

Process Design and Simulation of Biodiesel Production Line Using Jojoba Oil

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Abstract

The use of fatty acid methyl ester (FAME), produced from agricultural oils as a fuel in diesel engines has been proposed as an alternative to diesel from fossil resources. The several renewable sources and yet not widely known, jojoba seeds appears to be promising scope for cultivation in arid and semi arid areas. The Jojoba oil-wax is extracted from the seeds of the jojoba, which grows in semi desert areas in some parts of the world. The present work describes a process design and simulation for converting the Jojoba oil-wax to biodiesel by transesterification with methanol, catalyzed with potassium oxide (1.35wt% of the oil). The transesterification reactions have been carried out in a batch reactor at 25, 40 and 50 °C, with a molar ratio of methanol to oil of 6:1, and mixing with 600 rpm. The reaction conversion was found to be 83, 87, and 95% after 80, 50, and 25 min., respectively. The experimental data was used to build up and design a process for producing biodiesel (methyl jojoboate) with maximum attained conversion of 95%. Then, a complete design for the process including all down streams needed for purification and recovery has been developed and optimized using simulation software (ASPEN HYSIS 2006). According to this study, the maximum expected purification yields of methyl jojoboate as a final product, jojobyl alcohol and methanol recovery after fractionation process were found to be 99.14, 93.3 and 99.9% respectively.

Keywords: Biodiesel, jojoba oil, modeling and simulation, processes design

1. Introduction

The consumption and demand for the petroleum products are increasing every year due to increase in population and standard of living. The increase in the crude oil import affects the country's economy and its development^{1, 2, 7}. The major disadvantage of using petroleum based fuels is atmospheric pollution created by the use of petroleum diesel. Petroleum diesel combustion is a major source of greenhouse gas (GHG). Apart from these emissions, petroleum diesel is also major source of other air contaminants including NO_x, SO_x, CO, particulate matter and volatile organic compounds³⁻⁵. The acid rain, global warming and health hazards are the results of ill effects of increased polluted gases like SO_x, CO and particulate matter in atmosphere⁶. So the researchers play a great effort to define another option for solving these problems, Biomass has been focused on as an alternative energy source to produce diesel based biomaterial that could contribute to sustainable development⁷⁻¹², since it is a renewable resource and it fixes CO₂ in the atmosphere through photosynthesis. If biomass is grown in a sustained way, its combustion has no impact on the CO₂ balance in the atmosphere, because the CO₂ emitted by the burning of biomass is offset by the CO₂ fixed by photosynthesis^{20, 21, 28}. Biodiesel fuel can be made from new or used vegetable oils and animal fats. Unlike fossil diesel, pure biodiesel is biodegradable, nontoxic and essentially free of sulphur and aromatics. Biodiesel is a variety of ester-based oxygenated fuels derived from natural^{13,14}, renewable biological sources such as vegetable oils, which is synthesized by the transesterification reaction as shown in figure 1¹⁵⁻¹⁹. Biodiesel is used internal combustion engine as an alternative to fossil-based diesel fuel.

Vegetable oils were proposed as an alternative renewable fuel competing with petroleum was proposed in the beginning of 1980s. The advantages of vegetable oils as diesel fuel are liquid nature-portability, ready availability, renewability, higher heat content, lower sulfur content, lower aromatic content and biodegradability. In the contrary using vegetable oils suffer the disadvantages of having higher viscosity, lower volatility and the reactivity of unsaturated hydrocarbon chain²². In addition such edible oils are competing with the food supplement chain. Accordingly non edible oils are best nominates for biodiesel production especially if they can grow in low fertility land with using wastewater for irrigation. Jojoba plant is considered as one of the most promising source of oil to make biodiesel. The Jojoba oil (known as oil-wax) has a low chemical reactivity and a very high normal boiling point (398 °C) that gives this product very important physico-chemical properties and uses. One of the first uses of the Jojoba oil in the 1970s was the substitution of the sperm whale

oil, when whale hunting was banned worldwide, but it has many other uses in cosmetics, pharmaceuticals, dietetic foods, animal feeding, and lubrication. The Jojoba plant can grow and establish in a variable climatic conditions and could be planted in desert area and irrigate with low quality water or even wastewater. The Jojoba plant is unique among other plants in the sense that its seed contains a high percentage of oil, which ranges from 45 and 55wt %²³. The oil is practically colorless and odorless. It is almost free of oil triglycerides which indicate that jojoba oil is different from all known seed oils in the sense of being not a fat but a liquid wax²⁴. Jojoba oil is traditionally extracted from its seeds by cold pressing using cold oil expellers followed by solvent extraction. Prior to the extraction process, the seed has to be subjected to preparation procedures such as cleaning and de-hulling due to containing foreign materials that absorbs oil during oil extraction and thereby leads to oil loss. These materials like sand/dust, stones, mud ball, sticks, and leaves²⁵. Then, oil is extracted from the seed by cold pressing using cold oil expellers having cooling arrangement. In fact, oil extracted at low temperature found suitable for industrial grade oil while subsequent pressure on expeller would generate heat resulting in extraction of oil with poor quality, rendering it from being suitable for industrial use^{26, 29, 30}. In the present work, the preparation of biodiesel using jojoba oil and methanol been carried out in laboratory. Then, a complete design for the production process has been developed and optimized using simulation program (ASPEN HYSIS 2006).

