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Model for sulfide weathering in pyritic wastestone

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Abstract—The model for sulfide weathering in pyritic wastestone was studied based on the sulfide weathering rate in pyritic wastestone as well as relationship between the accumulating amount of sulfide weathered during pyritic wastestone weathering and some factors affecting weathering. The relationship is mainly based on the results of simulating experiment of pyritic wastestone weathering and analysis of field samples of the acid water.

The model may be practical to predict the rate of sulfide weathering in pyritic wastestone of Dexing Copper Mine and the quality of the acid mine drainage generated by the wastestone weathering.
Keywords: model; pyritic; wastestone; weathering.

INTRODUCTION

The process of the production of acid mine drainage by pyrite oxidation in pyritic wastestone is very complicated in natural environment as there is a sequence of chemical and microbial catalysis reactions. Some of calculation models of acid water quality and chemical equilibrium study were carried out by Ball and Jenne (Ball, 1978), Reardon and Beckie (Reardon, 1987), Harvie and Weare (Harvie, 1980), Boulegue (Boulegue, 1977), Berner (Berner, 1967), and Sato (Sato, 1960).

In this paper, the model for pyrite oxidation in pyritic wastestone was studied mainly based on the results of simulating experiments of pyritic wastestone weathering and selected the factors affecting weathering. The rate of sulfide weathering in the pyritic wastestone of Dexing Copper Mine and the quality of the acid mine drainage generated by the wastestone weathering were calculated. The result of the calculated quality of the acid water was compared with the measured result.

DESCRIPTION OF THE PARAMETERS IN THE MODEL

Pyritic wastestone weathering is a complicated process affected by many factors such as oxygen, microorganism, ambient temperature, weathering surface area of the wastestone, content of sulfide in the wastestone and so on. The factors considered are as follows:

Oxygen

In natural condition, oxygen in the wastestone dump is mainly due to the dissolved oxygen in rain and is brought into the dump during raining and due to the atmospheric oxygen permeated through the dump. Amount of oxygen permeated through the dump is closely related to the partial pressure, and the partial pressure is varied at the same place so small that the amount can be considered as a definite value. It was considered that the amount of oxygen in the wastestone dump is largely changed with rainfall. It may be considered that the effect of oxygen can be replaced by rainfall based on the results of simulation experiments of pyrite oxidation by leaching in open system and blowing oxygen in a closed system. The rates of pyrite oxidation, R, obtained by oxygen blowing and leaching are as follows:

$$R \propto MO^m \ ; \tag{1}$$

$$R \propto P^n \ , \tag{2}$$

where MO is oxygen concentration (in mole units), the exponent $m=0.49 \pm 0.05$ (1SD; Mickibben, 1986); P is the leaching amount (in rainfall units, mm), the exponent $n=0.465 \pm 0.035$ (1SD). It showed that MO is nearly proportional to P.

Microbial catalysis

The microbial catalysis is very important during pyrite oxidation. It has been proved by experiments that microbe is such an effective catalyst and that the rate of pyrite oxidation by the catalysis is increased to tens times to several orders of magnitude over chemical oxidation (Taylor, 1984; Zhong, 1987). The rate of pyrite oxidized by microbial catalysis is closely related to temperature. Although the weathering of all minerals is related to temperature, the effect of microbial catalysis varied with temperature on pyrite oxidation is much greater than the effect of chemical oxidation. So, temperature has been connected with microbial catalysis.

Surface area

It is proved by experiments (Bailey, 1976) that the rate of pyritic wastestone is

$$R \propto S^n \ , \tag{3}$$

where S is the surface area of wastestone weathered.

Content of sulfides in pyritic wastestone

It is well known that the amount of elements released from any mineral weathering is closely related to the total weatherable amount.

MATHEMATIC EXPRESSION OF THE MODEL

The accumulating amount of sulfide weathered in pyritic wastestone under natural condition, A, is defined as:

$$A = \sum a_i \qquad (i = 1, 2, 3 \cdots\cdots n) \ , \tag{4}$$

where a_i is the amount of sulfide weathered during pyritic wastestone weathering in the ith month:

$$a_i = W_i \ X_i \ R_i \ , \tag{5}$$

where W_i is the total amount of wastestone piled for i months; X_i is the average content of sulfide in wastestone at the ith month. $W_i X_i$ is the total amount of sulfide in wastestone dump on that time. R_i is the rate of sulfide weathering at month i in the dump.

