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Design of Reactor for The Production of PbO Particles

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ABSTRACT

The aim of this study was to design and analyze the batch reactor designs to produce PbO particles on an industrial scale. The method used in this research is to perform computational analysis and calculation of the reactor and its stirrer as well as the mass balance as the basis for calculations using the Microsoft Excel application. The study of reactor design is one of the key steps of a process design in industry, and these specifications are used as a reference in production costs. To produce PbO particles on an industrial scale (10,000× laboratory scale), are required two reactors and two stirrers. The calculation results show that the first reactor has a volume of 11.2334 ft^3 with a height of 3.2219 ft and requires one stirrer with a power of 163 Hp, while the second reactor has a volume of 7.3576 ft^3 with a height of 11.9503 ft and requires one stirrer with power 191 Hp. The results of this computation and analysis can be applied to the design and analysis of reactor performance as a learning medium and operating mechanism in a production system.
Keywords : *PbO particle, Reactor design, Mass Balance, Scale up for industry, Learning.*

ABSTRAK

Tujuan dari penelitian ini adalah merancang dan menganalisis desain reaktor batch untuk menghasilkan partikel PbO dalam skala industri. Metode yang digunakan dalam penelitian ini adalah dengan melakukan analisis komputasi dan perhitungan reaktor dan pengaduknya serta neraca massa sebagai dasar perhitungan dengan menggunakan aplikasi Microsoft Excel. Studi tentang desain reaktor menjadi penting karena merupakan salah satu tahapan penting dalam suatu desain proses dalam industri, bahwa spesifikasi tersebut digunakan sebagai acuan dalam biaya produksi. Untuk menghasilkan partikel PbO pada skala industri (10.000× skala laboratorium), diperlukan dua reactor dan dua pengaduk. Hasil perhitungan menunjukkan bahwa reaktor pertama memiliki volume 11.2334 ft^3 dengan tinggi 3.2219 ft dan membutuhkan satu pengaduk dengan daya 163 Hp, sedangkan reaktor kedua memiliki volume 7.3576 ft^3 dengan tinggi 11.9503 ft dan membutuhkan satu pengaduk. pengaduk dengan daya 191 Hp. Hasil komputasi dan analisis ini dapat diterapkan pada desain dan analisis kinerja reaktor sebagai media pembelajaran dan mekanisme operasi pada sistem produksi.
Kata Kunci: Partikel PbO, Desain reaktor, Neraca massa, Skala industri, Pembelajaran.

INTRODUCTION

PbO particles have a wide range of uses, including for filler for silicon rubber (El-Khatib et al. 2022), batteries (Das et al. 2021), electrode (Zhou et al. 2021), optoelectronic device (Gunasekaran et al. 2021), membrane (Hamid et al. 2020), memristor (Perla et al. 2020), resin (Ghaseminejad et al. 2021, Sabri et al. 2019), pigment (Araújo et al. 2015), and catalyst (Hashemi et al. 2014). Consequently, a number of methods have been devised for the production of PbO particles, including the ball milling-annealing method (Yazdan et al. 2021), the physical vapor deposition method (Abdulrahman et al. 2021), the chemical bath deposition method (Ahmed et al. 2021), and the single precursor method (Nafees et al. 2017). The single precursor method is one way to make PbO particles. A batch reactor type is required for this procedure. Batch reactors are containers where pollutants are kept and given time to properly mix and react to produce the desired results. In an ideal batch reactor, the quality, quantity, temperature, and pressure are all supposed to be the same at a particular moment (Sundar and Kanmani, 2020).

There have been many studies on batch reactor design and analysis, including reactors for ZnO-Mn (Otadi et al. 2021), biodiesel (Akubude et al. 2021; Talaghat et al. 2020), melamine (Taufiqurrahman and Fadilah, 2021), sugar (Saputro, 2021), short-chain fructooligosaccharides (Sánchez et al. 2020), copper extraction (Sodha et al. 2020), methyl esters (Amri and Frimacia, 2020), cheese whey fermentation (Lagoa et al, 2020), production of hydroxymethylfurfural (Rosenfeld et al. 2020), food waste fermentation (Qi et al. 2020), lignocellulosic ethanol (Karagoz et al. 2019), Fe_3O_4/ZnO nanocomposite (Fernández et al. 2019), anionic polymerization of isoprene (Rodriguez, 2019), grapesseed oil (Bassan et al, 2019), meat production (Allan et al. 2019), nanomaterial adsorbent (Luo and Crittenden, 2019), PEG (Nge et al. 2018), and carbonization of biomass (Merzari et al. 2018).