2. Materials and methods

2.1. Materials

The jojoba oil used in this work was supplied by the Egyptian Company of Natural Oils (Natoil Egypt), Cairo, Egypt. Methanol Alcohol used for transesterification reaction and KOH used as reaction catalyst, which was obtained from Elnasr Company for chemicals, Cairo, Egypt. HCL used for neutralization reaction, which was obtained from United Company for chemicals, Cairo, Egypt.

2.2. Methods

The production of biodiesel from jojoba oil and methanol was carried out according to a modified procedures carried out by Bouaid et. al²⁷. In the following a detailed description of the procedures is given. In all experiments, 60 grams of jojoba oil were used in each batch. First, KOH (1.35 % wt of whole reaction weight) was mixed with methanol (6:1 methanol: oil molar ratio considering an average molecular weight of Jojobyl oil-wax of 616 Dalton) to prepare potassium methoxide. Then, the potassium methoxide

mixed with the jojoba oil in 500 ml sealed-capped glass reactor for 80 min. the reaction mixture was vigorously stirred at 600 rpm using stirrer immersed into the reaction mixture and powered by hot plate magnetic stirring device. The reaction temperature was varied through heating using a hot plate. After the reaction was completed, a neutralization process was carried out using HCL. The cap of the reactor was removed and HCl was added drop wise to the reaction product until the pH reached a value of 7. To remove any catalyst residue and any excess acid, the neutralized product was washed with distilled water (5% of total reaction mass). Then, the product was allowed to settle for 8 h. At the end of the settling time, two layers were formed. The main layer was biodiesel (methyl jojobate) and the second layer was the jojobyl alcohol with methanol and other residue as traces of glycerin. The two layers were separated and dried at 80 °C in an oven to remove any traces of water and methanol. The experimental set-up and procedures are shown in Figure 2. The conversion of biodiesel was calculated by volume percent using volume equation (as followed by many researchers^{28 29 30}).

$$\text{conversion \%} = \frac{\text{Volume of Biodiesel product}}{\text{Total feed Volume (Oil+ Methanol)}} \times 100$$

2.3. Modeling and simulation

After optimizing the synthesis conditions of the biodiesel production, a simulation process utilizing these conditions has been carried out. The design capacities were based on jojoba oil feed of 100 ton/day. ASPEN HYSYS 2006 program was used in the design and simulation of the whole process.

The process flow diagram for the biodiesel production was designed to contain different unit processes as well as unit operations. Based on the synthesis procedures of the biodiesel that carried out in the laboratory, the production line was designed to start with a reactor for the carrying out the reaction followed by separation process to recover the produced biodiesel. The production process consists of four main units, specifically; feeding, reaction, separation, and distillation units. In the present work, we proposed three different modules for the production process. In all modules, the transesterification reaction was carried out in a convertor type reactor while the main difference in the three processes was in the design of fractionation units.

3. Result and discussion

3.1. Optimum Synthetic Biodiesel Conditions

The first step in this research was to carry out a synthesis process to optimize the reaction conditions for biodiesel using jojoba oil. The experimental set-up and procedures were described in the material and method section. The obtaining results in the present work were identical with that obtained by Bouaid et. al under the same reaction conditions. The maximum transesterification reaction was obtained after 80 min with methyl ester conversion of 83% at 25 °C. However, the results of both conversion and reaction time are considered non satisfactory from the industrial point of view. Since, the reaction time was quite large and the synthesis conversion was considerably low. Accordingly, many trails were carried out to enhance the reaction conversion through carrying out the synthesis under different temperatures to optimize the whole process. Table 1 shows the effect of temperature on the reaction time and maximum conversion. The results revealed that the maximum conversion of 95% by volume was obtained at 50 °C after 25 min. accordingly; the simulation process was carried out under these synthesis conditions. Based on these results, the simulation process was performed considering a reaction conversion of 95% at a temperature of 50 °C for 25 minutes reaction time using 6:1 methanol: oil molar ratio and a catalyst of 1.35 weight percent of the whole reaction weight.

3.2. Process Simulation

As we mentioned above, the production conditions were carried out under the optimum synthesis parameters obtained in the experimental part. Now, in the following we are going to present the data obtained using the three different proposed modules using ASPEN HYSYS 2006. The feed for the three different modules was assumed to be 100 ton/day of jojoba oil with having a maximum conversion of 95% by volume. In the following a brief description for each module will be given and the results of simulation will be discussed later. The main differences between the three Modules are in the design of the fractionation unit for the product purification.

