Extraction of manganese and zinc from
their compound ore by reductive acid leaching

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Abstract: Comprehensive utilization of low grade manganese−zinc compound ore containing lead and silver with a method of reductive acid leaching was studied. According to the φ−pH diagram of Mn−Zn−H$_2$O system, Mn and Zn can be leached simultaneously in the pH range of −2 to 5.61. The results showed that both hydrogen peroxide and sucrose were effective reductants which could intensify the simultaneous leaching of Mn and Zn into leachate as well as enrich Pb and Ag in the residue. 95.88% of Mn and 99.23% of Zn were extracted when the compound ore was leached with hydrogen peroxide in sulfuric acid media, meanwhile the contents of Pb and Ag in the residue were enriched to 13.21% and 489.36 g/t, respectively. When sucrose was used as the reductant, the leaching efficiencies of Mn and Zn separately achieved 98.26% and 99.62%, and contents of Pb and Ag in the residue were as high as 13.92% and 517.87 g/t, respectively.
Key words: manganese−zinc compound ore; hydrogen peroxide; sucrose; comprehensive utilization; manganese; zinc; leaching

1 Introduction

With the continual exploitation of mineral resources, the grades of exploitable mineral resources take on degressive tendence, and the ore compositions of mineral resources become more and more complicated. Therefore, the researches on comprehensive utilization of low grade polymetallic ore have great significance [1].

Over the past few decades, the researches on comprehensive utilization of manganese−iron compound ore containing zinc and lead were mainly focused on pyrometallurgical processes. The most representative traditional pyrometallurgical processes were pellet roasting and blast furnace smelting, in which Zn and Pb were separated from Mn and Fe by volatilization [2]. Although the utilization efficiencies of Fe and Mn by pyrometallurgical processes are relatively high, the recovery rates of Zn and Pb are not satisfactory. On the other hand, the volatilization of Zn can cause the nodulation in blast furnace and block the gas pipeline. Furthermore, these processes have the common disadvantages of high energy consumption, heavy pollution and high investment.

In recent years, many researchers have paid more efforts to hydrometallurgical leaching. However, manganese usually occurs as pyrolusite in low grade ores. Pyrolusite, which is a kind of high valence manganese oxide, needs to be converted to low valence state Mn (II) before leaching because Mn (IV) is insoluble in dilute acid and alkaline media [3,4]. The pyro-reduction processes of pyrolusite mainly used coals as reductant in industries [5−7]. Later on, sulfur and cornstalk instead of coal as reductant also have been explored in laboratory [8,9]. However, all these pyro-reduction processes require more energy consumption and lead to serious environmental pollution and large amount of greenhouse gas emissions [10]. Compared with the pyro-reduction processes, the directly reductive leaching processes, using pyrite, oxalic acid, hydrogen peroxide, glucose and CaS as reductants, have drawn more attention recently because of their low reagent consumption, high efficiency and environmental friendliness [11−14].

All these methods mentioned above were mainly focused on the recovery of Mn. However, hydrometallurgical research on the comprehensive utilization of manganese−zinc compound ore was

seldom reported. In this study, the material was a kind of manganese−zinc compound ore containing Pb and Ag. Combining with its characteristics, a method of reductive acid leaching was proposed to utilize the main valuable elements comprehensively. The reduction of pyrolusite as well as the extractions of Mn and Zn can be accomplished in one step leaching by this method. Mn and Zn were dissolved in solution, and Pb and Ag were enriched in the residue because the dissolutions of Pb and Ag were both negligible. The obtained residue containing high Pb and Ag can be mixed with lead concentrate appropriately and then used in lead smelting process [15,16].

2 Experimental

2.1 Material and reagents

The material used in this work was a kind of low grade manganese−zinc compound ore. In order to identify the main chemical composition and valuable elements in this ore, chemical multi-element analysis and chemical phase analysis have been done.

As shown in Table 1, the contents of Mn (27.38%), Zn (11.46%), Pb (4.06%) and Ag (150.53 g/t) in this compound ore are all relatively high, and these metallic elements need to be recovered effectively.

