

Absorption Studies on Capturing CO₂ by Using Spray Tower from Flue Gas

Varun ram Ramakrishnan., Rajeshkumar Kadarakarai

Department of Environmental Engineering, Government College of Technology, Coimbatore - 641013, Tamilnadu, India

DOI: <https://doi.org/10.51583/IJLTEMAS.2025.1408000079>

Abstract: Carbon dioxide is widely reported as the most important anthropogenic greenhouse gas, it accounts for the greatest portion of the global warming. CO₂ capture and utilization (CCU) are one of the leading technologies to capture and utilize CO₂. In this connection, a spray tower is used to study the capture of CO₂ from flue gas using NaOH solutions as the absorbing medium. The absorption efficiency of CO₂ by the spray tower is compared using different molarity of absorbents, such as NaOH solutions, at varying flow rates and with different fuels (cow dung, wood stick & charcoal with kerosene) for generating flue gas in the controlled environment. The spray tower absorption process demonstrates good performance in CO₂ capture. When using a 2 Molar concentration of NaOH solution and a flow rate of 200ml/min, the coconut shell as fuel and NaOH solution as the solvent shows excellent performance in the spray tower, reducing the inlet concentration of 894 ppm to an outlet concentration of 215ppm, with an efficiency of 76%. The absorbed CO₂ in the rich solution from the spray tower is utilized for growing algae, with the aqueous absorbent solution flowing continuously through the spray tower and algae bioreactor. The absorption of CO₂ by micro algae helps to reduce the energy consumption of CCU technology, resulting in savings in electric power and capital expenses. The overall CO₂ removal efficiency of the spray tower, using NaOH as the absorbing solution is 76%. This process contributes to the reduction of CO₂ emissions in the atmosphere and aids in mitigating global warming.

Keywords: spray tower, NaOH, aqueous solution, CO₂ Removal.

I. Introduction

The control of greenhouse gas is arguably the most challenging environmental policy issue facing India and other countries. CO₂, observed to be the major primary greenhouse gas (GHG) contributing to global warming, has seen a significant increase in atmosphere concentration (M.N. Anwar [2020](#)). Since the beginning of the industrial revolution around 1850, rising from 280 ppm to nearly 420 ppm in 2023 The IPCC's 6th Assessment outlines that climate changes will impact all regions of the globe, with the coming decades, experiencing an increase in heat waves, more warm seasons, and less cold seasons, which will become more severe with a 2°C of warming. Climate model simulations from around the world suggest that our planet's average temperature could be between 2 and 9.7°F (1.1 to 5.4°C) warmer by 2100. Additionally, CO₂ emissions arise from certain industrial and resource extraction processes, as well as from the burning of forests during land clearance Uncontrolled greenhouse gas emissions may lead to rise such as sea level rise and detrimental effects on life of Earth ([IPCC](#)). One approach to mitigate these issues is to reduce the consumption of such fuels, alternatively, capturing and storing emitted CO₂ also known as carbon capture and utilization, can prevent its release into the atmosphere. Some industrial processes can also utilize and store small amounts of captured CO₂ in manufactured products. This study aims to capture CO₂ using a spray tower from the flue gas through the absorption process and utilize the captured CO₂ for sustainable development (J. Vergragt [2011](#)). The control of greenhouse gas is primarily the most demanding environmental policy issue facing globally (Ahmad et al. [2022](#)). CO₂ is observed to be the major greenhouse gas leading to global warming. The purpose of CO₂ capture is to produce carbon- free electricity and fuels for transportation, as well as for small scale or distributed applications(Christian Azar 2006). The energy required to operate CO₂ capture system reduces the overall efficiency of power generation or other process processes, leading to increased fuel requirements, solid wastes and environmental impacts regarding to the similar type of plant without capture. The main application of CO₂ capture is likely to be at large point source such as fossil fuel power plants, fuel processing plants and other industrial plants.

There are four systems basically for capturing CO₂ from use of fossil fuels and biomass (Tinus Pulles [2022](#)).

1. Capture from industrial process streams.
2. Post-combustion capture
3. Oxy-fuel combustion capture
4. Pre-combustion capture.

