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Optimization of Pressure Swing Absorber (PSA) Geometry to Achieve Highest Methane Purity from the Egyptian Biogas Using Aspen HYSYS Simulation

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Abstract:
In Egypt, it is easy to obtain large amount of biogas from different available sources such as sewage, agricultural and livestock waste. It is important to purify the biogas from its acidic components (CO_2 and H_2S) before pumping it into the domestic natural gas network to meet the standards of these networks. In addition, the purifying process is required in case of using the very high purity methane in sophisticated devices such as X-Ray metal analyzer that requires pure methane for the purpose of alloys analyzing process. This article is aimed to purify the biogas from CO_2& H_2S gases, which are the main reasons of the acidic compounds formation. Moreover, the purifying process increases the biogas calorific value. In order to design an optimized biogas treatment cycle; numerical simulation was performed using Aspen HYSYS software. The results show that the optimum absorber dimensions are 1.7 m tray diameter, 1.4 m3 tray volume and 0.5 m tray spacing when the biogas enters the absorber at a temperature of 43 ^oC, a pressure of 25 bars, a flow rate of 13 m3/hour and Diethanolamine (DEA) concentration of 0.3.

Keywords: *Absorber Geometry -Aspen Hysys- Biogas upgrading -Egyptian biogas -Methane purity.*

1. Introduction

In Egypt, it is possible to generate a large amount of energy using different types of waste such as agricultural, livestock and sewage waste to overcome the energy crises by converting these types of waste to biogas [i]. Sour biogas contains two main acidic components where they must be removed before pumping biogas into the natural gas network to meet the standards of these networks [ii-iv]. In addition, it is possible to obtain a high -purity methane from the biogas that used for other expensive purposes other than energy and power generation such as research applications and calibration for sophisticated devices which [v,vi]. Biogas sweetening is the process in which CO_2 and H_2S are removed in order to protect the pipelines network and power engines from corrosion due to acidic effect, and to raise the calorific value of the treated biogas [ii, vii-x].

Most of biogas researches in Egypt focused only on utilization feasibility and production of the biogas from local resources [xi-xv], however there are only few researchers concentrate on the biogas quality improvement methods to raise its purity of the Egyptian biogas. Therefore, this paper aims to optimize to determine the optimum absorber dimensions and number of stages to achieve the highest purity of the Egyptian biogas using Aspen HYSYS 8.6 simulation program.

The numerical simulation plays an important role in facilitating the proper design of sweetening cycle and sizing of its equipment especially the absorber [xvi-xviii]. Aspen HYSYS 8.6 simulation software program is one of the most important and accurate programs that have been used in the design of gas treatment process [xix-xxii].

The detailed discussion of the ways of biogas upgrading to remove acidic contents (CO_2 and H_2S) to match the universal standard of engines and power stations and intensive study in using the simulation programs in the purification process of acid gases have been done [xxiii-xxvii]. However, these previous literatures did not provide a specific method to determine the optimum absorber dimensions to extract pure methane from biogas.

2. Methodology

Figure 1 describes the complete acid gases removal cycle (sweetening cycle) [xxviii] in which the acid gas removal steps are performed. The feed gas enters the absorber at temperature of 43 °C, pressure of 25 bar and flow rate of 5755 kg/hr from the bottom of the absorber column. The lean amine (DEA) enters at the top of the column at conditions of 43 °C, 25 bar and 5530 kg/hr. The amine DEA absorbs CO_2 and H_2S from the feed gas simultaneously. The sweet feed gas, which is free from CO_2 & H_2S, exits from the top of column, and the rich amine, exits from the bottom of the absorber. Then the rich amine passes through expansion valve in order to expand to 66.32°C and 2 bars and then it enter the separator. Rich amine exits from the separator by the same fore mention conditions to enter a Lean amine/ Rich amine (L/R) heat exchanger. The L/R heat exchanger transfers heat from lean amine into rich amine. The hot rich amine which exits from the exchanger enters a regeneration column to extract CO_2 from the rich amine to lean it for recycling purpose. While the lean amine enters a make-up tank at 84 °C and 1.05 bar which is just above atmospheric pressure and exits from it at 84 °C and 1.05 bars which equal the same inlet conditions of make-up tank. Then it is pumped to 84.5 ^{0}C and 25 bars and sequentially it is cooled at constant pressure process to 43°C to be sent to a recycler. Lean amine exits from recycler at 43°C and 25 bars. Finally, a sweet gas is obtained from the absorber after removing both CO_2& H_2S. All the previous conditions of temperatures, pressures and feed gas flow rates of the removal cycle are a result of running many simulation trials in order to get the highest methane purity from Egyptian biogas.

