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TECHNO-ECONOMIC ANALYSIS OF CARBON CAPTURE BASED ON ABSORPTION BY MEA AND SIMULATION USING ASPEN HYSYS

Falah Jiheel Ali ALI

Master`s Thesis

Supervisor

Asst. Prof. Dr. Engin SANSARCI

Istanbul, 2023

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The thesis titled TECHNO-ECONOMIC ANALYSIS OF CARBON CAPTURE BASED ON ABSORPTION BY MEA AND SIMULATION USING ASPEN HYSYS prepared by FALAH JİHEEL ALİ ALİ and submitted on 19/04/2023 has been **accepted unanimously** for the degree of Master Industrial Engineering.

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I hereby declare that this thesis meets all format and submission requirements of a Master`s Thesis.

Submission date of the thesis to the Institute of Graduate Studies: ____/____/____

I hereby declare that all information presented in this graduation project has been obtained in full accordance with academic rules and ethical conduct. I also declare all unoriginal materials and conclusions have been cited in the text and all references mentioned in the Reference List have been cited in the text, and vice versa as required by the abovementioned rules and conduct.

Falah Jiheel Ali ALI

Signature

DEDICATION

I would like to thank Allah, my God and The Almighty God, and his Prophet Mohammed for giving me the strength and courage to pursue knowledge indefinitely. I appreciate the advice from my great advisor, Dr Engin Sansarci, .for his supports . both technical and interpersonal, as well as his support throughout all phases of this study. Additionally, I would like to communicate my gratitude and special thanks to my parents, who supported and encouraged me emotionally all through the duration of this study. I also want to express my gratitude to my wife and daughter for their moral support and inspiration. I want to express my sincere gratitude to the ALTINBA UNIVERSITY for bestowing the MSc upon me and believing in me. Finally I don't forget to thankful my friend has volunteered their time to aid me; Alammar Omar.

PREFACE

Words of gratitude are inadequate to express the gratitude of what you did for me. I appreciate you always stepping up to assist me; however, don't assume that I won't remember what you did for me that day. Instead, know that all I can do is express my gratitude.

Many thanks; Dr Engin SANSARCI.

ABSTRACT

TECHNO-ECONOMIC ANALYSIS OF CARBON CAPTURE BASED ON ABSORPTION BY MEA AND SIMULATION USING ASPEN HYSYS

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Carbon Capture (the removal of Carbon dioxide from exhaust gas) has become a hot topic in recent years. There is an international agreement to limit greenhouse gas emissions in order to reduce global warming, and CO_2 is regarded as the most significant greenhouse gas. Large-scale CO_2 capture and storage is one method for reducing CO_2 emissions to the atmosphere.

There are several methods proposed for CO_2 removal or capture. The most developed method is to CO_2 absorbtion process in the water-amine solution and then desorb it. Many calculation models for CO_2 absorption removal have been developed. The accuracy, efficiency, and robustness of these models vary. When performing absorption column calculations in conjunction with flowsheet calculations, it is frequently debatable whether a detailed and complex model is superior to a simple and robust model.

In this work estimation techniques for CO_2 separation from atmospheric flare have been developed. Some experimental investigation has also been included to enhance and validate these methods. The emphasis has been on MEA-based absorption and desorption calculation methods (monoethanolamine). One objective of the project has been to calculate cost-

optimal process parameters. The majority of the calculations were carried out in conjunction with the method simulation model Aspen HYSYS. V12

The viscosity and density measurements in CO_2 charged solutions of MEA-water up to 80 oC have been correlated. The new viscosity information of CO_2 charged MEA solutions at higher temperatures have reduced the viscosity uncertainty under typical absorption conditions. For typical CO_2 absorption economic circumstances in MEA solutions, Murphree efficiencies have already been calculated. The deviation from the pseudo first order conditions is less than 10% for typical operating parameters below 50 oC, according to absorption rate calculations based on compounds tested in the liquid film and educated guess calculations. Murphree efficiencies as a function of temperature have been calculated for usual circumstances at column top or column bottom. These efficiencies are simple to incorporate into stage-by-stage column calculation models. The accuracy in calculating overall CO_2 removal efficiency utilizing Murphree efficiencies is comparable to that of more rigorous calculations, assuming that pseudo first order requirements are met and the temperature at a process is approximately constant.

In Aspen HYSYS, a CO_2 removal efficiency from exhaust gas of flares gas-powered power plant was calculated. The grade of total CO_2 removal and heat utilization have been determined as a result of circulation ratio, absorber temperature, and other parameters. The absorber was also simulated with Aspen Plus, using both constant Murphree efficiencies and simulation rate-based, and all of the simulations produced similar results as a function of the varying parameters. When compared between Aspen Plus rate-based calculations, Aspen HYSYS calculations have used varying Murphree efficiencies produce similar temperature profiles.

Split-stream configureurations were also included in the process simulation calculations. In Aspen HYSYS, a splitstream process using MEA with (28.5ton/year) CO_2 removed was calculated. However, cost estimates show that it is unclear whether a splitstream process is more cost effective than a standard process.The calculations also include equipment estimation and cost estimation. A cost optimum could be calculated through a series of calculations.

TECHNO-ECONOMIC ANALYSIS OF Carbon Capture CONCEPTS is divided into four sections: heat recovery for industrial surplus heat for CO_2 gas absorption cost calculation, CO_2 capture utilizing excess heat at an Amine plant, CO_2 Absorption Plant Cost Estimation Tool identifies the critical technical and economic elements and for Capturing CO_2 at an oil refinery Plant - based products on Steam Product Quality standards.

Keywords: Capture, Techno Economic, Aspen Hysys, Absorption , MEA

TABLE OF CONTENTS

Pages

LIST OF TABLES

Pages

LIST OF FIGURES

Pages

ABBREVIATIONS

CCS : Carbon Capture and Storage

IPCC : Intergovernmental Panel on Climate Change

SMR : Small Modular Reactors

IEA : International Energy Agency

PV : Solar Photovoltaics

BECCS: Bioenergy with Carbon Capture and Storage

DACCS: Regular Air Collects with Carbon Storage

IPCC : Intergovernmental Panel on Climate Change

FAED : Facilities in the Advanced Development Phase Have Completed the Front Engineering Design

MEA : Monoethanolamine

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

CFBs : circulating Fuidized beds

MOFs : molecular-Organic Frameworks

DMEA : DimethyLaminoethanol

CCR : Cost of CO_2 Removal

LCOH : Levelised Cost of Hydrogen

CCA : Cost of CO_2 Avoided

TOC : The total Overnight Capital Cost

FOM : Fixed Operating and Maintenance Costs

1. INTRODUCTION

1.1 BACKGROUND

a. Deep decarbonization in difficult-to-abate industries.

Because of the nature in their process industries, heat that requires high temperatures industries such as clinker, heavy industry, and biological treatment all contribute to atmospheric carbon. These are among the trickiest to decrease emissions of carbon from. It has been suggested in a number of assessments, such as those conducted by the Decarbonization Council and the Worldwide Economic Administration (IEA), that reaching net-zero carbon in certain especially tricky sectors may be unachievable absent CCS or, at best, more expensive. It is considered as one of the most cost-effective and mature options is CCS.

b. Enabling large-scale producing of hydrogen that is low carbon.

It is likely that protons will perform major role part in cutting emissions challenging-to-abate industries. It might be beneficial as a form renewable electricity for fuel and producing intermittent electricity. The combination of energy sources such as coals or conventional energy with CCS provides the greatest price approach for producing water. As long as there is a lack of abundant, low-cost wind energy for the hydrolysis that generates protons and high petroleum costs, this will remain the much more expense choice. Hydrogen must rise sharply itself from current level of 70 Mtpa to 425-650 Percent during the period by the 2050s if we are to tackle climate change hard-to-abate industries and reach climate impact.

c. Providing dispatchable low-carbon power

Decarbonizing electricity generation is critical to reaching emissions that are net-zero. Power plants with CCS provide electricity that is dispatchable and low in carbon in addition to grid-stabilizing services such as inertia, and voltage regulator. Solar photovoltaics (PV) and wind generation cannot provide grid-stabilizing services. CCS

works in tandem with renewables to help build a resilient and dependable low-carbon grid for future use.

1.2 PRODUCING NEGATIVE EMISSIONS

We need to find a way to make up for the pollutants that remain in the industries where it is most challenging to do so. CCS prepares the way for systems like biofuel using CCS including conventional air collection with climate regulation that can remove the greenhouse gases from the atmosphere. Although eliminating greenhouse gases isn't a magic bullet, the need for it only grows as days went on.

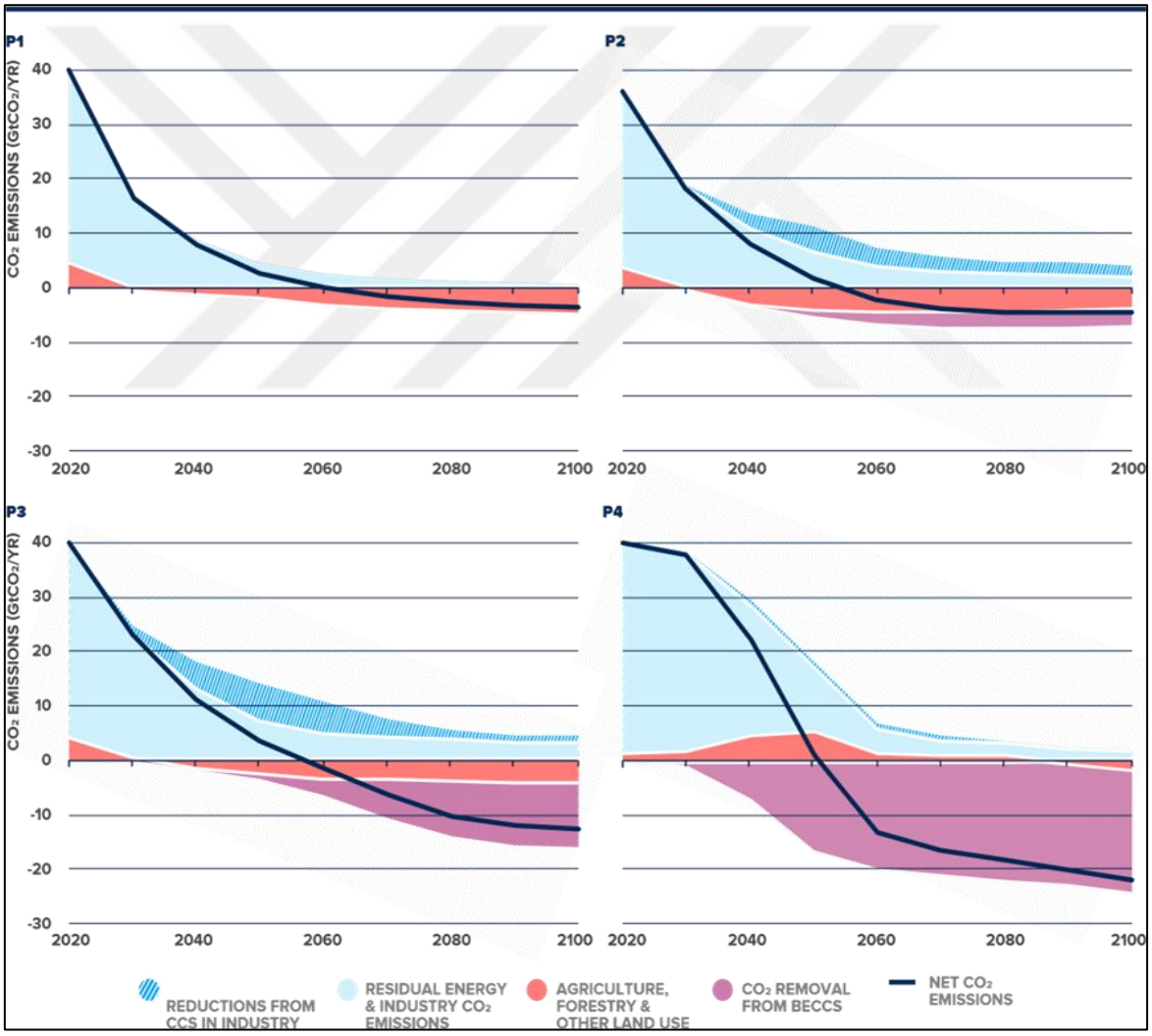


Figure 1.1: Illustrative Pathways in the IPCC Special Report on 1.5 Degrees Celsius [1]

1.3 THE STATUS OF CCS:2020 GLOBALLY

According to the Intergovernmental Panel on Climate Change (IPCC) special report, among both 350 and 1,200 megawatts of carbonic acid will need to be apprehended and deposited throughout that millennium. The 40 megajoules annually CO_2 that are securely stored now need to rise by a factor of 100 by 2050.Following the release of the 2019 Global State of CO_2 Capture and Storage, sixteen new commercial facilities have entered the project space in the planning stages. And, in support of the governor, the United States ranks first in the world, with 12 of the 16 facilities established the success of the United States has convincingly demonstrated that projects will move forward in 2020 when policies create a viable environment for investment.

Other facilities can be found in the UK (two of them), New Zealand, and Australia. There are currently 65 CO_2 capture and storage facilities. Two facilities have ceased operations, one caused by economic decline and the other caused by fire. Three construction constraints 13 facilities in the advanced development phase have completed the front engineering design (FAED) 21 facilities are in the early stages of development. CCS and Storage facilities that are currently operating to store 40 million tons of carbon dioxide permanently annually. There are 34 facilities in total. Last worker of experimental CCS and sacrificial facilities There are eight CCS testing facilities. CCS facilities that are currently in operation can hold. There are 34 facilities in total. The final employee of experimental and sacrificial CCS facilities CCS technology is used in eight test centers. Holding and restocking carbon is not an ideal solution, but it does necessitate proper use of it, as well as making the best use of the excess heat generated by his detention, so we have made an additional profit that lowers the cost of CCS [3].

1.4 CARBON CAPTURE TECHNOLOGY SOLVENT PROCESS

Very typically through the technique of solvents boiling. For the procedure of thread collection, in situations with a pretty modest amount of CO_2 (15–20%), the optimum strategy is to use the corrosive characteristic of CO_2 by employing reactionary absorbing in caustic solutions. Chemicals belong to the greatest popular keywords. A similar process has been popular for many years for CO_2 scrubbing in chemical processes. It has been a technology that is readily transferable to the applications of CCS. Figure (1.2) illustrates this process.

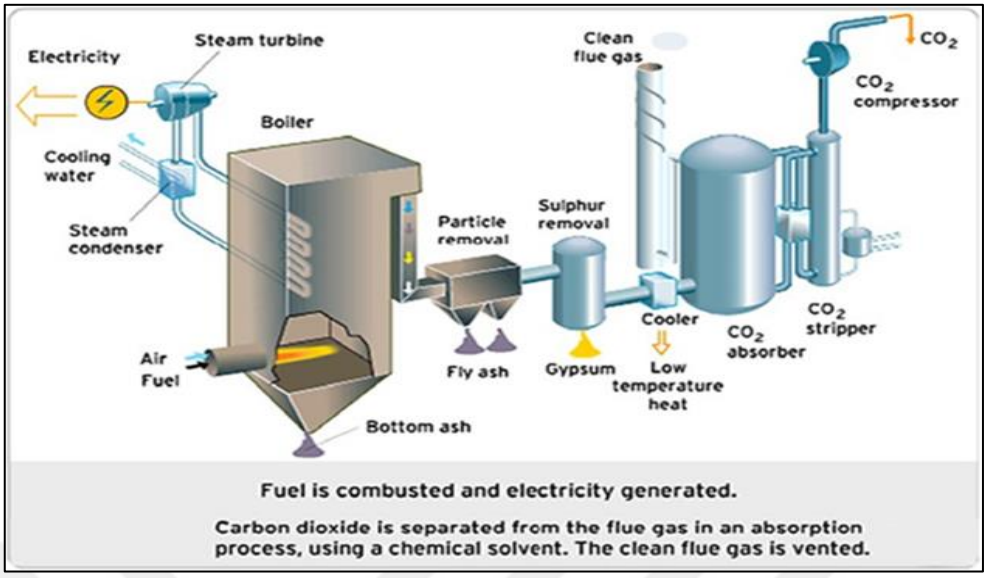


figure 1.2: The Amine Scrubbing Process Captures CO_2 from Power Plant Flue Gas After Combustion [3].

Monoethanolamine, or MEA, is the most commonly used amine solvent. In a scrubbing column, the flue gas that is rich in CO_2 is exposed to a soluble MEA solution with a concentration of (15–30 wt percent) at around 55°C and 1 bar pressure. At the paper's outlet, 0.4 mol CO_2 /mol MEA of CO_2 is loaded. After that, the MEA is boiled in a stripper's stack at 2 mbar and 120C to extract the CO_2. A significant amount of the entire collection cost is attributable to the fuel requisite for something like the stripped step While a new coal plant is being set up, some of the pressure caused must be sent to the peeling machine as opposed to compressor gas, which is used to create energy. For post-combustion processes, this efficiency penalty is typically 10%. Operational costs and capital amount 45 percent of process costs, while energy consumption accounts for more than 50 percent.

When it comes to controlling the expense of solvents recapture operations, the most important variables are speed of dynamic adsorption, solution deposition rate, and regenerative power.

Several researchers are focusing on improving oxidizing agent solvents and finding new high concentration of organic solvents for CO_2 collection. Increased cycle ability and smaller regenerating values obtained are two advantages that inhibited amines have over MEA.

Alternatives to MEA, such as (DMMEA), were studied. And even while though restricted aldehydes have a slower CO_2 oral bioavailability than MEA, catalysts like piperazine may boost that rate, and alkane combinations show promise. Ammonia's worth of 50 kJ mol is around 60percentage points higher that of MEA, but a cooled methanol procedure has been proposed as a significant replacement to capabilities provided at present, although significant differences in regeneration power are still a hurdle. Oxidation with repeated reprocessing and oxidation of tanks and pipes may be other major considerations when selecting an alkaline solution; optimizing the solvent's microstructure and the control parameters is seen as a difficult cross problem.

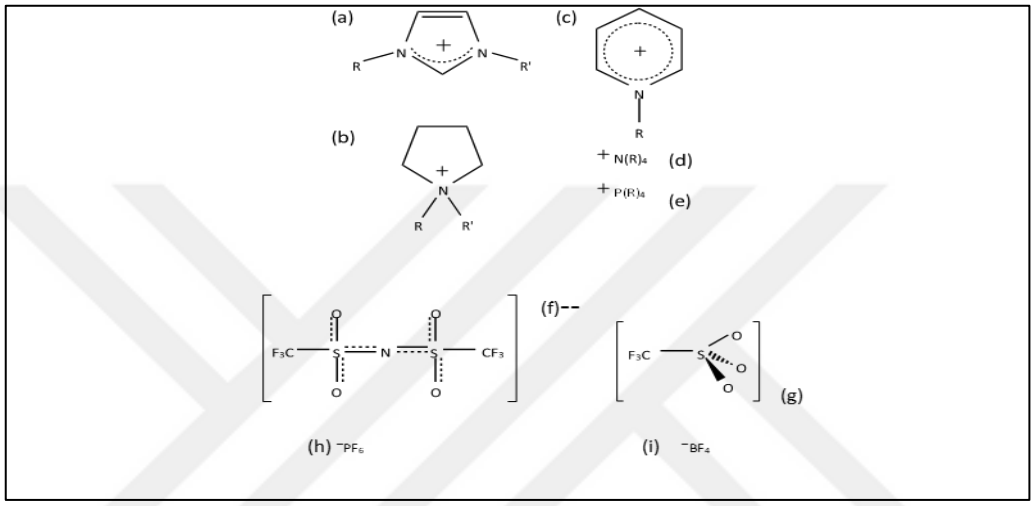
In the which was before stage of the phase of the design, in which CO_2 concentrations are greater and the disposal air velocity is always at elevated heat (2-7 MPa), as well as the resulting biogas with high CO_2 intensities, tangible liquids may be utilized by that rather than of responsive liquids (4). These advantage from weakened CO_2 conditional, that either reduces retrieval energy costs and performance costs. They also wear out faster and corrosion very little. For this reason, comment techniques usually have low have tend to have a lower expenditure for eluent acquisition.

