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MODELING OF THE CARBON IN PULP (CIP) PROCESS IN GOLD CYANIDE LEACHING PLANTS USING THE PLANT DATA

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Abstract: An improved method to model CIP plants by plant data is presented. The Turkish gold cyanide leaching CIP plants, Bergama Ovacik, Gumushane Mastra and Eskisehir Kaymaz were modeled by using gold concentrations of monthly carbon, solution and solids spot samples of adsorption tanks without a need of laboratory work. Five carbon adsorption models were used namely k-n, Nicol-Fleming, Dixon, Film Diffusion with Langmuir isotherm and Film Diffusion with Freundlich isotherm (Johns model). Several monthly obtained plant data were collected and modeled separately and model parameters as well as regression coefficient R^2 values were found by non-linear regression. By comparing R^2 values, the best fit model for the three CIP plants was determined as Film Diffusion with Langmuir Isotherm that R^2 values were above 0.95. Thus, by using the best fit model, the Kaymaz plant was optimized for existing 49 Mg per hour ore feed tonnage and plant parameters were predicted according to planned feed tonnage increase to 120 Mg per hour.

Key words: modeling, cyanide leaching, activated carbon, adsorption, gold

Introduction

Gold is predominantly produced from its ores by hydrometallurgical cyanide leaching process. The cyanide leaching process is applied by first grinding the ore below 75 micrometers and dissolving the gold as $Au(CN)_2^-$ by mixing the ground ore with dilute cyanide solution to obtain slurry above pH 10 and by supplying oxygen to leach tanks. Dissolution of gold-cyanide completes in about 24 hours. The hydrometallurgical reaction for extracting gold from its ores can be expressed as below:

$$Au^0 + 2CN^- + \frac{1}{2} H_2O + \frac{1}{4} O_2 \rightarrow Au(CN)_2^- + OH^-. \tag{1}$$

After dissolution of gold, the slurry passes through the carbon adsorption tanks. In those tanks, granulated activated coconut carbon is mixed into the slurry and the

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disolved gold is adsorbed by the carbon, leaving the barren solution. The adsorption phenomena can be defined by the reaction (Davidson and Sole, 2007; Pleysier et al., 2008):

$$2Au^0 + Ca^{+2} + 4CN^- + H_2O + ½O_2 \rightarrow Ca[Au(CN)_2]_2 + 2OH^- . \qquad (2)$$

According to Eq. 2, the adsorption ocurrs by the formation of the $Ca[Au(CN)_2]_2$ complex. The $Ca[Au(CN)_2]_2$ complex is adsorbed by carbon. In this adsorption reaction Ca comes from adition of lime into the pulp to obtain the pH of 10 or above.

The slurry passes through from first adsorption tank to the last one, while the activated carbon follows the direction in reverse order from the last tank to the first one. By this counter current flow of the slurry and the carbon the $Au(CN)_2^-$ complex is loaded onto the carbon. From the first adsorption tank the most Au loaded final activated carbon is obtained and by column elution method the loaded gold is gained by stripping it from carbon. To prevent the granulated carbon to move forward with the slurry, special sieves exist at the tanks discharge openings. Next, carbon is driven backward by special carbon pumps at certain times.

Adsorption of $Au(CN)_2^-$ by activated coconut carbon is a well proven process widely used to recover gold from slurry at cyanide leaching plants. In this research, modelling of adsorption of dissolved gold performed by using real CIP (carbon in pulp) plant data. For this aim, five kinetic models and the gold mass balance calculations were used together. After obtaining model parameters, optimization of the plant would be possible. By optimization of the plants according to those models, the optimum needed carbon amount in each tank, the residence time of the carbon for each tank, the stripping amounts per week, the adsorption tank amount and volumes and the stripping column volume could be determined for certain plant feed ore tonnages.

In this research, the present CIP plants in Turkey, Bergama Ovacik, Gumushane Mastra and Eskisehir Kaymaz plants were modelled.