Table 1 Main chemical composition of manganese−zinc compound ore (mass fraction, %)

Mn	Zn	Pb	Ag*	Al_2O_3
27.38	11.46	4.06	150.53	2.81

Fe	Cu	Cd	Co	Ni
4.41	0.05	0.33	0.01	0.02

* g/t

As seen in Table 2, the main phases of Mn are manganese dioxide (MnO_2) and manganese carbonate ($MnCO_3$). As shown in Table 3, 68.5% of Zn occurs as zinc oxide, and 29.84% of Zn combined with manganese.

Table 2 Results of chemical phase analysis of Mn in manganese−zinc compound ore

Phase	Mass fraction/%	Distribution/%
Manganese dioxide	13.23	48.32
Manganese carbonate	12.21	44.60
Ferromanganese oxide	1.72	6.28
Manganese silicate	0.22	0.80
Total	27.38	100

The reagents, such as sulfuric acid, sucrose, hydrogen peroxide and oxalate, used in this study, were all analytically pure. The grade of pyrite was 99%, and

the type of the coal was anthracite. Proximate analysis of anthracite coal and chemical composition of ash was shown in Table 4. Deionized water was used throughout all experiments.

Table 3 Results of chemical phase analysis of Zn in manganese−zinc compound ore

Phase	Mass fraction/%	Distribution/%
Zinc oxide	7.85	68.50
Combined with manganese	3.42	29.84
Zinc sulfide	0.085	0.74
Zinc ferrous	0.055	0.48
Zinc sulphate	0.05	0.44
Total	11.46	100

Table 4 Proximate analysis of anthracite coal and chemical composition of ash (mass fraction, %)

Proximate analysis of coal			Chemical composition of ash				
Fixed carbon	Ash	Volatile constituent	TFe	CaO	SiO_2	Al_2O_3	MgO
77.21	16.81	5.98	2.12	4.57	6.28	2.28	0.51

2.2 Methods

The raw material was crushed and finely ground to more than 70% finer than 0.074 mm. In each leaching experiment, 20.00 g of ground material and desired quantities of reductant were added to sulfuric acid solution, and the liquid-to-solid ratio was fixed as 5:1. Sulfuric acid was chosen as the lixiviant due to the characters of high boiling point and good stability. Because the hydrogen peroxide is instable and easily decomposed, reductive acid leaching experiments with this reductant were performed under the low leaching temperature of (25±0.5) °C and the slow agitation speed of 120 r/min in order to reduce its loss caused by decomposition of hydrogen peroxide. There were two methods of adding the hydrogen peroxide into the leaching system: one was that hydrogen peroxide was dropwise added at the beginning of the leaching, the other was that hydrogen peroxide was dropwise added after 30 min of leaching. Both of the two adding methods lasted for 15 min. A faster agitation speed of 400 r/min was applied and different temperatures of 50, 60, 70, 80 and 90 °C were tested in reductive acid leaching with other reductants, such as pyrite, pulverized coal, oxalate and sucrose. The fluctuation ranges of the leaching temperatures in this work are all within ±0.5 °C.

The analyses of Mn, Zn, Pb and Ag in solid and leachate were all implemented with an atomic absorption spectrometer (AA−6800, Shimadzu). Phase constitution analysis was employed to determine the distribution percentage of an element for its every phase in research

sample. Phase constitutions of Mn and Zn were identified with chemical dissolution method in the Analysis and Test Center of Changsha Research Institute of Mining and Metallurgy, China. Oxygen concentration was tested by dissolved oxygen meter (A336278, Milwaukee).

2.3 Theoretical basis

Based on the data in related literatures [17,18], the thermodynamic equilibrium systems of Mn−H₂O and Zn−H₂O were analyzed and calculated. The main equations of Mn−H₂O and Zn−H₂O systems were given in Tables 5 and 6, respectively.

The φ−pH diagrams of the Mn−H₂O system and Zn−H₂O systems can be drawn by setting p=101.325 kPa, [Mn]=1 mol/L and [Zn]=1 mol/L. Figure 1 shows the superposed φ−pH diagram for the Mn−H₂O and Zn−H₂O systems under standard conditions. The solid line in Fig. 1 represents the equilibrium line of Mn−H₂O system and the dotted line represents the equilibrium line of Zn−H₂O system. The area surrounded by thick lines represents the coexistence area of Mn^{2+} and Zn^{2+}. The existence of the coexistence area in the pH range of −2 to 5.61 indicated that Mn and Zn can be leached simultaneously in acid medium.

