

# Design Analysis of CO<sub>2</sub> Absorption through MEA of a 500 MW Coal fired Power Plant

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## Abstract

Greenhouse gas mitigation technology, mainly with respect to CO<sub>2</sub> is getting prominence in the light of climate change qualms. Many techniques have been used to reduce CO<sub>2</sub> emissions across the globe among which post combustion carbon capture stands the most promising one which if used can cast off more than 50% of the total CO<sub>2</sub> emissions which are emitted mainly from the industrial stacks. The study focused on the design analysis of CO<sub>2</sub> sequestration from a 500 MW coal fired power plant. Post combustion carbon capture technology with the use of MEA (mono ethanol amine) solvent was used for an optimized CO<sub>2</sub> recovery. The purpose of this study was to optimize the recovery and purity of CO<sub>2</sub> using a simulation software, Aspen Hysys. The design parameters considered were concentration of the solvent, absorber pressure, sieve diameter and number of plates in absorber and stripper. Through variation of process variables and equipment design specifications, maximum enhanced CO<sub>2</sub> recovery of 95% and purity of 99% has been achieved at an operational cost of \$57/ton.

**Keywords:** Post combustion capture, Chemical absorption, Optimization, CO<sub>2</sub> sequestration, Simulation

## Introduction

The Earth is warming; glaciers are thawing and so far very little are being done to counter global warming. The main source of the global warming is the increased use of fossil fuels, which upon combustion release significant quantities of carbon dioxide.[1]

The atmosphere is made up of several gases (greenhouse gases) that have the ability to reflect the radiations of the sun from the earth back to the earth as heat. These gases are observed to cause anthropogenic (human-induced) global warming. Global warming caused by greenhouse gases in the atmosphere acts like a mirror, which reflects back to the Earth a part of the heat radiation, which would otherwise be lost to space. The accumulation of carbon dioxide in the environment is recognized as a key contributor to the global warming problem caused by greenhouse gases.[2]

Thus greater the concentration of greenhouse gases like carbon dioxide in the atmosphere, the more heat energy is being reflected back to Earth and making it warmer by every passing day. The emission of carbon dioxide into the atmosphere is mainly due to the burning of fossil fuels (oil, gas, petrol etc.) which has been increased significantly over the past 50 years.[3]

So it is a fact that carbon dioxide is one of the major sources of the global warming and thus the carbon dioxide emissions has to be reduced or stopped in one way or the other. As we are dependent on the fossil fuels for taking energy, we need to devise some way to capture these emissions from the different sources producing it, and then utilize it in a positive way.[3]

To reduce these emissions, different carbon dioxide capturing technologies can be employed, depending upon

the location where the capture takes place. The capturing technologies include:

1. Pre-Combustion Capture
2. Oxy- Fuel Combustion
3. Post- Combustion Capture

### Pre-combustion capture

In pre-combustion capture, carbon and hydrogen in a fossil fuel are first separated and then combusted. The fuel source becomes chemically transformed into two gas streams consisting of hydrogen and CO<sub>2</sub>. In the process, air is purified in an air separation unit and pure oxygen (O<sub>2</sub>) is extracted from it. After then, oxygen (O<sub>2</sub>) is sent to the gasifier where it reacts with the fuel source to create a synthesis gas, or syngas. This syngas is a mixture of carbon monoxide and hydrogen. Then steam is added to the synthesis gas in a shift reactor, which converts carbon monoxide (CO) to carbon dioxide (CO<sub>2</sub>) and hydrogen (H<sub>2</sub>). This entire process results in two pure gas streams of carbon dioxide (CO<sub>2</sub>) and hydrogen (H<sub>2</sub>) which can then be used as follows:

- The hydrogen can be burned cleanly to produce steam which can be used to run a turbine to make electricity or for other industrial applications.
- The carbon dioxide (CO<sub>2</sub>) stream can be sequestered. [4]

### Oxy-Fuel Combustion

In oxy-fuel combustion fossil fuel is burned in the presence of pure oxygen. Burning of fuel in the presence of oxygen removes contaminants such as nitrogen from the exhaust stream and thus results in easy capture of carbon dioxide. In this process, air is purified in a distillation column to get

pure oxygen then pass through a heat exchanger. After this fuel is combusted in the presence of pure oxygen. The combustion is used to produce steam which will run a turbine to make electricity. The exhaust from oxygen combustion contains high concentration of carbon dioxide which can be sequestered.[4]