The process flow diagram of Module#1 is shown in Figure 3. The process starts with a feeding unit which consists of feeding pump (P-100) used for transferring of the jojoba oil to the transesterification reactor (convertor type reactor, CRV-100) through a heat exchanger (E-100) having two different controlling valves. One valve is used for flow control (VLV-100) and the other for temperature control (VLV-101). Methanol and potassium oxide were mixed in a mixing tank (V-100). Then the mixture (methoxide) was pumped to CRV-100 through a transfer pump (P-101) installed with a flow control valve (VLV-102). The product out from CRV-100 was delivered to neutralization reactor CRV-101. To the naturalization reactor CRV-101, HCL was added using a dosing pump (P-102) to lower the pH value to a neutralizing value (to a pH value of 7). The resulting mixture was transferred to a washing tank (V-101) with having a flow control valve (VLV-105). The washing was carried out using fresh water through a washing pump (P-103). Then, the

washed mixture was delivered to a separation vessel (V-102) using a transfer pump (P-104) having a control valve (VLV-107). The neutralized and washed mixture is separated into two streams. The first stream (stream number 30) is composed mainly from methanol and jojobyl alcohol and the other stream (stream number 31) from jojobyl alcohol and methyl jojoboate (biodiesel). The first stream was pumped using transfer pump (P-105) to a reboiled absorber (T-100) comprises ten stages that fractionating the feed into methanol from top and jojobyl alcohol from bottom. The second stream was delivered to a reboiled absorber (T-101) that involves ten stages and fractionating the feed into methanol from top and methyl jojoboate (the main biodiesel product) from bottom. The methanol coming out from the overhead of T-100 was used in heating of jojoba oil feed through heat exchanger E-100 then mixed with methanol coming out from the overhead of T-101 through mixing unit (MIX-100). Such methanol was containing impurities and it should be purified before reuse. Accordingly, it was delivered to a heating unit (E-101) then to a fractionating tower T-102 to be fractionated into methanol from the top and impurities-containing streams from the bottom. Finally, the purified recovered methanol was passing through an air cooler (E-102) and recycled to be used for methoxide preparation. On the other hand, the main product (methyl jojoboate) and byproduct (jojobyl alcohol) were cooled through heat exchangers E-104 and E-103 and stored through V-104 and V-103, respectively. Table 3 shows a summary for the simulation results while Table 4 shows the material balance and data conditions for Module#1. As recorded in the table 3, it was found that the purification yield of the biodiesel was 63.85% (care should be taken to distinguish between the reaction conversion of 95% and the yield of the biodiesel purification step) while at the same time the methanol recovery was 91.14%. Due to the low yield of biodiesel as well as the relatively low recovering yield of methanol, another module (module#2) was proposed.

The process flow diagram of Module#2 is shown in Figure 4. The process was carried out as described in module#1 however the fractionation unit was modified as follows. The neutralized and washed mixture was separated into two streams. The first stream (in this module, stream number 30), which composed mainly from methanol and jojobyl alcohol, and the other stream (stream number 31) from methyl jojoboate. The first stream was delivered to reboiled absorber (T-100) comprises ten stages that fractionating the feed into methanol from top and jojobyl alcohol from bottom. The jojobyl alcohol was cooled through cooler (E-102) and was stored in tank (V-105). It was found that the composition of methanol coming out T-100 was quite low. Accordingly, to overcome this problem in this module, we suggested furthering cooling the methanol vapors through air cooler (E-101) to reach certain value of vapor fraction. Then, the methanol vapors were flushed in vessel (V-103) which condensate water vapor with other liquid impurities in the bottom and high composition methanol vapor is recovered at the top. Then, the methanol vapors were

cooled in air cooler (E-104) and pumped through pump (P-105) to be stored in vessel (V-104) and recycled to use again in preparation of methoxide in tank (V-100). The second stream was delivered to a reboiled absorber (T-101) that involves twenty stages to get methyl jojobate (the main product, the biodiesel) from bottom. The product was cooled through cooler (E-103) and stored in vessel (V-106). The top T-101 and bottom of V-103 was mixed in mixer unit (MIX-100) and used as heating medium for heating of jojoba oil in heat exchanger (E-100). Table 3 shows a summary for the simulation results while Table 5 shows the material balance and data conditions for Module#2. As recorded in the table it was found that the yield of the purification step of the biodiesel was 75% while at the same time the methanol recovery was 82.4%. The result showed that the biodiesel yield increased almost by 10%. On the contrary, the methanol recovery reduced by almost 10%. So a third module (module#3) was proposed to enhance both biodiesel production and methanol recovery.

