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RESEARCH ARTICLE

CARBON DIOXIDE RECOVERY FROM UREA MANUFACTURING PLANT

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ABSTRACT

Carbon dioxide is one of the most important greenhouse gas that is threatening the present day human life as well as the quality of the environment, resulting in large scale effects (disasters) on the living organisms. The present work aims to employ process simulation software (Aspen Plus software) for the recovery of carbon dioxide evolved from the urea manufacturing plant. Though, commonly used solvent for the removal of carbon dioxide is Monoethanolamine, in this work CO_2 extraction was by studied by employing three more solvents i.e., Diethanolamine, Methyl diethanolamine and Diglycolamine. An effective UNIFAC method is used to estimate the CO_2 recovery (from carbon dioxide recovery plant). The recovery of CO2 is estimated at different absorber & stripper temperature conditions and concentrations of the solvent(s). The results of the solvents are compared to identify best operating parameters (solvent temperature and concentration). In absorber the overall percentage of CO_2 removal from the flue gas for all the solvents was found to be; 99.983% with Diglycololamine solvent (at 0.55 concentration (mole%) and 10°C temperature), 99.981% with Methyldiethanolamine solvent (at 0.55 (mole%) concentration and 5°C temperature), 99.74% with Diethanolamine solvent (at 0.5 (mole%) concentration and 8°C temperature) and 98.07% with Monoethanolamine solvent (at 0.2 mole% concentration and 8°C temperature). From the results of this study, Diglycolamine is the best solvent to remove carbon dioxide from flue gas.

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1. INTRODUCTION

Mainly carbon dioxide is emitted from industrial power plants, fertilizer plants, cement industries, iron and steel industries and fossil fuels 0. Carbon dioxide is very detrimentalfor the environment and living beings 0. Hence reusing it by recovering from the plant, instead of venting into the atmosphere is the real challenge before the scientific community. There are different methods available to capture carbon dioxide, such as chemical absorption, membrane separation, adsorption, pre-combustion capture, post-combustion capture and oxy-fuel combustion (Rick Strait and ManojNagvekar, 2010; Timothy S. Chung *et al*., 2011; Hongqun Yang *et al*., 2008). The present work aimed to employ process simulation software (Aspen Plus software) for the recovery of carbon dioxide evolved from the urea manufacturing plant and to find the best solvent (in terms of % CO_2 recovery) among the solvents under study and the corresponding operating parameter. Aspen is a process simulation software package, which is widely used by the chemical engineers and others involved in process production today. Using this simulation software and by appropriate selection of thermodynamic models we can predict the performance of the chemical process. By accurate optimization, we can model the thermodynamic properties to separate the non-ideal mixtures. It can handle very complex processes, including multiple column separation systems, chemical reactors, distillation of chemically reactive compound and electrolyte solutions 0. The proposed paper aims to recovery of carbon dioxide from flue (un-reacted) gases of an ammonia plant, which is used as a raw material in urea manufacturing process. Manufacturing of urea requires raw materials as carbon dioxide and ammonia. Ammonia plant acquires Hydrogen (from natural gas) and Nitrogen (from air), as a raw material. This proposed work contains Aspen Plus software to regulate the flue gas at a particular temperature and pressure and by this we can recover maximum possible carbon dioxide gas and can reuse to manufacture of urea. This paper proposes recovery of carbon dioxide using four solvents, these are Monoethanolamine, Diethanolamine, Methyl diethanolamine and Diglycolamine 0. In industries like power plants and fertilizer plants also, carbon dioxide should be removed in order to avoid poisoning

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the iron catalyst 0. The poisoning is caused by oxygen, from traces of carbon dioxide or water, absorbing onto the iron surface and thus preventing nitrogen absorption.

2. Simulation Process

The proposed model is simulated with a Carbon Dioxide Recovery plant consisting of an absorber and stripper (regenerator). The absorber removes CO_2 from flue gas by means of an aqueous solutions. The CO_2 removal was studied by using four solvents with varying concentrations and temperatures; Monoethanolamine (20-35%), Diethanolamine (20-35%), Methyl diethanolamine (20-55%) and Diglycolamine (20-55%) at temperature range of 5-50^{0}C, pressure 7atm and flow rate 547600kmol/hr. The feed is entering in absorber column at a temperature of 50^{0}C, pressure 6atm and flow rate 28731kmol/hr, is composed of Nitrogen, Argon, Oxygen, CO_2 and water in order to reproduce the composition of a typical exhaust gas coming out of a Carbon Dioxide Recovery plant 0. The lean solvent is fed into the absorber column. After removal of CO_2 gas from the flue gas, the lean solvent enters the top of the (stripper) distillation column for regeneration. In this paper absorber and stripper blocks are simulated individually. First, absorber block was simulated and based on the absorber results stripper block simulation was conducted to find the efficiency of CO_2 recovery as well as solvent recovery. Simulated Carbon Dioxide Recovery plant flow sheet has been given below. Carbon dioxide recovery plant was simulated using Aspen Plus software, which is the most commonly used tool for chemical engineering operations. Figure 2.1 shows the flow sheet of the absorber/stripper combined as displayed is Aspen Plus software 0.