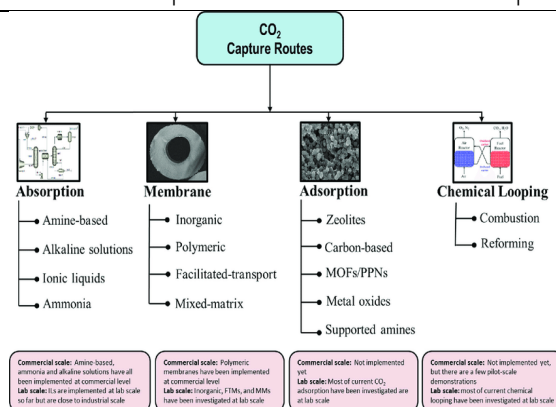


Fig 1 Methods and Techniques for CO₂ Capture

Types of CO₂ Capture Technologies:

1. Separation with Sorbents/ Solvents
2. Separation with membranes
3. Distillation of liquified gas stream & refrigerated separation

Separation with Sorbents/ Solvents

By passing the CO₂ containing gas in intimate contact with a liquid sorbent for achieving separation of CO₂ that is capable of capturing the CO₂. Sorbent loaded with the captured CO₂ is transported to a different vessel, where it releases the CO₂ (regeneration) after being heated, after any other change in the conditions around the sorbent. The final sorbent after the regeneration step is again sent back to capture more CO₂ through a cyclic process. In some way of this scheme the sorbent is a solid and does not circulate between the vessels because the sorption & regeneration are achieved by cyclic changes (pressure or temperature) in the vessel where the sorbent is available. A readily available fresh sorbent is always required to compensate for the natural decay of activity and/or sorbent losses. In sometimes, the sorbent may be a solid oxide which reacts with fossil fuel or biomass in a vessel for obtaining heat (Mainly CO₂). The spent sorbent is then recirculated to a second vessel where it is re-oxidized in air for re-use with some loss & make up of fresh sorbent.

Separation With Membranes

Membranes are specially made materials that allows some selected permeation of a gas by them. The selection of the membranes for different gases is closely related to the nature of the material and the flow of gas through the membrane is usually forced by the pressure difference across the membrane. Thus, high pressure streams are normally preferred for membrane separation. They are many different types of membrane materials (Polymeric, metallic, Ceramic) that may find application in CO₂ capture system preferably separate H₂ from the flue gas stream, CO₂ from a range of process streams or O₂ from air with separated O₂ subsequently aiding the production of a highly concentrated CO₂ stream. Worldwide R & D effort is in progress intended at the manufacturer of more preferable membrane materials for CO₂ capture in large application.

Distillation Of A Liquefied Gas Stream And Refrigerated Separation

A gas can be made liquid by a series of compression, cooling & expansion steps. Once in liquid form, the components of gas can be separated in a distillation column. Frozen separation process can be used to separate CO₂ from other gases.

Characteristics Of Sodium Hydroxide

Salt solutions are another group of chemical absorbents which are salt in nature and when dissolving in water, it can produce electrolyte solution. The main feature of this group is the low price. Because this study, NaOH chemical absorbent is used for capturing CO₂ from the flue gas by using by spray tower through post-Combustion method.

During the process of CO₂ absorption from flue gases using a NaOH solution, flue gas containing CO₂ enters a spray tower from the bottom and is mixed with NaOH solution from top to bottom. Once the gas is dissolved into the NaOH solution, the electrolysis reaction occurs. During the process of using NaOH solution to absorb the CO₂ in the emissions and when the NaOH solution exchanges energy with CO₂.

