Numerical Simulation to Optimize Di-Ethanol-Amine (DEA) Strength for Achieving the Highest Methane Purity from Biogas

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ABSTRACT

Biogas has to be purified to meet the quality standards. Carbon dioxide (CO_2) hydrogen sulfide (H_2S) and other sulfide compound are the main acid gases that may require complete or partial removal. Thus, acid gas removal simulation is an essential tool for control and operations in gas processing plant. Process simulator, plays an important role to accomplish these objective.This paper aims to determinethe optimum DEA (Di-Ethanol-Amine)strength to achieve the highest methane purity from Biogas using Aspen HYSYS simulation program.This simulation will use the DEA amine solvent with different strength for removing the CO_2 and H_2S simultaneously from an amount of feed biogas that has total volume flow rate about 13 m^3/h. Twenty stages of PSA (Pressure Swing Absorber) absorption columns which operate at pressure ranging from 25 to 26 bar and at temperature of nearly 43 °C.The results of this simulation process shows that pure methane (99 % purity) with zero percentage of CO_2 and H_2S is obtained at an optimum value of 0.3 of DEA strength.

Key words: Biogas, DEA, Aspen HYSYS, pure methane.

INTRODUCTION

Biogas[1,2,3] has to be purified to meet the quality standards[4] specified by the major pipeline transmission and distribution companies since the biogas contains others impurities such as liquids, sand, mercury and other gasses like nitrogen, helium and acid gases (carbon dioxide, hydrogen sulfide)[5]. Carbon dioxide (CO_2) hydrogen sulfide (H_2S) and other sulfide compound are the main acid gases that may require complete or partial removal as they can

cause corrosion, reduce the heating and sales values of the gas to meet gas purchaser's acceptance in distribution specification, safety and transport requirement.
The main removal processes are based on absorption[6,7] and determination of the solvent strength[8].
Thus, acid gas removal simulation is an essential tool for control and operations in gas processing plant because it can be used to stimulate and analyses the acid gas removal unit (AGRU) under different operating conditions [9,10].
Process simulator, such as Aspen HYSYS simulator, plays an important role to accomplish these objectives[11,12] .
Dr. Ahmed Abd El-Ati Ahmed [13] makes statistical study for Egyptianwaste anddiscussed the "Thermal & Biogas Production In Egypt", without the discussion of biogas quality improving methods.
Shaban D. Abou Hussein and Omaima M. Sawan[14] discussed The Utilization of Agricultural Waste as One of the Environmental Issues in Egypt by different methods without discussion of biogas upgrading methods.
Lars Erik Øi[15] discussed the ways of biogas upgrading to remove acidic contents (CO_2& H_2S) to match the universal standard for different applications especially operation of engines and power stations. He studiedthe CO_2 removal from biogas contents to be able to run engines and power plants. However, this paper did not provide a specific method to determine the optimum DEA strength to extract pure methane from biogas.
Rumyantseva and Watanasiri [16] studied intensively the use of simulation programs in the purification process of acid gases.However,they did not provide a recommendation on how to get highest degree of purity. Therefore, this paper aims to determinetheoptimum DEA strength to achieve the highest methane purity from biogas.

