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# Simulation of Biosynthesis Gas Process from Palm Oil Mill Effluent Sewage by Aspen HYSYS and SuperPro Designer

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## Abstract

In this work, the process of biogas production from palm oil factory effluent was simulated and then the produced biosynthetic gas was sweetened. For this purpose, the biogas production process from wastewater treatment was simulated using SuperPro Designer v9.0 software. Then, the resulting biogas entered the chemical absorption and reforming sections for sweetening and conversion to syngas, respectively, and these steps were simulated with Aspen HYSYS v11.0 software. The simulation results of the first stage showed that the effluent feed of this factory with a flow rate of 42000 kg/h and COD of 62000 mg/L leads to the production of 1786 kg/h biogas containing various compounds such as methane, carbon dioxide, hydrogen sulfide and water with the molar fraction of 0.446, 0.245, 0.178 and 0.040, respectively. In the chemical absorption section, MEA solvent 10 %wt. and solvent-to-gas molar ratio of 13.51 were used, which led to the efficient removal of CO<sub>2</sub> and H<sub>2</sub>S up to 1 ppm and 99.99%, respectively. The examination of temperature changes in the absorption tower also showed that the temperature increases along the absorption tower. In the methane steam-reforming unit, two different strategies were used: 1) plug flow reactor (with fluid package of Peng-Robinson-Stryjek-Vera) and 2) conversion and equilibrium reactors (with fluid package of Peng-Robinson). The results showed that the purity of hydrogen in the biogas produced in the second strategy (conversion and equilibrium reactors) was higher than the first one (plug flow reactor), and on the other hand, the purity of CO<sub>2</sub> was zero in the second strategy.

**Keywords:** Simulation; Biogas Production; Steam Reforming; SuperPro Designer Software; Aspen HYSYS Software.

## 1. Introduction

Today, with the progress of science and technology, energy production methods have significantly developed, and do not have the disadvantages of the older methods. Among these methods, energy production from biomass can be mentioned. Biogas is produced because of

anaerobic decomposition of organic compounds by biomass. The major part of this gas consists of methane and carbon dioxide<sup>1</sup>, and other compounds depend on the type of raw materials. Several biomass sources are urban

<sup>1</sup> Carbon Dioxide (CO<sub>2</sub>)



and industrial sewage, agricultural waste and livestock waste (Madaki and Seng, 2013).

With the ever-increasing population, food consumption, especially palm oil, is also on the rise. During the past decades, palm oil production has been dominated by Indonesia and Malaysia, with a total production of 85% of the total world production. In Malaysia, the palm oil industry has been the most important agriculture-based industry with the production of 37.2 million tons in the last two years. As a result, more agricultural land has been converted into palm oil plantations, which has reached 4.49 million hectares. Waste produced from palm oil factories has been declared as one of the main sources of environmental pollution. Although palm oil mills produce both solid and liquid wastes, palm oil mill effluent<sup>1</sup> is identified by operators as the most expensive and difficult waste to manage, (Lok et al., 2020). During the extraction of palm oil, approximately 5-7.5 tons of water are required for the production of each ton of crude palm oil. Conversion of more than 50% of consumed water into wastewater, which is usually known as palm oil factory effluent, has caused concern (Madaki and Seng, 2013).

On the other hand, it has been proven that palm oil factory effluent can be converted into renewable energy such as biogas (Tchobanoglous et al., 2003). This effluent has a high organic load with an average BOD of 2500 mg/L and COD of 51000 mg/L. Researchers have investigated and proved the possibility of producing biogas from this wastewater through biological process and chemical process (Shahidul et al., 2018). After decomposition, the wastewater releases biogas, which can be recovered as a useful biomass-based energy. If the emission of biogas is not controlled, it is harmful to the ozone layer due to its composition (a mixture of Methane (CH<sub>4</sub>) and CO<sub>2</sub> that are greenhouse gases). However, when properly exploited it can be the main source of energy production while removing CO<sub>2</sub>.

With technological advances in recent years, the use of high-speed reactors for biological treatment, such as digesters, anaerobic filters, anaerobic fluidized bed reactors, anaerobic baffled reactors, high-flow anaerobic sludge beds and other combined reactors has been studied and evaluated in wastewater treatment (Loh et al., 2013).

In Malaysia, since 1982, a conventional pond system consisting of series of anaerobic and aerobic ponds has been widely used to treat palm oil factory effluent. This is due to the availability of a large area of land, a permanent warm climate, and its suitability for high resistance wastewater treatment (Ahmed et al., 2015). Anaerobic decomposition or aerobic decomposition can be used to treat the desired wastewater.

Anaerobic decomposition method was used in this

study, which compared to other methods, in addition to not being energy-intensive, it also produces some energy in the form of biogas. The resulting biogas can be used to produce heat, hot water and electricity at a cheaper price than other fuels such as natural gas, propane and black oil, even if biogas energy recovery is not practical, this system is highly effective in controlling odors. Burning or using biogas can reduce the effects of conventional fossil fuels. Biogas can also be used as a rural energy source to help in the production and distribution of electricity by other methods of electricity generation.