In absorber flue gas is considered in entering at stage three, flows up through the column counter-current into the lean solution; CO_2 in the flue gas chemically reacts with the amine solvent, while the gas coming out of absorber (top) is vented to the atmosphere at stage one. The rich solvent enters the top of stripper (stage one) where it flows down through the column to the reboiler and returns to the absorber from the bottom to finish one circulation (as lean solution) (Chunli Han *et al*., 2011; James T. Yeh *et al*., 2001; Moioli *et al*., 2012; Kangkang Li *et al*., 2015). UNIFAC0method was selected in Aspen Plus in order to describe the interaction between carbon dioxide and the amine solvent and the absorber, stripper are selected to be RADFRAC columns 0. The absorber is specified as a three stage column with the flue gas introduced from the third stage and the lean solvent is introduced from the first stage (stages are counted from top). And the stripper is specified as a three stage column with rich solvent is introduced from the first stage, and lean solvent discharged from the reboiler located at bottom of the stripper (third stage). Diethanolamine (DEA) – About 20-25% for removing H_2S and CO_2. Methyldiethanolamine (MDEA) – About 30-55% for removing H_2S and CO_2. Diglycolamine (DGA) – About 50% for removing H_2S and CO_2.The range of the present study is, in present simulation process are; MEA and DEA= 0.2, 0.25, 0.3 and 0.35 concentrations while for MDEA and DGA = 0.2, 0.25, 0.3, 0.35, 0.4, 0.45, 0.5 and 0.55 concentrations were considered to evaluate co2 recovery. Lean temperature is maintained between 5 & 50°C with variation of 5°C interval.

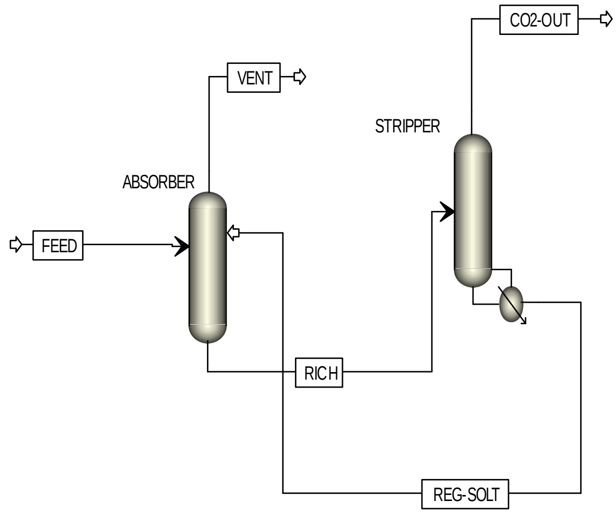

Figure 2.1. Simulated Carbon Dioxide Recovery plant

3. MATERIALS AND METHODS

Table 3.1 is the flue gas composition in the absorber 0.

Component	Composition (Vol%)
Nitrogen	0.7157
Argon	0.01
Oxygen	0.039
Carbon dioxide	0.0813
Water	0.154

Table 3.2 is the composition range of the flue gas analyzed in the Nagarjuna fertilizers and chemicals limited laboratory (by Gas Chromatography).

Component	Range of Composition
Nitrogen	69 to 71%
Argon	0.9 to 1.0%
Oxygen	2.5 to 4.5%
Carbon dioxide	8.0 to 9.0%
Water	16 to 19%

Table 3.3 presents are details of the different solvents studied in the present work to recover carbon dioxide. Literature the suggested 0 the following range of solvent concentrations for CO_2 recovery are; Monoethanolamine (MEA) - About 20% for removing H_2S and CO_2, and about 32% for removing only CO_2.

Effect of Temperature-Absorber

Temperature of absorption is one of the important parameter for CO_2 removal from the flue gas (containing CO_2). To study this, Aspen Plus software used to estimate the percentage CO_2 removal at temperatures varying from 5°C to 50°C and at different solvent concentrations.

Table 3.2. Different solvents studied and corresponding variables to recover carbon dioxide

Solvent	Concentration range of Study (weight %) Literature	Range (Present Study)	Temperature (°C)	
			Flue gas	Lean Solvent
MEA (Monoethanolamine)	About 20 and About 32	0.2-0.35	50	5-50
DEA (Diethanolamine)	About 20-25	0.2-0.35	50	5-50
MDEA (Methyl diethanolamine)	About 30-55	0.2-0.55	50	5-50
DGA (Diglycolamine)	About 50	0.2-0.55	50	5-50

Table 3.3. Boiling point of solvents

Solvent	Boiling Point (°C)
Monoetanolamine (MEA)	170
Diethanolamine (DEA)	280
Methyldiethanolamine (MDEA)	247
Diglycolamine (DGA)	221

4. RESULTS/OBSERVATIONS

4.1. Removal (mole %) of CO_2 from the Absorber with variation in solvent concentrations

Table 4.1.1. % Removal of CO_2 at different solvent concentrations of MEA

Temp.(°C)	Solvent Concentration (mole %)			
	MEA= 0.2	MEA= 0.25	MEA= 0.3	MEA= 0.35
5	95.64	96.74	97.51	98.07
10	94.37	95.73	96.7	97.41
15	92.99	94.62	95.8	96.67
20	91.58	93.46	94.84	95.87
25	90.29	92.4	93.96	95.13
30	89.65	91.85	93.49	94.72
35	88.96	91.28	92.98	94.3
40	87.95	90.42	92.27	93.69
45	86.73	89.38	91.37	92.93
50	85.37	88.21	90.41	92.09

