CARBON DIOXIDE (CO_2) ABSORPTION IN BLENDS OF AQUEOUS SOLUTIONS OF MONOETHANOLAMINE (MEA) AND L-SERINE

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FACULTY OF ENGINEERING
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CARBON DIXOIDE (CO_2) ABSORPTION IN BLENDS OF AQUEOUS SOLUTIONS OF MONOETHANOLAMINE (MEA) AND L-SERINE

ABSTRACT

Expansion in carbon dioxide discharges in the climate is a widespread matter that needs a conclusive determination in order to direct the creating hazard of environment change. Various examinations have been led over the end to settle this issue. The principal investigation of this study is to investigate the solubility of CO_2 in aqueous MEA + L-Ser solution. This is done by exploring the effect of various elements on the absorption process, for example, concentration, temperature and CO_2 loading. In this work, CO_2 solubility is estimated in the aqueous solution of monoethanolamine (MEA) + Serine (L-Ser) using a high-pressure CO_2 absorption reactor. The analysis was done at various pressure (50–200 psi) and under four distinct temperatures (303.15 K–333.15 K). The composition of aqueous solutions was used as 2.0 M MEA, 1.5 M MEA + 0.5 M L-SER and 1.0 M MEA + 1.0 M L-SER. It was seen that at a similar pressure; the CO_2 loading decreases with an increase in temperature. For sure, at a consistent temperature, the solution loading increases as the pressure builds, which shows that the response is exothermic response. It is prescribed to investigate more on the solubility of CO_2 absorption using original form of amino acids with various solvents like MDEA, DEA, DIPA and so forth.

Keywords: absorption, carbon dioxide, solubility, CO_2 loading, serine, MEA

PENYERAPAN KARBON DIOKSIDA DALAM CAMPURAN AKUEUS MONOETHANOLAMINE (MEA) AND L-SERINE

ABSTRAK

Memperluas pelepasan karbon dioksida dalam iklim adalah masalah yang meluas yang memerlukan penentuan konklusif untuk mengarahkan bahaya perubahan persekitaran. Pelbagai peperiksaan telah dipimpin pada akhirnya tidak banyak masa untuk menyelesaikan masalah ini. Penyiasatan utama tinjauan ini adalah untuk menentukan kelarutan CO_2 dalam larutan MEA + L-Ser berair dengan meneroka kesan pelbagai elemen pada proses penyerapan, misalnya, kepekatan, suhu dan pemuatan CO_2. Dalam karya ini, kebolehpasaran CO_2 dianggarkan dalam larutan berair monoethanolamine (MEA) + Serine (L-Ser) yang menggunakan reaktor penyerapan CO_2 tekanan tinggi. Analisis dilakukan pada pelbagai tekanan (50 – 200 psi) dan di bawah empat suhu yang berbeza (303.15 K - 333.15 K). Komposisi larutan berair digunakan sebagai 2.0 M MEA, 1.5 M MEA + 0.5 M L-SER dan 1.0 M MEA + 1.0 M L-SER. Telah dilihat bahwa pada tekanan yang sama, solusi berkurang dengan suhu yang mengembang. Yang pasti, pada suhu yang konsisten, pemuatan larutan berkembang ketika tekanan meningkat yang menunjukkan bahawa tindak balas adalah tindak balas eksotermik. Ia diresepkan untuk menyiasat lebih lanjut mengenai kebolehpecahan penyerapan CO_2 yang menggunakan bentuk asid amino asli dengan pelbagai pelarut seperti MDEA, DEA, DIPA dan sebagainya

Keywords: penyerapan, karbon dioksida, kelarutan, pemuatan CO_2, serine, MEA

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LIST OF SYMBOLS AND ABBREVIATIONS

% : Percentage

[Apaeim] : 1-(3-aminopropyl)-3-2-aminoethyl) imidazolium

[Cho][Lys] : Cholinium Lysinate

°C : Degree Celsius

AAILs : Amino Acid Ionic Liquids

AAS : Amino Acid Salt

Al : Aluminium

AMP : 2-Amino-2-Methyl-1-Propanol

ASV : Air Separation Unit

BZA : Benzylamine

Ca : Calcium

$CaCO_3$: Calcium Carbonate

CaO : Calcium Oxide

CCS : Carbon, Capture and Storage

CCU : Carbon, Capture and Utilization

CFB : Circulating Fluidized Bed

CH_4 : Methane

CO_2 : Carbon Dioxide

Conc. : Concentration

DEA : Diethanolamine

DIPA : Diisopropanolamine

DMF : N,N-Dimethylformamide

EGR : Enhance Gas Recovery

EOR : Enhance Oil Recovery

ESA : Electrical Swing Adsorption

GHG : Greenhouse Gases

H_2 : Hydrogen

H_2S : Hydrogen Sulphide

HCO_3^- : Hydrogen Carbonate

IGCC : Integrated Gasification Combined Cycle

ILs : Ionic Liquids

K : Kelvin

K_2CO_3 : Potassium Carbonate

KOH : Potassium Hydroxide

MAPA : N-Methyl-1,3-diaminopropane

MDEA : Methyl Diethanolamine

MEA : Monoethanolamine

$Mg(OH)_2$: Magnesium Hydroxide

Mg : Magnesium

MGA : Membrane Gas Adsorption

MOFs : Metal Organic Frameworks

mol% : Mole Percentage

mol/L : Moles per liter

MPa : Megapascal

N_2 : Nitrogen

Na : Sodium

Na_2CO_3 : Sodium Carbonate

NaOH : Sodium Hydroxide

NET : Negative-Emissions Technology

NH_3 : Ammonia

Ni : Nickel

NO : Nitric Oxide

NO_x : Nitric Oxides

O : Oxygen

ppm : Parts per million

psi : Pounds per square inch

PSA : Pressure Swing Adsorption

PZ : Piperazine

Ser : Serine

SEWGS : Sorption Enhanced Water Gas Shift

Si : Silicon

SO_2 : Sulphur Dioxide

TBAB : Sulphur Oxides

TBAF : Tetrabutylammonium Bromide

TBF : Tetrabutylammonium Fluoride

TEA : Triethylamine

TETA : Triethylenetetramine

THF : Tetrahydrofuran

TiO_2 : Titanium Dioxide

TSA : Temperature Swing Adsorption

VSA : Vacuum Swing Adsorption

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CHAPTER 1: INTRODUCTION

1.1 Background

Following the start of the industrial revolution, worldwide energy consumption is on the rise. Around 80% of global energy demand is met by power plants that burn fossil fuels to create electricity (Agency, 2012). Subsequently, a lot of GHG being delivered into the air, causing environmental change, an overall ecological catastrophe (Yang et al., 2008). The most important GHG that causes global warming is CO_2. Our current CO_2 content in the atmosphere is 415.77 ppm, which is more above the acceptable level (350 ppm). Currently, fossil fuels account for approximately 80% of our energy supply, while renewables account for barely 10%. According to forecasts, fossil fuels, which contribute to CO_2 emissions, will continue to be the front-runner in meeting our rising energy demands in the near future. As a result, we must develop technology for large-scale carbon collection, use, and storage in order to preserve a synergy between energy equivalence and environmental growth.

To diminish CO_2 emissions into the climate, two principal innovations are used: carbon capture and storage (CCS) and carbon catch and use (CCU) (Figure 1). CO_2 is caught and transported to a chosen storage location in CCS, whereas captured CO_2 is transformed into value goods in CCU. CO_2 is used as a feedstock in CCU for the production of fuels, carbonates, polymers, and chemicals. CO_2 may conceivably be used for further developed oil and gas recuperation (EOR, EGR) and the assembling of an assortment of mineral carbonates. CCU technology is quickly developing and has entered the demonstration phase. However, given the vast magnitude of CO_2 emissions, CCS remains the dominant CO_2 capture option in the industrial sector. Post-combustion CO_2

collection is the most widely used CCS system in the industrial sector because it can be simply adapted to existing CO_2 sources.

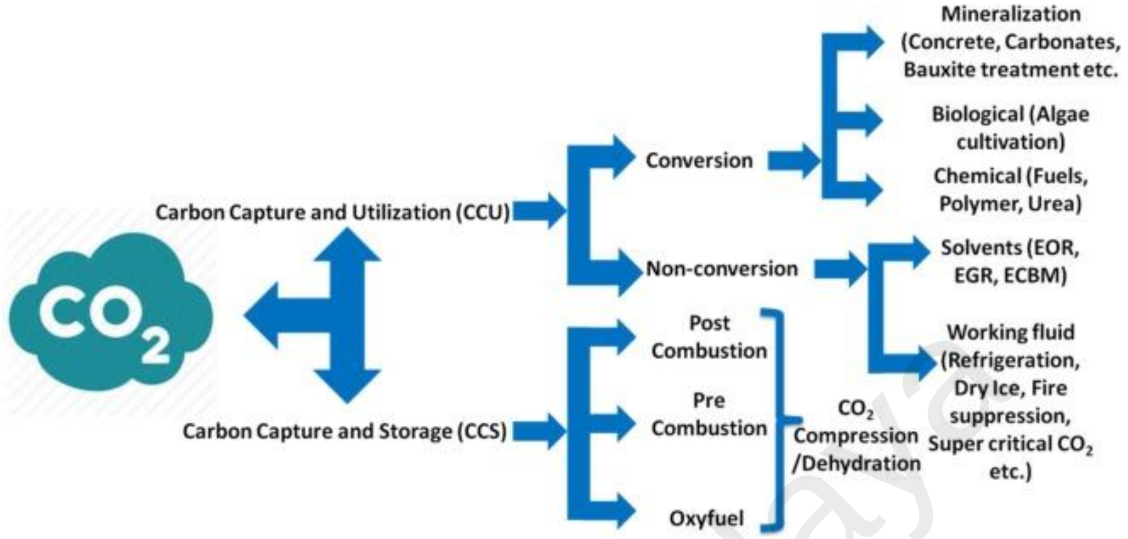

Figure 1.1: Different Types of Carbon Capture

Many climate projection models predict that in future, the average global temperature will have risen because of the increasing CO_2 levels in the atmosphere (Williams, 2002). As a result, reducing CO_2 emissions by using efficient technology has become a global problem (Rhodes, 2007). A great deal of study has been done on a global scale. As a result, many technologies have been developed (Dawodu & Meisen, 1996; Fawzy et al., 2018; Jamal & Meisen, 2001). Chemical solvent absorption is the most often used approach because of the significant research done on solvents and their significance (Akbar & Murugesan, 2012; Kumar et al., 2001).

Amine-based solvents like MEA, DEA, DIPA, TEA, and MDEA are regularly used for CO_2 absorption (Falkenstein-Smith et al., 2017; Kang et al., 2020; Raksajati et al., 2016). Although these solvents have been widely used for CO_2 absorption, following comprehensive research among these popular chemicals in commercial applications, several limitations have been found and documented. These solvents have been more susceptible to oxidative & thermal deterioration, resulting in a smaller service life. With amine-based solvents, consumption of hardware and stream lines, dissolvable exhaustion because of the expanded unpredictability, higher recovery energy, and poisonousness are largely issues (Alivand et al., 2019; Conway et al., 2014; Sun et al., 2005; Zhang et al., 2014).