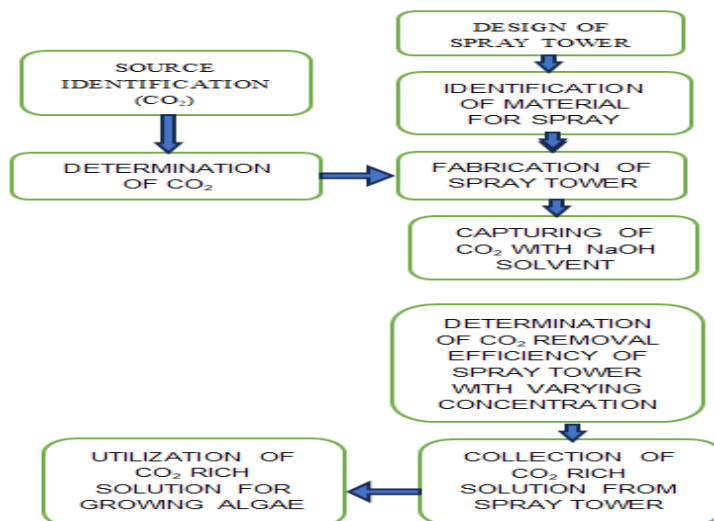
Objective Of The Project

1. To Identify the concentration of CO₂ emissions from a stationary source using CO₂ sensor.
2. To Analyse the CO₂ concentration at both Inlet and Outlet of the Spray tower.
3. To compare the CO₂ removal efficiency of spray tower under different conditions including varying fuel types, absorbent

concentration.

4. To explore the utilization of the concentrated CO₂ solution for algae production.

II. Methodology



Design Parameters Of Spray Tower

The primary objectives of the design procedures are to determine surface area of spray tower. In order to determine this parameter, the following steps may be performed

1. Determine the gas and liquid stream conditions entering and exiting the column
2. Determine the diameter of the spray tower
3. Determine the number of gas phase transfer units.
4. Determine the height and volume of spray tower
5. Collection efficiency of the individual droplet
6. Combined efficiency of all droplet

Design parameters of the spray tower for capturing CO₂ from the flue gas

1. Tower diameter = 0.15m
2. Height of spray section = 1m
3. Volume of spray section = 0.017m³
4. Inlet pipe for flue gas = 25mm steel pipe
5. Velocity of flue gas (As per BOP design calculation) = 8m /sec
6. Inlet pipe for liquid-NaOH solution= 25mm steel pipe

III. Materials And Methods

This section will present the chemicals used for the experiment lead with the spray tower and will specifically review the working principle as well as the experimental procedures applied.

Chemicals

The absorption solution is made by diluting NaOH pellets (sodium hydroxide, NaOH solid) in Deionized water. The flue gas is composed of CO₂ mixed with air.

Table 1: Preparation of absorption solution (NaOH solution)

S.NO	DESCRIPTION
1.	Weighed the required amount of solid NaOH (NaOH = 40 g/mol) in a beaker
2.	Pour the 40 grams of solid NaOH in a stirred beaker containing deionised water of 1 litre for

	1 molar concentration
3.	Accordingly, the aqueous NaOH solution is prepared for 2, 3, 4 & 5 molar concentration.
4.	Let the flask rest for 12 hours in a hood so that it cools down.

Spray Tower

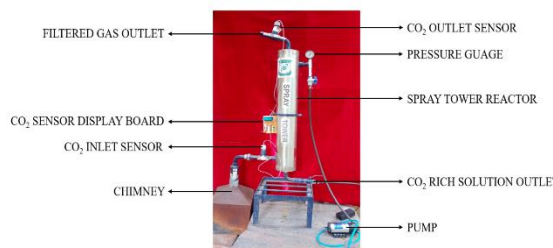


Fig 2 Spray tower for CO₂ capture setup

The tower has a diameter of 0.15 meters and features a spray section with a height of 1.00 meter, resulting in a spray section volume of 0.017 cubic meters and volume of 0.0706 cubic meters. The inlet pipes for both flue gas and liquid were made of 25 mm steel.

The gas-phase mixture of CO₂ and air was supplied by a homogeneous distributor plate at the base of the tower, while the aqueous solution injected by the spray nozzle at the top produced a counter-current flow configuration between the gas and liquid.



Fig 6 Coal

Description of Sensor:

Technical Specifications of MQ135 Gas Sensor

1. Operating Voltage: 2.5V to 5.0V
2. Power consumption: 150mA
3. Detect/Measure: NH₃, Nox, CO₂, Alcohol, Benzene, Smoke
4. Typical operating Voltage: 5V
5. Digital Output: 0V to 5V (TTL Logic) @ 5V
6. Analog Output: 0-5V @ 5V