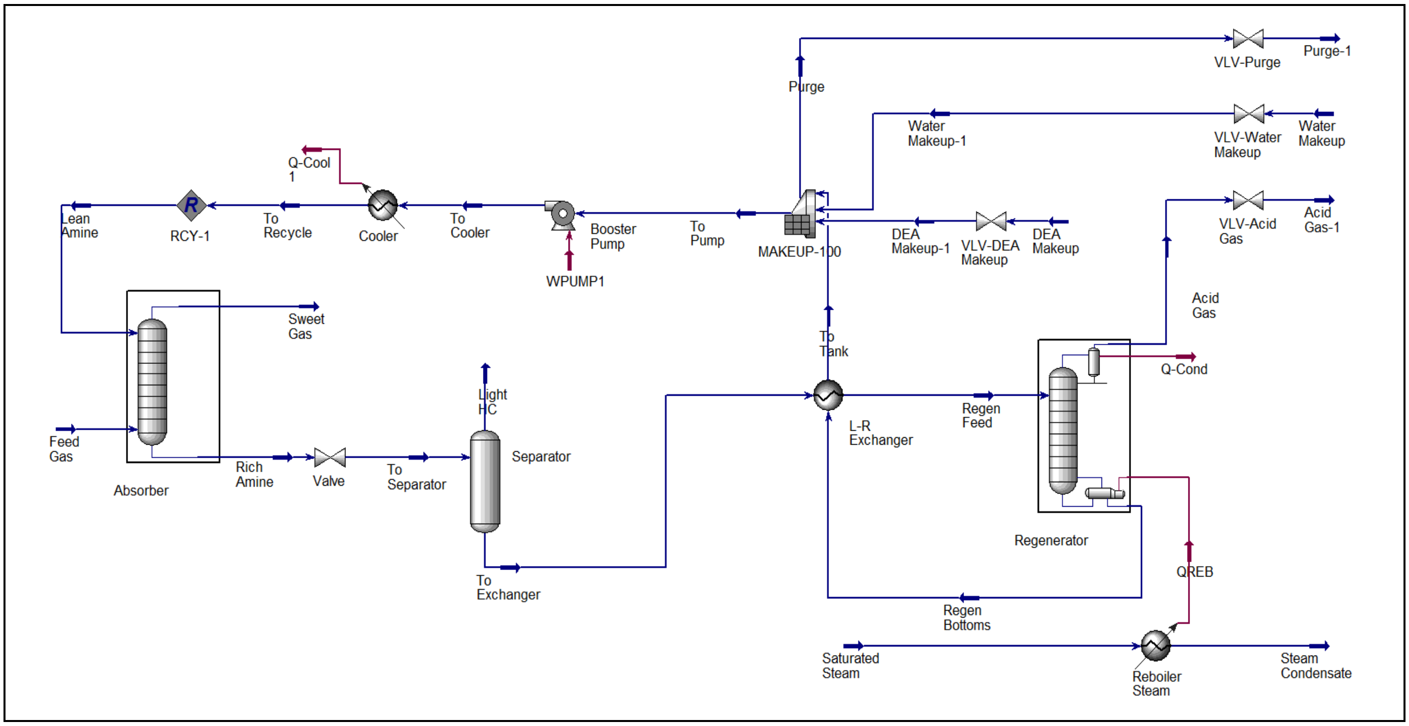

Figure 1: Complete Acid Gases Removal Cycle (sweetening Cycle) [xxviii]

The absorber column was selected from Aspen HYSYS model pallet which consists of multi stages having a sieve as construction as shown in Figure 2. The acid gas fluid package which contains DEA is also selected. The chemical composition of the Egyptian biogas obtained from the waste was defined in Table 1.

