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DESIGN AND FABRICATION OF 300 LITRES PAINT MIXING VESSEL

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ABSTRACT: *This research focuses on the design and fabrication of a 300 litre paint mixing vessel. The design was done using both mathematical calculations as well as SolidWorks software simulation. The process vessel dimensions were 845.3mm by 776.17mm, impeller blade was 232.9mm in diameter, agitator speed was 131.4rpm, and motor specification of 2 hp AC motor. The actual fabrication was made of mild steel using welding, machining, and forming techniques to join the vessel components, fabricate critical parts, and shape the vessel structure. Performance analysis of the vessel showed production of 300 litres paint under 30 minutes.*

KEYWORDS: *Solid Works, Simulation, Fabrication, Analysis, Machining*

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I. INTRODUCTION

The modern era has seen an enormous increase in production and construction work involving woods, stones, concrete, and metals, with paints used for both protection and appeal. As a result, there has been a significant increase in demand for paint and paint production equipment (Ntunde et al., 2019).

Humans have left an imprint on their environment in the form of painted images since prehistoric times, which both beautified their surroundings and expressed their thoughts and feelings (Omorusi, 2020). Paint is one of the oldest synthetic substances known, dating back to prehistoric times. Tens of thousands of years ago, clever humans discovered that combining coloured earth with a sticky liquid produced a substance that could be used to make a mark. Coloured rocks, earth, bones, and minerals were often ground into powders and mixed with egg or animal by-products to bind the solution and make paint. Through this process, Patterns and stories could be painted on rocks and inside caves using earthy tones of black, white, yellow, and red (Google Art and Culture, 2020).

Mixing is a critical operation in the chemical and allied industries because it is central to the achievement of homogeneity. Mechanical mixers are widely used in process industries such as chemical plants, food processing plants, paint plants, and so on to mix powders, semisolid jelly fluids, and so on. However, many factors influence mixing processes, including impeller type, vessel geometry, reactant nature, agitation speed, and mixing time, among others (Oyedeko et al., 2013; Jadhav et al., 2017). Paint production includes mixing, dispersion, thinning, adjustment, and filling. Each of these steps can be completed separately, or two or more of them can be completed in a single piece of equipment. Using rotating blades, all of the pigments are mixed together in a tub. The particles are wetted with a vehicle, and the flocculated aggregates are removed (Eneh, 2016).

Paint manufacturing is an important process with numerous applications. It is well known that combining binder, solvent, pigments, and additives in random proportions will result in a paint product, but its certified quality is determined by its ability to meet standard specification tests, where its best performance after application tells and distinguishes it from low quality products (Afolabi and Senibo, 2018). Furthermore, efficient paint mixing vessels improve the overall production efficiency and reduce operational costs. Optimal vessel design can minimize mixing time, energy consumption, and material waste, leading to enhanced productivity and profitability in the paint manufacturing industry (Chandra et al., 2021).

A paint mixer is a machine that mixes the various components of paint to form slurry in a homogeneous manner (paint). It has been established that mixing binder, solvent, pigments, and additives in random proportions will result in paint product, but its certified quality is dependent on its ability to meet standard specification test, where its best performance after application tells and distinguishes it from low quality product (Afolabi and Senibo, 2018). When compared to hand mixing, paint mixing machines produce standard quality paint because the quality of paint depends on how well its particles are blended together, and this type of blending can only be achieved consistently with the use of an automated paint mixer. Paint mixers consume less time and energy when making paint. Although commonly regarded as a single piece of equipment, such as a pump, a typical mixer is made up of several individual components, such as a motor, gear reducer, seal, shaft, impellers, and tank, all of which are often designed and purchased separately. Despite being highly customized for many applications, most mixers are a combination of standard components, sometimes modified, and frequently with unique characteristics such as shaft length (Mohtasim et al., 2019).