METHODOLOGY

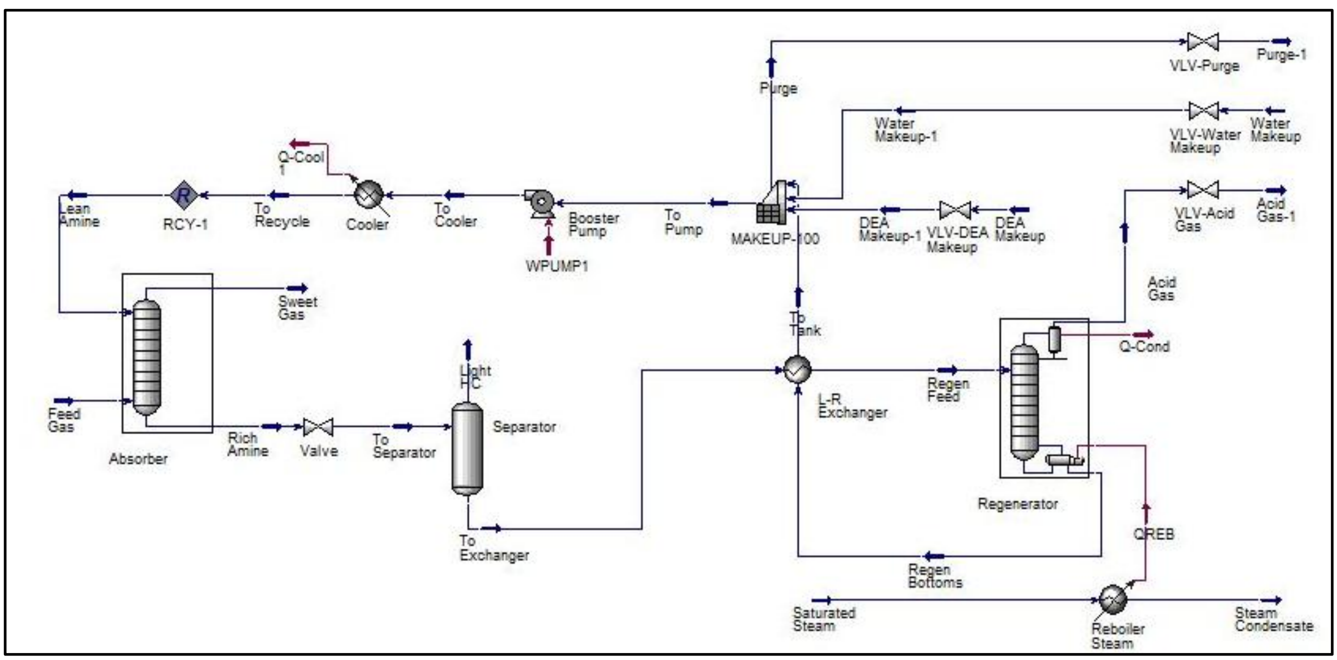

Fig 1: Complete Acid Gases Remval Cycle (sweeting Cycle)

As shown in the above figure (fig : 1) the acid gas removal steps are as follow:-

1- Feed gas enters Absorber at conditions of (43.4 ℃, 25.18 bar, 5755 kg/hr) from the bottom **o**f the absorber column.
2- The lean amine (DEA) enters at the top of the column at conditions of (43.33 ℃, 25 bar, 5530 kg/hr).
3- Amine absorbs CO_2 and H_2S from the feed gassimultaneously.
4- The sweet feed gas(biogas free from CO_2& H_2S) exit from the top of column, and the rich amine exit from the bottom.
5- Rich amine passes through expansion valve to reach to (66.32℃&2 bar) to enter separator.
6- Rich amine exit from separator by the same above conditions to enter the L/R heat exchanger.
7- L/R heat exchanger transfers the heat between rich amine and lean amine.
8- Rich amine will heat and lean amine will be cold and rich amine enters Regeneration columnto extract CO_2 from the rich amine to be lean amine and use it again.
9- Lean amine exit from Heat exchanger at (83.7 ^{0}C & 1.05 bar) to make up tank.
10- Lean amine exit from make-up tank at conditions (84 ^{0}C & 1.05 bar)
11- Then pumped it to (84.34 ^{0}C & 25 bar) and cooled it to be (43.33 ^{0}C & 25 bar) to enter the recycler.
12- Lean amine exit from recycler by the conditions of (43.33 ^{0}C & 25 bar)
13- Finally, sweet gas exit from the absorber after absorbing both CO_2& H_2S at (43.337 ^{0}C & 25 bar).
14- All above conditions (temperature, pressure and feed gas flow rates based in many simulation trials to get the highest methane purity from Egyptian biogas).

In order to optimize the DEA strength for highest methane purity the following steps will be performed:

1- The absorber column was selected from Aspen HYSYS model pallet.

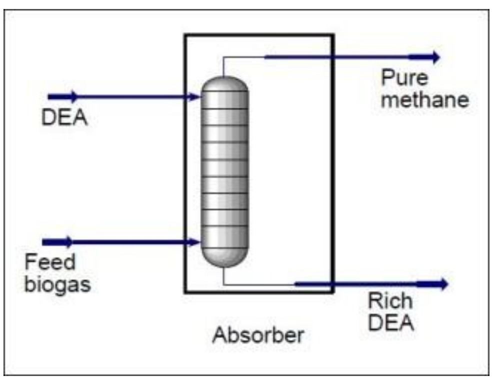

Fig2: Absorber column

2- The acid gas fluid package which containing DEA was also selected.
3- The component list which containing chemical composition of the biogasfrom the Egyptian waste was defined.Table 1 shows the feed Egyptian biogas composition in mole fraction [3].