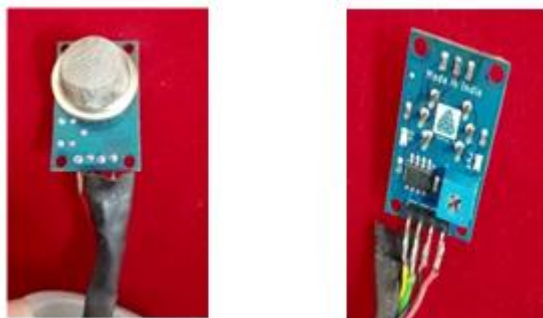


Fig 3 Sensor for measuring concentration of CO₂ in the inlet and outlet of spray tower

The MQ135 is one of the popular gas sensors from the MQ series of sensors that are commonly used in air quality control equipment. It operates from 2.5V to 5.0V and can provide both digital and analog output. The sensors are connected to digital display and thermostat for measuring the temperature and humidity with IC board.

Description of Fuels:

The flue gas is generated by burning cow dung, charcoal, wood sticks. The flue gas is produced in a controlled environment using a chimney, with a burning time of ten minutes. The CO₂ concentration in the flue gas is measured using air quality monitoring sensors connected in a display, both at the inlet and outlet of the spray tower. The display continuously monitors the CO₂ concentration to determine the efficiency of the spray tower while varying the types of fuel.



Fig 4 wood stick



Fig 5 Cow dung

When burning cow dung to generate the flue gas in the chimney, the resulting flue gas is directed to the bottom of the bottom of the spray tower via 1" GI pipe connected to the chimney. The NaOH solvent solution is pumped from a tank through another 1" GI pipe using an electric motor to create fine spray at the top of the spray tower. This arrangement establishes a counter current flow pattern between the flue gas stream and NaOH solution. Similarly, the same procedure is followed when using other fuels to produce flue gas in the chimney.

Discription of Algae:

Blue green algae also known as cyanobacteria, are primarily photosynthetic organisms. They are classified with in the prokaryotic kingdom along with bacteria. Cyanobacteria required light for grow and can't thrive in the absence of light. Apart from photosynthesis, algae are capable of nitrogen fixation, converting atmospheric nitrogen into compounds that can be used by living cells.

In this study, Microalgae are employed to consume CO₂ present in the CO₂ rich solution obtained from the spray tower after absorption process. Micro algae are selected due to their ability to utilize CO₂ as a primary building block and their rapid growth. They demonstrate significant potential in CO₂ mitigation, as cultivating 1 ton of micro algae can fix approximately 1.8 tonnes of CO₂.



Fig 6 Blue green algae

IV. Results and Discussion

General:

The results obtained for CO₂ removal efficiency with variation in NaOH solution concentration, absorbent flow and different fuel used to produce flue gas in the controlled environment are compared using charts. The continuous monitoring of CO₂ concentration at the inlet and outlet was performed to calculate the removal efficiency of the spray tower through the absorption process. The CO₂

rich solution collected from the spray tower is utilized for cultivating algae.

Result and Analysis

Effect of Naoh Solution Concentration

Effects of Cow Dung as Fuel:

The CO₂ removal efficiency of the spray tower with different concentrations of NaOH solution is tabulated below. In this particular case, the flow rate of NaOH solution is 200 ml/ min, cow dung was used as fuel to generate flue gas in the controlled environment with the assistance of chimney, with a burning time of 10 minutes. The experiments were conducted with NaOH solution concentration varying from 1 Molar, 2 Molar, 3 Molar, 4 Molar and 5 Molar.

Table 2 the effect of nAOH solution concentration on co₂ removal efficiency using cow dung as fuel

S.NO	Concentration of NaOH solution in molar	Removal efficiency of CO ₂ by spray tower
1.	1	66.94
2.	2	75.95
3.	3	63.77
4.	4	57.33
5.	5	53.22

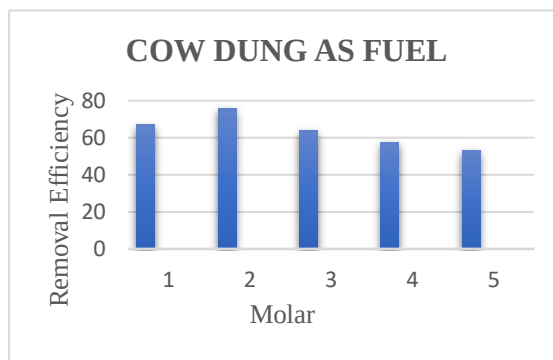


Fig 7 Effect of NaOH solution concentration on CO₂ removal efficiency by using cow dung as fuel

