pre-treatment of the ore with blinding agents. Several surfactants are known to have the ability of wetting the surface of carbon, passivating the surface of carbonaceous materials and thus, able to prevent the adsorption of dissolved gold onto fine-size carbonaceous materials present in the ore. Previous investigations have indicated that flotation reagents such as xanthates and pine oil, as well as non-polar hydrocarbons such as diesel oil, light oil, fuel oil and kerosene can be used to passivate carbonaceous materials in preg-rob ore[4]. For high-level of preg-rob ores, special treatments such as roasting, chlorination, nitric acid wash, biooxidation and pressure oxidation are required[5]. Pretreatment of preg-robbing gold ore can also be performed by using an adsorbent that has high adsorption strength to aurocyanide complex anions, such as ion exchange resins. In comparison to activated carbons, ion exchange resins generally have a higher adsorption capacity, higher selectivity and provide faster kinetics. Moreover, the use of an ion exchange (IX) resin would eliminate the cost of heating, such as that for reactivation of an activated carbon. The use of IX resin to treat preg-rob ore in a resin-in-leach (RIL) process can also be combined with pretreatment using blinding agents. In this case, the blinding agent will not passivate the resin, as in the case of activated carbon passivation, when the blinding agents are used in combination with the activated carbon[6]. In this paper, the effectiveness of a combined use of blinding agents (i.e. kerosene, diesel oil and pine oil) with activated carbon and three different types of ion exchange resins for treating an artificial preg-robbing ore is discussed.

2 Materials and Methods

2.1 Materials

The preg-robbing ore was simulated by mixing 2% (w/w) of fine activated carbon particles with a size of -200 mesh with gold ore sample received from the Pongkor Mine of PT. Antam, Tbk. in West Java, Indonesia. Preparation of the gold ore sample was performed to obtain the adequate amount of ore with a specified particle size distribution. Sample preparation was carried out by

crushing, milling, and homogenization to provide the ore sample with a particle size distribution of 100% -200 mesh. Chemical composition analysis of the ore sample was done by atomic absorption spectrophotometer (AAS). The chemical composition of the ore sample, showing the contents of Au, Ag, Fe, Cu and Zn, is presented in Table 1.

Table 1 Chemical composition of ore sample.

Element	Au	Ag	Fe	Cu	Zn
Content (ppm)	6.58	56	32,120	38	114

Leaching reagent was prepared by dissolving a certain amount of sodium cyanide (NaCN) salt in distilled water to obtain a cyanide concentration of 800 ppm. Prior to the cyanidation leaching test works, milk lime was added to adjust the slurry pH at 10.8 ± 0.3 . As mentioned earlier, three types of blinding agents were used, namely kerosene (C₁₂H₂₆), diesel oil (C₁₂H₂₃) and pine oil (C₁₁H₁₀BrN₅). The dosages of these blinding agents were varied at 4, 8, 12, 16, 50 and 100 ml/kg-ore. All of the blinding agents are not soluble in water.

The adsorbents used were commercial activated carbon and three types of ion exchange resins, namely Lewatit Monoplus MP 800, AF 5 and guanidine. MP 800 represents a strong base resin with cross linked polystyrene matrices and quaternary amine, while AF 5 and guanidine represent the resins with polymeric carbon matrices and weak base, respectively. The resin samples were received from Lanxess, GmbH, Germany. The physical characteristics of the adsorbents are presented in Table 2.

Table 2 Physical characteristics of adsorbents used in this work.

Parameter	Activated carbon	Adsorbent Type		
		AF 5	MP 800	Guanidine
Matrices (bulk material)	Carbon	Carbon	<i>polystyrene</i>	<i>polystyrene</i>
Particle size (mm)	2	0.4-0.8	0.62	0.7
Bulk density (g/L)	500-530	550-650	620	710
Surface area (m ² /g)	1000-1100	1200	NA	NA

2.2 Experimental Procedure

Fine activated carbon particles of 100% -200 mesh were prepared by milling of the commercial activated carbon commonly used in Pongkor Gold Processing Plant. The fine activated carbon particles were blended with the ore sample in a mixer to prepare artificial preg-robbing ore sample. A series of batch

cyanidation tests was conducted in a 600-mL glass reactor equipped with three baffles.

