Most Suited Extraction Techniques of Iron and Copper

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ABSTRACT

This paper explores and conducts a research review on 2 major metals - iron and copper, and discusses various methods of extraction for each one of them while also exploring considered factors to choose the best suited extraction technique such as- affordability, time taken to complete the process, ease of process, and quantity of metal extracted. This paper discusses the methods and results of various other papers which conduct studies on extraction techniques under the influence of factors such as temperature, pressure, time for extraction, amount of extraction etc. The paper goes into further detailed discussion with regards to the pros and cons of all the mentioned extraction techniques to recommend which of the techniques would be most suitable and practically feasible for each of these metals.

Keywords: iron, copper, extraction, factors

INTRODUCTION

Iron

Iron is one of the most commonly used metals. It is a chemical element having the symbol ‘Fe’, given by the International Union of Pure and Applied Chemistry (IUPAC), and the atomic number 26. It belongs to the first transition series, the period 4 and group 8 of the Modern Periodic table. Iron is a good conductor of both heat and electricity. Iron exists in solid state at Standard Temperature and Pressure (temperature-0ºC and pressure-1atm), is the fourth most common element in the earth’s crust and it forms much of the inner and outer core of the earth. Iron is used in production of steel (an alloy), architecture, vehicles, etc. Iron doesn’t exist in its pure form in nature. Rather, it exists in the form of ores (ores are naturally occurring solid materials from which a metal can be extracted). Some of the major iron ores are-

Magnetite (Iron (II, III) oxide-Fe3O4, Contains 72.4% Fe)
Hematite (Iron (III) oxide-Fe2O3, Contains 69.9% Fe)
Goethite (FeO(OH) , Contains 62.9% Fe)
Limonite (FeO(OH)·n(H2O), Contains 55% Fe)
Siderite (Ferrous Carbonate-FeCO3, Contains 48.2% Fe)
Pyrite (FeS2, also called Fool’s Gold)

Copper

Copper is a chemical element having the symbol ‘Cu’, as approved by the IUPAC. It has the atomic number 29 and it belongs to group 11, period 4 of the D-block in the Modern Periodic table. It is a soft, malleable and ductile metal (Ko et al., 2021), having a very high thermal and electrical conductivity. Copper is reddish-brown in color, and is one of the very few metals that can occur in a directly usable metallic form in nature, leading to its very early human use in several regions. Copper, like iron, occurs in solid form at STP. It is used as building material, as a constituent of various useful alloys like brass, bronze, and many more. Being a great conductor of electricity, copper is used in electrical wires and various other electrical equipment (Smyrak et al., 2021).

Some of the major copper ores found in nature are-

Chalcopyrite ($CuFeS_2$, Contains 34.5% copper)
Chalcocite, also known as copper glance (Cu_2S, Contains 79.8% copper)
Cuprite (Cu_2O, Contains 88.8% Cu)
Malachite ($CuCO_3.Cu(OH)_2$, Contains 55.1% Cu)
Covellite (CuS, contains 66.5% Cu)

MATERIALS & METHODS

Secondary research was conducted in order to find out best extraction techniques for both iron and copper. Various qualitative and quantitative factors were taken into consideration in order to reach a suitable verdict. Data used in this research was taken from research papers published in peer reviewed journals, and well known and accurate books. Various factors (affordability, time taken to complete the process, ease of process, and quantity of metal extracted) were carefully chosen that are important while comparing different extraction techniques. Reliable data from various researches was taken in consideration that helped choose the best technique based on that particular factor. Similar steps were followed for each of the factors. The extraction method that proved to be the best in most of the chosen factors was decided as the best one.

DISCUSSION AND RESULTS

Different Methods of Iron extraction

Various methods of iron extraction are in use. Some of them are discussed below.

- **Acidic Extraction:** Acidic Extraction methods are used for obtaining iron from its different ores like Ferrihydrite, lepidocrocite, goethite, hematite, magnetite, siderite, and ankerite. All information in this section is taken from a research paper by Raiswell et al. (1994). These methods are-

1) ***Buffered dithionite***. A buffered solution at a concentration of 50 gl^{-1} sodium dithionite in a pH 4.8 buffer is prepared. It consists of 0.35 M acetic acid and 0.2 M sodium citrate. Individual extractions are carried out using 50 mg of mineral or 0.2 g of sediment and 50 ml of extractant for around 2 hours. Replication of this extraction technique indicates a precision of ±3-4%. (Raiswell et al., 1994)
2) ***Cold HCl method.*** For 24 hours, a 80 ml 1 M HCl solution was reacted with about 50 mg of mineral or 0.5 g of sediment. Replication of this extraction technique indicates a precision of ±7%. (Raiswell et al., 1994)
3) *Boiling HCl method.* For 1 minute, approximately 0.05-0.1 g of sample and 5 ml concentrated HCl are brought to boil, and then further boiled again for 1 minute. The reaction is quenched by filling the tube with distilled water and then the sediment and solution washed into a volumetric flask. Average precision of ±5% is seen. (Raiswell et al., 1994)

