

Design of Reactor for The Production Crude Glycerol from Waste Cooking Oil**Andre Safrie Maulana**

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Email : Andre.s.m@upi.edu**Abstract (English)**

In this research, the design and analysis of a batch reactor for the production of crude glycerol from waste cooking oil as a raw material for making candles was carried out. This research was carried out with computational analysis and calculations of the reactor, stirrer and mass balance using the Microsoft Excel application. It is hoped that the manufacture of crude glycerol can be scaled up on a factory scale so that a place is needed to react the raw materials from which the crude glycerol is made. Based on the calculations from the batch reactor and agitator specifications for crude glycerol production at an industrial scale (4,500 times larger than the lab scale), a required volume specification of 49.6824 ft³ with a height of 2.0321 ft and one agitator with a power of 1300 Hp is determined. The calculations were performed using Microsoft Excel without considering effectiveness factors. Based on the calculation results, it can be concluded that the design and performance analysis of the reactor can be applied.

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Reactor, Design, Production of Crude Glycerol

Abstrak (Indonesia)

Pada penelitian ini dilakukan perancangan dan analisis reaktor batch produksi gliserol kasar dari minyak jelantah sebagai bahan baku pembuatan lilin. Penelitian ini dilakukan dengan analisis komputasi dan perhitungan reaktor, pengaduk dan keseimbangan massa menggunakan aplikasi Microsoft Excel. Pembuatan gliserol kasar tersebut diharapkan dapat ditingkatkan skalanya pada skala pabrik sehingga diperlukan tempat untuk mereaksikan bahan baku pembuatan gliserol kasar tersebut. Berdasarkan perhitungan spesifikasi reaktor batch dan agitator untuk produksi gliserol kasar pada skala industri (4.500 kali lebih besar dari skala lab), diperlukan spesifikasi volume sebesar 49.6824 ft³ dengan tinggi 2.0321 ft dan satu buah agitator dengan daya 1300. Hp ditentukan. Perhitungan dilakukan dengan menggunakan Microsoft Excel tanpa mempertimbangkan faktor efektivitas. Berdasarkan hasil perhitungan dapat disimpulkan bahwa desain dan analisis kinerja reaktor dapat diterapkan.

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Reaktor, Desain, Produksi Gliserol Mentah.

Introduction

Waste cooking oil is cooking oil that has been used several times. Waste cooking oil is usually produced from frying food using the deep-frying technique. Deep Frying is soaking all food ingredients in cooking oil. The remaining cooking oil is usually not thrown away immediately, but instead a little new cooking oil is added to be reused repeatedly (SETIADY, 2018). Waste cooking oil is also said to be waste cooking oil which contains compounds that are carcinogenic. Where the continued use of waste cooking oil can damage human health, cause cancer, deposition of fat in blood vessels, and the subsequent consequences can reduce intelligence. (Alamsyah et al., 2017).

Based on the results of the analysis of the peroxide value content in waste cooking oil, the higher the frequency of frying, the higher the peroxide value, and the peroxide value of waste

cooking oil used for frying repeatedly turns out to be much higher. Heating waste cooking oil repeatedly and at high temperatures (more than 170°-200°C) causes waste cooking oil to undergo processes of change in oil content. The oil will undergo an oxidation process so that the structure of the unsaturated fatty acid content (Cis) will change structure (Trans). The oxidation process in heating cooking oil will also cause the formation of peroxide and hydroperoxide compounds which are free radicals (Agoes, 2008). The initial indication of cooking oil damage is the creation of acrolein, which can cause throat irritation when consuming repeatedly fried food. Acrolein is produced through the hydration of glycerol, forming unsaturated aldehyde. Waste cooking oil experiences molecular breakdown, leading to a significant drop in its smoke point and, if stored, a rancid odor. Improper storage can cause a rancid odor due to the breakdown of triglyceride bonds into glycerol and free fatty acids (FFA) over time. (Ketaren, 2005). Table 1 described the composition of triglycerides in waste cooking oil.