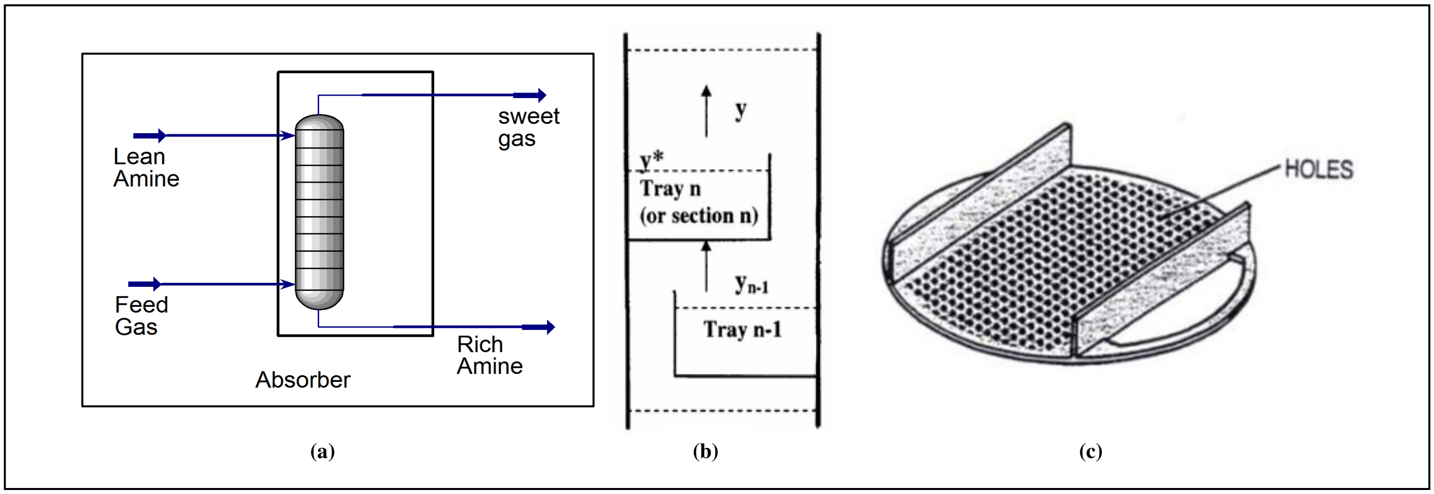

Figure 2: (a) The Absorber column (b) Absorber column internal lay out [xxix] (c) Absorber column tray (sieve) construction [xxx]

Component	Mole fraction	Volume fraction
Methane (CH_4)	0.7464	0.7466
Carbon dioxide (CO2)	0.2522	0.2522
Hydrogen sulfide (H_2S)	0.0004	0.0004
Water vapor (H2O)	0.0004	0.0001
Hydrogen (H_2)	0.0001	0.0001
Nitrogen (N_2)	0.0002	0.0002
Oxygen (O_2)	0.0003	0.0003

Table 1: Feed Egyptian biogas composition in mole fraction [xxxi]

An initial value of 0.2 is selected for DEA strength. The initial absorber working conditions for both feed gas and DEA are shown in Table 2. These initial conditions had been obtained after many simulation trials to get the highest methane purity.

Working condition	Unit	Lean DEA	Feed biogas
Vapor Fraction	-----	0	1
Temperature	°C	43	43
Pressure	bars	40	20
Molar Flow	kmole/h	2306	250
Mass Flow	kg/h	55286	5755
Liquid Volume Flow	m^3/h	54	13

Table 2: Initial absorber working conditions

The simulation cycle was run to insure absorber conversion using Aspen HYSYS for the purpose of system optimization. The optimum DEA strength was found 0.3 as explained in previous reference [xxviii].

3. Results and Discussion

The aim of the study is to investigate the effect of absorber geometry on the biogas treatment process using the simulation program Hysys. Simulation result includes the effect of absorber trays diameter, spacing and numbers upon the amount of CO_2, H_2S and methane at 30% concentration of DEA, which is the best result in the absorption processes of CO_2 and H_2S from the biogas as mention before.