It was observed that the concentration of NaOH solution significantly impact the CO₂ removal efficiency. At a 1 Molar concentration of NaOH solution, the CO₂ removal efficiency was 66.94%. As the concentration of NaOH solution increases, the CO₂ removal efficiency also rises to a high level. The maximum value of CO₂ removal efficiency is 75.95% achieved with a 2 Molar concentration of NaOH solution. However, when the concentration of NaOH solution exceed 2 Molar, the CO₂ removal efficiency start to decrease. For instant at 5 Molar concentration of NaOH solution, the CO₂ removal efficiency drops to 53.22% which is lower than the maximum value attained at 2 Molar concentration of NaOH solution with 75.95%.

Effects Of Wood Stick As Fuel:

The CO₂ removal efficiency of the spray tower with wood stick as fuel source is tabulated below. In this particular case, the flow rate of NaOH solution is 200 ml/min, wood stick was used as fuel to generate flue gas in the controlled environment with the assistance of chimney, with a burning time of 10 minutes. The experiments were conducted with NaOH solution concentration varying from 1 Molar, 2 Molar, 3 Molar, 4 Molar and 5 Molar.

Table 3 The Effect Of Naoh Solution Concentration On Co₂ Removal Efficiency Using Wood Stick As Fuel

S.NO	Concentration of NaOH solution in molar	Removal efficiency of CO ₂ by spray tower
1.	1	24.43
2.	2	74.25
3.	3	33.99
4.	4	33.69
5.	5	36.55

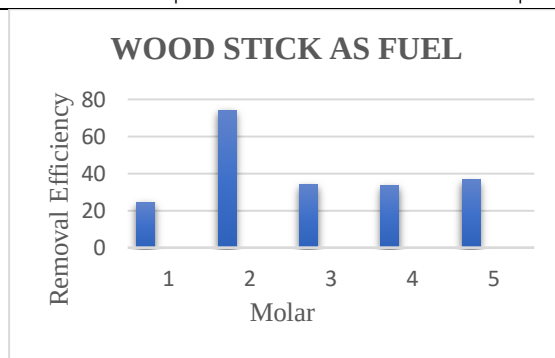


Fig 8 Effect of NaOH solution concentration on CO₂ removal efficiency by using wood stick as fuel

It was observed that the different fuel source significantly impacts the CO₂ removal efficiency. At a 1 Molar concentration of NaOH solution, the CO₂ removal efficiency was 24.43%. As the concentration of NaOH solution increases, the CO₂ removal efficiency also rises to a high level. The maximum value of CO₂ removal efficiency is 74.25% achieved with a 2 Molar concentration of NaOH solution. However, when the concentration of NaOH solution exceed 2 Molar, the CO₂ removal efficiency start to decrease. For instant at 5 Molar concentration of NaOH solution, the CO₂ removal efficiency drops to 36.55% which is lower than the maximum value attained at 2 Molar concentration of NaOH solution with 74.25%.

Effects Of Charcoal As Fuel:

The CO₂ removal efficiency of the spray tower with charcoal as fuel source is tabulated below. In this particular case, the flow rate of NaOH solution is 200 ml/min, charcoal was used as fuel to generate flue gas in the controlled environment with the assistance of chimney, with a burning time of 10 minutes. The experiments were conducted with NaOH solution concentration varying from 1 Molar, 2 Molar, 3 Molar, 4 Molar and 5 Molar.