It can be seen that the areas of ZnO and Zn^{2+} are both quite large, and ZnO transforming into Zn^{2+} only needs to change the value of pH. φ−pH diagram of the Mn−H₂O system shows that the higher manganese valence state corresponds to the higher potential value. This implies that the MnO can be transformed into Mn^{2+} more easily than MnO_2, and MnO_2 dissolving into Mn^{2+} decreases the pH value and reduces the potential value. From the above, the leaching of ZnO is much easier than that of MnO_2, and the reductant and acid should be added to regulate the potential and pH value so as to maintain Mn^{2+} and Zn^{2+} to coexist in solution.

3 Results and discussion

3.1 Effect of reductant type

The selection of efficient and environmentally friendly reductant is the key for the efficient utilization of this manganese−zinc compound ore. A promising reductant should meet the following requirements: 1) high leaching efficiencies of Mn and Zn, 2) fewer impurities brought in the leaching solution, 3) little toxicity and low cost.

In order to select a promising reductant, a series of contrast tests have been done, in which pyrite, pulverized coal, oxalate, sucrose and hydrogen peroxide were considered. The results obtained are shown in Table 7.

Table 5 Main electrode reactions and equilibrium equations in Mn−H₂O system

No.	Electrode reaction	Equilibrium equation
1	$Mn^{2+}+2e=Mn$	$\varphi=-1.1815+0.0295\lg a(Mn^{2+})$
2	$MnO+2H^+=Mn^{2+}+H_2O$	$pH=8.96-0.5\lg a(Mn^{2+})$
3	$MnO+2H^++2e=Mn+H_2O$	$\varphi=-0.6519-0.0591pH$
4	$Mn_3O_4+2H^++2e=3MnO+H_2O$	$\varphi=0.2214-0.0591pH$
5	$3Mn_2O_3+2H^++2e=2Mn_3O_4+H_2O$	$\varphi=0.8305-0.0591pH$
6	$Mn_2O_3+6H^++2e=2Mn^{2+}+3H_2O$	$\varphi=1.4851-0.1773pH-0.0591\lg a(Mn^{2+})$
7	$MnO_2+4H^++2e=Mn^{2+}+2H_2O$	$\varphi=1.2298-0.1182pH-0.0296\lg a(Mn^{2+})$
8	$Mn_3O_4+8H^++2e=3Mn^{2+}+4H_2O$	$\varphi=1.8123-0.2364pH-0.0887\lg a(Mn^{2+})$
9	$2MnO_2+2H^++2e=Mn_2O_3+H_2O$	$\varphi=0.9746-0.0591pH$
10	$MnO_4^-+4H^++3e=MnO_2+2H_2O$	$\varphi=1.7014-0.0788pH+0.0197\lg a(MnO_4^-)$
a	$2H^++2e=H_2$	$\varphi=-0.0591pH$
b	$O_2+4H^++4e=2H_2O$	$\varphi=1.229-0.0591pH$