Table 1. Feed Egyptian biogas composition in mole fraction [17]

Component	Mole fraction
Methane (CH_4)	0.7464
Carbon dioxide (CO_2)	0.2522
Hydrogen sulfide (H_2S)	0.0004
Water vapor (H_2O)	0.0004
Hydrogen (H_2)	0.0001
Nitrogen (N_2)	0.0002
Oxygen (O_2)	0.0003

4- An initial value of (0.2)is selected for DEA strength.
5- The initial absorber working conditions (pressure, temperature and flow rate) for both feed gas and DEA is shown in Table 2.

Table 2.Initial absorber working conditions

Working condition	Unit	DEA	Feed biogas
Vapour Fraction		0	1
Temperature	^0C	43.33	43.4
Pressure	bar	40	20.17
Molar Flow	kmole/h	2305.92	249.04
Mass Flow	kg/h	55285.58	5754.98
Liquid Volume Flow	m3/h	53.84	13.33

6- The simulation cycle was runto insure absorber conversion.
7- Finally the Aspen HYSYS case studies tool was used to draw the acid gas removal curves which are used in DEA strength determination.

RESULTS & DISCUSSION

Table 3 and Figure 3show that there is a reverse proportion between increasing the DEA strength and sweet gasH_2S mole fraction from point of (zero) up to (0.11) DEA strength. From point of (0.11) up to (0.26) DEA strength there is no more effect of DEA strength upon the sweet gas H_2S mole fraction.At DEA, strength of 0.27 there is a sudden decreasing on sweet gas H2S mole fraction due to DEA strength increasing and the sweet gasH_2S mole fraction equal to (zero). After (0.27) DEA strength there is no need to increase the DEA strength due to the stability of sweet gas H_2S value at (zero)

Table 3. Effect of DEA Strength on H_2S mole fraction

DEA strength	H_2S mole fraction	DEA strength	H_2S mole fraction	DEA strength	H_2S mole fraction	DEA strength	H_2S mole fraction
0	0.020925	11	0.002734	22	0.002734	33	0.000000
1	0.019972	12	0.002734	23	0.002734	34	0.000000
2	0.018884	13	0.002734	24	0.002734	35	0.000000
3	0.017663	14	0.002734	25	0.002734	36	0.000000
4	0.016295	15	0.002734	26	0.002734	37	0.000000
5	0.014755	16	0.002734	27	0.000000	38	0.000000
6	0.013008	17	0.002734	28	0.000000	39	0.000000
7	0.011000	18	0.002734	29	0.000000	40	0.000000
8	0.008790	19	0.002734	30	0.000000		
9	0.006580	20	0.002734	31	0.000000		
10	0.004469	21	0.002734	32	0.000000		