Real-world processes and unit operations can be represented in a software through process simulation (Petrides et al., 1995). Commercial process simulation tools have been commonly utilized in the chemical process industry since the 1960s. Apart from basic simulation and modelling of chemical processes, process simulation tools have also extended their role in design, optimization, and process and utility systems troubleshooting (Lok et al., 2020). There are reported works, using some commercial softwares such as SuperPro Designer and BioWin, for upgrading the design of wastewater treatment plants (Vitanza et al., 2016), evaluation of water recycling options (Petrides, 2001), etc. The main contribution and novelty of this paper consist in the presentation of a comprehensive simulation of biogas production from POME and then the sweetening of biogas to purify methane. To the best of our knowledge, no previous work has implemented this strategy.

For this purpose, after the stage of biogas production from wastewater treatment, the resulting biogas enters the chemical absorption and conversion sections (methane biogas reforming) to sweeten it and convert it into syngas. The simulation of the synthesis section (anaerobic reactions), leading to biogas production, was performed by the SuperPro Designer v9.0 software and the simulation of the chemical separation and conversion sections was performed by the Aspen HYSYS v11.0 software. The general structure of this article is as follows: 1) An overview of the biogas production process resulting from palm oil factory effluent treatment is provided. 2) The sweetening of biogas in order to remove the compounds of CO<sub>2</sub> and hydrogen sulfide<sup>2</sup> in the section of chemical absorption and 3) Syngas production in the reforming process (with two different strategies), respectively.

## 2. Designing the bio-syngas production process

In general, the bio-syngas production process from palm oil factory effluent includes three parts: synthesis, chemical absorption of CO<sub>2</sub> and H<sub>2</sub>S by

<sup>1</sup> Palm Oil Mill Effluent (POME)

<sup>2</sup> Hydrogen Sulfide (H<sub>2</sub>S)

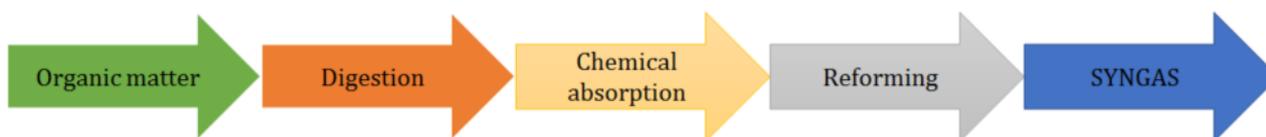


Fig. 1. Schematic of bio-syngas production steps

monoethanolamine<sup>1</sup> solvent, and conversion (methane biogas reforming). The schematic of the simulation steps of syngas production is shown in Fig. 1.

H<sub>2</sub>S and water in the biogas produced from palm oil factory effluent treatment are purified before being used in the gas engine to generate electricity. The permissible level of H<sub>2</sub>S concentration in a gas engine is usually below 200 mg/L, and higher amounts cause corrosion through the formation of sulfuric acid (Bijani et al., 2019). H<sub>2</sub>S content is reduced by using biological (Esmaili-Faraj and Nasr Esfahany, 2017), chemical or water scrubber (Esmaili Faraj et al., 2014; Esmaili-Faraj and Nasr Esfahany, 2016; Esmaili-Faraj et al., 2019).

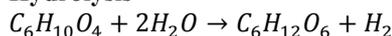
For palm oil factory effluent, biological scrubber is usually used due to low operating cost. Biological scrubbers or biological trickling filters purify the unwanted pollutants in the gas stream (Esmaili Faraj et al., 2012) by passing it through a bed of *Thiobacillus* microorganisms that feed on H<sub>2</sub>S. The amount of humidity is reduced through a gas dehumidifier, which can be a dryer, chiller or cyclone. The dehumidifier extracts water from biogas; which in turn prevents acid formation. To increase engine efficiency and reduce fuel gas consumption, high quality and low moisture biogas with relative humidity below 80% is necessary (Rahayu et al., 2015).

## 2.1. The mechanism of biosynthetic gas process from POME

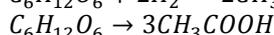
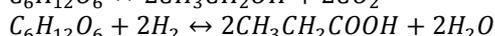
Anaerobic digestion process is primarily used for treatment of waste sludge and high strength organic wastes (Lok et al., 2020). The process involves the decomposition of organic matter by microorganisms in the absence of oxygen, forming digest and biogas as products. It poses advantages in terms of lower biomass yield and energy generation in the form of methane. The process can be operated in the mesophilic temperature range (30-35 °C) or thermophilic temperature range (50-60 °C). Due to the relatively low quality of treated effluent, anaerobic treatment is normally coupled with an aerobic process as the subsequent operating unit. Four basic steps are involved in the overall anaerobic oxidation of waste: (1) Hydrolysis, (2) Fermentation (acidogenesis), (3) Acetogenesis, (4) Methanogenesis. The following equations (Bajpai, 2017) and Fig. 2

summarize the reactive scheme for the anaerobic digestion of organic matter.