Ionic liquids, a class of aqueous solutions that is relatively new, are becoming a contender for sequential CO_2 capture. These materials, which consist of big cations and anions (see Figureure. They also have a fairly wide range of liquids and particularly high boiling points. Although they are expensive, they have the capacity to combine significant effects with greater regeneration returns and efficient recycling with very little solvent make-up. These procedures are still under investigation, but they seem to have a promising future.

1.5 PROCESSES OF SOLID ADSORPTION

Adsorption, like solvent processes, can be physical or reactive. Calcium Carbonate Synth (5) is the process that is closest to commercialization as a viable alternative to amine scrubbing (see Figure.1.3). At around 650°C, finely spilt calcium carbonate to the method of calcium carbonate or other metallic simples is calcined as lime, calcium oxide CaO. In this transferred to a carbonator container, where it is contacting at temperatures ranging from 900 to 950 degrees Celsius. with flue gases or another CO_2 -contain stream and exothermic reaction converted returned to $CaCO_3$. This output is discharged first from gasification

process then delivered alongside the limestone for squeezing, shipping, and storage before ever being reused returned to the improve air for a second round of graphite dixid elimination. The mineral adsorbent can be looped in the capture- emission cycle for a huge number of cycles (10–30). Adsorption contains capacity decreases with successive cycles as a result of reductions in particle micro-porosity (5), but renewal (e.g., using steam) is possible, allowing for further recycling of 'spent' adsorbent (6)(7).



Figurer 1.3: Ionic Liquids – typical Anions and Cations [8].

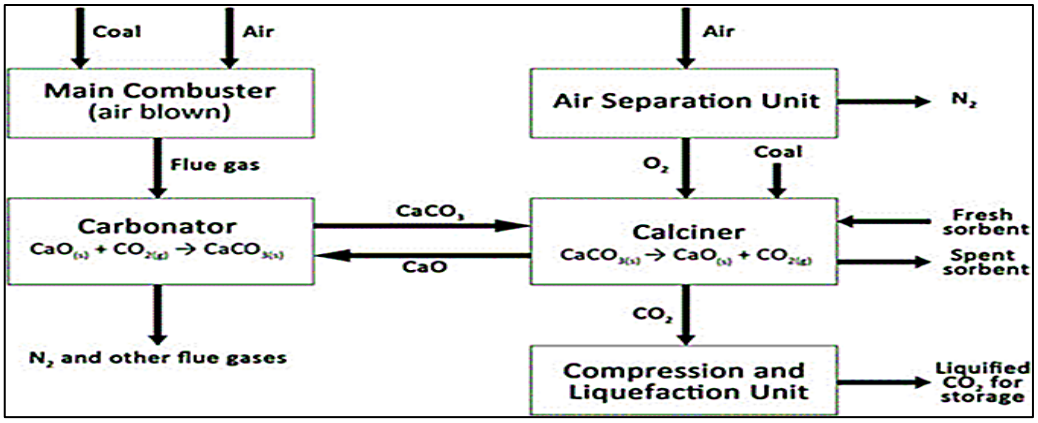


Figure 1.4: Diagram of The Calcium Looping Process As it is Used For Post-Combustion Capture, in Its Simplest Form.[9]

That's why bicarbonate duplication's cost-effectiveness in capturing CO_2 from either a backup system is so high [9]. It presents the possibilities for several benefits, along with the resource usage of CaO as an analyte and then as an important specific substance for clinker, a moderate effectiveness penalty, the utilization of knowledgeable big plant species, like

flowing fluidized (CFBs), that also reduces scale-up threat, or the show of strength of the new tech on intermediate crops. Adsorptive activation is one of the most pressing issues that has yet to be tackled. As contrasted to Microemulsion, therefore, this method has the potential to reduce the heat transport associated with CO_2 removal by as much as 7.5 percent, resulting in substantial resource and cost savings over the lifespan of a traditional nuclear plant [10]. Several CO_2 adsorbents have been studied as potential foundations for a shifting desorption absorption technique. They include biosorption methods including microporous and perhaps other built permeable materials reactive species including alkaline firm compounds [11], and reactive methods like oxidizing agent cellulose nitrate. [12-15]

1.6 OTHER CAPTURE PROCESSES

Calcium circling and oxidizing mechanisms are combined in chemistry looped (15). Regular interaction among air and indeed the oil and coal are prevented by utilizing a redox reaction as an oxidizing agent. To do this, material is cycled through two fluidizations, much as in calcium loops (see Figure. 1.5). In one reboiler the steel is oxidized of air and/or heat to create energy through an oxidation step; in the different powerplant the material is likely attributed to the material through response also with natural gas, yielding carbon dioxide (CO_2) and vapors, that may be detached by evaporation to yield a simple Greenhouse gas circulation for deformation and flash memory.

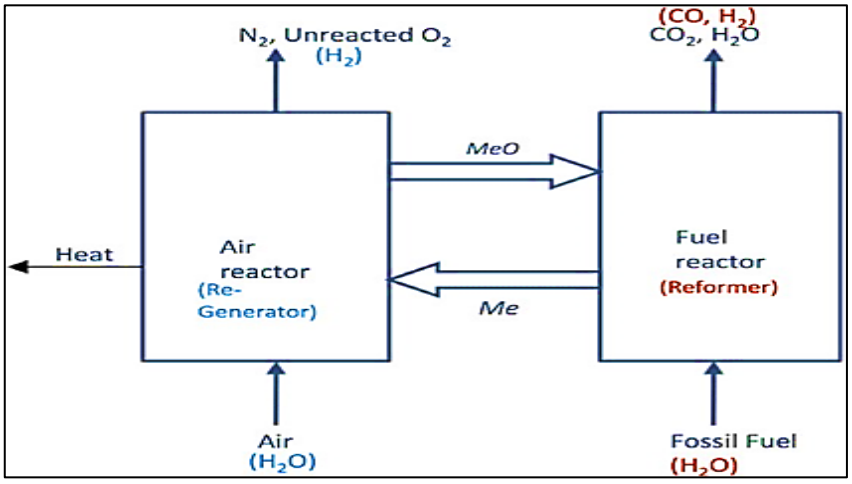


Figure 1.5: Chemical looped Burning Oversimplified Flow Chart (Metal, Me D e.g. iron, copper, nickel, cobalt).[16]

Long-term cycles cause sorbents to deteriorate, and this needs to addressed if total rates are to rise beyond 50% [53]. Several liquid and granular substrates, together with state-of-the-art H2 generation techniques, have been the focus of research into chemically looped burning[17-18]. The enthalpies of the electrochemical reaction, the lengthy deterioration pace of the oxidizing agent, and selecting the oxide(s) employed provide the greatest difficulties.

As shown in Figure. 1.6, a possible strategy is transmembrane segregation and capturing, which relies on the selected absorption of liquids via polymeric media caused by a tensile stress established by squeezing the wind ahead or establishing a vortex afterwards

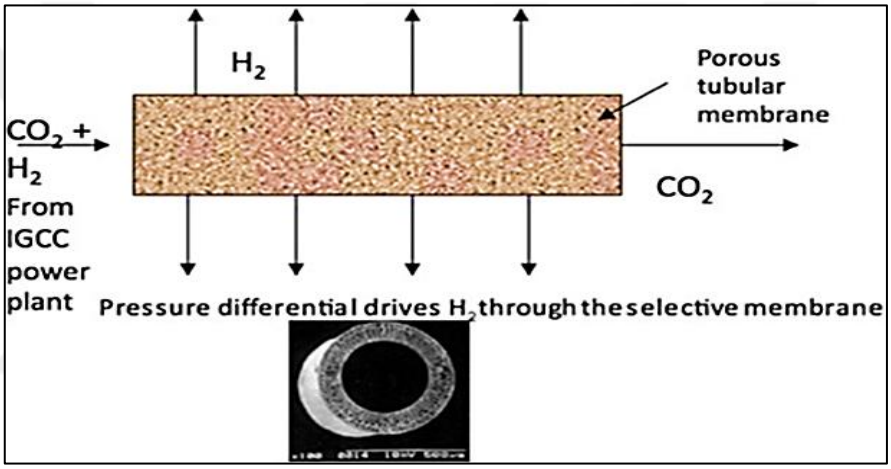


Figure 1.6: Liquid Separator Extraction from the Stream of Exhaust Gases for CO_2 Extraction.[19]

Membranes notably crucial monetary elements in the CCS network is the expense of compressed, that could be greatly reduced by using screens to capture CO_2 from elevated burning operations requiring considerable depressurization. The heat and gasses that are employed determine whether polymers, metallurgical, or conductive polymers are employed. Improving permeation is essential in capturing CO_2 off combustion gases to lessen the effectiveness hit of generating the tension gradient [19]

1.7 MAIN CHALLENGES

Nevertheless, there are certain significant hurdles that have to be overcome before this innovation can be widely used. Longevity of membranes and- doubts about reliability brought on by exposure to particles, SOx, NOx, and chemical contaminants; a flood of growing ones; and effective integration of power grids.

Other methods of CO_2 sequestration are indeed being researched for potential implementation in business settings, including: - Genetic acquisition, which involves the cultivation of microbes like seaweed or actinobacteria utilizing excess energy and CO_2 fumes from ignition, in place of water, bright sun, and oxygen. The adoption of bioengineered types of microorganisms with greater efficiencies is predicted to significantly increase the capturing capacity and frequencies of such platforms [20-21]. To that end, researchers are looking at using proteins as a physiological trapping approach. One of the aforementioned processes uses metabolic pathway to sequester v before releasing it into the atmosphere in a way that mimics the way mammals exhale nitrogen [22-23]. Scaling up biologically recapture techniques is difficult for reasons including the limited rate of increase growth of grass and also the difficulties in designing bioreactors.

Supercritical separating is an alternate approach of distinguishing hydrocarbons that uses chilling or pressures to make use of the differing boiling temps and vapor pressures of the elements in some kind of a combination, resulting in two discrete stages [24]. Freeze CO_2 at 75 degrees Celsius at force and temperature or pushing it above the vital juncture at 31 degrees Celsius and 74 bars, allows for its abandonment. Condensing separation's primary drawback is the considerable time, effort, and money required for decompression and refrigeration. Additional difficulty is preventing the development of ice by evaporating before chilling [25].

Using Carbon Dioxide into Structural Concrete [26-27]. Carbon dioxide (CO_2) seems to have the low absorption of any nitrogen negative cyclic chemical because it includes iron at its maximum redox potential (+4); however, limestones produced by interaction with oxygen molecules of liquid are also of shorter wavelengths. Even though it takes a very long time, ordinary aging of olivine additionally constitutes an oxidation reaction.

When exposed to carbon dioxide, particular types of rock formations respond significantly more quickly than others. These mineralization roles the narrower snaring mechanisms of microvascular caging and eroding in hydrates, and are therefore the primary means by which CO_2 is retained in tanks over the medium haul.

Yet, a lot of power is required to convert CO_2 to lower electronegativity. This can be achieved by means of highly reactive biomolecules either via electrolytic or superoxide radicals reducing [28], provided enough hydropower is obtainable [29].

1.8 FUTURE CO_2 CAPTURE DIFFICULTIES

There are now a number of pilot programs all across the globe that are putting into action professional or moderately CO_2 collecting technology. Given that this is the costliest step in the CCS process, much effort is still being put into developing more effective, less costly, and ecologically sound alternatives. Listened below are some of the most pressing concerns that need fixing:

i. Reduced acquisition workflow investment and operational costs

ii. Reduced contraction charges thanks to methods that can be performed at operating pressure.

iii. Low-Regeneration-Energy-Content CO_2 Adsorbents

iv. The use of vesicles for preferential, limited divide and encapsulate; the use of tinier, more effective gas switching devices.

v. the disconnection of earth's atmosphere at low cost the use of epithelial cells to their full potential.

1.9 ABSORPTION OF GASES

1.9.1 Introduction

The new main function in petroleum design is based on phase transition mass transport, which is mostly influenced by membrane permeability, and includes the elimination about one or more chosen components out of a gas by absorbed into a particular solution. Hence, alcohol may be reclaimed out of a solvents combination by dissolving the methanol in moisture while an air is vented out of the combustion gases. Immersion in waters is an additional method for purging a nitrogen combination.

The mechanism of gas separation in water may be treated as a physiological one in all three of these cases, without any noticeable impact from the biochemical reactions. Nevertheless, the precise absorbance rate is dependent on the kind of the molecular process that occurs when nitrites are consumed in water to generate sulfuric acid, and whenever carbon dioxide is collected in a salty alkaline mixture.

So, it is simple to distinguish between physiological chemisorption versus those which also entail a redox reaction. Bringing the vapor into close proximity to the water is the most essential aspect to think about when designing a facility for steam distillation, and the success of the facility will depend heavily on how well it facilitates interactions among the two components. At big deployments, packing and loaded columns are frequently employed for evaporation, and the overall machinery is identical to what is detailed in Chapter 11 for filtration. As will be shown in the next section, the procedure for carrying out the task is different.

Feeding gas enters at the row and the solvents is added somewhere at summit; the absorbent oxygen and mixture exit at the bottom, while the unconsumed constituents are evacuated at the upper edge. In contrast, the material's temperature is much below its melting point throughout the complex formation. Surrounding context, the dissemination of gases into a water, with only a relatively insignificant transition in the wrong direction. Diffusion, on the other hand, uncovering among both orientations, actually results in appropriate ratio counter diffusion in an ideal society. Immersion, where the concentration of water to gas circulation is significantly larger than in boiling, employs an alternate tray structure than vaporization. Additionally, compacted pillars have become increasing widespread as liquids retention premiums rise. The optimum connection like most compounds with low levels, and for others over a wide range, is described by Henry's law. This legislation may be expressed in Chapter11 as:

$$Pa"=" MCa \qquad (1.1)$$

Where: Pa; refers to pressure of the fume point component a

Ca: is the component's attentiveness in the fluid, then

M: Henry’s persistent [30]

2. LITERATURE REVIEW

Several techno-economic and simulation CCS studies have been completed previously, but detailed studies utilizing excess heat are uncommon. After comparing two distinct incoming gases, the procedures were adjusted to reduce initial investment. Filtration, the studies showed, leads to increased purity in released and sold gases.

The Aspen HYSYS has been employed in other research to find the optimal transmembrane architecture, stage counts, and reabsorb inputs for decreasing the total of CO_2 collection. (31)(32) As Hasan et al. Microbial absorbers and barriers were studied and adjusted as a means of dehydrating nitrogen oxides and capturing CO_2.

They concluded that the best technology is determined by the Carbon dioxide composition and gas flow rate. Other studies used membranes to model separations of CO_2 /N_2 mixtures. reduce membrane area and energy usage [33-34]

Historically, first-principles models have been used to assess the technoeconomic of these and other chemical technologies. Electrochemical reaction and electrical adaptive control and modelling often use plant simulation. In any case, the development of Statistical models has opened up new possibilities for statistics data modelling. An increasing number of models, such as ANNs, Stochastic phenomena, and retiree, have been added to the modelling of methods. [35-38]

Arithmetic modification, differentiation, and interpretation of the formulations provide easier access to the basic values guiding the observable occurrences. Conventional symbolism statistical measures, as will be covered in more depth further along the page, depend on symbols random forests, that are either complicated of formulas that may be paired with techniques to select the best suited predictions. Methodologies, both unpredictable and deterministic, may be used to tweak these formulations. Static approaches ensure connectivity to either a neighborhood or global maximum within about a lambda constraint [39].

According to researchers by Salkuyeh and Spanilla : Though with emission selling for as good as $100/phase Ii study, the analysis showed that thermal gas reformer small modular reactors SMR paired with energy production does not constitute the most cost-effective

option, and heterogeneous catalytic solutions are more attractive at reduced carbon costs[40-41].

At Fernandez study : That whenever a collection operation is combined with a petroleum wind farm, the controllability of the structure is enhanced. Approaches investigated included a static hydraulic fluid drol including steaming regulating, a rolling hydraulic fluid rol, unrestrained vapor evacuation, consistent grouper temperature, and modifying the turbine intake guiding impellers. There were considerable benefits observed, especially for component operations when the price for energy generation rises with the recapture percentage. They also underlined the need of maintaining a steady crank bait temperature as a means to reduce electricity consumption by the expander train[42] .

Wang research approved the transitional period occurrence was seen once the CO_2 feeding amount was higher than 1.04 mol Dioxide, with the top layer consisting of Post - combustion Mes and also the bottom layer consisting of thioesters. Surfoplane's high adsorption for acidity vapors boosted this same rate of CO_2 capture by the MEA technique by a factor of 2.7[43].

According to research Wei to address this issue, solvent-based CCS can be used to capture cabon dioxide in the exhaust gases from FCCU, but the energy consumed by the CCS plant's reboiler will undoubtedly reduce the refinery's economic benefits. In this paper, process simulation is used to investigate solvent-based carbon dioxide capture for FCCU in a real-world refinery [44]. Oko saied a wanting to trade cost precedent for the IL suggests that the upfront water solvents expense for the mixture will be greater. Yet, the value of the mobile phase is reduced for the mixture solution. [45].

According to research Kang an economically design should be found in order to widely adopt the rotating packed bed RPD for CCS. For this reason, it is necessary to have a provision for the RPB module in order to investigate issues like the impact of rotational on fluid flow, optimize the program's architecture to conserve power, etc. Analysis using models may save both time and cash contrasted to investigations using demonstration plants. A number of RPB systems, including the augmentation differentiator approach for a phenol solution, were created and evaluated, as have many values for the diffusional coefficients and interface area between gaseous and fluid phases[46].

The author Akachuku found that the convert augmentations for MEA by g-Al2O3 and H-ZSM-5 were 55percent and 74%, accordingly, or for MEA-MDEA, these was already 65% and 85.2%. For the catalytic Dioxide desorption process, a comprehensive mechanism of action LHHW rate model was created [47]. Emissions from raw uranium in China's Zhejiang were around twice the value of emissions from fossil fuels at around 700 or 500 grams per KW/h. It also increases depreciation once an ammonium liquid is employed for CO_2 extraction since it needs additional carbon to achieve burn than those of other biofuels[48-49].

3. PROPOSED METHODOLOGY

3.1 MATHEMATICAL MODEL OF CARBON DIOXIDE ABSORPTION PROCESS

As I maintained in an introduction about the importance of carbon dioxide capture process and known the process should be absorption the CO_2 from flow gasses by absorption tower. the best simulation should be doing for this process by using Aspen HYSYS 8.6 version software program as it shown in the background studies.

3.1.1 Cost of CO_2 Removal – CCR

The levelized expense of oxygen (LCOH), the expenditure of carbon dioxide averted (CCA), and indeed the expense of getting rid of carbon dioxide are now the key financial success criteria considered here (CCR). The preceding formulae determine these expenditures:

$$\mathrm{LCOH} = \frac{(\mathrm{TOC} * \mathrm{FCF} + \mathrm{FOM})}{(\mathrm{CF} * 8760)} + (\mathrm{FC} * \mathrm{HR}) + \mathrm{VOM} \qquad (3.1)$$

$$\mathrm{CCA} = \frac{\mathrm{LCOH}_{\mathrm{LCOH}} - \mathrm{LCOH}_{Non\ CCS}}{CO_2\mathrm{Removed}_{\mathrm{Removed}}} \qquad (3.2)$$

While TOC is the whole nighttime expense, FOM is the regular O&M expense, VOM is the vary O&M expense, FC is the diesel, CF is the base load, HR is the higher thermal flow of something like the operation, and FCF is the long - term debt determinant.

