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Techno-economic Comparison Of Biogas Upgrading Technologies (Amine Absorption vs Cryogenic Separation)

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Abstract
In this study, the most crucial operation is the separation of CO_2 from biogas, which is carried out by several technologies such as pressure swing adsorption, water scrubbing, amine scrubbing, cryogenic separation.
We aim to open a door to the new emerging sector of energy production, mainly, biogas production and utilization, by introducing state of art process design and optimization for two biogas upgrading technologies. Amine absorption and cryogenic separation, and assessing their pros and cons to alleviate orientation in this issue and point out research tendencies. Three aspects were chosen for the assessment: (1) process technology & product quality, (2) methane recovery & methane losses, (3) energy consumption &economy. The research was carried out using the process simulation software (aspen HYSYS 10), along with other commercial software such as exchanger design & rating (EDR), aspen process economic analyzer (APEA).
The plant section to be designed and analyzed is a part of biogas plant that is treating a stream from a digester system to obtain biomethane with CO_2 concentration compatible with injection into the grid. For more realistic, feed specification is collected from a real biogas production plant based on the proposed design, in this study utilizing both techniques namely amine absorption and cryogenic separation process, The finding results obtained using Hysys software v8.8 for the optimization study for upgrading the biogas showed that the amine absorption process was a better choice in terms of methane recovery and total cost.

Keywords: biomass, bioliquids, biofuels, biogas, and renewable sources

1. Introduction

Bioenergy is energy produced from renewable sources that are turned into fuel for heat and power generation. Bioenergy can be obtained from different types of biomasses, and the main one used is wood and wood waste bioenergy industry development is facing important issues, including the mitigation of climate change and decreasing the availability of fossil resources. [1]
Increasing the production of energy from renewable sources is a step toward a low-carbon economy that many countries around the world are adopting. In Europe, the share of energy from renewable in gross final energy consumption is in steady progress toward the European target for 2020 (20%), and it is growing despite the financial and economic crisis. Between 2005 and 2010 the electricity production from bioliquids/biofuels and biogas doubled and that from biomass (mainly wood and wood wastes) gives the largest contribution to the total share from renewable sources. Similar trends can be observed worldwide. A study of the worldwide trends of bioenergy production has been

carried out, highlighting the issues that require an in-depth analysis of the process design related aspects. [1] The utilization of biogas for biomethane production represents one of the thriftiest methods. However, the share of biomethane in renewable resources market is still considerably small. In European region Germany and Sweden are regarded at present as the main forerunners in terms of biomethane support.

The term biomethane is usually used for biogas upgraded to the level which is accepted for injecting into gas grid and/or for usage as a vehicle fuel. From that fact it is possible to call the upgrading process as a process of improving biogas up to the level of substitute natural gas (SNG) or compressed natural gas (CNG). The input refers to biogas originating from anaerobic digestion either in form of landfill gas or gas from controlled reactor.

The biogas that comes from anaerobic digestion is a mixture of two major components, methane (CH_4) and carbon dioxide (CO_2). In addition, biogas consists of minor portions of other components like siloxanes or (H_2S). Presence and fraction of the impurities is variable and depends mainly on types of substrates. Any biomethane (biogas) plant can use various combinations of substrates. In European region at present the substrates like manure or energy crops are employed at almost 50 % of all biomethane plants. [1]

One quarter of all plants processes sewage sludge and around one third relates to sewage sludge treatment. The lowest number belongs to landfill gas that is processed at 4 % of all biomethane plants. [1]

This research is focused on the design and evaluation of technologies related only to separation of CO_2 in biogas upgrading, mainly the amine absorption and cryogenic separation processes. The concept of this work is based on three aspects: (1) process technology & product quality, (2) methane recovery & methane losses. The research was carried out by exploration of available literature in form of various research studies, reports, scientific and company articles, and using the process simulation software (aspen HYSYS 10), along with other commercial software such as Exchanger design & rating (EDR), aspen process economic analyzer (APEA) [1]. The main scope of this study is to get a step forward to meet the job market requirements, by the integration between theoretical background that have been taken during the courses and the chemical engineering industry, giving the students deep understanding of the main chemical engineering applications (mass & energy balance, equipment sizing, cost estimation, process analysis and optimization, …etc.).

In addition, the study highlights a new emerging sector of energy production, mainly, biogas production and utilization, which found to be the trend for the energy producer worldwide. [1]

2. Material and Methods

The methodology followed in this research can be described in the next consecutive sections, and the process description in figure (2.1).