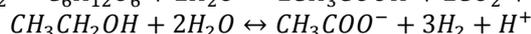
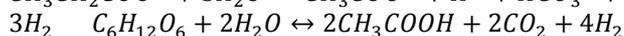
### Hydrolysis



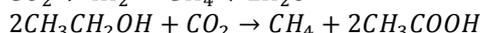
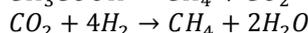
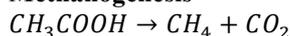
### Acidogenesis



### Acetogenesis



### Methanogenesis



The technology is widely utilized in various palm oil mills, as it is capable of handling a wide range of waste characteristics including solids, oils and greases, simple and relatively economical construction, large volume that can provide equalization of loads, use of low loading, high effluent quality, control and capture of greenhouse gases. However, the drawback is the low processing rate, requirement of huge land area, inefficiencies in feed flow distribution and maintenance of geo-membrane cover (Lok et al., 2020).

## 2.2. Simulation of biogas production from palm oil factory effluent treatment

Effluent from palm oil factory in Sembilan region in Malaysia is purified using covered stabilization pond process during anaerobic digestion and leads to biogas production. The composition of the wastewater feed of this factory with a flow rate of 42,000 kg/h and COD equal to 62,000 mg/L is also presented in Table 1. The simulation of the biogas production process from the effluent of this factory in the stabilization pond process was done using the data and information available in the literature by SuperPro Designer v9.0 software.

Fig. 3 shows the simulation schematic of biogas production unit from palm oil factory effluent. First,

<sup>1</sup> Monoethanolamine (MEA)

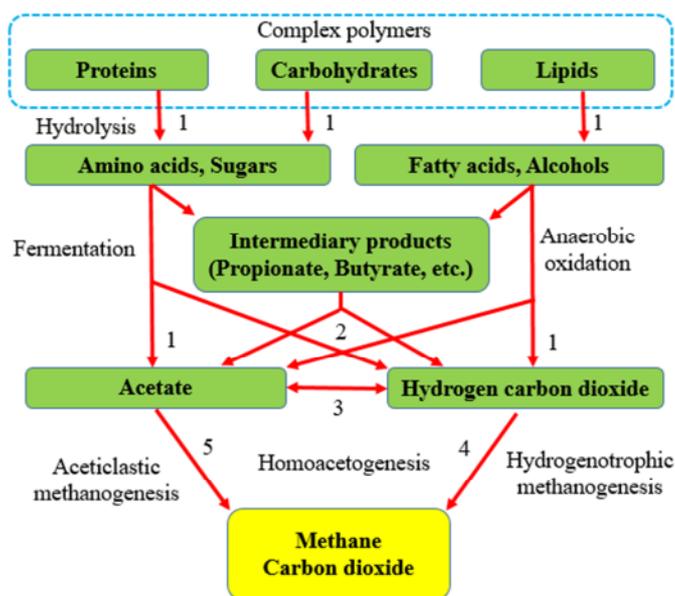


Fig. 2. Schematic of the proposed procedure for the anaerobic digestion of POME (Gujer and Zehnder, 1983)

Table 1. The composition of the effluent from palm oil factory [12]

Compound	Mass flow rate, (kg/h)	Mass fraction, (%)	Concentration, (g/L)
Carbohydrates	577	1.38	4.824
Proteins	482.5	1.15	4.034
Lipids	160	0.38	1.338
Water	40000	95.35	334.4
Sulphur	500	1.19	4.180
Biomass	1300	0.31	1.087

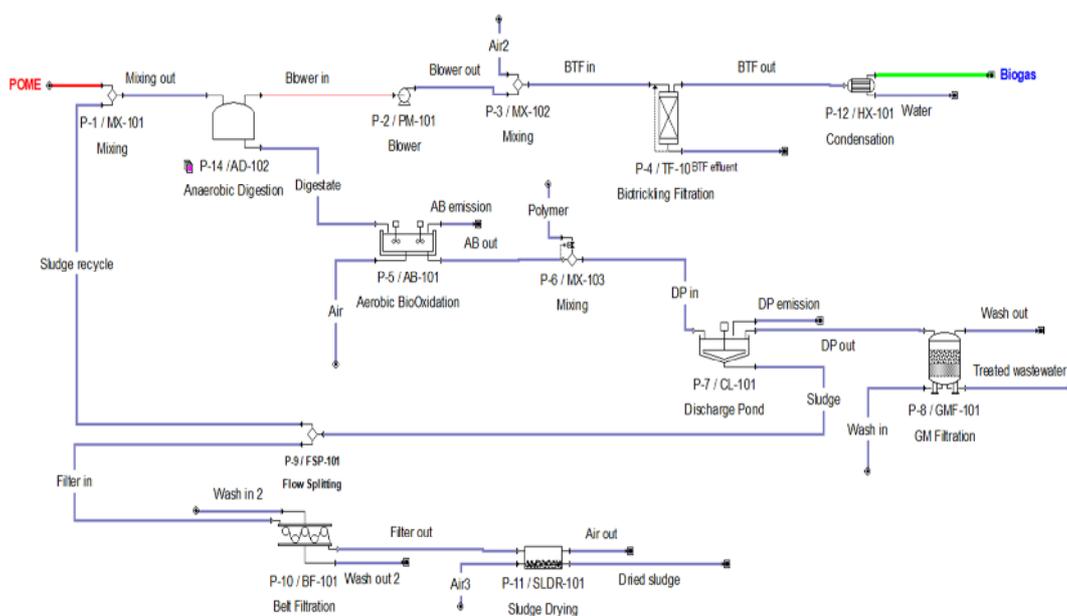


Fig. 3. Flow diagram of simulation of biogas production unit from palm oil factory effluent