Gold Mass Balance

The counter current slurry and carbon flow with gold mass balance are presented in Fig.1. According to Fig. 1, the parameters are described as follows:

C_0 – solution Au concentration of the feed slurry, ppm
C_n – solution Au concentration of the slurry in tank n, ppm
Q_0 – Au concentration of pregnant carbon in tank 1, ppm
Q_n – Au concentration of loaded carbon in tank n, ppm
$ADS1–n$ – adsorption tanks

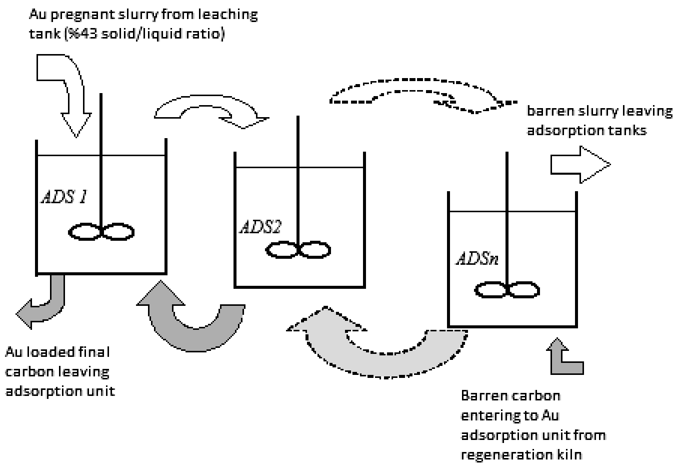

Fig. 1. Carbon adsorption unit of a carbon in pulp (CIP) Gold Ore Cyanide Leaching Plant

Mass balance can be defined by Eqs (3) and (4),

$$Vs(C_{n-1} - C_n) = Vc(Q_{n-1} - Q_n) \tag{3}$$

$$Vc = \frac{Mc}{tc}\,. \tag{4}$$

The parameters could be described as, *Vs* – solution flow rate in slurry Mg/hour; *Vc* – carbon flow rate Mg/hour, *Mc* – carbon amount in each adsorption tank, *tc* – carbon residence time in each tank as hours.

Gold Adsorption Kinetic Models

Adsorption kinetics of gold (*R*) can be described in general as (Fleming and Nicol, 1984);

$$R = \frac{dQ}{dt}, \text{ or } \quad R = \frac{Q_{n-1} - Q_n}{tc} \tag{5}$$

and adsorption kinetics *R* can be defined by following five models (Le Roux et al., 1991; Fleming and Nicol, 1984; Fleming et al., 2011; Syna, and Valix, 2003; Ahmed et al., 1992; Jones and Linge, 1989; Rees and Van Deventer, 2001; Adams et al., 1987).

Fleming *k,n* model

Fleming *k*,*n* model is the first carbon adsorption model defined by the equation:

$$\frac{\log(Q_{n-1}-Q_n)}{C}=\log k+n\log tc\,. \tag{6}$$

In this equation, k and n are model parameters, k is the rate constant, 1/hours, and n is a model parameter.

Nicol-Fleming model

This model includes an equilibrium constant as K as a difference from k,n model. The Nicol-Fleming model can be described as follows:

$$R=k(KC-Q)\,. \tag{7}$$

In Eq. 7 K is the equilibrium constant and k can be defined as rate constant.

Film diffusion model with Freunlich isotherm (Johns model)

Film diffusion models define the adsorption process assuming that dissolved gold is adsorbed onto the carbon surface by passing film layer which separates the carbon surface and the solution phase. Thus, the equation can be shown as follows:

$$R=Ackf\left(C-\left(\frac{Q}{k}\right)^n\right). \tag{8}$$

In Eq. 8 Ac is carbon film diffusion surface area, K, equilibrium constant, kf is film diffusion constant.

Film diffusion model with Langmuir isotherm

Film diffusion model with Langmuir isotherm can be defined as

$$R=Ackf\left(C-\left(\frac{bQ}{K-Q}\right)\right). \tag{9}$$

In Eq. 9 Ac is carbon film diffusion surface area, K is the equilibrium constant, kf is film diffusion constant and b is a model constant.

Dixon model

Dixon model can be defined as

$$R=k_1C(K-Q)-k_2Q\,. \tag{10}$$

In Eq. 10 k_1 is rate constant for gold adsorption and k_2 is defined as rate constant for gold desorption. Thus, this model takes into account existence of both adsorption and desorption phenomena at the same time. K is the equilibrium constant.

Material and method

In order to model the CIP plants, the samples that have been taken once a month were used. The samples include: solid (ore), solution, and carbons from each adsorption tank. While taking samples, the carbon amounts g/dm^3 slurry and solid concentration of slurry as %solid (w/w) for each tank were measured and noted.