The process flow diagram of Module#3 is shown in Figure 5. The process was carried out as described in module#1 but in this case the fractionation unit was modified as follows. The neutralized and washed mixture was separated into two streams. The first stream (in this module, stream number 30), which composed mainly from methanol and jojobyl alcohol, and the other stream (stream number 31) from methyl ester and jojobyl alcohol. The first stream was delivered to distillation column (T-101) comprises ten stages that fractionating the feed into methanol from top and jojobyl alcohol from bottom. The jojobyl alcohol (first grade composition) was stored in tank (V-106). The methanol was stored in vessel (V-105) and recycled to use again in preparation of methoxide in tank (V-100). The second stream was delivered to a second separator (V-103) that increases the percent of methyl jojobate in its layer. The separated layer (light liquid) was sent to a reboiled absorber (T-100) that involves ten stages to get methyl jojobate (the main product, the biodiesel) from bottom. The hot product was then used as a heating medium for heating of jojoba oil in heat exchanger (E-100) then it was cooled through cooler (E-101) and stored in vessel (V-107). Heavy liquid of V-103 and overhead of T-100 was mixed in MIX-100 to get another grade of jojobyl alcohol (second composition) and stored in V-104. Table 3 shows a summary for the simulation results while Table 6 shows the material balance and data conditions for Module#3. As recorded in the table, it was found that the yield of the purification step of the biodiesel was 99.41% while at the same time the methanol recovery was 99.91%.

It was clearly obtained that module#1 has the lowest quantity of methanol make up. For the products, the results showed that module#1 presents the highest biodiesel production rate, methanol recovery and lowest biodiesel composition while module#3 had the highest composition of biodiesel and methanol. For jojobyl

alcohol product, module#3 presents two grades of methyl alcohol could be produced. Module#3 presents the lowest equipment comprising for other modules.

Based on the obtaining results, it was becoming clear that module#3 could be the best candidate for biodiesel production using jojoba oil under the tested conditions. This module is characterized by the following features:

- Highest biodiesel composition.
- Highest methanol recycling number.
- Highest jojobyl alcohol production rate.
- Lowest equipments number.
- More Flexibility in operation.

4. Conclusions & Recommendations

In the present work, jojoba oil is proposed as precursor for biodiesel production as an alternative to petroleum-based diesel. The optimum operating parameters were found to be as follow:

- Using of potassium oxide with 1.35wt% as a catalyst.
- The transesterification reaction temperature of 50 °C.
- Molar ratio of methanol to oil is 6:1.
- Reaction time Of 25 min.

The experimental data was used for preparing a complete design for the process using simulation software (ASPEN HYSIS 2006). According to this study, the maximum expected yield of the purification of the methyl jojoboate and methanol recovery were found to be 99.14, and 99.9% respectively.

In the near future we are planning to investigate transesterification process through implementing of a pilot plant to carry out the production process of biodiesel to give more validation to the proposed process..

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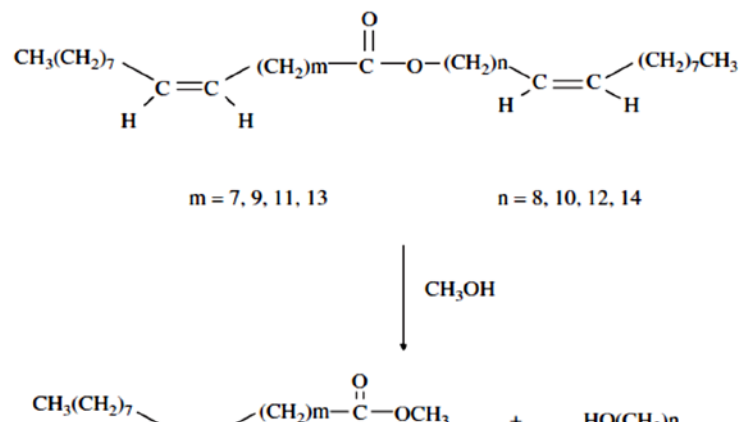


Figure 1: Transesterification reaction of Jojoba oil-wax with methanol, showing a general Structure for methyl jojoboate (bottom left) and jojobyl alcohol (bottom right).



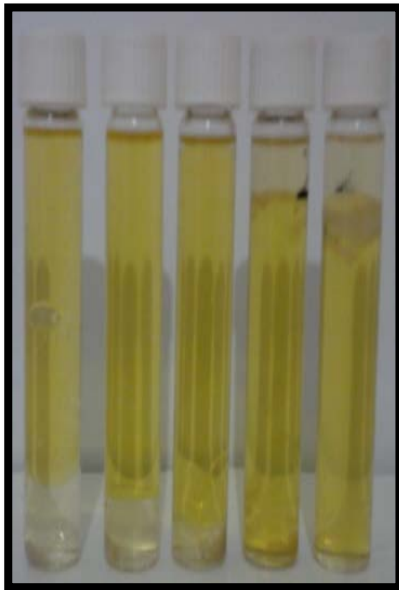
Methanol with potassium oxide forming methoxide



Jojoba oil



After the reaction finish



Products during washing with water



Methyl Jojoboate (biodiesel) and Traces of glycerin after settling



Methyl Ester (biodiesel)

