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Type Design of Continuous Stirred Tank Reactors (CSTRs) for Bath Bomb Lavender Production

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ABSTRACT

One of the most widely used complimentary bath products is lavender bath bomb, which has a pleasant scent, a foamy feel, and a relaxing effect. This is a chance to expand the production of bath bombs. The manufacture of lavender bath bombs on a large scale (industry) can be done using a continuous stirred tank reactors (CSTRs). This research aims to design a reactor to react the raw materials of lavender bath bomb through mixing reaction. The method used is by conducting computational analysis and calculation of the reactor and its stirrer and mass balance as the basis for calculation using Microsoft Excel. According to the computation results, the examined reactor needs one stirrer with a power of 141 horsepower and a total volume of 7.2334 ft^3 with a height of 27.1045 in. These computational and analytical results can describe the production system using the reactor as a learning tool.

Keywords: lavender bath bomb, mass balance, reactor design, industry

1. INTRODUCTION

Soap is one of the most basic needs in our day and age. It helps maintain the health of our skin and is used as a cleanser and deodorizer. Soap is a common everyday product and a skin cleanser. There are now many different kinds of soap being used, including liquid, bar, and cream soap[1].

One type of soap bar is a bath bomb. A bath bomb is a solid product that is readily available nowadays that looks like bath salts. Bath bombs fizz as they come into contact with water. Bath bombs are composed of base and acid formulations that release carbon dioxide gas as fizzing eruptions and bubbles when mixed with water[2].

Typically, citric acid and sodium bicarbonate are combined to make bath bombs. It is also possible to improve the bath bomb's ability to emit a calming and relaxing scent by adding essential oils[3]. One essential oil that can be added to bath bombs as an extra element is lavender essential oil. Lavender oil is made by

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distilling dried lavender plants. To make this lavender bath bomb, we can mix raw materials such as citric acid, baking soda, Epsom salt, corn starch, lavender essential oil, olive oil, food coloring.

Mixing can be done using a reactor. In the chemical industry, a reactor is a device that produces chemicals and provides a space for reactions to take place. Reactors are devices that provide a space for chemical reactions to take place, whether those reactions include the transformation of one substance into another. Certain changes might happen spontaneously or with the help of energy sources like heat. Reactor manufacturers have to make sure that reactions will provide the required end product as efficiently as possible in order to minimize operating expenses and optimize productivity[4].

A continuous stirred tank reactors (CSTRs) can be utilized to create lavender bath bombs. Because of its advantageous qualities from a control perspective, the CSTRs is a common piece of equipment utilized in the industry. The set of ordinary differential equations (ODE) describes the mathematical model of lumped parameters systems, which includes the CSTR[5].

Tabita et al have reported on the design of a reactor for the production of PbO particles[6]. So, in this case, the research is focused on the design of reactor which is CSTRs for lavender bath bombs by analyzing the design of CSTRs using computational analysis and calculation of reactors, stirrers, and mass balance using Microsoft Excel application to make lavender bath bombs in an industrial scale that is thousands of times larger than the laboratory scale

2. EXPERIMENTAL

2.1. Lavender Bath Bomb Making

The preparation of lavender bath bombs goes through various processes such as mixing dry ingredients, wet ingredients, mixing the whole batter, and molding the batter. The schematic of the lavender bath bomb making process is depicted in Figures 1 and 2.

The first step is to mix all the dry ingredients (50 kg corn flour, 50 kg citric acid, 115 kg sodium bicarbonate/baking soda, and 50 kg epsom salt). After that, the wet ingredients were mixed (5 kg of water, 10 kg of lavender essential oil, 5 kg of food coloring, and 5 kg of olive oil). This mixing is done to produce 200 kg of lavender bath bombs. Finally, the mixture is stirred and then molded and allowed to sit for at least a day in a cool room before use.