Aqueous solution of MEA as a fundamental amine is the most sensible substance dissolvable and has been used as a modern retentive for CO_2 capture because of its high sorption limit, modest, high temperature obstruction corruption, low permeability of hydrocarbons, and low nuclear weight. A few weaknesses incorporate low CO_2 absorption rate, high energy needs for recovery, vaporization misfortunes inferable from high fume pressure, high consistency, crumbling by means of amine oxidation, and functional issues like erosion, frothing, and fouling (Alivand et al., 2019; Brúder et al., 2011). Amine-based solvents have limitations that limit their usage in practical applications. As a result, scientists and researchers must now investigate novel solvent systems that may compensate for the shortcomings of present ones.

Ionic liquids (ILs) were recognized as revolutionary CO_2 absorbents throughout the last two decades. Because they all have low vapor pressures and stay liquid at extremely high temperatures, they do not harm the environment and offer less dangers to workers than commercial solvents. However, using ILs as carbon dioxide absorbents has significant disadvantages. The primary downsides incorporate high thickness, costly interest, poor CO_2 absorption capacity, and poor soundness to vent gas contaminations (Aftab et al., 2018; Cheng et al., 2017). As of late, there has been a ton of interest in an innovative pattern of ionic fluids produced using regular crude fixings like amino acids. AAILs are a choice rather than standard ionic fluids subject to petrochemical normal materials. Truly, AAIL refers to an ionic liquid whose anion has an amino functional group attached to it. This amino group can react with CO_2. Although that they can be great CO_2 capture solvents, they have a few inconveniences, including a weighty cost and an impressively enormous consistency when contrasted with alkanolamine solvents (Guo et al., 2019; Hamzehie & Najibi, 2016b; Ma'mun, 2014).

AAS solutions are being researched like as a substitute as alkanolamines. Despite their higher cost, these have low vapor pressures (owing to their ionic composition), great oxidative stability, minimal viscosity values, low binding strength, and strong chemical bonding with CO_2 (Ansaloni et al., 2017; Knuutila et al., 2011). Because amino acids have a greater surface tension over alkanolamines, they can be used in the membrane gas absorption (MGA) module (Ling et al., 2019; Mahmud et al., 2017). Precipitation of reaction products may occur when CO_2 is absorbed with salt solutions of amino acids. The existence of solids provides numerous intriguing advantages.

One of most major benefit is that precipitation of reactions decreases their fixation in the liquid phase, driving responses to shift toward the arrangement of new items and in this manner expanding CO_2 solubility (Portugal et al., 2007; Posch & Haider, 2013; Ramazani et al., 2015). Strong particles of the reaction products may increase uptake at the gas–liquid interphase owing to favorable associations in the middle of little particles just as the submerged gas. They can, then again, enhance viscosity and hence reduce the gas's diffusivity in the liquid phase (Martins et al., 2021).

1.2 Problem Statement

MEA is widely used in various processes due to its fast reaction kinetics with CO_2, low solvent cost, low hydrocarbon solubility, and other advantageous characteristics. However, MEA introduces the disadvantages of O_2- and SO_2- induced degradation, metal-corrosion, high vapor loss, and high absorbent regeneration energy. Amino acid, due to their physical and chemical properties, have been mentioned as attractive alternatives to alkanolamines as solvents for carbon dioxide absorption. Because most amino acids have no toxicity problems and are safe, amino acid-based solvent systems are becoming popular. Amino acids have the additional benefit of being able to contribute a salt effect. To get the proper salts of the amino acids, the carboxylate gathering can likewise be killed with potassium and lithium hydroxide (Suleman, Maulud, Syalsabila, & Shahid, 2020). The salt feature means that the substance is non-volatile, which is useful when working in stripping environments. A third advantage is the strong surface tension on aqueous solutions of amino acid ions, which consider it desirable to gas–liquid industrial application (Agency, 2012).

The goal of this study is to absorb carbon dioxide so that global warming can be reduced. Carbon dioxide (CO_2) emissions in the atmosphere must be reduced since they have a negative impact on living organisms. Monoethanolamine (MEA) and serine blends will be employed in this study. Most of the investigations used the salt form of serine rather than the natural state (Suleman, Maulud, Syalsabila, & Shahid, 2020). For this study, the original form of serine will be employed instead of its salt form in this study. The stirred cell reactor will be employed throughout this research since no liquid analysis is required (Ling et al., 2019).

1.3 Research Objectives

The aim of this research would be to investigate CO_2 absorption in MEA + Serine solution with the use of high-pressure CO_2 absorption reactor. In order to achieve the research's purpose, certain objectives must be met

- To determine the solubility of CO_2 in aqueous MEA + Serine (Ser) solution.
- To investigate the impact of different factors on the absorption process (concentration, temperature and CO_2 loading).
- To study the mechanisms of CO_2 absorption into aqueous solutions

1.4 Scope of the Research

Three separate sets of kinetic studies will be carried out with aqueous solution (MEA + serine: (1) Absorption studies at such a constant temperature both with varied concentrations of aqueous solution as absorption liquid (0.5 mol/L–2.0 mol/L) will be performed to determine the influence of aqueous solution concentration as absorption liquid upon that kinetics of the process. (2) The influence of the aqueous solution's degree of CO_2 loading on reaction kinetics will be examined. To accomplish these objectives, an aqueous solution (MEA + serine) will be loaded with CO_2, and the reaction rate constant for CO_2 absorption in this loaded solution at a given temperature will be computed. Titration will find out the precise loading of the solution.

1.5 Outline of the Thesis

The first chapter of this thesis discusses the notion of carbon capture and sequestration and argues for a more in-depth investigation of CO_2 capture. In Chapter 2, there is a discussion of the literature review on other researchers' investigations based on solvents, amino acids, and carbon capture technologies. The chemical, apparatus, equipment, and experimental technique used in this research study are presented and described in Chapter 3. The fourth chapter reviews the findings and expands on the reasons. Finally, Chapter 5 concludes with a proposal for future research.

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

Anthropogenic CO_2 is the most significant source of greenhouse gas globally. Carbon dioxide absorption has been discovered to be the most cost-effective method for reducing CO_2 emissions on an industrial scale. Carbon catch and capacity (CCS) is one way to reduce CO_2 emissions into the atmosphere. Researchers are investigating new solvent formations in order to make CO_2 a viable CCS option. This chapter covered the sources of carbon dioxide emissions and traditional solvents, as well as research findings on CO_2 absorption processes based on chemical and physical absorption (Rabensteiner et al., 2014). Aside from that, this chapter goes through the CCS methodologies in depth, as well as the research that has been done with them. In addition, this paper describes the usage of amino acids in the absorption process, comparing their effectiveness to that of other solvents. Finally, the effectiveness of the CO_2 absorption method is evaluated and contrasted.

2.2 CO_2 Emissions Sources

2.2.1 Sources from People

2.2.1.1 Combustion of Fossil Fuels/ Use

CO_2 emissions are primarily caused by the combustion of fossil fuels, which accounts for 87% of total emissions. The energy created by burning is utilized to generate electricity or power for transportation. It is also used in the industrial sector, power plants, airlines, and automobiles, besides these two uses (Borhani et al., 2015). However, CO_2 is produced as a byproduct of burning.

2.2.1.2 Sector of Electricity/ Heating

Coal, a carbon-intensive fossil fuel, is used heavily in the electricity and heating sectors. As a result, they emit a lot of carbon emissions. They handle 41% of CO_2 emissions. This industry handles most man-made CO_2 emissions (Shaikh et al., 2014).

2.2.1.3 Transportation Industry

Transportation emits 22% of CO_2, making the kit energy-intensive. Light-duty trucks, freight, and vehicles are the primary sources of pollutants. Other sources of emissions include marine transport and worldwide aviation (Zheng et al., 2014).

2.2.1.4 Manufacturing Industry

The industrial sector emits 20% of CO_2, making it the third largest emitter after transportation. Manufacturing, agriculture, mining, and construction are all examples of industries found in these sectors (Yu et al., 2017). Manufacturing emits a large quantity of CO_2 as greenhouse gases. This is because of the immediate utilization of petroleum products for the generation of heat and steam at various phases of manufacturing.

2.2.1.5 Changes in Land Use

Changes in land use create 9% of CO_2, with deforestation creating a massive contribution. CO_2 levels rise as forest area is removed because of deforestation. It also induced soil disturbance and increased the rate of decomposition, resulting in increased CO_2 emissions (Usman et al., 2018).

2.2.1.6 Industrial Methods

There are four significant modern cycles emitting CO_2. The first is concrete manufacture, which produces CO_2 as a side-effect of the heating of limestone. The following step is steel production. When oxygen is combined with carbon in iron to reduce its carbon content, carbon dioxide is generated. Fossil fuels are employed in chemical and petrochemical goods, which release CO_2. Finally, ammonia (NH_3) and hydrogen are produced (H_2). They employ natural gas or other fuels as the starting point for this process (Thompson et al., 2017).

2.2.2 Sources from Nature

Natural sources, besides human sources, release CO_2 into the atmosphere. The ocean-atmosphere system is changing, releasing 42.84% of CO_2. Plant and animal respiration is next, accounting for 28.56%, together with soil respiration and decay. Volcanic emissions produce just 0.03% of CO_2, which is a negligible amount (Tans, 2011).

2.3 Carbon Capture Technologies

2.3.1 Carbon Capture with Separation

This method necessitates the utilization of innovation to isolate CO_2 from a combination of gases. The gas stream might develop either before or after burning. A precombustion carbon capture technique occurs when a gas stream containing carbon dioxide is generated prior to combustion (Vaidya & Mahajani, 2005). In this scenario, the primary elements of the gas stream are CO_2 and H_2; alternatively, it is known as post ignition carbon capture, and the principal constituents of the gas stream are CO_2 and N_2. A few CO_2 separation methods are currently being used or improvement for the division of CO_2 from gas mixtures. Practically all detachment procedures are applicable to both processes.

2.3.1.1 Precombustion Carbon Capture

This technology offers the possibility of directly combusting fuel in a combustor. Fuel is initially transformed to a flammable gas. This gas is used to generate electricity. CO_2 is presented and sequestered from the gas produced by fossil fuels prior to combustion (Xie et al., 2019). Figure 2.1 depicts a schematic representation of the procedure.

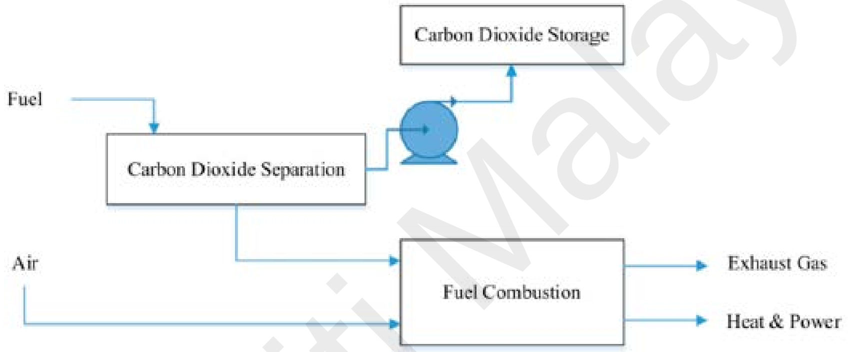

Figure 2.1: Pre-Combustion Carbon Capture

Initially, synthesis gas (syngas) is created from a fossil fuel. Syngas is a combination of mostly H_2 and CO_2 with a hint of CO_2. It is possible to do so by combining steam with a petroleum derivative. This is referred to as steam reforming. One more strategy of producing syngas is to deliver pure oxygen separated from air to a fossil fuel used to generate electricity (Zanone et al., 2018). When applied to liquid or gaseous fuels, this cycle is known as halfway oxidation. When used for solid fuels, it is referred to as gasification. This syngas is subsequently transformed to CO_2 from CO through a water-gas shift process.