### Post-Combustion Capture

It is the most commonly used process. In this process carbon dioxide is captured after the combustion of fuel. After the combustion of the fossil fuel, the flue gas is cooled and treated to get rid of SO<sub>2</sub>, NO<sub>2</sub> and other trace gases. After cooling, the gas is passed through a contact absorber which contains a liquid solvent that is usually an aqueous amine solution. The CO<sub>2</sub> is absorbed by the amine solution. Then the CO<sub>2</sub>-rich solution is passed to a stripper where the CO<sub>2</sub>-rich amine is separated into two streams i.e. the concentrated CO<sub>2</sub> stream and pure amine gas. Then the CO<sub>2</sub> stream is dehydrated, compressed and stored. [4]

Mainly used post-combustion carbon capture technologies are:

- Membrane Separation
- Adsorption
- Physical absorption
- Chemical absorption

### Membrane Absorption

In this technique flue gas is passed through a partially permeable thin film and specific operating conditions are applied to separate carbon dioxide. Because of the differences in physical and chemical properties of gas components, different molecules passed through the membrane at different rate. This technique is not commercial so far. Multiple stages or recycle of one of the streams is required as the efficiency of the membranes is not so high. This makes the process complex and increases the energy consumption and costs. Thus, membrane separation technology is not much applicable for capturing carbon dioxide.[5]

### Adsorption

Adsorption is based on physical attraction between active sites of the solid surface and the gas components. Column is packed with the solid adsorbent and carbon dioxide is then assimilated.

Adsorption is classified as pressure swing adsorption (PSA) and temperature swing adsorption (TSA). Under the current state of technology usage, adsorption is so far not considered suitable for large-scale separation of carbon dioxide from the flue gases because carbon dioxide selectivity of available adsorbents low. [6]

### Physical Absorption

According to Henry's law, carbon dioxide can be absorbed in a solvent and this technique is more suitable for gases having high partial pressure. The regeneration of the solvent is comparatively simple for this technique as it is carried out by pressure drop. However, if physical solvents are used for separation of carbon dioxide from flue gases,

not only compression power would be required but also extensive energy will be required for solvent circulation, as solvent regeneration usually takes place at atmospheric pressure.[7]

### Chemical Absorption

In this process flue gas is cooled and purified and then sent to an absorption column where it comes in contact with the solvent, in our case the solvent is MEA (mono ethanolamine). Carbon dioxide in the flue gas reacts with the MEA and absorbed in it. The bottom stream of the absorber contains the rich solvent which is transferred to the stripper where the absorption process gets reversed in the presence of heat. The bottom stream of the stripper is then sent back to the absorber, whereas the captured carbon dioxide is compressed and stored.

Chemical solvents are preferred for gases having low concentrations of carbon dioxide in the flue gas. The chemical absorption method is commonly used in chemical industries to separate and recover carbon dioxide from flue gas. The recovery of carbon dioxide by the process of chemical absorption shows the greatest promise of accomplishment for thermal power plants. [7],[8].

This study is carried out by using amine absorption which is a chemical absorption process. Amine absorption is well suited for CO<sub>2</sub> recovery from flue gas. The reaction between CO<sub>2</sub> and amines increases the driving force for the separation even at low partial pressures of CO<sub>2</sub>. The cost of this method is comparatively low.[9]

Different kinds of amines are available and the selection of amine depends on the composition and operating conditions of the feed gas. Amines are divided into three categories

- a) **Primary Amines:** Directly react with CO<sub>2</sub> and H<sub>2</sub>S and Carbonyl Sulfide (COS), mono-ethanol amine, diglycol amine agents are most commonly used primary amines.
- b) **Secondary Amines:** Directly react with CO<sub>2</sub> and H<sub>2</sub>S and reacts with some COS. Diethanol-amine and di-isopropanol amine (DIPA) are examples of secondary amines
- c) **Tertiary Amines:** Do not directly react with CO<sub>2</sub> for example methyl-di-ethanol amine (MDEA) [10]