3.2 TECHNO-ECONOMIC ANALYSIS OF CO_2 CAPTURE CONCEPTS

3.2.1 Sections

This section will further divide into 4 parts which is as follows –

i. Part – 1 - Cost estimation of water heating circuits for using waste heat from process industries with the aim of taking in carbon dioxide.

ii. Part – 2 - Amine-based CO_2 extraction utilizing waste heat from a brick factory.

iii. Part – 3 - Adsorbent Project Estimate Tool Highlights Key Physical and Socioeconomic Disparities in Current Sustainability Cost

iv. Part – 4 - Using Electrical Generation Alternatives for CO_2 Collection in a Crude Petrochemical Plant

3.2.2 Methodology

The contribution to the CO_2 stCap Project

The project's numerous research partners are given tasks using the CO_2 stCap. Workshops and consortium meetings were held in addition to industry visits. These project meetings were where some of the project choices and process parameters were made. Together with the project's research collaborators, the approach for this study was developed. It was also intended to codify the Expanded Extensive Component EDF estimation method mentioned.

3.2.3 Techno-Economic Methodology

The following is a discussion of the steps necessary to complete innovation research of a business.

i. To correct for motion and energy abnormalities, the Aspen Plus method may be used.

ii. Presented a high-level process flowchart and a brief summary of its size.

iii. Using input parameters for machinery sizing.

iv. Predicting expenses by applying contextual factors for subsets of hardware.

v. In-depth research into the most important monetary or technological elements to optimize the process.

The following section will provide an in-depth explanation of the methodology's primary components, beginning with the scope expenses of setting up and operating a CO_2 collecting plant using equivalent azo technique are assessed, beginning with a high-level overview.

A More Precise Factoring System Here, we demonstrate the EDF method for calculating potential fixed investment costs. Fulham's book details a similar technique called Personal

Part and Thread Estimation, which really is similar to this one[50]. The specific aspects of the devices, the origin of the purchase price, and indeed the configureuration considerations are occasionally available to audience of the open literature. The implementation variables are key to the EDF methodology used in this study for cost estimate and are explained in depth. Nils Henrik Eldrup is responsible for the development of these "improved detailed installation variables." He did this over the course of a number of years while working on a variety of projects. The EDF approach has had many benefits over approaches, together with improved cost openness, accurate estimations of beginning financial projections, a focus on optimizing small components of plant operation, and the capacity to perform innovation studies along with both emerging and established techniques. The bare minimum for a successful proposal is a description of required supplies and a concise flow schematic of the process pieces of information that must be gathered for this procedure. The following are the stages that make up the techno-economic analysis process that was carried out for this thesis:

3.2.3.1 Assumptions

The list of presumptions that were made for the research work that was done for this theory can be seen in Table 3.1.

Table 3.1: List of Economic Assumptions

Parameter	Value
Dollars and cents spent that year	2016
Organic Expense Ratio (%)	25 years (2-year construction time and 23-year operational lifetime)
Rare or common, singular in nature or Nth in a series	6.5
Greenfield or Brownfield?	Nth-of-a-kind
Expenses for upkeep as a proportion	Brownfield
The Cost of Energy (kWh)	3% of the EIC

Table 3.1: List of Economic Assumptions" Tables Continued."

Cost of chiller (m3)	0.12
the cost of imported steam (t)	0.02
Price of solvents (methyl ethyl acetate) (m3)	15
Destroying a chemical is expensive (m3)	1755
Individual Cost Per Operation (year)	444
Price of a Technician in Hours (year)	55
Typical Annual Work Hours	180
Cost of carbon dioxide collection	8000
saved costs in 2016 exchange rate	8.5

3.2.3.2 Simulations

The mass and energy balances provided by these simulations are utilized to size the machinery and assess the utility consumption that serves as the basis for the economic analyses. Simulating the procedure is not necessary since this phase may be carried out without the use of computers. The explanation of additional parameters and simulation of CO_2 capture plants.

3.2.3.3 Dimensioning of the equipment and its price

Machinery measurement is making a list every piping system, which would also contain the vehicle's height, the volume of units that will be required, and any other relevant details, and construction material The key assumptions used while dimensioning the equipment are described. Equipment cost is greatly influenced by the size of the piece of equipment and the materials used in its manufacture. Work environment including strain, humidity, hydraulic gradient, and corrosive risk all play a role in deciding which substance to use.

Table 3.2: Materials for Process Equipment based on Construction Materials.

Material of Construction	Material factor (f_{mat})
Wrought in harden able titanium	1.65
Fabricated from grade copper	1.10
A fiberglass fiber-reinforced polymer	1.0
Rare and unusual stuff	2.30

The Aspen Machine costs were estimated using the Diamond In-plant Economic Calculator for this study. The computer calculates the price of the necessary gear without resorting to a factorial method, instead basing its findings on data collected from the vendors themselves. It is essential that the cost of the machinery be modified for the appropriate dimensions, timeframe, and construction materials. The Aspen initiative is frequently the source of pricing increases for the vast percentage of building elements. This includes rare earth metals, wrought iron (SS), and corrosion resistance (CS). In this method, the implementation component worksheet (Part 3) is determined by the worth of metallic materials, so if the initial expense does not pertain to carbide, one must use substance elements (FMAT) to converting to carbide metal using Equation (3.3).

$$Equipment\ Cost_{CS} = Equipment\ Cost_{(SS,exotic,..)/f_{mat}} \quad (3.3)$$

3.2.3.4 Improved computation of the installation factor

Due to its emphasis on each individual piece of equipment from the time of purchase until it is installed, this technique is known as the Enhanced Detail Factor method. The core of this technique, which covers the straight charge, business charge, direction charge, commissioning cost, besides contingency cost, is the increased comprehensive installation elements. These variables are calibrated using several constructed plants as well as thorough approximated investigations. Using historical data for a particular site, it is also feasible to

calibrate the procedure to that location. The setup element may be determined using the installations component document, but only if the additional data is included:

a. Material expenses are determined by the NOK value of the value of carbide because as the assembly element spreadsheet is denominated in NOK. The Aspen In-plant Forecaster provides regionally specific estimates of project costs, that need to be converted to Norwegian Krone at a fixed translation value.

b. It is also necessary to include information regarding the sort of process plant, such as whether it handles solids or fluids.

The sub-factors shown in Figureure 3.1 are added together to get the overall installation factor (FTotal,CS). While setting up your various pieces of machinery, you'll need to take their individual needs into account. This ensures a precise and trustworthy estimation, the development of a single module at per appliance, and the consideration for every one of the components necessary to arrive at that expense, including the gear's base, rooftop, plus electricity.

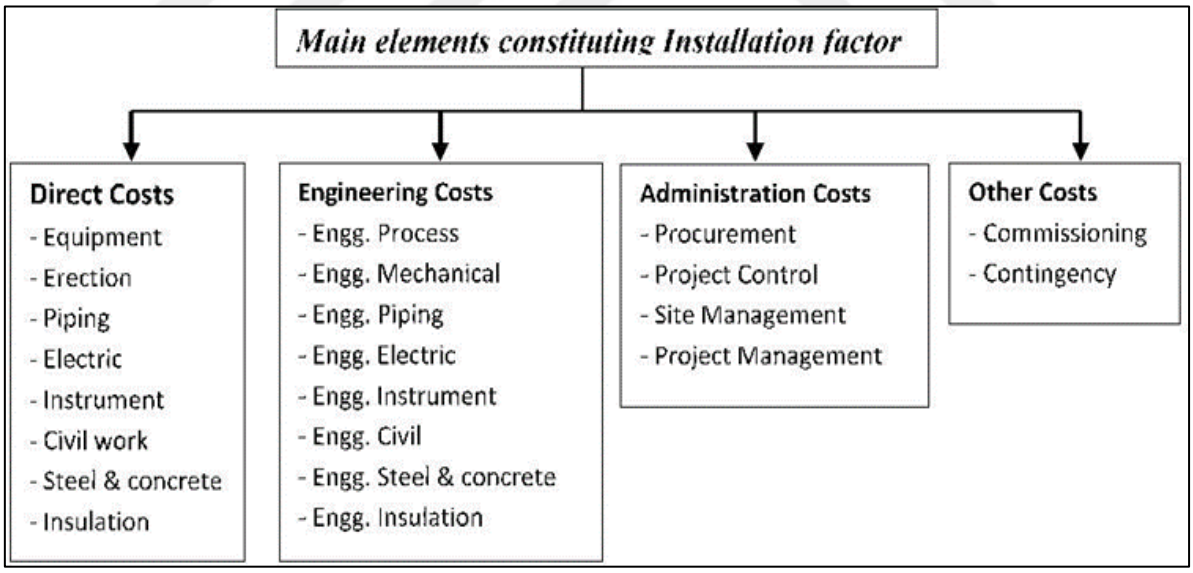


Figure 3.1: Main Elements Constituting Installation Factor.[51]

3.2.3.5 EDF Technique for calculating the total installation cost

Set of interventions costing (EIC) is calculated employing Systems (2) and (3) for CS, but also Calculations (1) and (4) with respect to the additional building materials. CS, the EIC

is estimated using Equations (3.4) and (3.5). The equipment cost is subtracted from the enhanced detailed individual installation factor to arrive at the overall equipment cost. The implementation factor has to be refigureured whenever a building's primary structural component deviates from CS. The equations should be used to get the combined capacity expense of the enterprise once the individual costs of establishing each appliance have been measured:

$$\mathrm{EIC_{CS}(NOK)} = \text{Equipment Cost}_{\mathrm{CS}}\ (\mathrm{NOK}) \times \mathrm{F_{Total,CS}} \quad (3.4)$$

$$\text{Where } \mathrm{F_{Total,CS}} = \mathrm{f_{direct}} + \mathrm{f_{engg}} + \mathrm{f_{administration}} + \mathrm{f_{commissioning}} + \mathrm{f_{contingency}} \quad (3.5)$$

$$\mathrm{EIC_{(SS,exotic)}(NOK)} = \text{Equipment Cost}_{\mathrm{CS}}\ (\mathrm{NOK}) \times \mathrm{F_{Total,SS,exotic..}} \quad (3.6)$$

$$\text{where } \mathrm{F_{Total,SS,exotic..}} = [\mathrm{F_{Total,CS}} + \{\mathrm{f_{mat}} - 1\}(\mathrm{f_{equip}} + \mathrm{f_{piping}})\}] \quad (3.7)$$

$$\text{Total Installed Cost (Nok)} = \Sigma(\text{EIC for all equipments}) \quad (3.8)$$

3.2.3.6 Currency and adjustments

When calculating the overall cost of installation, index regulation and currency regulation are both taken into account as necessary. If the cost that is needed, then the entire cost of the installation using a predetermined conversion rate, as stated in the equation given below (3.8).

$$Total\ Installed\ Cost = Total\ Installed\ Cost\ (NOK) \times Exchange\ rate \quad (3.9)$$

3.2.3.7 Annualized capital expenditure (CAPEX) calculation

The annualized component has to be determined first using Equation (3.9) in order to compute the annualized installed cost, which is also known as the annualized CAPEX. Equation (3.9) is for a building duration of one year and an operating lifespan of twenty-four years. To get the annualized installed cost, or price/yr, divide the total cost of installation by the annualized factor, as shown in the Equation given below (3.10).

$$Annualized\ factor = \sum_{n=1}^{24} \left[\frac{1}{(1+p)^n}\right] \quad (3.10)$$

$$Annualized\ CAPEX = \frac{Total\ installed\ cost}{Annualized\ factor} \tag{3.11}$$

Where p is the power rating (€/kW)

3.2.3.8 Calculation of cost of co_2 capture/avoided cost/cost of steam.

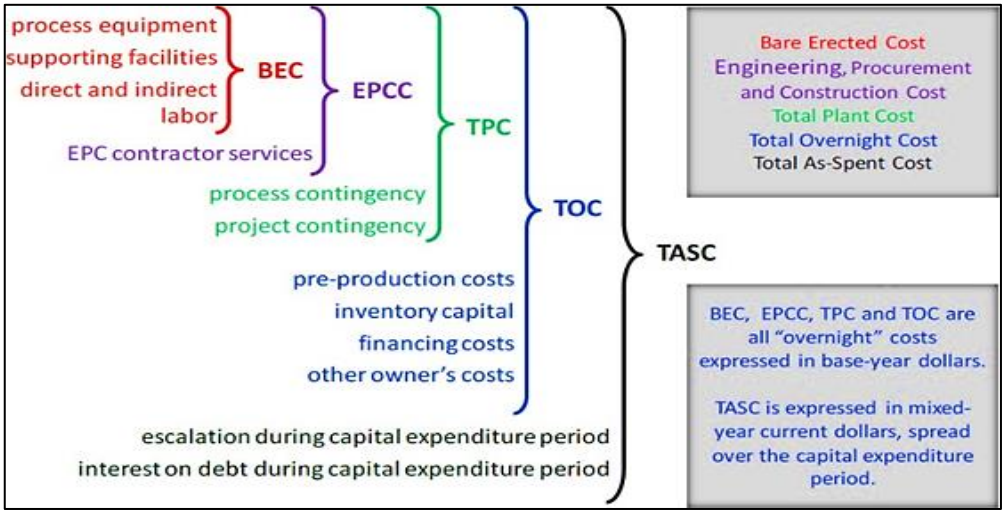
By reducing the entire periodic CAPEX and annually OPEX by the amount of CO_2 recovered or reduced, we can calculate the Combined cycle expenditure in Parts 2 and 3. This yields the CO_2 capture cost Equation (3.11). Either Aspen simulations or manual calculations may be used to determine the total quantity of CO_2 that has been sequestered.

$$CO_2\ capture/avoided\ cost = \frac{\text{Annualized CAPEX} + \text{Yearly OPEX}\ \left(\frac{\text{Currency}}{\text{yr}}\right)}{\text{Amount of } CO_2 \frac{\text{captured}}{\text{avoided}} \left(\frac{\text{t}}{\text{yr}}\right)} \tag{3.12}$$

When calculating the cost of steam for Part 1 and Part 4, the same formula as Equation (3.11) is used. This formula is found in Equation (3.12).

$$Steam\ cost\ \left(\frac{Rs}{ton}\right) = \frac{Yearly\ cost\ \left(\frac{Rs}{yr}\right)}{Steam\ produced\ \left(\frac{ton}{hr}\right) * Plant\ operating\ hours\ \left(\frac{hrs}{year}\right)} \tag{3.13}$$

According to the Association for the Advancement of Cost Engineering (AACE) to ensure the most accurate prediction possible, the EDF method examines each machine as its own venture and applies its own unique deployment variables to each item of machinery. It is critical to point out that the EDF approach sometimes doesn't factor in pricing flashpoints, amount owed all through the design stage, expenditures related to plot readiness and consider purchasing, fees related of protracted flowlines and handling equipment, outgoings related with skyscrapers and training courses, or additional fees charged mostly by landlord.



Figurer 3.2: Levels of Capital Costs as Described in the NETL Report [52].

3.2.3.9 Operational and maintenance costs

It is common practice to divide Facility management expenditures into constant Expenditure and dynamic Operating charge based on the number of minutes the business is in business each year. The Expense estimates rely on a variety of assumptions, such as the unit pricing for commodities, consumables, and energies, the quantity of employees and designers required, but also the headcount of factory working weeks yearly.

The recurring operating expenses include:

a. Maintenance costs

It was decided that 4% of the EIC would go toward the cost of yearly maintenance. This number, which is often reported in the literature to shift anywhere from 2% to 6% based being studied.

b. Operating labor costs

The yearly operator is calculated based on the number of shift employees, which equals six operators, plus one engineer.

The expenditures associated with are considered part of the functioning prices:

c. Basic resources,

d. Power,

e. Groundwater for conditioning

f. Hot water,

g. Cleaning chemicals,

h. Odds and Ends

Scheming of each of the adjustable expenses described earlier is accomplished by applying the overarching statement presented in Equation (3.13).

$$\begin{aligned} &Yearly\ Utility\ cost\ \left(\frac{Rs}{yr}\right) \\ &= Annual\ consumption\ \left(\frac{Unit}{hr}\right) \times \frac{operating\ hours}{year} \\ &\times Utility\ price\ \left(\frac{Rs}{unit}\right) \end{aligned} \tag{3.14}$$

where unit can be in m^3, kg or kWh.

OPEX does not take into account administrative expenses, taxes, insurance, the cost of the initial fill, the costs associated with pre-production.

3.2.4 Simulations and Specifications

3.2.4.1 Flue gas specifications

Table 3.3 provides an overview of the typical ranges for the various sectors that were considered for this Master thesis study. There is a clear indication of whether papers utilized the comparable material and where ones did not, in addition to whether ones focused on specific biogas in their research. This is because multiple parts have utilized the same data.

Table 3.3: Specifications For Flue Gases Utilized In Each Case Study.

Parameter	Flare gasses
Suggestion of vapor	Pre-calciner
Flow rate (kg/hr)	1611
Flue gas temperature in forexcess heat recovery (°C)	50
Flue gas temperature outafter heat recovery (°C)	40.3
Pressure (kPa)	150
CO_2 concentration (kg %)	2.4

3.2.4.2 Simulations of CO_2 capture

In Aspen Hysys, The CO_2 capture facility using amines after incineration has been modeled. Table 3.4 details the Mustang simulator settings. AspenTech's Aspen Hysys is a professional, flexible modelling platform. Concert performance is included in equilibrium-based calculations involving the aforementioned processes The Percent of respondents performance for a given level is determined by a shift in the molar mass of CO_2 between stages. Next, the difference between this shift and the shift which might occur if homeostasis were anticipated is calculated. For Adsorbent wedge sections, the weighted score performance is defined as follows: Through all seven levels, performance is established at 0.21, and it drops progressively to 0.11 through the end of the procedure in step 15. In the desorption column, the value of the Murphree efficiency for CO_2 has been held constant at 0.5. According to estimates, the efficiencies provided by the Murphree make it possible for each stage to be comparable to one metre of packing height. In order to reach a pressure of 96 bar, the carbon dioxide must first be compressed in four steps. This pressure is then pushed up to 120 bar.

Table 3.4: Simulation Parameters For A CO_2 Capture Plant Including Scenarios For Complete And Partial Capture.

Simulation parameter	Part 3	Part 2
Predicament	Completely Captured	Partial Capture
Analyses of the exhaust gas	Both Strings 1 and 2	String 1 only
Conditioning of Flue Gases	Moreover, this doesn't come with	Moreover, this doesn't come with
Quantity of captures	75 %	30 %
Component's gasifier velocity	60°C	70 °C
Heating of the combustion products entering the absorber	30°C	30 °C
Additive gas pressure input	1.21 bar	1.1 bar
Moles per second of inflow flue gas	11470 kgmol/h	5788 kgmol/h
Low Middle East and Africa (MEA) weather	40°C	40°C
Low pressure in the MEA	1.01 bar	1.01 bar
Rate of molecular flow in lean methyl ethanamide	96850 kgmole/h	527500 kg/h
Lean MEA's High Level of MEA	29.0 mass-%	29.0 mass-%
Lean Middle East and Africa (MEA) CO_2	5.3 mass-%	5.5 mass-%
Its absorber's generation count	15	15
In the absorption, there is a murphree efficient region.	0.11–0.21	0.11–0.21
Oxidizing agent pre-desorbed temperatures	104.6°C	101.2 °C
Estimated number of main character phases	10	10
Excellent main character performance	0.5	0.5
Flux-to-desorber-retention ratio	0.3	0.3
Tension from an attempt to figure	2.0 bar	2.0 bar

Table 3.4: Simulation Parameters For A CO_2 Capture Plant Including Scenarios For Complete And Partial Capture. "Tables Continued"

The frequency of the reaction chamber	120°C	120 °C
Electricity Tmin of the steam generator	117.1 MW	24.5 MW (only excess heat

3.2.4.3 Important things to consider regarding equipment dimensioning.

We have made some educated guesses about the size of the process equipment by using standard dimensioning parameters. The velocity that was determined by applying the k-factor of 0.15 metres per second to the Souders-Brown equation served as the basis for the design of the direct contact cooler unit. It is anticipated that the Direct contact cooler (DCC) has a total height of 15 metres, and the packing material that is used in it is stainless steel. The engine speed used to determine the height of the evaporator is 2.5 m/s, whereas the flowrate used to determine the width of the discharge pillar is 1 m/s. The stages inefficiencies were established, and the packaging heights of the adsorption and deactivation pillars are all one meter. There is an assumption that the absorbed gradient and the emission gradient are all also 22 meters high for a grand total of forty meters. Consider the size of the drainage, packed, solvent dispensers, rinse washes, characterized by activation, gaseous input, but also gas exit when calculating the absorber's altitude. Main character altitude is determined by a number of parameters, including those related to the condenser's intakes, packaging, liquids receiver, gases input, and basin.