Agitation was performed by mechanical stirrer with a constant rotation speed of 530 rpm. The agitation leaching test was carried out at room temperature, with 30% solids using an ore particle size distribution of 100% -200 mesh for 24 h. The weight of the ore sample used in the leaching test was 183 gram in which 2% (w/w) of the fine activated carbon particles was blended. The leaching test was performed using 800 ppm of sodium cyanide at a solution pH level of 10.8 ± 0.3 . Following the cyanidation testworks of the pre-treated ore, a series of batch adsorption tests was carried out using activated carbon and three types of ion exchange resins. Pregnant leach solution was prepared by cyanidation leaching of Pongkor ore under similar conditions as the previous leaching tests. Pretreatment with kerosene was done at a dosage of 16 ml/kg-ore for 30 minutes prior to the start of the cyanidation tests. For the carbon and resin-in-solution (CIS and RIS) tests, the adsorbents were agitated at a constant rotation speed of 200 rpm by a mechanical agitator in a 250 mL beaker glass with a solution volume of 200 mL. The pregnant leach solution had Au and Ag concentrations of 2.4 mg/l and 14.6 mg/l, respectively. The adsorption tests were performed at room temperature for 24 h under variations of pH. The solution pH was varied at 9.4, 10.5, 10.9, 11.4, and 11.7 using NH_3 solution. Furthermore, addition of fine activated-C followed by CIS and RIS was also conducted to evaluate the competition behavior between the fine activated carbon particles as artificial preg-robbing material and the adsorbent in adsorbing gold.

The synergistic effect of the pre-treatments using blinding agents and stronger adsorbent was studied by CIL and RIL tests. In this study, leaching of pre-treated artificial preg-robbing ore using 16 ml-kerosene/kg-ore and adsorption using four types of adsorbents was performed simultaneously. As in the CIS and RIS tests, the NaCN concentration used was 800 ppm. Pre-treatment with kerosene was done for 30 minutes prior to the start of the CIL and RIL tests. Solution samples were taken at certain times after the start of agitation for analysis of the dissolved Au concentrations with AAS. Recovery of Au was calculated from the ratio of the weight of dissolved Au and the initial weight of Au in the ore samples.

3 Results and Discussion

The profiles of gold recovery as a function of type and dosage of blinding agent are depicted in Figure 1(a). Low gold recovery was obtained from the 24-hour cyanidation test of gold ore mixed with fine activated carbon particles as artificial carbonaceous preg-robbing material. Pre-treatment of the artificial

gold preg-robbing ore with blinding agents improved gold recovery, where pre-treatment using kerosene demonstrated the highest gold recovery followed by diesel oil and pine oil. Pre-treatment using 16 ml-kerosene/kg-ore enhanced gold recovery from 65.5% to 90.9%. Increasing the blinding agent dosage enhanced gold recovery until a certain maximum level beyond which the increase of the blinding agent dosage resulted in a slight decrease of gold recovery. The dosage of blinding agent must be carefully determined. The excess use of blinding agent tends to reduce gold recovery due to chemisorption of Au-complex anions by the blinding agent's molecules. For kerosene, the dosage that resulted in the highest gold recovery was 16 mL/kg-ore. It is expected that the blinding agent molecules adsorbed onto the ore surface, thus hindering the contact between the carbonaceous materials in the ore and preventing the adsorption of gold. The blinding agent will be adsorbed onto the ore surface as anionic species, therefore adsorption of the anion complexes of aurocyanides ($\text{Au}(\text{CN})_2^-$) are avoided by a mechanism of electrostatic repulsion between the blinding agent anions and the aforementioned anions. The blinding agent covers the active sites of the carbonaceous materials in the ore and prevents adsorption of $\text{Au}(\text{CN})_2^-$ complex anions onto the fine particles of carbonaceous materials during leaching.