**Table 2.** Simulated composition of biogas

Compound	Mass flow rate, (kg/h)	Mass fraction, (%)	Concentration, (g/L)
<b>Refined biogas based on current factory specifications (Chan et al., 2015)</b>			
CO <sub>2</sub>	480.7	27.63	0.280
H <sub>2</sub> S	281.8	16.79	0.164
CH <sub>4</sub>	877.64	52.28	0.512
O <sub>2</sub>	36	2.14	0.021
Water	2.67	0.16	0.002
<b>Biogas produced from a covered stabilization pond (present study)</b>			
CO <sub>2</sub>	480.7	25.48	0.245
H <sub>2</sub> S	349.96	18.55	0.178
CH <sub>4</sub>	877.64	46.52	0.446
Water	78.38	4.15	0.04

the effluent from the factory is discharged to a digester (AD-102) for anaerobic digestion. This process includes different microbes responsible for the destruction of organic matter at each stage, which leads to the production of biogas and digested matter. The purification steps include the removal of H<sub>2</sub>S in a biological filter (TF-101) where the oxidation of H<sub>2</sub>S occurs and then the humidity is reduced through a chiller (HX-101). It is assumed to remove 70% of water for the chiller to reach the desired output flow according to the existing factory specifications. Then the digested material is fed to the aerobic pool (AB-101) for further decomposition of degradable materials and stabilization of sewage sludge. The wastewater flows to the discharge pond indicated by a sludge trap (CL-101). The sludge trap is responsible for separating wastewater from suspended particles based on gravity. Removal of biomass and dead biomass was assumed to be 99%, which allows maximum efficiency for the sludge collector.

A granular bed filtration (GMF-101) treatment stage is used to meet the strict regulations regarding effluent standards with a BOD of 20 ppm. The treatment process has 95% removal efficiency to achieve the desired effluent characteristics according to environmental regulations. The sludge output from CL-101 is divided into two streams, part of which is returned to AD-101, while the remaining part is dewatered using a belt filter (BF-101) combined with drying (SLDR-101). It is assumed that 99% of the biomass and dead biomass in the effluent sludge remain in BF-101 to provide maximum efficiency.

The simulation showed a COD removal efficiency of 92%, which is more than the real data and is attributed to an ideal system. This state may be due to a possible leak in the treatment unit, which causes unwanted particles to be released in the treated water effluent. Studies showed that 28 m<sup>3</sup> of biogas is produced for every ton of palm oil factory effluent (Gozan et al., 2018). The composition of biogas mainly includes biomethane (CH<sub>4</sub>) and CO<sub>2</sub> with a mass ratio of 65:35. Regardless of the production of side products, the results obtained in

Table 2 show that the simulated ratio is consistent with the above-mentioned values. Also, these values can be compared with the quality of the resulting biogas based on the specifications of the existing plant provided by Chan (Chan et al., 2015) (Table 2).

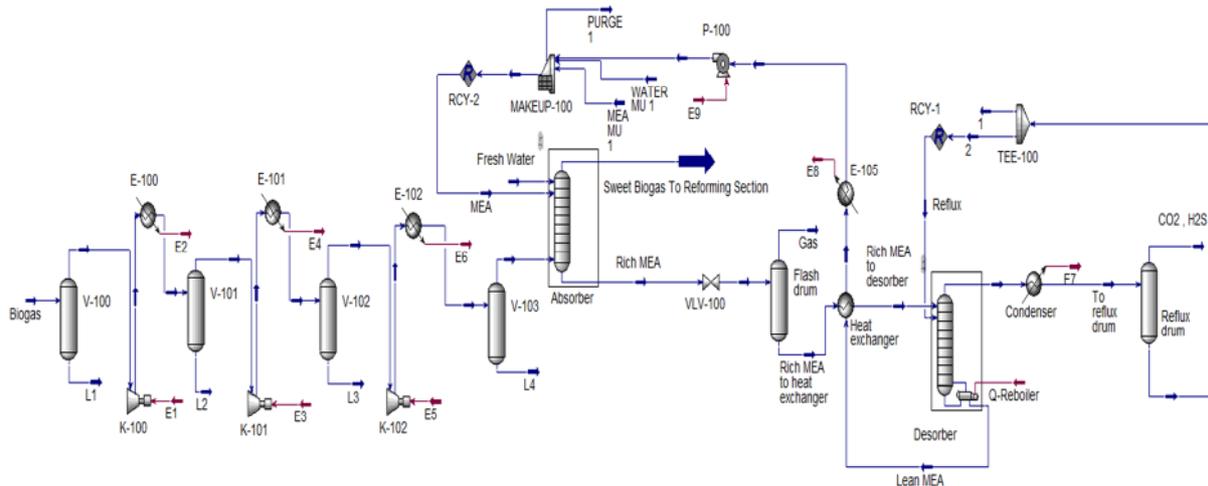
The produced biogas is colorless, odorless and smokeless when burning, and has a calorific value of 4,580 to 5,495 kcal per liter for a methane purity of 50 to 65%. Biogas can be used for heating purposes, fuel for internal combustion engines and power generation units, raw materials for chemical industries and organic fertilizer production. In this study, 877.64 kg of methane is produced per hour, which is equivalent to 1337865.6396 liters of methane per hour. In other words, it releases 6127424.62 to 7351571.68 kilocalories of energy in the form of fuel every hour. As mentioned, biogas produced from wastewater treatment contains compounds of methane, CO<sub>2</sub>, H<sub>2</sub>S and water. This stream is sent to the chemical absorption section in order to process and prepare the feed for the reforming unit. In the following, the simulation of the removal of CO<sub>2</sub> and H<sub>2</sub>S are presented.