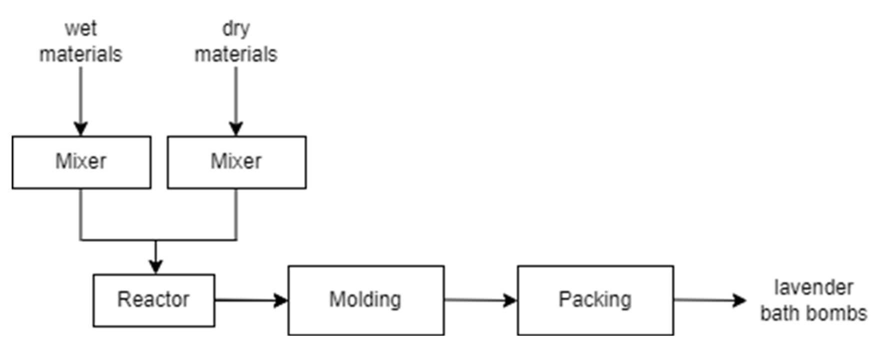

Figure 1. Lavender bath bomb manufacturing process

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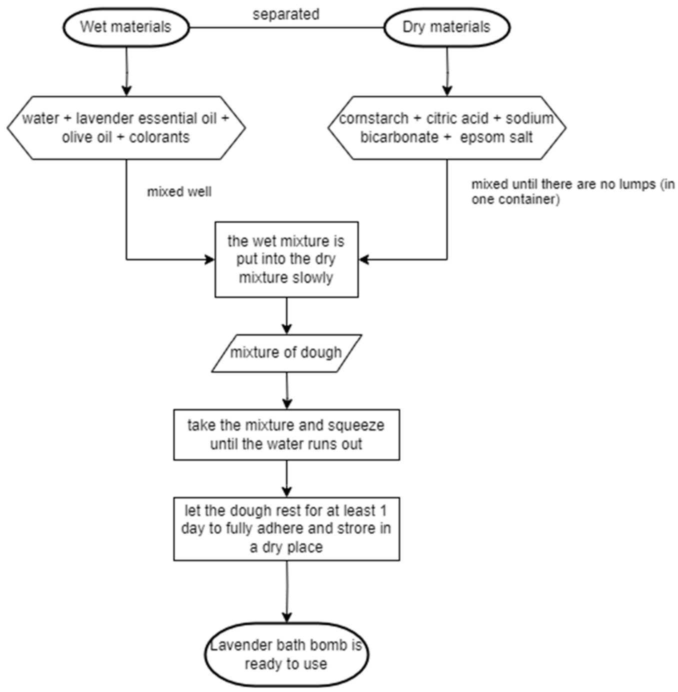

Figure 2. Schematic diagram of lavender bath bomb production

2.2. Mathematical Model for Designed Reactor

The material selected for the reactor is stainless steel SA 240 Grade M Type 316, upright cylinder type with a standard dished top lid and conical bottom lid with a peak angle of 120°, operating time of one hour, pressure of one atm, temperature of 20°C, and stirring equipment and cooling jacket. The assumptions of specifications are shown in Table 1.

Table 1. Assumptions of specifications design of reactor and stirrer

Spesicifications	**Reactor**
Type	An upright cylinder with a standard dished top cap and a conical bottom cap with a peak angle of 120°.
Temperature	25°C
Pressure	1 atm
Operation time	1 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	628.317 lb/h
Volumetric rate	6.0615 ft^3/h
Stirrer	
Type	Axial turbine 4 blade angle 45°

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The total incoming substance in the reactor was 628.317 lb/hour. When gathering data, mass balance analysis is done manually using the Microsoft Excel program (equation 1–18)[6]. Table 2 displays the calculated reactor and stirrer parameters.

Table 2. Calculation of reactor and stirrer parameters.

No	Section	Parameters	Equation	Eq
1.	Dimension of reactor	Total volume of reactor	$V_{total} = V\ material + V\ free\ space$ Where: Total volume of reactor (ft^3)	(1)
		Vessel dimension (d_i)	$V_{total} = V\ top\ lid + V\ cylin + V\ bottom\ lid$ $V_{total} = \frac{\pi\ di^3}{24\ tan\frac{1}{2}a} + \frac{\pi\ di^2}{4}\ x\ Lc + 0.0847\ di^3$ Where: $a = 120°$ $Lc = 1.5$ $\pi = 3.14$ d_i (in)	(2)
		Volume of liquid in cylinder (V_{Lc})	$V_{Lc} = V\ liq - \frac{\pi\ di^3}{24\ tan\frac{1}{2}a}$ Where: V_{Lc} (ft^3)	(3)
		Height of liquid in cylinder (H_{Lc})	$H_{Lc} = \frac{V\ Lc}{\left(\frac{\pi}{4}\right)\ x\ di^2}$ Where: H_{Lc} (in)	(4)
		Pressure of design (P_i)	$P_i = P_{atm} + P_{hydrostatic}$ $P_i = 14.7\ psia + \left(\frac{\rho\ (H_{Lc} - 1)}{144}\right)\ psia$ Where: $H_{Lc} = 2.2587$ ft P_i (psig)	(5)
		Cylinder thickness (t_c) and d_o standardization	$t_c = \frac{P_i d_i}{2(f.E - 0.6P_i} + C$ Where: $f = 18750$ $E = 0.8$ $C = \frac{1}{16}$ $d_o = d_i + 2t_c$ Where: d_o (ft)	(6)
		Height of cylinder (H_c)	$H_c = 2\ x\ d_i$ Where: H_c (in)	(7)
		Dimension of top lid (th_t)	$th_t = \frac{0.885\ x\ P_i\ x\ d_i}{2\ (f\ x\ E - 0.1P_i)} + C$	(8)