Table 4.1.2. % Removal of CO_2 at different solvent concentrations of DEA

Temp.(°C)	Solvent Concentration (mole %)			
	DEA= 0.2	DEA= 0.25	DEA= 0.3	DEA= 0.35
5	99.07	99.43	99.63	99.74
10	98.67	99.16	99.43	99.6
15	98.2	98.83	99.19	99.42
20	97.67	98.46	98.92	99.21
25	97.14	98.08	98.63	98.98
30	96.8	97.83	98.44	98.83
35	96.39	97.52	98.21	98.65
40	95.8	97.1	97.88	98.38
45	95.09	96.57	97.47	98.05
50	94.21	95.94	96.98	97.65

Table 4.1.3. % Removal of CO_2 at different solvent concentrations of MDEA

Temp.(°C)	Solvent Concentration (mole %)							
	MDEA= 0.2	MDEA= 0.25	MDEA= 0.3	MDEA= 0.35	MDEA= 0.4	MDEA= 0.45	MDEA= 0.5	MDEA= 0.55
5	98.714	99.19	99.488	99.678	99.804	99.887	99.942	99.981
10	98.249	98.87	99.256	99.51	99.681	99.796	99.877	99.931
15	97.721	98.49	98.984	99.311	99.534	99.687	99.794	99.868
20	97.146	98.08	98.682	99.088	99.365	99.559	99.696	99.794
25	96.584	97.67	98.382	98.859	99.194	99.426	99.593	99.714
30	96.282	97.45	98.204	98.72	99.081	99.337	99.522	99.655
35	95.98	97.23	98.038	98.586	98.974	99.251	99.451	99.596
40	95.531	96.88	97.78	98.395	98.822	99.13	99.354	99.519
45	94.992	96.48	97.466	98.152	98.636	98.986	99.239	99.428
50	94.372	96.02	97.113	97.881	98.426	98.817	99.106	99.324

Table 4.1.4: % Removal of CO_2 at different solvent concentrations of DGA

Temp.($^{\circ}$C)	Solvent Concentration (mole %)							
	DGA= 0.2	DGA= 0.25	DGA= 0.3	DGA= 0.35	DGA= 0.4	DGA= 0.45	DGA= 0.5	DGA= 0.55
5	99.3	99.6	99.77	99.87	99.93	99.97		
10	98.98	99.39	99.62	99.76	99.85	99.91	99.96	99.98
15	98.59	99.13	99.44	99.63	99.75	99.84	99.9	99.94
20	98.17	98.83	99.23	99.47	99.64	99.75	99.83	99.88
25	97.75	98.54	99.01	99.31	99.51	99.65	99.75	99.82
30	97.49	98.35	98.87	99.2	99.42	99.58	99.69	99.77
35	97.21	98.15	98.71	99.08	99.33	99.51	99.63	99.72
40	96.79	97.86	98.51	98.92	99.21	99.41	99.55	99.66
45	96.31	97.51	98.25	98.73	99.06	99.29	99.45	99.58
50	95.76	97.12	97.96	98.5	98.88	99.15	99.34	99.49

4.2. Comparison of CO_2 removal from the Absorber with variation in solvents and same solvent concentration

Table 4.2.1: % Removal of CO_2 at same solvent concentrations

Temp.($^{\circ}$C)	Solvent Concentration (mole %)			
	MEA= 0.2	DEA= 0.2	MDEA= 0.2	DGA= 0.2
5	95.64	99.07	98.714	99.3
10	94.37	98.67	98.249	98.98
15	92.99	98.2	97.721	98.59
20	91.58	97.67	97.146	98.17
25	90.29	97.14	96.584	97.75
30	89.65	96.8	96.282	97.49
35	88.96	96.39	95.98	97.21
40	87.95	95.8	95.531	96.79
45	86.73	95.09	94.992	96.31
50	85.37	94.21	94.372	95.76

Table 4.2.2: % Removal of CO_2 at same solvent concentrations

Temp.($^{\circ}$C)	Solvent Concentration (mole %)			
	MEA= 0.25	DEA= 0.25	MDEA= 0.25	DGA= 0.25
5	96.74	99.43	99.1931	99.6
10	95.73	99.16	98.8658	99.39
15	94.62	98.83	98.4896	99.13
20	93.46	98.46	98.0766	98.83
25	92.4	98.08	97.6743	98.54
30	91.85	97.83	97.447	98.35
35	91.28	97.52	97.2259	98.15
40	90.42	97.1	96.885	97.86
45	89.38	96.57	96.4839	97.51
50	88.21	95.94	96.0199	97.12

Table 4.2.3: % Removal of CO_2 at same solvent concentrations

Temp. ($^{\circ}$C)	Solvent Concentration (mole %)			
	MEA= 0.3	DEA= 0.3	MDEA= 0.3	DGA= 0.3
5	97.51	99.63	99.488	99.77
10	96.7	99.43	99.256	99.62
15	95.8	99.19	98.984	99.44
20	94.84	98.92	98.682	99.23
25	93.96	98.63	98.383	99.01
30	93.49	98.44	98.204	98.87
35	92.98	98.21	98.038	98.71
40	92.27	97.88	97.78	98.51
45	91.37	97.47	97.466	98.25
50	90.41	96.98	97.113	97.96