### 2.3. Chemical absorption

One of the most efficient methods to remove CO<sub>2</sub> and H<sub>2</sub>S is the chemical absorption method. MEA and dimethyl ethanolamine<sup>1</sup> are widely used, which are applied in this simulation. In the chemical absorption section, there are two stages of condensation and separation. The schematic of the simulation process is shown in Fig. 4. The biogas produced in the wastewater treatment section, before entering the absorption tower, is condensed again to a higher pressure in the condensation section. Because in chemical absorption, in order to accelerate the reactions between MEA with CO<sub>2</sub> and H<sub>2</sub>S, the pressure must be high. In addition, the output product of this unit is the feed of the reforming unit, and the equilibrium reaction in the methane reforming section is carried out more favorably at higher

<sup>1</sup> Dimethyl Ethanolamine (DMEA)





**Fig. 4.** Process flow diagram of simulation of chemical absorption unit

pressures. Equations (1), (2) and (3) show the gas compression ratios in three compressors

$$P_{\text{Outlet}}^{\text{K-100}} = 4 P_{\text{Inlet}}^{\text{K-100}} \quad (1)$$

$$P_{\text{Outlet}}^{\text{K-101}} = 4 P_{\text{Inlet}}^{\text{K-101}} \quad (2)$$

$$P_{\text{Outlet}}^{\text{K-102}} = 3.906 P_{\text{Inlet}}^{\text{K-102}} \quad (3)$$

The temperature of the flow coming out of the compressor should not exceed 190 °C, but if this happens, it should be cooled immediately to enter the next compressor. The temperature of the cooler outlet is 50 °C. Also, the pressure drop in the coolers is 2 psi. As a result of cooling the exhaust gas from the compressors, liquid droplets may be formed, which will cause severe damage to the compressor. To separate these droplets after each cooling step, the flow enters the two-phase separator. Finally, biogas rich in CO<sub>2</sub> and H<sub>2</sub>S, after three stages of compression and cooling, is absorbed from the top of the V-103 separator under a temperature of 50 °C and a pressure of 6048 KPa and enters the tenth tray of the tower.

In the absorption column, pollutants pass through the solvent and enter the liquid phase. In this tower, 10 %wt. MEA solvent is used. Increasing the percentage of CO<sub>2</sub> and H<sub>2</sub>S separation below 4 ppm is the main goal in this unit. To achieve this amount of absorption, the number of trays in the absorption tower was considered to be 10, and the ratio of solvent to gas was 13.51 (on a molar basis). If a solution with higher concentration of MEA is used, the ratio of solvent to gas is significantly reduced, but problems such as corrosion, foaming and reduction of the equipment's useful life is occurred. As can be seen in Fig. 5, the MEA solvent of 10 %wt. with the operating conditions considered in the absorption tower is able to

reduce the amount of CO<sub>2</sub> and H<sub>2</sub>S up to 1 ppm. Also, based on relations (4) and (5), it can be seen that 99.999% of CO<sub>2</sub> and H<sub>2</sub>S from biogas has been absorbed by the solvent

$$\text{CO}_2_{\text{absorbed}} = \frac{y_{\text{CO}_2}^{\text{Sweet Biogas}} - y_{\text{CO}_2}^{\text{Biogas}}}{y_{\text{CO}_2}^{\text{Sweet Biogas}}} \quad (4)$$

$$\text{H}_2\text{S}_{\text{absorbed}} = \frac{y_{\text{H}_2\text{S}}^{\text{Sweet Biogas}} - y_{\text{H}_2\text{S}}^{\text{Biogas}}}{y_{\text{H}_2\text{S}}^{\text{Sweet Biogas}}} \quad (5)$$

According to Fig. 5, the examination of temperature changes in the absorption tower also shows that the temperature in the absorption tower has an increasing trend from top to bottom, and in the range of trays 7 to 10, this increase is accompanied by a greater slope, and this range is where the absorption reactions occur. It is caused by the phenomena of mass transfer and heat transfer. Therefore, it can be said that if the amount of absorption increases, the temperature profile will also have an upward trend.