The results of the water shift gas reaction stay at high strain, making CO_2 emission simpler. It is taken out at room temperature. The rest of the gas is mostly hydrogen with a few contaminants. In a combined cycle power plant, this gas is used to create electricity

(Zheng et al., 2017). High pressure (usually 2–7 MPa) and high CO_2 solubility (15–60% by volume) prior to CO_2/H_2 separation need less energy for CO_2 absorption and pressure than post burning carbon capture. The energy consumption in this interaction, however, is generous because of the air detachment and improving or gasification processes (Yu et al., 2012).

Using SEWGS technology to lessen the energy penalty is one option. This strategy takes into consideration the mix of water gas shift response with CO_2 absorption (Wei et al., 2014). By eliminating CO_2 from the result of the water gas shift reaction, SEWGS enhances the rate of CO conversion. As a consequence, CO_2 emissions are reduced even further. The interaction is almost same for any non-renewable energy source, but in case a fuel other than gaseous petrol is used, additional refining steps need be incorporated because of the greater pollutions produced (Thompson et al., 2017).

Table 2.1: Studies on Pre-Combustion Carbon Capture

Author	Year	Findings
(Conway et al.)	2010	The collection of CO_{2s} utilizing methyl diethanol amine solution was contrasted with different techniques. It is advocated for keeping away from more moderate suppositions to improve efficiency.
(Martín et al.)	2011	The CO_2 adsorption capability of hyper crosslinked polymers was investigated. These polymers outperformed zeolite-based materials and commercial activated carbon in terms of CO_2 uptake. They also demonstrated high selectivity for CO_2 and a low heat of adsorption.
(Dash et al.)	2012	3 distinct Metal Organic Framework materials were evaluated as adsorption materials. When contrasted to commercial activated carbon, the USO-2-Ni Metal natural structure yielded good results.
(García et al.)	2012	When activated carbon was utilized for adsorption, the partial pressure of CO_2 was shown to be the most influential. It was directly related to carbon capture capacity and conversely relative to temperature.

Table 2.2: Studies on Pre-Combustion Carbon Capture (continued)

Author	Year	Findings
(Haghtalab & Gholami)	2013	The PSA technique for precombustion carbon capture was the subject of a parametric analysis research. For improved separation performance, they tested several process setups and circumstances. The separation improved when the operating temperature and desorption pressure were reduced. The separation was unaffected by adsorption pressure.
(Moioli et al.)	2014	Instead of using oxygen-blown gasification, they employed air-blown gasification. Air-blow gasification was competitive in terms of efficiency penalty and carbon capture.
(Jiang et al.)	2015	As a sorbent, they employed a mesoporous amine-TiO_2. This low-cost sorbent was stable and easy to renew without losing its capacity or selectivity.
(Park et al.)	2015	Three physical absorbents were used to design a two-stage precombustion CO_2 collecting technique. In terms of energy usage, Selexol was discovered to be the most efficient precombustion carbon capture technique.
(Dai & Deng)	2016	At high pressure and temperature, the partition execution of an ionic-liquid based film contactor was investigated. The membrane contactor grew moist at high pressure, making it less efficient. The temperature has little impact on the procedure.
(Babu et al.)	2016	Tetrahydrofuran was shown to be superior to other semiclathrate hydrate formers. At 282.2 K and 6 MPa, the most extreme convergence of THF was 5.56 mol%.
(Yang et al.)	2016	The combination of 5% TBF + 10% TBAB was found to be the best suited for hydrate-based CO_2 collection.
(Mitchell et al.)	2017	The CO_2-H_2-TBAF semiclathrate hydrate procedure that has been proposed. Except for THF, CO_2 has the highest gas uptake when employed as a promoter. Furthermore, the procedure is carried out at room temperature.
(Usman et al.)	2017	Carbon capture utilizing a layer contactor and PSA proved too expensive to be industrially viable.
(Zhai & Rubin)	2019	It demonstrated that carbon absorption utilizing an IL is comparable to the selexol procedure.

2.3.1.2 Post Combustion Carbon Capture

This technology is employed in existing power plants without requiring large plant modifications. As a result, when compared to other CCS methods, it has the benefit of being easier to retrofit. It is the most basic method of CO_2 collection. CO_2 is removed from power plant exhaust flue gases using this technology (Vasantha et al., 2012). Flue gases normally escape at ambient pressure. The CO_2 content in these gases is extremely low. The driving force is insufficient to extract CO_2 from the pipe gas due to the low convergence of CO_2. Figure 2.2 depicts a schematic representation of post combustion carbon capture.

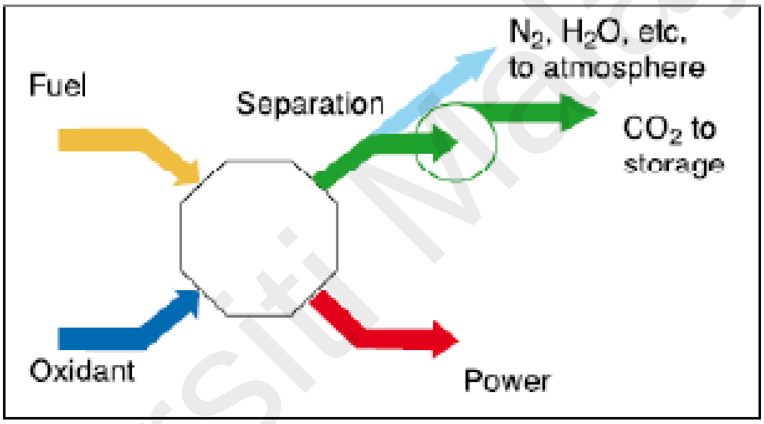

Figure 2.2: Post Combustion Carbon Capture

To manage a large volume of flue gases, large-scale equipment with a significant capital cost is necessary. As a result, a cost-effective method for capturing CO_2 from exhaust gas must be found. In addition, the flue gas contains a variety of pollutants, including SO_x, NO_x, fly ash, and others. With current technology, they make the separation process more expensive. For a variety of reasons, separating CO_2 from flue gas is difficult (Shariff et al., 2016). The high temperature of the flue gas causes special equipment design. Before separating CO_2, the gas must be cleansed.

Table 2.3: Studies on Post Combustion Carbon Capture

Author	Year	Findings
(Guo et al.)	2010	They made and tried high-permeance layers and utilized an extraordinary method that pre-owned approaching burning air as a range gas. More spotlight was put on film permeance rather than selectivity.
(Houghton)	2010	A unique PSA superstructure was presented in order to construct and assess the best Cycle configuration for CO_2 collection techniques. PSA cycles with a purity of 98% may be predicted using the superstructure.
(Feng et al.)	2010	Distinctive pure and diluted ionic liquids were examined as prospective solvents and contrasted to MEA and water, which are currently the most used solvents. The energy requirement of one of the ionic liquids was lower than that of the reference dissolvable.
(Du Preez et al.)	2011	Two MOFs were thoroughly investigated for their potential application as adsorbents in temperature swing adsorption for post-combustion carbon capture. In each case, Mg_2 (dobdc) produced a superior outcome. They came to the conclusion that a MOF must have a robust CO_2 adsorption site in order to be beneficial in post-combustion carbon collection via temperature swing adsorption.
(Noorani & Mehrdad)	2011	Carbonic anhydrase generated from thermophiles was shown to have the ability to speed up the post-combustion capture process.
(Lee et al.)	2012	Because of their high surface area and customizable qualities and characteristics, they recommended using nanoparticles as absorbents. The only issue was the high cost of manufacture and the lengthy synthesis procedure.
(Portugal et al.)	2013	Proposed changes to three-layer stages and cryogenic partition to improve post-combustion carbon capture efficiency. The suggested process' capture cost remained equivalent to current innovations.
(Ramazani et al.)	2013	They tried an assortment of zeolite materials for use as adsorbents in carbon catch after burning. Among the zeolites, Ca-A ($Na_{0.28}Ca_{0.36}AlSiO_4$) has the greatest CO_2 uptake among the zeolites.
(Said et al.)	2014	To examine the influence of membrane characteristics on CO_2 absorption, a numerical model was proposed. CO_2 collection was shown to be improved by increasing membrane length and number of fibers. The removal of CO_2 was enhanced with a diminishing in layer thickness, inward fiber range, while absorption was lowered.

Table 2.4: Studies on Post Combustion Carbon Capture (continued)

Author	Year	Findings
(Shakerian et al.)	2014	A correlation of an aqueous amine solution and alkali as a solvent was revealed. The absorption and loading capacity of aqueous ammonia were found to be higher while needing less energy for recovery. However, retention should be done absorption at a lower temperature by chilling the pipe gas.
(Shariff et al.)	2016	Thirty alternative aqueous amine solutions were tested for improved performance, and six of them outperformed the reference MEA. The finest among them was 2-ethylaminoethanol, which had strong CO_2 retention, low absorption heat, and a high motor reaction with CO_2 elimination.
(Zhang)	2016	A numerical model was proposed to determine the best working parameters for corrosive gas assimilation in the empty fiber layer module. Compound solvents absorbed CO_2 significantly better than physical solvents. Among single solvents, piperazine performed the best. CO_2 removal efficiency was 20% greater in the blended absorbent solution.
(Thompson et al.)	2017	The amine absorber was subjected to two-stage stripping in order to reduce costs and improve performance. The heat from the first stripper was employed in the secondary stripper. Different chemicals' emissions were compared. The overall amine, ammonia, and aldehyde emission levels were comparable to earlier reported studies.
(Scholes et al.)	2018	A 2D model for a CO_2-piperazine film retention framework was proposed. They recommended the ideal gas speed, permeable speed, CO_2 conc., and dissolvable for the best results.

2.3.1.3 CO_2 Separation Technology

For removing CO_2 from gas mixtures, a variety of separation processes are available. The major technologies may be divided into five categories. Retention, adsorption, the clathrate hydrate process, film innovation, and calcium circling carbon capture are the technologies involved. The invention and performance enhancement of various solvents is the major focus of research in the absorption process. The focus of adsorption technology is on novel and modified materials (Rubin et al., 2012). For better execution, the clathrate hydration division strategy is being tried with different thermodynamic advertisers. For further developed execution, film-based examination uses layers made of different materials, including composite and crossover layers (Ramezani, Mazinani, Di Felice, Darvishmanesh, et al., 2017).

(a) Absorption

The method involved with retaining CO_2 in a dissolvable to eliminate it from a gas stream has been used on a modern scale for over 50 years, but in modern applications, the fractional tension of the gas streams is a lot more prominent. This cycle might be partitioned into two kinds: actual ingestion and substance assimilation (Rochelle Gary, 2009). The realistic underneath portrays an exhaustive order of the retention-based CO_2 gathering innovation.

