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Carbon Capture and Storage with Ionic Liquids: Industrial Flue Gas Trapping in Calcination Process

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Abstract: Despite significant advancements in this area, techniques for collecting commercialised CO_2 relying on absorption processes still have significant limits. The main barriers to CO_2 capture include high capital costs, lower absorption, and desorption rates, evaporation of solvents and usage of corrosive solvents. Ionic liquids (ILs) and CO_2 capture have received a lot of interest recently. Different amines are currently used as solvents, however, ILs are a viable option due to their unique features, such as their affinity to collect CO_2 molecules and their minimal vapour pressure. Since greenhouse gas emissions, particularly those of carbon dioxide have a significant impact on global warming, and this subject is generating increased public concern. The carbon capture, use, and sequestration technique appears to be effective in lowering carbon dioxide concentrations in the atmosphere. An overview of previous engineering and research work on many topics, previous engineering and research work on many topics, CO_2 capture techniques is provided in this study.

Key words: Carbon capture and storage, ionic liquids, calcination process.

Introduction

Carbon dioxide is widely employed in the production of greenhouse gases, which gather infrared light and convert it to heat, raising global temperatures and contributing to climate change. The combustion of fossil fuels consumes more than 80% of all energy. When comparing the growth in greenhouse gas emissions, carbon dioxide is primarily utilised. Carbon dioxide concentrations in the atmosphere grew by 270 ppm during the pre-industrialisation era, and 415 ppm now result from a 0.7 percent increase in global average temperature during the previous 150 years. Around 60% of the world suffers annual record-high temperatures. According to the Global Carbon Project 2018, taking action to decrease and control anthropogenic CO_2 emissions is now more critical than ever (Sivakumar et al, 2014a, b; Venkatesan et al., 2015, 2016a). To prevent global warming, a range of CO_2 capture techniques, such as absorption by liquid solvents, membranes, biological processes, solid materials, and so on, have been developed. However, because amine and CO_2 have a strong chemical interaction, the desorption process appears to be difficult, resulting in large desorption costs and environmental damage. Other disadvantages of ILs include high viscosity and high expense, which limit their usage in large-scale industries (Aishwarya et al., 2010a; Venkatesan et al., 2016b). Scientific institutions

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have demonstrated, using independent reports, that the CO_2 emission problem cannot be understated due to the possible hazard resulting from the disruption of nature's natural balance. The Intergovernmental Panel on Climate Change (IPCC) predicts that CO_2 levels in the atmosphere will reach 570 parts per million (PPM) by 2100 (Venkatesan et al., 2019, 2018, 2022). Other disadvantages of ILs include high viscosity and high expense, which limit their usage in large-scale industries. Furthermore, extensive research into the interaction of composite absorbents/solid materials with CO_2 as well as the reaction between absorbents and CO_2 is required (Freund et al., 2016; Li et al., 2015; Liu et al., 2011; Olajire, 2010). The most difficult issue is lowering the entire cost of the CO_2 collection procedure. As a result, the CO_2 separation procedure should also be considered. CO_2 separation technologies include absorption, adsorption, and cryogenics. Membranes are often employed in the CO_2 separation process, and novel and advanced membranes modified with amines, ILs, or other chemicals are frequently reported due to their superior separation performance (Venkatesan et al., 2020, 2014). During the pre-combustion process, the fuel is gasified to produce syngas. Syngas including CO and H_2 is supplied to the water-gas-shift reactors. Steam causes the conversion of CO into CO_2 and H_2 (Karunanidhi et al., 2021; Venkatesan et al., 2012, 2022).