Table 4.2.4. % Removal of CO_2 at same solvent concentrations

Temp. (˚C)	Solvent Concentration (mole %) MEA= 0.35	DEA= 0.35	MDEA= 0.35	DGA= 0.35
5	98.07	99.74	99.6784	99.87
10	97.41	99.6	99.5102	99.76
15	96.67	99.42	99.3115	99.63
20	95.87	99.21	99.088	99.47
25	95.13	98.98	98.8597	99.31
30	94.72	98.83	98.7204	99.2
35	94.3	98.65	98.5862	99.08
40	93.69	98.38	98.395	98.92
45	92.93	98.05	98.1521	98.73
50	92.09	97.65	97.8815	98.5

4.3. Removal (mole %) of CO_2 from the stripper with variation in solvent concentration and same solvents

Table 4.3.1: % Removal of CO_2 at different solvent concentrations of MEA

Temp. (˚C)	Solvent Concentration (mole %) MEA= 0.2	MEA= 0.25	MEA= 0.3	MEA= 0.35
8	99.96	99.95	99.95	99.94
13	99.95	99.95	99.94	99.94
17	99.95	99.94	99.93	99.93
22	99.94	99.93	99.92	99.92
27	99.93	99.92	99.91	99.9
32	99.92	99.91	99.9	99.89
36	99.9	99.89	99.88	99.87
41	99.88	99.87	99.86	99.85
46	99.86	99.84	99.83	99.82
51	99.82	99.81	99.79	99.78

Table 4.3.2. % Removal of CO_2 at different solvent concentrations of DEA

Temp. (˚C)	Solvent Concentration (mole %) DEA= 0.2	DEA= 0.25	DEA= 0.3	DEA= 0.35
8	99.18	98.94	98.68	98.38
13	98.99	98.68	98.33	97.94
17	98.72	98.31	97.84	97.29
22	98.31	97.91	97.24	94.22
27	97.81	97.02	96.07	94.89
32	96.71	95.42	93.76	91.62
36	95.09	92.99	90.19	86.46
41	90.17	85.69	79.81	72.57
46	75.17	67.38	59.69	55.08
51	59.06	58.39	60.24	56.46

Table 4.3.3. % Removal of CO_2 at different solvent concentrations of MDEA

Temp. (˚C)	Solvent Concentration (mole %) MDEA= 0.2	MDEA= 0.25	MDEA= 0.3	MDEA= 0.35	MDEA= 0.4	MDEA= 0.45	MDEA= 0.5	MDEA= 0.55
8	99.92	99.907	99.897	99.89	99.884	99.879	99.877	99.875
13	99.909	99.893	99.882	99.873	99.867	99.862	99.859	99.858
17	99.895	99.879	99.867	99.857	99.851	99.846	99.842	99.84
22	99.877	99.859	99.846	99.836	99.828	99.823	99.82	99.818
27	99.856	99.835	99.82	99.809	99.802	99.796	99.794	99.792
32	99.828	99.805	99.789	99.776	99.769	99.764	99.762	99.762
36	99.801	99.777	99.758	99.745	99.738	99.733	99.732	99.732
41	99.76	99.731	99.711	99.698	99.691	99.688	99.689	99.691
46	99.703	99.67	99.65	99.638	99.634	99.633	99.636	99.642
51	99.625	99.588	99.567	99.559	99.56	99.562	99.57	99.581

Table 4.3.4. % Removal of CO_2 at different solvent concentrations of DGA

Temp=	Solvent Concentration (mole %)							
(˚C)	DGA= 0.2	DGA= 0.25	DGA= 0.3	DGA= 0.35	DGA= 0.4	DGA= 0.45	DGA= 0.5	DGA= 0.55
8	99.88	99.86	99.84	99.82	99.8	99.79		
13	99.86	99.83	99.81	99.79	99.77	99.76	99.75	99.75
17	99.84	99.81	99.78	99.76	99.74	99.73	99.72	99.71
22	99.82	99.78	99.75	99.72	99.7	99.68	99.67	99.67
27	99.78	99.74	99.7	99.67	99.64	99.63	99.62	99.62
32	99.74	99.68	99.64	99.6	99.58	99.56	99.55	99.55
36	99.69	99.63	99.58	99.54	99.51	99.5	99.49	99.49
41	99.62	99.55	99.49	99.45	99.42	99.4	99.39	99.4
46	99.53	99.44	99.37	99.32	99.29	99.27	99.27	99.28
51	99.39	99.28	99.19	99.14	99.11	99.11	99.11	99.14

4.4. Comparison of CO_2 removal from the stripper with variation in solvents and same solvent concentration

Table 4.4.1: % Removal of CO_2 at same solvent concentrations

Temp.	Solvent Concentration (mole %)			
(˚C)	MEA= 0.2	DEA= 0.2	MDEA= 0.2	DGA= 0.2
8	99.96	99.18	99.9197	99.88
13	99.95	98.99	99.9093	99.86
17	99.95	98.72	99.8949	99.84
22	99.94	98.31	99.8774	99.82
27	99.93	97.81	99.8557	99.78
32	99.92	96.71	99.8283	99.74
36	99.9	95.09	99.8014	99.69
41	99.88	90.17	99.7596	99.62
46	99.86	75.17	99.7034	99.53
51	99.82	59.06	99.625	99.39