A series of gold adsorption tests was further carried out on pregnant leach solution of pre-treated ore with 16 mL kerosene/kg-ore, which was regarded as the best condition obtained for the pre-treatment. The effect of residual blinding agent on the adsorption of gold by activated carbon and IX resins was evaluated. The percentages of gold recovered onto activated carbon from the pregnant-leach solution of the pre-treated ore as a function of time at various pH levels are presented in Figure 1(b). The investigation results showed that activated carbon did not perform effectively in a solution that contains residual blinding agent. The maximum gold adsorption percentage was only 48.3%. The low recovery of gold is believed to be associated with the passivation of activated carbon by the residual blinding agent molecules as they do to carbonaceous materials in the ore. Adsorption of gold onto activated-C performs better at lower pH, indicated by higher adsorption percentages of gold. On the other hand, solution pH during cyanidation must be kept high (approximately above 9.5) to avoid cyanide hydrolysis and HCN gas generation occurring at low pH.

Lewatit Monoplus MP 800 is an anion exchange resin of the strong base type. Figures 2(a) and 2(b) show profiles of Au adsorption percentages as a function of time at various pH onto Lewatit Monoplus MP 800 and guanidine resin, respectively. Lewatit Monoplus MP 800 resin demonstrated much higher Au recovery than activated carbon. The highest Au adsorption (98.3%) was obtained at pH 9.4 after 24 h of stirring. The rates of gold adsorption were also

significantly faster. Variations of solution pH in the range of 9.4-11.7 did not significantly affect Au recovery onto this type of resin. The presence of residual kerosene in the solution did not affect the performance of this resin in adsorbing gold.

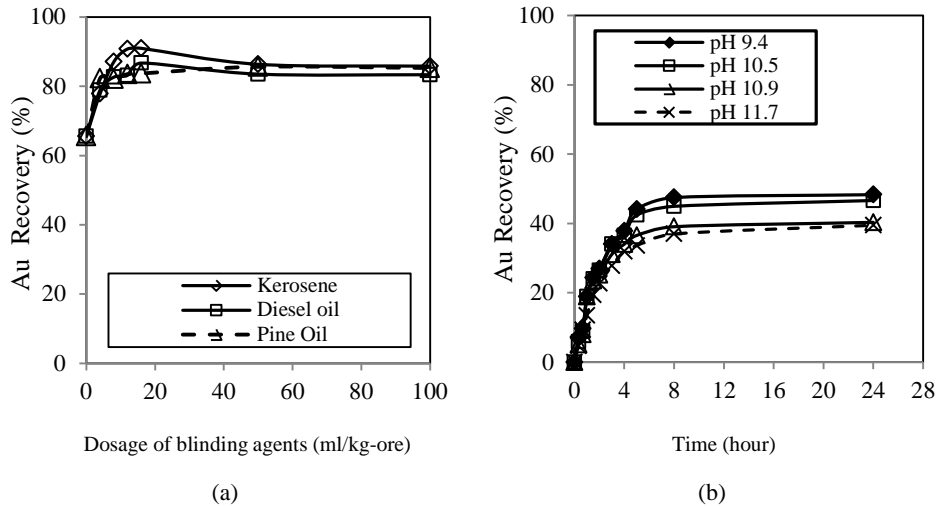


Figure 1 Profiles of (a) gold recovery as a function of type and dosage of blinding agent, (b) gold recovery onto activated carbon as a function of time at various pH levels.