Table 1. The average of separate 8 months sampling data from Mastra CIP plant

Average of 8 months for Mastra CIP plant				Av. tonnage: 59 Mg/h
Adsorption tanks	Au conc. in ore, ppm	Au conc. in solution C, ppm	Au conc. in carbon Q, ppm	Solid concentration %40
Feed slurry	2.63	6.45	-	gCarb/dm^{3}pulp
ADS1	0.86	0.81	4386	15.5
ADS2	0.79	0.74	3101	3.1
ADS3	0.72	0.47	2407	5.8
ADS4	0.67	0.27	1930	6.1
ADS5	0.62	0.20	1555	5.1
ADS6	0.58	0.14	1307	5.4
ADS7	0.58	0.09	1209	5.1
ADS8	0.53	0.10	993	13.4

Table 2. The average of separate 36 months sampling data from Ovacik CIP plant

Average of 36 months for Ovacik CIP plant				Av. tonnage: 97 Mg/h
Adsorption tanks	Au conc. in ore, ppm	Au conc. in solution C, ppm	Au conc. in carbon Q, ppm	Solid concentration %43
Feed slurry	1.21	3.64	-	gCarb/dm^{3}pulp
ADS1	0.75	1.39	5645	18.3
ADS2	0.55	0.71	3263	6.3
ADS3	0.47	0.53	2385	6.4
ADS4	0.39	0.30	1551	6.2
ADS5	0.35	0.17	1105	6.4
ADS6	0.34	0.09	820	6.6
ADS7	0.31	0.06	663	7.6
ADS8	0.31	0.03	544	9.5

Besides, ore throughput as Mg/h and tank volumes were taken into account. The average of monthly data for the Mastra, Ovacik and Kaymaz plants are shown in Tables 1-3.

Table 3. The average of separate 8 months sampling data from Kaymaz CIP plant

Average of 8 months for Kaymaz CIP plant				Av. tonnage: 49 t/h
Adsorption tanks	Au conc. in ore, ppm	Au conc. in solution *C*, ppm	Au conc. in carbon *Q*, ppm	Solid concentration %42
Feed slurry	1.58	3.91	-	gCarb/Lpulp
ADS1	0.99	0.85	3387	13.6
ADS2	0.87	0.43	1171	4.3
ADS3	0.78	0.17	754	6.1
ADS4	0.75	0.09	483	6.2
ADS5	0.74	0.04	301	4.4
ADS6	0.73	0.02	360	6.1
ADS7	0.73	0.03	286	1.5
ADS8	0.71	0.02	434	7.9

By using mass balance (Eqs. 3 and 4) and data of Tables 1-3, tc_n for each adsorption tank ADSn and further, model parameters could be found by the calculation method as shown in Table 4.

Table 4. model parameters for different 5 models

Models	Model parameters
k, n model	*k,n*
Nicol-Fleming model	*K,k*
Johns model	*Ac.kf, n, K*
Film-diff. with Lang. isot.	*Ac.kf, b, K*
Dixon model	*k1, k2, K*

The model parameters presented in Table 4 were found by non-linear regression method. For each month, the model parameters and R^2 values were determined, thus it would be possible to determine the best fit model(s) for the CIP plants.

Furthermore, after model parameters were found, the plant *tc* and *Mc* values can be determined to obtain desired *Q* and C values by using model parameters. Besides, for different tonnage Mg/h ore feedings, the *tc* and *Mc* can be re-calculated to obtain the same *Q, C*. Thus, optimization of the CIP plants would be possible after finding the model parameters by using the real plant data.

Results and discussion

The model parameters and the regression coefficient (R^2) values for each models were calculated by nonlinear regression method and these R^2 values obtained by each models were compared to determine the nearest values to "1", thus, to find the best fit model for these three CIP plants. The R^2 values vs months were presented in Figs. 2-4.

