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FULL LENGTH ARTICLE

Theoretical effect of concentration, circulation rate, stages, pressure and temperature of single amine and amine mixture solvents on gas sweetening performance

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Abstract This simulation experiment performed by Aspen Hysys is about theoretical investigation of gas sweetening performance of single amine solvents MEA[1], MDEA[2], DEA[3], DGA[4], DIPA[5] and mixed amine solvents DGA–MEA, DEA–MDEA and SULFOLANE[6]–MDEA. Sweet gas having very high percentage of methane is produced by MEA (95.36%), DGA–MEA (95.37%), DEA–MDEA (95.51%) and SULFOLANE–MDEA (95.10%) and DGA (93.76%) shows lowest performance. DGA, SULFOLANE–MDEA, MDEA remove H_2S at a lower circulation rate and DEA, DIPA need higher but satisfactory circulation rate. Increasing stage number shows positive effect on DEA, DIPA and SULFOLANE–MDEA. Pressure change has no significant effect. Temperature increase and methane percentage are negatively correlated for all solvents (except low circulating DIPA). With temperature increase H_2S composition increases for DEA–MDEA, DGA–MEA; CO_2 increases for DEA–MDEA, DGA–MEA and high circulating SULFOLANE–MDEA.

1. Introduction

Sour gas is a fossil fuel coming from gas wells containing methane, ethane and other hydrocarbons as well as oxygen, nitrogen, water carbon-di-oxide and hydrogen sulfide. The raw gas that comes from underground gas wells directly is referred as sour gas because of the presence of H_2S or both H_2S and CO_2. If H_2S is present in NG then it causes severe corrosion to pipelines, turbines, compressors and other equipment. H_2S is also a poisonous chemical, if it is exposed to environment for leakage it will cause harm to humans and animals in the surroundings. On the other hand, NG having high amounts of CO_2 is low efficient to be burned and CO_2 is also responsible for corrosion in pipeline because it forms carbonic acid by reacting with water vapor [1]. So reducing H_2S and CO_2 is a compulsory case for natural gas treatment process. In a gas treatment plant gas stream undergoes two major

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Table 1 Composition of Sour Gas (collected from laboratory of Chemical Engineering Department, BUET).

Name of the component	Composition
Methane	0.863413
Ethane	0.039246
Propane	0.008830
i-Butane	0.000748
n-Butane	0.000467
n-Pentane	0.000491
n-Hexane	0.000280
H_2O	0.046721
N_2	0.001766
CO_2	0.020377
H_2S	0.017661

treatment processes, the first process is sweetening where the amount of H_2S and CO_2 is reduced and amine or amine mixture is used for gas sweetening process and the other one is dehydration process to decrease water content. Maximum allowable limit of natural gas stream for H_2S is 4 ppm and for CO_2 is 2% [2].

2. Amine and amine mixtures

Choice of suitable solvent for gas sweetening depends on several criteria. Capability of removing H_2S and CO_2, pickup rate of hydrocarbons, heat requirement of solvent regeneration, vapor pressure, foaming, selectivity, thermal stability, corrosive nature, cost, availability etc. are considered during designing of a gas sweetening unit [3]. In this simulation experiment MEA, MDEA, DIPA, DEA, DGA, SULFOLANE–MDEA blend, DGA–MEA blend and DEA–MDEA blend are used as sweetening solvent. Primary amine MEA, the oldest in modern gas sweetening plants is used having concentrations between 10% and 20% (wt), the used concentration of DGA is between 50% and 65% (wt), DEA is between 25% and 35% (wt), MDEA is between 30% and 50% (wt), DIPA is between 30% and 40% (wt), SULFOLANE–MDEA is between 40–35% and 40–40% (wt), DGA–MEA is between 10–15% and 5–20% (wt) and DEA–MDEA is between 25–10% and 35–15% (wt) [3][4].

Chemical reactions for MEA and DGA are (R refers to amine) [3]-

$$RNH_2 + H_2S = RNH_3HS$$

$$RNH_2 + H_2O + CO_2 = RNH_3HCO_3$$

Chemical reactions for DEA are

$$R_2NH + H_2S = R_2NH_2HS$$

$$2R_2NH + CO_2 = R_2NCOOR_2NH_2$$

Chemical reactions for MDEA and DIPA are

$$R_2NCH_3 + H_2S = R_2NHCH_3HS$$

$$R_2NCH_3 + CO_2 + H_2O = R_2NHCH_3HCO_3$$

3. Fluid package

Aspen Hysys has initiated a new fluid package for amine system in a gas processing plant from 8.3 version named Acid Gas, but this fluid package can be applied only on some components. For MEA, MDEA, DEA, DGA, DIPA and SULFOLANE–MDEA mixer Acid Gas is used. In other three cases, for DGA–MEA blend, DEA–MDEA mixture and MEA; NRTL fluid package is used. The simulation systems where Acid Gas fluid package is used generally take much longer time to converge than NRTL, and also in Acid Gas fluid packaged systems for low circulation rates take two or three hundred iterations to converge, on the contrary less than 50 iterations is enough for any amount of circulation rate in NRTL systems.