Comparing batch reactors to other types of reactors, some of their benefits can be constructed, operated, and controlled with ease; shape can be adopted according to requirements; fewer number of pipe networks and channels required as compared to other techniques; a single basin can be used for homogenization; and frequently low cost (Roy and Aditya, 2015).

Therefore, this research was conducted to design and analyze the batch reactor designs with computational analysis and calculation of the reactor, its stirrer, and the mass balance using the Microsoft Excel application to produce PbO particles on an industrial scale that is ten thousand times bigger than lab scale.

METHODS

1. Synthesis of PbO particles

The precise processing conditions and preparation steps are shown in Figure 1. The method is applied after the experiments of M. Nafees, et al., (2017). As a start, $PbCl_2$ and $H_2C_2O_4$ are dissolved in distilled water under vigorous stirring at room temperature. Next, white precipitate of lead oxalate (PbC_2O_4) was formed which was collected and washed with absolute ethanol and distilled water several times to remove the traces of impurities. Afterwards, PbC_2O_4 was dried by aging for 7 h at 60 °C. To make the oxide, dry PbC_2O_4 was heated for 3 h at 425 °C in a muffle furnace. After cooling naturally to room temperature, red-colored PbO was formed and collected for characterization. Chemical reactions involved in the synthesis are:

$$H_2C_2O_4 + PbCl_2 \rightarrow PbC_2O_4 + 2HCl$$

$$PbC_2O_4 + O_2 \rightarrow PbO + CO_2 + CO$$

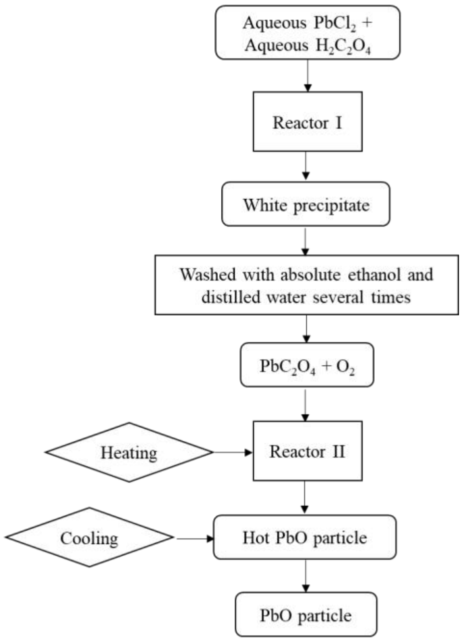

Figure. 1. Schematic diagram of the PbO particle preparation process using the single precursor method.

2. Mathematical model for designed reactor

The material chosen for both reactors is stainless steel SA 240 Grade M Type 316 with an upright cylinder type with dished standard top cover and conical bottom cover with apex angle of 120° and for both stirrers are High Alloy Steel SA 240 Grade M type 316 with axial turbine type 4 blade angle of 45°. The assumptions of specifications are shown in Table 1.

Table 1. Assumptions of specifications design of reactor and stirrer.

Specifications	Reactor	
	I	II
Type	An upright cylinder with dished standard top cover and conical bottom cover with apex angle of 120°	

Temperature	25 °C	
Pressure	1 atm	
Operation time	An hour	
Construction material	Stainless steel SA 240 Grade M Type 316	
Allowable Stress (f)	18750	
Welding	Double welded butt joint	
Corrosion factor	0.0625	
Amount of incoming substance	8146.0709 lb/h	6241.6282 lb/h
Volumetric rate	8.9867 ft^3/h	5.8861 ft^3/h
	Stirrer	
	I	II
Type	Axial turbine 4 blade angle 45°	
Impeller material	High Alloy Steel SA 240 Grade M type 316	
Shaft material	Hot Roller Steel SAE 1020	

The operating temperature and pressure of the reactor are set at room temperature and pressure (RTP) with an operating time of one hour. In the first reactor, the total incoming substance was 8146.0709 lb/hour, while in the second reactor it was 6241.6282 lb/hour. The specifications for the first and second stirrers are identical. According to study by Anggraini (2018), mass balance analysis is performed manually using the Microsoft Excel application when collecting data (equation 1-18). The reactor and stirrer parameters that were calculated is shown in Table 2.