- ***Separation using solvent extraction method and Tri-n-butyl Phosphate (TBP).*** TBP can be used to extract Fe from chloride media. Fe (III) can be separated from its chloride solution by this technique. $FeCl_3$ is used as iron source in aqueous solution. TBP and Kerosene are mixed to provide the organic phase. A flask containing equal volumes (20ml) of aqueous, mixture of hydrochloric acid and definite initial concentration of Fe and organic phases is taken. The mixture is mechanically agitated for 30 minutes at 400 rpm. Mixture is then separated using a decanting funnel for 15 min, allowing full separation. The metal content of the aqueous phase is determined by atomic absorption spectroscopy and then the organic phase is estimated by mass balance calculations. (Sadeghi, &Alamdari, 2014)

Factors considered when choosing the best iron extraction technique

1) ***Affordability.*** Since the cold HCl method requires very few materials, it can be considered the most affordable technique for iron extraction.
2) ***Easy to carry out.*** Separation using solvent extraction method and Tri-n-butyl Phosphate (TBP) isn't as easy as it consists of methods like separating through decanting funnel (Sadeghi, &Alamdari, 2014). Timed extraction data for the dithionite technique (Canfield, 1988) and the cold HCI technique (Leventhal and Taylor, 1990) have shown that the longer extraction times used (dithionite-2 hour, cold HCl-24 hour) are simple to control such that any resulting variations in the amounts of iron extracted are minimal. The boiling HCl method on the other hand has been criticized as it requires careful control of the extracting conditions, especially due to the short 2 min extraction time (Leventhal and Taylor, 1990).
3) ***Quantity of iron obtained.*** Referring to Table 1 below, it can be observed that the boiling HCl method is the best technique in regards to this factor, as it can be used to obtain the most amount of iron as this method extracts nearly all of the total iron content present in the ores (like Ferrihydrite, magnetite, ankerite, etc). Referring to the table below, it can be observed thatthe Dithionite method leads to wastage of iron from some of the ores like magnetite, siderite, and ankerite but is good when extracting from ores like ferrihydrite, lepidocrocite, goethite and hematite. The cold HCl method is the worst in this case as it causes a large wastage of iron when extracting from ores like lepidocrocite, Goethite, magnetite and hematite.

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Table 1: Weight (%) Fe extracted from the above minerals using each extraction, compared to the total iron content.

Mineral	Iron Extracted (weight%)			
	Dithionite	*Cold 1 M HCl*	*Boiling 12 M HCl*	*Total*
Ferrihydrite	54.2 ±2.2	55.3 ±3.9	54.2 ±2.7	54.2
Lepidocrocite	63.5 ±2.5	35.5 ±2.5	59.0 ±3.0	63.3
Goethite	63.0 ±2.0	0.21 ±0.01	56.9 ±2.8	63.0
Hematite (powder)	68.6 ±2.7	4.54 ±0.32	66.3 ±3.3	69.9
Magnetite	4.10 ±0.16	2.65 ±0.19	71.7 ±3.6	72.3
Siderite	9.59 ±0.38	35.2 ±2.5	38.7 ±1.9	43.6
Ankerite	2.38 ±0.10	17.2 ±1.2	16.2±0.8	17.6

Source: Raiswell et al. (1994)

4) ***Time taken.*** The quickest method is the boiling HCl method of extraction (2 min) and the longest one is cold HCl method (24 hours).

Different Methods of Copper Extraction

1) ***Extraction of copper from low grade ores and scraps.*** Copper is extracted from low grade ores through hydrometallurgy. It is leached out using acid or bacteria . The solution which contains Cu^{2+} cation is treated with H_2 or scrap iron. Reactions involved are-

$$Cu^{2+} (aq) + Fe (s) \rightarrow Cu (s) + Fe^{2+} (aq)$$
$$Cu^{2+} (aq) + H_2 (g) \rightarrow Cu (s) + 2H^{+} (aq)$$

(Narlikar et al., 2015)

2) ***Leaching of Cuprite (Copper oxide) through NH_4OH (Ammonium Hydroxide).*** Cuprite is a difficult oxide to leach under acidic conditions, so leaching in an ammoniacal medium (basic) can be used (Aracena et al., 2018). The leaching process is performed in a 2 L glass reactor equipped with a variable mechanical stirrer, a heating element, a thermocouple, a porous liquid sample tube and a water-cooled condenser to minimize the solution loss from evaporation (Aracena et al., 2018). Figure 2 (Aracena et al., 2018) below shows the experimental equipment.