Table 6 Main electrode reactions and equilibrium equations in Zn−H₂O system

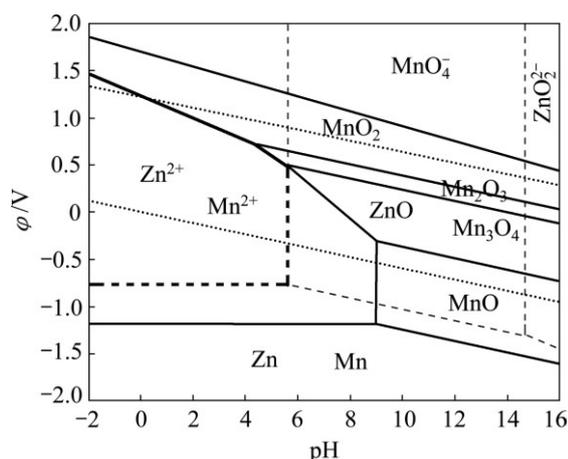| No.	Electrode reaction	Equilibrium equation
11	$Zn^{2+}+2e=Zn$	$\varphi=-0.7631+0.0296\lg a(Zn^{2+})$
12	$ZnO+2H^++2e=Zn+H_2O$	$\varphi=-0.4313-0.0591pH$
13	$ZnO_2^{2-}+4H^++2e=Zn+2H_2O$	$\varphi=0.4313-0.1182pH+0.0296\lg a(ZnO_2^{2-})$
14	$ZnO+2H^+=Zn^{2+}+H_2O$	$pH=5.61-0.5\lg a(Zn^{2+})$
15	$ZnO_2^{2-}+2H^+=ZnO+H_2O$	$pH=14.66+0.5\lg a(ZnO_2^{2-})$
a	$2H^++2e=H_2$	$\varphi=-0.0591pH$
b	$O_2+4H^++4e=2H_2O$	$\varphi=1.229-0.0591pH$

Fig. 1 Superposed φ−pH diagram for Mn−H_2O and Zn−H_2O systems (p=101.325 kPa, [Mn]=1 mol/L and [Zn]=1 mol/L)

Table 7 Results of reductive acid leaching using different reductants

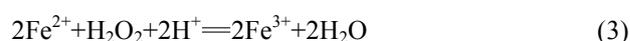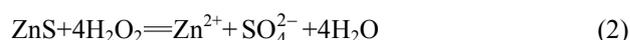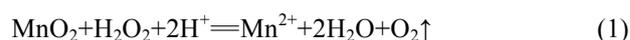| No.	Reductant	Temperature/°C	Leaching rate/%		Residue rate/%
			Mn	Zn	
1	None	25	40.64	87.26	60.31
2	None	80	49.84	95.74	55.70
3	Pyrite	80	89.91	95.00	79.65
4	Coal	80	85.59	97.63	292.30
5	Oxalate	80	93.01	33.44	54.25
6	Sucrose	80	98.40	99.67	28.76
7	Hydrogen peroxide	25	95.73	99.18	31.20

The leaching rates of Mn are less than 50% under the condition of leaching without reductant, and the results are consistent with the phase constitution of Mn, i. e., more than 48% of Mn occurs as MnO_2. Besides, the leaching rates of Zn are also lower than those of reductant acid leaching with coal, sucrose and hydrogen peroxide. This implies that a part of Zn is combined with MnO_2. It can also be seen from Table 7 that, the leaching rates of Mn and Zn obtained under leaching temperature of 80 °C are higher than those under 25 °C. This reveals that the leaching temperature influences the leaching rates of Mn and Zn to a certain degree.

When using pyrite or coal as reductant, the leaching rates of Mn are both improved obviously but still lower than 90%. However, a lot of impurities will be brought in the leaching system with the addition of these reductants [10]. Furthermore, the lead and silver cannot be enriched efficiently due to the high residue rate, especially when coal is used. High dosage of coal also results in high production cost. When oxalate is used as reductant, the leaching rate of Mn is increased to 93.01%. However, the zinc leaching rate is only 33.44% due to the formation of zinc-oxalate precipitates [19].

When sucrose and hydrogen peroxide are used, the leaching rates of Mn and Zn are both more than 95%. Compared with other residue rates shown in Table 7, the residue rates gained by using hydrogen peroxide and sucrose as reductants are relatively low. By combining with the chemical multielement analysis and the chemical phase analysis in Section 2.1, the total contents of manganese and zinc compounds in compound ore were calculated about 69%, and the main chemical phases of Mn and Zn were $MnCO_3$, MnO_2 and ZnO which can be dissolved by reductive acid leaching with hydrogen peroxide and sucrose, thus the low residue rates were almost consistent with the corresponding leaching rates shown in Table 7, and a small amount of impurities have been leached. Moreover, the element compositions of the hydrogen peroxide and sucrose are C, H and O, which would be decomposed as CO_2 and H_2O when used as reductants, so fewer impurities are brought in leaching system [20]. Comprehensively considering, both sucrose and hydrogen peroxide are promising reductants.