For many years, MEA has been used exclusively for the removal of H<sub>2</sub>S and CO<sub>2</sub> because of its high reactivity and low solvent cost. MEA has very fast reaction rate with CO<sub>2</sub> even at low partial pressures as compared to other amines. MEA has comparatively high biodegradability, and MEA has no adverse effect to the human health, water organisms and animals. But the emissions of ammonia and nitrogen generated from decomposition of amine, if emitted in high concentrations, can cause acidification and eutrophication.[11]

### Methodology

The key components of the CO<sub>2</sub> capture system are the absorption and regeneration processes. The removal of CO<sub>2</sub> from the flue gases occur at the absorption tower

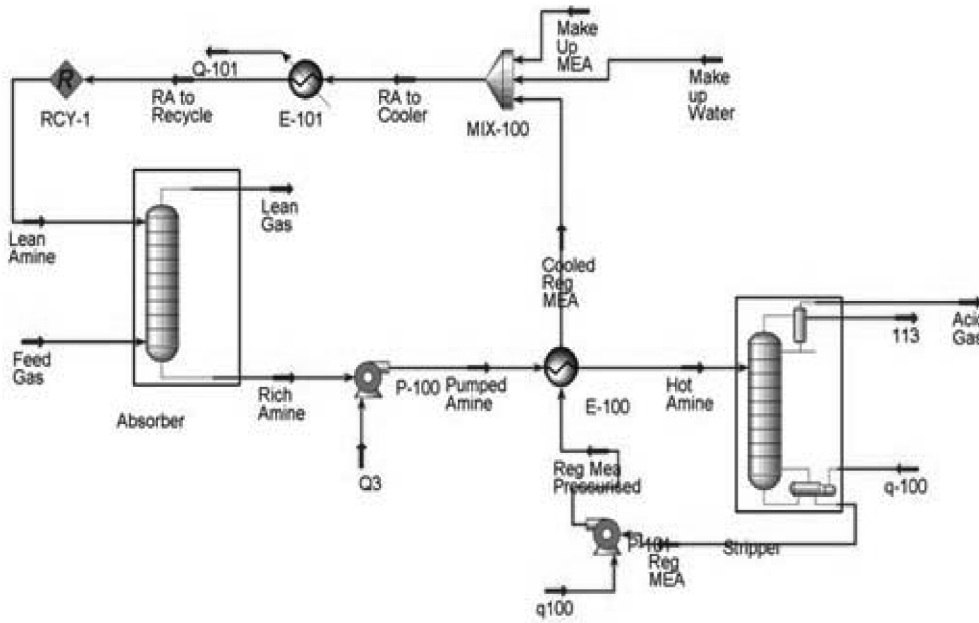


Fig 1. Aspen Hysys Process Flow Diagram

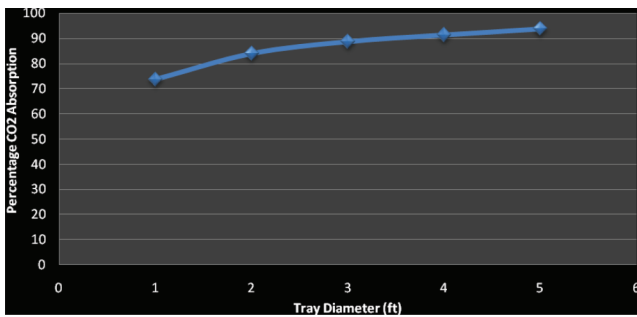


Fig. 2: Percentage CO2 Absorption and Tray Diameter

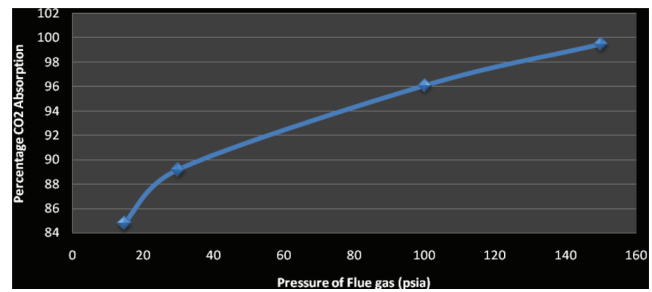


Fig. 5: Percentage CO2 Absorption and Flue Gas Pressure

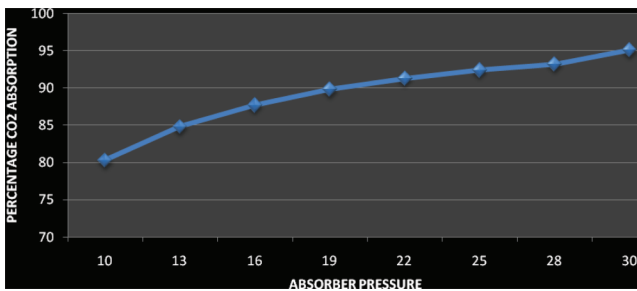


Fig. 3: Percentage CO2 Absorption and Absorber Pressure