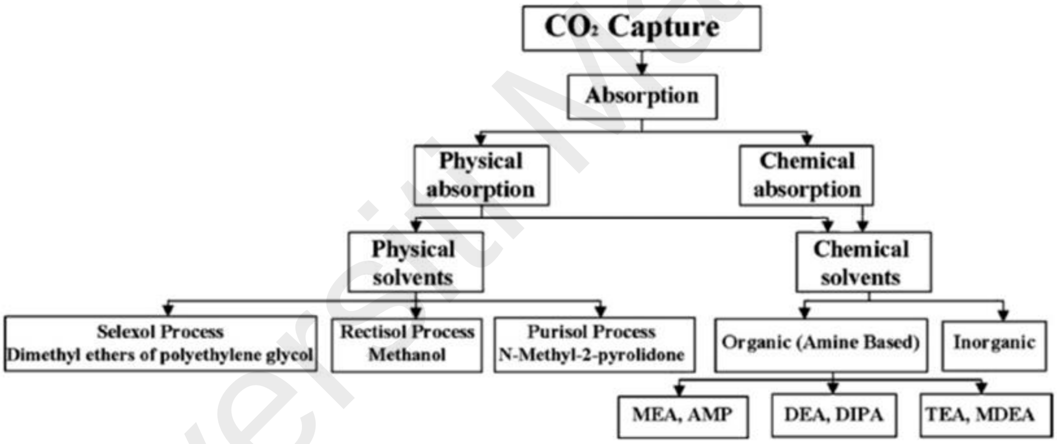

Figure 2.3: Types of Absorption Process for CO_2 Capture

Chemical absorption is a process in which a solvent combines with CO_2 to generate chemical compounds. Later on, CO_2 is eliminated from the chemical components. If the solvent is chemically inert, however, it does not react with CO_2. It physically absorbs CO_2 (Ramezani, Mazinani, Di Felice, & Van der Bruggen, 2017). Physical absorption is the term for this procedure. CO_2 is absorbed in two steps, chemically and physically. In a counterflow, the treated gas is at first carried into contact with the dissolvable stream. The dissolvable retains CO_2 from the gas stream at this progression. At the point when this dissolvable is warmed to desorb CO_2 in a stripping segment, it is recovered. From the highest point of the segment, pure CO_2 is collected. After that, it's compressed and saved.

The CO_2 lean solvent that has been regenerated is returned to the absorber (Qiang et al., 2020). The procedure is depicted in the diagram below.

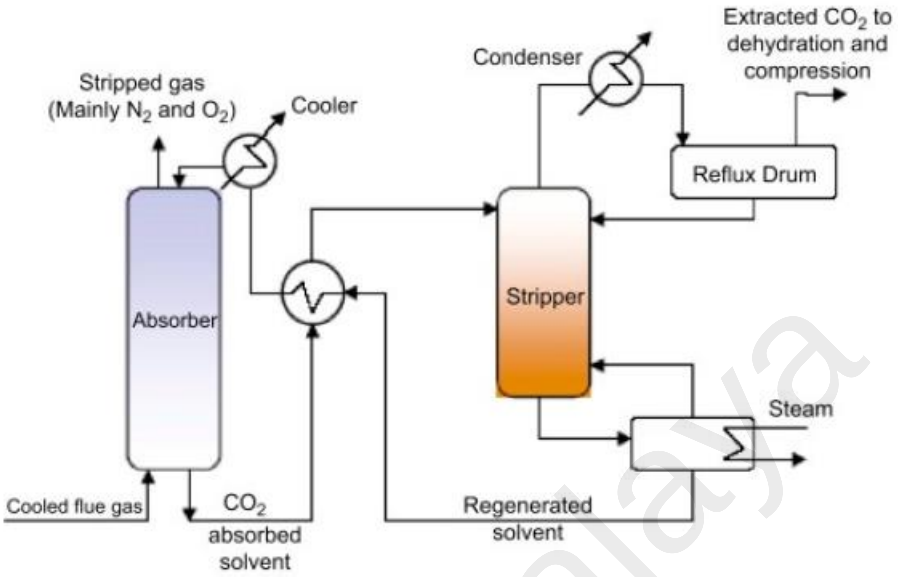

Figure 2.4: CO_2 Absorption Plant

The initial step of the interaction works best at high tensions and low temperatures, though the subsequent stage works best at high tensions and low temperatures. At low tensions, synthetic ingestion is more favorable for CO_2 capture (Allam et al., 2013). This is favorable for the post burning cycle when amine or carbonate arrangements are used as solvents. Actual solvents, either natural or inorganic, are used in case of actual assimilation. CO_2 has no substance response with them. Henry's law of fume fluid blend balance is utilized in this cycle (Portugal et al., 2007).

The measure of gas disintegrated in a unit volume of a dissolvable is corresponding to the halfway strain of the gas in balance with the dissolvable at any temperature, as shown by this law. Since the actual retention process is pressure subordinate, it performs better compared to synthetic ingestion at higher CO_2 pressure, for example, in an IGCC (Raksajati et al., 2016). Because of the more noteworthy halfway strain of CO_2 in syngas, which makes it more fitting for precombustion carbon capture, an actual retention strategy is proposed for utilization in IGCC. One more benefit of actual solvents is that they need less energy to recover (Lepaumier et al., 2011).

The disadvantage of this method is that solvent capacity is highest at low temperatures. As a result, the gas stream should be cooled before the retention interaction can start. This outcomes in a decline in productivity (Mouhoubi et al., 2020). Selexol, Rectisol, and Purisol are some of the commercially available physical absorption techniques. Selexol was discovered to be more energy efficient than other examined solvents for absorbing CO_2. The rationale for this was the lower energy consumption required to replenish the solvent, as well as the simplicity of the process architecture (Ling et al., 2019). In the post-burning carbon capture process, the incomplete pressure of CO_2 in the vent gas stream is extremely low. Accordingly, the aim of this strategy' study is to recognize a reasonable dissolvable.

Table 2.5: Benefits and Drawbacks of Various Absorption Technology for Physical Absorption

Absorption technology	Benefits	Drawbacks
Fluor process (Propylene Carbonate)	Technology that has been demonstrated to work. Solvent that isn't corrosive. CO_2 selectivity is high.	In the input gas stream, there is a low tolerance for H_2S. Due to its high-water solubility, feed gas must be dried.
Rectisol Process (Chilled Methanol)	Low-cost solvent. In a single procedure, it is possible to eliminate a large number of impurities. CO_2 and H_2S have a high selectivity.	High energy costs for refrigeration. H_2S has a higher selectivity than CO_2. Due to its high-water solubility, feed gas must be dried.
Selexol Process (DMEPG)	Not susceptible to deterioration. Vapor pressure is quite low. CO_2 and H_2S may be captured from syngas using a two-stage procedure.	CO_2 partial pressure must be high. Viscosity of the solvent is high. Expensive solvents.

Table 2.6: Benefits and Drawbacks of Various Absorption Technology for Chemical Absorption

Absorption Technology	Benefits	Drawbacks
Amine systems (MEA, DMEA etc.)	Technology that has been demonstrated to work. Low initial investment. Other solvent systems can use this as a benchmark.	Loading capacity is limited. Sorbent regeneration needs a lot of energy. Degradation of items that is hazardous. Mist formation causes a loss of solvent. Resilience to NO_x, SO_2, and O_2 is low.
Bi-phasic liquid solvents	Energy utilization is diminished. Destructiveness is diminished.	Higher tension drops.
Potassium carbonate system	Higher limit with respect to dissolvable stacking. Recovery energy prerequisites are decreased. Minimal expense dissolvable. Destructiveness is diminished.	Response time is slow. Additives are expensive. Fouling of the system.
Aqueous Ammonia	Regeneration energy requirements are reduced. Low-cost solvent.	Solvent loss is high. Lowering the operating temperature.
Chilled Ammonia	Regeneration energy requirements are reduced. There is no deterioration of the solvent. Low-cost solvent. By-product that can be sold.	Operating temperatures are below freezing. Possibility of fouling.
Task specific and Reversible Ionic Liquids	Low dissolvable misfortune and unpredictability. Solidness is fantastic. Ingestion heat is very low. Dual-mode, high-capacity loading.	Cost of manufacture is high. With the presence of water, absorption efficiency is reduced. The rate of absorption is slowed by high viscosity.
Sodium Hydroxide	Chemicals are inexpensive and plentiful. Other sectors have benefited from proven technology.	A lot of energy is required. Water and solvent loss are both high.

(b) Adsorption

Utilizing a strong surface, this is the procedure of separating a part from a combination. Between the strong stage adsorbent surface and CO_2, dissimilar to retention processes, physical or synthetic linkages are shaped. The main impetus for adsorption is the intermolecular communications between strong surfaces and gases. In view of the adsorbent pore size, temperature, tension, and surface power, single or various layers of the gas can be ingested (Kim et al., 2021).

The adsorbent is first filled a segment. The CO_2-bearing gas stream is then directed through this section. During the stream to immersion of the adsorbent, CO_2 appends to the strong surface of the permeable (Hu et al., 2016). At the point when the CO_2 adsorption surface gets soaked, it is eliminated and desorbed in a progression of cycles. For single bed CO_2 adsorption, four separate recovery cycles are regularly used. Pressure swing adsorption (PSA), temperature swing adsorption (TSA), electrical swing adsorption (ESA), and vacuum swing adsorption (VSA) are the four regeneration cycles (Falkenstein-Smith et al., 2017).

(c) Membrane Technology

Layers are semi-penetrable boundaries made of assorted materials that, through different techniques, may isolate unmistakable parts from a blend. Natural or inorganic materials can make films. In non-worked with layers, the arrangement dissemination process happens. In the wake of being broken down in the layer, the saturate diffuses through it (Feng et al., 2013). The halfway strain of CO_2 is identified with the amount of CO_2 broke down per unit volume. The incomplete strain of CO_2 remains fairly high on account of precombustion capture. In this situation, non-worked with film division method is more valuable.

Spiral wound, level sheet, and empty fiber modules would all be able to profit from layers. For a given acidic gas, they may be particular or non-specific. For carbon capture, film innovation might be partitioned into two classes: gas detachment layers and gas retention layers (Dai & Deng, 2016). This technique has the advantage of not causing sobbing, entrainment, frothing, or flooding, which are regular issues when using a pressed segment. They likewise highlight a bigger surface region and worked on fluid and gas stream rate control. The crucial downside of layers is that they are less effective at lower CO_2 solubility. At the point when the CO_2 focus in the gas stream falls underneath 20%, the layer loses its adaptability and becomes unusable (Choi et al., 2012). Subsequently, it is inadmissible for use in the post-ignition catch method.

(d) ***Clathrate Hydrate Process***

Water molecules plus a variety of other chemicals, such as CO_2, N_2, H_2, and O_2, combine to produce gas hydrates or clathrate hydrates, which are ice-like crystal formations (Shaikh et al., 2014). Small gas molecules become trapped within water molecule holes. Different gases have different concentrations in the crystals than they do in the original gas mixture. The fundamental thought behind CO_2 detachment is to specifically segment CO_2 from a gas blend between the strong hydrate gem stage and the vaporous stage by producing a hydrate gem (Ling et al., 2019).

At a temperature of 273.9 K, the most reduced tension needed to make hydrate is 5.56 MPa. Syngas pressure following the water gas shift response is commonly 2–7 MPa, yet post-ignition pipe gas pressure is practically at environmental tension (Suleman, Maulud, Syalsabila, Shahid, et al., 2020). Thus, pressure of the gas stream is needed to speed up the creation of hydrates.