4. Experiment

In this simulation experiment it is considered that two sour gas streams come from two gas wells. From one well 25 MMSCFD (1245 kml/h) sour gas enters in the separator at

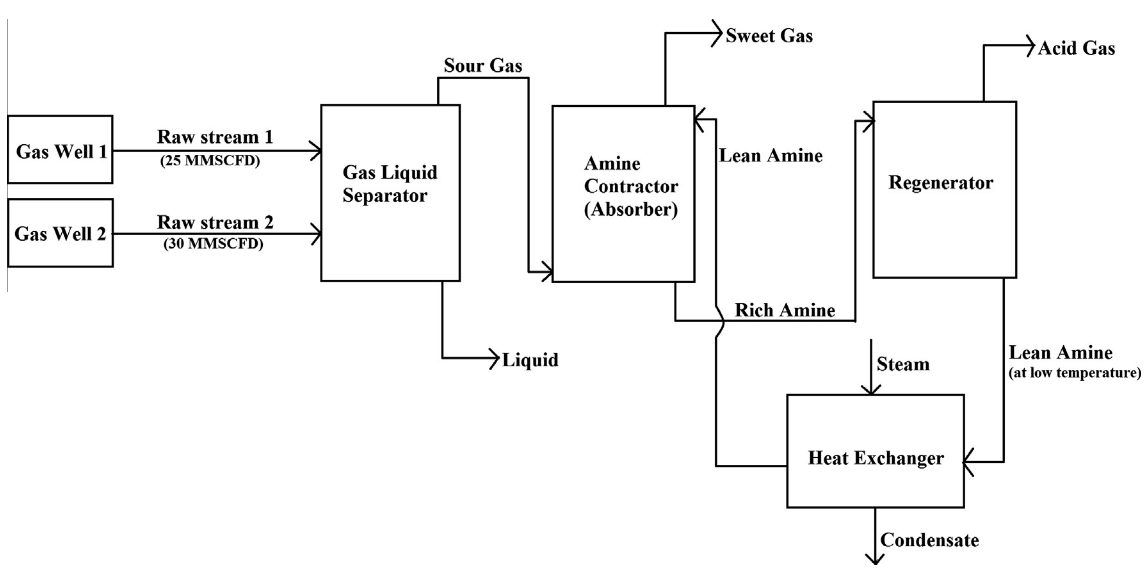

Figure 1 Simplified flow-chart of gas sweetening unit.

450 psia (3103 kPa) pressure and 80 °F (26.67 °C) temperature. From other well 30 MMSCFD (1494 kml/h) sour gas enters in the separator at 420 psia (2896 kPa) pressure and 70 °F (21.11 °C) temperature. It is assumed that composition of both gas stream is same, the composition is given in Table 1. In a separator liquid and gaseous part of the sour streams are separated and this separated liquid is brought from the bottom and gas coming from the top of the separator is sent to the bottom of the amine contractor, this unit acts as absorber. In the amine contractor the solvent (lean amine) is introduced through top at 30 °C temperature and 300 psia pressure, sour gas and solvent meet each other counter-currently after coming

Table 2 Circulation rate of MEA solution and composition of sweet gas.

Amine Amount (mole/h)	Amount of Sweet Gas (mole/h)	Composition of CO_2	Composition of H_2S	Composition of CH_4
MEA = 10% (wt)				
1000	2584	.0214	.0182	.9148
1200	2583	.0214	.0181	.9152
1500	2582	.0214	.0180	.9155
2500	2580	.0212	.0176	.9159
5000	2575	.0209	.0167	.9171
10,000	2564	.0204	.0148	.9194
20,000	2543	.0192	.0111	.9242
30,000	2522	.0180	.0073	.9289
40,000	2502	.0168	.0037	.9336
50,000	2484	.0155	.0009	.9375
70,000	2459	.0128	0	.9410
100,000	2425	.0087	0	.9450
120,000	2403	.0060	0	.9477
150,000	2370	.0023	0	.9513
170,000	2351	.0008	0	.9528
205,000	2321	.0001	0	.9536
210,000	2317	0	0	.9536
MEA = 15% (wt)				
800	2586	.0214	.0182	.9141
1000	2584	.0214	.0181	.9149
1200	2583	.0214	.0180	.9153
1500	2581	.0213	.0179	.9156
2500	2579	.0212	.0175	.9161
4000	2576	.0210	.0169	.9168
8000	2566	.0206	.0153	.9189
15,000	2550	.0197	.0124	.9224
30,000	2516	.0178	.0063	.9302
50,000	2476	.0151	.0003	.9385
60,000	2462	.0137	0	.9401
70,000	2450	.0123	0	.9415
100,000	2412	.0079	0	.9458
120,000	2387	.0051	0	.9486
150,000	2352	.0015	0	.9521
180,000	2321	.0002	0	.9534
195,000	2307	.0001	0	.9536
200,000	2303	0	0	.9536
MEA = 20% (wt)				
750	2587	.0214	.0182	.9139
1000	2583	.0214	.0181	.9150
1500	2581	.0213	.0179	.9157
3000	2577	.0211	.0172	.9165
6000	2569	.0208	.0159	.9182
10,000	2559	.0202	.0141	.9204
20,000	2533	.0189	.0095	.9260
50,000	2467	.0147	.0001	.9391
70,000	2439	.0117	0	.9421
100,000	2397	.0071	0	.9466
120,000	2369	.0041	0	.9495
150,000	2330	.0009	0	.9527
170,000	2308	.0002	0	.9534
180,000	2297	.0001	0	.9535
185,000	2292	0	0	.9536