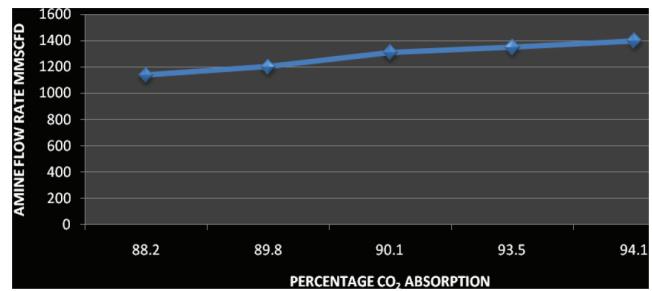


Fig. 6: Percentage CO2 Absorption and Amine Flow Rate

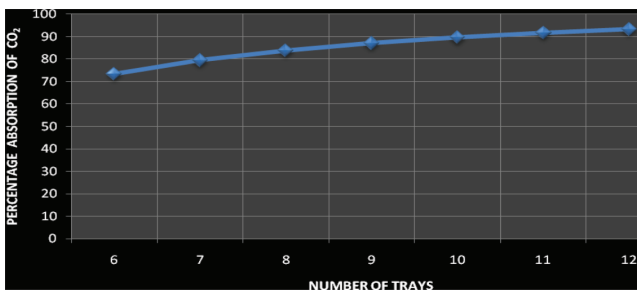


Fig. 4: Percentage CO2 Absorption and Number of Absorber Trays

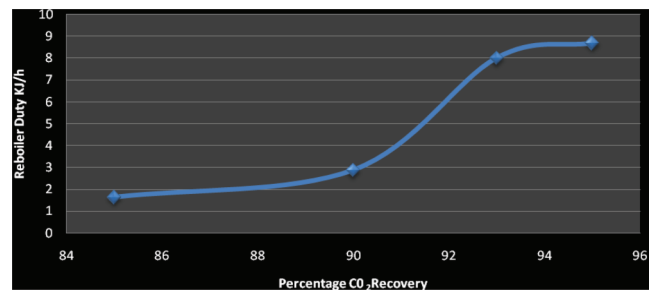


Fig. 7: Re boiler Duty and Percentage CO2 Recovery

**Table 1:** Absorber Specifications

Feed gas temperature	35°C
Lean amine temperature	48°C
Lean amine flow rate	1400 MMscfd
Feed Gas flow rate	379 MMscfd
Feed gas pressure	30 psia
Lean amine pressure	29.5 psia
Pressure top stage	28 psia
Pressure bottom stage	29psia
CO <sub>2</sub> Absorption	<b>99.6%</b>

**Table 2:** Stripper Specifications

Rich amine flow rate	1411 MMscfd
Acid gas flow rate	51.89 MMscfd
Regenerated amine flow rate	1359 MMscfd
Top stage pressure	29 psia
Bottom stage pressure	30 psia
Acid gas temperature	45.6°C
Regenerated amine temperature	124°C
CO <sub>2</sub> Purity	<b>99%</b>
CO <sub>2</sub> Recovery	<b>95%</b>

**Table 3:** Recovery vs Cost Per Ton Of Carbon Dioxide

Recovery %	Purity %	Cost per ton CO <sub>2</sub> \$
85	99	27
90	99	34
<b>95</b>	<b>99</b>	<b>57</b>