According to the results of experiments, the amount of sulfide weathered by chemical weathering, Ah (in ton unit) can be expressed by the function as follows:

$$Ah = f(S, X, O) \quad , \tag{6}$$

where S is the weathering surface area of the wastestone (m^2), X is the content of sulfide in wastestone dump (ton / ton), O is the concentration of oxygen in the weathering system (mole unit).

The amount of sulfide weathering in the dump should be changed with the surface area, the content of sulfide and oxygen concentration in the weathering system, the differential equation should be

$$dAh = \frac{\partial Ah}{\partial S} dS + \frac{\partial Ah}{\partial X} dX + \frac{\partial Ah}{\partial O} dO. \tag{7}$$

As the content of oxygen in the dump is changed with rain as natural leaching solution besides oxygen permeated through the dump affected by the partial pressure in the atmosphere, Equation (7) can be written as

$$dAh = \frac{\partial Ah}{\partial S} dS + \frac{\partial Ah}{\partial X} dX + \frac{\partial Ah}{\partial P} dP. \tag{8}$$

where P is the leaching amount (in rainfall unit, mm).

As the amount of sulfide weathering by microbial catalysis was related to the surface area of wastestone in contact with microbe, content of sulfide in the wastestone at that time, and that the amount of sulfide weathering Ab should be:

$$Ab = f(\mathrm{S}, \mathrm{X}, \mathrm{B}) \quad , \tag{9}$$

where B is the factor of microbial catalysis.

$$dAb = \frac{\partial Ab}{\partial S} dS + \frac{\partial Ab}{\partial X} dX + \frac{\partial Ab}{\partial B} dB. \tag{10}$$

The differential equation of total amount of sulfide weathered should be

$$dA = dAh + dAb \quad . \tag{11}$$

$$dA = \left(\frac{\partial Ah}{\partial S} + \frac{\partial Ab}{\partial S}\right) dS + \left(\frac{\partial Ah}{\partial X} + \frac{\partial Ab}{\partial X}\right) dX + \frac{\partial Ah}{\partial P} dP + \frac{\partial Ab}{\partial B} dB \quad . \tag{12}$$

It is assumed that the relationship between microbial catalysis and temperature is

$$B \propto \mathrm{T}^n \quad , \tag{13}$$

where T is the temperature of the earth surface (℃); n is a constant. The differential equation should be

$$\frac{\partial Ab}{\partial B} dB = \frac{\partial Ab}{\partial T} dT \quad . \tag{14}$$

The surface area of the wastestone weathering is suggested as follows:

$$S = \frac{W}{Wa} Sa \quad , \tag{15}$$

Where Wa, the weight of a wastestone particle with D, the average available diameter (in meter), Sa is the surface area of the particle assuming to be spherical in the simulation experiments, the surface area of the wastestone weatherings was calculated.

$$S' = \frac{6W}{D\rho} \quad , \tag{16}$$

where ρ is the density of the wastestone (in T/ m^3).

$$dS = \frac{\partial S}{\partial W} dW + \frac{\partial S}{\partial D} dD \quad , \tag{17}$$

Therefore,

$$\frac{\partial Ah}{\partial S} dS = \frac{\partial Ah}{\partial W} dW + \frac{\partial Ah}{\partial D} dD \quad , \tag{18}$$

and

$$\frac{\partial Ab}{\partial S} dS = \frac{\partial Ab}{\partial W} dW + \frac{\partial Ab}{\partial D} dD \quad . \tag{19}$$

Having the Equations (14), (18) and (19) put into Equation (12), we will get

$$dA = (\frac{\partial Ah}{\partial W} + \frac{\partial Ab}{\partial W})dW + (\frac{\partial Ah}{\partial D} + \frac{\partial Ab}{\partial D})dD + (\frac{\partial Ah}{\partial X} + \frac{\partial Ab}{\partial X})dX + \frac{\partial Ah}{\partial P} dP + \frac{wAb}{\partial T} dT \quad . \tag{20}$$