Cylinder and tubing temperature transfers are the primary focus of this research. Assumptions for the total efficiency of thermal transference are as described in the following: 550 W/ (m^2.K) for the svelte heating element; 1,200 W/(m^2.K) for something like the heavy ammonium warmer; 400 W/(m^2.K) for something like the reaction chamber; 1010 W/(m2.K) for something like the condensing; and 750 W/(m^2.K) for something like the turbo chargers. In some circumstances, a plate and frame heat exchanger are investigated as a potential alternative to a lean/rich heat exchanger.

Machines that use gravitational force are the best option when using rich halide and light ammonium systems. Using the simulation-generated capillary stream velocity and pumped capacity, the expense of the engine's hardware may be calculated.

3.2.5 Sensitivity Analysis

Sometimes, the layout requirements aren't highlighted in the expenses which are traditionally published in the scientific documentation for recapture systems. It is impossible to reduce costs absent investigating the specifications, and it is similarly impossible to minimize expenses before investigating the give a reasonable. In order to examine every single one of the important economical and mechanical factors, this mentioned advantages two methods for doing data set of a method by the given scenario.

a. A analysis is done on the important design factors, such as the steam pressure (and temperature), and the total heat transfer coefficient values for the heat recovery steam generator and condenser are studied for excess heat recovery networks. A sensitivity study of the flue gas flow rate, CO_2 capture efficiency, modifying reboiler temperature, and ΔT_{min} in the lean/rich heat exchanger is carried out for CO_2 capture facilities.

b. An variables by taking into account the likelihood of the occurrence of various values. These include initial investment, expected lifetime, macroeconomic variables, operational expenditures, vapor expenditures, and the overall operational costs. energy costs, running hours, and total operating costs are the economic factors that have been chosen.

3.3 CO_2 CAPTURE PROCESSES COST ESTIMATION USING VARIOUS SOLVENTS/BLENDS

3.3.1 Simulations in Aspen Hysys

This section will first go through the processes involved in simulations. Both of these processes were detailed in the chapter before this one. The study starts with the definition of a basic case in which the absorber is loaded with 30 weight percent MEA as a solvent. The pertinent particulars for this scenario are going to be presented in the following. The work continues with the use of various amounts of additional solvents as well as mixes of those

solvents as the solvent. The purpose for this is so that we may have CO_2 removal procedures that are improved rather than just the baseline scenario. Also, an ideal mixture that optimizes the removal process in regulating parameters, particularly regeneration energy, will be sought after, and it will be attempted to be found.

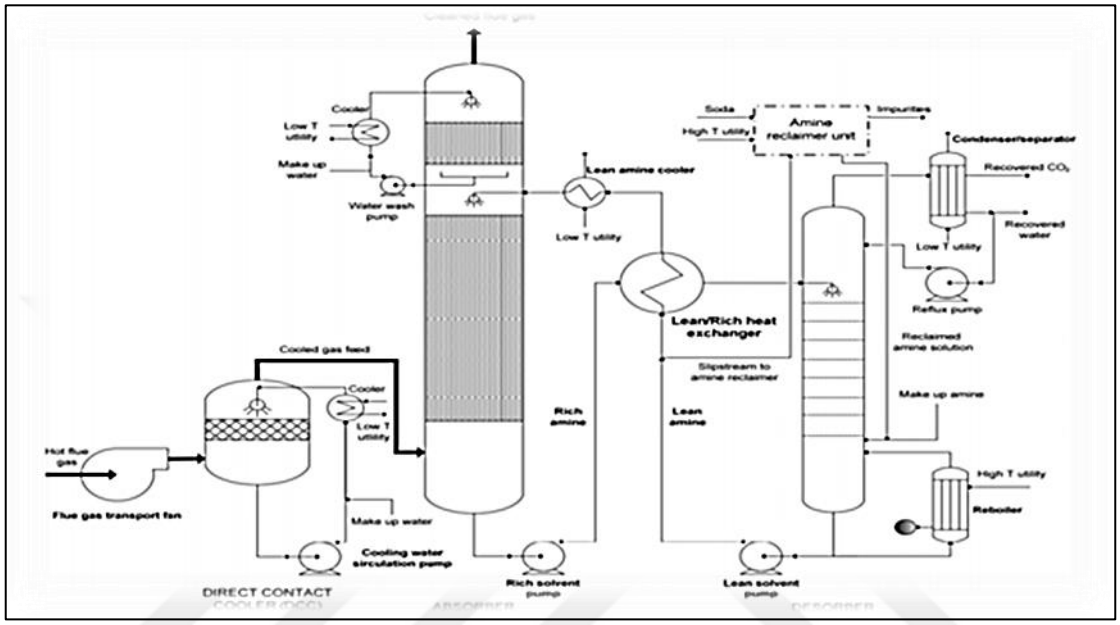


Figure 3.3: Typical CO_2 Removal Process Plant Flowchart [53].

3.3.1.1 Specification of base case simulation

The first attributes for the various components that will be taking part in the process. After that, the package definition for the software has to be completed. The present effort is based on a chemical solvents and acid gas package, which is providing support for amines and the blends of those amines. The lack of tri-amine combinations in the different additives and ethylene oxide bundle employed in this investigation is a limitation of the research. This is one of the limits of the package.

The next step in the process is specifying the pieces of equipment to be used, along with the streams that will enter and exit each component. It is necessary, first and foremost, to establish a practicable base case in order to be able to compare the impacts of using various solvents and their respective mixes which describes a scenario using an optimized process that contains 30% MEA solvent. In the basic scenario, it has also been anticipated that the

lean/rich heat exchanger will have an efficiency of removal of 85% and a minimum approach temperature of 10°C and that the lowest approaches value for the slender water heater will just be 10 degrees Celsius, whereas the performance of evacuation will be 85%.

Aspen HYSYS versions 10 and 12 have been used to model various carbon dioxide removal processes. The requirements that relate to the basic case are shown in Table 3.5.

Table 3.5: Details On How CO_2 Will Be Filtered Out of The Simulator.

Parameter	Value	Unit
Gasification velocity entering the processing system	30	℃
Flue compressed nitrogen at the operation entrance	130	kPa
Gas stream velocity at the intake	1511	kg/h
Intake gas CO_2 percentage	2.4	kg%
Intake gas moisture	3.50	$mol\%$
Comparison of pre- and post-pump temperatures for light amino group	110	℃
Compressed amine in front of the sulfide pumping	250	kPa
Rich pumping results in increased ammonium concentration	300	kPa
Reduced ammonium absorption capacity	201	kPa
Insulation thin an ionic rate	117500	$kgmol/h$
carbon dioxide concentration in low amino group	0.01	kg %
The absorber's cycle count	10	-

Table 3.5: Details On How CO2 Will Be Filtered Out Of The Simulator." Tables Continued."

Massive pressure of rich amines just before the pump	110	kPa
High-pressure ammonium solution	200	kPa
No of desorber's trays	6 + Reboiler + Condenser	-
Insulating efficacy in terms of its phases	120	℃
Level performance in a desorber	0.25	-

however, the basic scenario was also simulated with the efficiency of stages set at 0.17. The Aspen HYSYS programmed made the proposal that this figureure be used for the base scenario, although it is impossible for it to be practical.

In addition to the basic scenario, which used MEA at a concentration of 30 weight percent as the solvent, All three percentages of MEA (35, 40, and 45 wt%) were modeled in the Denitrification modeling approach. The figure given below shows the Aspen HYSYS flowchart used in the initial ruling simulations.

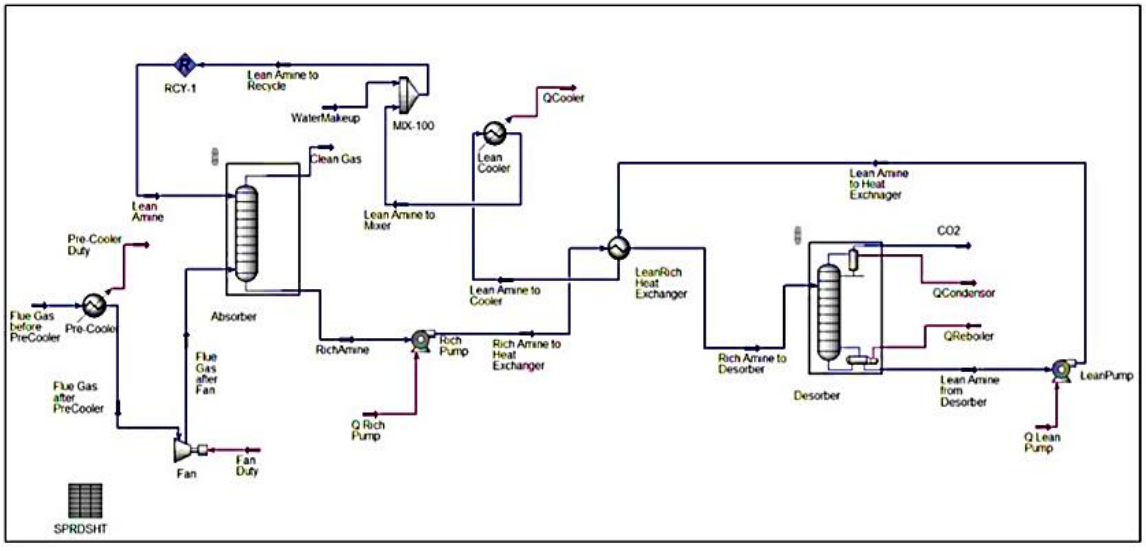


Figure 3.4: Flowchart Of The Common CO_2 Removal Procedure From Aspen HYSYS

3.3.1.2 Other solvents and mixes specification

In order to recreate the typical removal process, a number of additional solvents, including MDEA and piperazine (PZ), as well as blends of these solvents, such as MEA plus MDEA and MEA plus PZ, have been used. This has been done in order to simulate the process. The criteria for the base case have been used as the basis for the design of the procedures in many of the cases. The cases that were simulated are broken down and summarized in the following table. In every conceivable situation, the removal efficacy is 85%, and the temperature difference between approaches only varies by a maximum of 10 degrees Celsius.

The following is a list of the seven classifications that each of the simulated standard removal procedures may be placed into:

i. Standard removal method using amine blends of MEA and PZ with 30 weight percent amine.

ii. Standard removal technique using amine mixes of MEA and PZ with 40 weight percent amine.

iii. Standard removal technique using amine mixes of MEA and MDEA containing 30 weight percent.

iv. Standard removal technique using amine mixes of MEA and MDEA containing 40 weight percent.

v. Standard removal technique with amine mixes of MEA and MDEA containing 50 weight percent of each amone.

vi. Standard removal technique using amine mixes of MDEA and PZ containing 40% by weight of amine.

vii. Standard removal technique with amine mixes of MDEA and PZ containing 50 weight percent amine.

Table 3.6: Process Simulations For The Conventional Procedure Using Different Solvents And Mixes.

50 wt% MDEA+PZ	50% MDEA	45% MDEA+5%PZ	40%MDEA+10%PZ	35%MDEA+15% PZ
40 wt% MDEA+PZ	40% MDEA	35% MDEA+5% PZ	30% MDEA+10% PZ	25% MDEA+15% PZ
50 wt% MEA+MDEA	50% MEA	45% MEA+5%MDEA	40%MEA+10%M DEA	35%MEA+15%M DEA
40 wt% MEA+MDEA	40% MEA	35% MEA+5% MDEA	30% MEA+10% MDEA	25% MEA+15% MDEA
30 wt% MEA+MDEA	30% MEA	25% MEA+5% MDEA	22.5% MEA+7.5% MDEA	20% MEA+10% MDEA
40 wt% MEA+PZ	40% MEA	35% MEA+5% PZ	30% MEA+10% PZ	25% MEA+15% PZ
30 wt% MEA+PZ	30% MEA	27.5% MEA+2.5% PZ	25% MEA+5% PZ	22.5% MEA+7.5% PZ

Table 3.6: Process Simulations For The Conventional Procedure Using Different Solvents And Mixes.” Tables Continued.”

30%MDEA+20% PZ	25%MDEA+25% PZ	20%MDEA+30% PZ	15%MDEA+35% PZ	10%MDEA+40% PZ
20% MDEA+20% PZ	15% MDEA+25% PZ	10% MDEA+30% PZ	5% MDEA+35% PZ	40% PZ
30%MEA+20%M DEA	25%MEA+25%M DEA	20%MEA+30%M DEA	15%MEA+35%M DEA	10%MEA+40%M DEA
20% MEA+20% MDEA	15% MEA+25% MDEA	10% MEA+30% MDEA	5% MEA+35% MDEA	40% MDEA
15% MEA+15% MDEA	10% MEA+20% MDEA	5% MEA+25% MDEA	30% MDEA	
20% MEA+20% PZ	15% MEA+25% PZ	10% MEA+30% PZ	5% MEA+35% PZ	40% PZ
20% MEA+10% PZ	15% MEA+15% PZ	10% MEA+20% PZ	5% MEA+25% PZ	30% PZ

Table 3.6: Process Simulations For The Conventional Procedure Using Different Solvents And Mixes.” Tables Continued.”

	5%MEA+45%M DEA		5%MDEA+45% PZ
	50%MD EA		50%PZ

In addition to table 3.6, two further instances were simulated, one of which had a mix of 30 weight percent MEA and 5 weight percent PZ with the identical parameters as the tabulated examples with ME values of 0.3 and 0.35.

3.3.1.3 Specifications for the process of vapors compression

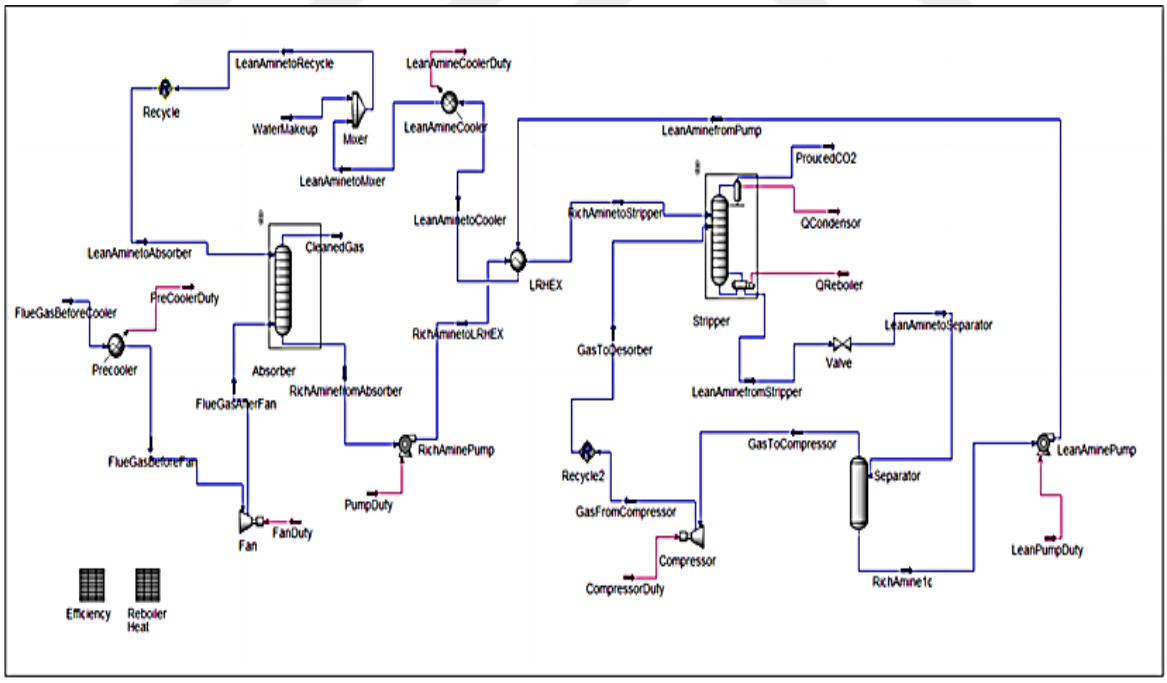


Figure 3.5: Process For Removing CO_2 From Vapour Recompression Flowsheet Developed By Aspen.

The vapour recompression process was modelled using a MEA solvent of 30 weight percent. It was expected that the removal efficiency for the simulated situation would be 85%, and

the lean minimum approach temperature would be set at 10°C. Additionally, it was assumed that now the efficiency of each level in the absorber was 0.25.

The requirements and standards for the process of vapor recompression are, for the most part, the same. The addition of a regulator, a sieve, and a compressor to the normal procedure is the most significant change brought about by this study. The pressure of the stripper's output stream is lowered from 200 kPa to 100 kPa as a result of the valve, which corresponds to the changes in the process parameters. A linear valve with a 50% opening is responsible for bringing about this decrease in pressure. The separator is operating at a pressure of 100 kPa. At a pressure of one hundred kilopascals, the liquefied portion of the inflow stream into the separator emerges out the bottom of the separator item. The vapour exits the separator at a pressure of one hundred kilopascals (kPa). In point of fact, the pressure of the liquid has to be brought up to 300 kPa, while the pressure of the vapour needs to be brought up to 200 kPa.

In a further development, amine mixtures of 30% MEA and 15% annual MDEA were simulated during the gaseous depressurization operation., as well as 30% MEA and 5% PZ. Bott noted that mixes have the same parameters as the simulation given before in terms of Logarithmic mean temperature difference LMTD. At a setting of five centigrade, a svelte evaporator coil was utilized to model vapors researchers and industry for a mixture of thirty wt percentage MEA and fifteen weighted percentage MDEA.

3.3.2 Economy of the Project

First and foremost, this portion of the work comprises explanations that are essential for cost estimate methodologies, as well as the contents of CAPEX and OPEX. The performed cost estimate for simulated processes is the next topic covered in this chapter. The feasibility of the project has been calculated using data taken from the most recent version of the Aspen In-Plant Cost Estimator.

3.3.2.1 OPEX and CAPEX

In general, expenditures may be broken down into two distinct categories: operational expenditure and capital expenditure, sometimes known as CAPEX and OPEX respectively (OPEX). In point of fact, the term "CAPEX" refers to one-time payments made for the

purpose of obtaining services, as well as the purchase of tangible assets and items. Due to the fact that they have an effect on the production capacity of the company over the course of an extended period of time (Dikov, 2020), many businesses see CAPEX as a kind of significant investment. One further reason for their significance is that they have rather high starting prices.

[54] divided CAPEX into the following categories:

a. Property acquisition

b. Laying pipe,

c. Hooking up utilities to existing structures are the three main steps in developing a place.

d. Apartments and workspaces used for official purposes.

CAPEX does not include funding for ground and buildings in this work.

OPEX, which stands for operational costs or expenditure, on the other hand, refers to the continuing cost of running a product, service, or system. This category also includes relevant money for system maintenance. Workers' salary and pay, taxes, raw materials, replacement parts, and rent costs are all instances of OPEX [54].

3.3.2.2 CAPEX

Initial capital expenditure (CAPEX) estimates are made for this development by sizing and defining individual unit piece in terms of its measurements. Many different approaches can be taken to determine or ascertain the price of manufacturing machinery. Depreciation projections can be derived from a variety of multiple locations, such as contractor quotes, allocated pricing, private facts from successful works, business libraries, publications, and even the website.

Although having direct knowledge of the latest information from either the producer on every component in the plant is ideal, sometimes this isn't possible recommended that using in-house data from prior projects is a useful way to analyses the project's economics.