Methodology

Necessity of the study

Post-combustion is easier to implement as a retrofit option in existing power plants than the other two options. Therefore, pre-combustion and oxy-combustion procedures can only be employed in new power plants. The solvent comes into contact with the flue gas in the tall columns or towers (also known as absorbers) during this phase, allowing the solvent to absorb CO_2 from the flue gas. The rate of CO_2 absorption with solvent is a critical element in chemical absorption processes. High absorption rates are seen as an asset for an industrial-scale absorption process because they help minimise the capital costs of CO_2 collection. Mono-ethanolamine, tertiary amines such as methyl diethanolamine), and sterically hindered amines such as 2-amino-2-methyl-1-propanol are the most commonly used absorbents in CO_2 capture systems. Some of the disadvantages of using amines include a high absorbent make-up rate and high energy consumption during high-temperature absorbent regeneration operations that necessitate substantial equipment. Other drawbacks include high building costs, high equipment corrosion rates, and amine degradation in flue gases by SO_2, NO_2, and O_2. These disadvantages stem from amines' inherent toxicity, high vapour pressures, and high energy requirements for regeneration.

Materials and Methods

Using a bucket elevator, fine ground gypsum is moved from storage silos into the calciner before passing through the diverter gate outside of chamber 1. Using HAG, the required setpoint temperature of roughly 550–580°C creates the necessary heat combined with hot air and is used to generate the heat for the process.

The materials were then dried and fluidised inside the calcination chamber using hot air. Each zone's exit gas (flue gas) is drawn to the chimney by an induced draught fan as the hot air moves through within each tube. The traditional approach of trapping flue gases in this situation will mostly be carried out utilising "Baghouse dust collectors." As the name implies, a shaker baghouse shakes accumulated dust out of the bags and into a collection hopper at the base of the baghouse. Filter bags are fastened to the tube sheet in a shaker baghouse by being tensioned and hung from the top of the filter housing with the bottom left open. Shaker bags do not have any internal cages. The dust is drawn upward into the interior of the bags where the airstream enters from below where the bags are placed. The impurities on the dusty side are trapped as the airstream passes through the filter bags. Near the top of the collector, clean gas is exhausted and dust cake falls into a hopper at the base of the baghouse after being released from the bags and is then removed.

Adsorption Setup for Carbon Capture

Adsorbents with high working capacities can be created by regenerating them at high temperatures via temperature swing adsorption. This study considers a rotary wheel adsorber since it can efficiently meet these requirements. The fundamental challenge in post-combustion capture for gas-fired power plants is the low CO_2 content in the flue gas (4-8 percent by volume). High-selectivity adsorbents are required to accomplish relatively high CO_2 uptake at low partial pressures, hence the separation technique should be based on either highly strong physisorption or chemisorption with heat regeneration. For this adsorption system, we use pre-existing materials and connect them to the exit ducts from which the flue gases exit. The departure temperature must be taken into account. Figure 1 represents the model of adsorption setup.

In those calcination operations, the exit flue gas temperature normally ranges from 190 to 230°C, depending on the inlet temperature we supply to keep the process running. The flue gas is also affected by the feed rate delivered inside the chamber. As a result, the exit flue gas can be linked to the incoming feed and temperature.

Varying industries have different standards for the usual calcination and trapping of flue gases depending on the type of material used to generate the intended output. The main challenge from a process standpoint is developing effective separation technologies with short temperature cycles. In this study, we present a detailed account of the development process for novel materials and processes employed in the "Adsorption Materials and Procedures for Gas-Fired Power Plants".

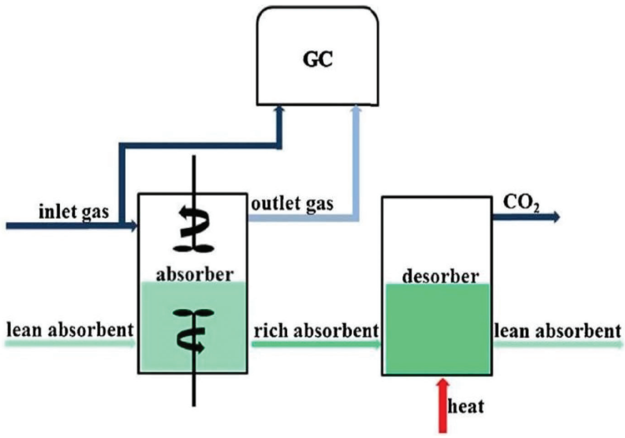

Figure 1: Adsorption setup for carbon capture.