into contact solvent which reduces composition of H_2S and CO_2 and it results in an increase of composition of CH_4. The bottom outlet of the contractor is rich amine solution and top outlet is sweet gas. Rich amine is then sent to the regenerator. Low temperature lean amine is produced from the bottom of the regenerator and acid gas is released from the top. Then temperature of lean amine is increased by passing through a heat exchanger and this lean amine is recycled to the amine contractor and this cycle repeats. Fig. 1 shows a simplified flow-chart diagram of gas sweetening unit. When simulation tests are operated to study the effect of concentration and circulation rate; temperature, pressure and stage number are kept constant. When simulation tests are operated at constant concentration and the circulation rate of amines with varying stage numbers then temperature and pressure are kept fixed. During simulation experiments to observe the effect of temperature only the temperature is changed and amine circulation rate, amine concentration, pressure and stage number are kept unchanged. Similarly, when pressure is changed to study the effect of pressure then other parameters are kept constant.

5. Effect of amine concentration and circulation rate

The composition of sweet gas for varying MEA circulation rates is given in Table 2. Attraction to H_2S is stronger than CO_2 for MEA. The maximum sweetening capability of MEA of this raw gas is 95.36% irrespective of concentration although concentration and performance are positively correlated. In rich amine solution the range of methane is

Table 3 Circulation rate of MDEA solution and composition of sweet gas.

Amine amount (mole/h)	Amount of sweet gas (mole/h)	Composition of CO_2	Composition of H_2S	Composition of CH_4
MDEA = 30% (wt)				
1550	2558	.0144	.0020	.9244
1600	2556	.0143	.0016	.9249
1800	2550	.0140	.0002	.9270
2000	2546	.0134	0	.9286
5000	2534	.0099	0	.9320
10,000	2524	.0073	0	.9345
20,000	2509	.0045	0	.9375
40,000	2487	.0021	0	.9397
70,000	2461	.0008	0	.9412
100,000	2437	.0004	0	.9420
125,000	2418	.0002	0	.9424
170,000	2383	.0001	0	.9429
180,000	2375	.0001	0	.9430
185,000	2372	0	0	.9431
MDEA = 40% (wt)				
1150	2556	.0145	.0010	.9248
1200	2555	.0144	.0007	.9253
1400	2550	.0137	0	.9272
1600	2546	.0132	0	.9286
2000	2543	.0126	0	.9295
3000	2539	.0116	0	.9305
10,000	2522	.0073	0	.9347
30,000	2494	.0030	0	.9392
60,000	2463	.0011	0	.9416
100,000	2427	.0004	0	.9430
150,000	2383	.0001	0	.9440
180,000	2357	.0001	0	.9444
185,000	2353	0	0	.9445
MDEA = 50% (wt)				
850	2558	.0149	.0011	.9244
900	2556	.0147	.0006	.9251
1000	2553	.0142	.0001	.9261
2000	2549	.0135	0	.9277
2500	2540	.0120	0	.9303
5000	2532	.0099	0	.9325
12,000	2516	.0065	0	.9360
30,000	2489	.0029	0	.9400
60,000	2455	.0010	0	.9425
120,000	2394	.0002	0	.9446
150,000	2365	.0001	0	.9454
175,000	2341	.0001	0	.9460
180,000	2336	0	0	.9461

0.07–0.10% and ethane is 0.0–0.01% in 10% (wt) solution, methane is 0.08–0.12% and ethane is 0.0–0.01% in 15% (wt) solution and methane is 0.10–0.14% and ethane is 0.01–0.02% in 20% (wt) solution.

The composition of sweet gas for varying MDEA circulation rates is given in Table 3. Like MEA, MDEA also shows more aptitude for H_2S. Gas sweetening capability of MDEA solution depends on concentration. The maximum sweet gas produced by MDEA according to concentration is 94.31%, 94.45% and 94.61% methane by 30%, 40% and 50% (wt) MDEA. In rich amine solution the range of methane is 0.06–0.07% and ethane is 0.0% in 30% (wt) solution, methane is 0.07–0.08% and ethane is 0.01% in 40% (wt) solution and methane is 0.08–0.09% and ethane is 0.01% in 50% (wt) solution.

The composition of sweet gas for varying DIPA circulation rates is shown in Table 4. Fondness toward H_2S of DIPA is stronger than CO_2. The gas sweetening performance of DIPA solution is concentration dependent. The maximum sweet gas produced by DIPA is 94.15%, 94.18% and 94.20% methane by 30%, 35% and 40% (wt) DIPA. In rich amine solution the range of methane is 0.04–0.05% for all DIPA solutions.

The composition of sweet gas for varying DEA circulation rates is shown in Table 5. Like DIPA, DEA also has strong affinity to H_2S. Ability of DEA to sweeten gas is concentration dependent. The maximum sweet gas produced by DIPA according to concentration is 94.17%, 94.20% and 94.24% methane by 25%, 30% and 35% (wt) DEA. In rich amine solution the range of methane is 0.05–0.06% for all DEA solutions.

The composition of sweet gas for varying DGA circulation rates is shown in Table 6. Unlike other amine solutions or amine mixture solutions DGA shows attraction more to CO_2 than H_2S. Again maximum concentration of methane reduces with an increase in DGA concentration, 93.90%, 93.77% and 93.76% methane by 50%, 58% and 65% DGA. In rich amine solution the range of methane is 0.03% for all DGA solutions.