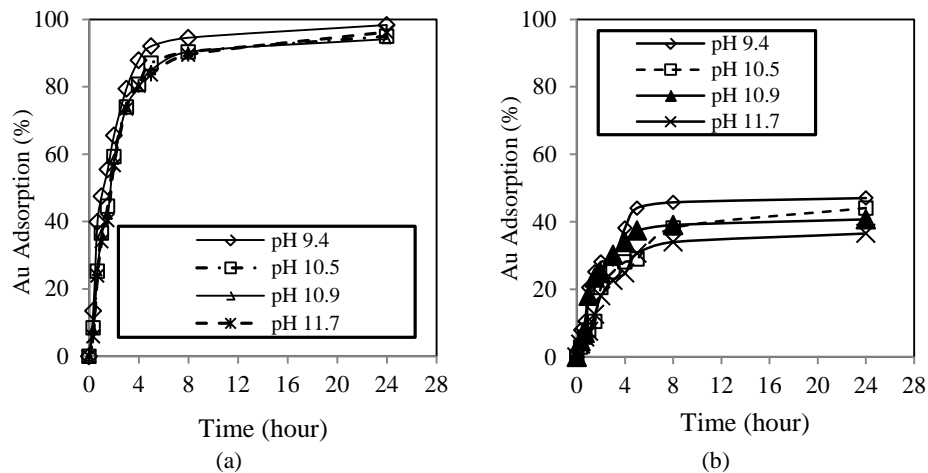


Figure 2 Profiles of gold adsorption percentage as a function of time at various pH levels onto (a) Lewatit MP 800 resin and (b) guanidine resin.

Lewatit AF 5 is a type of resin with polymeric carbon as a matrix. It can be predicted that the adsorption properties of this resin are comparable to those of activated carbon. However, as can be seen in Table 1, this resin has a much finer particle size than activated carbon, which results in a better loading capacity and adsorption kinetics. The highest adsorbed gold percentage was 96.2%, significantly higher than that using activated carbon but lower than the percentage of adsorption onto MP 800 resin. Similar to adsorption onto activated carbon, Au adsorption onto AF 5 resin performs better at lower pH. Guanidine resin is a weak base type of IX resin. This weak base resin exhibited poor performance. The highest Au adsorption was 47.1%. Low capacity of guanidine resin is associated with the structure of the resin. This type of resin has a tertiary amine group that needs to be activated at acidic condition in order to have the positive charge required to attract complex Au complex anions from the solution by releasing chloride ions. In a strong alkaline solution, the functional amine groups attached to the polymeric matrix tend to stay in the form of a free base[7].

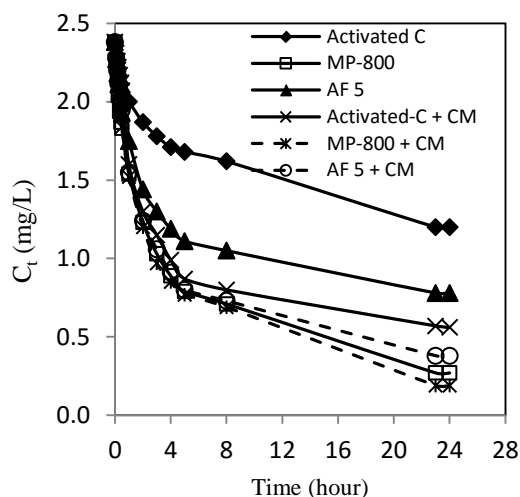


Figure 3 Profiles of gold concentration remained in solution as a function of time at pH 10.5 for various adsorbents in the absence and presence of artificial carbonaceous material.

Figure 3 shows the profiles of the residual concentration of gold as a function of time at pH 10.5 for various adsorbents in the absence and presence of artificial carbonaceous materials in the solution. It can be seen that the presence of fine activated carbon particles significantly reduces the equilibrium concentration of Au in the solution for the adsorption test using activated-C. This result indicates that the fine activated-C particles adsorb gold stronger than the coarser activated carbon adsorbent.