3.1. Effect of Absorber Diameter

Figure 3 shows that there is a reverse relation between absorber diameter and CO_2 % in the treated biogas. At the point, which the absorber diameter equal to 1.7 m, the CO_2 % reached to 0.0. Therefore, an absorber diameter of 1.7 m is selected as an optimum diameter.

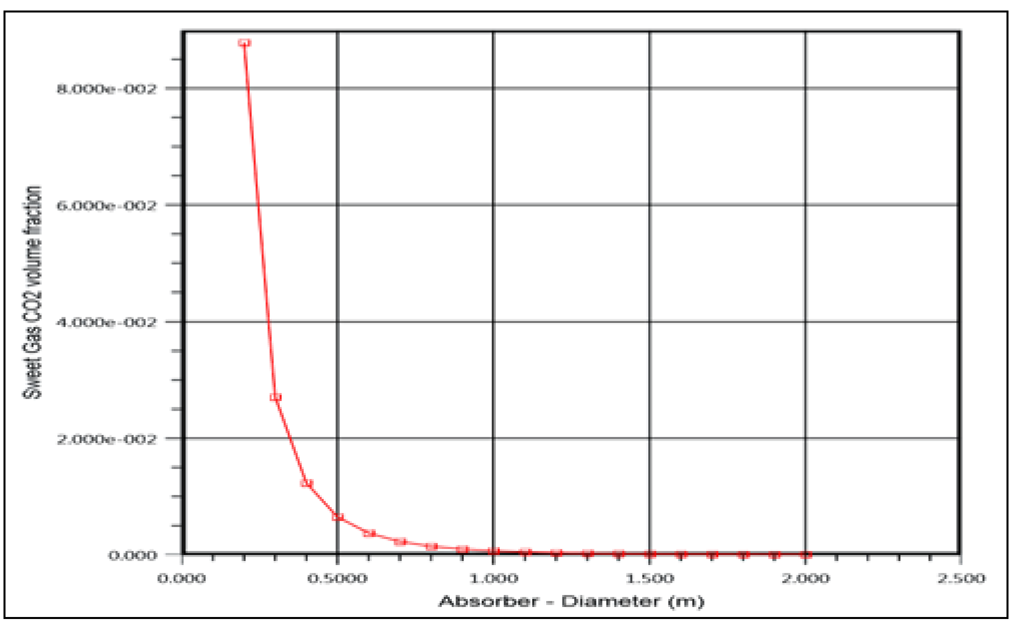

Figure 3: Effect of Absorber Diameter on Sweet Gas CO_2 Contents

There is also a reverse relation between absorber diameter and H_2S contents in the sweet gas as shown in Figure 4. The H_2S reaches its minimum value of 0.0 at an absorber diameter of 0.2 m. This leads to select the same diameter of 1.7 m, which meets the minimum CO_2 and H_2S content in sweet gas product.