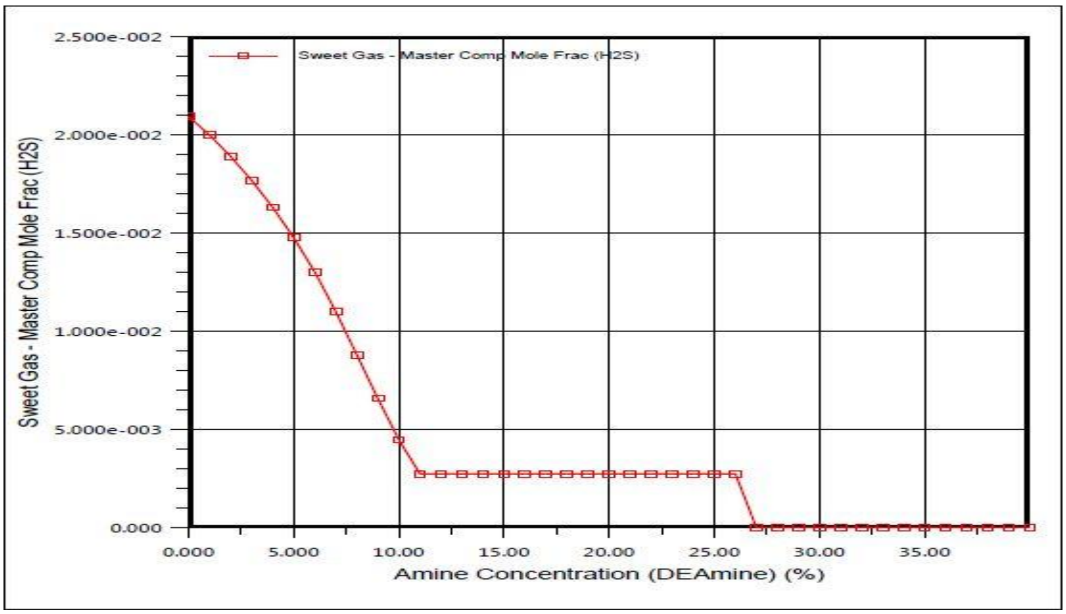

Figure 3: Effect of DEA Strength on H_2S mole fraction

Table 4 and Figure 4show that there is a reverse proportion between increasing the DEA strength and sweet gasCO_2mole fraction from point of (zero) up to (0.25) DEA strength. From point of (0.26) up to (0.28) DEA strength The sweet gas CO2 mole fraction tends to be (zero)
After point (0.28) DEA strength there is a little effect of DEA strength upon the sweet gas CO_2mole fraction.

Table 4. Effect of DEA Strength on CO_2mole fraction

DEA strength	CO_2 Mole fraction	DEA strength	CO_2 Mole fraction	DEA strength	CO_2 Mole fraction	DEA strength	CO_2 Mole fraction
0	0.286847	11	0.171431	22	0.038275	33	0.000141
1	0.277126	12	0.159040	23	0.027497	34	0.000130
2	0.267188	13	0.146494	24	0.017820	35	0.000110
3	0.256979	14	0.133639	25	0.008606	36	0.000099
4	0.246590	15	0.120916	26	0.002311	37	0.000091
5	0.236179	16	0.108426	27	0.000949	38	0.000084
6	0.225777	17	0.108426	28	0.000503	39	0.000078
7	0.214737	18	0.108426	29	0.000368	40	0.000073
8	0.204128	19	0.071455	30	0.000247		
9	0.193053	20	0.059996	31	0.000198		
10	0.182339	21	0.049112	32	0.000169		

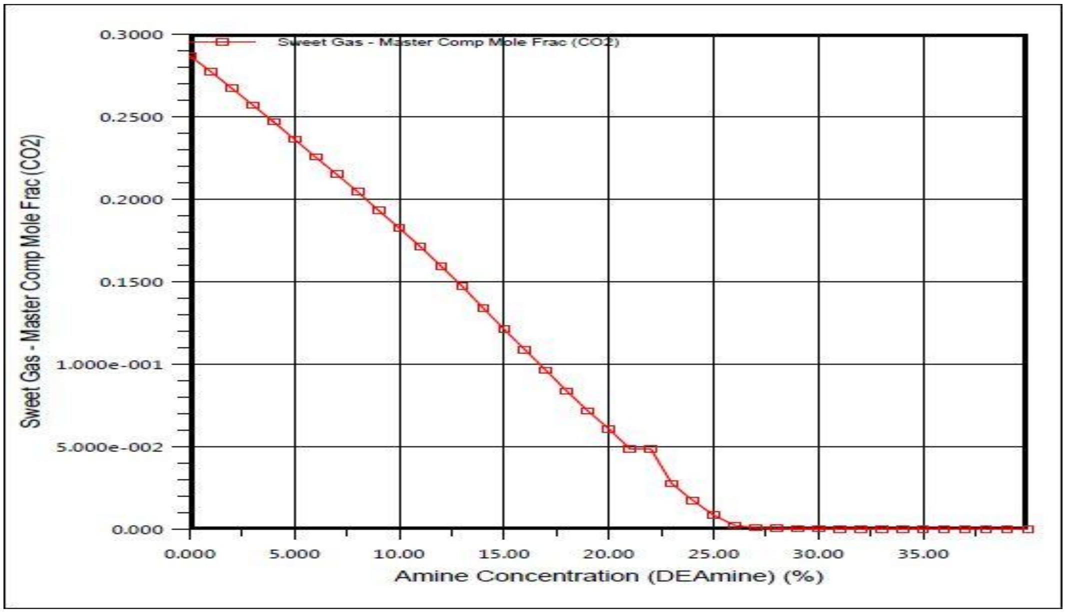

Figure 4: Effect of DEA Strength on CO_2 mole fraction

Table 5 and Figure 5 show that from point of (zero) up to (0.20) DEA strength there is no effect of DEA strength upon the methane purity. From point of (0.20) up to (0.26) DEA strength there is a direct proportion between increasing the DEA strength and the methane purity. After (0.27) DEA strength there is little effect of DEA strength up on methane purity