3.2 Intensification of Mn and Zn simultaneous leaching with H_2O_2

Hydrogen peroxide is not only a kind of reductant but also an oxidant. Hence, the ferrous oxide and sulfides such as FeS and ZnS could be oxidized along with the reduction of pyrolusite, without bringing in any impurities [20]. The oxidation of ZnS is beneficial to the increase of Zn leaching rate, and the oxidation of Fe^{2+} is favorable to the subsequent iron removal in process of lixivium purification [21]. The possible reaction equations are proposed as follows:

$$MnO_2+H_2O_2+2H^+═Mn^{2+}+2H_2O+O_2\uparrow \tag{1}$$

$$ZnS+4H_2O_2═Zn^{2+}+SO_4^{2-}+4H_2O \tag{2}$$

$$2Fe^{2+}+H_2O_2+2H^+═2Fe^{3+}+2H_2O \tag{3}$$

In order to find the optimum conditions of reductive acid leaching with hydrogen peroxide as reductant, four main factors, including sulfuric acid concentration, adding method of hydrogen peroxide, hydrogen peroxide dosage and leaching time, were investigated in the following sections.

3.2.1 Effect of sulfuric acid concentration and H_2O_2 adding method

As shown in Fig. 2, the leaching rates of Mn and Zn with two adding methods are both increased with the increase of sulfuric acid concentration until 2.16 mol/L. Besides, the leaching rates of Zn are higher than those of Mn in the whole abscissa range.

It can also be seen that, at all sulfuric acid concentration levels, the leaching rates of Mn and Zn with adding method II are higher than those with adding

method I. The likely reasons for this are as follows: in the initial stage of leaching, large numbers of bubbles were released, which was due to the dissolution of carbonate in sulfuric acid medium, and the bubbles might result in the loss of hydrogen peroxide; when hydrogen peroxide was added after 30 min of leaching, the loss of hydrogen peroxide which was caused by CO_2 bubbles can be avoided, for the carbonate was almost reacted with sulfuric acid. Hence, more MnO_2 is reduced by adding hydrogen peroxide with method II, and thus more zinc combining with manganese minerals can also be leached.
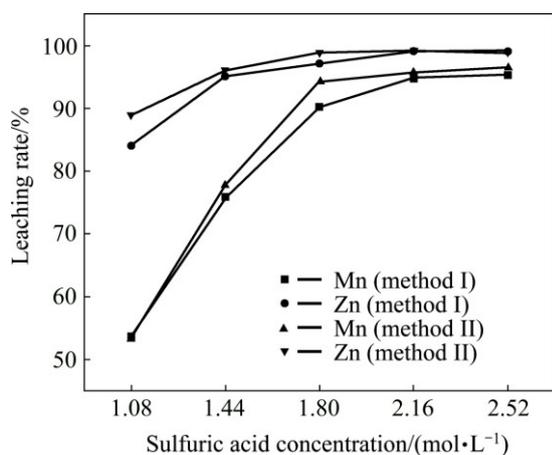

Fig. 2 Effect of sulfuric acid concentration and H_2O_2 adding method on leaching rates of Mn and Zn (1.28 mol/L H_2O_2, leaching time 2 h, agitation speed 120 r/min, oxygen concentration 7.7 mg/L, 25 °C)

According to the analysis of the superposed φ−pH diagrams for Mn−H_2O and Zn−H_2O systems in Section 2.3, the leaching of ZnO is much easier than that of MnO_2. As shown in Tables 2 and 3, the main chemical phase of Zn is ZnO in this compound ore, meanwhile, MnO_2 is the highest percentage chemical phase of Mn. Therefore, the leaching rates of Zn are higher than that of Mn.

3.2.2 Effect of H_2O_2 dosage and leaching time

The effects of hydrogen peroxide dosage and leaching time on leaching rates of Mn and Zn were studied by varying the hydrogen peroxide dosage from 0 to 1.48 mol/L and leaching time from 1 to 3 h. The results are given in Fig. 3.