Similarly, the presence of fine activated carbon also reduces the equilibrium gold concentration in the solution in the adsorption test using AF-5 resin. However, the decrease of the equilibrium gold concentration in the solution was lower than that in the adsorption using activated carbon. Different from activated carbon and AF-5 resin, the presence of fine activated carbon only slightly affected gold adsorption onto MP-800 resin. This indicates that MP-800 is a strong adsorbent of gold that is more predominant than fine activated carbon particles that simulate carbonaceous materials in ore.

As has been widely accepted, the adsorption rate of dissolved ions onto activated carbon and ion exchange resins can be controlled by three distinctive processes: diffusion through fluid film on the surface of the adsorbent, diffusion through adsorbent particles, and chemical reaction. The kinetics analysis reveals that gold adsorption onto activated-C and MP-800 resin is controlled by diffusion through a fluid film on the surface of the adsorbents. This is in accordance with typical kinetics of adsorption of solutes from dilute solution, which is usually controlled by diffusion through fluid film on the surface of the adsorbent. Following Qiu et.al.[8], for adsorption kinetics controlled by external film diffusion, the rate of solute accumulation in solid adsorbent particles is equal to $V_p \left(\frac{\partial \bar{q}}{\partial t} \right)$, where \bar{q} represents the average solute concentration in adsorbent phase and V_p is the volume of the adsorbent particles. Based on mass balance analysis, the rate of solute accumulation in the adsorbent equals to the rate of solute transfer across the liquid film, which is the proportional surface area of the adsorbent particle (A_s) and the concentration driving force for solute diffusion through the liquid film. The concentration driving force for solute diffusion through fluid film is equal to $C - C_i$, in which C is the solute concentration in the bulk of solution and C_i is the solute concentration on the interface of the adsorbent particles and the liquid film. Hence, the rate of accumulation of solute on the adsorbent particles can be formulated as follows [8]:

$$V_p \left(\frac{\partial \bar{q}}{\partial t} \right) = k_f A_s (C - C_i) \quad (1)$$

in which k_f is the mass transfer coefficient of the solute through liquid film. Eq. (1) can be further re-written in Eqs. (2) and (3), as follows:

$$\frac{\partial \bar{q}}{\partial t} = k_f \frac{A_s}{V_p} (C - C_i) \quad (2)$$

$$\frac{\partial \bar{q}}{\partial t} = k' (C - C_i) \quad (3)$$

in which $k' = k_f \frac{A_s}{V_p}$. The value of k' is dependent on the surface area of the adsorbent, bead or particle size of the adsorbent and the effective volume of the adsorbent particles.

The concentration of adsorbed solute in adsorbent phase (q) can be determined from the difference between the initial solute concentration in the solution and the solute concentration remaining in the solution after a certain period of adsorption. At equilibrium, the concentration of solute in adsorbent phase can be determined as follows:

$$q_e = \frac{(C_o - C_e)V_s}{V_a} \quad (4)$$

where C_o and C_e are the initial and equilibrium concentrations of solute in the solution (mg/L), respectively, V_a is the volume of the adsorbent (g) and V_s is the volume of the solution (L).

Based on Eqs. (3) and (4), the kinetics model used for analysis of the gold adsorption can be derived as follows:

$$\ln\left(\frac{C_e}{C_e - C_t}\right) = k't \quad (5)$$

in which C_e is the equilibrium concentration of gold in the adsorbent, which is correlated with the equilibrium concentration of the gold in the solution and C_t is the concentration of the gold in the adsorbent at time t . If the rate of gold adsorption is controlled by external diffusion through the fluid film, the plot of $\ln(C_e/(C_e - C_t))$ versus t would be linear with a gradient of k' . The profiles of $\ln(C_e/(C_e - C_t))$ versus t from the gold adsorption test data using activated carbon and MP-800 resin in the absence and presence of carbonaceous materials during the first 30 minute of adsorption are shown in Figure 4(a) and 4(b), respectively.