Table 4.4.2. % Removal of CO_2 at same solvent concentrations

Temp.	Solvent Concentration (mole %)			
(˚C)	MEA= 0.25	DEA= 0.25	MDEA= 0.25	DGA= 0.25
8	99.95	98.94	99.9072	99.857
13	99.95	98.68	99.893	99.834
17	99.94	98.31	99.879	99.81
22	99.93	97.91	99.8594	99.777
27	99.92	97.02	99.8353	99.736
32	99.91	95.42	99.8052	99.683
36	99.89	92.99	99.7765	99.631
41	99.87	85.69	99.7307	99.549
46	99.84	67.38	99.6698	99.438
51	99.81	58.39	99.5883	99.281

Table 4.4.3: % Removal of CO_2 at same solvent concentrations

Temp.	Solvent Concentration (mole %)			
(˚C)	MEA= 0.3	DEA= 0.3	MDEA= 0.3	DGA= 0.3
8	99.95	98.68	99.8973	99.84
13	99.94	98.33	99.8819	99.81
17	99.93	97.84	99.8668	99.78
22	99.92	97.24	99.8457	99.75
27	99.91	96.07	99.8202	99.7
32	99.9	93.76	99.7889	99.64
36	99.88	90.19	99.7575	99.58
41	99.86	79.81	99.7105	99.49
46	99.83	59.69	99.6496	99.36
51	99.79	60.24	99.5671	99.19

Table 4.4.4: % Removal of CO_2 at same solvent concentrations

Temp. (˚C)	Solvent Concentration (mole %)			
	MEA= 0.35	DEA= 0.35	MDEA= 0.35	DGA= 0.35
8	99.94	98.38	99.8896	99.817
13	99.94	97.94	99.8734	99.788
17	99.93	97.29	99.8575	99.759
22	99.92	94.22	99.8356	99.718
27	99.9	94.89	99.809	99.668
32	99.89	91.62	99.7764	99.604
36	99.87	86.46	99.7449	99.541
41	99.85	72.57	99.6981	99.445
46	99.82	55.08	99.6379	99.317
51	99.78	56.46	99.5589	99.141

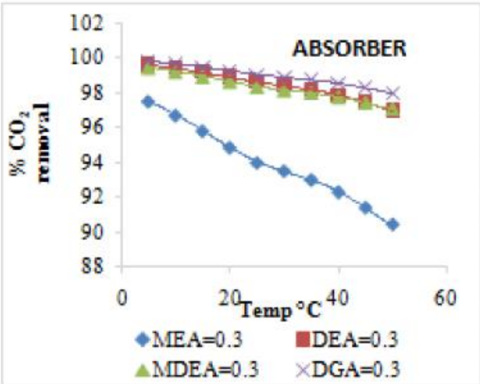

Figure 4.2.3: Temperature profiles of CO_2 removal with solvent concentration at 6atm absorber pressure

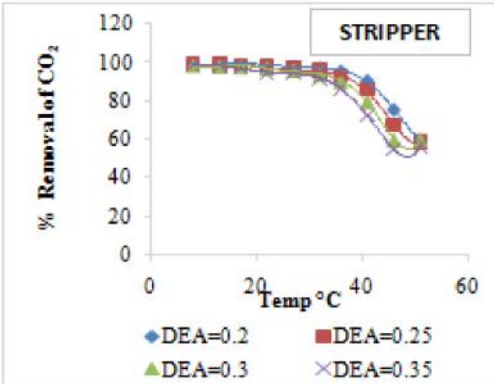

Figure 4.3.2: Temperature profiles of CO_2 removal with solvent concentration at 6atm stripper pressure

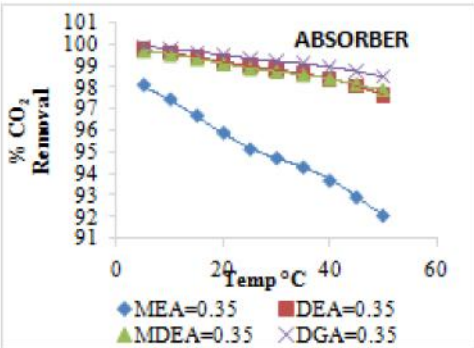

Figure 4.2.4: Temperature profiles of CO_2 removal with solvent concentration at 6atm absorber pressure

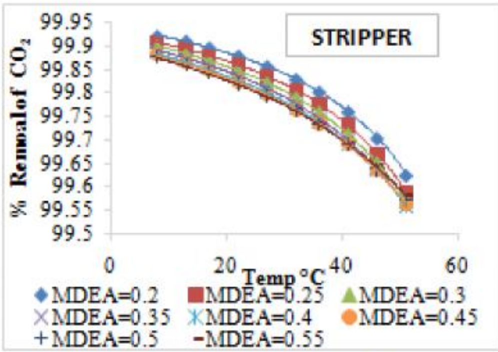

Figure 4.3.3: Temperature profiles of CO_2 removal with solvent concentration at 6atm stripper pressure

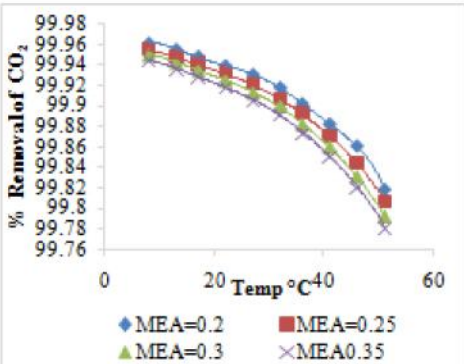

Figure 4.3.1: Temperature profiles of CO_2 removal with solvent concentration at 6atm stripper pressure