Necessary parameters needed to be noted for our process

- Actual temperature
- Hot air generator pressure
- Flue gas ID fan speed
- CO_2 exit temperature
- Feed Rate

Flue Gas Capturing Comparison

Calcination is the method of heating a substance to high temperatures to remove water and other volatile chemicals, leaving behind a solid residue. This process is frequently employed in manufacturing applications such as cement manufacture to obtain the end product. The emission of flue gases, which can include a number of pollutants such as carbon dioxide, nitrogen oxides, sulphur oxides, and particulate matter, is one of the key environmental problems related to calcination. These pollutants have the possibility of damaging both the environment and the health of humans.

Previously, flue gas trapping in calcination processes was accomplished which use scrubbers or bag filters. Scrubbers use liquid to remove pollutants from the flue gas stream, while bag filters use fabric to prevent mixing the CO_2 from limestone breakdown with the flue gas of fuel combustion, the CO_2 utilised as the circulating carrier gas is used to heat the gypsum. Figure 2 represents the calciner unit fixed with adsorption setup.

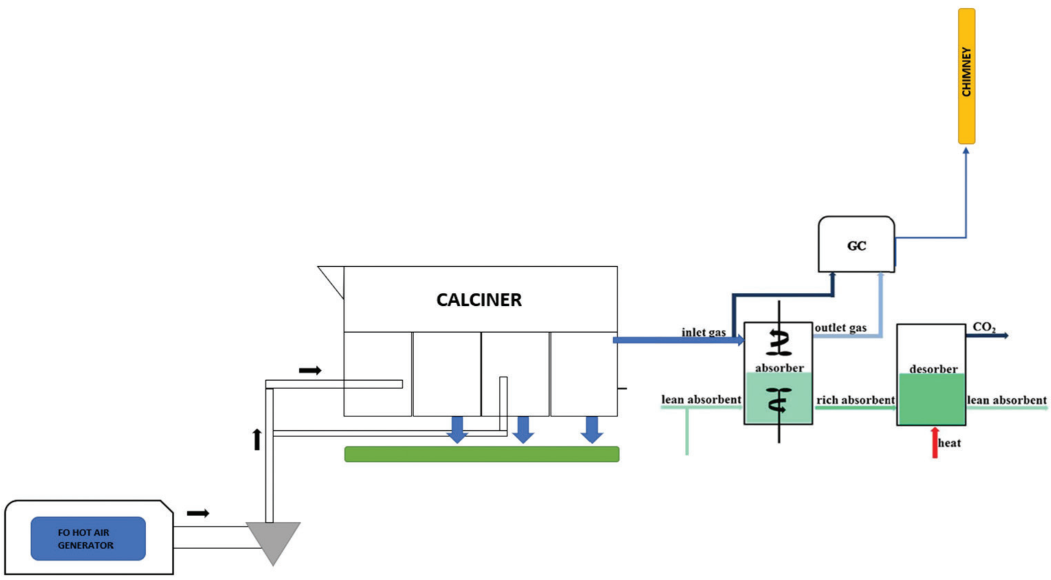

Figure 2: Calcination process with adsorption setup.

Flue Gas Capturing Using the Adsorber

As was already established, using bag house filters to capture or trap flue gases during the calcination process has a highly detrimental impact on trapping. Flue gas emissions may be larger in some cases, causing the chimney to emit black smoke that will undoubtedly harm the atmosphere.

The HAG burner's wider set point range, which enables the fuel to burn outside of the necessary range while the combustion blower is functioning more frequently, is to blame for this. For optimum suction pressure so that the exit flue gases may be filtered via the baghouses, the matching ID fan should also be driven at a higher frequency (50 Hz). The enclosed residues can be released and disposed off if air cleansing is necessary. Table 1 shows the input parameters and the outcomes of the adsorption process.