As can be seen in Figure 4, a linear correlation was obtained between the value of $\ln(C_e/(C_e - C_t))$ versus t for Au adsorption data using activated-C and MP-800 resin. This result confirms that the rates of Au are controlled by diffusion of the solute through the liquid film on the surface of the adsorbent. The presence of artificial carbonaceous materials in the solution reduced the gold adsorption onto the activated carbon indicated by alteration of the slope of the regression line and the lower value of k' . In contrast, the presence of artificial carbonaceous materials in the solution only slightly affected the gold adsorption onto the MP-800 resin with no alteration of the value of k' . This indicates that the rate of gold loading onto the MP-800 resin is significantly faster than that by fine activated carbon, which simulates carbonaceous materials in the ore.

The synergistic effect between pretreatment using a blinding agent and adsorption using ion exchange resin was also investigated by conducting resin-in-leach (RIL) tests of pre-treated artificial preg-robbing ore. The resin used was only MP-800, which has demonstrated the best performance in adsorbing gold. The results were compared with the carbon-in-leach test (CIL) of the pre-treated artificial preg-robbing ore and the CIL of the ore without pre-treatment.

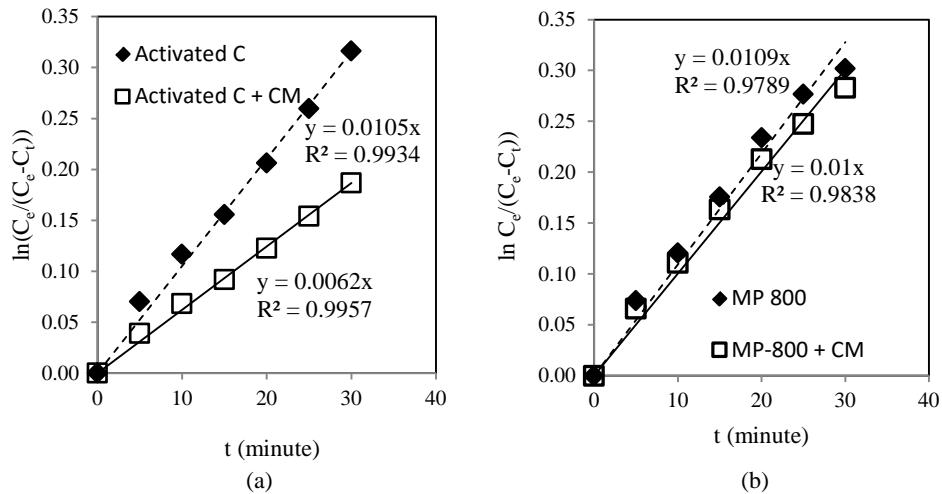


Figure 4 Profiles of $\ln(C_e/(C_e - C_t))$ vs. t for Au adsorption in the absence and presence of simulated carbonaceous materials (CM) for (a) activated-C and (b) MP-800.

The investigation results showed great improvement of Au recovery in the RIL test using resin MP-800 in comparison to those from the CIL test without pre-treatment. Gold recovery after 24h of RIL testing of the pretreated ore was 99.5%, while the CIL test without pre-treatment resulted in an Au recovery of 86.1%. A comparison of Au recoveries from the cyanidation test without pre-treatment, pre-treatment + cyanidation, pre-treatment + CIL and pretreatment + RIL using MP-800 resin is shown in Figure 5. The synergistic effect of pre-treatment using kerosene and RIL using MP-800 resin in improving gold recovery was confirmed by the testwork results.