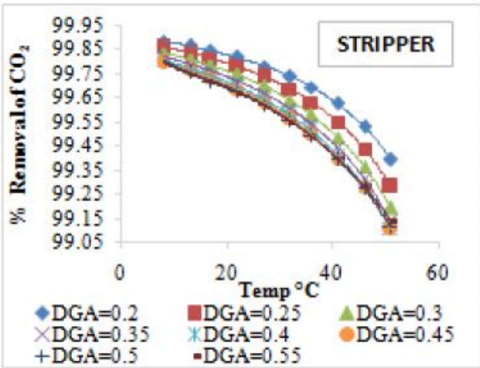

Figure 4.3.4: Temperature profiles of CO_2 removal with solvent concentration at 6atm stripper pressure

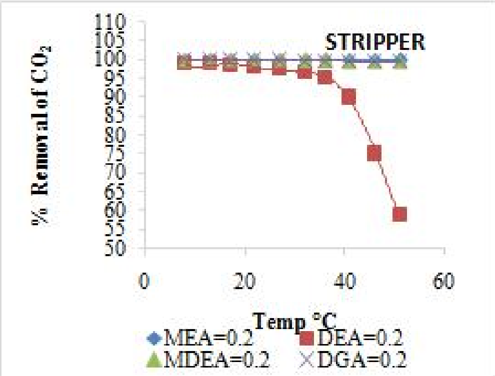

Figure 4.4.1: Temperature profiles of CO_2 removal with solvent concentration at 6atm stripper pressure

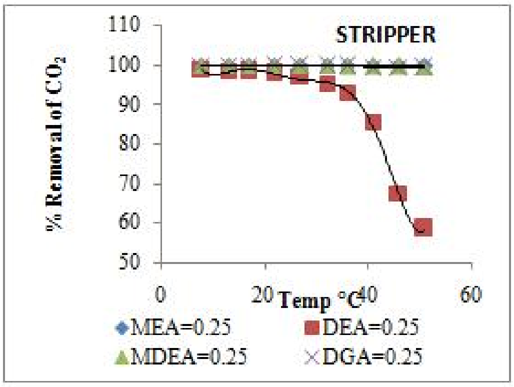

Figure 4.4.2: Temperature profiles of CO_2 removal with solvent concentration at 6atm stripper pressure

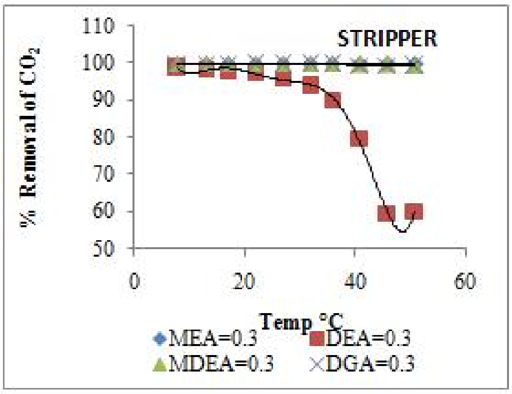

Figure 4.4.3: Temperature profiles of CO_2 removal with solvent concentration at 6atm stripper pressure

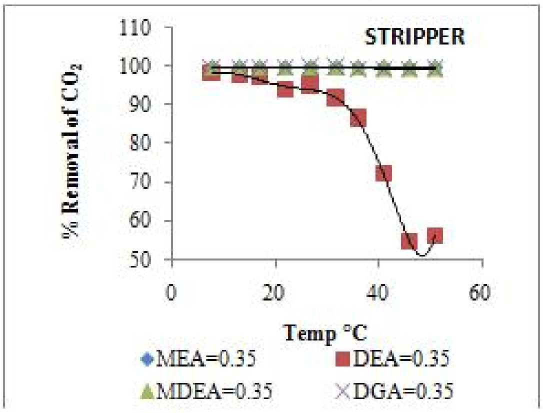

Figure 4.4.4: Temperature profiles of CO_2 removal with solvent concentration at 6atm stripper pressure

The solvents taken up for this study include Monoethanolamine, Diethanolamine, Methyldiethanolamine and Diglycolamine. From the simulation study the amount of carbon dioxide removed was found, from which the percentage of CO_2 removal in the asorber has been estimated at different temperatures of absorber. The results of the study were presented in the table number 4.1.1 to 4.2.4. Figure 4.1.1, 4.1.2, 4.1.3 and 4.1.4 is a plot of percentage CO_2 removal as a function of temperature (at a given solvent concentration) for the absorber using Monoethanolamine, Diethanolamine, Methyldiethanolamine and Diglycolamine respectively. Figure 4.1.1 indicates that with increasing temperature the percentage CO_2 removal is decreasing sharply. The rate of fall in percentage CO_2 removal was observed to be phenomenal with 0.2% (mole) Monoethanolamine as solvent. It was found that with 0.2% (mole) Monoethanolamine, the percentage of CO_2 removal decreased from 95.64 to 85.37% as the temperature of absorption is increased from 5°C to 50°C. Figure 4.1.2 indicates that with increasing temperature the percentage CO_2 removal is decreasing sharply. The rate of fall in percentage CO_2 removal was observed to be phenomenal with 0.2% (mole) Diethanolamine as solvent. It was found that for 0.2% (mole) Diethanolamine, the percentage CO_2 removal decreased from 99.07 to 94.21% as the temperature of absorption is increased from 5°C to 50°C. Figure 4.1.3 & 4.1.4 indicates that with increasing temperature the percentage CO_2 removal is decreasing sharply. The rate of fall in percentage CO_2 removal was observed to be phenomenal with 0.2% (mole) Methyldiethanolamine and Diglycolamine as solvent. It was found that for 0.2% (mole) Methyldiethanolamine and Diglycolamine, the percentage CO_2 removal decreased from 98.714 to 94.372% and 99.3 to 95.76 respectively as the temperature of absorption is increased from 5°C to 50°C.