Where the Aspen HYSYS 10 simulator, Aspen process economic analyzer, Aspen EDR 8.8, and Excel 2010 were utilized for design, analyzing, and optimization of the research.

2.1 Amine Absorption process

A continuous scrubbing system is used to separate CO_2 from the flue gas stream. As illustrated in Figure (2.1), the system consists of two main unit operations: an absorber where CO_2 is removed, and a regenerator (or stripper), where CO_2 is released (in concentrated form) and the original solvent is recovered. In addition to auxiliary equipment that provides the required condition for absorption and

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stripping, such as heat exchangers, compressors, pumps...etc.
For the building of the base case simulation, the starting point was with the same process setup of the natural gas cleaning using DEAmine, and then the modification is implemented in order to be suitable for the simulation of biogas upgrading technology. Figure (2.1) shows how plant is represented within the simulator.

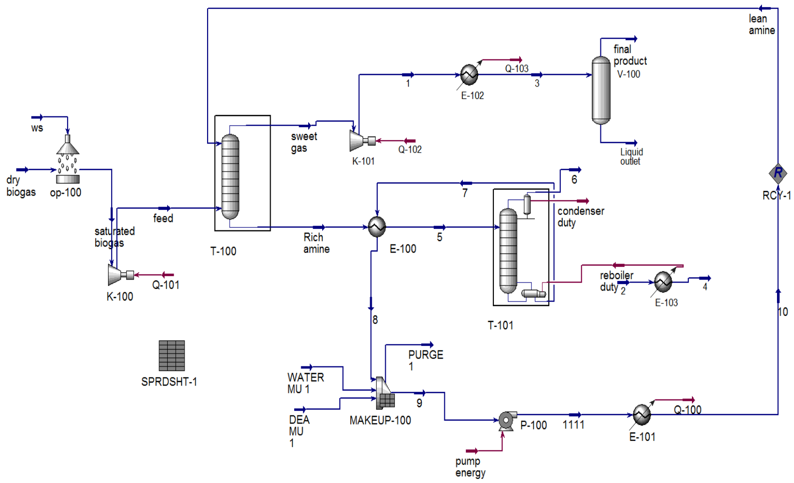

Figure 2.1 Describes the amine absorption process

Initially, the optimization was done on the amine solution in order to select the amine strength and flow rate, where the case study feature in aspen HYSYS is used to examine different amine flow rate at three amine strength (20wt%, 25wt%, 30wt%), and study their influence on the CO_2 fraction in the sweet gas as well as reboiler duty. Figure 2.2 shows the effect of the amine strength and flow rate on the reboiler duty, where observed that the reboiler duty is decreased as the amine strength and/or flow rate is decreased

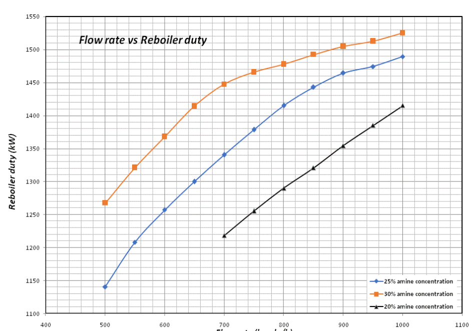

Figure 2.2

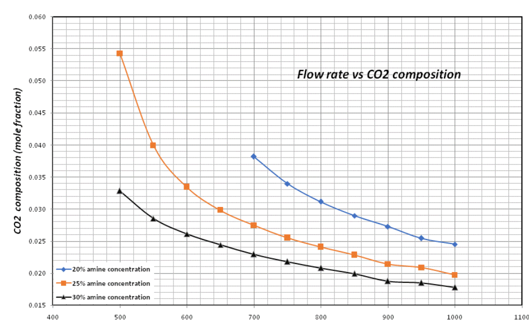

Figure 2.2

In the other hand, an increase in the CO_2 fraction was observed as a consequence of the reduction in the amine strength and/or flow rate as shown in figure 2.3, and to have a better decision the amine strength of 25wt% was selected, which allows for a farther reduction in the amine flow rate.

2.2 Cryogenic separation process

The term cryogenic refers to the very low temperatures application Cryo, where the different temperature related properties of the gas species is used to separate them from each other.Although, the cryo-technology have been used for natural gas applications for many years, it is somewhat a new technique for the biogas applications (upgrading, liquefaction and transportation).

