

CO₂ Capture from Flue Gas by Amine Absorption; using HYSYS

A Technical and Economical Analysis



**A Thesis Submitted to the Department of Chemical Engineering, School of
Chemical and Materials Engineering (SCME), NUST, Islamabad, in the
partial fulfillment of the requirements for the degree of**

Master of Science (MS)

In

Energetic Materials Engineering

Submitted by

Hafiz Nadeem Ijaz Khokher

Supervisor: Dr. Arshad Hussain

School of Chemical and Materials Engineering (SCME)

National University of Science and Technology (NUST)

H-12 Campus Islamabad

2011

**In the name of Allah, The most Gracious,
most Compassionate".**

*Our Lord! Grant us good in this world and good in
the life to come and keep us safe from the torment
of the Fire. (2:201)*

Dedication

Dedicated to,

My dearest family; Respected parents, wife and kids

(Abdullah, Hamna & Saad)

Contents

Abbreviations

List of Tables

List of Figures

Abstract

Acknowledgements

Chapter 1

Introduction:	1
1.1 Background	1
1.2 The greenhouse effect and global warming	1
1.2.1 CO ₂ emission from energy sources in USA	2
1.3 Carbon captures technologies	5
1.3.1 Pre-combustion capture	6
1.3.2 Oxy-fuel (Integrated)	6
1.3.3 Post combustion Capture	7
1.3.4 Adsorption	8
1.3.5 Cryogenic separation	8
1.3.6 Membrane separation	9
1.3.7 Absorption	9

Chapter 2

Absorption of Gases:	12
2.1 Introduction	12
2.2 Conditions of equilibrium between liquid and gas	13
2.3 The mechanism of absorption	14
2.3.1 The two-film theory	14
2.3.2 Diffusion in the liquid phase	15
2.3.3 Rate of absorption	16
2.4 Overall coefficients	17

2.5	Absorption accompanied by the liberation of heat	18
2.6	Packed Column	19
2.7	Plate towers for gas absorption	20
2.7.1	Number of plates by use of absorption factor	22
2.7.2	Selection of plate type	24
2.8	Choice of plates or packing	25
2.9	Approximate column sizing	26
2.9.1	Plate spacing	26
2.9.2	Column diameter	27

Chapter 3

	HYSYS Software:	29
3.1	HYSYS	29
3.2	Basics of HYSYS	30
3.3	HYSYS Fluid Package Property View	42
3.3.1	Set up Tab	43
3.3.2	Property Package Selection Group	44
3.3.3	Equations of State (EOS)	44
3.3.4	Amines Property Package in HYSYS	45
3.4	HYSYS Hot Keys	46

Chapter 4

	Process Selection and Research Work:	49
4.1	Research Case	49
4.2	Selection of Amine-based Absorption Process	50
4.3	Process Optimization	51
4.4	Parameters and Data of processing Cases	52
4.4.1	Case # 1	52
4.4.2	Case # 2	53
4.4.3	Case # 3	57
4.4.4	Case # 4	60

4.4.5	Case # 5	63
4.4.6	Case # 6	66
4.5	Comparison of Energy Cost for different Processing Cases	70
4.6	Spread sheet for process optimization (Case # 6)	71
4.7	Optimized process Parameters	74

Chapter 5

	Economical Analysis:	75
5.1	Cost Estimation	75
5.1.1	Data for Purchase cost of Equipment	75
5.1.2	Data for Gas Capturing Cost	77
5.2	Purchase Cost of Equipment	79
5.3	Gas capturing Cost	80
5.4	Summary of Cost Estimation	81
5.5	References for Equipment Cost estimation	82
5.6	Discussion about capturing cost	82
5.7	Comparison of CO ₂ Capturing cost Data	83

Chapter 6

	Results, Conclusion and Recommendations:	84
6.1	Discussion about Results	84
6.2	Effect of Feed (gas and solvent) and column operating Pressure on operating cost	84
6.3	Conclusion	85
6.4	Outlook	86

	References	87
--	-------------------	-----------

Abbreviations

IGCC:	Integrated Gas fired Combined Cycle
ASU:	Air Separation Unit
PSA:	Pressure Swing Adsorption
TSA:	Temperature Swing Adsorption
ESA:	Electrical Swing Adsorption
MEA:	Mono Ethanol Amine
DEA:	Di-Ethanol Amine
MDEA:	Methyl Di- Ethanol Amine
HETP:	Height of Equivalent Theoretical Plate
HTU:	Height of Transfer Units
PFD:	Process Flow Diagram
BIP:	Binary Interaction Parameters
PC:	Pulverized Coal
NGCC:	Natural Gas fired Combined Cycle
SOFC:	Solid Oxide Fuel Cells
MMSCFD:	Million Standard Cubic Feet per Day
MSCF:	Metric Standard Cubic Feet
TCI:	Total Capital Investment
LMTD:	Log Mean Temperature Difference
PEC:	Purchase Equipment Cost
FCI:	Fixed Capital Investment
WCI:	Working Capital Investment
GCC:	Gas Capturing Cost
MJ:	Mega Joule
KW:	Kilo Watt