Table 5.Effect of DEA Strength on Methane purity

DEA strength	Methane purity	DEA strength	Methane purity	DEA strength	Methane purity	DEA strength	Methane purity
0	0.935921	11	0.935921	22	0.958377	33	0.996632
1	0.935921	12	0.935921	23	0.968216	34	0.996658
2	0.935921	13	0.935921	24	0.978909	35	0.996693
3	0.935921	14	0.935921	25	0.987805	36	0.996718
4	0.935921	15	0.935921	26	0.994390	37	0.996742
5	0.935921	16	0.935921	27	0.995711	38	0.996765
6	0.935921	17	0.935921	28	0.996180	39	0.996787
7	0.935921	18	0.935921	29	0.996347	40	0.996808
8	0.935921	19	0.935921	30	0.996484		
9	0.935921	20	0.935921	31	0.996547		
10	0.935921	21	0.947073	32	0.996592		

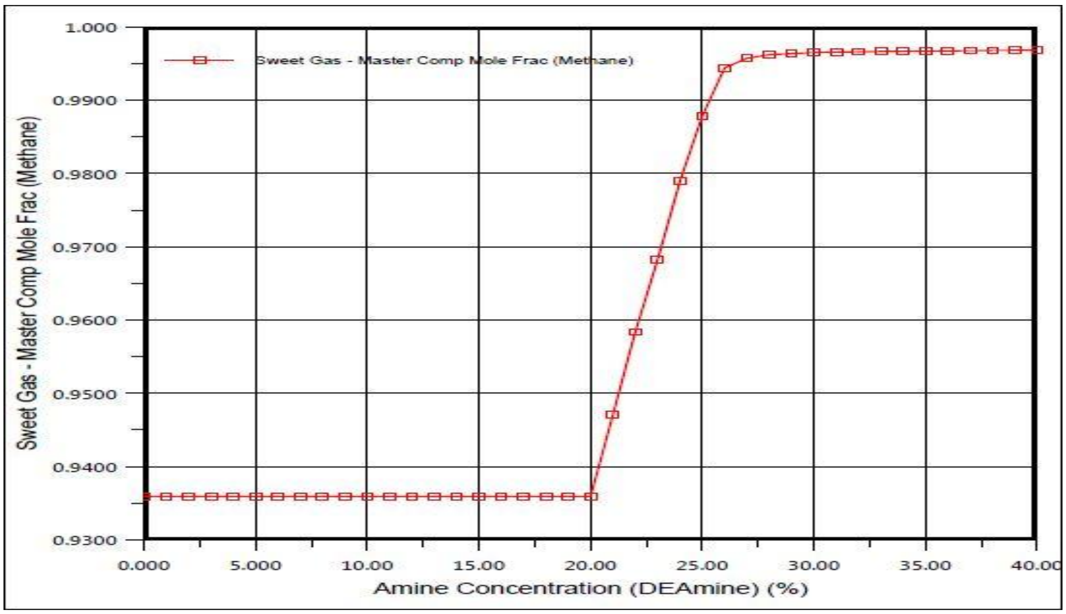

Figure 5: Effect of DEA Strength on Methane purity

After studying the previous tables (from table 3 to table 5)and previous figures (from figure 3 to figure 5) we note that the following:-

1- There is no effect of DEA strength up on the methane purity before (0.20)
2- There is very little effect of DEA strength after (0.27) up on both of sweet gas (H_2S, CO2) mole fraction and also methane purity.
3- We need to optimize the DEA strength value to determine the optimum point which meets the highest methane purity with minimum sweet gas (H_2S andCO_2) mole fraction
4- There is no need to repeat the DEA strength effect upon the sweet gas H_2S contentsdue to the small value of H_2S biogas contents which fade once we start the upgrading (sweeting) process

Table 6 and Figure6show that there is a reverse proportion between increasing the DEA strength and CO_2 mole fraction, in the same time there is a direct proportion between increasing the DEA strength and the methane purity.At DEA strength of 0.28, the CO_2 mole fraction tends to be zero and the methane purity tends to the highest value. Beyond of 0.28 DEA strength, it is observed that avery little increase in methane purity and very little decrease in CO_2 mole fraction. It is concluded from Table 3 and Figure 3 that strength of 0.3 of DEA is the optimum selection for the sweeting simulation.