Commercial databases, as previously indicated, are also accessible and may be utilized to estimate equipment costs

CapEx can be calculated with the use of the Aspen In-Plant Cost Calculator, which requires precise information for each part of the cleanup operation. As was discussed in the previous section, factors such as unit dimension, quantity of necessary parameters, and architectural features all play a role in determining the final price tag. All of the operational characteristics, including strain, humidity, erosion, as well as hydraulic conductivity, have a direct impact on the materials that can be used [57]

3.3.2.3 Techniques of enhanced detailed factor (EDF)

Cash expenses, operational expenses, payroll taxes, installation fees, and high implementation ends up costing are all examples of additional expenses that should be reported for. Every single one of the provided labels has its own set of related concepts. Fabrication, sewage, electrical, measurement, construction of the operates, stone and metal framing, and insulate are all examples of ever more particular sections for which only expenditures are assigned. In the following, we list a few of them.

Table 3.7: Main Elements Constituting Installing Factor.

Direct costs	Engineering costs	Administration costs	Other costs
Equipment	Process	Purchasing	Commissioning
Erection	Mechanical	handling a program	Contingency
Pippin	Piping	Facility administration	
Construction	Insulator	Leadership in Strategic Planning	
Electromagnetic	Technology		
Instrumentation	Steel and Ceramic		
Metal and cement	Electromagnetic		
Encapsulation	Instruments		

The equipment prices derived first from Aspen In-Plant Cost calculator need to be adjusted by those variables so that they take into account everything listed in table 3.17. After that, the associated with replacing price to every item is shown.

3.3.2.4 Material factor

As was said before, the recycling facility is organized such that each component handles that specified resource. Steels such as tungsten and chromium are used for this purpose. This means we need to start including the cost in our calculations for everything. The EDF table's CS construction provides the impetus for the adjustment.

We've listed the components of each kind of substance above.

Table 3.8: Material Considerations For Various Types Of Building.

Sort of Material	Material Factor
SS316 Welded Sterling Silver	1.55
SS316 corrosion resistance	1.20
Fiberglass-reinforced polymer	1.0
Rare and unique components	2.33

Looking more closely at table 3. 8, we can see that corrosion resistance is separated into two distinct categories: soldered and milled. Welded stainless steel elements in the CO_2 capture removal facility.

a. "Rich amine pumping"

b. Skinny ammonium pumps

For pumps, the machined variety features:

a. The absorption,

b. stripping,

c. lean rich heat exchanging,

d. lean amine cooling, condensing,

e. rebuilding stages:

Here is a table detailing the metal and chemical element parameters for each given machine component. This data was derived from the article "Costing of Equilibrium Adsorption Units for Pollution Reduction - Methods and Hypotheses" [57]

Table 3.9: Material Specifications And How They Affect Equipment.

List of equipment	Material	Material factor
Thermal Storage	SS316	1.75
Insulating	SS316	1.75
Stripping Device	SS316	1.75
Fan damp heater	SS316	1.75
chiller heater rich	SS316	1.75
ammonium motor	SS316	1.75
Pump for reducing anionic levels	CS	1.0
Compressor	SS316	1.3
Separator	SS316	1.3

To properly adapt the material to the EDF table, the cost of the equipment associated with each individual item has to be split by the material factor. This table may be found towards the conclusion of the appendix. So,

$$equipment\ cost_{CS} = \frac{equipment\ cost_{cost}}{f_{mat}} \tag{3.15}$$

where, *f_mat* may be taken from table 3.19, and the value that is obtained after doing so can, at the moment, be used to locate an acceptable. This coefficient may be used for the material known as carbon steel. Therefore, the coefficient has to be transformed into a form that is applicable to SS material. Formula 3.22 is the tool that is used for this assignment.

$$f_{t,SS} = f_{t,CS} + [f_{m,SS} - f_{m,CS}] + [f_{p,SS} - f_{p,CS}] \quad (3.16)$$

where *f_(t,SS)* represents the total cost factor of stainless steel and *f_(t,CS)* represents the total cost factor of carbon steel, *f_(m,SS)* represents the material cost factor of stainless steel, and *f_(m,CS)* represents the cost factor of carbon steel. Finally, *f_(p,SS)* represents the piping cost factor of stainless steel and *f_(p,CS)* represents the cost factor of carbon steel.

The total cost of installation for each piece of equipment may be determined by taking the apparatus charge from the Aspen In-Plant and multiplying it by the computed factor. The total CAPEX is the sum of the CAPEX for each individual component.

3.3.2.5 Cost index for chemical engineering plants

The prices of the equipment that are provided in section 5.4 pertain to the year 2016, while the project in question will be carried out in the year 2022. Due to the fact that the value of money might fluctuate from one period to the next, it is necessary to make adjustments to the costs. This objective may be accomplished with its help.

Since Aspen In-Plant Cost Estimator version 10 only contains data for 2016, and the present project won't be finished until 2021, the CEPCI figureures for 2016 and 2021 should be combined to get an accurate CAPEX estimate.

Table 3.10: Chemical Engineering Plant Cost Index

Year	Chemical Engineering Plant Cost index (CEPCI)
2016	542
2021	655.7

This adjustment is done with:

$$Cost_{2021} = Cost_{2016} \times \frac{CEPCI_{2021}}{CEPCI_{2016}} \quad (3.17)$$

3.3.2.6 Power law

The concept of power law refers to a functional connection in which one quantity is calculated based on its proportionate relationship with another variable. This relationship can be expressed mathematically as 3.24, where Cost1 represents the calculated cost for the aptitude of Items 1 is denoted by Q1, the potential of Below by Q2, and the scalability variable, or cost exponents, e, is defined as the difference between the expected costs of Items 1 and 2. (Orangi, Farsi Madan, Fajferek, Saeter, & Bahri, 2020).

To illustrate, let's say you're calculating the price of a reaction vessel with a certain capability. Q1 is Cost1, then the cost of an absorber column that is functionally identical but has a capacity that is different from Q2 will be connected in the manner that:

$$Cost_2 = Cost_1 \left(\frac{Q_2}{Q_1}\right)^e \tag{3.18}$$

The scaling constant typically has a range of $0.4 < e < 0.9$, for its valve, but 0.65 is believed to be the average value.

3.3.2.7 Opex

It was explained that CAPEX may encompass a variety of different things. In this particular endeavor, the scope of OPEX is restricted to include just steam, power, cooling water utilities, and raw material. The needed solvents or mixtures of such solvents serve as the work's raw material.

In order to accomplish the goal of the reboiler, it is necessary for this project to provide steam utility. In addition, the cooling water utility meets the criteria. In conclusion, electricity is necessary for the operation of lean and rich pumps, as well as fans and compressors.

It is necessary to first explain a number of pertinent factors before moving on to the OPEX calculations for the simulated operations.

a. Plant lifetime

The amount of time available is a crucial factor in any endeavor. Therefore, it needs to be taken into consideration while doing an economic analysis of the project. It is safe to presume that CO_2 capture plants have a lifespan of twenty years based on the findings of several studies. Different recommendations have been made, which may be found in a few other books.

For the sake of this study, the lifespan of the project is considered to be twenty years.

b. Discount rate

The value of money changes throughout time. Additionally, carbon dioxide removal facilities are being built for a sizable time period. Therefore, it is appropriate to reflect changes in the worth of money during the course of the project.

Interest rates vary from 7% to 14%. In this study, the parameter is 7.5%, which is considered to remain constant during the project's duration (Cost Estimation of CO_2 Absorption Plants for CO_2 Mitigation). Other works have additional assumptions. For instance, work assumes a 7% annual discount rate [54].

c. Maintenance cost

Any expenses made by a person or organization to maintain the assets in excellent operating order are referred to as maintenance expenditures. An example of this kind of expense is paying money to maintain equipment.

Typically, this expense is assumed to be a constant percentage of the entire cost of installation (total CAPEX). This variable is a 2%-5% range. According to, 4% is the sweet spot to aim for. The authors Hassan estimated that this cost would amount to 5% of total CAPEX. To determine the OPEX cost for removal procedures, this part uses an assumption of 4% [55].

c. Utilities cost

As was previously indicated, part of the machinery in the CO_2 removal facilities needs utilities. Although the exchanger makes use of steaming, the heat exchangers and weak

amine conditioners depend on power, while motors and turbines need power supply. However, as utility are an ongoing expense, they have to be factored into the OPEX total.

There is a wide range of utility costs identified in the studies. Electricity costs 0.4 (NOKkWh) according to [54], with steaming costing 0.1 (NOKkWh) but also water costing 0.033 (NOK/m3). for cooling water. Table 3.21 contains costs for the utilities used in this project.

Table 3.11: Price projections for the utility project

Utility	Value	Unit
Power	0.132	$[kWh]$
Vapor	0.032	$[kWh]$
Cooling aquatic	0.022	[€ $/m^3$]

a. Annual hours of operation

The yearly working hours reference to the sum amount of time throughout which the entire institution is used for any and all marketing gain.

Based on the capturing unit, this period of time differs among researches. Acording to Norman reported this parameter as 8322 [hours per year] for the steel sector, 7840 [hours per year] for pulp, 7320 [hours per year] for cement, and 8760 [hours per year] for silicon. Additionally, this value is expected to be 8000 [hours] each year based on steam production. This period was expected to be 7450 hours per year [55].

a. Cost of solvent

Three distinct solvents, MEA, MDEA, and PZ, have been employed in this investigation, as was already indicated. The two least priced amines are MEA and DEA. Below is a list of several amines' prices.

Table 3.12: Price of Amine

Amine	Value	Unit
Diethylamine	66.40	[€/$litre$]

Table 3.12: Price of Amine "Table Continued"

MEA	30.50	[€/$litre$]
PZ	68.70	[€/$litre$]
EDA	31.70	[€/$litre$]
MDEA	51.60	[€/$litre$]
DEA	25.70	[€/$litre$]

In this effort, the value for MEA is extracted from (Aromada et al., 2020) work, 2069 [m^3].

Cost for MDEA and PZ is intended correspondingly from table 3.22 which principal to 4660 [m^3] for PZ and 3494 [m^3] for MDEA.

3.3.2.8 Estimating costs for simulated instances

When it comes to CAPEX, each simulated instance is, first and foremost, stated in terms of size, material, and number-based specifications. Additionally, each procedure was modified in terms of the installation cost factor depending on the EDF technique and the materials that were provided. The overall CAPEX was calculated by adding together the costs of each individual piece of plant machinery and equipment.

As was indicated, the calculation of OPEX necessitates taking a number of different aspects into consideration. In section 5.7, a concise explanation was provided for those that were significant. The parameters, together with their explanations, are shown in table 3.23 given below:

Table 3.13: Important Factors To Consider When Calculating OPEX.

Parameter	Value	Unit
The Biological Age of a Plant	30	[year]
Discounted percentage	6.5%	-
Expenses incurred for upkeep	4% of total CAPEX	-
Price of power	0.12	[kWh]

Table 3.13: Important Factors To Consider When Calculating OPEX."Table Continued"

What the price of steam	0.02	[kWh]
Amount of money spent on coolant	0.02	[€/m^3]
Prices for the MEA and the MDEA	209	[€/m^3]
Pricing for PZ	3594	[€/m^3]
Time spent working each year	460	[€/m^3]
We expect to see CEPCI in 2016 and 2020,	8000	[hours/year]

OPEX is calculated annually since it relates to running costs (Orangi et at., 2020). Any various cost expense may be estimated with the help of Equation 3.25. (Aromada et at., 2020).

$$Variable\ operating\ cost\ (year) = consumption\ (\text{unit}/hour) \times unit\ price\ (unit)\ opeational\ hours\ (hour/year) \tag{3.19}$$

Therefore, you need to do the calculation for each year. This may be accomplished by the use of the annualised factor (Aromada, Eldrup, Normann, & Øi 2020).

$$Annualized\ factor = \sum_{1}^{n} \frac{1}{(1+i)^n} \tag{3.20}$$

where, i indicates the interest rate and n is plant lifetime.

For the sake of this study, we will assume that the interest rate will remain the same throughout all of the computation years: 7.5%. In addition, the lifespan of a plant is estimated to be twenty years.

It is important to note that in certain studies, only a negligible portion of the plant's lifespan is allocated to the building period. For example, in (Aromada, Eldrup, Normann, & Øi 2020), the overall lifespan of the plant was expected to be 25 years, with the first two years being devoted to its development. This work does not incorporate the aforementioned assumption.

The application of the annualized factor to the total CAPEX ultimately results in the annualized CAPEX.

$$Annualized\ CAPEX = \frac{Total\ CAPEX}{Annualized\ factor} \tag{3.21}$$

3.3.2.9 Economy Analysis

The total yearly cost is used to determine the economy of each simulated process, taking into account:

$$total\ annual\ cost\ (\text{Currency/year}) = annualized\ CAPEX\ (year) + annual\ OPEX\ (year) \tag{3.22}$$

In the present study, the basic case is taken to be a reference so that the total yearly cost of additional processes that require MDEA and PZ or their mixes may be compared. These other processes include the usage of solvents.

The cost of CO_2 capture is another factor that may be considered when contrasting various procedures from an economic point of view. This cost is described as:

$$Annual\ cost\ of\ captured\ Co_2$$

$$= \frac{total\ annual\ cost\ (Rs/year)}{mass\ flow\ rate\ of\ captured\ Co_2 (kg/year)} \tag{3.23}$$

Both of the established metrics in 3.28 and 3.29 are utilized to determine whether or not there has been an economic improvement as a result of using solvents or their blends as opposed to the base scenario, which utilizes MEA at a concentration of 30 weight percent.

As was indicated previously, the method of removing CO_2 using amines is an energy-intensive process that utilizes a significant amount of energy in the reboiler for the purpose of regeneration. Therefore, one may get this parameter by the use of a simulated process.

$$regeneration\ energy = \frac{\text{applied steam in proces } \left[\frac{MJ}{h}\right]}{\text{Mass flow rate of caprture } CO_2 \left[\frac{kg}{h}\right]} \quad \left[\frac{MJ}{kg}\right] \tag{3.24}$$

All simulation workflows have this value calculated in order to discover how using non-native liquids or solution mixtures affects the overall system.

3.3.2.10 Guidelines for aspen in-plant cost estimator cost estimating

The work that is being done right now to analyze the economy has been met with certain challenges. These issues, along with some potential solutions to them, will be enumerated and discussed in this section.

Having an absorber of such a massive scale in order to achieve the desired outcome of the operation comes at a significant financial expense to the facility. Therefore, it is not unreasonable to have smaller things that take up the same amount of space in the packaging. The large absorber is cut up into sixteen smaller absorbers as part of this procedure.

i. Because it is one of the most significant pieces of machinery in the plant, the lean rich heat exchanger has to have a big contact area in order to fulfil the objectives of the plant. It is impossible to heat this large of an area with just one heat exchanger, thus it is best to look into using many, smaller ones. The relevant assumption is one 1000 m2 per shell. Therefore, the huge area of the lean rich heat exchanger is split into many smaller areas, each of which is the same as the others.

ii. As was remarked upon before, the flue gas flow rate in this operation is rather high. Therefore, the supposed fan for the process has to be strong enough, and as a result, its size needs to be increased. Due to the size of the fan required for this task, an "out of range size" mistake was made in the cost calculation. This mistake may be remedied by supposing the operation of two parallel fans that are both smaller and similar in design.

iii. In most of the studies, just one of the examples is looked at from an economic perspective, while the rest of the cases are computed using the power law. This procedure could not be much easier, but the findings would be subject to a far larger degree of uncertainty. Inside the scope of this job, comprehensive estimates are provided for each and every simulated situation, as well as for every piece of applicable equipment within the plant. A method of this kind requires more time, but the results are more accurate.

iv. The major pieces of plant equipment are the only ones that count toward the economy of the current job. There are a few more things that might be considered for CAPEX that are more realistic. In addition, regarding the OPEX, it is necessary to include human resources such as employees and engineers in the calculations.

4. RESULTS

4.1 SIMULATION RESULTS

Every simulation that is discussed in this chapter was performed using Aspen HYSYS version 10. We have looked at the simulated instances in terms of renewal vigor, lean amine lading, rich amine loading, and cyclic lading. The extracted findings will have an explanation provided, which is devoted to the discussion of the outcomes. This will allow overall costs for removal plants to be reduced, in addition to other improvements.

4.1.1 Dimensioning and Equipment

First and foremost, this section consists of dimensioning, which explains the sizes and materials of the main pieces of equipment used in the CO_2 removal process. In addition to this, the criteria that were used to pick eaequch individual component of the plant will be discussed. In addition to that, the applicable equations for each piece of apparatus are provided in this chapter. The data that is provides the necessary information for the economic analysis of the scheme. The following provides a concise explanation of each component found in the plant.

4.1.2 Absorption Column

The transfer of class from the vaporous stage to a gooey flush is what we mean when we talk about absorption, which is the most critical step in a CO_2 removal plant. Gas absorption, gas scrubbing, and gas washing are some of the other names that have been used to refer to this procedure. This method is used in the separation of gas mixtures, the recovery of compounds, and the elimination of contaminants [56].

The flue gas and liquid solvent flow in a counter-current direction throughout the absorption process. In other words, flue gas, which may include carbon dioxide, The solvents, on the other hand, joins the row first from summit. In this line, you'll locate the phone gadgets that inserted in order to give the highest possible surface area for interaction between the flue gas and the liquid solvent [54].

There are several variants of the absorption column to choose from. In this particular piece of work, a packaging kind is used. The table that follows presents the required specs for the absorber that will be used in this project.

Table 4.1: Details on the Absorption Column

Parameter	Symbol	Unit	Specification	Note
Gas Velocities	-	-	Packed	Specified
Columnar Variety	$\boldsymbol{v_{gas}}$	$[m/s]$	2.5	Specified
True Volumetric	V	$[m^3/s]$	Extracted from simulation	Specified
Efficiency Size	N_{stages}	-	10	Specified
Pages count	$h_{packing}$	$[m/stage]$	1	Specified
Level of Filling	$V_{packing}$	$[m^3]$	Based on formula 3.15	Calculated
Measurement of packed content	H	$[m]$	40	Estimated
Elevation of Parameter	D	$[m]$	0.897	Calculated
Type of Packaging	-	-	SS316	Specified
Sleeve Polymer	-	-	Structured	Specified

Using the formula 4.1 that is provided below, one may get the value of the absorption column. In addition to the packing height, the column should have room for a bottom liquid reservoir as well as a water wash column. Because of this, [54] proposed that an additional height be added to the column in order to give enough area for the input, top and bottom outputs, and auxiliary equipment. It should be brought to everyone's attention one stage is presumed to be equivalent to one metre of height. In order to calculate the overall packing height, then, the number of steps must be multiplied by one metre.

Ali et al., (2019) proposed that the intake gas speed to the preoccupation support is 2.5 *[m⁄s]* per second. Because of this assumption, the formula for estimating the diameter of the column is 4.1.

$$D = \sqrt{4.\frac{\dot{V}}{\pi.v_{gas}}} \tag{4.1}$$

Where, D (m) is the predicted absorber publication's width, V ̇(m^3/s) while v_gas (m/s) is the expected intake gas velocity to the absorber, is the actual gas volumetric flow rate that is being delivered to the column.

For the purpose of calculating the overall volume of the packing, the formula 4.2 is used.

$$V_{packing} = \frac{\pi.D^2}{4}.N_{stages} \tag{4.2}$$

V_packing (m^3) is the amount of space used by the packing in the absorber, D (m) is the diameter that was determined, and N_stages represent the total number of steps in the column.

According to Arachchige and Melaaen, there are two distinct types of packing materials that may be used for gas absorption, and these are structured packing and random packing. Figureure 4.1 below presents an example of structured packing [57]. When it comes to large-scale Equilibrium adsorption pillars, organized packed is preferred over randomised packaging due to its higher performance, bigger capacities, and minimum velocity decrease along the pillar . Figure 4.1 illustrates how the overall material transference factor may be increased by the use of accomplish things since there is more gas-to-liquid transition zone.