List of Tables

Table 1.1	U.S Energy-Related Carbon Dioxide Emissions by End-User Sector
Table 1.2	Percent Change In U.S Energy-Related Carbon Dioxide Emissions by End-User Sector
Table 2.1	Concentration vs. Partial pressure of solute gas
Table 3.1	Property package filter
Table 3.2	Equation of state methods
Table 4.1	Lean solvent flow rate vs. Lean loading (Case # 1)
Table 4.2	Lean solvent flow rate vs. Thermal duty and Recovery of acid gas (Case # 1)
Table 4.3	Lean solvent flow rate vs. Lean loading (Case # 2)
Table 4.4	Lean solvent flow rate vs. Thermal duty and Recovery of acid gas (Case # 2)
Table 4.5	Lean solvent flow rate vs. Lean loading (Case # 2)
Table 4.6	Lean solvent flow rate vs. Specific Thermal duty of reboiler (Case # 2)
Table 4.7	Lean solvent flow rate vs. Lean loading (Case # 3)
Table 4.8	Lean solvent flow rate vs. Thermal duty and Recovery of acid gas (Case # 3)
Table 4.9	Lean solvent flow rate vs. Lean loading (Case # 3)
Table 4.10	Lean solvent flow rate vs. Specific Thermal duty of reboiler (Case # 3)
Table 4.11	Lean solvent flow rate vs. Lean loading (Case # 4)
Table 4.12	Lean solvent flow rate vs. Thermal duty and Recovery of acid gas (Case # 4)
Table 4.13	Lean solvent flow rate vs. Lean loading (Case # 4)
Table 4.14	Lean solvent flow rate vs. Specific Thermal duty of reboiler (Case # 4)
Table 4.15	Lean solvent flow rate vs. Lean loading (Case # 5)

Table 4.16	Lean solvent flow rate vs. Thermal duty and Recovery of acid gas (Case # 5)
Table 4.17	Lean solvent flow rate vs. Lean loading (Case # 5)
Table 4.18	Lean solvent flow rate vs. Specific Thermal duty of reboiler (Case # 5)
Table 4.19	Lean solvent flow rate vs. Lean loading (Case # 6)
Table 4.20	Lean solvent flow rate vs. Thermal duty and Recovery of acid gas (Case # 6)
Table 4.21	Lean solvent flow rate vs. Lean loading (Case # 6)
Table 4.22	Lean solvent flow rate vs. Specific Thermal duty of reboiler (Case # 6)
Table 4.23	Energy cost for different processing cases
Table 5.1	Purchase cost of equipment
Table 5.2	References for Equipment Cost estimation
Table 5.3	Comparison of CO ₂ Capturing cost Data
Table 6.1	Feed gas & solvent pressure vs. Power consumption

List of Figures

- Figure 1.1** Cause for global warming; Carbon dioxide emissions in million tons per year over the last 200 years
- Figure 1.2** Annual greenhouse gas emission
- Figure 1.3** Green house gas emissions by sectors
- Figure 1.4** Carbon dioxide emissions by major fuels in USA
- Figure 1.5** Types of post combustion CO₂ capture methods
- Figure 1.6** Separation using membrane
- Figure 2.1** Concentration profile for absorbed component A
- Figure 2.2** Driving forces in the gas and liquid phases
- Figure 2.3** Equilibrium curve modified to allow for the heat of solution of the solute
- Figure 2.4** Packed Absorption Columns
- Figure 2.5** Plate tower-nomenclature for fluid streams
- Figure 2.6** Graphical representations of changes in a plate column
- Figure 2.7** Effect of Absorption factor and number of plates on degree of absorption
- Figure 2.8** Cost data for vertical pressure vessel/column
- Figure 2.9** Cost data of trays
- Figure 3.1** A layout of chemical process plant
- Figure 3.2** Adding components to the simulation
- Figure 3.3** Selecting a Fluids Package
- Figure 3.4** Flow chart to select the best thermodynamic model
- Figure 3.5** Add reaction tab
- Figure 3.6** Options in add reaction tab
- Figure 3.7** Selection of components for reaction

