

Carbon Dioxide Capture and Utilization for Sustainable Metal Recovery

Investigator:

Prof. Vikram Singh, Dept. of Chemical Engineering, IIT Delhi

Objective

The aim of the proposed work is to develop a disruptive technology to recycle heavy metals from waste using carbon dioxide captured from flue gas. There are many chemical-based technologies available for the recycling of waste metals which are hazardous to the environment. This work proposes a technology that uses captured carbon dioxide from the flue gas mixture to leach the metals out of the waste. Using the solvent extraction process, the leached metal is further purified. The proposed work has the following objectives:

1. Capture carbon dioxide from a mixture of nitrogen and carbon dioxide (~15%, representative of flue gas) using an aqueous ammonia solution (15-20%). A packed bed scrubber (or a helical coil) will be used for capturing the carbon dioxide.
2. Utilizing the captured carbon dioxide solution of ammonia-ammonium carbonate to leach metal like Nickel, Cobalt, Copper, and Zinc out of metal waste like e-waste, industrial waste, mine waste, etc. Optimum process parameters involving aqueous media concentration, temperature, the efficiency of metal recovery will be identified for the proposed task.
3. Transfer the approach of the above developed technology to recycle the cathode material of lithium-ion batteries containing metals like Ni, Co, and Cu, keeping the aqueous media still an ammonium-ammonium carbonate solution.

Introduction

In this work, we propose to capture carbon dioxide from effluent gas and utilize the captured carbon dioxide for extracting critical minerals from waste. In the past, mineral carbonates have been formed using captured carbon dioxide. In this work, we use the captured carbon dioxide to extract heavy metals like Copper, Nickel, Cobalt, and Zinc from waste.

Several effective CO₂ emission reduction strategies such as Carbon Capture and Storage (CCS) are developed to capture CO₂ from flue gases as the gradual increase in emissions of CO₂ from power plants, steel plants, and other human activities have negative impacts on the global environment. At present, the chemical absorption process of CO₂ using MEA (Monoethanolamine) solvent is commonly used in almost all industrial applications to remove CO₂ from flue gas (1-4). However, this process has several disadvantages: high energy requirement for solvent regeneration, high solvent loss due to evaporation, solvent degradation, corrosion problems, etc. Aqueous ammonia solution fulfills the characteristics of a good solvent and, therefore, is used to remove CO₂ from blast furnace gas and coke-oven gas. Ammonia solution is found to offer higher CO₂ removal efficiency and CO₂ absorption capacity compared to MEA solution (5-8). In this research work, attention is given to build up a continuous CO₂ absorption and metal extraction process. Carbon Dioxide will be

absorbed from CO₂- N₂ flue gas mixtures using an aqueous ammonia solution. The products (aqueous ammonium carbonate solution+free ammonia) from the absorption process will be utilized in the metal extraction process. Metal waste from steel industry, used electronic material (9,10), Li-ion batteries will be used in the process. The shredded metal waste will be dissolved in the ammonia-ammonium carbonate solution in the presence of air to conduct the extraction experiment, and separation of leached solution. Metal can be directly extracted from the leached solution using the precipitation method (fig. 2). At the same time, the metal can be further purified using the solvent extraction method using a CFI. Thus, after carbon dioxide capture, instead of storing or sequestering CO₂ in various forms in the environment, it is efficiently utilized in the metal extraction process to handle the challenge of gradual increase in metal waste.

Methodology:

The problem can be divided into three parts: absorption of CO₂ using the aqueous ammonia solution (figure 1), using the mixture of aqueous ammonia and ammonium carbonate solution to leach the required metal from the waste (figure 2), and then finally using the leached solution to precipitate the required metal salt (figure 2). The artificial flue gas mixture is formed by mixing CO₂ gas and N₂ gas in a mixing chamber and heating it. Flow rates are controlled by mass flow rate controllers such that the ratio of the flow rate of N₂ and CO₂ is maintained around 85:15 (v/v) representing the flue gas composition. This artificial flue gas mixture is injected into the CO₂ scrubber at the bottom.

In the first part of the problem an absorption column will be used to transfer carbon dioxide from the gas phase to the aqueous ammonia phase. The aqueous ammonia will be recycled through the gas absorption column. The proposed CO₂ scrubber is a packed bed absorber made of stainless steel of a certain height and inner diameter, and ceramic raschig rings (or other packings) will be used as a packing material. According to Bai and Yeh (1997) and Pelkie et al. (1992), forward reactions of ammonium carbonate and ammonium bicarbonate crystal formations are mostly favorable at room temperatures (7, 9). At higher temperatures, 38-60 C, backward reactions are favorable (7, 12). Therefore, for our experiments, reaction temperatures will be maintained at around 25-30 C (room temperature).

During the experiment, the unreacted CO₂ from the scrubber is passed through a CO₂ analyser to measure CO₂ concentration continuously. From there, we can get CO₂ concentration vs. time data to study the absorption experiment. The ammonia-ammonium carbonate solution is continuously recycled with the concentration of ammonia and carbon dioxide also measured frequently.

The shredded metal waste (preferable particle size of 0-8mm) is directly used in the metal (Copper, Nickel, Zinc, Cobalt) extraction experiments where ammonia-ammonium carbonate solution is used as a leaching solvent. A round-shaped glass container can be used as a reactor heated from the bottom. Also, an agitator is used for the better dissolving of bulk wastes in the leaching solvent. Air is purged from the bottom of the reactor in cases when metal needs to be oxidized. A flow meter controls the airflow rate, and an agitator speed controller controls the agitator speed. A heating bath with a thermostat is required to control the temperature, and an additional thermometer is there to observe the temperature change during fluctuation. A pH meter is used to detect the pH values during the leaching process.