Figure 4.2.1, 4.2.2, 4.2.3 and 4.2.4 is a plot of percentage CO_2 removal as a function of temperature (at a given solvent concentration) for the absorber using Monoethanolamine, Diethanolamine, Methyldiethanolamine and Diglycolamine respectively. Figure 4.2.1 is variation of CO_2 removal from the absorber with variation in solvents and at the same solvent concentration. It is observed that with increasing temperature the percentage CO_2 removal is decreasing sharply for all the solvents under study. The rate of fall in percentage CO_2 removal was observed to be very steep with 0.2% (mole) Monoethanolamine while for the other solvents the rate of reduction is more or less uniform. It was found that for 0.2% (mole) Monoethanolamine, the percentage CO_2 removal decreased from 95.64 to 85.37% as the temperature of the absorber is increased from 5°C to 50°C. Figure 4.2.2 is variation of CO_2 removal from the absorber with variation in solvents and at the same solvent concentration. It is observed that with increasing temperature the percentage CO_2 removal is decreasing sharply for all the solvents under study. The rate of fall in percentage CO_2 removal was observed to be very steep with 0.25% (mole) Monoethanolamine while for the other solvents the rate of reduction is more or less uniform. It was found that for 0.25% (mole) Monoethanolamine, the percentage CO_2 removal decreased from 96.74 to 88.21% as the temperature of the absorber is increased from 5°C to 50°C. Figure 4.2.3 is variation of CO_2 removal from the absorber with variation in solvents and at the same solvent concentration. It is observed that with increasing temperature the percentage CO_2 removal is decreasing sharply for all the solvents under study. The rate of fall in percentage CO_2 removal was observed to be very steep with 0.3% (mole) Monoethanolamine while for the other solvents the rate of reduction is more or less uniform. It was found that for 0.3% (mole) Monoethanolamine, the percentage CO_2 removal decreased from 97.51 to 90.41% as the temperature of the absorber is increased from 5°C to 50°C. Figure 4.2.4 is variation of CO_2 removal from the absorber with variation in solvents and at the same solvent concentration. It is observed that with increasing temperature the percentage CO_2 removal is decreasing sharply for all the solvents under study. The rate of fall in percentage CO_2 removal was observed to be very steep with 0.35% (mole) Monoethanolamine while for the other solvents the rate of reduction is more or less uniform. It was found that for 0.35% (mole) Monoethanolamine, the percentage CO_2 removal decreased from 98.07 to 92.09% as the temperature of the absorber is increased from 5°C to 50°C.

Effect of Temperature-Stripper

Temperature of stripper is one of the important parameter for the solvent regeneration and subsequent recycle into the absorber. To study this, Aspen Plus software used to estimate the percentage CO_2 removal from the rich solvent with temperatures varying from 8°C to 51°C. From the simulation study the amount of carbon dioxide removed was found, from which the percentage of CO_2 removal in the stripper has been estimated at different temperatures of stripper. The results of the study were presented in the table number 4.3.1 to 4.4.4
Figure 4.3.1, 4.3.2, 4.3.3 and 4.3.4 is a plot of percentage CO_2 removal as a function of temperature (at a given solvent concentration) for the stripper using Monoethanolamine, Diethanolamine, Methyl diethanolamine and Diglycolamine respectively. Figure 4.3.1 indicates that with increasing temperature the percentage CO_2 removal is decreasing progressively at all the concentrations under study. At 0.2% (mole) concentration of the solvent the percentage CO_2 removal was found to be high. It is observed from the results that with 0.2% (mole) Monoethanolamine as solvent, the percentage CO_2 removal is decreased from 99.96% to 99.82% as the temperature of the absorber is increased from 8°C to 51°C.

Figure 4.3.2 indicates that with increasing temperature the percentage CO_2 removal is decreasing sharply. From 8°C to 32°C temperatures of stripper, the percentage CO_2 removal is decreasing at a slower rate, while from temperature higher than 36°C the percentage CO_2 removal is very steep. At 0.2% (mole) solvent concentration the percentage CO_2 removal was found to be highest. It was found that for 0.2% (mole) Diethanolamine, the percentage CO_2 removal is decreased from 99.18% to 59.06% as the temperature of the absorber is decreased 8°C to 51°C.

Figure 4.3.3 and 4.3.4 indicates that with increasing temperature the percentage CO_2 removal is decreasing progressively. For both the solvents, at 0.2% (mole) concentration the percentage CO_2 removal was found to be highest. Forther it was noticed that for 0.2% (mole) Methyl diethanolamine and Diglycolamine, the percentage CO_2 removal is decreased from 99.92% to 99.625% and 99.88% to 99.39 respectively as the temperature of the absorber is increased from 8°C to 51°C.