Table 1 Composition of triglycerides in waste cooking oil (Mahreni, 2010)

Fatty Acid	Composition (%)
Lauric	9,95
Myristic	0,19
Palmitic	8,90
Palmitoleic	0,22
Stearic	3,85
Oleic	30,71
Lanoleic	54,35
Arachidic	0,29
Gidoleic	0,18
Linoleic	0,27
Bahenic	0,61

Glycerol is a trihydroxy alcohol consisting of 3 carbon atoms, each carbon atom has an -OH group. One glycerol molecule can bind one, two, three fatty acid molecules in the form of esters, which are called monoglycerides, diglycerides and triglycerides. (Arbianzah, 2019). Glycerol is made by transesterification by reacting waste cooking oil and methanol using a base catalyst (Aziz et al., 2008).

A reactor serves as a location for various reactions to take place, whether they involve chemical transformations leading to a material transitioning from one state to another. These alterations may occur spontaneously or with the aid of external energy, such as heat. When producing reactors, it is crucial to guarantee that the reaction achieves optimal efficiency in generating the desired end product. This is essential for industries involved in reactor manufacturing to minimize operational expenses while maximizing product yield. The commonly encountered type of reactor in industrial settings is the stirred reactor, also referred to as a Continuous Stirred Tank Reactor (CSTR) (Mata & Smith, 1981).

This study involves the design and analysis of a batch reactor for producing crude glycerol from waste cooking oil, which will be used as a raw material for making candles. The reactor,

stirrer, and mass balance were analyzed computationally using Microsoft Excel. The scaling up of crude glycerol production to a factory level requires a reaction site for the raw materials used in its manufacture.

Method

1. Synthesis of Crude Glycerol

Crude Glycerol synthesis is based on an alcoholysis reaction (Sahi et al., 2017). The process of candle making begins with the production of crude glycerol through an alcoholization reaction using methanol and NaOH as a catalyst, as illustrated in Figure 2. The methanol and NaOH are dissolved with the aid of a stirrer. Once fully dissolved, the solution is added to the waste cooking oil and stirred for approximately 45 minutes. After the formation of two layers, the solution was transferred to a decanter and left overnight to allow for complete separation. The bottom product, crude glycerol, was then obtained. Subsequently, the crude glycerol was heated to 70°C to evaporate any remaining methanol. Figure 1 illustrates the process for producing crude glycerol.