Table 3 The Effect Of Naoh Solution Concentration On Co₂ Removal Efficiency Using Coal As Fuel

S.NO	Concentration of NaOH solution in molar	Removal efficiency of CO ₂ by spray tower
1.	1	40.86
2.	2	47.89
3.	3	64.13
4.	4	65.24
5.	5	63.62

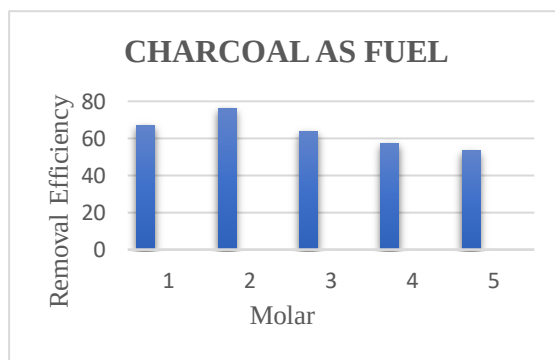


Fig 9 Effect of NaOH solution concentration on CO₂ removal efficiency by using Coal as fuel

It was observed that the different fuel source significantly impacts the CO₂ removal efficiency. At a 1 Molar concentration of NaOH solution, the CO₂ removal efficiency was 40.86%. As the concentration of NaOH solution increases, the CO₂ removal efficiency also rises to a high level. The maximum value of CO₂ removal efficiency is 65.24% achieved with a 4 Molar concentration of NaOH solution. However, when the concentration of NaOH solution exceed 4 Molar, the CO₂ removal efficiency start to decrease. For instant at 5 Molar concentration of NaOH solution, the CO₂ removal efficiency drops to 63.62% which is lower than the maximum value attained at 4 Molar concentration of NaOH solution with 65.24%.

Summary

An experimental study on CO₂ capture was conducted using a spray tower with fine spray of NaOH solution. The spray tower was

utilized for the CO₂ capture, employing fine sprays of NaOH with different concentrations including 1,2,3,4 and 5 Molar concentration as well as water. Additionally, various fuels were used to further investigate the process. The CO₂ removal efficiencies were measured at different concentrations and flow rates of NaOH solutions, while taking into account the variation in the choice of fuel

The obtained results were then compared to the CO₂ removal efficiency of the spray tower under different conditions, including varying concentrations of NaOH solutions and flow rates, as well as diverse fuel source

This comprehensive experimental study allowed for a deeper understanding of CO₂ capture within the spray tower system, highlighting the impact of different factors, including solution concentration, flow rate and fuel types on the overall CO₂ removal efficiency

V. Conclusion

In this study, alkaline solution of NaOH was used to absorb CO₂ from a flue gas emitted by various fuel sources using spray tower in lab scale. A novel spray tower and system was designed and fabricated to capture CO₂. The experiments were conducted with constant flow rates of different concentration of NaOH solution as well as constant concentration of NaOH solution with varying flow rate. The study also investigated the effect of different fuel sources on the absorption process

The Spray tower was demonstrated using NaOH solution with a 2 molar concentration and a fixed flow rate of 200ml/min. flue gas was generated using different fuel such as cow dung, wood stick and charcoal. Cow dung as fuel the inlet concentration of CO₂ was measured using sensors, which recorded values of 944 ppm, the outlet concentration of CO₂ from the spray tower was measured at 227 ppm. The overall CO₂ removal efficiency achieved through the spray tower was 76%. Wood stick as fuel, the inlet concentration of CO₂, was measured using sensors, which recorded values of 936 ppm, the outlet concentration of CO₂, from the spray tower was measured at 241 ppm. Charcoal as fuel, the inlet concentration of CO₂ was measured using sensors, which recorded values of 906 ppm, the outlet concentration of CO₂ from the spray tower was measured at 310 ppm. The overall CO₂ removal efficiency achieved through the spray tower was 66%.

Reference

1. IPCC reports 2020 [IPCC — Intergovernmental Panel on Climate Change](#)
2. **Sources of Carbon Dioxide and Environmental Issues** 02 January 2020-[M. N. Anwar](#) et.al https://link.springer.com/chapter/10.1007/978-3-030-29298-0_2
3. **Journal of King Saud University - Science** Volume 35, Issue 5, July 2023, 102693 Ahmad et al. 2022 <https://doi.org/10.1016/j.jksus.2023.102693>
4. storage, and the escape from the fossil-fuel lock-in [Volume 21, Issue 2](#), May 2011, Pages 282-292 J. Vergragt ,Nils Markusson <https://doi.org/10.1016/j.gloenvcha.2011.01.020>
5. CO₂ emissions from biomass combustion Accounting of CO₂ emissions from biomass under the UNFCCC [Michael Gillenwater](#) & [Klaus Radunsky](#) <https://doi.org/10.1080/17583004.2022.2067456>