After the absorption unit, the bottom flow of the absorption tower, which contains an amine solution rich in acid gases, with a temperature of 62.66 °C and a pressure of 6070 kPa, first enters a pressure relief valve, and its pressure is reduced to 450 kPa to achieve a successful disposal process. Then it enters the two-phase separator to separate light gases. At this stage, due to the high-pressure liquid flow, a small part of the light gases is separated from the amine solution. Fig. 4 shows the liquid exiting from the separator which first enters the heat exchanger and its temperature is increased to 98 °C by the downward flow of the desorption tower which it enters. This increase in temperature has two main reasons: 1) In the desorption process the efficiency of mass transfer increases with temperature and

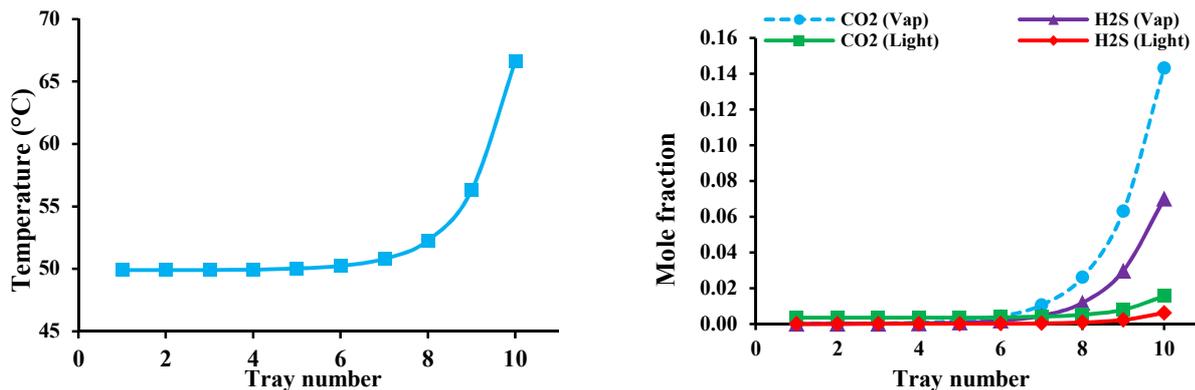


Fig. 5. The curve of temperature changes (right side) and CO<sub>2</sub> and H<sub>2</sub>S absorption profile in the chemical absorption tower (left side)

decreases with pressure rise. 2) Energy optimization by decreasing the thermal load of the reboiler. The output stream from the heat exchanger, which contains the rich amine solution, is fed to the tower from tray No. 1.

The reason for using desorption tower is that CO<sub>2</sub> and H<sub>2</sub>S are removed from the rich amine solution, and a solvent free of CO<sub>2</sub> and H<sub>2</sub>S is produced for reuse in the absorption tower. Desorption curve of these compounds is shown in Fig. 6. It is evident that this tower with 34 trays was able to reduce the amount of CO<sub>2</sub> in the clean amine solution to 0.2 mol% and reduce the amount of H<sub>2</sub>S to almost zero under the pressure of 165.5 kPa, reflux ratio of 410 kmol/h. This optimal solution is fed to the absorption tower for reuse.

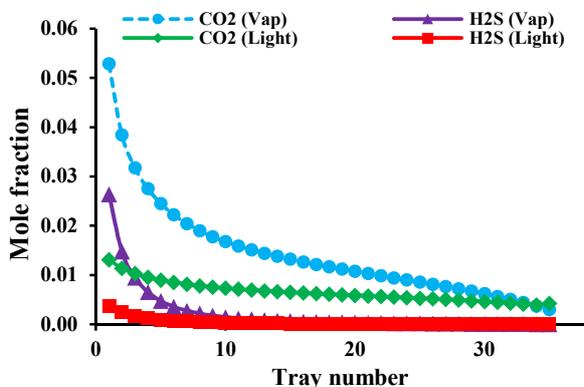


Fig. 6. CO<sub>2</sub> and H<sub>2</sub>S removal profile in the desorption tower

Steam with a temperature of 116.8 °C, which is produced by the tower reboiler, is the acidic compounds removal agent. This steam flow, with its high temperature and low pressure, creates the driving force of the desorption process and leads the acidic compounds along with it to the top of the tower. After that, the flow from the top of the tower enters a condenser, which is cooled to 50 °C and then enters the two-phase separator. In the separator, a large amount of water is separated, a part of which is injected into the

desorption tower from tray No. 1 as a reflux flow, and its excess amount is produced as sour water with a flow rate of 64 kmol/h. The product at the bottom of the absorption tower (pure amine) loses some of its heat after exchanging heat with the pure amine in the heat exchanger and leaves the exchanger with a temperature of 86.33 °C. This flow then reaches the temperature and pressure of the absorption tower by the cooler and pump and is injected into the tower from the upper tray with a flow rate of 520 kmol/h.