Figure 4.1: Structured (right) and Random (left) Packing [58]

4.1.3 Desorption Column

In order to extract CO_2 from solution using a desorption column, heat is required. The amine that has been regenerated enters the cyclic removal process seen from bottom, although the collected atmospheric carbon dioxide escapes first from base off the stack. The theater is at the bottom of the column, and the condensing is at the apex. There are a lot of parallels to be seen between the construction and operation of an absorption column and this column. Calculating the dimensions of this piece of machinery using formulas 3.14 and 3.15 is also part of the process. According to Ali et al., (2019) an entrance velocity of flow to column of 1.0 m⁄s i s a good choic e. The column may be constructed according to the par ameters listed in table 4.2.

Table 4.2: Desorption Column Specifications

Parameter	Symbol	Unit	Specification	Note
The Rate of Flow	-	-	Packed	Specified
Columnar Structure	$\boldsymbol{v_{gas}}$	[m/s]	1	Specified
Value of genuine	V	[$A\ \boldsymbol{m^3/s}$]	Table K.2	HYSYS
Fluid velocity	$\boldsymbol{N_{stages}}$	-	6 + reboiler + condenser	Specified

Table 4.2: Desorption Column Specifications."Tables Continued

Phase count	$\boldsymbol{h_{packing}}$	$[m/_{stage}]$	1	Specified
Packaging heights	$\boldsymbol{V_{packing}}$	$[m^3]$	Based on formula 3.15	Calculated
Measurement of packed content	H	$[m]$	20	Assumed
Elevation of Straight	D	$[m]$	0.9 Based on formula	Calculated
Tube of Columns	-	-	SS316	Specified
Type of Packaging and Sleeve Polymer	-	-	Structured	Specified

4.1.4 Lean / Rich Heat Exchanger

In order to recoup energy during the isolation procedure, a skinny exchanger is used. In other sense, the leaner oxidising agent in the hooker's dregs acts as a liquid state, warming up the rich alkaline solution at the absorber's base. The amount of time spent reboiling rich amines decreases when the temperatures of the amines is raised. [54].

In order to accomplish the objectives of this study and fulfil the requirements, a heat exchanger of the shell and tube type, as illustrated in figureure 4.2, is used. According to Aromada, Eldrup, Normann, and Øi (2020), this particular kind of heat exchanger is the most durable.

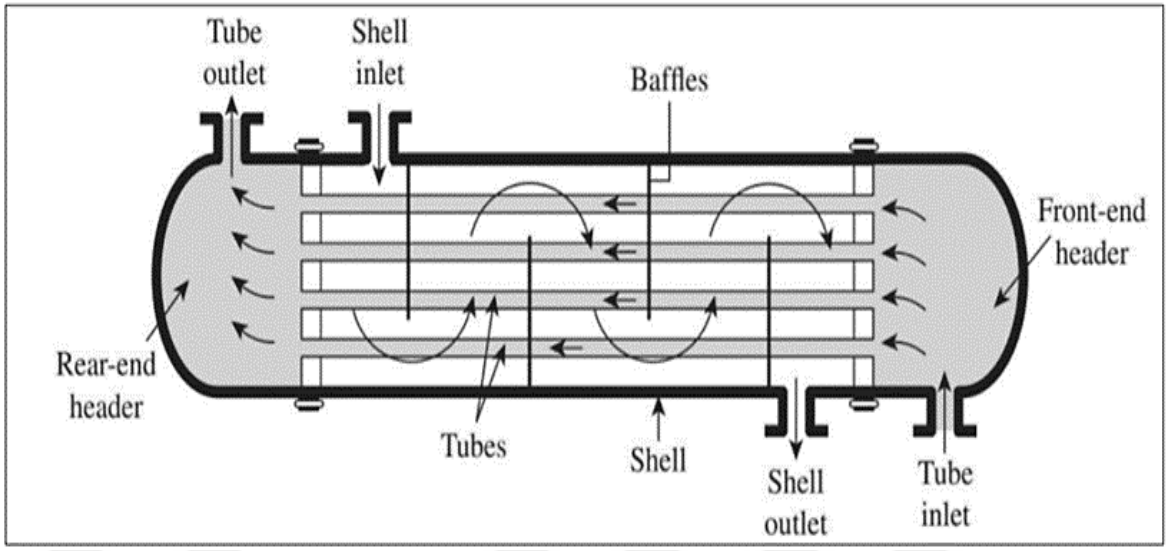


Figure 4.2: Shell and Tube Heat Exchanger

Formula 4.3 is used to calculate the size of the lean rich heat exchanger. which can be seen below.

$$A.\frac{\dot{Q}}{U.\Delta T_{lm}} \tag{4.3}$$

where, A (m^2) reveals the heat exchanger's overall area, $\dot{Q}$ (kW) is heat exchanger duty and U (W/m^2K)

U (W/m^2K) is the global coefficient of heat transfer. Equation 4.4 computes ΔT_{lm}, the following, using a logarithmic mean temperature difference.

$$\Delta T_{lm} = \frac{\Delta T_{out} - \Delta T_{in}}{\ln \frac{\Delta T_{out}}{\Delta T_{in}}} \tag{4.4}$$

Where, ΔT_{lm} (℃) shows temperature using a logarithmic minimum technique, ΔT_{out} (℃) is referred to as the differential between the heat exchanger's cold and hot entrance streams, ($\Delta T_{hot,in}$, $-\Delta T_{cold,in}$), and ΔT_{ln} (℃) the distinction between hot and cold outlet streams, ($\Delta T_{hot,in}$, $-\Delta T_{cold,in}$).

In their 2019 multi-part work, Cost Estimate of Adsorbent Plants for Current Sustainability - Technique and Hypotheses, Ali, Eldrup, Normann, Skagestad, and I adopt a whole water transport factor, U, of 500 (W/m2 K) for lean rich heat exchangers.

The table that follows is a listing of the pertinent specs for the lean rich heat exchanger. . Because of this, it is separated into many more manageable parts. The assumption used for this division is that the most common size of shell on the market is 1000 m2. Therefore, the total number of heat exchangers that are less capacious is computed.

A scaling factor of 0.65 has to be employed in each and every instance when approximating the charge of the overall smaller heat money changer.

Table 4.3: Lean-rich Heat Exchanger Specifications

Parameter	Symbol	Unit	Specification	Note
Types of Heating Systems	-	-	U-Tube Flow	Specified
Designation: TEMA	-	-	BEU	Specified
Heating capacity / Work load	$\dot{Q}$	$[kW]$	Based on simulations	HYSYS
The temperature coefficient of expansion and contraction	U	$[^{W}/_{m2K}]$	[62]	Specified
inlet heat	$\boldsymbol{T_{hot,in}}$	[°C]	Based on simulations	HYSYS
transfer temperatures	$\boldsymbol{T_{hot,out}}$	[°C]	Based on simulations	HYSYS
Thermal storage outlet temperatures	$\boldsymbol{T_{cold,in}}$	[°C]	Based on simulations	HYSYS

Table 4.3: Lean-rich Heat Exchanger Specifications"Tables Continued."

Calorie content of the chilly air entering the exchangers	$\boldsymbol{T_{cold,out}}$	[℃]	Based on simulations	HYSYS
outgoing cold-flow exchangers temperatures	$\boldsymbol{\Delta T_{lm}}$	[℃]	Based on formula 4.4	HYSYS/Calculated
Average Temperatures	A	[m^2]	Based on formula 4.3	Calculated
Distinction on a Linear Scale	-	-	SS316	Specified
Space needed in its entirety	-	-	316LW	Specified

4.1.5 Reboiler

A reboiler is a kind of heat exchanger that is positioned at the base of a desorption column. Its purpose is to bring the liquid to a boil and produce vapour. The majority of reboilers are heat exchangers with shells and tubes, and steam is often utilized to deliver the necessary amount of heat. The dimensions of the lean rich heat exchanger and the reboiler are entirely comparable to one another. Consequently, the most current formulae offered, compute the entire area for the reboiler.

The next table, 4.4, provides further parameters for the reboiler that will be used in the projec. [62]. An anticipated value of 800 (W/m2 K) for the Reboiler's total coefficients of heat transfer, or U.

Table 4.4: Reboiler Specification.

Parameter	Symbol	Unit	Specification	Note
Types of Heating Systems	-	-	U-Tube Flow	Specified
Designation: TEMA	-	-	BEU	Specified
Heating capacity / Work load	$\dot{Q}$	[kW]	Based on simulations	HYSYS
The temperature coefficient of expansion and contraction	U	[W/m^2K]	[62]	Specified
inlet heat	$\boldsymbol{T_{hot,in}}$	[°C]	Based on simulations	HYSYS
transfer temperatures	$\boldsymbol{T_{hot,out}}$	[°C]	Based on simulations	HYSYS
Thermal storage outlet temperatures	$\boldsymbol{T_{cold,in}}$	[°C]	Based on simulations	HYSYS
Calorie content of the chilly air entering the exchangers	$\boldsymbol{T_{cold,out}}$	[°C]	Based on simulations	HYSYS
outgoing cold-flow exchangers temperatures	$\boldsymbol{\Delta T_{lm}}$	[°C]	Based on formula 4.4	HYSYS/Calculated
Average Temperatures	A	[m^2]	Based on formula 4.3	Calculated
Distinction on a Linear Scale	-	-	SS316	Specified
Space needed in its entirety	-	-	316LW	Specified

4.1.6 Condenser

The transfer of heat to another material is required for the process of condensation. Because of this, water that has been cooled down is utilized to remove heat from the gaseous stream.

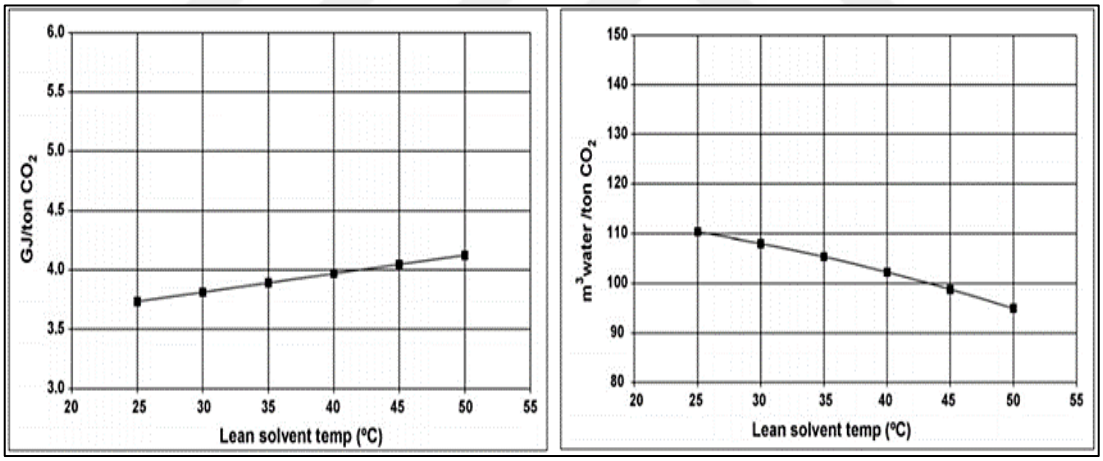
To calculate the required condensation surface for heat transfer, we apply equations 3.16 and 3.17. Ali is assuming that the condenser's total heat transfer efficiency, or U, is 1000 (W/m^2 K) [62]. The condenser's full range of characteristics and specifications are detailed in Table 4.5.

Table 4.5: Condenser Specification.

Parameter	Symbol	Unit	Specification	Note
Types of Heating Systems	-	-	U-Tube Flow	Specified
Designation: TEMA	-	-	BEU	Specified
Heating capacity / Work load	$\dot{Q}$	$[kW]$	Based on simulations	HYSYS
The temperature coefficient of expansion and contraction	U	$[W/m^2K]$	[62]	Specified
inlet heat	$\boldsymbol{T_{hot,in}}$	[°C]	Based on simulations	HYSYS
transfer temperatures	$\boldsymbol{T_{hot,out}}$	[°C]	Based on simulations	HYSYS
Thermal storage outlet temperatures	$\boldsymbol{T_{cold,in}}$	[°C]	Based on simulations	HYSYS
Calorie content of the chilly air entering the exchangers	$\boldsymbol{T_{cold,out}}$	[°C]	Based on simulations	HYSYS
outgoing cold-flow exchangers temperatures	$\boldsymbol{\Delta T_{lm}}$	[°C]	Based on formula 4.4	HYSYS/Calculated
Average Temperatures	A	$[m^2]$	Based on formula 4.3	Calculated
Distinction on a Linear Scale	-	-	SS316	Specified
Space needed in its entirety	-	-	316LW	Specified

4.1.7 Lean Amine Cooler

Lean amine coolers are a specific kind of heating element that use moisture to reduce the temperatures of a slender ammonium discharge to an ideal point. The efficiency of the stripping as a whole depends heavily on the degree of the lean amine; hence this variable must be fine-tuned. It was considered in several studies that 40 centigrade is the ideal value for the entry heat of lean amino group to absorber. According to research Abu-Zahra, there should be a resolution in between the quantity of coolant needed in the leaner ammonium warmer and thus the volume of regenerated power needed in the stripping. They modeled a 90% oxidizing agent filtration with 30% MEA as the solutes and found that raising the temperatures of toned halide prior to it being invented to the adsorbent improves the quantity of restoration power production needed to carry out the procedure while simultaneously lowering the quantity of refrigerant duty requisite for such toned amine refrigerator. Yet, the necessity of conditioning increases when light halide is fed to the absorption at a cooler pressure. Hence, optimizing the thermostat is essential [61].



Figureure 4.3: For a 90% MEA-Based Removal Procedure, Evaluation of Lean Amine Temperature and Regeneration Energy (left) and Cooling Water (right)[61].

Formulas 4.3 and 4.4 are used to compute the total area of the lean amine cooler that is needed.[62]. For the sake of this discussion, let's say that the leaner anionic coolers have an average ratio of heat transport of 800 (W/m^2 K).

Dimensioning needs for the lean amine cooler are detailed in Table 4.6table, which provides essential parameters and specifications.

Table 4.6: Lean Amine Cooler Specifications

Parameter	Symbol	Unit	Specification	Note
Types of Heating Systems	-	-	U-Tube Flow	Specified
Designation: TEMA	-	-	BEU	Specified
Heating capacity / Work load	$\dot{Q}$	$[kW]$	Based on simulations	HYSYS
The temperature coefficient of expansion and contraction	U	$[W/m^2K]$	[62]	Specified
inlet heat	$\boldsymbol{T_{hot,in}}$	[°C]	Based on simulations	HYSYS
transfer temperatures	$\boldsymbol{T_{hot,out}}$	[°C]	Based on simulations	HYSYS
Thermal storage outlet temperatures	$\boldsymbol{T_{cold,in}}$	[°C]	Based on simulations	HYSYS
Calorie content of the chilly air entering the exchangers	$\boldsymbol{T_{cold,out}}$	[°C]	Based on simulations	HYSYS
outgoing cold-flow exchangers temperatures	$\boldsymbol{\Delta T_{lm}}$	[°C]	Based on formula 4.4	HYSYS/Calculated
Average Temperatures	A	$[m^2]$	Based on formula 4.3	Calculated
Distinction on a Linear Scale	-	-	SS316	Specified
Space needed in its entirety	-	-	316LW	Specified

4.1.8 Pumps

Pumps may often be categorized in a limitless number of ways, depending on their size, kind, or usage. The rich pumping and the slim pumping are two distinct types of pumps used in the oxidizing agent CO_2 collecting process.

Table 4.7: Rich and Lean Pumps Specification.

Parameter	Symbol	Unit	Specification	Note
Model of Item	-	-	Centrifugal	Specified
Strength of Driver Model	-	-	Motor	Specified
Flux proportional	P	$[kW]$	Based on simulations	HYSYS
Pump thermodynamic	$\dot{\boldsymbol{V}}$	$[^{l}/_{s}]$	Based on simulations	HYSYS
effectiveness Diffuser substance	-	-	SS316	Specified
Slim ammonium aqueous	-	%	75	Specified
Amino-Rich Aqueous Heads	$\Delta \boldsymbol{H}_{\boldsymbol{lean}}$	$[m]$	70	Specified

At the absorber's bottom, the rich amine flows into the rich compressor, which then delivers it to the prostitute's head end. The slim compressor also provides the power required to drive the thin ammonium circulation first from ablation publication's foundation to the absorb page's top. In general, the power generated among these compressors must be sufficient to compensate for a wide range of limitations, such as

a. Losses caused by friction in the piping

b. The loss of pressure in the lean rich heat money changer that is located between the two supports.

c. The alteration in pressure among the absorption column and the desorption column

d. A decrease in pressure in the lean amine cooler.

For the sake of this study, it has been assumed that the rich pump and the lean pump are both centrifugal pumps with an adiabatic efficiency of 75%.

The needed power may all be retrieved from simulations and used in the dimensioning process of a pump. It is believed that the fluid head for rich pumps is 50 (m), whereas the fluid head for lean pumps is 70 (m).

The necessary parameters and specifications for Rich and Lean Pumps are outlined in the following Table 4.7.

4.1.9 Fan and Compressor

Fans and compressors are examples of the kinds of turbomachinery equipment that are used to augment the driving power of a fluid by the addition of energy. A fan is included in the CO_2 removal process so that the requisite driving power of flue gas may be supplied to counteract the pressure drop that occurs in the absorption column. The rotating fan in this investigation was considered to have a thermodynamic performance of 75%.

A compressor is employed in the evaporative depressurization cycle with a fan to compensate for the increase in stream water due to peeling intensity. In this study, 200 kPa is used as the stripping strength(kPa). This goal may be accomplished by using a centrifugal compressor that has an adiabatic efficiency of 75%. The following is a list of pertinent characteristics and standards for the dimensioning of the fan.

Table 4.8: Fan Specification

Parameter	Symbol	Unit	Specification	Note
Item type	-	-	Centrifugal	Specified
Driver type	-	-	Motor	Specified
Driver power	P	$[kW]$	Based on simulations	HYSYS
Venturi flow frequency in reality	$\dot{V}$	$[m3/hr]$	Based on simulations	HYSYS
Model of Item	-	-	CS	Specified
Venturi flow frequency in reality	-	%	75	Specified
Faster than thermal waste minimization	-	$[rpm]$	1800	Specified

The necessary specifications for the compressor to be used in the vapour recompression process are listed in Table 4.9.

Table 4.9: Compressor Specification.

Parameter	Symbol	Unit	Specification	Note
Item type	-	-	Centrifugal	Specified
Driver type	-	-	Motor	Specified
Driver power	P	$[kW]$	Based on simulations	HYSYS

Table 4.9: Compressor Specification." Tables Continued."

Venturi flow frequency in reality	V	$[m3/hr]$	Based on simulations	HYSYS
Model of Item	-	-	CS	Specified
Venturi flow frequency in reality	-	$[kPa]$	Based on simulations	HYSYS
Faster than thermal waste minimization	-	$[kPa]$	Based on simulations	HYSYS

Because of the high flow rate of flue gas in this job, the size of the fan is significantly increased. It is thus presumed that there are two fans operating in order to provide the necessary driving power for the procedure. For the sake of this division, we will assume that the scaling factor is 1.

4.1.10 Separator

The use of a vertical divider accomplishes this goal well. The fact that liquid is the predominant phase of flow was the primary factor in deciding to go with the vertical one. The Sounder – Browns (Ks) method is used for the dimensioning of the separator, and the corresponding equation is: (Moshfeghian, 2015).

$$V_{Gmax} = K_s \sqrt{\left(\frac{\rho_L - \rho_G}{\rho_G}\right)} \tag{4.5}$$

where, V_{Gmax} (m/s) specifies the maximum gas velocity that is allowed, Ks (m/s) defines as

sizing parameter, $\rho_L(kg/m^3)$ demonstrates the density of the liquid phase and $\rho_G(kg/m^3)$ refers to the density of the flow's gaseous phase.