If the relationships among the factors obtained from simulating experimental results and analytical results of the acid water are put into Equation (20), the accumulated amount of sulfide weathered, A, can be found by integrating Equation (20). The amount of sulfide weathered in the *i*th month, a_i, should be

$$a_i = A_i - A_{i-1} \tag{21}$$

Total amount of residual sulfide in the dump at the end of *i*th month should be

$$W_i X_i = W_i X - a_i \quad , \tag{22}$$

where X is the content of sulfide in unweathered wastestone.

The rate of sulfide weathering in the pyritic wastestone at the *i*th month R_i will be:

$$R_i = \frac{a_i}{W_i X_i} \quad . \tag{23}$$

FINDING COEFFICIENTS OF THE FACTORS AND THE RELIABILITY TEST

The computer program of the model was completed and was carried out by IBM-PC. The coefficients of the factors were found by the experimental data. The statistic reliability of the rate equation was determined by F test. The reliability coefficient (P) was much less than 0.001. The result shows that the model may be used for predicting the pyritic wastestone weathering.

TEST OF THE MODEL

Based on the monthly average of meteorological data from 1982 to 1986, the practicability of the model is tested by calculating the sulfide weathering rate in the pyritic wastestone of Yangtaowu wastestone dump in Dexing Copper Mine and the concentration of iron, aluminium, sulfur, copper and the acidity of the acid mine drainage generated by the pyritic wastestone weathering. The calculated results of pH values and concentration of the elements in the acid water in different periods of the dump used are listed in Table 1.

Table 1 Concentration of some elements and pH values of different stages of the dump used

Year	Month	pH	Concentration, ppm			
			Fe	Al	S	Cu
At first		7.84	3.47	75.2	7.38	/
		7.13	8.27	76.9	17.93	/
1969	08	4.46	206.2	154.7	481.5	5.43
1974	08	3.90	406.9	235.9	966.1	10.89
1979	08	3.19	955.7	462.4	2316.7	26.12
1984	08	2.68	1763.9	802.1	4342.1	49.00
1985	08	2.59	1963.2	886.5	4845.7	54.63
1986	08	2.49	2203.4	988.6	5454.4	61.49
1987	08	2.36	2588.0	1152.7	6432.8	72.52
1988	08	2.24	2982.8	1321.8	7441.2	83.89
1989	08	2.14	3371.2	1488.7	8436.6	95.11

The calculated concentration of iron in the acid mine drainage was compared with the measured results between 1985 and 1988 (Fig.1). The calculated result was found in good agreement with the measured result. The correlation coefficient (R) was more than 0.9 ($P< < 0.001$). The model may be consi- dered to be resonable.

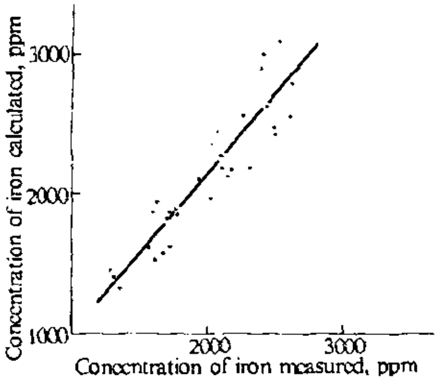

Fig. 1 Relationship between calculated and measured iron concentration

ESTIMATION OF PYRITIC WASTESTONE WEATHERING OF YANGTAOWU WASTESTONE DUMP IN THE FUTURE

The quality of the acid mine drainage generated by the pyritic wastestone weathering of Yangtaowu dump in Dexing Copper Mine was estimated by the model after the dump being stopped to use. The estimated result of different period is listed in Talbe 2. It shows that the acidity and concentration of some elements in the acid mine drainage are still high in the next few decades (pH < 1.9 in 1992).