Before the experiment, the ammonia-ammonium carbonate solution from the CO₂ scrubber is kept in the container for a period to reach the desired reaction temperature, and then shredded metal waste is added. Leaching solutions is collected at certain time intervals for further electrowinning process. The residue is collected and sent for XRF/SEM analysis.

The leaching solution after filtration is charged into a heated reactor or evaporator. In the evaporator, temperatures are high enough to lead to the vaporization of ammonia and some carbon dioxide. With a decrease in the ammonia concentration, metal salt will precipitate. The ammonia emission from the top of the reactor can be used back in step 1 involving the capture of carbon dioxide from flue gas. The precipitated metal salt will be analyzed for the metal content to estimate the yield of the process.

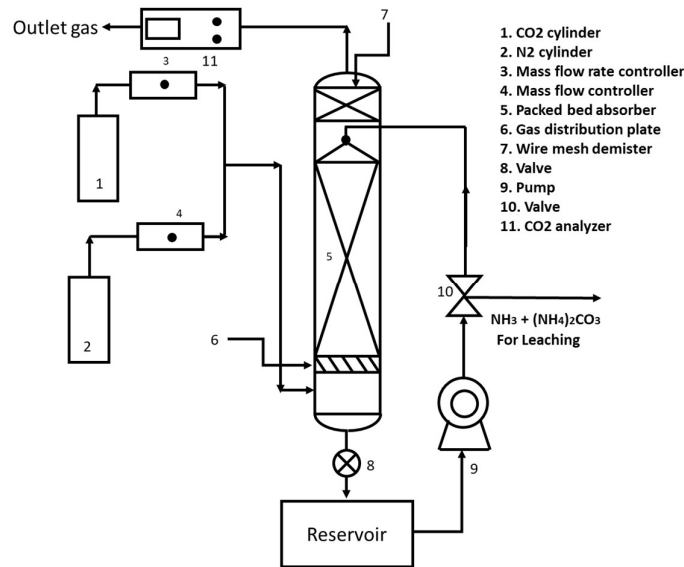


Figure 1. Schematic diagram of carbon dioxide capture process using aqueous ammonia solution in a counter current operation. Controlled flow rate of carbon dioxide and nitrogen mixture of gases is injected from the bottom of a packed bed. The aqueous ammonia solution from the top will scrub off the CO₂ from the gas mixture.

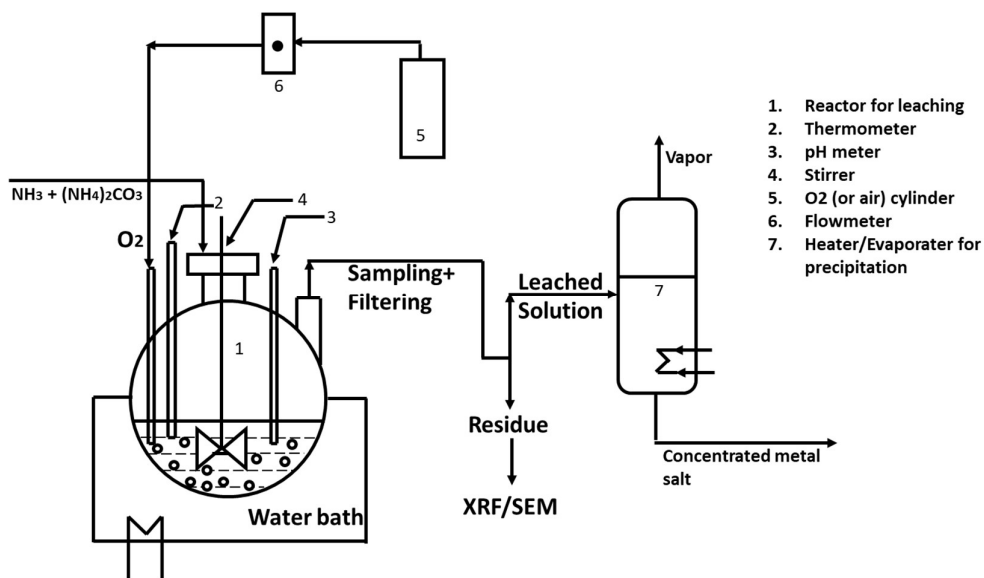


Figure 2. Schematic diagram of the metal extraction process using the captured carbon dioxide. The extraction is carried in two steps, leaching followed by precipitation. In this set-up a pure metal salt is being recovered. Pure metal can be recovered by carrying out the electrowinning process instead of the precipitation step.

Budget

S. No	Item	Year 1	Year 2	Year 3	Total
1	Equipments (reactor, mass flow-rate controller, flowmeter, pumps, adsorption column, pH meter, valves, heater, stirrer, waterbath, MPAES)	48,00,000	1,00,000	1,00,000	50,00,000
2	Consumables (CO ₂ , NH ₃ , and N ₂ cylinders, metal scrap, ammonium carbonate, aqueous ammonia, ICP test, XRD, XRF etc.)	2,00,000	5,00,000	3,00,000	10,00,000
3	Man Power (JRF/Ph.D.student, research associate/attendant)	6,00,000	6,00,000	6,00,000	18,00,000
4	Travel	0	2,50,000	2,50,000	5,00,000
5	Contingency	2,00,000	3,00,000	3,00,000	8,00,000
6	Institute Overheads (@ 20%)	11,60,000	3,50,000	3,10,000	18,20,000
7	Total	69,60,000	21,00,000	18,60,000	109,20,000

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