Table6. Optimization of DEA strength

DEA strength	CO_2 mole fraction	Methane purity
0.20	0.0582	0.9379
0.22	0.0361	0.9602
0.24	0.0153	0.9813
0.26	0.0018	0.9949
0.28	0.0003	0.9962
0.30	0	0.9965
0.32	0	0.9966
0.34	0	0.9967
0.36	0	0.9967
0.38	0	0.9968

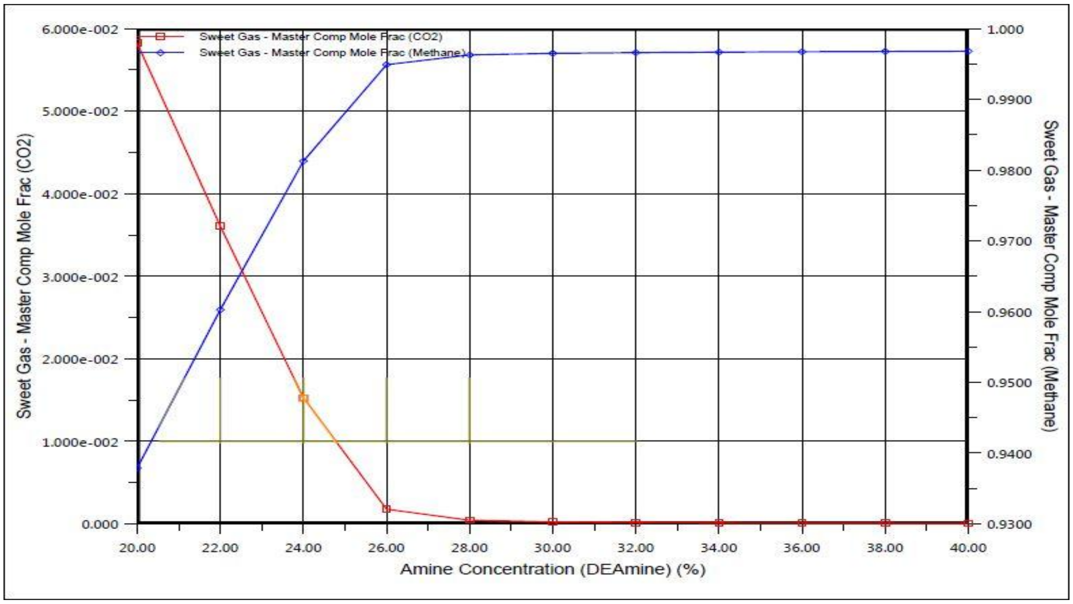

Figure 6:Optimization of DEA strength

Table 7 illustrates the final composition of biogas after upgrading process. This table shows that a 99 % purity of methane was obtained at an optimum DEA strength of 0.3.

Table 7. Composition of Upgraded Biogas

Component	Mole fraction
Methane (CH_4)	0.9949
Carbon dioxide (CO_2)	0
Hydrogen sulfide (H_2S)	0
Water vapor (H_2O)	0.0042
Hydrogen (H_2)	0.0001
Nitrogen (N_2)	0.0003
Oxygen (O_2)	0.0004
Di-Ethanol-Amine (DEA)	0

CONCLUSION

Aspen HYSYS simulation program was used to determine the optimum DEA (Di-Ethanol-Amine)strength in order to achieve the highest methane purity from Biogas. DEA amine solvent with different strength was used to remove the CO_2 and H_2S simultaneously from an amount of feed biogas with total volume flow rate about 13 m^3/h. 20 stage PSA (Pressure Swing Absorber) absorption column has pressure ranging from 25 to 26 bar and temperature 43 ^{0}C was used. It is found that the optimum DEA strength to obtain pure methane of 99 % purity from the Egyptian biogas is 0.3.

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