Figure 2: Biodiesel synthesis steps in batch reactor

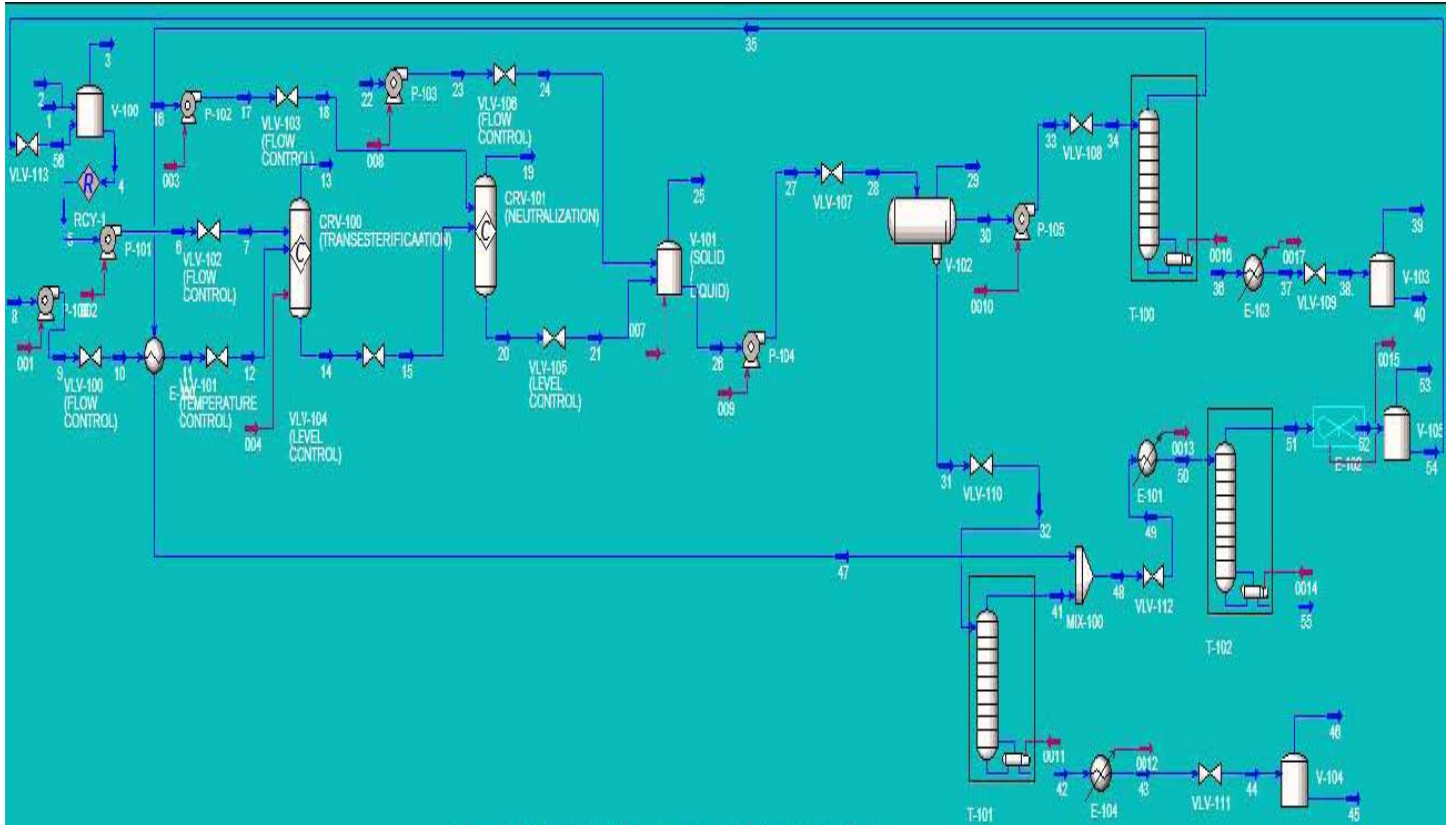


Figure 3: Biodiesel Production from Jojoba Oil Module#1

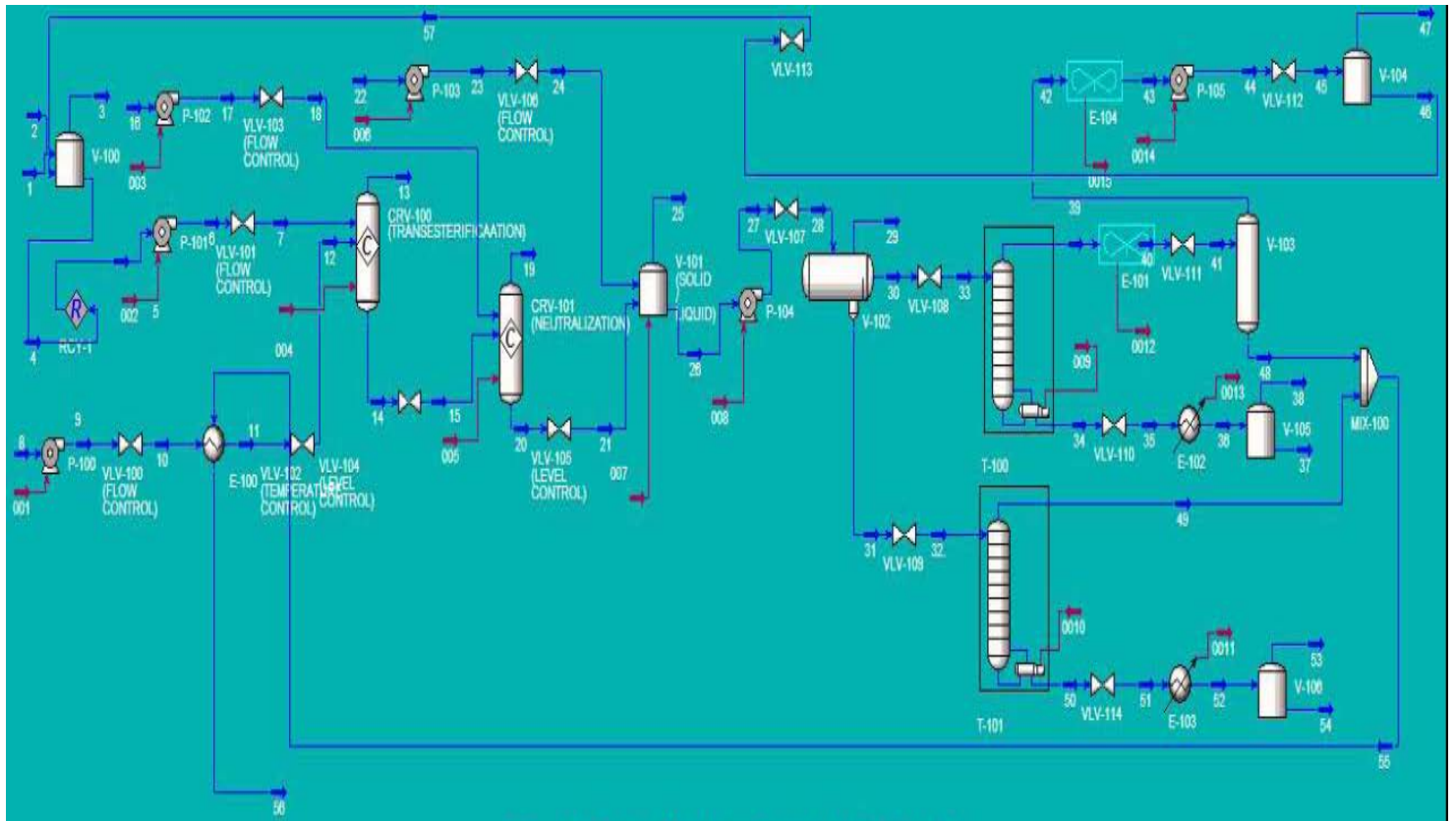


Figure 4: Biodiesel Production from Jojoba Oil Module#2

Table 1: The Effect of Temperature on the Reaction Time and Maximum Conversion

Temperature (°C)	Time (min.)	Conversion (%)
25	80	83
40	50	87
50	25	95

Table 2: Summary of Results Analysis using ASPEN HYSIS

		Module#1	Module#2	Module#3	
Feed					
Jojoba oil	m3/hr	4.84	4.84	4.84	
	Mass %	98.5	98.5	98.5	
Methanol make up	m3/hr	0.7	0.88	0.84	
	Mass %	100	100	100	
KOH	kg/hr	84.6	84.6	84.6	
	Mass %	100	100	100	
Washing water	m3/hr	0.17	0.17	0.17	
	Mass %	100	100	100	
Products					
Methyl jojoboate	m3/hr	3.94	3.14	2.3	
	Mass %	63.85	75	99.14	
Jojobyl alcohol	m3/hr	0.55	0.1	1.4	0.8
	Mass %	99.4	97.4	72.5	93.3
Methanol Recycle	m3/hr	2.26	1.36	1.9	
	Mass %	91.14	82.4	99.91	
Equipments					
Towers	Reboiled Absorber	3	2	1	

	Distillation Column	0	0	1
Vessels		6	7	7
Reactors		2	2	2
Pumps		6	6	5
Heat Exchangers		1	1	1
Coolers		2	2	1
Air coolers		1	2	0
Heaters		1	0	0
Control Valves		14	15	14
Mixers		1	1	1
Total		37	38	33