Figure 3(a) shows that the hydrogen peroxide dosage plays a critical role in the reductive acid leaching process. Compared with leaching results obtained without hydrogen peroxide, the leaching rate of Mn is rapidly increased from 40.64% to 95.73% when 1.28 mol/L hydrogen peroxide is used, and the leaching rate of Zn is also increased from 87.26% to 99.18%. The result can be explained by the fact that the MnO_2 is insoluble in sulfuric acid solution in the absence of a

reductant [4]. High valence state Mn(IV) in the form of MnO_2 was converted to MnO in the presence of reductant hydrogen peroxide, and MnO could be easily leached in sulfuric acid solution. Moreover, the hydrogen peroxide dosage has a great influence on the reduction degree of MnO_2 [14]. Therefore, the more the hydrogen peroxide is used, the higher the manganese leaching rate is. Meanwhile, the increase of leaching rate of Zn may mainly be attributed to the oxidation of ZnS and the exposure of zinc which is wrapped by manganese phases.
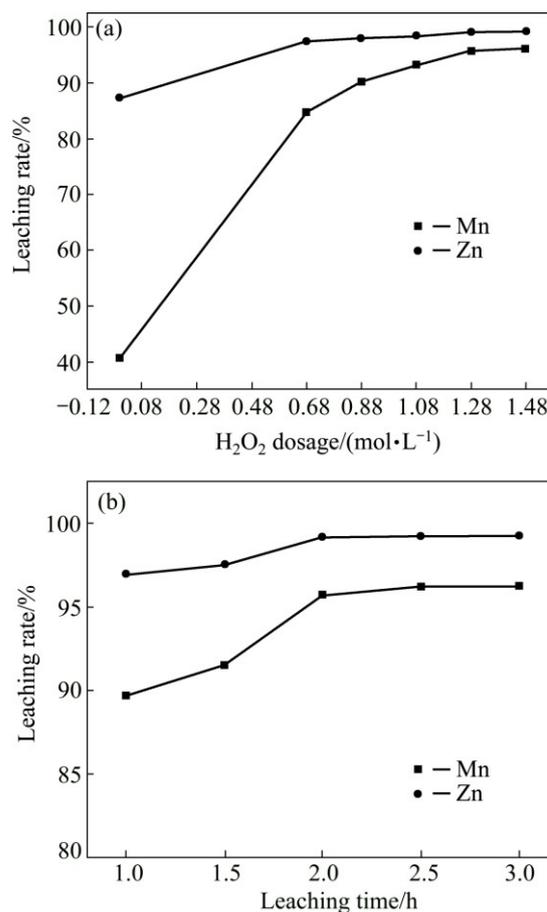

Fig. 3 Effect of H_2O_2 dosage (a) and leaching time (b) on leaching rates of Mn and Zn (2.16 mol/L H_2SO_4, H_2O_2 added 30 min later, agitation speed 120 r/min, oxygen concentration 7.7 mg/L, 25 °C)

As shown from Fig. 3(b), leaching rates of Zn and Mn give similar trend, and they are both increased with the extension of leaching time until 2 h, and then keep steady. After 1 h of leaching, the leaching rates of Mn and Zn are separately attained 89.70% and 96.94%. This means that most of the Mn and Zn in the compound ore have been leached, especially the components like $MnCO_3$ and ZnO which can be leached easily. As the leaching time is inadequate, there are parts of the Mn and Zn remaining to be dissolved, and this part of Mn may be MnO_2 and Zn is combined with it. The chemical phase analysis of Zn in Table 3 shows that more than 29% Zn

is combined with Mn and the leaching rates of Mn and Zn shown in Table 7 can support this assumption. Thus, when MnO_2 is gradually reduced and leached as the leaching time prolonging, the leaching rate of Zn is increased at the same time.

From the above, optimal reaction conditions are established as follows: 2.16 mol/L sulfuric acid, 1.28 mol/L hydrogen peroxide added after 30 min of leaching, and 2 h leaching time. 95.73% of Mn and 99.18% of Zn are extracted under the optimum conditions, and meanwhile, the contents of Pb and Ag in the residue are 12.99% and 479.67 g/t, respectively.