The composition of sweet gas for varying SULFOLANE–MDEA mixer circulation rates is given in Table 7. SULFOLANE–MDEA mixer shows affinity more to H_2S than CO_2. Both mixtures absorb all H_2S faster. The performance of more concentrated (40–40%) (wt%) solution is better, it absorbs both H_2S and CO_2 at almost same rate and the methane composition of sweet gas stream becomes 95.1% whereas in case of 40–35% (wt%) solution methane composition is 94.88%. In rich amine solution the range of methane is 0.21–0.22% in 40–35% (wt%) solution and 0.22–0.23% in 40–40% (wt%) solution. Ethane composition is 0.03% in both solutions.

The composition of sweet gas for varying DGA–MEA blend circulation rates is given in Table 8. Both DGA–MEA blends perform equally and show similarity with SULFOLANE–MDEA mixers. The maximum methane composition for 10–15% (wt) solution is 95.37% and for 5–20% (wt) solution is 95.36%. The possible reason is, both blends have same

Table 4 Circulation rate of DIPA solution and composition of sweet gas.

Amine amount (mole/h)	Amount of sweet gas (mole/h)	Composition of CO_2	Composition of H_2S	Composition of CH_4
DIPA = 30% (wt)				
2850	2522	.0044	0	.9371
7000	2516	.0029	0	.9386
20,000	2505	.0015	0	.9399
50,000	2486	.0005	0	.9409
80,000	2468	.0002	0	.9412
120,000	2444	.0001	0	.9414
155,000	2424	.0001	0	.9415
160,000	2421	0	0	.9415
DIPA = 35% (wt)				
2550	2521	.0037	0	.9378
2700	2520	.0035	0	.9381
7000	2516	.0027	0	.9388
30,000	2498	.0010	0	.9405
70,000	2473	.0003	0	.9413
100,000	2456	.0002	0	.9415
130,000	2438	.0001	0	.9417
155,000	2424	.0001	0	.9418
160,000	2421	0	0	.9418
DIPA = 40% (wt)				
2000	2531	.0034	.0033	.9341
2200	2523	.0028	.0011	.9371
2500	2519	.0031	0	.9385
3500	2519	.0031	0	.9384
6000	2516	.0028	0	.9388
15,000	2508	.0016	0	.9399
50,000	2485	.0005	0	.9412
60,000	2479	.0004	0	.9414
100,000	2455	.0001	0	.9418
150,000	2426	.0001	0	.9419
155,000	2423	0	0	.9420

Table 5 Circulation rate of DEA solution and composition of sweet gas.

Amine amount (mole/h)	Amount of sweet gas (mole/h)	Composition of CO_2	Composition of H_2S	Composition of CH_4
DEA = 25% (wt)				
2800	2519	.0030	0	.9385
3500	2516	.0019	0	.9395
5000	2514	.0016	0	.9399
25,000	2498	.0004	0	.9410
75,000	2466	.0001	0	.9415
98,000	2451	.0001	0	.9417
100,000	2450	0	0	.9417
DEA = 30% (wt)				
2250	2525	.0032	.0006	.9362
2400	2520	.0028	0	.9381
4000	2514	.0017	0	.9398
10,000	2509	.0010	0	.9405
50,000	2481	.0002	0	.9415
70,000	2467	.0001	0	.9417
100,000	2447	.0001	0	.9419
105,000	2444	.0001	0	.9420
110,000	2441	0	0	.9420
DEA = 35% (wt)				
1900	2529	.0024	.0020	.9364
2100	2521	.0019	.0003	.9377
2300	2516	.0017	0	.9398
3600	2515	.0017	0	.9398
5000	2513	.0015	0	.9400
8000	2510	.0012	0	.9404
10,000	2508	.0010	0	.9406
11,000	2508	.0010	0	.9406
20,000	2501	.0006	0	.9411
40,000	2486	.0003	0	.9415
80,000	2459	.0001	0	.9421
115,000	2435	.0001	0	.9424
120,000	2431	0	0	.9424

Table 6 Circulation rate of DGA solution and composition of sweet gas.

Amine amount (mole/h)	Amount of sweet gas (mole/h)	Composition of CO_2	Composition of H_2S	Composition of CH_4
DGA = 50% (wt)				
1175	2535	0	.0023	.9330
1250	2530	0	.0013	.9348
1300	2526	0	.0007	.9360
1350	2523	0	.0003	.9371
1400	2520	0	.0001	.9382
1425	2520	0	.0001	.9385
1450	2518	0	0	.9390
DGA = 58% (wt)				
950	2535	0	.0018	.9329
1050	2528	0	.0007	.9354
1100	2525	0	.0002	.9360
1125	2523	0	.0001	.9373
1150	2522	0	0	.9377
DGA = 65% (wt)				
800	2533	0	.0015	.9335
825	2532	0	.0013	.9340
850	2530	0	.0010	.9346
875	2528	0	.0006	.9354
900	2526	0	.0003	.9360
925	2525	0	.0001	.9366
950	2523	0	.0001	.9372
975	2522	0	0	.9376

Table 7 Circulation rate of SULFOLANE–MDEA blend and composition of sweet gas.