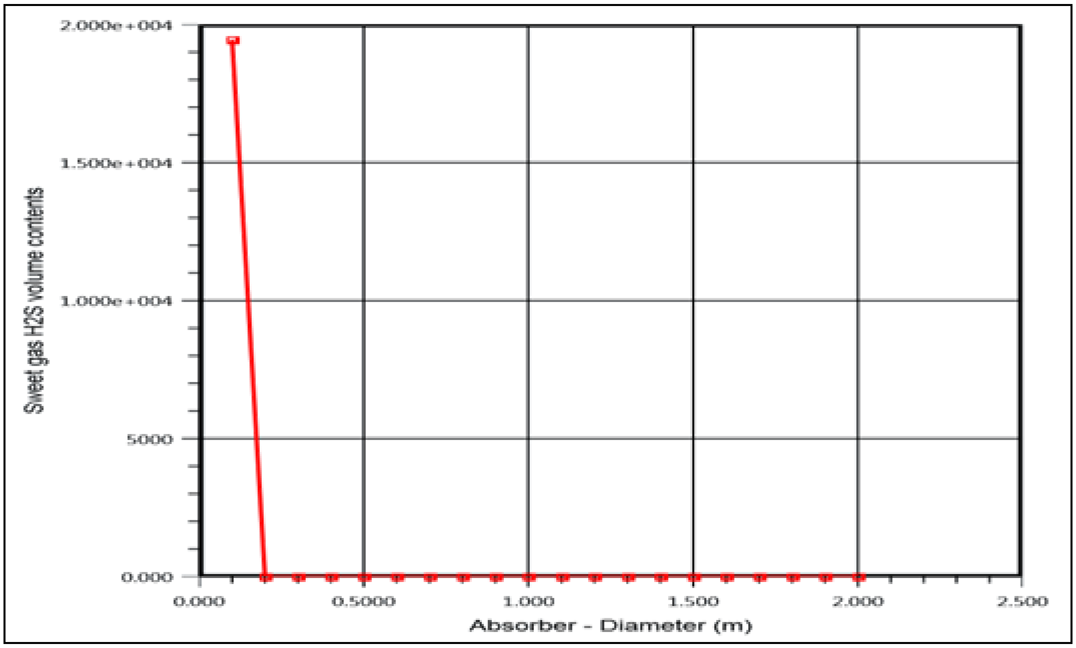

Figure 4: Effect of Absorber Diameter on Sweet Gas H_2S Contents

Figure 5 shows the methane content in the biogas against the absorber diameter. At the point, which the absorber diameter equal to 1.7 m, the methane content tends to be constant. As a result, 1.7 m absorber diameter is selected as the optimum value to achieve maximum methane purity from Egyptian biogas.

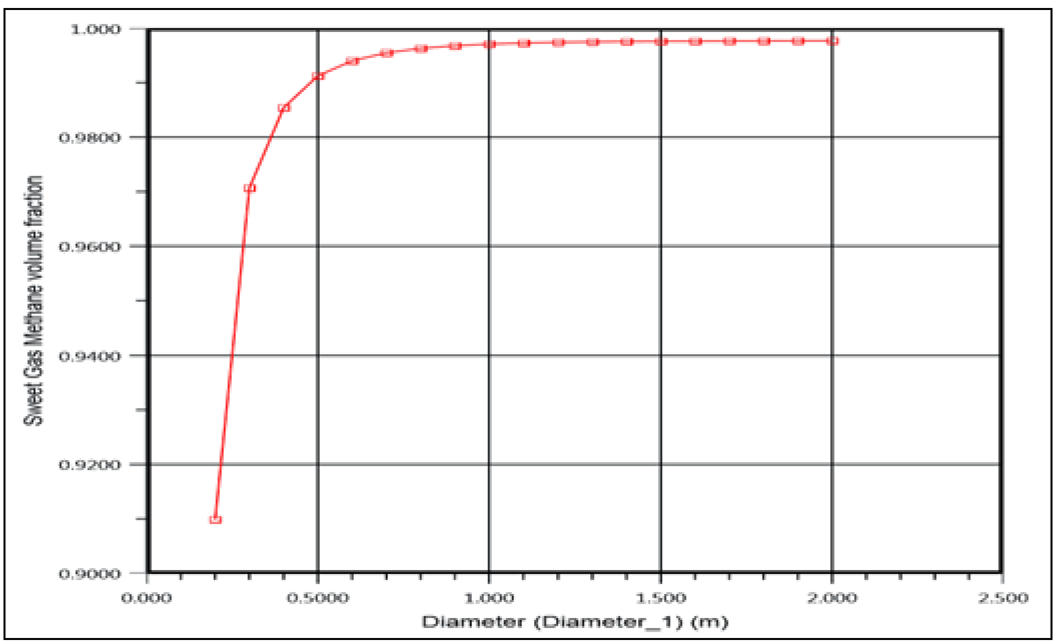

Figure 5: Effect of Absorber Diameter on Sweet Gas Methane Contents

3.2. Effect of Absorber Number of Stages

Figure 6 shows the effect of number of trays stages upon the content of CO_2. The rate of decreasing of CO_2 with the number of stages is high at lower numbers of stages and deceases with the increase of stages number. There is no effect on the concentration of CO_2 if the stages number increases than 20 stages so that it is taken as an optimum number.