A scale-up verification experiment has been done with 200.00 g of ground material in 2 L beaker under the optimal conditions described above, 60.47 g leaching residue is obtained, and the chemical multi-element analysis of the residue is shown in Table 8. The leaching rates of Mn and Zn are separately calculated to be 95.88% and 99.23%. The content of Pb in the residue is 13.21% and the content of Ag is 489.36 g/t, and both are enriched more than 3.25 times. Compared with the leaching rates of Mn and Zn, and the contents of Pb and Ag in basic experiment under the same conditions, the results of the scale-up verification experiment have a little difference, and the difference is within the range of permissible error.

Table 8 Main chemical components of reductive acid leaching residue by H_2O_2 (mass fraction, %)

Mn	Zn	Pb	Ag*	Al_2O_3
3.73	0.29	13.21	489.36	0.80

Fe	Si	Ca	Co	Ni
5.63	25.67	2.28	0.006	0.017

* g/t

3.3 Intensification of Mn and Zn simultaneous leaching with sucrose

In this section, reductive acid leaching was carried out in sulfuric acid solution in the presence of sucrose. Although sucrose is a kind of non-reducing sugar, it is used as reductant for it can be hydrolyzed to glucose and fructose in acid medium, and both glucose and fructose are reducing sugar [22]. The leaching process of MnO_2 can be described by the following reaction equation:

$$24MnO_2 + C_{12}H_{22}O_{11} + 48H^+ = 24Mn^{2+} + 12CO_2 + 35H_2O \tag{4}$$
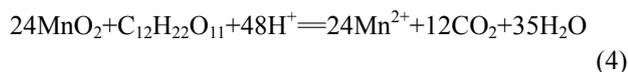
The effect of sucrose dosage and leaching temperature on leaching rates of Mn and Zn are presented in Fig. 4. From the results shown in Fig. 4(a), it can be observed that the leaching rate of Mn is rapidly increased with the increase of sucrose dosage, and the leaching rate of Zn is also slightly increased. In addition, sucrose dosage of 43.8 mmol/L is adequate for the

reductive acid leaching. This indicates that the sucrose is an efficient reductant for pyrolusite, which is in accordance with results in Ref. [23], and the impact trend of sucrose dosage on the leaching rates is similar to that of hydrogen peroxide.
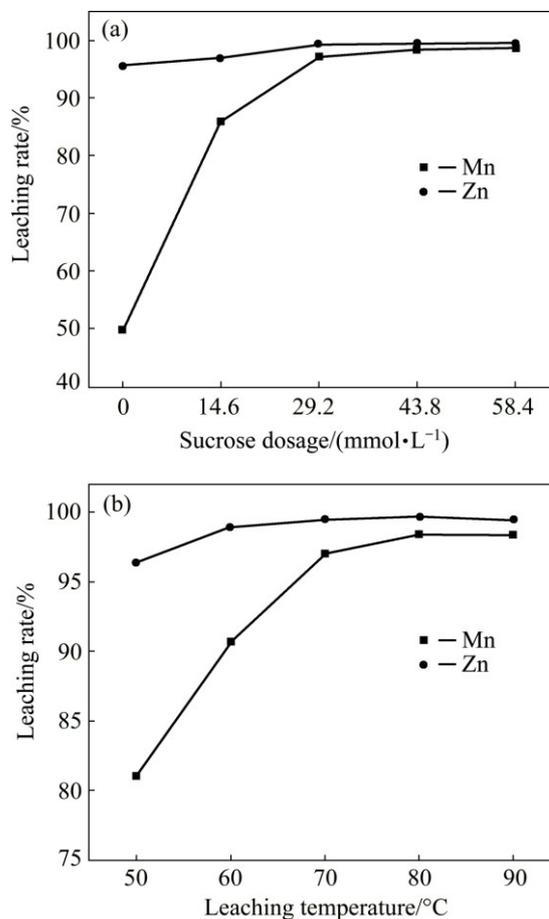

Fig. 4 Effect of sucrose dosage (a) and leaching temperature (b) on leaching rates of Mn and Zn (2.16 mol/L H_2SO_4, leaching time 2 h, agitation speed 400 r/min)

As indicated in Fig. 4(b), the leaching rates of Mn and Zn are increased with the increase of leaching temperature until they reached the maximum at 80 °C, and afterward are basically unchanged. The leaching rates of Mn and Zn respectively reached 98.40% and 99.67% under the optimum conditions of sucrose dosage of 43.8 mmol/L and leaching temperature of 80 °C, and meanwhile, the contents of Pb and Ag in the residue are separately as high as 14.10% and 520.39 g/t, respectively.