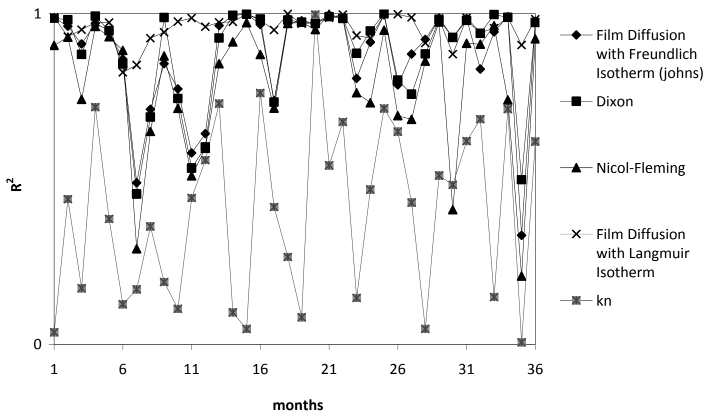

Fig. 2. Regression coefficient (R^2) values for different models for Ovacik CIP plant data

As shown in Fig. 2, the best fit model for Ovacik CIP plant is film diffusion model with Langmuir isotherm as its R^2 value is nearest to 1. For the Ovacik CIP plant using film diffusion model for optimization study, more reliable predictions would be performed such as carbon amount in each tank for the desired final carbon gold loading and final solution gold content for a different plant feed ore tonnage and thus for different slurry flow rates.

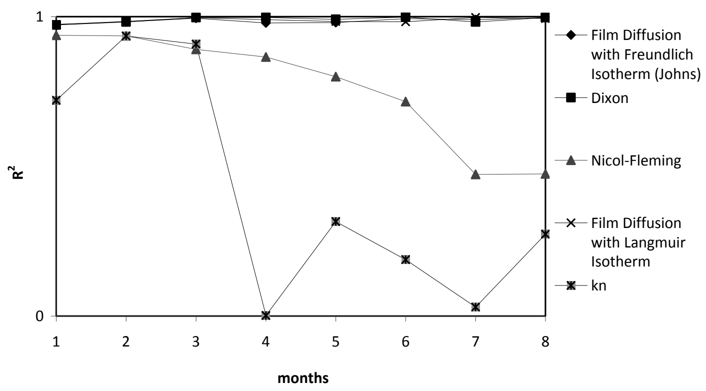

Fig. 3. Regression coefficient (R^2) values for different models for Mastra CIP plant data

As presented in Fig. 3, the Film diffusion and Dixon models are better (R^2 values are closed to 1) than the k,n and Nicol-Fleming models. Thus, for the Mastra plant the Film diffusion models and Dixon model would supply most realistic predictions for the selected CIP model parameters as carbon amount in each tank and desired final carbon gold concentrations.

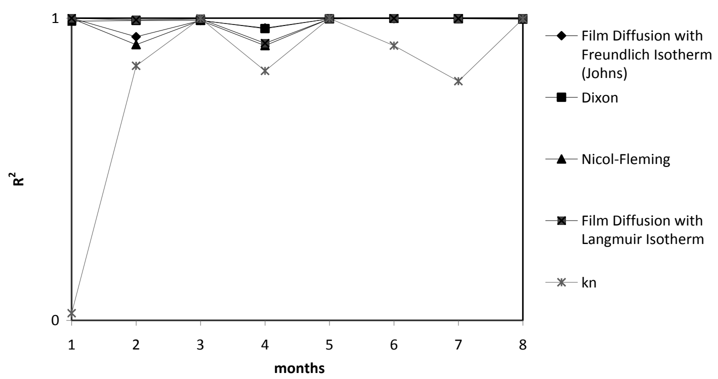

Fig. 4. Regression coefficient (R^2) values for different models for Kaymaz CIP plant data

According to Fig. 4, the Film diffusion and Dixon models are the best fit models to Kaymaz adsorption unit. Thus, the Film diffusion and Dixon models would be used for the most appropriate optimization results for the Kaymaz plant.

According to the Tables 1-3, in the Ovacik CIP tanks, solution gold ppm values *C*, continue to decrease through the last tank, indicating the adsorption continues regularly till last tank giving a reasonable final *C* value in the last tank. This phenomena shows that no optimization is required for Ovacik CIP plant. Besides, when Kaymaz and Mastra plants are observed, the *C* values reduction finishes before the last tank, indicating that optimization would be beneficial for these two plants. This may be the reason that three models best fit for the Kaymaz and Mastra CIP plants. However, when the Ovacik plant was investigated, the models show different fitting results. Thus, the Film diffusion model with Langmuir isotherm is the best fit model for Ovacik and this model will be taken into account for the optimization processes of the plants since this model fits well all the three CIP plants.

Optimization of Kaymaz CIP Plant

The whole data (all *C* and *Q* values for each tanks of 8 months) were used to model the plant according to the Film diffusion model with Langmuir equation. The model graph is shown in Fig. 5.