Amine amount (mole/h)	Amount of sweet gas (mole/h)	Composition of CO_2	Composition of H_2S	Composition of CH_4
SULFOLANE–MDEA = 40–35 (wt%)				
350	2578	.0165	.0088	.9171
750	2567	.0163	.0055	.9207
1000	2560	.0156	.0041	.9229
2000	2537	.0124	0	.9307
5000	2514	.007	0	.9363
10,000	2494	.0039	0	.9395
20,000	2463	.0017	0	.9424
30,000	2435	.0008	0	.9440
40,000	2409	.0004	0	.9451
50,000	2383	.0002	0	.9461
75,000	2318	.0001	0	.9484
80,000	2306	0	0	.9488
SULFOLANE–MDEA = 40–40 (wt%)				
250	2579	.0179	.0086	.9167
300	2578	.0179	.0086	.9172
500	2573	.0177	.0065	.9189
700	2569	.0174	.0055	.9202
1000	2560	.0167	.0036	.9230
1500	2545	.0152	.0005	.9278
3000	2530	.0115	0	.9321
6000	2510	.0068	0	.9368
10,000	2492	.0041	0	.9397
20,000	2459	.0016	0	.9431
30,000	2430	.0008	0	.9449
40,000	2402	.0004	0	.9463
50,000	2374	.0002	0	.9475
75,000	2306	.0001	0	.9504
80,000	2292	0	0	.9510

amount of water (75 wt%). In rich amine solution the range of methane is 0.11–0.16% and ethane is 0.01% in both solutions.

The composition of sweet gas for varying DEA–MDEA mixture circulation rates is given in Table 9. DEA–MDEA mixtures also displays similarity with other blends. 25–10% (wt) solution sweets raw gas having maximum 95.45% methane, on the other hand 35–15% (wt) solution's highest capacity is to produce sweet gas of 95.51% methane. In rich amine solution the range of methane is 0.16–0.23% and ethane is 0.01–0.02% in 25–10% (wt) solution and methane is 0.29–0.37% and ethane is 0.02–0.03% in 35–15% (wt) solution.

6. Effect of number of stages

The composition change of sweet gas with a number of stages is shown in Table 10 for DEA solution, in Table 11 for DGA solution, in Table 12 for DIPA solution, in Table 13 for MDEA solution and in Table 14 in SULFOLANE–MDEA blend.

25 wt% DEA solution with circulation rate 3500 mol/h produces sweet gas having 0.28% CO_2 and 93.87% methane when the amine contractor has 17 stages. After increasing the stages to 24 percentage of CO_2 decreases to 0.12% and methane increases to 94.02%, change of both components is significant (Table 10).

1250 mol/h 50 wt% DGA solution produces sweet gas of 0.01% CO_2, 0.14% H_2S and 93.48% methane when the amine contractor is made of 12 number of plates. When the number of plates is 30 then there is no CO_2, 0.11% H_2S and 93.49% methane. With a good change in number of plates causes very small change in composition of sweet gas (Table 11).

7000 mol/h DIPA solution of 30 wt% with 17 stages is responsible for the production of sweet gas of 0.40% CO_2 and 93.76% CH_4. Same DIPA solution produces sweet gas consisting 0.20% CO_2 and 93.95% CH_4 for 24 stages (Table 12).

30 wt% MDEA solution with a circulation rate of 1600 mol/h produces sweet gas having 1.52% CO_2, 0.10% H_2S and 92.48% methane when the amine contractor has 16 stages. After increasing the stages to 27 percentage of CO_2 decreases to 1.32% and H_2S increases to 0.23%, methane increases to 92.52%, except methane change of other components is significant (Table 13).

When the circulation rate of the SULFOLANE–MDEA blend is small (1000 mol/h), the composition of CO_2, H_2S and methane in sweet gas is almost unchanged with an increase in the number of stages, whereas with ten times more circulation rate (10,000 mol/h) in sweet gas composition of CO_2, H_2S and methane changes noticeably with the change in the number of stages. For the latter case, composition of CO_2 decreases from 0.55% to 0.17%, on the contrary composition of methane rises from 93.80% to 94.17% (Table 14).

For 10 wt% MEA change of plates from 16 to 30 does not have any effect for circulation rate of 1200 mol/h and 10,000 mol/h, in both cases the composition of sweet gas

Table 8 Circulation rate of DGA–MEA blend and composition of sweet gas.

Amine amount (mole/h)	Amount of sweet gas (mole/h)	Composition of CO_2	Composition of H_2S	Composition of CH_4
DGA–MEA = 10–15 (wt%)				
500	2592	.0214	.0183	.9121
1000	2583	.0214	.0180	.9150
2000	2579	.0213	.0176	.9161
3000	2576	.0211	.0171	.9167
5000	2570	.0208	.0161	.9179
10,000	2556	.0201	.0136	.9209
20,000	2527	.0187	.0086	.9270
30,000	2499	.0173	.0038	.9331
50,000	2458	.0142	0	.9397
70,000	2426	.0109	0	.9430
100,000	2379	.0059	0	.9478
120,000	2348	.0028	0	.9508
140,000	2320	.0008	0	.9528
160,000	2294	.0001	0	.9535
170,000	2282	.0001	0	.9537
175,000	2276	.0001	0	.9537
180,000	2270	0	0	.9537
DGA–MEA = 5–20 (wt%)				
500	2592	.0214	.0183	.9121
1000	2583	.0214	.0180	.9150
2000	2579	.0213	.0176	.9161
3000	2576	.0211	.0171	.9167
5000	2570	.0208	.0161	.9179
10,000	2556	.0202	.0136	.9209
20,000	2527	.0188	.0086	.9271
30,000	2499	.0173	.0037	.9331
50,000	2458	.0142	0	.9397
70,000	2426	.0110	0	.9429
90,000	2395	.0077	0	.9461
120,000	2348	.0030	0	.9507
140,000	2319	.0009	0	.9527
150,000	2306	.0004	0	.9532
170,000	2282	.0001	0	.9536
175,000	2276	0	0	.9536