A scale-up verification experiment of reductive acid leaching with sucrose has also been done by using 200.00 g of ground material in 2 L beaker under the optimal conditions above. The obtained leaching residue is 58.24 g, and Table 9 shows the chemical multi-element analysis of the residue. The calculated leaching rates of Mn and Zn are 98.26% and 99.62%, respectively. The content of Pb in the residue is enriched to 13.92% and

Ag is enriched to 517.87 g/t, and both enrichment ratios are more than 3.42. Compared with the results of its basic experiment under the same conditions, the differences between them are also within the range of permissible error, and the results show a good reproducibility.

Table 9 Main chemical components of reductive acid leaching residue by sucrose (mass fraction, %)

Mn	Zn	Pb	Ag*	Al_2O_3
1.62	0.15	13.92	517.87	0.97
Fe	Si	Ca	Co	Ni
6.59	27.84	2.47	0.007	0.02

* g/t

From the results presented above, it can be seen that high leaching rates of Mn and Zn and enrichment ratios of Pb and Ag are achieved by reductive acid leaching with both hydrogen peroxide and sucrose. Reductive acid leaching by using hydrogen peroxide as reductant can be carried out at room temperature, which can obviously reduce the energy consumption. Besides, the Fe^{2+} can be oxidized by hydrogen peroxide along with the reduction of MnO_2 without bringing in any impurities. There still exist some cons, for example, the price of hydrogen peroxide is more expensive and the adding method is inconvenient. Compared with hydrogen peroxide, the reductive acid leaching by using sucrose has the advantages of low dosage, cheap price and convenient use. However, its leaching temperature needs 80 °C and it will no doubt increase the energy consumption. In summary, both hydrogen peroxide and sucrose are efficient reductant for comprehensive utilization of the manganese−zinc compound ore, and have a very good application prospect in reductive acid leaching.

4 Conclusions

1) Manganese and zinc can be leached simultaneously by using reductant and sulfuric acid to regulate the potential and pH value of leaching system, and the Pb and Ag can be enriched effectively in the residue.

2) Compared with pyrite, coal and oxalate, hydrogen peroxide and sucrose are both effective in intensifying the simultaneous leaching of Mn and Zn.

3) 95.88% of Mn and 99.23% of Zn are extracted by reductive acid leaching using hydrogen peroxide as reductant. Meanwhile, the Pb and Ag in the residue are enriched to 13.21% and 489.36 g/t, respectively.

4) The leaching rates of Mn and Zn by reductive acid leaching with the reductant of sucrose reaches 98.26% and 99.62%, respectively, and the contents of Pb and Ag in the residue are as high as 13.92% and

517.87 g/t, separately.

5) The method proposed in this study has the advantages of mild reaction conditions, high efficiency and little environment pollution.

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还原酸浸法从锰锌复合矿中综合回收锰和锌

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摘 要：采用还原酸浸法对含铅、银的低品位锰锌复合矿进行综合利用。通过绘制 Mn−Zn−H_2O 系的 φ−pH 图并对其进行分析可知，锰和锌在 pH−2~5.61 的酸性条件下可以同时浸出。实验结果表明：双氧水和蔗糖都是强化锰和锌同时浸出的有效还原剂，并且有利于铅和银在渣中富集。当以双氧水为还原剂配合硫酸对复合矿进行还原浸出时，锰和锌的浸出率分别为 95.88%和 99.23%，同时铅和银在渣中的品位分别富集到 13.21%和 489.36 g/t。当以蔗糖为还原剂时，锰和锌的浸出率分别为 98.26%和 99.62%，同时铅和银在渣中的品位分别富集到 13.92%和 517.87 g/t。

关键词：锰锌复合矿；双氧水；蔗糖；综合利用；锰；锌；浸出

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