It is safe to presume that the recommended value of KS is 0.081. Additionally, the density of the stream's liquid and gas phases is determined by simulations of their operations. Therefore, in accordance with formula 4.5, $V_{Gmax}$is computed, which, when combined with formula 4.6, yields the separator's diameter.

$$D_{min} = \sqrt{\frac{(4/\pi)q_a}{(F_g V_{Gmax})}} \tag{4.6}$$

where, $Dmin$ (m) is the minimum width the separation may have, q an is indeed the gasification rates at the circumstance wherein it's actually traveling in meters per second, and is the fraction of the cross-sectional region that can be used to move gas; for a vertically divider, it is considered that somehow this quantity equals 1. (Moshfeghian, 2015). (Orangi et al., 2020).

$$L/_{D_{min}} = 2.5 \tag{4.7}$$

where the height of the application is denoted by the unit L (m).

Below you will find a list that contains all of the necessary separator criteria.

Table 4.10: Separator Item Specifications.

Parameter	Symbol	Unit	Specification	Note
Separator alignment	-	-	Vertical	Specified
Length	D_{min}	$[m]$	Based on 4.6	Calculated
Measurement	L	$[m]$	Based on 4.7	Calculated
Solid	-	-	SS316	Specified

4.1.11 Non-listed Equipment

Only the most important pieces of equipment are described here since the purpose of this work is to do early research on a CO_2 removal process using amines other than MEA and

their mixes. This process does not include the use of an immediate contacting cooled (DCC), mixers, or solenoid valves.

The next step in this process is to estimate the costs. So, the estimated cost of each activity is increased by 20% well above projected expenditure computed to include non-listed assets in order to provide additional appropriate opinions based on the frugality of activities.

One of the most important aspects of this research is the CCS system. The system was modeled as a separate case to obtain detailed results. In this case, the composition and main physical elements are also reported to the main streams engaged in the simulation in the table above.

4.2 TECHNICAL RESULT

To carry out an effective technical analysis, the main results must be compared to those of another system. Both the advantages and disadvantages of our plant can thus be highlighted.

4.2.1 Sensitive Analysis

Flexibility evaluation takes place by varying four control point: desorber pressures, slack preload, content % of MEA in the mixture, and the amount of carbon dioxide in the combustion products. Evey practical characteristic has its other settings held constant, only the currently mandated factor is changed to see how it affects the remaining performing settings, such as the reboiler's precise task and the level of regenerating.

4.2.1.1 Stripper pressure

Table 4.11 displays the results of changing only the main character pressures from 1 to 3 bars (objective) when keeping all additional variables same. Table 4.3 shows how the amount of energy needed for regenerating varies as a function of altitude. Reducing the volume in the stripping has a positive influence on reboiler values. As the solvent's movement speed and emissions reduction intake are both kept constant, a fixed quantity of carbonic acid is taken up by the stripping before leaving the extractor. Thus, the rich software's L/G proportion and pollutants extraction are unaffected by the altitude. As the volume in the stripping is raised, the warmth and slope both improve, permitting for a greater quantity of CO_2 to be removed. As less freshwater needs to be drained, the work of the

heating diminishes, which suggests that the process of regenerating gets simpler since there's fewer pieces of moisture around with Atmospheric CO_2 to strip everything out. The electricity consumption of the reboiler located at the prostitute's base decreases as pressures rises. Nevertheless, raising the force causes a raised temperature across all of the whole strippers, which in turn degrades the MEA.

MEA degradation is minor at 110oC, but it accelerates as the temperature approaches 130oC [73]. To avoid degradation, the temperature should be kept between 120 and 124oC. It was shown that a 31% decrease in particular heating workload could be achieved by raising tension from 2 to 3 bar. As can be seen in Figureure 4.4, there is a dramatic shift in reflux duty only when tension rises between 1 to 1.5 bars. Yet the pace of decline diminishes and the sharpness of the line flattens down as time goes on. As the stripper's strength in the processing facility is just 2 bars, the MEA degrading process cannot commence until much that really are reached.

4.2.1.2 Regeneration degree

The level of regenerating is measured by how much carbon dioxide is recovered from either the rich solvents that is discharged from either the remover. That's the proportion by which rich loaded differs from lean loaded.

$$\text{Degree of Regeneration } (\%) = \frac{Rich\ Loading - lean\ loading}{Rich\ Loading} \times 100 \qquad (4.8)$$

In spite of changes in remover temperature, the solvents in the absorption remains unaffected by the captured carbonic acid. It is clear from Figure 4.4 that spinner bait intensity will have no effect on the level of regenerating.

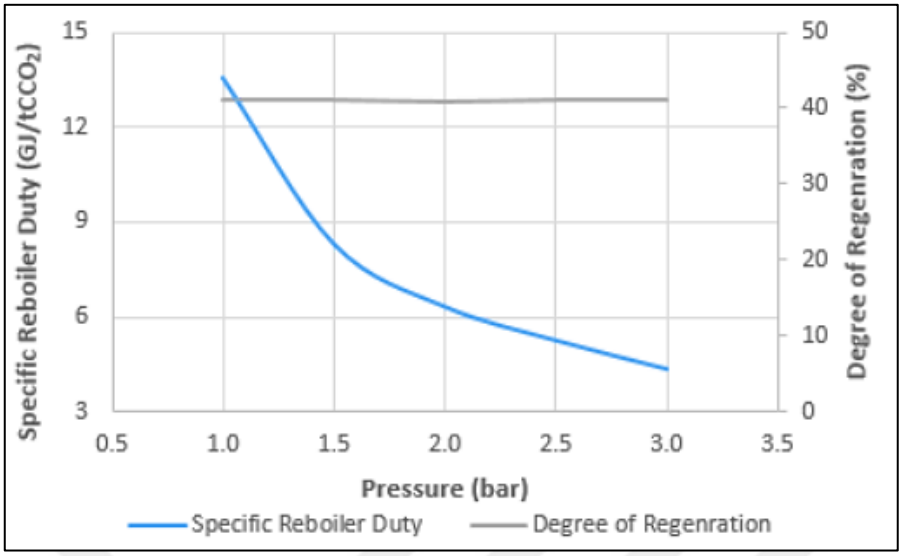


Figure 4.4: Depicts the Varying Effect of Pressure on Specific Reboiler Duty and Degree of Regeneration.

4.2.1.3 Lean loading

Table 4. 3. Water in the supernatant streams drops when the mixture lean density is raised while the MEA content % is maintained. With a higher CO_2 pressure and a reduced ability to store freshwater, a rich fluid reduces the specific reboiler duty [74]. For the liquid to effectively remove the atmospheric CO_2 from the exhaust gas, its hydraulic conductivity to grow in relation to the Coal greenhouse gases. Thus, the reboiler's workload grows in tandem with the solvent's throughput rate. But, by increasing the collected mass flow velocity, particular heater demand is reduced. Thus, the suitable target of the steam generator would be almost steady when subjected to a particular amount of lean loading. So, lean loading may be seen as an implementation of recommendations for determining the optimal valuing given the control factors. In this situation, the optimum heating duty is determined to be 0.15 mol CO_2/mol.

Table 4.11: Shows the Process Variables that Affect Lean Loading.

Process variables	Ranges
Reduced form of carbon monoxide (in mol percent)	9.7
Dispersion of flue gases (in kilograms per hour).	72
Stress from an immediately takes (bar)	2
Total percent of carbon dioxide eliminated	85
Quantity of MEA per gravity pound (g/g)	30
Concentrations of Fat (mol CO_2/mol MEA	0.10-0.30

4.2.1.4 Degree of regeneration

There is a direct correlation between the level of regenerating and the reboilers designated function. As shown in Figureure 4.5, the heater workload and percentage of regenerate decline with increasing lean loaded. The ability of a solvent to collect CO_2 diminishes as low content increase because of the increasing amount of carbon monoxide in the solution. Because of this, there's a reduced solvents synthesis and a lower carbon dioxide level in the rich channel.

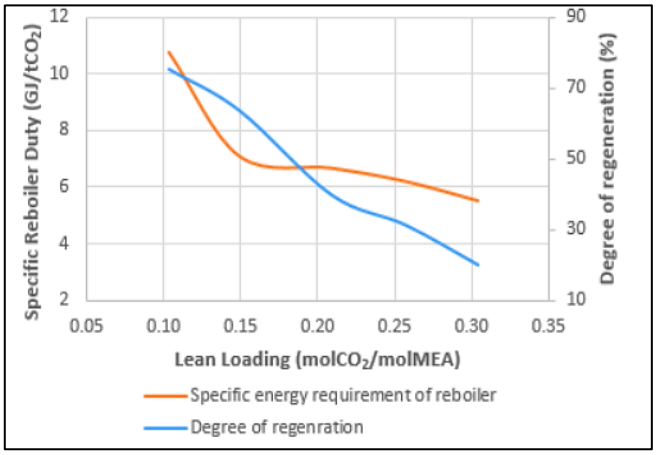


Figure 4.5: The Changes in Slack Pressure Affect Reboiler Workload and Rejuvenation Intensity.

4.2.1.5 MEA Weight percentage

In this set of calculations, the MEA sufficient quantity is changed whereas the remainder of characteristics are maintained, as indicated in Table 4.5. As compounds of MEA are reaction mixture needed to capture one photon of CO_2, an atmospheric CO_2 concentration of (0.5) mol CO_2/mol MEA is possible. When the MEA content of the leaner solution rises while the CO_2 concentration stays the same, the solution will be able to bind more Oxygen ions. Because of this, the L/G ratio drops because less solvent is being pumped through the absorbance to soak up the CO_2.

More carbon dioxide is ingested by MEA at maximum mass percentages, leading to greater rich feeding. In order to maintain a greater surface tension of carbonic acid somewhere within the strippers, a larger rich input is required. (0.4-0.47) mol CO_2/mol MEA [74] is a rich preload that may be achieved in production lines. It is challenging to attain a valuing of (0.47) mol Dioxide MEA owing to the small distance of the stripping at the volume basis, where it approaches a maximum of 0.425. As even the fluid velocity of the fluid drops and also the rich dose goes up, the heater works less. If the amount of MEA in the average mass increases from 20 to 40%, the particular heater capacity decreases form 7.90 to 5.5 GJ/TCO_2. Compounds were introduced to get the MEA percentage up to at least 30% over the legally required 20%. Once the MEA concentration is raised to 40 percent, the corrosive impact is noticeable. [75].

Table 4.12: Variables in the Process for Varying Strength of MEA

Process variables	Ranges
Stress from an immediately takes (bar)	2
Mass flow rate of flue gases (kilograms per hour).	72
Ratio of CO_2 to other gases (in mol%)	9.7
Length to Breadth Ratio	8.8-2.1
Using the exchanger (kW)	21-14.17
Total percent of carbon dioxide eliminated	85
Heavy Saturation (mol CO_2/mol MEA).	0.318-0.425
Reduced Input (in mol CO_2/mol of MEA)	0.208
Quantity of MEA per unit of weight (g/	20-40

4.2.1.6 Degree of regeneration

There is a definite relation involving reboiler general work and regenerating level after changing the MEA liquid content. Figure 4.6 depicts the decrease in Adsorption processes from combustion gases as a function of increasing MEA concentrations in the fluid. Rich overloading, the gap above rich and leaner fatigue strength, and therefore regenerate intensity, all improve with greater MEA content in the liquid. The heater load in the extractor is decreased as the proportion of CO_2 extracted rises, keeping the peeling process more efficient.

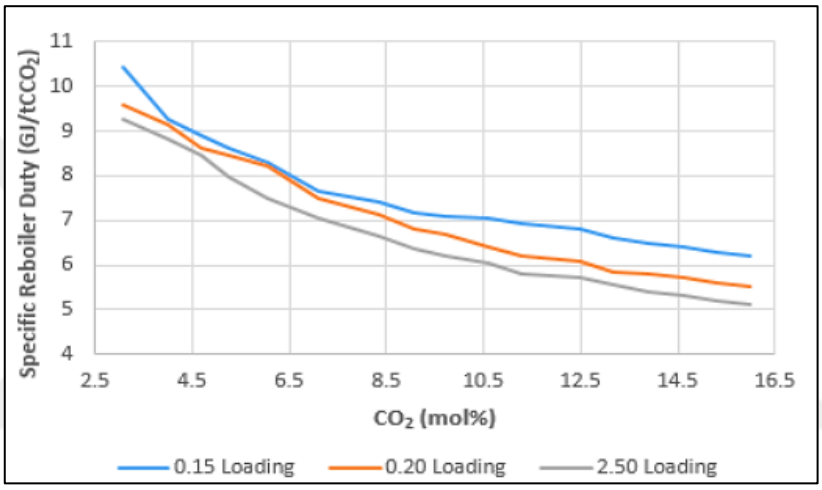


Figure 4.6: The Effect of CO_2 Concentration on Specific Duty of Reboiler.

4.2.1.7 CO_2 Concentration impact on L/G ratio

An elevation in the concentration of carbon dioxide in the air boosts the CO_2 mole fraction in the combustion products, which in turn increases the number of solvents being released. As a consequence, greater fluid particles are needed to collect increasing amounts of CO_2. High discharge results vary between 85 and 210 kg/h for (0.15) mol Greenhouse gas MEA addition, with CO_2 content in the gasification varying between 3 and 16 mn / m. An increment of 0.2 mol Dioxide MEA, or 60%, is achieved by unloading. There is a similar 60percent on average boost in fluid heat flux. Hence, higher levels of carbon dioxide in the combustion products causes a higher liquid volume of water because of the upsurge in fluid CO_2 workloads.

4.2.1.8 CO_2 Composition in flue gas

As shown in Figure 4.4, When flue gas temperature and tension of CO_2 rises, the reboiler's issue notice drops. Biogas may have a carbon dioxide concentration anywhere from 3 to 16 ml of methanol. Three shapes depicting the range of solution dynamic loads are shown in Figureure 4.6. In Table 4.13, we see that we change just the CO_2 level gradient one per reloading, while keeping all other operation variables the same.

Table 4.13: Process Variables For CO_2 Varying Concentration In Flue Gas.

Process variables	Rages
Reduced form of carbon monoxide (in mol percent)	3-16
Mass transfer of flue gases (in kilograms per hour).	72
Stress from an immediately takes (bar)	2
Total percent of carbon dioxide eliminated.	85
Quantity of MEA per weight kilogram (g/g)	30
Concentrations of Fat (mol CO_2/mol	0.15-025

4.2.1.9 The influence of CO_2 concentration on the degree of regeneration

There will be a smaller need for a steam generator if the extent of regenerate is proportionate to the ability to separate. Since more CO_2 particles can be absorbed by a fixed volume of MEA solution, the rich dosage increases over time. With a larger disparity between rich and leaner loads, rejuvenation is enhanced when rich dosage is enhanced. Since the solution is unable to absorb quite enough carbon dioxide from the combustion products as it formerly did, this same rich dosage cannot rise as rapidly as it might under leaner conditions. What's seen in Figure. 4.5. While the quantity of CO_2 collected and the level of renewal are both dependent on the heavy loaded (0.15-0.25) mol Dioxide MEA, it is obvious that these two factors are very sensitive to variations in leaning loaded. When the level of carbon dioxide in the gasifier is maintained, the regenerated percentage is 54% at 0.15 mol) CO_2 /mol MEA and 18percent of total at 0.32 mol CO_2/mol MEA.

4.2.1.10 CO_2 Concentration and specific reboiler duty.

Figure 4.7 is a graph displaying the relationship between the CO_2 content of flue gas and the amount of work done by the heat exchanger. Higher CO_2 content is responsible for most of the reduction in individual heat exchanger load. The rate-limiting step in the absorbance activation process with Generally understood is the volume fraction of CO_2, that also rises with increasing Concentrations of CO_2. Due to increased solubility, separation becomes simpler when the carbon dioxide is taken up by the fluid. [76]. Investigations on Carbon dioxide were performed by Akram et al. [74], who started with 4.5 mol% Atmospheric carbon dioxide and varied the Combined cycle rates despite maintaining the same solution volume of water. When the CO_2 content is raised from (3) mol% to (16) mol%, the same patterns are seen in each situations, despite the fact that the rate of CO_2 collection is set at(85)% in the present research. The soil moisture of the fluid flows reduces once the solution lean dosage is increased whilst MEA mass % is fixed. Due to higher dioxide levels and lower air percentage in rich solvents, the efficient heater obligation is reduced [74].

As CO_2 levels grow, more solvent must be pumped through the system to remove the molecule again from waste gases. Thus, the reboiler's workload grows in tandem with the solvent's throughput rate. Yet, by raising the speed at which collected CO_2 is released, particular heating obligation may be reduced. There is a 7.47% decrease in reboiler definite purpose when solution dosage is increased between (0.15) to (0.209) mol CO_2/mol MEA. Hence, (0.25) mol CO_2/mol MEA provides a further decrease in reboiler specialized duty. CO_2

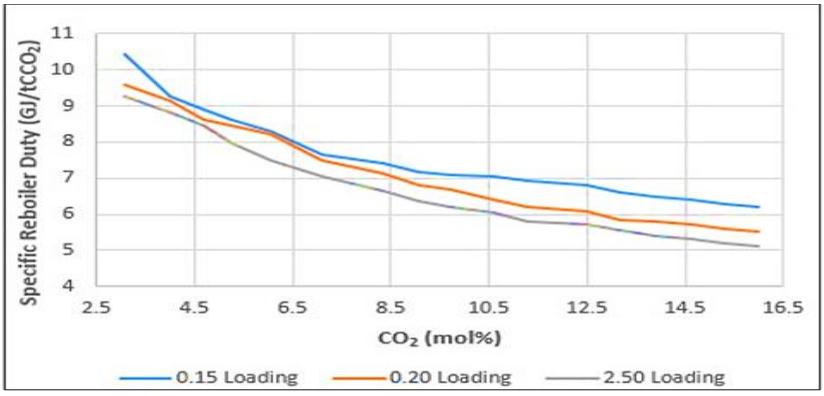


Figure 4.7: Effect of CO_2 Concentrations on Specific Duty of Reboiler.

5. OVERALL CONCLUSION

The effectiveness of various methods for calculating CO_2 capture from atmospheric exhaust gas, particularly from a natural gas-fired power plant, has been examined. The MEA calculation techniques for the absorption and desorption processes have received the most attention. The procedure simulation model Aspen HYSYS was used to perform the majority of the calculations. Calculating cost-optimal process parameters has been one objective of the work.

In collaboration with NTNU/SINTEF, measurements of pressure drop, liquid standby, liquid distribution, and efficacious mass transfer areas were made in a column with a 0.5 m diameter. The estimation of mass transfer parameters has also utilized literature correlations. The experiments verify structured packing's effectiveness under typical process conditions. Murphree efficiencies for CO_2 absorption into MEA under standard conditions in column top. Both precise calculations based on pressure contour in the liquid film and approximation methods have been used to calculate efficiencies and absorption rates.

According to the calculations, the deviations from pseudo-first order conditions are generally minimal under most operating conditions. Murphree efficiencies measured from a pseudo first-order expression should be as accurate for calculating the overall capturing CO_2 efficiency as more exact calculations, so long as the pseudo first-order conditions are satisfied and the temperature at the stage is roughly constant.

Aspen HYSYS has calculated a carbon dioxide capture system for a natural gas-fired substation. What is the relationship between circulating speed, absorbers heat, and some other variables, CO_2 removal grade and thermal consumption have been calculated. These calculations are quick and reliable because the majority of them were done with constant Murphree efficiencies. There are no important deference when process simulations for the conventional procedure using different solvents and mixes many amines (mixing MEA, MDEA and PZ) to absorption CO_2 from flow gasses as showing in table 3.6.

Each increase in partial pressure of carbon dioxide, striping pressure, MEA weight ratio and lean loading lead to increase in cost of reboiler duty. Increased rich loading provides a greater difference in both rich and lean loading, resulting in an increased. Although the extent of rejuvenation is inversely linked to a rise in fluid air velocity, which is approximately 60%,

the general function of the steam generator is positively correlated with the amount of regenerating. Hence, a higher levels of carbon dioxide in the waste gases causes a higher solvents volume of water because of a spike in solvents Greenhouse gas dynamic loads.