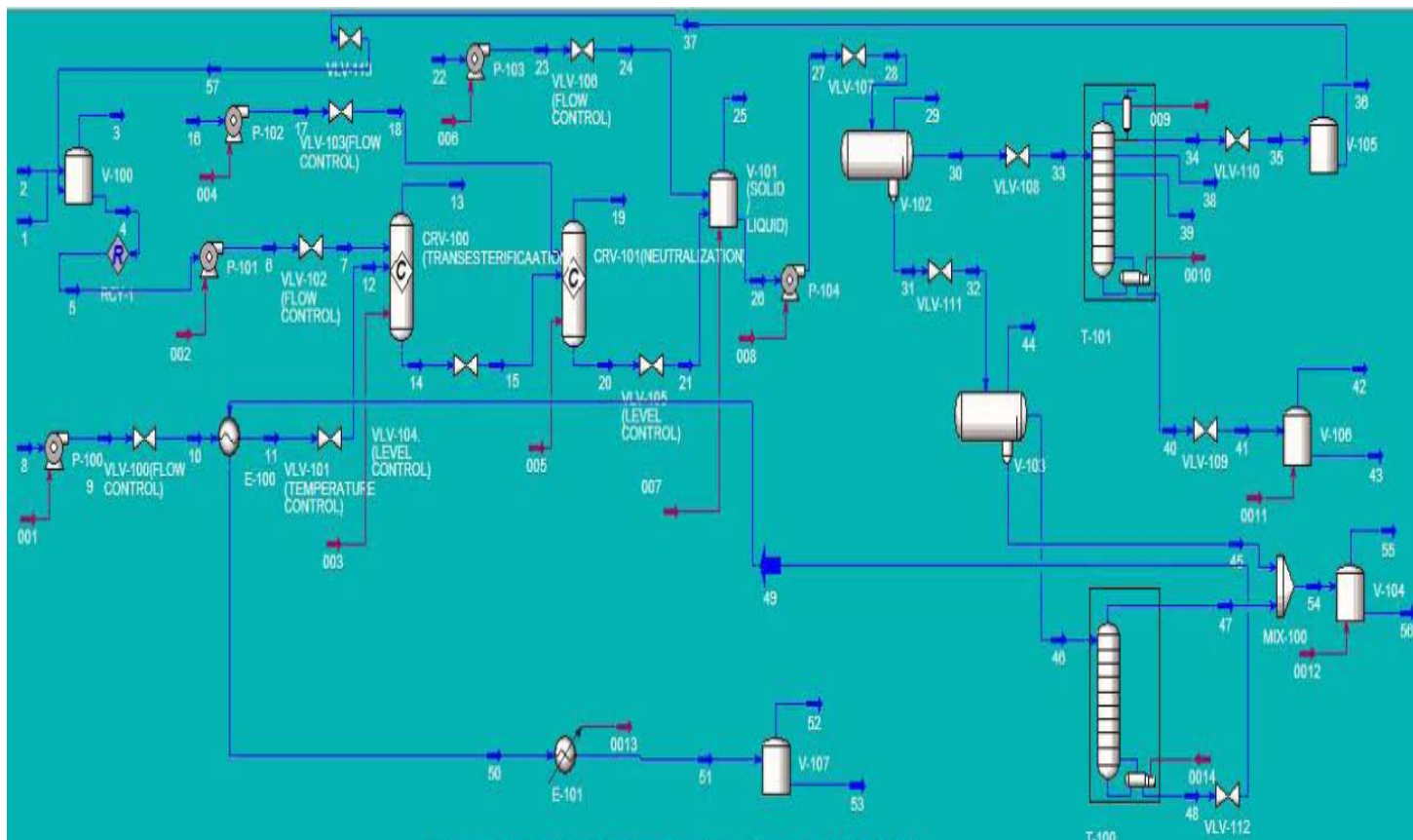


Figure 5: Biodiesel Production from Jojoba Oil Module#3

Table 4: Material Balance and Data Conditions for Module#1

Name (stream no.)	1	2	7	8	12	56	32	34	35	36
Module#1	Feeding unit						Fractionation unit			
Vapour fraction	0	0	0	0	0	0	0	0	1	0
Temperature [°c]	25	25	48.74397669	25	50.0177852	68.20267571	20.869902	21.1645966	101.891443	315.42214
Pressure [kpa]	101.3	101.3	150	101.3	160	101.3	102.31874	203.312491	80	152
Molar flow [kgmole/h]	1.508	17.3981717	74.18168653	6.2128928	6.212892795	56.36755775	15.737685	74.77811225	73.02788963	1.75022262
Mass flow [kg/h]	84.5988	557.470488	2486.698195	4194.2618	4194.261797	1843.872038	3943.0235	2935.90954	2330.25362	605.65591
Liquid volume flow [m³/h]	4.14e-02	0.70058627	3.054323202	4.85253854	4.852538537	2.265861931	4.1887229	3.35092039	2.80073771	0.5501826
Heat flow [kj/h]	0	-4208302.3	-1755072	-8260479	-8067316.90	-13335141.1	-8879696.	-19254408.2	-14771009.1	-974378.83