Paint mixer can be operated using an electric motor. The electric motor is attached to the machine's extreme with a pulley. This method is quick, but it requires the use of electricity. When the required chemicals are poured into the mixing chamber, the motor rotates. A belt drive is employed to transmit load from the driving shaft of the motor to the driven shaft of the agitator. An agitator is installed in a vessel to ensure that the contents in the vessel become homogeneous and remains in a proper mixed state (Agrawal, 2001; chemicalenginneringworld.com, 2020). After the required mixing time, the switch is turned off, and the tap can be opened to pour the mixture.

Hand mixers have always are been for paint production and this method requires more manpower, takes a longer time and produces paint with inconsistent quality. Also most paint mixers in the market are imported and very expensive. Some paint mixers have control panels that are difficult to understand, requiring training and time for an inexperienced operator to understand the functions and operate the machinery.
Therefore, paint mixers are needed because it produces consistent high quality of paint with less manpower and lesser time. Paint mixers that are both affordable and understandable are required for small and medium-sized businesses, as well as schools.

The aim of this paper is to present a design and fabricate a 300 litres paint mixing vessel made from locally sourced materials that are less expensive for small and medium-sized businesses to afford while also producing standard paint. The Objectives of this paper are:-

i. To design and fabricate a cylindrical tank with a mixing capacity of 300 litres.
ii. To design and fabricate an agitator for a 300 litres paint mixer.
iii. To specify the type of electric motor that will be suitable for a 300 litres paint mixer.
iv. To evaluate the economic costing for the production of a 300 litres paint mixer.
v. To analyse the performance of the paint mixer.

II. MATERIAL AND METHODS

For the design of the 300 litres paint mixer machine, the following factors were taken into consideration in the design process and development of all parts of the machine:

- Electrical actuators AC motor was chosen instead of DC stepper motor because of the power requirement and its speed which will be suitable for this design.
- Minimum energy requirement was considered.
- Materials used for the fabrication were locally sourced from available materials.
- The materials which will be used for the design will be light in weight so as to reduce the weight concentration on the mixer.

A. MATERIALS SELECTION

For the purpose of this work, due to economic considerations, and material availability as well as the type of paint the machine will be required to produce, paint has anti-rust properties so mild steel was mostly used for the container due to its low cost. The following machine components were employed in the construction of the 300 litres paint mixing machine:

i. Cylindrical container/tank
ii. AC electric motor
iii. Bearing support
iv. Belt/Pulley
v. Shaft
vi. Machine frame
vii. Shaft
viii. Discharge valve.
ix. Impeller / Rotating metal plate

Details of the different components of the 300 litres paint mixing machine are presented in Table 1.

Table 1: Component Description for Paint Mixer

S/N	**Component**	**Function**	**Material**	**Selection Criteria**
1.	Cylindrical Container/Tank	It holds the paint ingredients for the mixing process	Mild steel	Low cost, Lower maintenance, Higher strength and hardness
2.	Shaft	It transmits torque and motion from the electric motor to mix the ingredient in the container	Cast iron	Lower maintenance, Higher strength and hardness
3.	Frame	It supports the machine firmly	Mild steel	Low cost, High strength and Durability
4.	Belt/Pulley	It rotates the shaft	Rubber	Low cost, Flexible, Durability and Suitability
5.	Bearing	To allow free movement of the shaft	Cast iron	Stability, Suitability Durability and available
6.	Discharge valve	For drainage of the paint	Plastic	Corrosion resistance Attractive appearance Lower maintenance

7.	Impeller/Rotating metal plate	Impeller is a mechanical agitator use for mixing	Metal	High strength, Durability, Corrosion resistance, Stability Suitability

The design drawing of the paint production machine is shown in Fig.1.