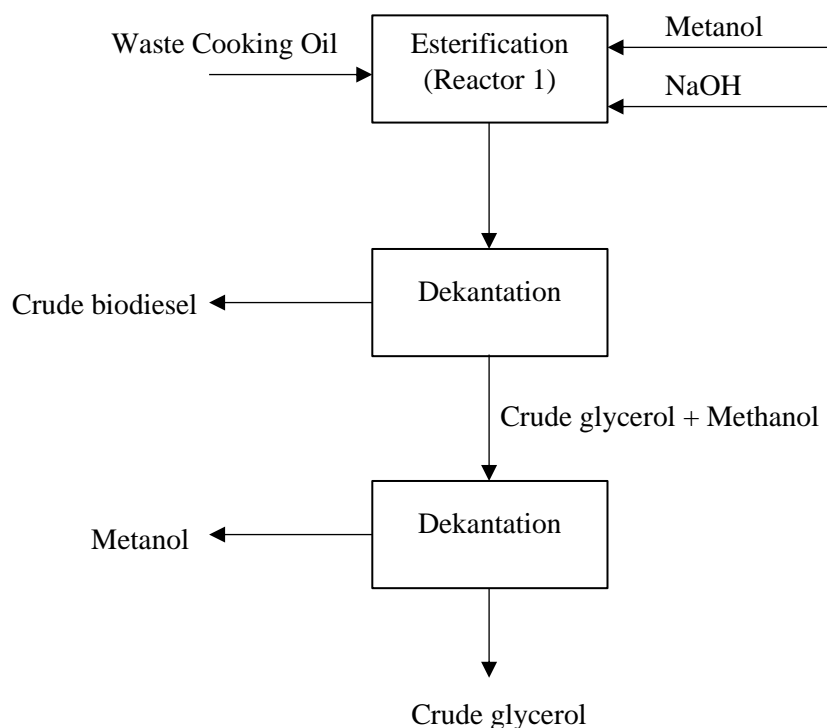


Figure 1 scheme for making glycerol by alcoholysis reaction

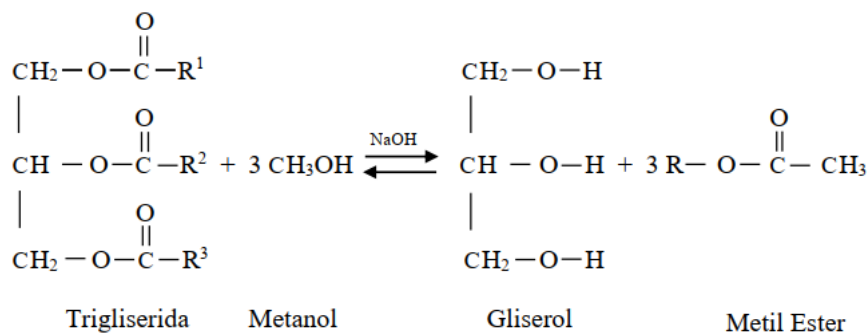


Figure 2 Mechanism Esterification Reaction (Mahreni, 2010)

2. Mathematical model for designed reactor

The material selected for the reactor is SA 240 Grade M Type 316 stainless steel with an upright cylinder type with a standard dished top cover and a conical bottom cover with an apex angle of 120° and the agitator is SA 240 Grade M Type 316 high alloy steel with an axial turbine type 4 blade angle of 45°. The assumptions of specification are shown in table 2.

Table 2 Assumptions of specifications design of reactor and stirrer

Specifications	Reactor
Type	Upright cylinder with standard dished top and conical bottom with 120° apex angle
Temperature	30°C
Pressure	1 atm
Operation time	45 minute
Construction time	Stainless steel SA 240 Grade M Type 316
Allowable Stress (<i>f</i>)	18750
Welding	Double welded butt joint
Corrosion Factor	0.0625
Amount incoming substance	2079.1796 lb/h
Volumetric rate	39.7459 ft ³ /h
Stirrer	
Type	Axial Turbine with 4 Blades at an Angle of 45°
Impeller material	High Alloy steel SA 240 Grade M type 316
Shaft material	Hot Roller Steel SAE 1020

The reactor was operated at room temperature and pressure (RTP) for 45 minutes with a total incoming substance of 2079.1796 lb/hour. Mass balance analysis was performed using Microsoft Excel application to collect data (equation 1-18). Table 3 presents the calculated parameters for the reactor and stirrer. (Anggraini, 2018).