Name (stream no.)	40	41	42	45	47	49	50	51	52	55
Module#1	Fractionation unit									
Vapour fraction	0	1	0	0	0.9794107	0.98872960	0	0.99994964	0	0
Temperature [°c]	40	143.44959	331.566213	40	63.139545	62.73572883	90.0338362	70.87726644	68.2031702	89.83021248
Pressure [kpa]	147	101.3	152	151.5	55	55	202.649993	100	101.3	150
Molar flow [kgmole/h]	1.7502262	5.60115434	10.13653098	10.136531	73.0278896	78.62904397	78.629044	56.36755775	56.3675578	22.2614862
Mass flow [kg/h]	605.65591	221.85889	3721.16464	3721.164	2330.2536	2552.11252	2552.11252	1843.87203	1843.8720	708.240485
Liquid volume flow [m³/h]	0.5501826	0.2564431	3.93227983	3.932279	2.8007377	3.05718084	3.05718085	2.26586193	2.2658619	0.79131891
Heat flow [kj/h]	-1214970.5	-1068699.6	-5257055.09	-7484270.	-14962883	-16031582.1	-18789112	-11212957.8	-13335141.	-5584286.07

Name (stream no.)	1	2	7	8	12	57	32	33	37	39
Module#2	Feeding unit					Fractionation unit				
Vapour fraction	0	0	0	0	0	0	0	0	0	0.99999999
Temperature [°c]	25	25	9.962293116	25	50.01778576	21.6116492	21.4768414	20.2734058	40	82.2751846
Pressure [kpa]	101.3	101.3	106	101.3	120	102.3	175	175	102	80
Molar flow [kgmole/h]	1.50802139	21.8	58.04704442	6.22860796	6.228607963	35.8941694	18.9060892	54.9274196	0.21642755	54.710992
Mass flow [kg/h]	84.6	698.513434	1916.699901	4204.87095	4204.87095	1134.83822	4597.04406	1712.35182	70.9960526	1641.35576
Liquid volume flow [m³/h]	4.14e-02	0.87783826	2.329119457	4.86481276	4.864812765	1.36582106	4.793038	2.02209673	6.43e-02	1.95776777
Heat flow [kj/h]	0	-5273024.8	-14116742.5	-8281485.8	-8087943.33	-8851933.4	-10364162	-13922347	-143067.57	-11333948

Name (stream no.)	41	42	44	46	48	49	50	54	55	56
Module#2	Fractionation unit									
Vapour fraction	0.6560687	1	0	0	0	1	0	0	0.7714169	0.6514117
Temperature [°c]	65.31429	65.314292	21.591995	21.611649	65.3142927	252.202494	337.83975	40.0047062	72.244549	58.437884
Pressure [kpa]	60	60	162.3	102.3	60	101.3	152	92	60	35
Molar flow [kgmole/h]	54.71099	35.894169	35.8941694	35.8941694	18.8168226	11.09545918	7.81063002	7.810630021	29.9122818	29.9122818
Mass flow [kg/h]	1641.355	1134.8382	1134.83822	1134.83822	506.5175451	1696.252925	2900.79114	2900.791136	2202.77047	2202.77047
Liquid volume flow [m³/h]	1.957767	1.3658210	1.36582106	1.36582106	0.591946703	1.655823365	3.13721464	3.137214638	2.24777007	2.24777007
Heat flow [kj/h]	-1214053	-7299961.	-8851933.3	-8851933.3	-4840573.44	-3431515.74	-3972863.5	-5839658.83	-8272089.2	-8464599.8

Table 6: Material Balance and Data Conditions for Module#3

Name (stream no.)	1	2	7	8	12	57	32	33	34	36
Module#3	Feeding unit						Fractionation unit			
Vapour Fraction	0	0	0	0	0	0	0	0	0	1
Temperature [°C]	40	40	49.69679772	40	50.01782879	66.8602527	20.7710056	21.6268576	66.86025266	66.8602527
Pressure [kPa]	101.3	101.3	106	101.3	120	101.3	205	195	101.3	101.3
Molar Flow [kgmole/h]	1.50802139	20.877806	68.45362121	6.20722776	6.207227765	47.1583469	14.0024215	70.7621662	47.15834693	0
Mass Flow [kg/h]	84.6	668.964586	2268.190348	4190.43739	4190.437392	1513.66038	3590.19856	3056.00712	1513.660384	0
Heat Flow [kJ/h]	5306.45026	-5014545.4	-16195405.2	-8138384.	-8059364.18	-11179302	-8075149.9	-18654563	-11179302.4	0

Name (stream no.)	39	40	43	45	46	47	49	50	53	56
Module#3	Fractionation unit									
Vapour Fraction	7.50E-03	3.44E-05	0	0	0	1	0	0	0	0
Temperature [°C]	96.7359377	115.7155441	40	20.7710057	20.7710057	264.29329	355.5524053	342.597156	40.0004693	40
Pressure [kPa]	185	185	150	205	205	101.3	150	125	99	101.3
Molar Flow [kgmole/h]	19.6044978	3.999321434	3.999321434	1.01067341	12.9917481	7.63933372	5.352414381	5.35241438	5.35241438	8.650007126
Mass Flow [kg/h]	640.700823	901.6459107	901.6459107	143.472752	3446.72581	1415.7638	2030.962008	2030.96201	2030.96201	1559.236555
Heat Flow [kJ/h]	-5003359.6	-1989712.43	-2071698.31	-402128.21	-7673021.7	-2669320.7	-2560429.7	-2638406.7	-4098969.5	-3892406.6