- Figure 3.8** Reaction balancing
- Figure 3.9** Adding % age conversions
- Figure 3.10** Addition of reaction to reaction set
- Figure 3.11** Addition of reaction set to fluid package
- Figure 3.12** Simulation Basis Manager
- Figure 3.13** Adding material stream
- Figure 3.14** Adding energy stream
- Figure 3.15** Allocation of stream name
- Figure 3.16** Placing a unit
- Figure 3.17** Specifying material stream and its unit
- Figure 3.18** Specifying the composition
- Figure 3.19** Input composition for stream
- Figure 3.20** Worksheet/data check for stream
- Figure 3.21** Adding desired property in workbook
- Figure 3.22** Printing of workbook
- Figure 3.23** Fluid package property view
- Figure 3.24** property package selection
- Figure 3.25** Property package selection group
- Figure 3.26** Selection of thermodynamic & vapor phase model
-
- Figure 4.1** Flow Sheet for CO₂ Capturing from Flue Gas by Amine absorption Process
- Figure 4.2** Loading vs. Lean solvent flow rate (Case # 2)
- Figure 4.3** Lean loading vs. Specific thermal duty (Case # 2)
- Figure 4.4** Loading vs. Lean solvent flow rate (Case # 3)
- Figure 4.5** Lean loading vs. Specific thermal duty (Case # 3)
- Figure 4.6** Lean Loading vs. Solvent flow rate (Case # 4)
- Figure 4.7** Lean loading vs. Specific thermal duty (Case # 4)
- Figure 4.8** Lean Loading vs. Solvent flow rate (Case # 5)

- Figure 4.9** Lean loading vs. Specific thermal duty (Case # 5)
- Figure 4.10** Lean Loading vs. Solvent flow rate (Case # 6)
- Figure 4.11** Lean loading vs. Specific thermal duty (Case # 6)
- Figure 5.1** Breakdown of investment costs
- Figure 6.1** Feed gas & solvent pressure vs. Power consumption

Abstract:

Global warming due to the emission of greenhouse gases from different sources; mainly from industrial sector is a severe environmental issue in this modern world. CO₂ is the main constituent of greenhouse gases emitted from industries and playing a significant part in raising the atmospheric temperature. In developing countries emissions are expected to grow rapidly in next 15 years and surpass emissions of industrialized countries near 2018. Power plants are considered to be the major source for CO₂ emission. In addition to power plants, industrial sources like cement plants, oil refineries, iron and steel plants, ammonia & hydrogen production plants, and natural gas processing facilities are also being considered for application of CO₂ capture technologies. Active research work is being carried out and efforts are being made to establish and optimize the processes to capture CO₂ from flue gas.

Presently; amine absorption process has been reported as the most feasible and effective process for CO₂ capture at large scale. By employing this process acid gas can be recovered efficiently with required purity. Choosing the right solvent is important because, the lower temperature for solvent regeneration lowers the energy cost of CO₂ capture. In this research work amine absorption process for removal of CO₂ from flue gas emitted from coal fired plant containing about 13% CO₂ has been simulated and optimized using Amine Package in HYSYS 3.2. Optimization study has been carried out by simulating number of cases by varying pressure of solvent and feed gas. DEA as a solvent has been selected for use in comparison to MEA, since MEA is more corrosive and degradable solvent than DEA.

Economical analysis has also been carried out according to standard methods and procedures described in literature. With CO₂ removal of $\geq 90\%$, heat consumption is calculated to 3.57 MJ/kg CO₂ removed, close to a literature value of 4.0 MJ/kg CO₂. Calculated value of gas capturing cost is 1.60 \$/MSCF or 30.70 \$/ton of product. These values are well with in the range as reported in established processes for CO₂ capture and also align with the relevant literature and research work.

Acknowledgements:

1. First of all I am grateful to almighty Allah who gives us the sense, consciousness and energy to analyze and resolve the problems.
2. I want to salute my parents who made best of their efforts to let us know the importance of moral values and difference between right and wrong in this materialistic world.
3. I really oblige and recognize the involvement and sincere efforts made by my respected supervisor Dr. Arshad Hussain to carry out this research work. During this work his valuable and worthy guidelines always helped a lot to tackle the problems; without his instructions and guidance it would have not been possible to complete this project work. His continual encouragement was the source of immense confidence for me to overcome the difficulties and proceed further.
4. Last but not the least I would like to pay my gratitude to my family and management of my organization (NDC) for their unconditional support and cooperation during this study period. I am also thankful to my sincere friends and staff of SCME who helped me for arrangement and installation of HYSYS software.

Hafiz Nadeem Ijaz