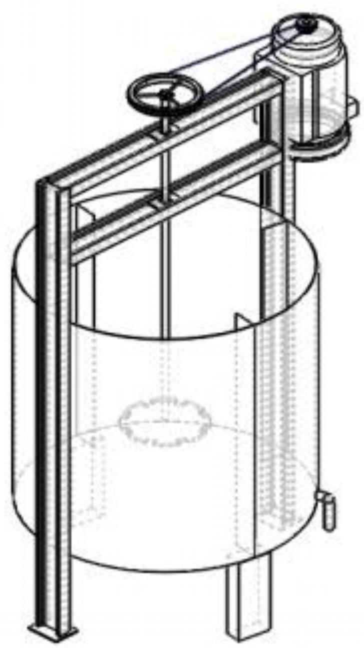

Fig.1: 3-Dimensional Design showing the internals of the paint mixer

B. DESIGN CALCULATIONS

This comprises of the following parameters:

i. Capacity of the vessel
ii. Dimensions of vessel
iii. Speed of the electric motor
iv. Torque transmitted by the electric motor.
v. Diameter of the shaft

a. Tank design

I. Capacity of the Tank

The mixing capacity of a drum is taken as 75% of the total drum, therefore the total capacity is calculated as

$$V_t = \frac{V_m}{0.75} \quad (1)$$

Where V_t = Tank volume
V_m = Mixing volume

$$V_t = \frac{0.300}{0.75} = 0.400m^3 = 400\ litres$$

II. Dimensions of Tank

The dimension of one sheet of galvanized steel plate is 4ft by 8ft (1219.2mm by 2438.4mm); we use the length of the sheet to be circumference 'C' of the tank

$$Diameter\ d = \frac{C}{\pi} \quad (2)$$

$$d = \frac{2438.4}{\pi}$$

$$d = 776.17mm \cong 0.77617m$$

$$Radius\ r = \frac{d}{2} \quad (3)$$

$$r = \frac{0.77617}{2}$$

$$r = 0.3881m$$

From $V_t = \pi r^2 h$, we can have

$$Tank\ height\ h = \frac{V_t}{\pi r^2} \quad (4)$$

$$h = \frac{0.400}{\pi \times 0.3881^2}$$

$$h = 0.8453m$$

$$Mixing\ capacity\ height = \frac{V_m}{\pi \times r^2} \quad (5)$$

$$h_m = \frac{0.300}{\pi \times 0.3881^2}$$

$$h_m = 0.6340m$$

$$Width\ of\ Baffle\ W_b = \frac{1}{10} \times d \quad (6)$$

$$W_b = \frac{1}{10} \times 0.77617$$

$$W_b = 0.0776m$$

$$Lenght\ of\ Baffle\ L_b = Height\ of\ Tank$$

$$L_b = 0.8453m$$

b. Impeller design

Now, following empirical relations are used to find the impeller specifications as taken from "Handbook of Industrial Mixing Science and Practice"

$$Diameter\ of\ Impeller\ d_i = 0.3 \times d \quad (7)$$

$$d_i = 0.3 \times 0.77617 = 0.2329m$$

C. POWER REQUIREMENT

According to Acquah, *et al.*, 2020

$$Impeller\ power\ P = \frac{10hp}{1000\,gallons} \times volume\ of\ mixture\ (gallons) \quad (8)$$

$$0.300m^3 = 79.2517gallons$$

$$P = \frac{10}{1000} \times 79.2517$$

$$P = 0.7925hp$$

Assuming 90% loading for a motor (10% losses of usable energy, in the form of work through the motor, shear gear and bearing),

$$minimum\ horsepower\ at\ 90\%, P^1 = \frac{100}{90} \times P \quad (9)$$

$$P^1 = \frac{100}{90} \times 0.7925 = 0.8806hp$$

Rounding off P^1 to the nearest standard size gives the minimum horsepower of 1.0hp

$$P^1 = 1.0hp = 0.746kW$$

$$Impeller\ speed, N_i = \sqrt[3]{\frac{P}{N_P \rho D_T{}^5}}$$ (Ray Sinnot, 2008) (10)

Where; P = P^1 =Power

N_P = The power number (according to chempedia.info, N_p for High Shear Disk is 0.2)

$\rho =$ Density (According to Powers, (1990), liquid density of emulsion paint is $1.26kg/m^2$