Table 2 Estimated quality of the acid water of Yangtaown dump after the dump stop use

Year	Month	pH	Concentration, ppm			
			Fe	Al	S	Cu
1992	01	2.10	3561.4	1570.7	8925.1	100.62
	02	1.94	4302.9	1891.1	10836.1	122.16
	03	2.07	3687.7	1625.1	9249.8	104.28
	04	2.25	2951.1	1308.2	7360.1	82.97
	05	2.18	3222.6	1424.8	8055.3	90.81
	06	2.21	3105.4	1374.4	7755.0	87.42
	07	1.98	4081.7	1795.3	10264.9	115.72
	08	1.96	4218.5	1854.6	10618.0	119.70
	09	1.81	5024.9	2204.5	12705.0	143.23
	10	1.84	4846.6	2127.0	12242.8	138.02
	11	1.89	4571.4	2007.5	11530.3	129.98
	12	2.49	2210.1	991.5	5471.5	61.68
2000	01	2.18	3223.8	1425.3	8058.4	90.84
	02	2.02	3895.1	1714.1	9783.8	110.30
	03	2.15	3338.1	1474.5	8351.5	94.15
	04	2.33	2671.3	1188.3	6645.4	74.92
	05	2.26	2917.1	1293.6	7273.0	81.99
	06	2.29	2811.0	1248.1	7001.9	78.93
	07	2.07	3694.8	1628.6	9268.0	104.48
	08	2.04	3818.6	1681.2	9586.9	108.08
	09	1.89	4548.6	1997.6	11471.2	129.32
	10	1.92	4387.2	1927.7	11053.9	124.61
	11	1.97	4138.1	1819.8	10410.5	117.36
	12	2.57	2000.5	902.4	4940.2	55.69
2024	01	2.43	2391.0	1068.6	5931.3	66.87
	02	2.27	2889.0	1281.6	7201.2	81.18
	03	2.40	2475.8	1104.8	6147.0	69.30
	04	2.58	1981.2	894.2	4891.2	55.14
	05	2.51	2163.5	971.7	5353.2	60.35
	06	2.54	2084.8	938.2	5153.6	58.10
	07	2.31	2740.4	1217.9	6821.6	76.90
	08	2.29	2832.3	1257.3	7056.3	75.55
	09	2.14	3373.8	1489.8	8443.2	95.18
	10	2.17	3254.1	1438.3	8136.1	91.72
	11	2.22	3069.3	1358.9	7662.6	86.38
	12	2.82	1483.6	683.7	3636.1	40.99

Fig. 2 shows the tendency of the acidity variation of the acid mine drainage generated by the pyritic wastestone weathering at Yangtaowu dump in Dexing Copper Mine. It could be seen that the acidity of the acid water was gradually increased in the duration of the dump use, and the increasing tendency will be not stopped untill several years after the dump stopped to use, and then it will be decreased little by little.

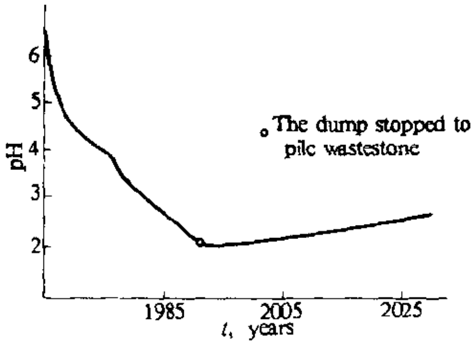

Fig. 2 Variation tendency of acidity of the acidic water at Yangtaowu dump

CONCLUSION

According to the results of F test, it could be considered that the model for the pyritic wastestone weathering which has been studied mainly based on the results of simulation experiments and analytical data of field samples of the acid mine drainage of Dexing Copper Mine and relations among the affecting factors to the wastestone weathering is rather reasonable.

The model was tested by calculating the rate of the wastestone weathering at Yangtaowu dump in Dexing Copper Mine and the quality of the acid water generated by the wastestone weathering, and by comparison of the results with the measured data between 1985 and 1988. The model might be available for estimating the rate of the pyritic wastestone weathering of Dexing Copper Mine and the quality of the acid water generated by the wastestone weathering in the natural environment.

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