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			Where: th_t = top lid thickness (in) $$h_t = 0.169x\ d_i$$ Where: h_t = height of top lid (in)	
		Dimension of bottom lid (th_b)	$$th_b = \frac{P_i d_i}{2(f\ x\ E - 0.16)cos\left(\frac{1}{2}a\right)} + C$$ Where: $a = 120°$ th_b = bottom lid thickness (in) $$h_b = \frac{\frac{1}{2}d_i}{tan\frac{1}{2}a}$$ Where: $a = 120°$ 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)
2.	Stirrer	Impeller diameter (D_a)	$$D_a = D_t\ x\ 0.5$$ Where: $D_t = 78$ D_t (ft)	(11)
		Impeller Height from Tank Bottom (Z_i)	$$Z_i = \frac{D_t}{3}$$ Where: $D_t = 78$ Z_i (ft)	(12)
		Impeller length (l)	$$\frac{l}{D_a} = \frac{1}{4}$$ Where: l (ft)	(13)
		Impeller width (W)	$$\frac{W}{D_a} = \frac{1}{5}$$ Where: W (ft)	(14)
		Number of stirrer (n)	$$n = \frac{H_{liquid}}{2xD_a}$$ Where: $H_{liquid} = 62$	(15)
		The stirring power (H)	$$P = \frac{\varphi x\rho x n^3 x d_i^5}{g_c}$$ Where; $\varphi = 0.9$ $g_c = 32.2\ lb.\frac{ft}{s^2}.lbf$ P (Hp)	(16)

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			$H = (0.1 + 0.15)P + P$ 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)	
		Shaft diameter of stirrer (*D*)	$D^3 = \frac{16xT}{\pi xS}$ $T = \frac{63025xH}{N}$ $S = 20\%\ x\ 36000 \frac{lb}{in^2}$ Where: *S* = maximum allowable design shearing stress $\frac{lb}{in^2}$ *N* = stirrer rotation (100 rpm) *T* = torsion moment (lb.in) $\pi = 3$ *D* (in)	(17)
		Shaft length of stirrer (*L*)	$L = h + (l - Z_i)$ Where: $h = L_c + h_t$ *L* (ft)	(18)

3. RESULTS AND DISCUSSION

CSTR is used for stirring-assisted reactions involving suspended particles and homogenous reactions. The bulk of stirred tank applications are continuous operations. The main parts of CSTR are the stirrer and tank. Usually, these reactors contain an exit port, an inlet port, and any extra equipment that may be required, such as heaters, thermometers, shutters, etc[7]. One of the most important parts of building a reactor of the CSTR type is the stirrer. In Figure 3, components of a stirred reactor are displayed.

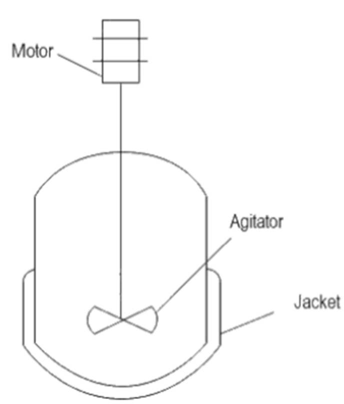

Figure 3. Design of Continuous Stirred Tank Reactors (CSTRs)[8]

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The reaction that takes place in the reactor determines the quality of the product that is produced. Reactor efficiency can be assessed by monitoring the flow of products the reactor produces and the raw materials it receives. We may calculate the amount of entering and outgoing mass to manage raw materials in the subsequent process by using the input and output composition to calculate the mass balance of the process feed from the reactor.