Table 3 Calculation of reactor and stirrer parameters

Section	Parameters	Equation	Eq
Dimension of reactor	Total Volume of Reactor	$Total\ Vol.\ of\ reactor = precursor\ vol. + 20\% \times blank\ pspace\ Vol.$	(1)
	Vessel dimension (d_i)	<p>Where Total vol. of reactor (ft^3) $Total\ Vol. = V_{bottom\ lid} + V_{cylinder} + V_{top\ lid}$</p> $Total\ Vol. = \left(\frac{\pi d_i^3}{24 \tan\left(\frac{1}{2}\alpha\right)} \right) + \left(\frac{\pi d_i^3}{4} \times Lc \right) + 0.0847 d_i^3$	(2)
	Volume of liquid in the cylinder (V_{lc})	$V_{lc} = V_{liquid} - V_{bottom\ lid}$	(3)
	Height of liquid in the cylinder (H_{lc})	<p>Where V_{lc} (ft^3) $H_{lc} = \frac{V_{lc}}{\left(\frac{\pi}{4}\right) d_i^2}$</p>	(4)
	Pressure of design (P_i)	<p>Where H_{lc} (in) $P_i = P_{atm} + P_{hydrostatic}$ $P_i = 14,7\ psia + \left(\frac{\rho(HL - 1)}{144} \right) psia$</p>	(5)
	Cylinder thickness (t_c) and d_o standardization	<p>Where $HL = 5.1463$ P_i (psig) $t_c = \left(\frac{p_i \times d_i}{2(f \times E - 0.6P_i)} \right) + C$</p>	(6)
	Height of cylinder (L_c)	<p>Where $d_o = d_i + 2t_c$ d_o (ft) $Total\ Vol. = V_{bottom\ lid} + V_{cylinder} + V_{top\ lid}$</p> $Total\ Vol. = \left(\frac{\pi d_i^3}{24 \tan\left(\frac{1}{2}\alpha\right)} \right) + \left(\frac{\pi d_i^3}{4} \times Lc \right) + 0.0847 d_i^3$	(7)
	Dimension of top lid	<p>L_c (in) $th_t = \frac{0.885 \times P_i \times d_i}{2(f \times E - 0.1P_i)} + C$</p> <p>Where $th_t =$ top lid thickness (in) $h_t = 0.169 \times d_i$</p> <p>Where</p>	(8)

Dimension
bottom lid

$$th_b = \frac{P_i \times d_i}{2(f \times E - 0.16) \cos\left(\frac{1}{2}\alpha\right)} + C \quad (9)$$

Where

$$\alpha = 120^\circ$$

th_b = bottom lid thickness (in)

$$h_b = \left(\frac{\frac{1}{2}h_t}{\tan\left(\frac{1}{2}\alpha\right)} \right)$$

Where

$$\alpha = 120^\circ$$

h_b = height of bottom lid (in)

$$\text{Height of reactor} = h_t + L_c + h_b + s_f \quad (10)$$

Height of reactor

Where

$$s_f = 2.5$$

Height of reactor (ft)

Stirrer

Impeller diameter (D_a)

$$\frac{D_a}{D_t} = 0.5 \quad (11)$$

Where

$$D_t = 77.6250$$

Impeller diameter (ft)

$$\text{Impeller height from the bottom of the tank } (Z_i) \quad \frac{Z_i}{D_t} = \frac{1}{3} \quad (12)$$

Impeller height from the bottom of the tank (Z_i)

Where

Impeller diameter from the bottom of the tank (ft)

$$\text{Impeller length } (l) \quad \frac{l}{D_a} = \frac{1}{4} \quad (13)$$

Impeller length (l)

Where

Impeller length (ft)

$$\text{Impeller width } (W) \quad \frac{W}{D_a} = \frac{1}{5} \quad (14)$$

Impeller width (W)

Where

Impeller width (ft)

$$\text{Number of stirrer } (n) \quad n = \frac{H_{liquid}}{2 \times D_a^2} \quad (15)$$

Number of stirrer (n)

Where

$$H_{liquid} = 61.7559$$

$$\text{The stirring power } (H) \quad P = \frac{\varphi \times \rho \times n^3 \times D_i^5}{g_c} \quad (16)$$

The stirring power (H)

Where

$$\varphi = 0.9$$

$$g_c = 32.2 \text{ lb.ft/s}^2.\text{lbf}$$

P (Hp)

$$H = (0.1 + 0.15)P + P$$

Where

0.1 = estimation of the amount of power leakage in the process and bearing from the input power