Simulation of the base case with a virtual unit operation OP-100 that used to convert biogas from dry base composition to wet base composition in order to simulate the feed gas specification as shown in figure 2.4, and this is done using a water stream w with a temperature and pressure same as the dry biogas stream.
The optimization is performed just using aspen HYSYS where the main parameters that influence the overall efficiency of the cryogenic separation process are compression power, methane losses and refrigerant flow rate.
The optimization of the compression process is done firstly, by using two stage compressors with inter cooling based on the compression ratio available (max. is 9) and outlet stream temperature limits, optimization on the inter stage pressure is performed where the optimum is found at 9 bar that gives a minimum total power consumption

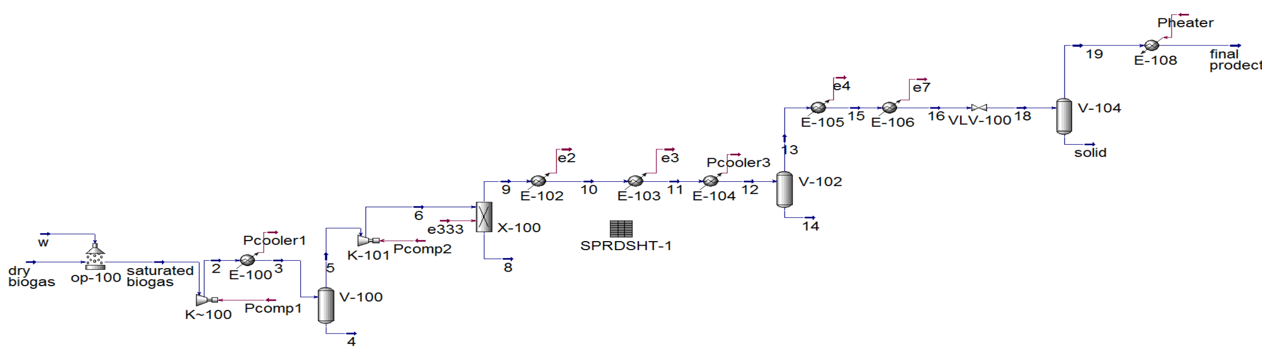

Figure 2.4 Describes the base case setup process flow sheet

3. Results screening and Discussion

3.1 Results of amine absorption process

3.1.1 comparison between base case and Optimized case

As shown in table (3.1) and figure (3.1),(3.2), the total energy and power consumption in the optimized case are reduced by 73% and 11% respectively in comparison with the base case, in the other hand the methane losses are in the entire system is reduced by 27% and consequently the methane recovery in the upgraded biogas stream is increased from 99,91% to 99,93%, while the CO_2

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mole fraction remains within the limits (<3%), and moreover, even though the methane purity is slightly decreased.

Table 3.1Comparison between the optimum case and base case for amine absorption process

	Base case	Optimized case
Total duty (kw)	6436.5	1711
Total power (kw)	111.5	98.88
Methane recovery	99.91**%**	99.93**%**
Methane losses	0.086%	0.062%
Upgraded biogas composition		
Comp. mole percent (CO_2)	2.24%	2.9%
Comp. mole percent (Methane)	97.4%	97%

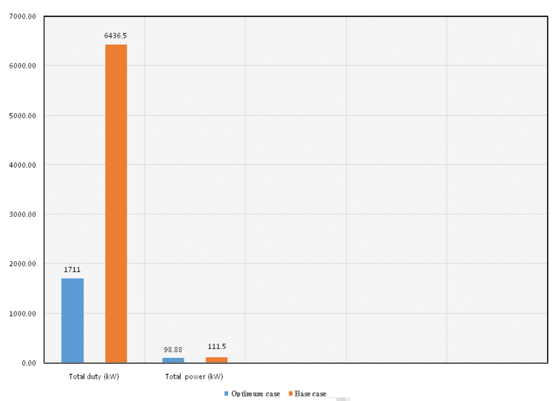

Figure 2.3

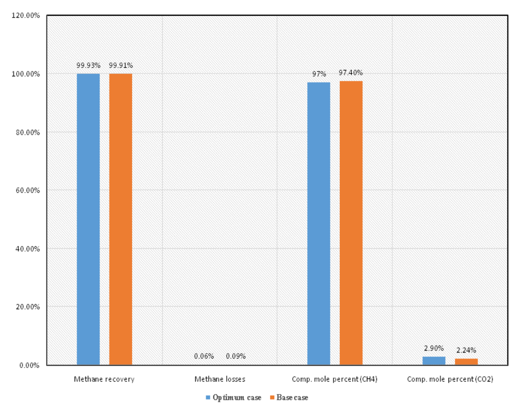

Figure 2.4

3.1.2 Result of material and Energy balance

Dashboard of the process is shown in table (3.2), which is screening the main parameters controlling the entire process, while the results of material and energy balance for the main streams in the process especially the boundary streams is shown in table (3.3)