A modified version of the method utilised to generate ethyl methyl imidazole was used in this process. The CO_2 concentration was measured before, during, and after adsorption using a packed-bed column and a CO_2 detector. Approximately 0.05 g of the adsorbent was present in the column. A modified version of the procedure was utilised to create ethyl methyl imidazole in this process. A packed-bed column and a CO_2 detector were used to measure CO_2 concentrations before, during, and after adsorption.

This method was modified to create ethyl methyl imidazole. To measure the CO_2 concentration before, during, and after adsorption, a packed-bed column and a CO_2 detector were combined. The aim of 90+% recovery and 95+% purity of CO_2 from the capture process cannot be met in this circumstance using this process.

Desorption of CO_2

To reduce the amount of energy needed to compress the CO_2, desorption of dissolved CO_2 from solvent at the highest pressure possible is helpful. The impact of heating the DMEPEG solvent to 140°C for CO_2 desorption (as opposed to CO_2 desorption at 65°C) on the regeneration (desorption) of CO_2 at different pressure stages is quantified in this study. The power from depressurising solvent is recovered via a hydraulic power recovery turbine (HPRT). To give the combination of dissolved gas (mostly CO_2) enough time to separate from the liquid solvent, the depressurised solvent is transported to the flash tank. Polar molecules typically make up physical solvents (such as glycol ethers) as well as syngas and natural gas impurities (such as H_2S and CO_2). The degree to which their molecules are comparable at the molecular level determines a gas's propensity to dissolve in a given solvent. The adsorbent cycle is negatively impacted by the smaller amount of adsorbent because it increases the CO_2 adsorption capacity per mass of adsorbent and adsorption rate while decreasing breakthrough time.

Adsorption Performance

The effectiveness of imidazole was assessed using a gas mixture including CO_2 (15%) and N_2 (85%). The CO_2 signal from the gas analyser begins to drop over time, suggesting that a part of the CO_2 from the incoming stream has been adsorbed onto the adsorbent. The CO_2 concentration in the gas analyser increased over time until it approached the limit. The CO_2 concentration in the gas analyser increased over time until it approached the feed stream's original concentration, demonstrating

Table 1: Input parameters and observed values of exit flue gases while using adsorption setup

Feed rate		*Burner temperature*			*Induced draft*		*Flue gas*
Set point	*Actual*	*Oil flow*	*Set point*	*Feed back*	*Frequency*	*Backpressure*	*Exit temperature*
TPH	TPH	LPM	ºC	ºC	Hz	mmHg	ºC
17	16.9	9	610	611	22.3	0.4561	205.6
17	17.1	8.9	590	598	22.3	0.4552	207.4
20	19.8	9.8	625	630	22.3	0.455	206.3
20	19.9	9.1	630	632	22.3	0.4551	204.6
20	19.35	9.1	635	636	22.3	0.4553	200.5
20	17.71	8.6	640	645	22.3	0.4545	189.7
20	18.23	8.1	650	659	22.3	0.4588	119.7

that the adsorption process was complete. EMIM was effectively produced and tested for CO_2 capture in this study. XRD evaluation demonstrated that after being impregnated with chitosan, sod-ZMOF kept its crystallinity. BET and FTIR analyses revealed ionic liquid was successfully impregnated into imidazole. The most CO_2 captured was 2144 mg CO_2/g at a flow rate of 25, 50 m^3, and 1 bar. Additionally, temperature and feed increased, and the amount of CO_2 adsorbed dropped. The flow rates were raised. Figure 3 represents the adsorption performance of the process corresponding to the input parameters.

Carbon Capture Storage Benefits

CO_2 is artificially pumped into subsurface rock formations beneath the Earth's surface. Overlying rocks in these natural reservoirs form a seal, containing the gas. However, there are some risks associated with underground storage, which we will cover later (Venkatesan, 2018).