remains constant. For DEA–MDEA (35–15 wt%) mixture three circulation rates are used, 5000 mol/h, 30,000 mol/h and 50,000 mol/h and in each case the number of stages is changed from 15 to 28. For the first two amine streams the composition of sweet gas is totally unaffected, for the rest one negligible amount of change is observed. The same scenario is observed for DGA–MEA (10–15 wt%) mixture with a circulation rate of 1000 mol/h, 10,000 mol/h and 30,000 mol/h, range of changed stages is 15 to 28.

7. Effect of pressure

For each circulation rate of certain composition of amine or amine mixture pressure of that amine or amine mixture is changed from 100 psia to 600 psia and the effect is shown in Table 15. The change of pressure has very small effect on composition of sweet gas, which can be considered as negligible.

8. Effect of temperature

The temperature is changed from 20 °C to 40 °C with 5 °C interval for each circulation. Each amine or amine blend is circulated with two circulation rates as well as two different compositions and the results are shown in Table 16. In the case of DEA, with increase in temperature the composition of CO_2 falls quickly, on the other hand, the composition of methane decreases slowly. For DGA, the composition of H_2S shows very small change but methane composition displays a quick downward trend with temperature increase. For high "amine circulation rate/sour gas" ratio DIPA behaves like DEA, but for low ratios methane composition rises with temperature although CO_2 composition decreases. For MDEA and MEA when amine/sour gas ratio is small, the temperature has significant effects only on methane and this composition goes down with the temperature for both large and small ratios, but for large ratios CO_2 composition decreases by MDEA and increases by MEA. DEA–MDEA and DGA–MEA mixtures show similar behavior like MEA, additionally H_2S composition also increases when the amine sour gas ratio is high. When SULFOLANE–MDEA blend is used at low amine sour gas ratio, CO_2 and H_2S composition increase and methane composition decreases though with high amine sour gas ratio both CO_2 and methane composition go down with temperature. In some simulation operations the percentage of one component (either CO_2 or H_2S) is zero from 20 °C to 40 °C. In that

Table 9 Circulation rate of DEA–MDEA blend and composition of sweet gas.

Amine amount (mole/h)	Amount of sweet gas (mole/h)	Composition of CO_2	Composition of H_2S	Composition of CH_4
DEA–MDEA = 25–10 (wt%)				
500	2591	.0214	.0182	.9123
1000	2582	.0213	.0179	.9152
2000	2577	.0212	.0173	.9164
3000	2573	.0210	.0166	.9172
5000	2565	.0206	.0154	.9188
10,000	2545	.0197	.0122	.9228
20,000	2506	.0179	.0057	.9308
30,000	2470	.0159	.0007	.9375
50,000	2423	.0117	0	.9424
75,000	2365	.0062	0	.9479
90,000	2332	.0032	0	.9510
100,000	2310	.0015	0	.9526
120,000	2271	.0002	0	.9541
130,000	2253	.0001	0	.9544
135,000	2244	0	0	.9545
DEA–MDEA = 35–15 (wt%)				
500	2590	.0213	.0180	.9125
1000	2579	.0213	.0175	.9156
2000	2571	.0211	.0166	.9172
3000	2565	.0208	.0157	.9184
5000	2553	.0203	.0138	.9207
10,000	2521	.0191	.0091	.9264
20,000	2462	.0168	.0008	.9369
30,000	2422	.0138	0	.9404
50,000	2345	.0079	0	.9466
75,000	2251	.0013	0	.9533
90,000	2201	.0001	0	.9548
95,000	2185	.0001	0	.9550
100,000	2169	0	0	.9551

Table 10 Change of composition of sweet gas with number of stages for DEA solution.

Number of Stages	Composition of CO_2	Composition of H_2S	Composition of CH_4
17	.0028	0	.9387
18	.0024	0	.9390
19	.0022	0	.9393
20	.0019	0	.9395
21	.0017	0	.9397
22	.0015	0	.9399
24	.0012	0	.9402

Table 11 Change of composition of sweet gas with number of stages for DGA solution.

Number of stages	Composition of CO_2	Composition of H_2S	Composition of CH_4
12	.0001	.0014	.9348
14	0	.0014	.9348
15	0	.0014	.9348
16	0	.0013	.9348
20	0	.0013	.9348
22	0	.0011	.9349
26	0	.0011	.9349
30	0	.0011	.9349

Table 12 Change of composition of sweet gas with number of stages for DIPA solution.

Number of Stages	Composition of CO_2	Composition of H_2S	Composition of CH_4
17	.0040	0	.9376
18	.0036	0	.9379
19	.0032	0	.9383
20	.0029	0	.9386
21	.0026	0	.9388
22	.0024	0	.9391
24	.0020	0	.9395

Table 13 Change of composition of sweet gas with number of stages for MDEA solution.