operating at low temperature conditions, of maximum tray temperature 65°C to enhance absorption. The feed gas enters from the bottom at 35°C and interacts with the lean amine coming from the top of the tower at 48°C resulting in an exothermic reaction in which the CO<sub>2</sub> gets attached to the MEA molecules. Two streams are generated; the lean gas which is the CO<sub>2</sub> free gas and the rich amine stream which includes the 99% recovered CO<sub>2</sub>. The next part of the system involves the regeneration of the amine by stripping off the loosely bonded CO<sub>2</sub> to the amine by the application of heat. So before the rich amine goes into the stripper it gets heated up in a shell and tube heat exchanger. The heating fluid on the shell side of the exchanger is the regenerated amine which needs to be cooled down for the recycling into the absorption tower. Once the rich amine is at desired temperatures it moves into the stripper where it is regenerated. Here pure CO<sub>2</sub> gas with negligible amount of water leaves the tower from above as acid gas at 45°C and regenerated amine leaves from the bottom at 124°C. The next objective is to bring the regenerated amine back to lean amine specification which includes the drop in temperature through the shell and tube heat exchanger as well as cooler and adding up the makeup water and makeup MEA to match the composition of the lean amine entering the absorption tower.

## Results and Discussion

The most important parameters for the optimization of CO<sub>2</sub> recovery plant using an absorption method are absorber pressure, sieve diameter, reboiler and condenser duty and number of plates in absorber and stripper columns.

Aspen Hysys was used throughout to perform simulations and find results while varying parameters described above.

Fig 2 shows the effect of tray diameter variation to the percentage absorption of CO<sub>2</sub>. Results show that percentage recovery of CO<sub>2</sub> is increased by increasing the tray diameter. Increasing the diameter from 1ft to 5ft the percentage absorption was increased by 20%.

Fig 3 shows the effect of absorber pressure variation on percentage absorption of CO<sub>2</sub>. Results show that percentage absorption of CO<sub>2</sub> is increased by increasing the absorber pressure, 95 percent absorption of CO<sub>2</sub> is obtained at 30psia. Increasing the absorber pressure by three times i.e. 10psi to 30psi percentage absorption was increased by 15% i.e. 80.3% to 95.1%.

Fig 4 shows the effect of variation of number of trays of absorber on the percentage absorption of CO<sub>2</sub>. Results show that percentage absorption of CO<sub>2</sub> is enhanced by increasing the number of trays of absorber. Increasing the number of absorber trays from 6 to 12, percentage

absorption of CO<sub>2</sub> was increased by 20 percent i-e from 73.4 to 93.3 percent.

Fig 5 shows the effect of flue gas pressure variation to the percentage absorption of CO<sub>2</sub>. Results show that percentage recovery of CO<sub>2</sub> is enhanced by increasing the pressure of flue gas.

Fig 6 shows the effect of amine flow rate variation to the percentage absorption of CO<sub>2</sub>. Results show that by increasing the pressure of flue gas increases the percentage absorption of CO<sub>2</sub>. 94 percent absorption of CO<sub>2</sub> is obtained at 1400MMScfd. Flow rates greater than this result in high corrosion of the vessel.

Fig. 7 shows the effect of reboiler duty variations to the CO<sub>2</sub> recovery. Results show that there is a drastic change in the reboiler duty as the purity of CO<sub>2</sub> is increased from 85 to 95 percent. As the recovery was increased from 85 to 90 percent the reboiler duty was nearly doubled. Further increment from 90 to 95 percent of CO<sub>2</sub> recovery caused and an increase in reboiler duty by approximately 400 percent. Even at this escalated reboiler duty the cost per ton capture CO<sub>2</sub> was observed to be at \$57/ton. This value is within the limits of sequestered CO<sub>2</sub> through amines worldwide.

### Conclusion

The conclusion for the optimized carbon dioxide removal from a 500 MW power plant is as

- A 99.6% absorption of CO<sub>2</sub> was achieved taking the lean amine flow rate to 1400 MMscfd. Flow rates greater than this result in high corrosion of the vessel.
- In order to maintain high purity of CO<sub>2</sub> the reboiler duty was adjusted till the optimum results were obtained. There is a drastic change in the reboiler duty as the purity of CO<sub>2</sub> is increased from 85 percent onwards.
- Height and diameter of the vessels were optimized to obtain the maximum absorption and recovery of CO<sub>2</sub>.
- An economic analysis was made which resulted in \$57/ton CO<sub>2</sub> removed. This analysis was made on 95% CO<sub>2</sub> recovery with 99% purity at stripper section. Cost of sequestration per ton of CO<sub>2</sub> changes with change in recovery and purity of CO<sub>2</sub>.

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