## 2.4. Conversion (reforming unit)

In this section, the steam reforming of methane in the treated biogas is investigated in two different ways and the results related to the compositions of the final product are presented.

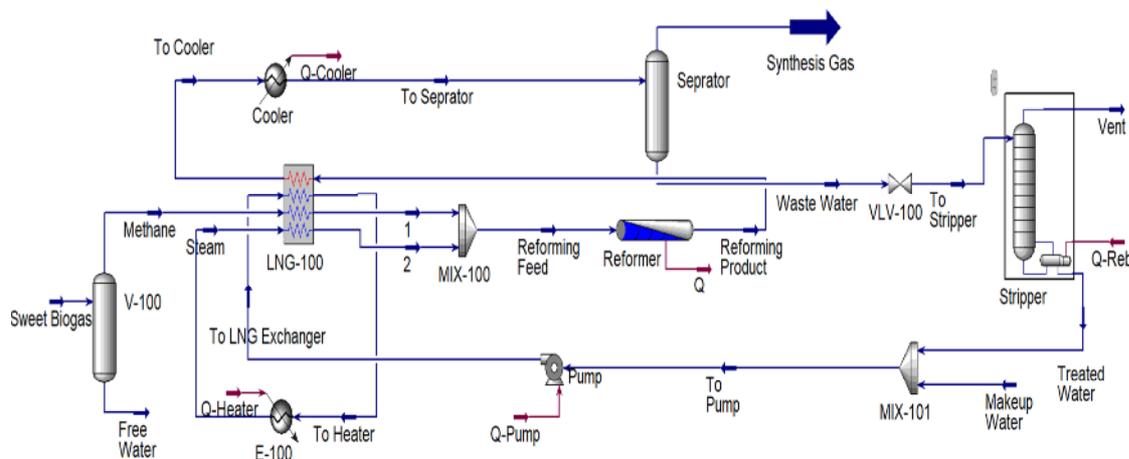
### 2.4.1. First strategy of reforming

In the first strategy, the Peng-Robinson- Stryjek-Vera third-order equation of state (PRSV) is used. In this simulation, according to Fig. 7, the flow of biogas reaches a temperature of 598 °C in the hot box by the output flow from the plug flow reactor and enters the reactor along with water vapor of 377 °C. The specifications related to the optimal conditions of the plug flow reactor are listed in Table 4.

Fig. 8 shows the curve of changes in the composition of methane, hydrogen and carbon monoxide<sup>1</sup> throughout the reactor. As can be seen, the concentration of methane has reached almost zero, while, the concentrations of hydrogen and CO gradually increased along the length of the reactor and remained almost constant after the length of 3 meters. It is obvious that most of the reactions were carried out in the inlet area up to 3 meters from the reactor.

As mentioned, the steam output from the reformer, which is at an operating temperature of 960.7 °C, a pressure of 6010 KPa and a molar composition

<sup>1</sup> Carbon Monoxide (CO)



**Fig. 7.** Process flow diagram of the simulation of methane reforming section according to the first strategy

**Table 4.** Considered conditions for the plug flow reactor

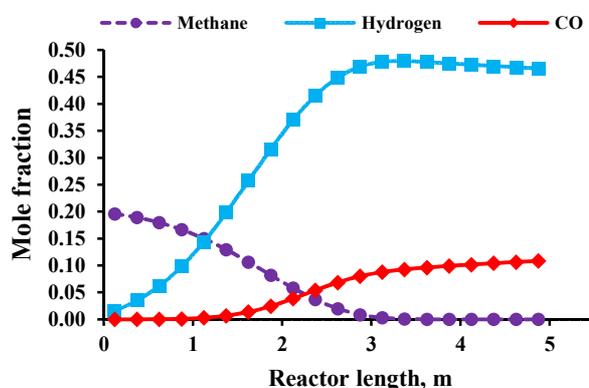
Parameters	Value
Length (m)	5
Diameter (m)	0.2
Porosity	0.04
Number of tubes	420
Pressure drop (KPa)	40

consisting of 46.58% hydrogen, 38.08% water, 10.85% CO and a small amount of oxygen and CO<sub>2</sub>, enter the hot box and preheat the biogas by its energy. After its energy is lost, this flow reaches a temperature of 226.5 °C and leaves the hot box and finally enters a cooler at constant pressure. This stream is cooled to 80 °C in the cooler to condense the existing vapors. After that, this flow is separated in the two-phase separator to be used again. The top flow of the two-phase separator with a composition of 74.55% hydrogen, 17.37% CO, 5.6% CO<sub>2</sub> and the remaining small amount of oxygen and water as syngas produced from this process with a flow rate of 27.5 ton/day. The bottom stream of the two-phase separator enters a desorption tower as sour water with a flow rate of 1306 kg/h to be regenerated for reuse in the reforming cycle.

#### 2.4.2. Second strategy of reforming

In the second strategy (Fig. 9), Peng-Robinson's equation of state is used, and instead of a plug flow reactor, a conversion reactor and two equilibrium reactors are used.