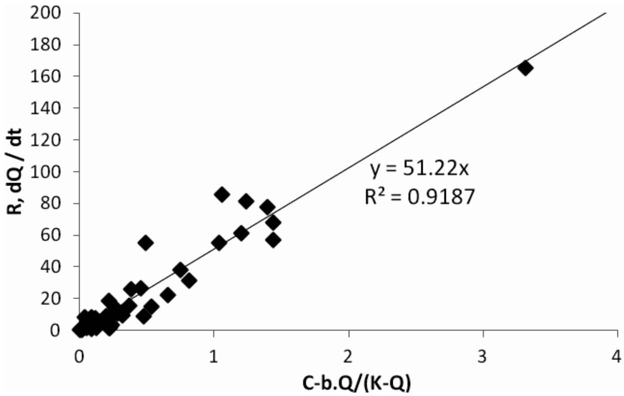

Fig. 5. Film diffusion model with Langmuir isotherm graph for Kaymaz CIP plant (8 months data)

By using a graphical form of equation (Fig. 5), the model parameters are determined by $Ac{\cdot}kf$ = 51.22; K = 13699; b= –1.789 for the nonlinear regression method. Figure 5 gives a characteristic model graph for the Kaymaz ore with determined parameters, $Ac{\cdot}kf$, K and b. Thus, by using these parameters in conjunction with Eqs. 3-4 the optimization could be performed. Optimization processed for two different situations that is first by acceptance of the same ore feed tonnage and second, estimating the increased ore tonnage up to 120 Mg/h. The optimization result are presented in Tables 5-7.

By using the best fit model, the Kaymaz CIP plant were optimized for the present ore tonnage and for the increased tonnage as 120 Mg per hour which is planned for the future. By the modeling process, required strip times/week for the 4 Mg capacity elution column; the residence time of carbon in each tank, tc, the carbon concentration in each tank gcarb/dm^3 pulp, solution and carbon gold concentrations in each tank were predicted.

Table 5. Kaymaz Cyanide leach plant CIP unit data without optimization

strip column capacity: 4Mg carb			Av. tonnage: 49 Mg/h		
Adsorption tanks	Au concentration in solution *C*, ppm	Au concentration in carbon *Q*, ppm	solid concentration 42%		
Feed slurry	3.91	-	Av. gCarb/dm^{3}pulp	tc, hours	strip times/week
ADS1	0.85	3387	6.3	11	5
ADS2	0.43	1171	6.3	11	
ADS3	0.17	754	6.3	11	
ADS4	0.09	483	6.3	11	
ADS5	0.04	301	6.3	11	
ADS6	0.02	360	6.3	11	
ADS7	0.03	286	6.3	11	
ADS8	0.02	434	6.3	11	

Table 6. Kaymaz Cyanide leach plant CIP unit data after optimization by the present ore feed tonnage

strip column capacity: 4 Mg carb			Av. tonnage: 49 Mg/h		
Adsorption tanks	Au concentration in solution *C*, ppm	Au concentration in carbon *Q*, ppm	solid concentration 42%		
Feed slurry	3.91	-	Av. gCarb/dm^{3}pulp	tc, hours	strip times/week
ADS1	1.93	5865	3.8	17.2	2
ADS2	1.01	2985	3.8	17.2	
ADS3	0.54	1652	3.8	17.2	
ADS4	0.28	961	3.8	17.2	
ADS5	0.15	591	3.8	17.2	
ADS6	0.07	390	3.8	17.2	
ADS7	0.03	281	3.8	17.2	
ADS8	0.01	221	3.8	17.2	

Table 7. Kaymaz Cyanide Leach plant CIP unit data after optimization
for 120 Mg per hour ore feed tonnage

strip column capacity: 4 Mg carb			Av. tonnage: 120 Mg/h		
Adsorption tanks	Au concentration in solution *C*, ppm	Au concentration in carbon *Q*, ppm	solid concentration 42%		
Feed slurry	3.91	–	Avr. gCarb/dm^{3}pulp	tc, hours	strip times/week
ADS1	1.93	5865	9.3	17.2	5
ADS2	1.01	2985	9.3	17.2	
ADS3	0.54	1653	9.3	17.2	
ADS4	0.28	962	9.3	17.2	
ADS5	0.15	593	9.3	17.2	
ADS6	0.07	392	9.3	17.2	
ADS7	0.03	283	9.3	17.2	
ADS8	0.01	223	9.3	17.2	

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