Table 2. Calculation of reactor and stirrer parameters.

Section	Parameters	Equation	Eq
Dimension of reactor	Total volume of reactor	$Total\ vol\ of\ reactor = precursor\ vol + 20\% \times blank\ space\ vol$ where total vol of reactor (ft^3)	(1)
	Vessel dimension (d_i)	$Total\ vol = V_{bottom\ lid} + V_{cylinder} + V_{top\ lid}$ $Total\ vol = \left(\frac{\pi d_i^3}{24\tan\left(\frac{1}{2}\alpha\right)}\right) + \left(\frac{\pi d_i^2}{4} \times L_c\right) + 0.0847\ d_i^3$ where α = 60° L_s= 1.5 d_i (in)	(2)
	Volume of liquid in the cylinder (V_{lc})	$V_{lc} = V_{liquid} - V_{bottom\ lid}$ where V_{lc} (ft^3)	(3)
	Height of liquid in the cylinder (H_{lc})	$H_{lc} = \frac{V_{ls}}{\left(\frac{\pi}{4}\right) d_i^2}$ where H_{lc} (in)	(4)
	Pressure of design (P_i)	$P_i = P_{atm} + P_{hydrostatic}$ P_i = 14,7 psia+ $\left(\frac{\rho(HL-1)}{144}\right)$ psia where HL = 5.1463 P_i (psig)	(5)

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Section	Parameters	Equation	Eq
	Cylinder thickness (t_c) and d_o standardization	$t_c = \frac{P_i \times d_i}{2(f \times E - 0.6P_i)} + C$ where f = 18750 E = 0.8 C = 1/16 $d_o = d_i + 2t_c$ where d_o (ft)	(6)
	Height of cylinder (H_c)	$H_c = 2 \times d_i$ where H_c (in)	(7)
	Dimension of top lid	$th_t = \frac{0.885 \times P_i \times d_i}{2(f \times E - 0,1P_i)} + C$ where th_t = top lid thickness (in) h_a= 0.169× d_i where h_t = height of top lid (in)	(8)
	Dimension of bottom lid	$th_b = \frac{P_i \times d_i}{2(f \times E - 0,16) \cos\left(\frac{1}{2}\alpha\right)} + C$ where α = 120° th_b = bottom lid thickness (in) $h_b = \frac{\frac{1}{2}h_t}{\tan(\frac{1}{2}\alpha)}$ where α = 120° h_b = height of bottom lid (in)	(9)
	Height of reactor	$Height\ of\ reactor = h_t + L_c + h_b + s_f$ where s_f = 2.5 height of reactor (ft)	(10)
Stirrer	Impeller diameter (D_a)	$\frac{D_a}{D_t} = 0.5$ where D_t = 77.6250 impeller diameter (ft)	(11)
	Impeller height from the bottom of the tank (Z_i)	$\frac{Z_i}{D_t} = \frac{1}{3}$ where impeller diameter from the bottom of the tank (ft)	(12)
	Impeller length (l)	$\frac{l}{D_a} = \frac{1}{4}$ where impeller length (ft)	(13)