Different ways are used in literature to specify the conditions of the adsorptive column. You can specify the reflux, CO_2 concentration, or condenser temperature. In this study, it is anticipated that the ideal condenser temperature will be the one that produces the least amount of reflux. This reflux ratio ranges from 0.1 to 0.3. Justifications for low reflux:

Reduced energy usage, Reduced condenser size.Reasons for having a high reflux: Reduced amine loss and lower CO_2 loading in revived (lean) amine and Easier control of reflux

REFERENCES

[1] Intergovernmental Panel on Climate Change (IPCC). Global warming of 1.5°C. An IPCC Special Report on. (2018) the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change. https://www.ipcc.ch/sr15/ .(2022). Global Warming of 1.5 ºC.

[2] https://www.globalccsinstitute.com/resources/global-status-report/previous-reports/ (2022) Global Status Report 2020.

[3] (GlobalCCS Institute,2020. The Global status of CCS:2020. Australia.).

[4] Blanchard, L. A.; Gu, Z. Y.; Brennecke, J. F. (2001). High-Pressure Phase Behavior of Ionic Liquid/ CO_2 Systems. J. Phys. Chem. B, 105, 2437-2444.

[5] McEwen, A. B.; Ngo, H. L.; LeCompte, K.; Goldman, J. L. (1999). Electrochemical properties of imidazolium salt electrolytes for electrochemical capacitor applications. J. Electrochem. Soc., 146, 1687-1695.

[6] Visser, A. E.; Swatloski, R. P.; Reichert, W. M.; Griffin, S. T.; Rogers. R. D. (2000). Traditional extractants in nontraditional solvents: Groups 1 and 2 extraction by crown ethers in room-temperature ionic liquids. Industrial and Engineering Chemistry Research, 39, 3596-3604.

[7] Chun, S.; Dzyuba, S. V.; Bartsch, R. A. (2001). Influence of Structural Variation in Room-Temperature Ionic Liquids on the Selectivity and Efficiency of Competitive Alkali Metal Salt Extraction by a Crown Ether. Analytical Chemistry, 73, 3737-3741.

[8] N. Mac Dowell, N. Florin, A. Buchard, J. Hallet, A. Galindo, G. Jackson, C. Adjiman, C. Williams, N. Shah, P. Fennell. An overview of CO_2 capture technologies. Energy and Environ. Sci., 2010, 3, 1645–1669).

[9] Smiglak, M.; Reichert, W. M.; Holbrey, J. D.; Wilkes, J. S; Sun, J.; Thrasher, J. S.; Kirichenko, K.; Singh, S.; Katritzkyc, A. R.; Rogers, R. D; (2006). Combustible ionic liquids by design: is laboratory safety another ionic liquid myth?. Chem. Commun., no. 24, 2554-2556. [DOI: 10.1039/b602086k].

[10] Uerdingen, M.; Treber, C.; Balser, M.; Schmitt, G.; Werner, C. (2005). Corrosion behaviour of ionic liquids. Green Chem., 7, 321-325. [DOI: 10.1039/b419320m].

[11] Perissi, I.; Bardi, U.; Caporali, S.; Lavacchi, A. (2006). High temperature corrosion properties of ionic liquids. Corros. Sci., 48, 2349-2362.

[12] Pernak, J.; Czepukowicz, A.; Pozniak, R. (2001). New Ionic Liquids and Their Antielectrostatic Properties. Ind. Eng. Chem. Res., 40, 2379-2383.

[13] Swatloski, R. P.; Holbrey, J. D.; Memon, S. B.; Caldwell, G. A.; Caldwell, K. A.; Rogers, R. D. (2004). Using Caenorhabditis elegans to probe toxicity of 1-alkyl-3-methylimidazolium chloride based ionic liquids. Chem. Commun., 668-669.

[14] Pernak, J.; Sobaszkiewicz, K.; Mirska, I. (2003). Anti-microbial activities of ionic liquids. Green Chem., 5, 52-56.

[15] Zhao, D.; Liao, Y; Zhang, Z. (2007). Review-Toxicity of Ionic Liquids. Clean, 35, 42-48.

[16] E.J. Maginn, Research: Ionic Liquids, http://www.nd.edu/~ed/Research/IL_toxicology.htm l (May 23, 2008).

[17] Wells, A. S.; Coombe, V. T. (2006). On the freshwater ecotoxicity and biodegradation properties of some common Ionic Liquids. Organic Process Research & Development, 10, 794-798.

[18] Landry, T. D.; Brooks, K.; Poche, D.; Woolhiser, M. (2005). Acute Toxicity Profile of 1-Butyl-3-Methylimidazolium Chloride. Bull. Environ. Contam. Toxicol., 74, 559-565.

[19] Bernot, R. J.; Brueske, M. A.; Evans-White, M. A.; Lambert, G. A. (2005). Acute and chronic toxicity of imidazolium-based ionic liquids on Daphnia magna. Environ. Toxicol. Chem., 24, 87-92.

[20] Gathergood, N.; Garcia, T. M.; Scammells, P. J. (2004). Biodegradable ionic liquids: Part I. Concept, preliminary targets and evaluation. Green Chem., 6, 166-175.

[21] Del Sesto, R. E.; Corley, C.; Robertson, A.; Wilkes, J. S. (2005). Tetraalkylphosphonium-based ionic liquids. Journal of Organometallic Chemistry, 690, 2536-2542.

[22] Docherty, Kathryn M., Susanne Z. Hebbeler, and Charles F. Kulpa Jr. "An assessment of ionic liquid mutagenicity using the Ames Test." Green Chemistry 8.6 (2006): 560-567.

[23] Seddon, K. R. "The international george papatheodorou symposium: proceedings." Institute of Chemical Engineering and High Temperature Chemical Processes, Patras, Greece (1999): 131-135.. North Am. Chapter Assoc. Comput. Linguist. Hum. Lang. Technol. - Proc. Conf., vol. 1, no. Mlm, pp. 4171–4186, 2019.

[24] Figureueroa, J. D.; Fout, T.; Plasynski, S.; McIlvried, H.; Srivastava, R. D. (2008). Review: Advances in CO_2 capture technology - The U.S. Department of Energy's Carbon Sequestration Program. International Journal of Greenhouse Gas Control., 2, 9-20.

[25] Chang, H.; Shih, C. M. (2005). Simulation and Optimization for Power Plant Flue Gas CO_2 Absorption-Stripping Systems. Separation Science and Technology, 40, 877-909.

[26] Liu, Y. D.; Zhang, L. Z.; Watanasiri, S. (1999). Representing Vapor-Liquid equilibrium for an aqueous MEA- CO_2 system using the Electrolyte NonrandomTwo-Liquid Model. Ind. Eng. Chem. Res., vol. 38, no. 5, 2080-2090.

[27] Welton, T. (1999). Room temperature ionic liquids: Solvents for synthesis and catalysis. Chem. Rev., 99, 2071–2084.

[28] Anthony, J. L.; Aki, S. N. V. K.; Maginn E. J.; Brennecke, J. F. (2004). Feasibility of using Ionic Liquids for Carbon dioxide capture. Int. J. Environmental Tech. and Management, Vol. 4, Nos. 1/2, 105-115.

[29] Rogers, R. D.; Seddon, K. R.; Volkov, S. (2000). Green industrial applications of ionic liquids. Kluwer Academic Publishers, The Netherlands.

[30] Anthony, J. L.; Maginn E. J.; Brennecke, J. F. (2002). Solubilities and Thermodynamic Properties of Gases in the Ionic Liquid 1-n-Butyl-3-methylimidazolium Hexafluorophosphate. J. Phys. Chem. B, 106, 7315-7320.

[31] Sinnott, R. (2014). Chemical engineering design (Vol. 6). Elsevier.

[32] Hoorfar, M.; Alcheikhhamdon, Y.; Chen, B. A Novel Tool for the Modeling, Simulation and Costing of Membrane Based Gas Separation Processes Using Aspen HYSYS: Optimization of the CO_2 / CH4 Separation Process. Comput. Chem. Eng. 2018, 117, 11−24.

[33] Ahmad, F.; Lau, K. K.; Shariff, A. M.; Murshid, G. Process Simulation and Optimal Design of Membrane Separation System for CO_2 Capture from Natural Gas. Comput. Chem. Eng. 2012, 36, 119− 128.

[34] Hasan, M. M. F.; Baliban, R. C.; Elia, J. A.; Floudas, C. A. Modeling, Simulation, and Optimization of Postcombustion CO_2 Capture for Variable Feed Concentration and Flow Rate. 1. Chemical Absorption and Membrane Processes. Ind. Eng. Chem. Res. 2012, 51, 15642−15664.

[35] Gabrielli, P.; Gazzani, M.; Mazzotti, M. On the Optimal Design of Membrane-Based Gas Separation Processes. J. Membr. Sci. 2017, 526, 118−130.

[36] Thompson, M. L.; Kramer, M. A. Modeling Chemical Processes Using Prior Knowledge and Neural Networks. AIChE J. 1994, 40, 1328−1340.

[37] Lee, J. H.; Shin, J.; Realff, M. J. Machine Learning: Overview of the Recent Progresses and Implications for the Process Systems Engineering Field. Comput. Chem. Eng. 2018, 114, 111−121.

[38] Bradford, E.; Imsland, L.; Zhang, D.; del Rio Chanona, E. A. Stochastic Data-Driven Model Predictive Control Using Gaussian Processes. Comput. Chem. Eng. 2020, 139, No. 106844.

[39] Shrivastava, R.; Mahalingam, H.; Dutta, N. N. Application and Evaluation of Random Forest Classifier Technique for Fault Detection in Bioreactor Operation. Chem. Eng. Commun. 2017, 204, 591−598.

[40] Sahinidis, N. V. BARON: A General Purpose GlobalOptimization Software Package. J. Global Optim. 1996, 8, 201−205.

[41] Khojasteh Salkuyeh Y, Saville BA, MacLean HL. Techno-economic analysis and life cycle assessment of hydrogen production from natural gas using current and emerging technologies. Int J Hydrogen Energy 2017;42:18894e909. https://doi.org/10.1016/J.IJHYDENE.2017.05.219

[42] Spallina V, Shams A, Battistella A, Gallucci F, van Annaland MS. Chemical looping technologies for H2 production with CO_2 capture: thermodynamic assessment and economic comparison. Energy Procedia 2017;114:419e28. https://doi.org/10.1016/J.EGYPRO.2017.03.1184 .

[43] Fernandez, E. S., del Rio, M. S., Chalmers, H., Khakharia, P., Goetheer, E. L., Gibbins, J., & Lucquiaud, M. (2016). Operational flexibility options in power plants with integrated post-combustion capture. International Journal of Greenhouse Gas Control, 48, 275-289.

[44] Wang, L., Zhang, Y., Wang, R., Li, Q., Zhang, S., Li, M., ... & Chen, B. (2018). Advanced monoethanolamine absorption using sulfolane as a phase splitter for CO_2 capture. Environmental science & technology, 52(24), 14556-14563.

[45] Wei, M., Qian, F., Du, W., Hu, J., Wang, M., Luo, X., & Yang, M. (2018). Study on the integration of fluid catalytic cracking unit in refinery with solvent-based CCS through process simulation. Fuel, 219, 364-374.

[46] Oko, E., Zacchello, B., Wang, M., & Fethi, A. (2018). Process analysis and economic evaluation of mixed aqueous ionic liquid and monoethanolamine (MEA) solvent for

CO_2 capture from a coke oven plant. Greenhouse Gases: Science and Technology, 8(4), 686-700.

[47] Kang, J. L., Sun, K., Wong, D. S. H., Jang, S. S., & Tan, C. S. (2014). Modeling studies on absorption of CO_2 by monoethanolamine in rotating packed bed. International Journal of Greenhouse Gas Control, 25, 141-150.

[48] Akachuku, A., Osei, P. A., Decardi-Nelson, B., Srisang, W., Pouryousefi, F., Ibrahim, H., & Idem, R. (2019). Experimental and kinetic study of the catalytic desorption of CO_2 from CO_2 -loaded monoethanolamine (MEA) and blended monoethanolamine–Methyl-diethanolamine (MEA-MDEA) solutions. Energy, 179, 475-489.

[49] Songolzadeh, M., Soleimani, M., Takht Ravanchi, M., & Songolzadeh, R. (2014). Carbon dioxide separation from flue gases: a technological review emphasizing reduction in greenhouse gas emissions. The Scientific World Journal, 2014.

[50] Fulham, L., Book, A. S., Blais, J., Ritchie, M. B., Gauthier, N. Y., & Costello, K. (2020). The effect of hypervigilance on the relationship between sexual victimization and gait. Journal of interpersonal violence, 35(19-20), 4061-4082.

[51] Aromada, S. A., Eldrup, N. H., & Øi, L. E. (2021). Capital cost estimation of CO_2 capture plant using Enhanced Detailed Factor (EDF) method: Installation factors and plant construction characteristic factors. International Journal of Greenhouse Gas Control, 110, 103394.

[52] Hoffmann, J. W., Hackett, G. A., Lewis, E. G., & Chou, V. H. (2017). Derate mitigation options for pulverized coal power plant carbon capture retrofits. Energy Procedia, 114, 6465-6477.

[53] Wang, M., Lawal, A., Stephenson, P., Sidders, J., & Ramshaw, C. (2011). Post-combustion CO_2 capture with chemical absorption: A state-of-the-art review. Chemical engineering research and design, 89(9), 1609-1624.

[54] Kallevik, O. B. (2010). Cost estimation of CO_2 removal in HYSYS (Master's thesis, Høgskolen i Telemark).

[55] Bartczak, P., Norman, M., Klapiszewski, Ł., Karwańska, N., Kawalec, M., Baczyńska, M., ... & Jesionowski, T. (2018). Removal of nickel (II) and lead (II) ions from aqueous solution using peat as a low-cost adsorbent: A kinetic and equilibrium study. Arabian Journal of Chemistry, 11(8), 1209-1222.

[56] Hasan, M. F., Baliban, R. C., Elia, J. A., & Floudas, C. A. (2012). Modeling, simulation, and optimization of postcombustion CO_2 capture for variable feed concentration and flow rate. 2. Pressure swing adsorption and vacuum swing

adsorption processes. Industrial & engineering chemistry research, 51(48), 15665-15682.

[57] Seader, J. D., & Henley, E. J. (2006). Adsorption, ion exchange, and chromatography. In Separation Process Principles (pp. 568-570). John Wiley & Sons.

[58] Arachchige, U. S. P., & Melaaen, M. C. (2012). Aspen plus simulation of CO_2 removal from coal and gas fired power plants. Energy Procedia, 23, 391-399.

[59] Brickett, L. (2015). Carbon dioxide capture handbook. National Energy Technology Laboratory.

[60] Zhao, N., Zhang, Y., Li, B., Hao, J., Chen, D., Zhou, Y., & Dong, R. (2019). Natural gas and electricity: Two perspective technologies of substituting coal-burning stoves for rural heating and cooking in Hebei Province of China. Energy Science & Engineering, 7(1), 120-131.

[61] AACE International, Skills & Knowledge of Cost Engineering. 2007: Morgantown, WV 26501 USA.

[62] Abu-Zahra, M. R., Schneiders, L. H., Niederer, J. P., Feron, P. H., & Versteeg, G. F. (2007). A parametric study of the technical performance baced on.

[63] Ali, H., Eldrup, N. H., Normann, F., Skagestad, R., & Øi, L. E. (2019). Cost Estimation of CO_2 Absorbtion Plants for CO_2 Mitigation - Method and Assumptions. Greenhouse Gas Control, 88, 10-23.

[64] Ali, H., et al., Cost estimation of heat recovery networks for utilization of industrial excess heat for carbon dioxide absorption. International Journal of Greenhouse Gas Control, 2018. 74: p. 219-228.

[65] Arachchige, U. S., & Melaaen, M. C. (2012). Blended Amines' Effect on Post Combustion CO_2 Capture. Environment Poluution and Remediation. Montreal, Quebec, Canada: ResearchGate.

[66] Arachchige, U. S., & Melaaen, M. C. (2012). Selection of Packing Material for Gas Absorption. European Journal of Scientific Research, 87, 117-126. Retrieved from http://www.europeanjournalofscientificresearch.com/.

[67] Aromada, S. A., Eldrup, N. H., Normann, F., & Øi, L. E. (2020). Simulation and Cost Optimization of different Heat Exchnagers for CO_2 Capture. SIMS2020.

[68] Brickett, L. (2015). CARBON DIOXIDE CAPTURE HANDBOOK. National Energy Technology Laboratory. Retrieved from www.netl.doe.gov.

[69] Cavallo, C. (2011). thomasnet.com. (Thomas Industry) Retrieved from https://www.thomasnet.com/articles/process-equipment/shell-and-tube-heat-exchangers/.

[70] Gerrard, A.M., Guide to Capital Cost Estimating. 2000, Warwickshire, UK: Institute of Chemical Engineers (IChemE).

[71] Jilvero, H., et al., Techno-economic Analysis of CCS at an Aluminum Production Plant – Comparison of Post-combustion Capture Using MEA and Ammonia. Energy Procedia, 2014. 63: p. 6590-6601.

[72] Jilvero, H., et al., Techno-economic evaluation of an ammonia-based postcombustion process integrated with a state-of-the-art coal-fired power plant. International Journal of Greenhouse Gas Control, 2014. 31: p. 87-95.

[73] Kallevik, O. B. (2010). Cost estimation of CO_2 removal in HYSYS. Porsgrunn: Universirty of SouthEastern Norwegian.

[74] Mathisen, A., et al., Cost Optimised CO_2 Capture from Aluminium Production. Energy Procedia, 2014. 51: p. 184-190.

[75] Moshfeghian, M. (2015, September 15). PetroSkills. Retrieved from http://www.jmcampbell.com/tip-of-the-month/2015/09/gas-liquid-separators-sizingparameter/.

[76] Øi, L.E., et al., Simulation and Cost Comparison of CO_2 Liquefaction. Energy Procedia, 2016. 86: p. 500-510.

[77] Øi, L.E., Removal of CO_2 from exhaust gas, in Department of Process, Energy and Environmental Technology. 2012, Telemark University College.

[78] Orangi , S., Farsi Madan, F., Fajferek, K. G., Sæter, N. T., & Bahri, S. (2020). Process simulation and cost estimation of CO_2 capture in Aspen HYSYS using different estimation methods. Project cource, University of South-Eastern Norwegian, Porsgrunn.

[79] Park, K. and L.E. Øi, Optimization of gas velocity and pressure drop in CO_2 absorption column. Linköping Electronic Conference Proceedings, 2017. SIMS58: p. 292-297.

[80] Seader, J. D., & Henley, E. J. (2006). Absorption and Stripping . In Separation Process Principles (p. 194). Wiley.

[81] Smith, R., Chemical Process Design and Integration. 2005, England: John Wiley & Sons Ltd.

[82] Wong, S., Module 4: CO_2 compression and transportation to storage sites, in in Building capacity for CO_2 Capture and Storage in the APEC region: A training manual for policy makers and practitioners. 2012, APEC: Singapore.

[83] Yu, F., Process design for chemical engineers. 2014: Ten Books, Inc.

[84] Van Wagener, D. H., & Rochelle, G. T. (2011). Stripper configureurations for CO_2 capture by aqueous monoethanolamine. Chemical engineering research and design, 89(9), 1639-1646.

[85] Akram, M., Ali, U., Best, T., Blakey, S., Finney, K. N., & Pourkashanian, M. (2016). Performance evaluation of PACT Pilot-plant for CO_2 capture from gas turbines with Exhaust Gas Recycle. International Journal of Greenhouse Gas Control, 47, 137-150.

[86] Notz, R., Mangalapally, H. P., & Hasse, H. (2012). Post combustion CO_2 capture by reactive absorption: Pilot plant description and results of systematic studies with MEA. International Journal of Greenhouse Gas Control, 6, 84-112.

[87] Tönnies, I., Mangalapally, H. P., & Hasse, H. (2011). Sensitivity study for the rate-based simulation of the reactive absorption of CO_2. Energy Procedia, 4, 533-540.