

Modeling and simulation of atmospheric acid leaching of nickel-copper matte

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Abstract

This abstract summarizes a case study of modeling and simulation of atmospheric leaching process of nickel-copper matte. To understand the nature of the leaching process during the stage of operation, the leaching mechanism of the matte is explained. Through simulation the effects of different parameters on nickel leaching were investigated, mainly operating temperature, and acid concentration. The modeling of this process was performed on a computer simulation package known as Aspen Plus. Under atmospheric pressure 68.8% of nickel, 14.05% of iron, 24.92% of copper, 10.66% of cobalt and 4% of zinc are extracted under suitable conditions of sulfuric acid concentration and reaction temperature.

Key words: Nickel-copper matte, atmospheric leaching process, computer simulation.

1. Introduction

Nickel is commonly found in iron meteorites as the alloys kamacite and taenite. Recently, relatively great attention has been paid to the research on the recovery of nickel from secondary resources: spent catalyst [1], waste battery [2, 3] and tailings [4]. Nickel ores are of two types [5]: (1) Primary sulphide deposits associated with mafic and ultramafic rocks, (2) Near-surface laterite deposits formed over olivine-rich host rocks following intense weathering. The sulphide ores have been the major source of nickel; however, the lateritic ores have been estimated to constitute about 73% [6] of the known nickel reserves of the world. According to the latest data by the USGS, world nickel reserves amount to 80,000,000 metric tons. From the chart below, one can see that Australia and New Caledonia hold currently 45% of the world's nickel reserves [7].

As a result of the high nickel production costs associated with traditional pyrometallurgical techniques and the depletion of high-grade sulphide ores, renewed interest has been developed concerning the production of the nickel and cobalt by high pressure acid leaching (HPAL) of nickel laterites. Industrial leaching processes generally comprise multiple leaching autoclaves that accommodate 3-phase (solid-liquid-gas) systems that exhibit complicated chemistry and kinetics. Given that leaching processes are principally the location of hydrometallurgical refinery bottlenecks, it is essential that these processes operate optimally to ensure maximum refinery throughput [8]. Understanding how changes in process and operating conditions influence the performance of the leach is of paramount importance in arriving at this state of operation.

2. Material mass balance

Material quantities, as they pass through processing operations, can be described by material balances; and such balances are statements on the conservation of mass. The law of conservation of mass leads to what is called a mass or a material balance. If the unit operation, whatever its nature is seen as a whole it may be represented diagrammatically as a box, as shown in Figure 1. The mass going into box must balance with the mass coming out. If there are no chemical changes occurring in process unit, the law of conservation of mass will apply also to each component, so that for a component A

$$m_A \text{ in entering materials} = m_A \text{ in the exit materials} + m_A \text{ stored in plant} \quad (1)$$

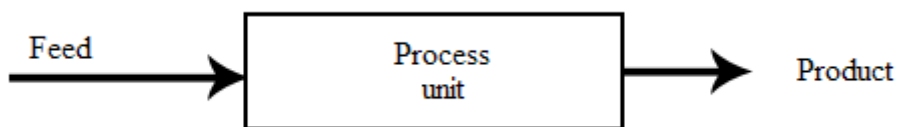


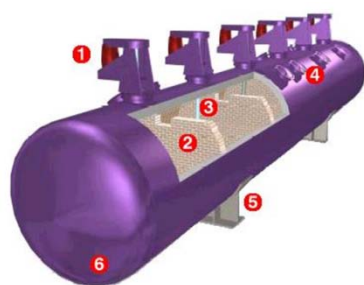
Figure 1. Schematic process flow for mass balance

The occurrence of a chemical reaction in a process brings some complications into the material balance. The theory of the propitiations in which chemical species combine with one another “stoichiometry” appears essential. The stoichiometric equation of the reaction imposes constraints on the relative amounts of reactant and products in the input and output streams. In addition, a material balance on a reactive substance does not have the simple form $\text{input} = \text{output}$, but must include a generation or consumption term, Eq. 2.

$$\text{In} - \text{Out} + \text{Generation} = \text{Accumulation} \quad (2)$$

$$\left[\begin{array}{c} \text{Rate of flow} \\ \text{of } j \text{ into} \\ \text{process unit} \end{array} \right] - \left[\begin{array}{c} \text{Rate of flow} \\ \text{of } j \text{ out of} \\ \text{process unit} \end{array} \right] + \left[\begin{array}{c} \text{Rate of generation} \\ \text{of } j \text{ by chemical} \\ \text{reaction} \end{array} \right] = \left[\begin{array}{c} \text{Rate of accumulation} \\ \text{of } j \text{ within the} \\ \text{process unit} \end{array} \right]$$

500 kg NiSO ₄ produced day	1 kmol NiSO ₄ 154.766 kg NiSO ₄	1 kmol H ₂ SO ₄ reacted 1 kmol NiSO ₄ produced
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1 Motor Drive Assembly for Agitator
2 Compartment Divider
3 Agitator Shaft

4 Service Nozzles
5 Support Saddle
6 Carbon Steel Shell/Lead and Brick Lined

Figure 2. Schematic of a horizontal acid leach autoclave

3. Nickel refinery process model and Aspen modeling

For nickel leaching process, autoclave is the basic unit operation, figure 2. An autoclave contains mechanical agitators and the compartments that are separated by weir gates. Basically, the leaching is performed in a compartment from which the content is conveyed into next compartment and so forth. For the present study case, the process model comprises three central unit operations: leaching reactors (autoclave compartments), tank and thickener. Tank was modeled as perfect mixer, whereby the output rate is equal to the sum of the input rates; the tank receives the dissolved metals. Thickeners were modeled as perfect splitters; it mixes all its feed streams then splits the resulting mixture into two or more streams according to substream specifications. Two unit operation models are used to model the leaching reactor: stoichiometric reactor model for carrying out the reactions and splitter model to separate the minerals no dissolved from the dissolved minerals. Within the leaching reactor the equilibrium data and the kinetics are not known, the atomic and mass balances are specified; the operating conditions are 90°C and 1 atm. Here a leaching reactor can be understood as one compartment of the autoclave.