$D_T =$ Diameter of vessel

$$N_i = \sqrt[3]{\frac{0.746}{0.2 \times 1.26 \times (0.77617)^5}}$$

$$N_i = 2.19\ rev/s = 131.4RPM$$

D. SHAFT DESIGN

$$Continuous\ torque\ for\ shaft, T_c = \frac{P}{2\pi N_i} \quad (11)$$

$$T_C = \frac{0.746 \times 10^3}{2\pi \times 2.19} = 54.21Nm$$

$$Design\ torque\ input, T_{in} = T_C \times service\ factor \quad (12)$$

For a high shear impeller, a service factor of 1 can be used. (Paul, et al., 2004)

$$T_{in} = 54.21 \times 1$$

$$T_{in} = 54.21Nm$$

$$Maximum\ force\ on\ shaft, F_m = \frac{T_{in}}{2.2d} \quad (13)$$

$$where\ d = impeller\ diameter$$

$$F_m = \frac{54.21}{2.2 \times 0.2329} = 105.80\ N$$

I. Shaft Diameter

The shaft is a solid shaft having little or no axial loading. According to Hall et al., (1988), the diameter of a shaft is given by the equation (14).

$$d^3 = \frac{16}{\pi S_s}\sqrt{(k_b m_b)^2 + (k_t m_t)^2} \qquad (14)$$

Where M_t is the torsional moment (Nm);

M_b is the bending moment (Nm);

K_b is the combined shock and fatigue factor applied to the bending moment

K_t is the combined shock and fatigue factor applied to the torsional moment

S_s is the allowance shear stress (N/m^2)

For this type of vertical shaft bending moment is zero i.e. = 0

Therefore the first equation reduces to equation (15)

$$d^3 = \frac{16}{\pi S_s}\sqrt{(k_t m_t)^2} \qquad (15)$$

According to Hall et al. (1988), the shear stress S_S for the casted iron material used for shaft is 55 N/m^2 and for the rotating shaft with minor shock load = 1.0 Also torsional moment m_t is given by equation (16)

$$m_t = \frac{P}{2\pi N} \qquad (16)$$

$$m_t = \frac{0.746 \times 10^3 \times 60}{2 \times \pi \times 131.4} = 54.21\ Nm$$

Therefore diameter of the shaft will be given as

$$d^3 = \frac{16}{\pi \times 55 \times 10^6}\sqrt{(1.0 \times 54.21)^2}$$

$$d^3 = 5.02 \times 10^{-6}$$

$$d = 0.0171m$$

II. Moment of Inertia on the Shaft

$J = \frac{\pi \times D^4}{32}$, for circular solid shaft (Ntunde et. al., 2019) (17)

Where D is diameter of the shaft

$$J = \frac{\pi \times (0.0171)^4}{32} = 8.39 \times 10^{-9}\ N$$

E. FABRICATION

The major components of the paint mixer which include the tank, support frames, agitator, discharge valve and electric motor were assembled into a unique solid structure by different joining methods like welding and fastening.

i. The vertically oriented cylindrical tank: This was made of 845.3mm height by 776.17 mm diameter, steel sheet. The steel sheet was cut, rolled to form a cylinder and the edges welded to seal.
ii. Baffles consisting of three equally spaced steel plates of 1.82mm thickness and 77.61mm width were welded to the inner walls of the vessel.
iii. Support frame was welded to the cylinder.
iv. Agitator: A high shear sawtooth impeller was fabricated from iron plate, cut at the edges and bent into alternating teeth of 5cm height and a total diameter of 23.5cm which was fastened firmly to the shaft which is a vertical steel rod using nut and bolt.
v. Two pulleys, one attached to the motor and another to the top of the shaft and a belt was used to deliver rotary motion to the agitator suspend in the tank.

vi. The shaft is supported on two horizontal frames 25cm apart with bearings attached at their point of contact to enable rotation of the shaft.
vii. The two horizontal bars are fastened to the vertical frames using nut and bolt.
viii. Product outlet: the bottom of the tank is fitted with a discharge tap.