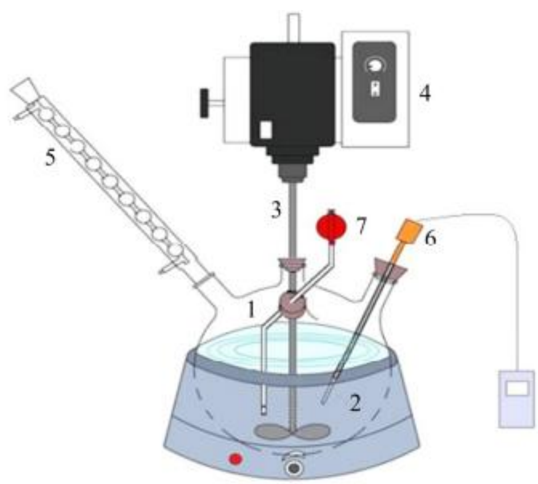

Fig. 2 Experimental equipment: 1—Glass reactor; 2—Heating element; 3 — Metal stirring rod; 4 — Mechanical stirrer; 5—Condenser; 6—Thermocouple; 7—Sampling

The reactor is loaded with a 1.0 L of ammonium hydroxide leaching solution. The solution is heated to a desirable temperature (temperature of 45 ºC gives maximum extraction rate of copper of about 85.0%), and 1.78 g of solid sample is added into the reactor. The reaction is then allowed to proceed and liquid samples are extracted at various times to determine the copper concentrations by atomic absorption spectroscopy (AAS) (Aracena et al., 2018).

3) ***Heap leaching***. This method can be used for extraction from copper oxide and copper sulfide ores (Toro et al., 2021). Excavated crushed ores are stacked on an impermeable pad, and then dilute H_2SO_4 is poured from the top of a reactor. The movement of leachate along with H_2SO_4 through a fixed bed of ore particles enables the target metal to be leached into the aqueous phase, and then the same is collected downward through gravity. This type of leaching is called heap leaching. It then goes through solvent extraction and electro-winning, giving us pure copper at cathode (Kang et al., 2021).

Factors considered to choose the best extraction technique for copper-

1) ***Affordability***. Due to several controlled factors such as the stirring speed, temperature, ammonium hydroxide concentration, and particle size during Leaching of Cuprite (Copper oxide) through NH_4OH (Ammonium Hydroxide), this method could be considered expensive. Heap leaching on the other hand is widely used due to its low operational cost. As high-grade copper ores are depleting globally, this approach is economical and facile as it focuses on extraction from low grade copper ores (Kang et al., 2021).

2) ***Easy to carry out.*** The leaching of Cuprite (Copper oxide) through NH_4OH (Ammonium Hydroxide) method can be considered a little difficult to carry out due to various controlled factors which can affect the % of copper extracted (Aracena et al., 2018).According to Kang et al (2021), heap leaching is very easy to perform. The method of extraction of copper from low grade ores and scraps is relatively easier due to very less chemical reactions involved.

3) ***Time taken.*** Though the construction time for the heap leaching method is short, the proper extraction of copper from the ore may take around 7 days (Kang et al., 2021). The leaching of Cuprite (Copper oxide) through NH_4OH (Ammonium Hydroxide) method takes relatively less time.

CONCLUSION

Iron

As discussed in Section 2.1 of the paper, iron can be extracted using buffered dithionite method, cold HCl method, boiling HCl method and separation using solvent extraction method and Tri-n-butyl Phosphate (TBP). Similarly, factors such as affordability, time taken to complete the process, ease of process, and quantity of metal extracted were explored in Section 2.2. Cold HCl method would be considered most affordable as this process requires the least materials. Both cold HCl and dithionite techniques would be easier to carry out due to longer extraction times, whereas boiling HCl method would not be as easy to perform as it requires careful controlling of the extraction conditions. Separation using solvent extraction method and Tri-n-butyl Phosphate (TBP) would also be relatively difficult due to involvement of complex processes. Boiling HCl method would be considered best in regards to the quantity of iron extracted from the ores as most of the total iron content in the ores is extracted using this method. On the other hand, cold HCl method would be due to the wastage of iron during extraction. Boiling Cl method would be considered best in terms of total time taken for completion of the process as it just takes about 2 minutes to complete, whereas cold HCl would be the worst as it takes 24 hours to complete. Considering the above factors, the most practical and feasible technique which will maximize the extraction of iron will be the boiling HCl method.

Copper

As discussed in Section 2.3 of the paper, copper can be extracted using the method of extracting copper from low grade ores and scraps, heap leaching method and Leaching of Cuprite (Copper oxide) through NH_4OH (Ammonium Hydroxide) method. As further discussed in Section 2.4, factors such as affordability, time taken to complete the process, and ease of process were explored. Heap leaching would be considered cheaper than Leaching of Cuprite (Copper oxide) through NH_4OH (Ammonium Hydroxide) method because of its low operational cost. Similarly, heap leaching would be relatively easier to carry out. The method of Extraction of copper from low grade ores and scraps would also be relatively easy due to very less reactions involved. On the contrary, leaching of cuprite through NH_4OH (Ammonium Hydroxide) method will take less time. Considering the above factors, the most practical and feasible technique which will maximize the extraction of copper will be the heap leaching method.

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