Section	Parameters	Equation	Eq
	Impeller width (W)	$\frac{W}{D_a} = \frac{1}{5}$ where impeller width (ft)	(14)
	Number of stirrer (n)	$n = \frac{H_{liquid}}{2 \times {D_a}^2}$ where H_{liquid} = 61.7559	(15)
	The stirring power (H)	$P = \frac{\varphi \times \rho \times n^3 \times {D_i}^5}{g_c}$ where φ = 0.9 g_c = 32.2 lb.ft/s^2.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 from input power H (Hp)	(16)
	Shaft diameter of stirrer (D)	$D^3 = \frac{16 \times T}{\pi \times S}$ $T = \frac{63025 \times H}{N}$ $S = 20\% \times 36000 \frac{lb}{in^2}$ where S = maximum allowable design shearing stress ($\frac{lb}{in^2}$) N = stirrer rotation = 100 rpm T = torsion moment (lb.in) π = 3 D (in)	(17)
	Shaft length of stirrer (L)	$L = h + (l - Z_i)$ where $h = L_c + h_t$ L (ft)	(18)

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RESULTS AND DISCUSSION

The complete calculation results are shown in Table 3. The first reactor functions to react oxalic acid and lead (II) chloride, while the second reactor functions to react lead (II) oxalate with oxygen. The calculation shows that the first reactor has a volume of 11.2334 ft3 with a height of 3.2219 ft and requires one stirrer with a power of 163 Hp, while the second reactor has a volume of 7.3576 ft3 with a height of 11.9503 ft and requires one stirrer with power 191 Hp.

Table 3. Reactor and stirrer performance parameters designed based on calculations.

Section	Parameter	Results	
Dimension of reactor		I*	II*
1.	Total volume of reactor	11.2334 ft^3	7.3576 ft^3
2.	Vessel dimension (d_i)	73.2984 in	73.2984 in
3.	Volume of liquid in the cylinder (V_{lc})	8.2313 ft^3	11.3319 ft^3
4.	Height of liquid in the cylinder (H_{lc})	3.7725 in	4.6429 in
5.	Pressure of design (P_i)	1.7720 psig	2.8520 psig
6.	Cylinder thickness (t_c)	0.0581 in	0.0555 in
7.	d_o standardization	6.1384 ft	6.1418 ft
8.	Height of cylinder (H_c)	10.7739 in	10.7739 in
9.	Top lid thickness (th_t)	0.0587 in	0.0563 in
10.	Height of top lid (h_t)	12.3874 in	12.3874 in
11.	Bottom lid thickness (th_b)	0.0538 in	0.0486 in
12.	Height of bottom lid (h_b)	21.1845 in	21.1845 in
13.	Height of reactor	3.2219 ft	11.9503 ft
Stirrer		I#	II#
14.	Impeller diameter (D_a)	3.2344 ft	3.2344 ft
15.	Impeller height from the bottom of the tank (Z_i)	2.1541 ft	2.1541 ft
16.	Impeller length (l)	0.8086 ft	0.8086 ft
17.	Impeller width (W)	0.6469 ft	0.6469 ft
18.	Number of stirrer (n)	1 piece	1 piece
19.	The stirring power (H)	163 Hp	191 Hp
20.	Shaft diameter of stirrer (D)	4.2315 in	4.4609 in
21.	Shaft length of stirrer (L)	3.6719 ft	3.6719 ft

*: first and second reactor

#: first and second stirrer

The designed reactor and stirrer design model is shown in Figure 2. PbO synthesis requires a heating temperature of 450 °C and then cooled at room temperature in the range of 20-25 °C. Therefore, the hot fluid used is oleic acid and the cold fluid is water. The hot fluid enters at a temperature of 450 °C and leaves at a temperature of 25 °C. The cold fluid enters at 20 °C and leaves at 90 °C. After a red particle formed, the process to production the PbO particle has finished and collected in a final product tank.

Therefore, this batch reactor and stirrer specification calculation one meets the requirements and standards for learning of designing the reactor and operating mechanism in a production system, but without the calculation of the effectiveness factor.