(e) ***Calcium Looping Technology***

To extract CO_2 from a gas stream, the calcium looping carbon capture system employs a different approach. An immediate connection among CO_2 and CaO happens in this methodology (Zhang et al., 2018). This response makes strong calcium carbonate, which can be isolated from different gases effortlessly. This method' key reversible reaction is as follows:

$$CaO + CO_2 \leftrightharpoons CaCO_3$$

Exothermic is the forward response, regularly known as the carbonation response. The converse response is called calcination response, which is endothermic. The underlying speed of a carbonation response is truly fast, yet eventually, it dials back drastically (Shuaib et al., 2014). The calcination reactor requires an enormous amount of hotness to be conveyed at a high temperature because of the endothermic response. Inside the calcination reactor, this hotness is often given by oxy ignition of coal or petroleum gas. CO_2 is compacted and put away when it is recuperated from the calcination reactor. This strategy might capture carbon both previously, then after the fact consuming. In a precombustion carbon catch gasifier, the accompanying response is the planned key response (Mitchell et al., 2019).

$$CO + H_2O + CaO \leftrightharpoons CaCO_3 + H_2$$

The calcium looping technique has certain benefits for precombustion carbon collection. At the point when hydrogen is used as a fuel, $CaCO_3$ and CaO improve the pace of tar breakdown, which is muddled. The pace of change from CH_4 and CO to H_2 is similarly expanded when CO_2 is taken out from the gas blend. This method is most commonly used in post-combustion carbon capture (Denman, 2007).

2.3.2 Carbon Capture by Water Condensation

In terms of electricity generation, this approach is relatively new. Rather than giving air to the ignition chamber, unadulterated oxygen is used. Most of the burning items are CO_2 and steam. Consolidating steam captures the CO_2 convergence of the combination (Agarwal et al., 2010). None of the CO_2 division advances laid out in the past segment are required. This strategy is all the more monetarily practical. The strategy is known as oxy-combustion carbon capture on the off chance that the oxygen is made utilizing an Air Separation Unit (ASU). One more technique for conveying oxygen is to use a metal oxide and a substance circling process called compound circling burning (Hu et al., 2016).

2.3.2.1 Oxy-Combustion Carbon Capture

Fuel is burned in practically pure oxygen rather than air in this manner. This strategy delivers a blend of water and carbon dioxide as pipe gas. Fuel is combusted in air in a customary power plant, and the nitrogen noticeable all-around capacities as a temperature controller. The fire temperature ascends unnecessarily high because no N_2 is available in the combustor of oxy fuel burning (Feng et al., 2013). To keep up with the temperature taken care of, recovered CO_2 is blended in with unadulterated oxygen and took care of into the combustor. Infusing steam into the burning chamber is one more way to deal with keep the fire temperature inside the predefined range. Build-up eliminates water from the item subsequent to consuming. The CO_2 is cleaned and compressed to supercritical pressure before being transported or reused in the cycle.

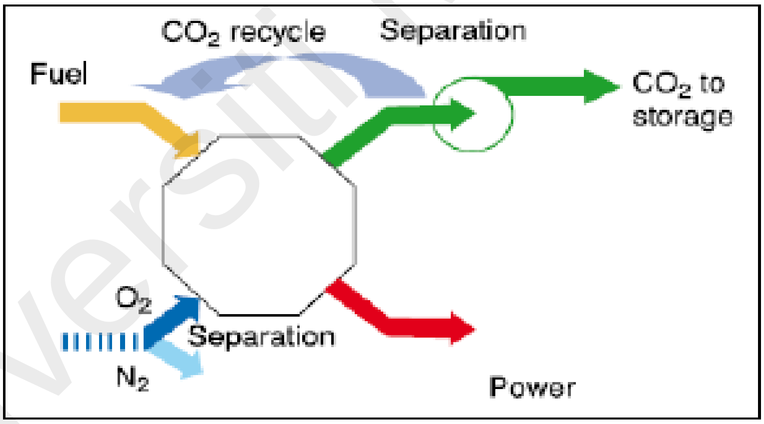

Figure 2.5: Oxy Combustion Carbon Capture

Because CO_2 and N_2 have distinct properties, the chemical pathway and combustion parameters of oxy combustion differ from those of normal air-fuel combustion (Huang et al., 2014). These irregularities in combustion properties necessitate more investigation in order to fully comprehend and apply this technology. When compared to ordinary combustion, oxygen fuel combustion provides several advantages. In a traditional air firing system, there is still a significant quantity of N_2. Nitrogen requires a lot of heat before it can be released into the atmosphere, however with oxy combustion, this mass N_2 isn't there (Li et al., 2019).

There is no or very little NO_x creation in this process due to the lack of nitrogen. The combustion products include no other important contaminants. As a result, the oxy fuel combustion process is less costly than the carbon capture systems previously addressed. The high operating expense of creating O_2 and pressurizing CO_2 after burning is the method's principal downside. One of the most difficult aspects of this technology is producing high-purity oxygen at a reasonable cost (Noorani & Mehrdad, 2021).

Table 2.7: Studies on Oxy-Combustion Carbon Capture

Author	Year	Work
(Riaza et al.)	2011	The joining of an oxyfuel burning interaction with a CO_2 assortment technique utilizing Mg $(OH)_2$ was shown.
(Stanger & Wall)	2011	The impact of Sulphur on CO_2 catch during oxy burning was illustrated.
(Said et al.)	2012	In an oxy fuel climate, NO outflow, start temperature, and burnout with coal and biomass were explored. When N_2 was substituted with CO_2, the ignition temperature rose. As a result of the addition of biomass, the temperature dropped.
(Allam et al.)	2013	The Allam power cycle, a CO_2-put together cycle based with respect to oxy ignition with almost zero emanations, was proposed.
(Leckner & Gómez-Barea)	2014	For oxy ignition, a prepared to-change over air terminated CFB heater was contrasted with a recently fabricated oxy fuel CFB evaporator. It was more helpful with the new plan.
(Vellini & Gambini)	2015	The examination looked on a further developed supercritical steam cycle power plant with CO_2 catch dependent on oxy fuel ignition. For a high oxygen age rate, an oxygen transport layer was used.
(Scaccabarozzi et al.)	2016	The enhancement of a NET power oxy burning cycle was concentrated mathematically.
(Hamzehie & Najibi)	2016	A ceramic membrane catalytic reactor was used to assess CO_2 selectivity and O_2 permeability
(Climent Barba et al.)	2016	For improved performance, several oxy turbine power cycles with total carbon capture were analyzed.

Table 2.8: Studies on Oxy-Combustion Carbon Capture (continued)

Author	Year	Works
(El Hadri et al.)	2017	The impact of recuperator execution on a semi-shut oxy burning blended cycle was explored.
(Lucquiaud & Gibbins)	2017	Diverse incredibly basic CO_2 cycles for power age were examined.

2.3.3 Correlation of Different Combustion Technologies for CO_2 Capture

The three CO_2 absorption frameworks talked about above are analyzed in Table 5. Pre-ignition is frequently used in coal-gasification offices, albeit post-burning and oxyfuel combustion can be used in coal and gas-terminated plants. The most advanced CO_2 collecting technology is currently post-combustion technologies (Portugal et al., 2009).

Table 2.9: Benefits and Drawbacks of the Different CO_2 Capture Technologies

Capture Process	Benefits	Drawbacks
Post-combustion	Innovation is more developed than different choices, and it tends to be retrofitted into existing offices effortlessly.	Low CO_2 conc. affects capture effectiveness.
Pre-combustion	High CO_2 focuses further develop sorption productivity; completely settled innovation that has been monetarily conveyed at the imperative scale in a few modern areas; retrofit potential for existing plants.	High parasitic power need for sorbent recovery; temperature-related hotness moves trouble and effectiveness corruption challenges connected with the use of hydrogen-rich gas turbine fuel; Due to the limited number of gasification facilities now functioning on the market, there is a lack of experience; existing sorption systems have significant capital and operational expenses.
Oxyfuel combustion	High CO_2 conc., which further develops assimilation proficiency; mature air partition innovation; less measure of gas to be dealt with, requiring a more modest heater and other hardware.	High effectiveness endures because of the energy punishment; cryogenic O_2 age is costly; and erosion issues might arise.
Chemical looping combustion	The central burning item, CO_2, stays unmixed with N_2, wiping out the energy-concentrated air division process.	The interaction is as yet being developed, and there isn't sufficient skill with enormous scope tasks.

2.4 Solvents for Carbon Dioxide Absorption

2.4.1 Chemical Absorption Solvents

2.4.1.1 Conventional Amine Based Solvents

For carbon dioxide (CO_2) and hydrogen sulphide (H_2S), amine-based solvents have been used in gas-treatment systems. It is seen as a potentially useful technique for reducing CO_2 emissions. Power plants, cement manufacture, and iron and steel production are all examples of industrial operations that use amine-based solvents. In a publication, Alivand et al. (2019) stated that aqueous monoethanolamine (MEA) is efficient and inexpensive for most industrial uses. It does, however, have significant drawbacks that must be overlooked. MEA uses a lot of energy during the regeneration process, and this, along with its high volatility, leads to equipment corrosion and toxicity, as well as limited thermal stability and solvent deterioration. A researcher investigates and debates the most efficient methods for reducing solvent deterioration. Chi and Rochelle (2002) conducted an experiment using the carbamate polymerization process, claiming that thermal degradation of MEA occurs at high temperatures, whereas oxidative degradation happens near the bottom of the absorber in the presence of oxygen.

Organic carboxylic acids react with amine during solvent degradation to generate heat-stable salts, according to Lepaumier et al. (2011). According to D. Jouravleva (2000), salt builds up, making it difficult to regenerate and absorb CO_2. When a result, as the amount of heat-stable salt grows, the maintenance and operational costs rise. Using an aqueous MEA solution, Ling et al. (2019) explored how different factors affect the carboxylic acid. When carboxylic acid is introduced to MEA solution, they discovered that the equilibrium stability and pH values drop. This means that any acidic breakdown products should be avoided in MEA solutions in order to improve absorption and reduce energy consumption.

2.4.1.2 Sterically Hindered Amine Solvents

This kind of amine enhances CO_2 absorption rate when compared to primary and secondary amines. It also cuts down on energy usage (Hüser et al., 2017). In a research, Choi et al. (2012) employed 2MPD as a promoter to improve the reaction rate of sterically hindered amines (AMP) and tertiary amines (TEA and MDEA). When compared to MEA, this is owing to their poor mass transfer rate. The mas transmission rate of mixed aqueous solutions was investigated in this work. When 2MPD is added to the combined solvents, the reaction rate significantly rises. This shows that mixed solvents outperform MEA in terms of absorption and may replace MEA in industrial processes without requiring innovation.

2.4.1.3 Non-Amine Based Solvents

Non-amine-based solvents have been recommended as a potential substitute for amine-based solvents. Sodium carbonate (Na_2CO_3) and potassium carbonate (K_2CO_3) are two instances of these solvents. Na_2CO_3 performs well in the assimilation of carbon dioxide from vent gas and is an obviously better choice than MEA. Using Na_2CO_3, it has a high CO_2 loading limit and can eliminate CO_2 when foreign substances are available and at a low pace of solubility (Knuutila et al., 2009).