The mass balance is used to ensure the amount of material entering and leaving a process since it is based on the law of conservation of mass. Stated differently, there is equal intake and outflow throughout. Mass balancing calculations can be used as a reference to select the appropriate sort and size of chisel to provide the process volume[9]. Table 3 shows the results of mass balance calculations of lavender bath bomb production.

Table 3. Calculation of mass balance of lavender bath bomb production

Component	Mr (g/mol)	Reactants			Product			
		Mass	Mol	Fr.Mol	Mol	Fr.Mol	Mass	Fr. Mass
Citric acid	192,194	50,000	0,260154	0,075059	0,013008	0,003753	2,5	0,005955
Corn starch	162,14	50,000	0,308375	0,088971	0,061229	0,017666	9,927729	0,023649
Baking soda	84,007	115,000	1,368934	0,394959	1,121787	0,323654	94,238	0,224485
Epsom salt	120	50,000	0,4154	0,11985	0,168254	0,048544	20,25201	0,048242
Lavender oil	18,05	10,000	0,554017	0,159843	0,306871	0,088537	5,539013	0,013195
Olive oil	17,93	5,000	0,278862	0,080456	0,031716	0,009151	0,56867	0,001355
Food coloring	17,84	5,000	0,280269	0,080862	0,033123	0,009557	0,590913	0,001408
Bath bomb	165,42		0	0	1,730023	0,49914	286,1804	0,681712
Total		285,00	3,47	1,00	3,46601		419,7967	1

From these data it can be seen that the total inlet mass of lavender bath bomb production is 285 kg/hour. The results of calculations that have been carried out using the formula in Table 2 can be seen in Table 4.

Table 4. Calculations of reactor and stirrer performance parameters designed

No	Section	Parameters	Equation
1.	Dimension of reactor	Total volume of reactor	7.5769 ft^3
		Vessel dimension (d_i)	21.39 in
		Volume of liquid in cylinder (V_{Lc})	5.6336 ft^3
		Height of liquid in cylinder (H_{Lc})	27.1045 in
		Pressure of design (P_i)	1.6229 psig
		Cylinder thickness (t_c)	0.0636 in
		d_o standardization	21.5173 in
		Height of cylinder (H_c)	1.9084 in
		Dimension of top lid (th_t)	th_t = 0.0635 in h_t = 3.6149 in
		Dimension of bottom lid (th_b)	th_b = 0.0648 in h_b = 6.1820 in
		Height of reactor	1.4737 ft
2.	Stirrer	Impeller diameter (D_a)	3.2343 ft
		Impeller Height from Tank Bottom (Z_i)	2.1562 ft
		Impeller length (l)	0.8085 ft
		Impeller width (W)	0.6468 ft
		Number of stirrer (n)	1 piece
		The stirring power (H)	141 Hp
		Shaft diameter of stirrer (D)	2.0404 in
		Shaft length of stirrer (L)	1,2122 ft

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The designed reactor and stirrer design model is shown in Figure 4. As per G.G. Brown's book, the stirrer plan was selected. The stirrer that will be employed is an axial turbine with four blades positioned at a 45-degree angle and a SA 240 Grade M type 314 high alloy steel impeller. In addition, hot-rolled SAE 1040 steel was utilized to construct the stirrer shaft[10]

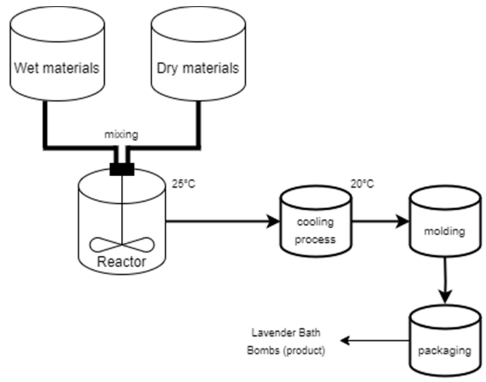

Figure 4. PFD on the manufacture of lavender bath bomb

4. CONCLUSION

Based on the computational outcomes of the CSTRs design, one reactor and one stirrer with a specified volume of 7.5769 ft3, height of 27.1045 in, and a power of 141, were obtained for the industrial production of lavender bath bombs. Microsoft Excel was used for the computation, although an efficacy factor count was omitted. Consequently, the computation and analysis outcomes can be applied to the design and analysis of reactor performance as a teaching tool and a production system's working mechanism.

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