0.15 = estimation of the amount of belt or gear leakage form input power

H (Hp)

$$D^3 = \frac{16 \times T}{\pi \times S} \quad (17)$$

$$T = \frac{63025 \times H}{N}$$

$$S = 20\% \times 36000 \text{ lb/in}^2$$

Where

S = maximum allowable design shearing stress (lb/in²)

N = stirrer rotation = 100 rpm

T = torsion moment (lb.in)

$\pi = 3$

D (in)

$$L = h + (l - Z_i) \quad (18)$$

Shaft length of stirrer (L)

Where

$h = L_c + h_t$

L (ft)

Result and Discussion

The dimensions typically comprise the diameter of the vessel, the thickness of the cylinder, and the length of the cylinder. The calculation of the stirrer from the reactor is included in the dimensions of each component. The calculation and determination of the upper and lower lids of the reactor, as well as the thickness of these lids, must be considered next.

The reactor volume was calculated to be 49.6824 ft³, with a vessel diameter of 40.0366 in, a cylinder height of 4.4029 in, and a cylinder thickness of 0.0682 in. After obtaining the vessel diameter, the height of the top and bottom caps was calculated to determine the overall height. The top cap has a calculated height of 6.7662 inches with a thickness of 0.0676 inches, while the bottom cap has a calculated height of 11.5713 inches with a thickness of 0.0740 inches. Therefore, the overall height of the reactor is 2.0321 feet. Table 3 shown the parameters of design reactor based on complete calculation.

Table 4 Reactor parameters designed based on calculations.

No	Parameters	Results
1	Total volume of reactor	49.6824 ft ³
2	Vessel dimension (d_i)	40.0366 in
3	Volume of liquid in the cylinder (V_{lc})	36.9400 ft ³
4	Height of liquid in the cylinder (H_{lc})	50.7291 in
5	Pressure of design (P_i)	4.3040 psig
6	Cylinder thickness (t_c)	0.0682 in
7	D_o standardization	3.3477 ft
8	Height of cylinder (L_c)	4.4029 in
9	Top lid thickness (th_t)	0.0676 in
10	Height of top lid (h_t)	6.7662 in
11	Bottom lid thickness (th_b)	0.0740 in
12	Height of bottom lid (h_b)	11.5713 in
13	Height of reactor	2.0321 ft

The size of each component, including the stirrer, which is also known as an agitator, needs to be taken into consideration. The stirrer typically consists of a series of motors as a drive pad and an impeller or blade that is adjusted to the organic material being used. Stirring during the process

of forming crude glycerol creates a flow pattern in the reactor. The flow pattern can be adjusted based on the flow velocity. In this design, axial flow is used, which causes flow parallel to the rotation axis.

The result of the stirrer calculation are shown in table 5. The number of stirrer is 1 piece with impeller diameter 38.8125 feet, impeller height from the bottom of the tank 25.875 feet, impeller width 7.7625 feet and impeller length 9.7031 feet. It is known that the plate used in the stirrer is an axial turbine type 4 blades angle of 45° . Turbine stirrer type is a type of stirrer that has many blades and is shorter in size.

Table 5 Stirrer parameters designed based on calculations.

No	Parameters	Results
1	Impeller diameter (D_a)	38,8125 ft
2	Impeller height from the bottom of the tank (Z_i)	25,875 ft
3	Impeller length (l)	9,7031 ft
4	Impeller width (W)	7,7625 ft
5	Number of stirrer (n)	1 piece
6	The stirring power (H)	1300 Hp
7	Shaft diameter of stirrer (D)	8,6500 in
8	Shaft length of stirrer (L)	1,8543 ft

Conclusion

Based on the calculations from the batch reactor and agitator specifications for crude glycerol production at an industrial scale (4,500 times larger than the lab scale), a required volume specification of 49.6824 ft³ with a height of 2.0321 ft and one agitator with a power of 1300 Hp is determined. The calculations were performed using Microsoft Excel without considering effectiveness factors. Based on the calculation results, it can be concluded that the design and performance analysis of the reactor can be applied.

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