Aside from sodium carbonate, K_2CO_3 is one more regular advertiser for CO_2 ingestion (Sartori et al., 1987). Borhani et al. (2015) observed that K_2CO_3 is a productive CO_2 capture dissolvable, however that the response rate is unstable, bringing about restricted mass exchange. He prescribed that an advertiser be added to support the speed of ingestion reaction. Using his thought, Ahmed and Wiheeb (2020) did an examination to perceive how adding six distinct kinds of amino corrosive salts impacted CO_2 solubility experiment. Not set in stone at the finish of his examination that adding amino corrosive salts upgrades carbon dioxide loading and effective recovery rate, bringing down working expenses. Kim et al. (2012) accomplished one more work utilizing 2-methylpiperazine and piperazine, added to a non-watery arrangement of K_2CO_3, which essentially upgrades CO_2 capture limit over MEA.

2.4.1.4 Solvents Blends

The utilization of amine solvents for CO_2 solubility builds recovery energy and adds to dissolvable decay. This issue can be settled by using amine blends, which have a considerably higher CO_2 solubility rate (Chi & Rochelle, 2002). Brúder et al. (2011) used piperazine (PZ) enacted 2-amino-2-methyl-1-propanol (AMP) to lead a CO_2 retention try. He found that, when amine blends are used rather than MEA, the cycle limit is more prominent.

Derks (2006) checked out the energy of carbon dioxide solubility in PZ arrangements while Sun et al. (2005) checked out the subsequent response model in a similar dissolvable. At the point when a little amount of PZ is added, the pace of CO_2 solubility ascends, as per their discoveries. Choi et al. (2012) led research that approved their thought, expressing that merging two amines lessens the dissolvable recovery energy and has a high response rate. Conway et al. (2014) utilized watery dissolvable mixes (BZA, MEA, sterically hindered and tertiary amines) to research carbon dioxide mass exchange and cyclic limit, which seems to be a reasonable dissolvable for carbon capture.

2.4.1.5 Ionic Liquids

This is a different type of solvent that may be used to absorb CO_2. Ionic liquids (ILs) have a low vapor pressure and high boiling point, allowing them to selectively absorb

CO_2. As a result, the energy required for regeneration was reduced. Because of their characteristics, using ILs as a solvent looks to be a potential CCS method (Rubin et al., 2012). ILs, on the other hand, have a low mass transfer capacity and a high viscosity. The rate of CO_2 reaction in MDEA is considerably improved by increasing ionic liquid concentrations.

Kang et al. (2020) made amino gathering functionalized imidazolium-based AAILs utilizing amino corrosive anions, tracking down that 1-(3-aminopropyl)- 3-(2-aminoethyl) imidazolium ([Apaeim]) had a higher solubility limit than MEA. According to the findings, altering the quantity of amino groups in the IL will be a potential strategy to modulate carbon dioxide absorption capability. Li et al. (2019) developed choline-based AAILs and tested their CO_2 solubility. When compared to other proteins, [Cho] [Lys] contributes a better absorption capacity.

2.4.1.6 New Generation Solvents

New generation solvents are being used to cut down on energy use and make CO_2 absorption a cost-effective method. Zheng et al. (2014) examined the stage change conduct of triethylenetetramine (TETA) in ethanol (TETA/ethanol) during CO_2 elimination. As shown by him, strong precipitation happens in the TETA/ethanol dissolvable yet not in the TETA/water dissolvable. Cheng et al. (2017) found that when N-methyl-1,3-diaminopropane (MAPA) and N, N-dimethylformamide (DMF) are joined, a strong encourage is created when CO_2 is captured.

2.4.2 Physical Absorption Solvents

2.4.2.1 Sulfinol

Sulfinol is essentially used to eliminate hydrogen sulfide, carbon dioxide, and an assortment of different foreign substances from normal and manufactured gas. The utilization of this dissolvable lifts CO_2 absorption limit while bringing down recovery energy (Huang et al., 2014). As indicated by Dash and Bandyopadhyay (2016), joining alkanol amines with sulfolane brings down the dissolvable recovery energy. Because of the great mass organization of sulfolane, consolidating MDEA, sulfolane, and water for CO_2 absorption brings down carbon dioxide dissolvability.

2.5 Amino Acids for CO_2 Absorption

2.5.1 Inorganic Amino Acids with Ammonia

Yang et al. (2014) performed research in which amino acids were introduced to ammonia and the vapor loss was measured. He experimented with a variety of amino acids, demonstrating that taurine is one of the most effective. The effect on vapor loss is improved by adding NH_3 solvent. Another researcher discovered that combining ammonia and sodium sarcosinate improves CO_2 loading. Supplementing this amino acid increases the ammonia absorption mechanism (Yu et al., 2012).

2.5.2 Organic and Inorganic Salts of Amino Acids

Albeit amino acids are believed to be a compelling substitute for amine in CO_2 solubility, they have a slower pace of absorption and less CO_2 loading at pH 7. Because of this issue, bases like KOH, NaOH, and LiOH are used to degrade amino acids and increment their importance. MEA and MAPA can likewise be used to further develop

CO_2 capture. At the point when Ciftja et al. (2013) researched the deprotonation stage between amino acids and MEA, he found that balance didn't happen completely. Moreover, Aronu et al. (2010) concentrated on the exhibition of MAPA in blend with amino acids, and found that amino corrosive salts are impressively steadier than MEA. Be that as it may, he used KOH as the base in his trial, and amine-amino corrosive salts were displayed to work better compared to KOH.

Beside the kind of solvents and bases used, there are distinct different elements that may impact carbon dioxide's absorption. Increasing CO_2 partial pressure, according to Kumar et al. (2003), will enhance loading capacity. Because of its exothermic nature, increasing the temperature of the solution reduces chemical absorption. With different types of amino acids, Yuan et al. (2017) examined the cyclic capacity of MEA and PZ. The desorption rate increases as the initial rate of absorption drops, according to the findings. This is because amino acids have a bigger substituted side group and carboxyl group due to their structure.

2.5.3 Amino Acids Based Ionic Liquids

Notwithstanding how ionic fluid lifts CO_2 loading limit, is cheap, non-harmful, and easy to get, it has a high thickness. Subsequently, amino corrosive based ionic fluids have been used to expand CO_2 solubility. Not every amino corrosive might be joined with ionic fluids (Vasantha et al., 2012). Many analysts made novel types of amino-based ionic acids to perceive how they responded to carbon dioxide ingestion. Lu et al. (2017) used a cell reactor to direct an investigation and found that, at an immersion point, the response rate diminishes with time. Nonetheless, the dissolvable seems to be steady, with less energy degradation (Xue et al., 2011).

2.5.4 Amino Acids with Carbonate Salts

Carbonate salts have been used in several studies for CO_2 absorption. This is because it is inexpensive and available in a variety of locations (Hu et al., 2016). However, the reaction rate is minimal, and the absorption kinetics diminishes as temperature and partial pressure rise. Several promoters have been used to improve the response rate as a result of this problem (Borhani et al., 2015).

Figure 2.6: Different Amino Acids with K_2CO_3 Solution (Hu et al., 2016; Sanchez-Fernandez, Heffernan, van der Ham, Linders, Goetheer, et al., 2014; Shen, Feng, Zhao, et al., 2013; Thee et al., 2014)

Amino acids	K_2CO_3 concentration	Amino acid concentration (M)	T(K)	Absorption rate
Arginine	35	0.077	322	0.44
Arginine	35	0.387	322	1.35
Histidine	35	0.104	322	1.54
Glycine	30	1	333	22
Sarcosine	30	1	333	45
Proline	30	1	333	14

As observed from the table, raising the temperature and amino acid content in K_2CO_3 solution boosts CO_2 absorption rate. In comparison to other amino acids, sarcosine performs well in potassium carbonate solution.

2.5.5 Inorganic Amino Acids Salts with Alkanol Amines

At the point when PZ is added to amino acids, layer contactors gain a critical benefit in the ingestion cycle. It brings down the surface pressure of the used arrangement (Song et al., 2012). PZ enhances the reaction rate and absorption capacity when used as a solvent with amino acids. Ramezani, Mazinani, Di Felice and Van der Bruggen (2017) carried out a successful experiment in which potassium lycinate was combined with MEA to boost its performance. The concentration of amino acids in the solution rises, increasing the rate of corrosion. However, raising the temperature of the solution improves density, viscosity, and CO_2 loading.

CHAPTER 3: RESEERCH METHODOLOGY

In this study, the CO_2 absorption in blends aqueous solution of MEA + L-Serine were experimentally measured at three (3) different concentration of each of the solutions. The absorption experiment was conducted at four (4) different temperatures (303.15 K, 313.15 K, 323.15 K & 333.15 K) over CO_2 partial pressures ranging from 50 psi–200 psi (344.75 kPa–1379 kPa).

3.1 Chemicals

Monoethanolamine (MEA), L-Serine, Distilled Water, Carbon Dioxide (CO_2) gas

3.2 Apparatus

Electronic Balance, Beaker, Pipette, Hot Plate, High Pressure CO_2 Absorption Reactor, Magnetic Stirrer, 50 mL Volumetric Flask, 30 mL Clear Refillable Glass Bottle, Parafilm, Weighting Dish

3.3 Preparation of Aqueous Solutions

Three (3) different concentrations of L–Ser and MEA were prepared separately ranging from 0.5 M–2.0 M. different concentrations of blended MEA and L–Ser later were prepared. Table 3.1 shows the amount of each chemical used in order to achieve the desired concentrations for both MEA and L-Ser.

Table 3.1: Amount of MEA and L-Ser for Each Sample

Solution	Amount of MEA (g)	Amount of L-Ser (g)
2.0 M MEA	3.1	-
1.5 M MEA + 0.5 M L - Serine	2.3	1.3
1.0 M MEA + 1.0 M L - Serine	1.5	2.7

3.3.1 Preparation of MEA + L-Serine

A specific amount of MEA was transferred to a beaker to be measured by electronic balance. Serine was collected in a weighing dish while being measured by electronic balance. The sample is later mixed with 10 mL of distilled water in a beaker. It is placed on a hot plate together with a magnetic stirrer to dissolve the serine completely. The dissolved serine solution and MEA solution is transferred into a 25 mL volumetric flask. Distilled water was then added to the etched line on the neck of the flask and mixed thoroughly.

3.4 CO_2 Absorption Experiment

3.4.1 Experimental Procedure

High pressure CO_2 absorption reactor was equipped with a thermocouple, a stirring impeller, which is linked to a data acquisition system (PC). Glass insert was provided together with reactor clamp and clamp belt to hold the sample securely. Type J thermocouple were used to measure the temperature in the reactor and water bath. Water bath is provided to heat the reactor to desired temperature set point.

Figure 3.1: High Pressure CO_2 Absorption Reactor Set - Up

3.4.2 Experimental Procedure

Before beginning the experiment, the main and bench valves of CO_2 and Compressed Air were opened. The reactor controller and PC were turned on. Gas tank outlet valve was closed while the inlet valve was opened to pressurize the gas tank to desired set point pressure. Gas tank and water bath temperature are heated to desired temperature. Both the pressure and temperature were allowed to stabilize.

20 mL of aqueous solution of MEA + L – Serine was placed in glass insert and into the lower part of the reactor before securing it with reactor clamp and clamp belt. After securely placing the sample, the reactor was lowered into the water bath. The temperature may stabilize to the desired temperature before beginning the experiment.

Once all the pressure and temperature of the gas tank and water bath were stabilized, the stirrer were turned on at a speed of 200–300 RPM. To begin the experiment, the gas tank outlet valve and reactor inlet valve were opened to introduce the gas into the reactor cell. Pressure drop will be observed and the gas tank pressure were allowed to be stable. Once the pressure was maintained for more than 30 minutes, the initial and final pressure of the gas tank was recorded. The procedure is repeated for all the different samples, pressures and temperatures.