Basaltic rock formations are also attractive CO_2 storage sites. Basalt, a volcanic rock, is one of the most frequent forms of rock found in the Earth's crust. Is carbon sequestration and storage a viable option? The amount of CO_2 emitted by various fossil fuels varies. According to research, carbon capture and storage can reduce emissions by more than 80-90 percent, making it an exceptionally effective technique of preventing carbon dioxide from entering the environment. Carbon capture and storage (CCS) is a tried-and-true method of lowering emissions that permanently eliminates CO_2 from the atmosphere. These cycles may improve heat transfer and need less energy to compress steam. Improving environmental stewardship: Carbon capture and storage can indicate a commitment to responsible environmental stewardship and can assist enterprises in reducing their environmental effect. Moreover, sustainable geothermal energy can be generated by harvesting geothermal heat from the same sites where it is introduced.

Results and Discussion

In this work, ionic liquids are used to investigate the desorption kinetics and processes, which are critical for estimating how much energy is required to renew CO_2 and building CO_2 capture reactors. The physical and chemical adsorption of CO_2 on EMIM is effectively described by Avrami's model. For the physical and chemical desorption of CO_2, the values of ionic liquids were calculated to be 15.86 kJ/mol and 57.15 kJ/mol. Processes for capturing CO_2 present several technical, financial, and environmental difficulties. The benefits and advantages of the CO_2 capture procedure employing