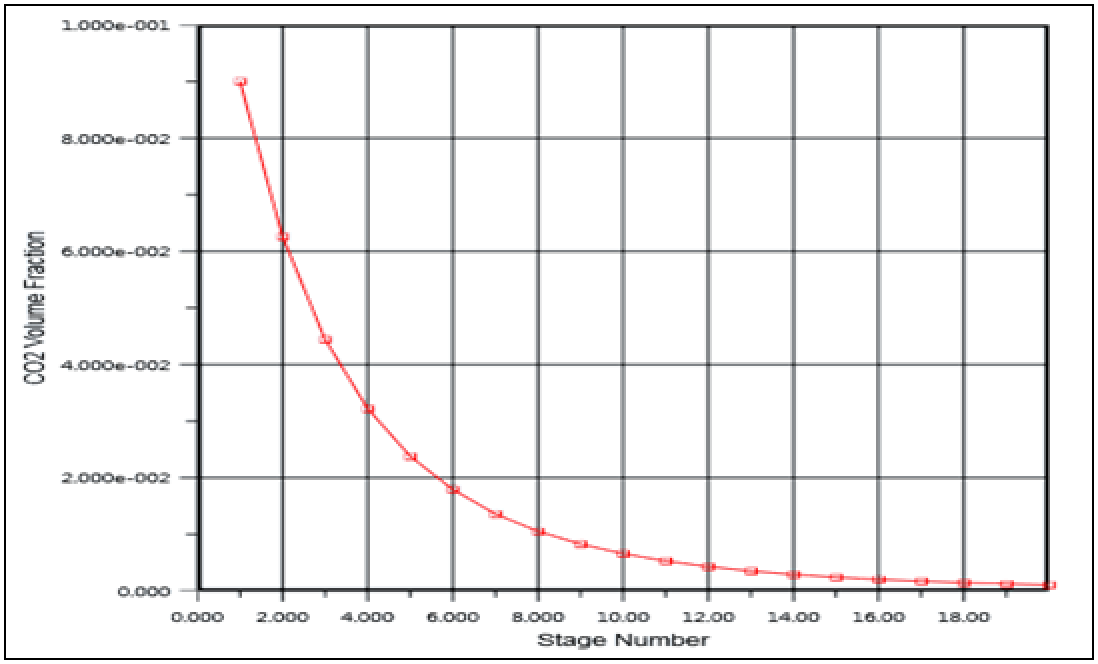

Figure 6: Effect of Absorber Number of Stages on Rich Amine CO_2 Contents

In Figure 7, the effect of stages number upon the amount of H_2S is shown. It is clear from the figure that there no effect on the H_2S content if the stages numbers increase than 20 therefore it taken as optimum number for eliminating H_2S to its minimum value.