3.5 Calculation for CO_2 loading

The CO_2 loading experiments for blend solution of MEA + L – Ser were conducted at different concentrations of each of the solutions, at different temperatures (303.15 K, 313.15 K, 323.15 K & 333.15) and four different pressures (50–200 psia). The pressure drops over time in the reactor because of CO_2 absorption in solution until the gas–liquid equilibrium state was continually monitored by the pressure transmitter every minute. The equilibrium state was determined when there was no change in the pressure of the reactor for at least 30 minutes.

$$PV = nRT$$

$$n = \frac{PV}{RT}$$

Where,

P = Pressure (Pa)

V = Volume (m^3)

R = Gas Constant

= 8.3145 m^3Pa/mol. K

T = Temperature (K)

$\Delta n = n(CO_2) = no. of\ moles\ of\ CO_2\ absorbed\ by\ samples$

$$\Delta n_{50} = \frac{P_1V_1}{RT} - \frac{P_2V_2}{RT} (1)$$

$\frac{P_1V_1}{RT} = Initial\ n(CO_2)\ at\ Gas\ Tank\ (GT)\ at\ 50\ psi$

$\frac{P_2V_2}{RT} = Final\ n(CO_2)\ in\ system\ except\ reactor\ at\ 50\ psi$

$$\Delta n_{100} = \Delta n_{50} + \left[\left(\frac{P_1V_1}{RT} + \frac{P_3V_3}{RT}\right) - \frac{P_2V_2}{RT}\right] (2)$$

$\frac{P_1V_1}{RT} = Initial\ n(CO_2)\ at\ Gas\ Tank\ (GT)\ at\ 100\ psi$

$\frac{P_2V_2}{RT} = Final\ n(CO_2)\ in\ system\ except\ reactor\ at\ 100\ psi$

$\frac{P_3V_3}{RT} = n(CO_2)\ in\ pipe$

$$\Delta n_{150} = \Delta n_{100} + \left[\left(\frac{P_1V_1}{RT} + \frac{P_3V_3}{RT}\right) - \frac{P_2V_2}{RT}\right] (3)$$

$\frac{P_1V_1}{RT} = Initial\ n(CO_2)\ at\ Gas\ Tank\ (GT)\ at\ 150\ psi$

$\frac{P_2V_2}{RT} = Final\ n(CO_2)\ in\ system\ except\ reactor\ at\ 150\ psi$

$$\frac{P_3V_3}{RT} = n(CO_2)\ in\ pipe$$

$$\Delta n_{200} = \Delta n_{150} + \left[\left(\frac{P_1V_1}{RT} + \frac{P_3V_3}{RT}\right) - \frac{P_2V_2}{RT}\right] \quad (4)$$

$$\frac{P_1V_1}{RT} = Initial\ n(CO_2)\ at\ Gas\ Tank\ (GT)\ at\ 200\ psi$$

$$\frac{P_2V_2}{RT} = Final\ n(CO_2)\ in\ system\ except\ reactor\ at\ 200\ psi$$

$$\frac{P_3V_3}{RT} = n(CO_2)\ in\ pipe$$

$$V_{Total} = V_{GR} - V_P - V_R$$

$V_{Total} = 0.00109666\ m^3$

$\boldsymbol{V_1 = 0.001\ m^3}$

$V_2 = 0.00109666\ m^3 - 0.00002\ m^3$

$\boldsymbol{V_2 = 0.00107666\ m^3}$

$V_3 = V_2 - V_1$

$V_3 = 0.00107666\ m^3 - 0.001\ m^3$

$\boldsymbol{V_3 = 0.00007666\ m^3}$

$$\boldsymbol{CO_2\ Loading\ Capacity\ (\alpha) = \frac{\Delta n}{n_{solvent}}}$$

$$\boldsymbol{n_{solvent} = n_{MEA} + n_{L-Serine}}$$

CHAPTER 4: RESULTS AND DISCUSSION

The CO_2 absorption experiment was conducted at 50 – 200 psi for each sample in a high-pressure CO_2 absorption reactor. It is done in a continuous flow for each sample. The reactor is equipped with a water bath to heat the samples in the reactor. The temperature of the water bath was set up 2–5◦C more than the desired temperature. The experiment is conducted for four (4) different temperatures (303.15 K–333.15 K) for three (3) samples (2.0 M MEA; 1.5 M MEA + 0.5 M L-SER; 1.0 M MEA + 1.0 M L-SER). Table 4.1–4.4 contains the experimental CO_2 solubility data measured at 303.15 K–333.15 K.

Table 4.1: Solubility Data for CO_2 Absorption at 303.15 K

Samples	CO_2 Loading (α)
2.0 M MEA	0.68
	0.7625
	0.8075
	0.845
1.5 M MEA + 0.5 M L-SER	0.525
	0.59
	0.6725
	0.7
1.0 M MEA + 1.0 M L-SER	0.37
	0.415
	0.4425
	0.485

Table 4.2: Solubility Data for CO_2 Absorption at 313.15 K

Samples	CO_2 Loading (α)
2.0 M MEA	0.6525
	0.7825
	0.845
	0.8875
1.5 M MEA + 0.5 M L-SER	0.495
	0.56
	0.6125
	0.715
1.0 M MEA + 1.0 M L-SER	0.29
	0.335
	0.3925
	0.425

Table 4.3: Solubility Data for CO_2 Absorption at 323.15 K

Samples	CO_2 Loading (α)
2.0 M MEA	0.6725
	0.7575
	0.8975
	0.845
1.5 M MEA + 0.5 M L-SER	0.415
	0.4875
	0.5325
	0.7075
1.0 M MEA + 1.0 M L-SER	0.2625
	0.42
	0.4675
	0.515

Table 4.4: Solubility Data for CO_2 Absorption at 333.15 K

Samples	CO_2 Loading (α)
2.0 M MEA	0.565
	0.6525
	0.6875
	0.735
1.5 M MEA + 0.5 M L-SER	0.51
	0.5425
	0.72
	0.7525
1.0 M MEA + 1.0 M L-SER	0.23
	0.285
	0.45
	0.5475