Table (3.2)

Name	feed	Lean Amine	Rich Amine	5	6
Temperature [◦C]	102.589	44.000	63.700	107.500	43.984
Pressure [bar]	2.600	2.200	2.500	2.450	1.000
Molar Flow [kgmole/h]	48.098	650.000	663.441	663.441	15.567
Mass Flow [kg/h]	1196.457	14783.511	15393.315	15393.315	647.371
Heat Flow [kcal/h]	-8.41E+06	-1.92E+08	-1.97E+08	-1.94E+08	-5.89E+06
Comp Mole Frac (Methane)	0.66860	0.00000	0.00003	0.00003	0.00128
Comp Mole Frac (CO_2)	0.31463	0.00065	0.02196	0.02196	0.90685
Comp Mole Frac (H_2O)	0.01677	0.94527	0.92503	0.92503	0.09188
Comp Mole Frac (DEAmine)	0.00000	0.05408	0.05299	0.05299	0.00000

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Table 3.3 Continued

Name	7	WATER MU 1	DEA MU 1	PURGE 1	final product
Vapor Fraction	0.000	0.000	0.000	0.000	1.000
Temperature [◦C]	113.113	64.344	64.344	64.737	20.000
Pressure [bar]	1.500	1.450	1.450	1.450	7.950
Molar Flow [kgmole/h]	647.874	2.124	0.002	0.000	33.233
Mass Flow [kg/h]	14745.944	38.265	0.233	0.000	560.995
Liquid Volume Flow [m3/h]	14.434	0.038	0.000	0.000	1.776
Heat Flow [kcal/h]	-1.87E+08	-6.01E+05	-1.05E+03	0.00E+00	-2.82E+06
Comp Mole Frac (Methane)	0.00000	0.00000	0.00000	0.00000	0.96705
Comp Mole Frac (CO_2)	0.00070	0.00000	0.00000	0.00000	0.02972
Comp Mole Frac (H_2O)	0.94504	1.00000	0.00000	1.00000	0.00323
Comp Mole Frac (DEAmine)	0.05426	0.00000	1.00000	0.00000	0.00000

3.2 Results of cryogenic separation process

3.2.1 Comparison between base case and optimum case

Object	Variable	Value	Unit
Feed gas	Molar Flow	48.1	Kmol/hr
Feed gas	Comp Mole Frac (Methane)	0.6686	
Feed gas	Comp Mole Frac (CO_2)	0.3146	
Feed gas	Comp Mole Frac (H_2O)	0.0168	
Final product	Molar Flow	33.23	
Final product	Comp Mole Frac (Methane)	0.967	
Final product	Comp Mole Frac (CO_2)	0.0297	
Final product	Comp Mole Frac (H_2O)	0.0032	
Lean amine	Amines Recirculation Rate	14.47	m^3/h
Lean amine	Amine Strength	25	Wt%
Lean amine	Acid Gas Loading	0.01203	
Lean amine	Temperature	44	◦C
Rich Amine	Acid Gas Loading	0.4144	
Regenerator	Reflux Ratio	5	
Regenerator	Reboiler Duty	1297	kW
Regenerator	Feed Stream Temperature	93	◦C

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As shown in table 3.4, and Figures 2.5 , 3.4 The Comparison between base case and optimum case for cryogenic separation processdue to the implementation of heat integration process the total energy consumption in the optimized case is reduced by 44% in comparison with the base case, in the other hand, implementation of the methane recovery stage reduces the methane losses in the entire system by 76% and consequently the methane recovery in the upgraded biogas stream is increased from 85.15% to 95.91%, however, it causes slight increasing in the total power compression from 230.7 KW to 241.7KW, moreover, the CO_2 mole fraction in the upgraded biogas remains within the limits (<3%), even though the methane purity is slightly decreased.

Table 2.4 Comparison between base case and optimum case for cryogenic separation process

	Base case	Optimized case
Total duty (kw)	371.8	207.9
Total power (kw)	230.7	241.7
Methane recovery	85.15%	95.91%
Methane losses	14.61%	4.09%
Upgraded biogas composition		
Comp. mole percent (CO_2)	1.35%	2.31%
Comp. mole percent (Methane)	98.65%	97.69%