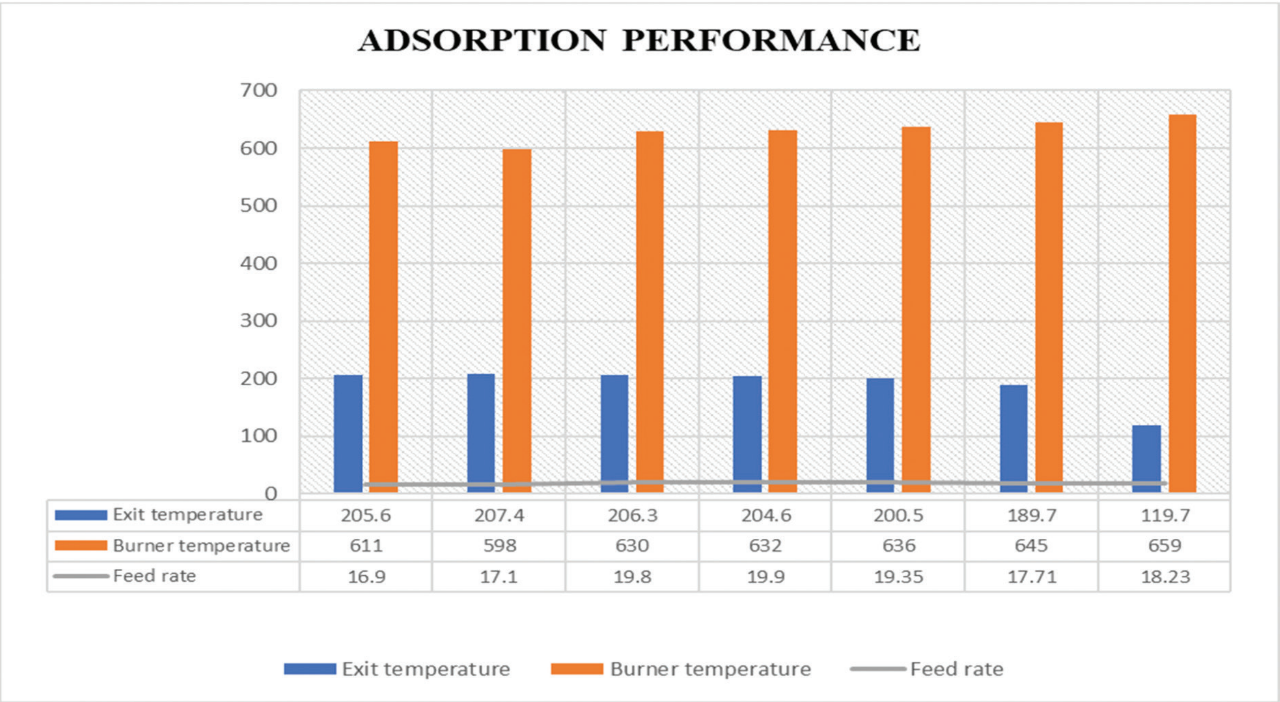

Figure 3: Adsorption performance.

ILs are discussed in this experiment. Significant initial and continuing expenses, solvent degradation, high solvent losses, solvent toxicity, solvent corrosion, the requirement for large absorption equipment, and high energy consumption during solvent regeneration are the main shortcomings of current CO_2 capture technologies.

The advantages and benefits of the CO_2 capture procedure employing ILs are discussed in this experiment. The main disadvantages of current CO_2 capture systems include high initial and continuing expenses, solvent degradation, significant solvent losses, solvent toxicity, solvent corrosion, the requirement for large absorption equipment, and high energy consumption during solvent regeneration.

The commercial use of ILs to absorb CO_2 is heavily influenced by their cost. The following are the main conclusions:

- On a fixed bed, the adsorption and desorption characteristics were studied.
- In the adsorption process, the CO_2 adsorption capacity and rate decrease as the adsorption temperature rise; the CO_2 adsorption capacity decreases as the gas flow increases, but the adsorption rate increases; the CO_2 adsorption capacity and rate increase as the CO_2 concentration rises; and the CO_2 adsorption capacity and rate increase as the adsorbent filling content rises.

Conclusion

For capturing CO_2, an ionic liquid called 1-ethyl-3-methylimidazolium ([EMIM]) was used. This ionic liquid had a high CO_2 absorbency and can effectively capture CO_2 from flue gas streams at low pressures, according to the results. By heating or changing the pressure, the trapped CO_2 could be easily released from the ionic liquid.

To avoid mixing CO_2 from gypsum decomposition with the flue gas of fuel combustion, a lime calcination method with CO_2 heating and air cooling was developed in this work. The comprehensive analysis of this project enables the engineers to create a model that would be more effective than the current carbon capture method.

Based on the use of technologies elsewhere, CCS is technically viable in the majority of big, stationary CO_2 point sources. Natural gas processing (NGP), where CO_2 removal from natural gas is necessary to boost heating value and/or meet pipeline criteria, already uses CO_2 separation technology.

Following are some of the consequences of carbon capture:

- Carbon capture's primary purpose is to reduce the quantity of carbon dioxide in the atmosphere, which is a key contributor to climate change. The amount of CO_2 emitted into the atmosphere can be lowered by capturing and storing carbon, resulting in lower greenhouse gas emissions.
- Carbon capture technology can be used in the transportation sector to capture CO_2 emissions from automobiles and aeroplanes.
- Carbon capture technology can also be used to absorb CO_2 emissions from livestock and fertilisers in agriculture. Soil carbon sequestration, for example, is a method that involves absorbing CO_2 from the atmosphere and storing it in soil using specific farming practises.
- The calorie content of coal gas has little effect on unit energy consumption.

Awareness and Education

To raise knowledge about carbon capture, governments, non-profit organisations, and industry groups can initiate public education campaigns. Social media campaigns, television commercials, and community outreach programs are examples of such campaigns. Schools and universities can provide educational programs on carbon capture and its potential environmental benefit. Engineering, environmental science, and public policy courses may be included. Carbon capture technology studies can be conducted by scientists and researchers, and their findings can be published in academic journals and other publications. This can contribute to a better understanding of the potential benefits and drawbacks of carbon capture. International organisations such as the United Nations and the World Bank can collaborate to promote carbon capture technology and assist governments throughout the world in implementing it.

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