Table 1. Mass fraction of elements in the feed matte

Element	Ni	NiS	Fe	FeS	FeS2	Cu	CuS	Cu2S	Co	Zn
Mass %	15	50	2	5	3	5	8	8	3	1

This case study deals with the leaching of nickel-copper matte. The principal phases present in the matte are metallic nickel (Ni^0), millerite (NiS), metallic copper (Cu^0), chalcocite (Cu_2S), CuS, metallic cobalt (Co^0), metallic zinc (Zn^0), metallic iron (Fe^0) and pyrrhotite (FeS), Pyrite (FeS2). Nickel contributes to approximately 65% of the total particulate feed, Table 1.

4. Leaching mechanism based on process chemistry

Based on the literature data for Ni-Cu matte leached in acidic solution, $CuSO_4-H_2SO_4-O_2$, and the characterization of the leaching liquor and residues, the principal leach chemistry is the leaching of metals with simultaneous precipitation of aqueous copper via the cementation process and the atmospheric pressure oxidative dissolution in the sulfuric acid. The actual reacting system is a much more complex series-parallel reaction network involving, among other characteristics, metals oxidation and the progressive oxidation of sulfides. Through cementation process, metallic nickel is being leached according to reaction (1). The dissolution of metallic iron is believed to proceed according to the well-known reaction of cementation of copper by metallic iron, reaction (2).



For the leaching of metals by direct acid attack; in the absence of an oxidant, such as air or oxygen, some of the nickel, cobalt and copper from the alloys are believed to be leached by the sulfuric acid according to the following reactions:



The other possible reactions are the leaching of NiS, FeS, CuS and Cu_2S by the sulphuric acid, reactions (6) through to (9).



5. Results and discussion

The Aspen simulation flow sheet is illustrated in figure 3. The feed stream 1 enters at a flow rate of 20 kg/h, while feed stream 2 enters at a flow rate of 40 l/h; feed composition is summarized in Table 1. Atm-LCH is a leaching reactor. To model an autoclave of three compartments, three leaching reactors are arranged in series. The output of the atm-LCH1 is split into two streams, 4 and 5, the minerals not leached are conveyed into atm-LCH2 for further leaching through stream 5. For the last leaching reactor, it is fed through stream 9; streams 12 and 13 are the output. Streams 2, 6, and 10 are sulphuric acid streams added to atm-LCH1, atm-LCH2 and atm-LCH3, respectively. Streams 4, 8, and 12, mineral dissolved, are conveyed into the tank prior further processing of recovering dissolved minerals. To gain a deep insight in the operation and effect of changes in operating conditions, sensitivity analyses were performed

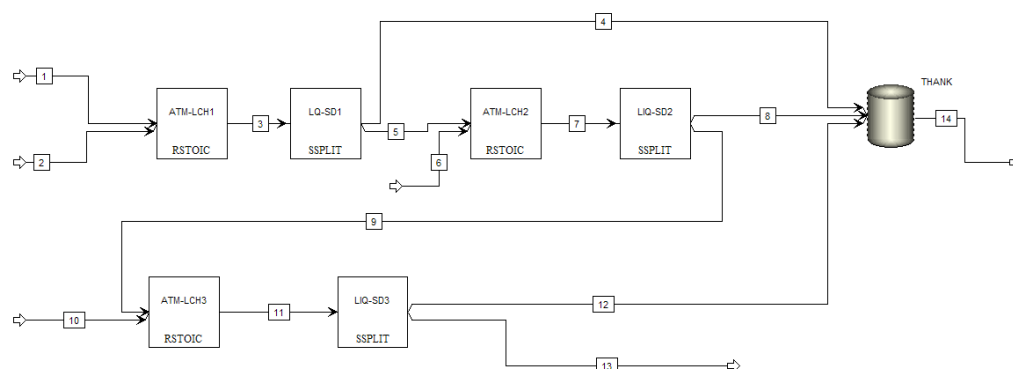


Figure 3. Aspen simulation flowsheet

The discussions and remarks are produced from the first compartment, atm-LCH1. From simulation results, the sulfides are leached to a high extent than their respective metals. The most suitable leaching conditions are as follows: sulfuric acid concentration of 10 M, and reaction temperature of 70 °C. On the other hand, all minerals in the matte are leached but to different rates; for each component of matte as a standalone, 42.83% of metallic nickel, 76.6% of nickel sulfide, 7.75% of metallic iron, 18.2% of iron sulfide (pyrrhotite), 11.33% of Pyrite, 20.5% of metallic copper, 26.31 of copper sulfide, 26.31 of chalcocite, 10.66% of metallic cobalt and 4% of metallic zinc can be extracted through an autoclave of three compartments under the thereof operating temperature and acid concentration.

6. Conclusions

(1) The effects of sulfuric acid concentration on the nickel extraction efficiency are remarkable; the effect of reaction temperature is not mild. Extraction efficiency of nickel and other minerals in the matte is improved by increasing both sulfuric acid concentration and reaction temperature to certain optimal values, 10 M and 70 °C, respectively. (2) Considering the components of matte based on element, 68.8% of nickel, 14.05% of iron, 24.92% of copper, 10.66% of cobalt and 4% of zinc can be extracted under suitable conditions of sulfuric acid concentration and reaction temperature.

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