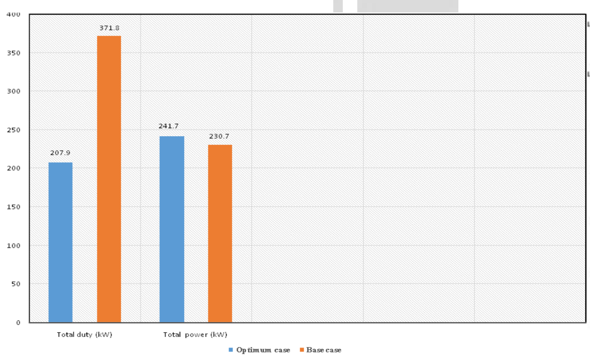

Figure 2.3

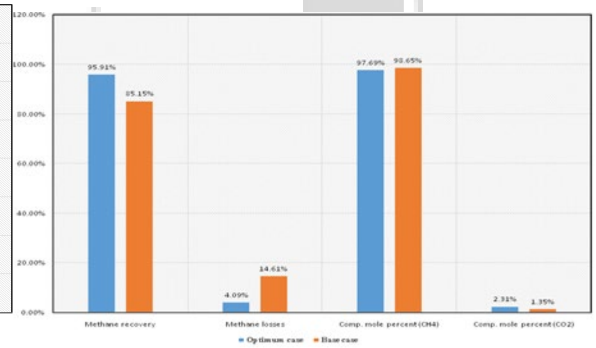

Figure 2.6

3.2.2 Results of material and energy balance

Table 2.5 Material streams condition and composition

Name	Dry biogas	feed1	9	13	14
Vapor Fraction	1.000	1.000	1.000	1.000	0.000
Temperature [C]	15.000	13.728	15.000	-40.000	-40.000
Pressure [bar]	1.030	1.030	72.000	71.850	71.850
Molar Flow [kgmol/h]	47.292	51.554	50.769	43.770	6.999
Mass Flow [kg/h]	1183.339	1270.729	1256.553	1042.281	214.272
Liquid Volume Flow [barrel/day]	381.939	412.184	410.038	353.570	56.468
Heat Flow [kcal/h]	-2.01E+06	-2.16E+06	-2.14E+06	-1.78E+06	-4.21E+05

Comp Mole Frac (Methane)	0.67894	0.67815	0.688642	0.72218	0.47891
Comp Mole Frac (CO_2)	0.32106	0.30664	0.311358	0.27782	0.52109
Comp Mole Frac (H_2O)	0.00000	0.01521	0	0.00000	0.00000
Comp Mole Frac (H_2S)	0.00000	0.00000	0	0.00000	0.00000

Table 3.5 Continues

Name	20	17	18	solid	final product
Vapor Fraction	0.498	0.000	0.721	0.000	1.000
Temperature [C]	-61.662	-61.000	-112.855	-112.855	20.000
Pressure [bar]	30.000	71.700	8.050	8.050	7.900
Molar Flow [kgmole/h]	6.999	43.770	43.770	12.231	31.539
Mass Flow [kg/h]	214.272	1042.281	1042.281	515.949	526.332
Liquid Volume Flow [barrel/day]	56.468	353.570	353.570	98.480	255.090
Heat Flow [kcal/h]	-4.21E+05	-1.81E+06	-1.81E+06	-1.16E+06	-6.23E+05
Comp Mole Frac (Methane)	0.47891	0.72218	0.72218	0.06523	0.97693
Comp Mole Frac (CO_2)	0.52109	0.27782	0.27782	0.93477	0.02307
Comp Mole Frac (H_2O)	0.00000	0.00000	0.00000	0.00000	0.00000
Comp Mole Frac (H_2S)	0.00000	0.00000	0.00000	0.00000	0.00000

Table 2.6 Energy and power consumption

Equipment	Power
E-100	136.06 kW
E-104	44.072 kW
E-107	22.980 kW
E-108	3.0757 kW
K-100	125.6 kW
K-101	116.1 kW
Total coolers and heaters duty	206.19 kW
Total compressors power	241.81 kW

4. Conclusion

Biogas sector is taken as a research field in this project, in particular, the biogas upgrading (acid gas removal), where two upgrading techniques were examined (amine absorption and cryogenic separation) in order to check the applicability and select the best option.
Three aspects were chosen for the assessment (1) process technology & product quality, (2) methane recovery & methane losses (3) energy consumption &economy.
The simulation results show that both techniques can be applied, and they were similar in terms of product quality, Based on, the amine absorption has more preference over the cryogenic separation in terms of methane recovery and economy.

The amine absorption process proposed was better than cryogenic separation process in terms of methane purity, methane recovery and cost. Where the methane recovery when utilizing the amine absorption technique was 4% better than cryogenic separation process. Furthermore the estimated total cost for the amine absorption process was 12.7% lower than when using cryogenic separation process. However, both techniques showed that the purity is almost the same.

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