Table 2: Materials Costing and Evaluation

S/N	Materials	Specifications	Quantity/Quality	Cost (₦)
1	Bearing		2	7,500.00
2	Bolts and nuts		10 units	1,500.00
3	Steel Angle Bar	3.5 inches	1 full length	3,500
4	Mild steel	16 Gauge	2 full lengths	80,000.00
5	Iron rod		½ length	1,600.00
6	Electric motor	2hp single phase	1	70,000.00
7	Pulleys	25mm, diameter	2	12,000.00
8	v-belt	Impregnated rubber	1	700.00
9	Cable		2 ½ length	900.00
10	Filling stone		1	1,200.00
11	Discharge valve		1	2,800.00
12	Transport			25,750.00
13	Frame	3x1.5 inches H-Channel	1 full length	20,500.00
14	Welding electrode	Gauge 12	Half pack	3,000
15	Paint	Oil paint	1	6,500
16	Filler			1,700
17	Mild steel (impeller blade)	14 Gauge	40mmx40mm	2,000
18	Flat bar	1 inches	1 full length	1,500
19	Sandpaper		5 cm long	500
20	Cutting stone		2	1,600
21	Labor cost			39,500.00
	Total		-	**280,650**

III. RESULTS AND DISCUSSION

A. DESIGN CALCULATIONS

The design and fabrication of a 300-litre paint mixing vessel were successfully completed, addressing the specific requirements and challenges associated with the paint manufacturing industry. The results of the study include the design specifications of the vessel, the fabrication process employed, and the evaluation of the vessel's performance.

The design specifications of the 300-liter paint mixing vessel were determined based on industry standards and specific requirements for paint manufacturing. The volume of mixing was assumed to be 75% of the total tank volume, equation (1) was used to get the total tank volume to be 400 litres.

The vessel dimensions, including height and diameter were optimized to accommodate the desired volume of paint and ensure proper mixing action. A flat-bottom cylindrical tank was designed. The length of a full mild steel plate was taken to be the circumference of the cylinder and used to get the diameter using equation (2) the diameter was gotten to be 0.77617m. The volume of the tank is related to the height of the tank equation (3) was used to calculate for the radius which was 0.3881m. Since the tank was cylindrical, the value gotten from equation (3) was substituted into equation (4) to get the height of tank of 0.8453m. Using the mixing volume which is 300 litres, equation (5) was used to calculate the mixing capacity height which was gotten to be 0.6340m.

Baffles were incorporated into the vessel design to enhance mixing efficiency by minimizing swirl and improving fluid flow patterns. The width of baffle was taken to be one-tenth of the vessel diameter, equation (6) was used and the width of baffle was given to be 0.0776m and the length of the baffle was taken to be the total height of the vessel which was 0.8453m.

The impeller design, including the blade shape, and size, was carefully chosen to achieve efficient mixing and dispersion of raw materials. The diameter of the impeller disk was calculated using equation (7) and 0.2329m was gotten to be the value.

Equation (8) was used to calculate the impeller power to be 0.7925hp but 90% loading of the motor was assumed and this was used to find the minimum horsepower using equation (9). The minimum horsepower at 90% was calculated to be 1.0hp and this was taken to be the actual power required to drive the impeller. The impeller speed was calculated to be 131.4rpm from equation (10).

The continuous torque for the shaft was calculated to give 54.21Nm from equation (11), and the design torque input was calculated using equation (12) to be 54.21Nm considering a service factor of 1. The maximum force on shaft was obtained as 105.80N from equation (13). The general formula for diameter of the solid shaft is equation (14) with an assumption of little or no axial loading, and considering the allowable shear stress, torsion and bending moment on the shaft, but since the bending moment was zero, equation (15) was derived and a value of 0.0171m was gotten as the shaft diameter after using equation (16) to calculate for the value of torsional moment which was gotten to be 54.21Nm. Moment of inertia of the shaft was calculated to be 8.32 $\times 10^{-9}$ N from equation (17)

B. MATERIAL SELECTION

Material selection for the vessel construction was based on compatibility with paint ingredients and resistance to corrosion or chemical reactions.