Number of Stages	Composition of CO_2	Composition of H_2S	Composition of CH_4
16	.0152	.0010	.9248
18	.0147	.0012	.9250
20	.0143	.0016	.9249
23	.0137	.0016	.9254
25	.0134	.0020	.9253
27	.0132	.0023	.9252

Table 14 Change of composition of sweet gas with number of stages for of SULFOLANE–MDEA blend.

SULFOLANE–MDEA = 40–35 (wt%) 1000 mol/h				SULFOLANE–MDEA = 40–35 (wt%) 10,000 mol/h		
Number of Stages	Composition of CO_2	Composition of H_2S	Composition of CH_4	Composition of CO_2	Composition of H_2S	Composition of CH_4
16	.0158	.0039	.9229	.0055	0	.9380
18	.0157	.0040	.9229	.0047	0	.9388
20	.0156	.0041	.9229	.0039	0	.9395
22	.0156	.0041	.9229	.0033	0	.9401
26	.0156	.0042	.9229	.0023	0	.9410
30	.0155	.0042	.9229	.0017	0	.9417

Table 15 Effect of pressure on sweet gas composition.

Amine (wt%)	Circulation rate (mole/h)	Pressure (psia)	Composition of CO_2	Composition of H_2S	Composition of CH_4
DEA 25%	2800	100	.0029	0	.9386
DEA 25%	2800	600	.0030	0	.9384
DEA 25%	25,000	100	.0004	0	.9411
DEA 25%	25,000	600	.0004	0	.9410
DGA 50%	1300	100	0	.0008	.9361
DGA 50%	1300	600	0	.0007	.9359
DGA 65%	825	100	0	.0011	.9342
DGA 65%	825	600	0	.0013	.9338
DIPA 40%	2200	100	.0029	.0010	.9372
DIPA 40%	2200	600	.0027	.0011	.9371
DIPA 40%	60,000	100	.0004	0	.9414
DIPA 40%	60,000	600	.0003	0	.9414
MDEA 50%	900	100	.0147	.0006	.9251
MDEA 50%	900	600	.0147	.0007	.9249
MDEA 50%	12,000	100	.0065	0	.9360
MDEA 50%	12,000	600	.0064	0	.9360
MEA 10%	2500	100	.0212	.0176	.9160
MEA 10%	2500	600	.0212	.0176	.9159
MEA 10%	30,000	100	.0180	.0073	.9290
MEA 10%	30,000	600	.0180	.0074	.9288
DEA 35%–MDEA 15%	3000	100	.0208	.0157	.9184
DEA 35%–MDEA 15%	3000	600	.0208	.0157	.9183
DEA 35%–MDEA 15%	20,000	100	.0166	.0008	.9370
DEA 35%–MDEA 15%	20,000	600	.0166	.0008	.9368
DGA 5%–MEA 20%	2000	100	.0213	.0176	.9161
DGA 5%–MEA 20%	2000	600	.0213	.0176	.9160
DGA 5%–MEA 20%	20,000	100	.0187	.0086	.9271
DGA 5%–MEA 20%	20,000	600	.0188	.0087	.9269
SULFOLANE 40%–MDEA 35%	1000	100	.0156	.0040	.9230
SULFOLANE 40%–MDEA 35%	1000	600	.0156	.0041	.9228
SULFOLANE 40%–MDEA 35%	20,000	100	.0017	0	.9425
SULFOLANE 40%–MDEA 35%	20,000	600	.0016	0	.9424

cases, the composition change with temperature happens only for the present component in sour gas and so, the absent component is not discussed for that operations.

9. Result and discussion

Size and installation cost of a gas sweetening plant depends on the amount of sour gas and amine and the number of stages. During regeneration of amine solvent it undergoes several depressurization and heat exchange which makes it low pressure and low temperature stream, before sending regenerated lean amine solvent to sweetening plant it needs to be pressurized and heated. So pressure and temperature of inlet lean amine solvent have effect on operating cost. During design of a gas sweetening plant number of stages, concentration and circulation rate, pressure and temperature are chosen carefully so that cost and performance are both optimized.

9.1. Concentration and circulation rate

MEA, MDEA, DIPA, DEA, SULFOLANE–MDEA blend, DGA–MEA blend and DEA–MDEA blend reacts more quickly with H_2S than CO_2, only DGA shows opposite behavior. For any component or mixture for the same circulation

Table 16 Effect of temperature on sweet gas composition.