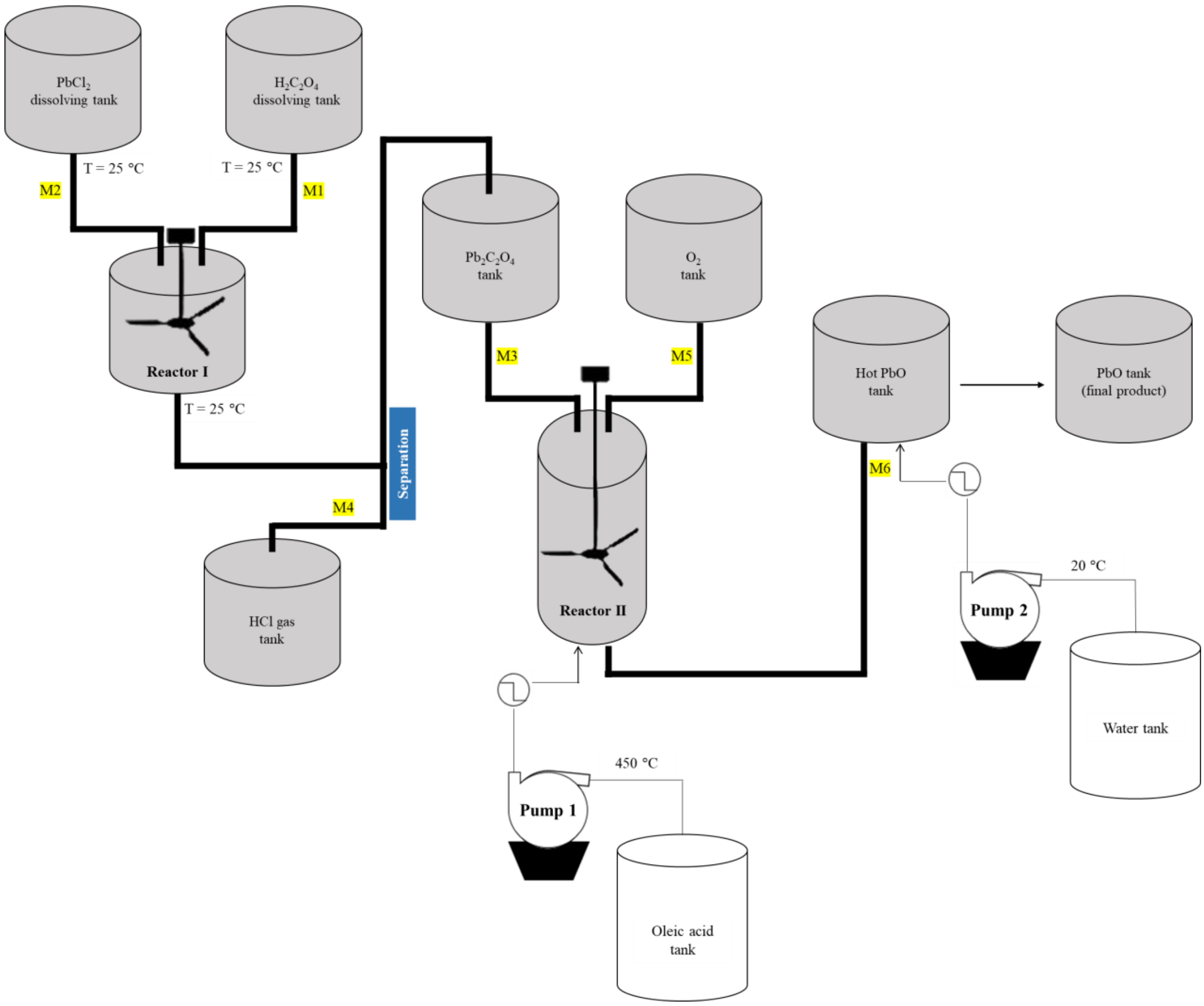

Figure 2. PFD on the synthesis of PbO particles.

CONCLUSION AND RECOMMENDATION
CONCLUSION

Calculation of the batch reactor and stirrer specifications for producing PbO particles at industrial scale (ten thousand times larger than the lab scale) obtained two reactors and two stirrers are required with the specification volume are 11.2334 ft3 and 7.3576 ft3, height are 3.2219 ft and 11.9503 ft, each one of reactors need one stirrer with a power 163 Hp and 191 Hp; respectively. The calculation was done through Microsoft Excel, but without an effectiveness factor counting. As a result, the calculation and analysis results can be used to the design and analysis of reactor performance as a learning medium and operating mechanism in a production system.

RECOMENDATION

In order to evaluate the design and calculations that have been made, it is required for future researchers to determine the efficacy factor of the reactor and its stirrer.

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