The materials selected for the construction of the 300L paint mixer and their costs are listed in table 4.2. Paint has anti-rust properties and because of this mild steel was chosen as the primary material for the vessel construction due to its high strength, durability, weldability and low cost.

The material thickness was determined to ensure structural integrity and meet safety standards. A 3x1.5 inches H-channel was used for the frame of the mixer due to it strength and durability. A 2 hp electric motor was specified for the mixer because the power required by the impeller alone was 1 hp; the extra power of the motor is to handle external loads like the weight of the shaft, pulley weight and friction from the bearings. This will prevent the motor from overheating and getting damaged when the mixer is operated for a very long period. Two pulleys and a v-belt were used to transmit rotary motion from the electric motor to agitator shaft because this method of transmission is lighter, cheaper and easier to construct and maintain than mechanical gears. Nuts and bolts were used to assemble the shaft, motor and supporting beams on the frame to make them easily detachable during maintenance and to enable replacement of the components. Discharge valve was attached to the mixer to help in removing the paint after production. All the materials were locally sources and the cost of production was Two Hundred and Eighty Thousand Six Hundred and Fifty Naira Only (₦280, 650.00).

C. EVALUATION PERFORMANCE

The performance of the fabricated 300-liter paint mixing vessel was evaluated through rigorous testing and analysis. Mixing experiments were conducted using representative paint formulations to assess the vessel's ability to achieve uniform dispersion of raw materials.

The variable considered was time. The paint mixer produced 300 litres of paint in about 30 minutes, 20 minutes for production and 10 minutes for discharging compared to the conventional hand mixing method which takes about 1 hour to produce one batch i.e. 200 litres of paint. The paint was applied in the Student's Affairs building as well as departmental offices.

The results demonstrated that the designed and fabricated paint mixing vessel met the desired performance criteria. The vessel exhibited efficient mixing characteristics, with uniform dispersion of pigments, binders, solvents, and additives. The mixing time was optimized, reducing production cycle time and improving overall productivity. Power consumption was minimized, resulting in energy savings and cost efficiency.

Fig 2: The Fabricated paint mixer

Fig.3: The paint mixer discharging paint after production

Fig.4: One batch of paint produced by the paint mixer

IV. CONCLUSION AND RECOMMENDATIONS

A. CONCLUSION

In conclusion, this project, Design and Fabrication of a 300 litre Paint Mixing vessel was achieved, and the following was gotten:

i. A cylindrical mixing chamber with mixing capacity of 300 litres was fabricated using mild steel.
ii. A 22.9mm diameter sawtooth high shear impeller gotten from mild steel was used to fabricate the agitator.
iii. 2 hp AC motor was specified for the paint mixer.
iv. The cost to produce the paint mixer was evaluated to be Two Hundred and Eighty Thousand Six Hundred and Fifty Naira Only (₦280,650).
v. The performance of the paint mixer showed it was efficient as it was used to produce high quality paint.

Through this project we have come to the conclusion that the design of an industrial mixer is a standard procedure that one needs to follow. Thus, a mixing station can be designed based on the process requirements by following the standard procedure by having ample knowledge concerning the process.
The design has been able to tackle the problems of mixing paint locally by hand and by manually operated machines, which are not only primitive but both time and energy consuming. Further research could improve and reduce the common errors to the minimum allowable limit.

B. RECOMMENDATIONS

The following are recommended:

i. Adequate measurement of the mixing ratio should be made to enhance mass production.
ii. Future designs of the paint production machine should include a viscometer for monitoring the viscosity, as well as a heating element so that the machine will be able to produce other forms of paint aside from emulsion paint.
iii. An automatic feeder system can be put in place to improve speed and efficiency of the production process especially on a large scale.

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