Temperature (°C)	Amine wt% + amount (ml/h)	Composition of CO_2	Composition of H_2S	Composition of CH_4	Amine wt% + amount (ml/h)	Composition of CO_2	Composition of H_2S	Composition of CH_4
20	DEA 25% + 3500	.0030	0	.9394	DEA 35% + 20,000	.0013	0	.9413
25		.0024	0	.9395		.0009	0	.9413
30		.0019	0	.9395		.0006	0	.9411
35		.0013	0	.9392		.0003	0	.9407
40		.0012	0	.9387		.0002	0	.9400
20	DGA 50% + 1250	0	.0010	.9377	DGA 65% + 850	0	.0008	.9371
25		0	.0012	.9363		0	.0009	.9369
30		0	.0013	.9348		0	.0010	.9346
35		0	.0013	.9332		0	.0009	.9334
40		0	.0015	.9312		0	.0009	.9319
20	DIPA 30% + 50,000	.0014	0	.9410	DIPA 40% + 3500	.0070	0	.9357
25		.0010	0	.9410		.0049	0	.9372
30		.0005	0	.9409		.0032	0	.9384
35		.0002	0	.9405		.0019	0	.9390
40		.0001	0	.9398		.0010	0	.9390
20	MDEA 30% + 1600	.0142	.0013	.9266	MDEA 50% + 30,000	.0034	0	.9405
25		.0142	.0012	.9261		.0032	0	.9403
30		.0143	.0016	.9249		.0029	0	.9400
35		.0143	.0017	.9239		.0026	0	.9397
40		.0143	.0019	.9226		.0023	0	.9391
20	MEA 10% + 1000	.0214	.0182	.9155	MEA 20% + 12,000	.0007	0	.9537
25		.0214	.0182	.9152		.0022	0	.9518
30		.0214	.0182	.9148		.0041	0	.9495
35		.0214	.0181	.9144		.0059	0	.9472
40		.0214	.0181	.9140		.0074	0	.9451
20	DEA–MDEA(25–10) + 30,000	.0143	0	.9405	DEA–MDEA(35–15) + 2000	.0210	.0164	.9182
25		.0152	.0002	.9392		.0210	.0165	.9177
30		.0159	.0007	.9375		.0211	.0166	.9172
35		.0165	.0017	.9355		.0211	.0167	.9167
40		.0170	.0029	.9332		.0211	.0168	.9160
20	DGA–MEA(10–15) + 2000	.0212	.0175	.9169	DGA–MEA(10–15) + 30,000	.0162	.0009	.9376
25		.0212	.0175	.9165		.0168	.0022	.9354
30		.0213	.0176	.9161		.0173	.0037	.9331
35		.0213	.0176	.9155		.0177	.0051	.9309
40		.0213	.0176	.9149		.0181	.0063	.9288
20	SULFOLANE–MDEA(40–35) + 20,000	.0018	0	.9431	SULFOLANE–MDEA(40–40) + 1000	.0159	.0022	.9258
25		.0017	0	.9428		.0163	.0029	.9244
30		.0017	0	.9424		.0167	.0036	.9230
35		.0016	0	.9419		.0171	.0044	.9213
40		.0014	0	.9413		.0173	.0049	.9200

rate the performance increases with heavier concentration, on the other hand for a constant concentration there is a positive correlation between performance and concentration. DEA–MDEA shows most effective sweetening efficiency, can produce 95.51% NG and DGA have lowest efficiency, maximum sweetening capacity is 93.76%. Although 2% CO_2 is allowable, in this simulation circulation rate is increased until both H_2S and CO_2 become zero to observe performance of the solvents. When only H_2S removal efficiency is considered then performance of solvents is as follows, DGA > MDEA > SULFOLANE–MDEA > DEA > DIPA > DEA–MDEA > DGA–MEA > MEA. For maximum concentration the circulation rate of DGA and MDEA is around 975–1100 mol/h, circulation rate of SULFOLANE–MDEA is more than 1500 mol/h, circulation rate of DEA and DIPA is around 2200–2500 mol/h and range of circulation rate of DEA–MDEA, DGA–MEA and MEA is about 25,000 to more than 50,000 mol/h, which remove almost all H_2S from sour gas.

9.2. Number of stages

Both DEA and DIPA increase methane percentage significantly with an increase in the number of stages, although comparatively small circulation rate of DEA and DIPA with 17 stages or less produce sweet gas of less than 4 ppm H_2S and less than 2% CO_2, which is the main target of gas sweetening plant. With increase in the number of plates, performance of DGA to reduce H_2S is very poor and methane percentage remains almost constant. For lower circulation rates SULFOLANE–MDEA solution also acts similarly like DGA, but at higher circulation rates it shows satisfactory results like DEA and DIPA. MDEA shows very different behavior, when stage number increases CO_2 percentage decreases but H_2S percentage increases on the other hand, methane percentage changes slightly. Stage number has no/negligible effect on MEA, DEA–MDEA blend and DGA–MEA blend.

9.3. Pressure and temperature

In this simulation study, pressure from 100 psia to 600 psia has no significant effect on any amine or amine mixer from lower to higher circulation rate. Except lower circulating DIPA, methane percentage decreases with increase in temperature. In case of DEA–MDEA and DGA–MEA composition of H_2S increases with temperature and for DGA composition of H_2S does not show a significant change. When high circulating MEA, DEA–MDEA, DGA–MEA or low circulating SULFOLANE–MDEA is used in sweetening then CO_2 composition increases with temperature and other solvents show opposite behavior.

10. Conclusion

Although no single amine can be found that can act perfectly as sweetening solvent but during sweetening plant design to choose a suitable solvent cost, availability, environmental issues, loss, corrosive behavior, viscosity, degradation are considered as well as capability of removing H_2S and CO_2. Achieving the sales gas quality at a lower operating cost is the ultimate goal of a gas treatment plant. In Bangladesh, generally sales gas contains 95–96% methane. One thing should be remembered that after gas sweetening process sweet gas is dehydrated, in the latter process composition of water reduces and methane percentage increases. So, achieving maximum performance of amine by producing sweet gas having zero percentage of H_2S and/or CO_2 from sweetening unit is not necessary, because it will increase operation costs.

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