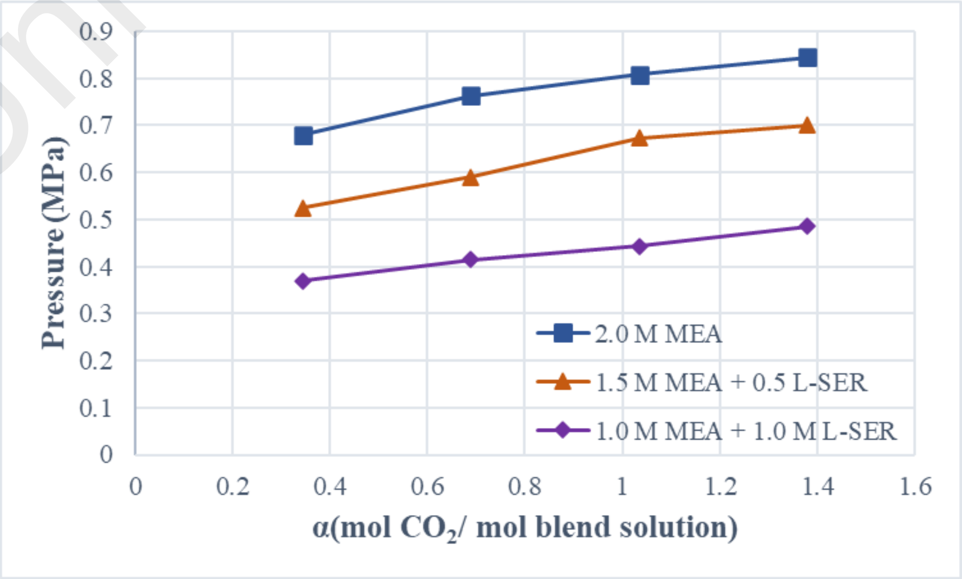

Figure 4.1: Quantity of Consumed Moles of CO_2 at 303.15 K

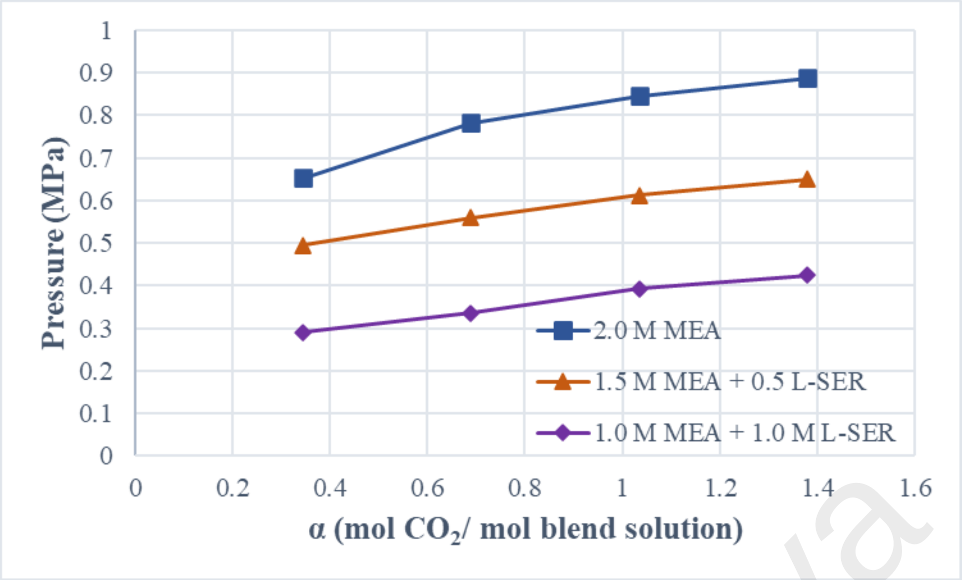

Figure 4.2: Quantity of Consumed Moles of CO_2 at 313.15 K

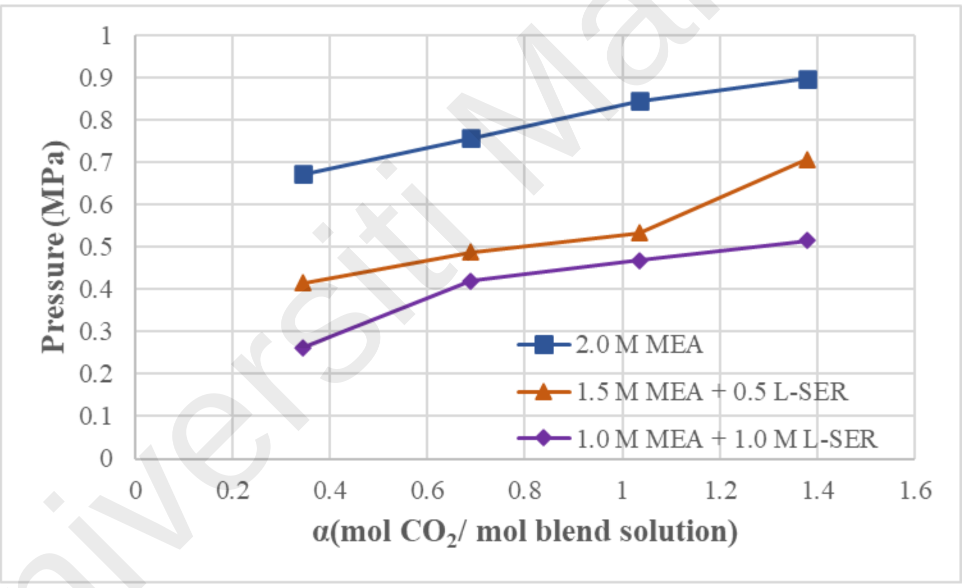

Figure 4.3: Quantity of Consumed Moles of CO_2 at 323.15 K

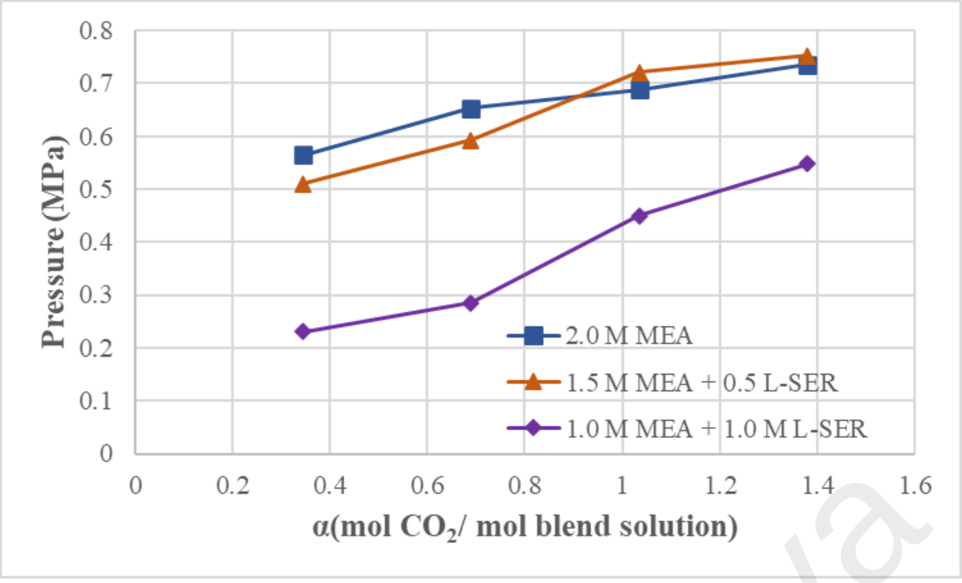

Figure 4.4: Quantity of Consumed Moles of CO_2 at 333.15 K

The CO_2 loading into the blends of MEA + L-SER at various concentrations at the temperature of 303.15 K, 313.15 K, 323.15 K and 333.15 K are displayed in Figure 4.1–4.4. These figures show that at a temperature and pressure, the number of absorbed moles of CO_2 increases with the increasing the concentration of monoethanolamine (MEA) in the solutions. The reaction between MEA +L-Ser and CO_2 changed as the CO_2 loading increases. At low CO_2 loading, CO_2 absorption into MEA was an exothermic response, and the response was quick. At high CO_2 loading, the response became unstable and would be decomposed easily. In this period, some of MEA reacts with CO_2 to form carbamate, and some of MEA additionally could reacts with HCO_3^- to form carbamate.

Besides, at given pressure and temperature, the solubility didn't monotonically increase with an increase in the equilibrium pressure. As should be visible in Figure 4.1 – 4.4, these curves have greatest points and when arriving at these most extreme points, have reverse proportionality with pressure. This should be visible on Figure 4.1 at the temperature of 323.15 K, the CO_2 loading for 2.0 M MEA decreases from 0.8975 to 0.845. This shows that 150 psi is the most extreme point for 2.0 M MEA. Other than that, it can likewise be seen that at 333.15 K for 2.0 M MEA, the quantity of CO_2 loading is lower compared with different temperatures. Comparing as far as the concentration of serine in the mix, the quantity of consumed moles of CO_2 decreases as the concentration of serine increases in the solutions.

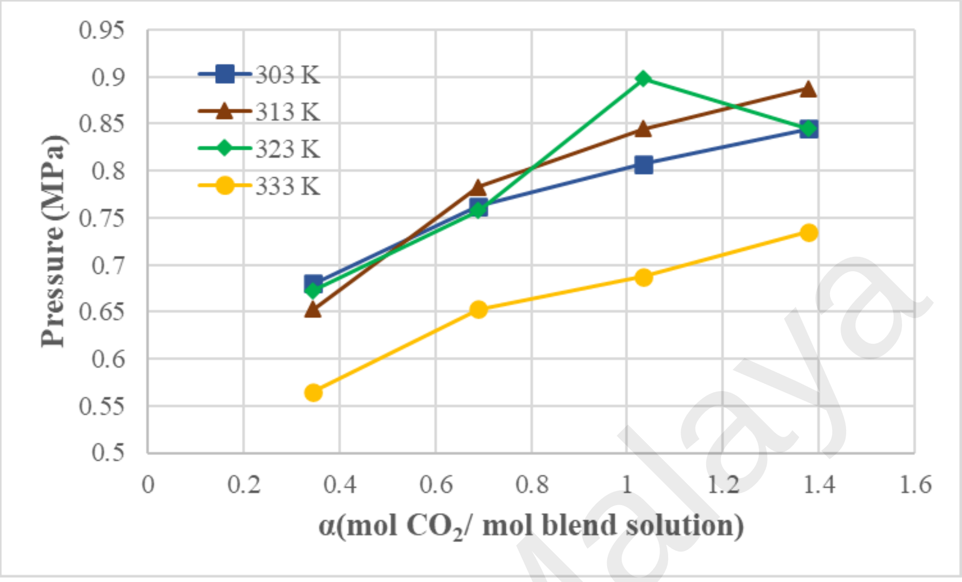

Figure 4.5: Impact of Temperature on CO_2 Loading for 2.0 M MEA

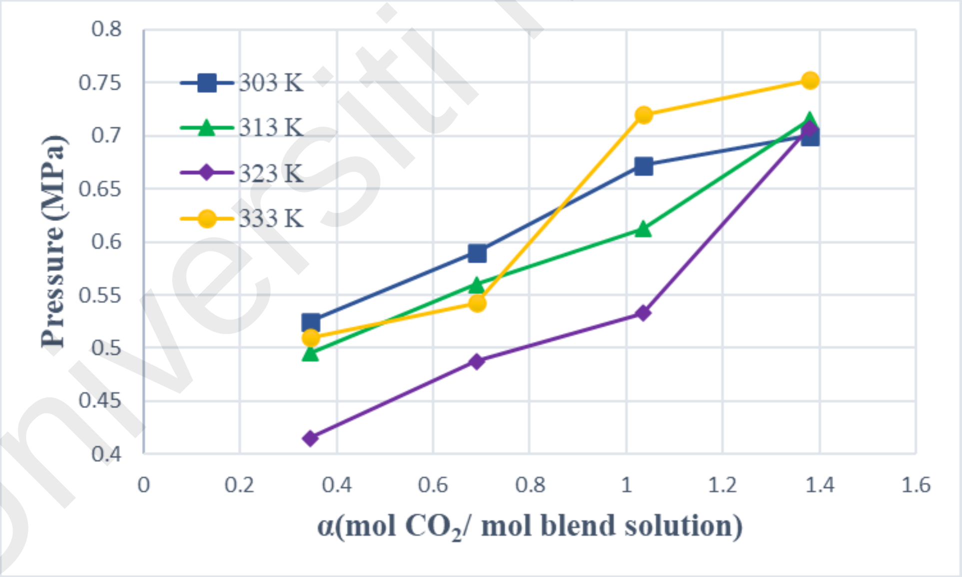

Figure 4.6: Impact of Temperature on CO_2 for 1.5 M MEA + 0.5 M L-SER

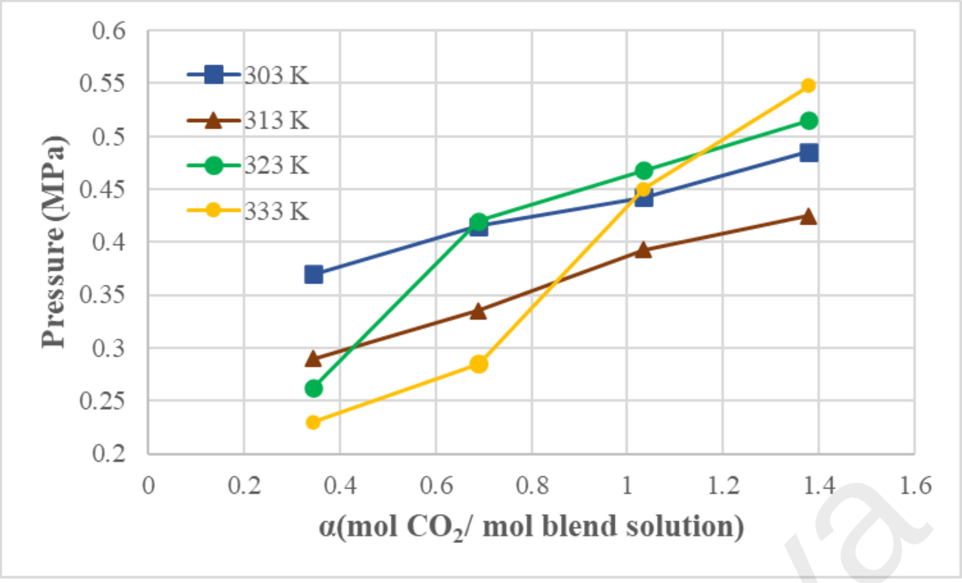

Figure 4.7: Impact of Temperature on CO_2 for 1.0 M MEA + 1.0 M L-SER

The impact of temperature on CO_2 capture efficiency is displayed in Figure 4.5–4.7. It very well may be seen that CO_2 capture efficiency increases by increasing the temperature. Increasing temperature will influence reaction process and gas – fluid balance. Then again, raising temperature can increase the response rate with CO_2 and lower the thickness of solutions, subsequently further developing the fluid stage mass transfer process and the solubility of CO_2. Then again, increasing temperature will prompt the decrease of CO_2 solubility in the aqueous solution, which is unbeneficial to absorption process. In this work, it is observed that increasing temperature somewhat further develop the CO_2 capture efficiency, which implies the previously mentioned beneficial outcomes for response are more compelling. The efficiency of CO_2 solubility with an increase in temperature shows that it is likely brought about by exothermic nature of absorption reaction between the CO_2 and amine groups.

CHAPTER 5: CONCLUSION

Alkanolamines such as MEA are one of the best chemical solvents to reduce the CO_2 emissions because its low cost, high resistance to thermal degradation, and high absorption rate, even though it has disadvantages. The aim of this research was to study CO_2 solubility in MEA + L-Ser solution with the utilization of high-pressure CO_2 absorption reactor. In this investigation, the solubility of CO_2 in blends of MEA + L-Ser solution was inspected at various temperatures, pressures, and concentrations. The experiment solution loading data showed that at a similar pressure, the solution decreases with increasing temperature. For sure, at a steady temperature, the solution loading increases, as the pressure builds, which shows that the response is exothermic response.

In this study, there is no studies of kinetics discussed. This was because the experiment is conducted in a continuous flow. For future recommendation, kinetic study can be studied. There have been many researches on the various solvents together with many absorbents as a promoter. However, researchers mainly used amino acids salt formation. There is no research on CO_2 absorption using amino acid original forms. For future recommendation, more research on CO_2 absorption using the original form of different amino acids with various solvents such as MDEA, DEA, DIPA and etc.

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