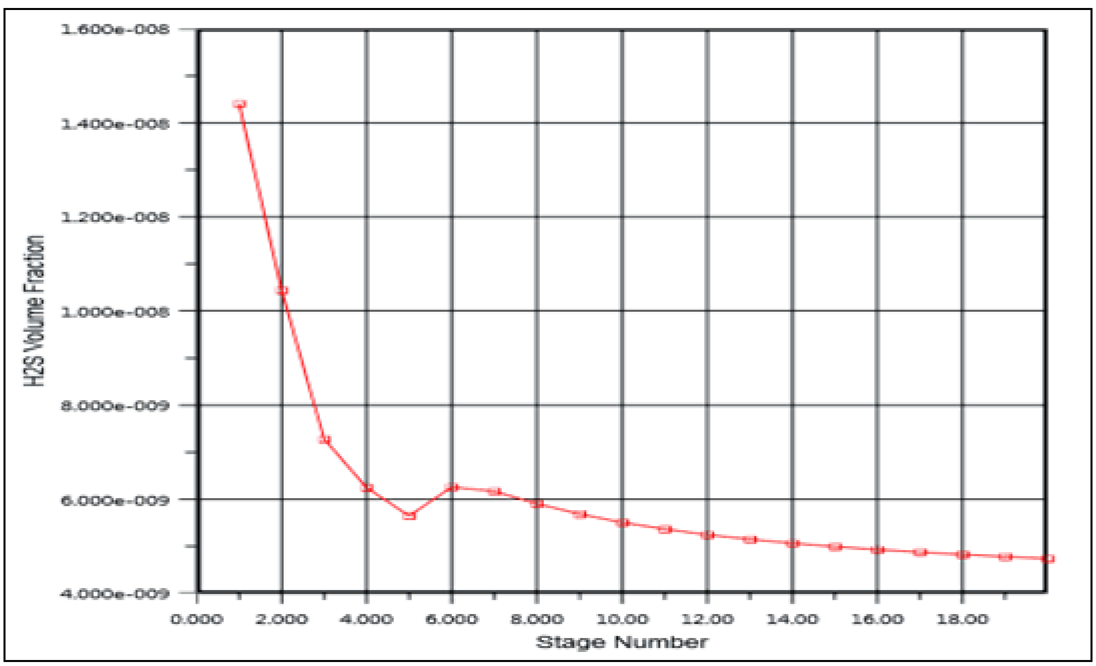

Figure 7: Effect of Absorber Number of Stages on Rich Amine H_2S Contents

Figure 8 emphasizes that the optimum number of absorber number of stages is 20,that is the number at which the maximum methane purity is achieved.

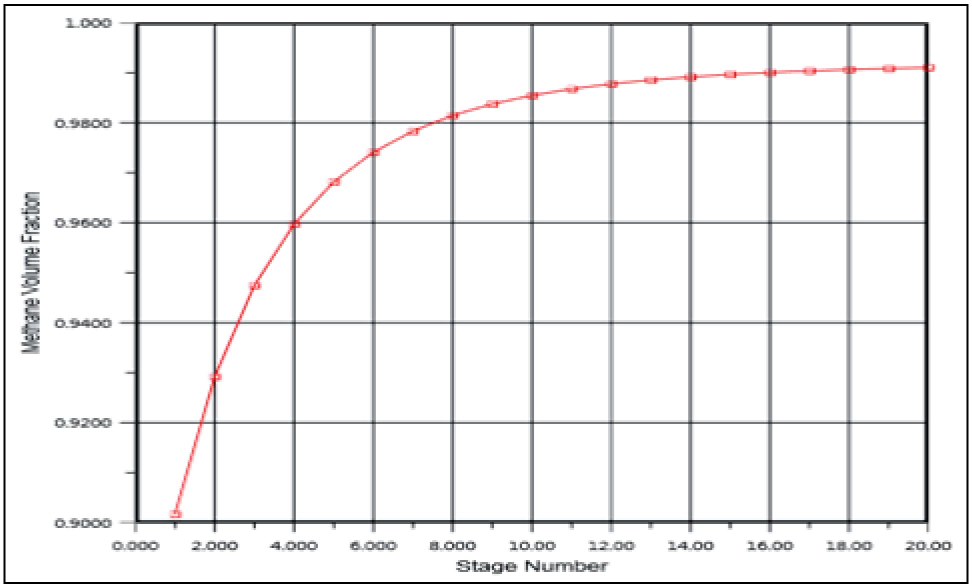

Figure 8: Effect of Absorber Number of Stages on Rich Amine Methane Contents

3.3. Effect of Absorber Tray Spacing

Simulation results shows that the tray spacing has no effect on the percentage of the CO_2 or methane purity. That is due to the pressure inside the absorber helps to push the gases inside column trays holes easily during the absorption process. Therefor the main factors that should be taken into consideration are the geometrical dimensions of the trays, the even distribution of the trays in the absorber and the right numbers of trays. In addition, easy replacement of the blocked trays and easy service of them will affect the treatment process. Table 3 shows the final volume fractions of the sweet gas after treatment process.

Component	Mole fraction	Volume fraction
Methane (CH4)	0.9949	0.9949
Carbon dioxide (CO2)	0	0
Hydrogen sulfide (H2S)	0	0
Water vapor (H2O)	0.0042	0.0042
Hydrogen (H2)	0.0001	0.0001
Nitrogen (N2)	0.0003	0.0003
Oxygen (O2)	0.0004	0.0004

Table 3: Composition of Upgraded Biogas

4. Conclusion

Aspen HYSYS simulation program was used to determine the optimum absorber geometry in order to achieve the highest methane purity from Biogas. Absorber with different diameters, number of stages and spacing was used to remove the CO2 and H2S simultaneously from an amount of feed biogas with total volume flow rate about 13 m^3/h. The simulation results showed that the optimum PSA column diameter m is 1.7 m, the optimum tray spacing is 0.5 m and the optimum PSA number of stages is 20 stages

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