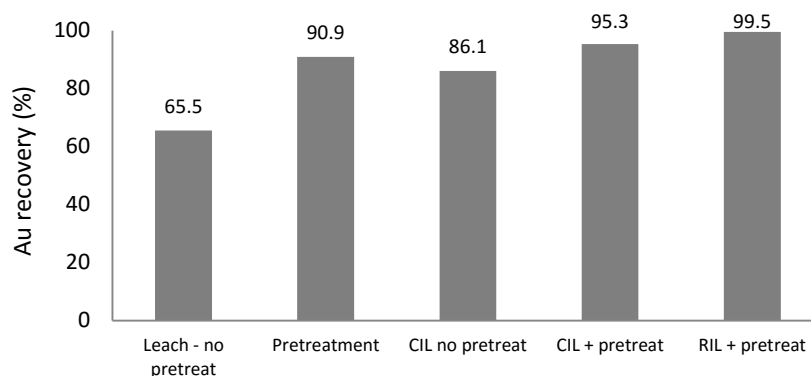


Figure 5 Comparison of Au recoveries from testworks under various conditions.

4 Concluding Remarks

The presence of artificial carbonaceous materials at 2% (w/w) in gold ore significantly reduces gold recovery. Pre-treatment of artificial preg-robbing ore prior to cyanidation by mixing with kerosene, diesel oil and pine oil for 0.5h improves gold recovery by passivating the carbonaceous materials. At the same dosage, the highest effectiveness of pre-treatment in terms of achieved gold recovery was demonstrated by kerosene followed by diesel oil and pine oil. The dosage of blinding agent must be carefully adjusted to prevent passivation of the activated carbon used in the CIL process at the excess of the blinding agent dosage. In comparison to activated carbon, the use of a strong basic IX resin with crosslinked polystyrene as functional group and carbon-based resin gave remarkably higher gold recovery, better loading capacity and faster kinetics of gold adsorption in the presence of preg-robbing materials. An excess of blinding agent does not influence the performance of a strong basic IX resin with crosslinked polystyrene. The synergistic effect of pre-treatment using a blinding agent followed by resin-in-leach provides an attractive option for processing preg-robbing ore.

Acknowledgements

The authors would like to thank PT.Antam, Tbk. for providing the ore sample, blinding agents and activated carbon used in the research work. Our gratitude is also extended to Lanxess GmbH, Germany for providing the IX resins.

References

- [1] Tan, H., Feng, D., Lukey, G.C. & Van Deventer, J.S.J., *The Behaviour of Carbonaceous Matter in Cyanide Leaching of Gold*, *Hydrometallurgy*, **78**, pp. 226-235, 2005.
- [2] Rees, K.L. & Van Deventer J.S.J., *Preg-robbing Phenomena in Cyanidation of Sulphide Gold Ores*, *Hydrometallurgy* **58**, pp. 61-80, 2000.
- [3] Geodal, W.R., *A New Method for Determining of Preg-robbing in Gold Ores*, *Minerals Engineering*, **18**, Elsevier, pp. 1135-1141, 2005
- [4] Afenya, P.M., *Treatment of Carbonaceous Refractory Gold Ores*, *Minerals Engineering*, **4** (7-11), pp. 1043-1055, 1991.
- [5] Adams, M.D., *Advances in Gold Ore Processing*, *Developments in Mineral Processing*, **15**, Elsevier, 2005.
- [6] Green, B.R., Kotze, M.H. & Wyethe, J.P., *Developments in Ion Exchange: the Mintek Perspective*, *Journal of Metals (JOM)*, **54**(10), pp. 37-43, 2002
- [7] Mubarak, M.Z. & Blassmara, K., *Gold Adsorption Behaviour Onto Activated Carbon and Some Anion Exchanger Resins*. Proceedings of the 3rd International Symposium on Novel Carbon Resource Sciences. November 2-3, 2009, Fukuoka, Japan.
- [8] Qiu, H., Lu, LV., Zhang, Q.J., & Zang, W.M., *Critical Review in Adsorption Kinetic Models*. *Journal of Zhejiang University, SCIENCE A*, ISSN 1862-1775, **10**(5), pp. 716-724, 2009.