The reactions defined for this simulation are conversion type for the conversion reactor and equilibrium type for the equilibrium reactor. The biogas flow with a temperature of 49.84 °C and a pressure of 6070 kPa, consisting of 93.42% of methane, 6.34% of oxygen and 0.24% of water along with steam of 150 °C,



**Fig. 8.** The curve of changes in the mole fraction of methane, hydrogen and CO during the plug flow reactor

enters the two stages of the heat exchanger and finally with a temperature of 870 °C and a pressure of 3334 kPa, it enters the conversion reactor. In this reactor, the goal is to convert methane to other compounds, and the percentage of methane conversion is 100, which is considered to be completely consumed. The lower flow of the reactor contains a liquid flow, but the upper flow is a gas flow, the majority of which is hydrogen. Next, the top flow of the conversion reactor first enters a cooler and cools down to a temperature of 355 °C. In the following, this stream reacts in two equilibrium reactors and finally exits from the second equilibrium reactor. This outflow consists of 75.99% hydrogen, 14.43% CO<sub>2</sub>, 6.09% CO, 1.2% water and 1.3% oxygen. This flow enters a cooler and temperature is reduced to 35 °C, and due to this severe temperature reduction, the existing water vapors become water droplets. For this purpose, the stream enters a two-phase separator. Finally, the flow separated from the water droplets enters a desorption tower to produce a syngas product consisting of 91.96%

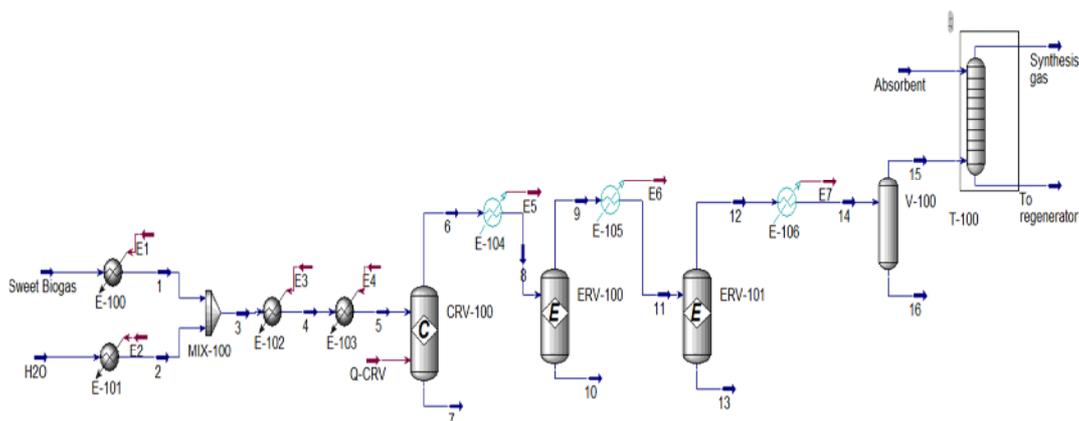


Fig. 9. Process flow diagram of the simulation of methane reforming section according to the second strategy

Table 5. Comparison of the molar composition of bio-syngas produced from the first and second strategies of the reforming unit

Compound	First strategy	Second strategy
Hydrogen	0.7455	0.9196
CO	0.1737	0.0681
Oxygen	0.0156	0.0107
CO <sub>2</sub>	0.0560	0
Water	0.0092	0.0015

hydrogen, 6.81% CO, 1% oxygen and a small amount of water by removing acidic compounds.

#### 2.4.3. Comparison of the first and second strategy of the reforming unit

As can be seen in Table 5, the molar composition of bio-syngas produced in each of the above two strategies is different. The purity of hydrogen in the bio-syngas produced in the second strategy is higher than in the first one, and on the other hand, the purity of CO<sub>2</sub> in the second strategy is zero. Therefore, the second method can be used as a suitable alternative to the conventional method of using a plug flow reactor.

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## 3. Conclusion

In this article, the design and simulation of bio-syngas process from biomass was investigated. Biogas produced from anaerobic reactions has compounds that can be transformed into valuable products. For this purpose, the biogas production process obtained from the wastewater treatment of palm oil factory was simulated. Studies have shown that 28 m<sup>3</sup> of biogas is produced for every ton of palm oil factory effluent. Then, a chemical absorption unit was used to remove CO<sub>2</sub> and H<sub>2</sub>S from biogas and achieve the desired product. The solvent used in the absorption tower was a 10% solution of MEA in water, which was able to reduce the amount of CO<sub>2</sub> and H<sub>2</sub>S to 1 ppm.

The biogas produced from this part, which is free of CO<sub>2</sub> and H<sub>2</sub>S, and more than 93% of its mole fraction is methane, became the feed of the reforming unit. In the reforming unit, two different strategies were investigated and based on the obtained results, the purity of hydrogen in the bio-syngas produced in the second strategy was higher than the first one. On the other hand, the purity of CO<sub>2</sub> in the second strategy was zero. Therefore, the second strategy can be used as a suitable alternative.

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