Figure 4.4.1, 4.4.2, 4.4.3 and 4.4.4 are a plot of percentage CO_2 removal as a function of temperature (at a given solvent concentration) for the stripper using Monoethanolamine, Diethanolamine, Methyldiethanolamine and Diglycolamine respectively. Figure 4.4.1 is the variation of CO_2 removal with the variation of different solvents and same solvent concentration. It indicates that with increasing temperature the percentage CO_2 removal is decreasing sharply. At DEA 0.2% (mole) concentration as the temperature is increased from 8°C to 36°C the %CO2 removal is relatively decreasing from 99.18% to 95.09%, there after from 41°C onwards the percentage CO_2 removal is decreased to very steep from 90.17% to 59.06%. It was found that for 0.2% (mole) Monoethanolamine, the percentage CO_2 removal decreased from 99.96% to 99.82% with the increase in temperature from 8°C to 51°C.

Figure 4.4.2 is the variation of CO_2 removal with the variation of different solvents and same solvent concentration. It indicates that with increasing temperature the percentage CO_2 removal is decreasing sharply. At DEA 0.25% (mole) concentration and temperature is increased from 8°C to 32°C the %CO2 removal is relatively decreasing from 98.94% to 95.42%, there after from 36°C the percentage CO_2 removal is decreased to very steep from 92.99% to 58.39%. It was found that for 0.25% (mole) Monoethanolamine, the percentage CO_2 removal decreased from 99.95% to 99.81% with the increase in temperature from 8°C to 51°C.

Figure 4.4.3 is the variation of CO_2 removal with the variation of different solvents and same solvent concentration. It indicates that with increasing temperature the percentage CO_2 removal is decreasing sharply. At DEA 0.3% (mole) concentration and temperature is increased from 8°C to 32°C the %CO2 removal is relatively decreasing from 98.68% to 93.76%, thereafter 36°C the percentage CO_2 removal is decreased to very steep from 90.19% to 60.24%. It was found that for 0.3% (mole) Monoethanolamine, the percentage CO_2 removal decreased from 99.95% to 99.79% with the increase in temperature from 8°C to 51°C. Figure 4.4.4 is the variation of CO_2 removal with the variation of different solvents and same solvent concentration. It indicates that with increasing temperature the percentage CO_2 removal is decreasing sharply. At DEA 0.35% (mole) concentration and temperature 8°C to 32°C the %CO2 removal is relatively decreasing from 98.38% to 91.62%, thereafter 36°C the percentage $\%CO_2$ removal is decreased to very steep from 86.46% to 56.46%. It was found that for 0.35% (mole) Monoethanolamine, the percentage CO_2

removal decreased from 99.94% to 99.78% with the increase in temperature from 8°C to 51°C.

From all the above four solvents results Monoethanolamine is the best solvent to recover carbon dioxide. Monoethanolamine produce the best results among the four solvents. Because MEA boiling point is 170°C and it's about 20% for removing H_2S and CO_2, and about 32% for removing only carbon dioxide. Another three solvents are removing both H_2S and CO_2. Summary of the results are presented in the table no. 4.5 and 4.6.

Table 4.5. Results summery-Absorber

Solvent	Highest CO_2 removal at		% CO_2 removal
	Concentration (mole %)	**Temperature (°C)**	
Monoethanolamine	0.35	5	98.07
Diethaolamine	0.35	5	99.74
Methyldiethanolamine	0.55	5	99.981
Diglycolamine	0.55	10	99.983

Table 4.6. Results summery-Stripper

Solvent	Highest CO_2 removal at		% CO_2 removal
	Concentration (mole %)	**Temperature (°C)**	
Monoethanolamine	0.2	8	99.96
Diethaolamine	0.2	8	99.18
Methyldiethanolamine	0.2	8	99.919
Diglycolamine	0.2	8	99.88

5. Conclusion

The study of CO_2 removal by means of Monoethanolamine, Diethanolamine, Methyldiethanolamine and Diglycolamine has been performed using Aspen Plus software for the flue gas from urea reactor containing 8% of CO_2 concentration. In absorber the overall percentage CO_2 removal in this study was found to be 99.983% with Diglycolamine as solvent **(**at 0.55 concentration and 10°C temperature**)**. And for the other three solvents CO_2 results were found to be 99.981% with Methyldiethanolamine solvent (at 0.55 concentration and 5°C temperature), 99.74% with Diethanolamine solvent (at 0.35 concentration and 5°C temperature) and 98.07% with Monoethanolamine solvent (at 0.35 concentration and 5°C temperature). In stripper the overall percentage CO_2 removal in this study was found to be 99.96% with Monoethanolamine solvent at (0.2 concentrations and 8°C temperature). And another three solvents CO_2 results were found to be 99.919% with Methyldiethanolamine solvent at (0.2 concentration and 8°C temperature), 99.88% with Diglycolamine solvent at (0.2 concentration and 8°C temperature), and 99.18% with Diethanolamine solvent at (0.2 concentration and 8°C temperature). From the above results Monoethanolamine can be considered to be most effective and the best solvent to recover Carbon dioxide from urea manufacturing plant flue gas stream.

In both the absorber and stripper, the operating pressure considered was 6 atm while performing all the calculations.

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