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Design and Construction of an Electrically Operated Paint Mixing Machine

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Author's contribution

The sole author designed, analyzed and interpreted and prepared the manuscript.

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ABSTRACT

An electrically operated paint-mixing machine was developed. The machine consisted of a mixing drum with a capacity of 30.6 L. The test was carried out by mixing 25%, 50%, and 75% of the total mixing capacity of the machine, and the time taken for the constituents to be thoroughly mixed were recorded. The mixer member (agitator) was used to mix the paint components by the use of an electric motor. For easy mixing of denser paint components i.e. paints with high viscosity, particularly oil-based (or enamel) paint, a hydraulic lift, with a travel height (distance) of about 40 cm, was introduced to move the mixing disc vertically in the upward (up to a height of 19 cm above the drum) and downward direction (up to a height of 15 cm above the bottom of the drum) to prevent clogging of the paint components while mixing. The hydraulic mechanism also allows the operator to remove the drum after mixing as well as to install the drum in place before starting the mixing operation. The machine was powered with a 0.74 hp (550 W) electric motor, which transmitted the rotary motion of the driving component through a V-belt to the driven component which was supported with two bearings. The test results obtained from the running of the machine showed that the time taken to mix thoroughly 30.6 L of paint constituents was 102 minutes. This was done to study the reliability and the time taken to accomplish the thorough mixing of the paint components. To achieve this, the volume of paint constituents (L) ranged from 10.2 L at 35 minutes to 30.6 L at 102 minutes. This finding elucidates the ability 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, and as well serves as an innovation in the paint industry.

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1. INTRODUCTION

The will to create different colors is as old as time. The importance of color has throughout history been significant on many different levels, mostly it has served as a way for living organism to signal something to its surroundings [1]. From prehistoric times, humans have left an imprint on their environment in the form of painted images, which both beautified their world and expressed their thoughts and feelings. It may be that primitive man scratched trees or rocks with stones as a way of identifying a track, indicating a source of food or water, or even marking territory.

At some stage, however, humans discovered that pigments worked more effectively when mixed with a medium such as water or saliva, and painting was born [2]. Paint is one of the oldest synthetic substances known, with a history stretching back into prehistoric times [3].

Paint is a mixture composed basically of solid coloring matter (the pigment) and liquid (the vehicle). It is applied as a coating to various types of surfaces, including dwellings, public buildings, factories, bridges, ships, and storage tanks. The purpose of coating may be decorative, as in beautifying of objects and provision of aesthetics; protective, as in preservation against weather, moisture, solar radiation, chemicals, and mechanical damage; or functional, as in communication of an impression. It serves utility and art purposes [4]. Paint production is an important process which has wide applications in several fields. Paint is a term used to describe a number of substances that consist of a pigment suspended in a liquid or paste vehicle such as oil or water [5].

The manufacture of paint involves mixing, dispersion, thinning, adjustment and filling. Each of these steps may be accomplished separately, or two or more of them can be accomplished together in one piece of equipment. All the pigments are mixed in a tub with the help of rotating blades. The particles are wetted with vehicle, and the flocculated aggregates are eliminated [4]. Process industries like chemical plants, food processing plants, paint industry etc. largely employ mechanical mixers to carry out mixing of powders, semisolid jelly fluids etc. [6]. Paints can be produced at the cottage, small, medium, and large-scale levels. Some of the machines required for operations include roller mills, sand mills, attrition mixers, etc. An electric manual mixer is one of the most important machines used in paint production [7].

Paint mixing is mostly done locally by hand or by stick, or by manually operated machines which involves moving a lever to turn the shaft on which the agitator is attached, which mixes the paint. These local methods of mixing paint are not only primitive, but time and energy consuming. Hence, the need for an electrically operated paint mixing machine.

The specific objective of this project is to design and construct an electrically operated paint mixing machine. Other objectives of this project include:

- To construct a relatively cheap and affordable paint mixing machine.
- To create employment opportunities for individuals who desire to be self-employed in the area of paint mixing and production, and hence reduce the unemployment rate in the society.
- To preserve the foreign exchange rate which would have been used to buy the foreign made machine.

An importance of the study is to eliminate hydrocarbon products like petrol and its derivatives from environmental pollution.

2. MATERIALS AND METHODS

In the design of the paint mixing machine, the following factors were considered:

- Stress induced on the shaft when subjected to torsion
- The strength and rigidity of the shaft when transmitting power under various operating and loading conditions
- The amount of power to be transmitted to the shaft through the electric motor
- The reliability of the machine, durability, and its safety during use
- The type of manufacturing processes to be employed at low cost of production
- Versatility, portability, and ease of maintenance of the machine

2.1 Design Calculations

2.1.1 Capacity of the mixing drum

This can be determined from the relation below

$$v_d = \frac{\pi d_d^2 h}{4} \quad (1)$$

Where,

d_d = 38 cm
h = 36 cm

Therefore, the volume of the drum,

$$v_d = \frac{\pi \times 38^2 \times 36}{4}$$

= 40828.138 cm^3
= 0.0408 m^3

This is the total capacity of the drum. The mixing capacity of the drum is taken as 75% of the total capacity, and it is calculated as,

$$v_m = {}^3/_4 \times 0.0408$$

= 0.0306 m^3 = 30.6 L

2.1.2 Speed of the agitator (impeller)

$$\frac{D_S}{D_L} = \frac{N_L}{N_S} \quad (2)$$

Where,

D_S = 68 mm
D_L = 160 mm

Speed of motor (N_S) = 1400 rev/min

Thus, to determine the speed of the agitator, we have

$$\frac{68}{160} = \frac{N_L}{1400}$$

Therefore, $N_L = 595$ rev/min

2.1.3 Electric motor sizing

i. Power transmitted by the motor:

$$P_o = \frac{1.73\eta_m \times P_i \times \cos\phi}{1000} \quad (3)$$

Where P_i = 550 W (0.74 hp) = Rated power of the electric motor

The standard efficiency of a 1 hp motor is about 75%. Thus, an electric motor of 0.74 hp will have an efficiency of 55.5% i.e. η_m = 55.5% = 0.555

The power factor of the motor is given as 0.71 i.e. $\cos\phi$ = 0.71

Thus, to determine the power transmitted by the motor, we have

$$P_o = \frac{1.73 \times 0.555 \times 550 \times 0.71}{1000}$$

= 0.375 kW

ii. Torque transmitted by the motor:

$$T = \frac{60P_o}{2\pi N_S} \quad (4)$$

Where,

P_o = 0.375 kW = 375 W

N_S = 1400 rev/min

Therefore, $T = \frac{60 \times 375}{2\pi \times 1400}$

= 2.56 N-m = 2560 N-mm

2.1.4 Belt design

Table 1. Dimensions of standard V-belts

Type of belt	Thickness (mm)	Top width (mm)
A	8	13
B	11	17
C	14	22
D	19	32
E	23	38

Source: (Khurmi and Gupta, 2015)

Speed of the belt:

$$v_s = \frac{\pi D_S N_S}{60} \quad (5)$$

i.e. $v_s = \frac{\pi \times 0.068 \times 1400}{60}$

= 4.985 m/s^2

Length of belt:

$$L = \frac{\pi}{2}(D_L + D_S) + 2x + \frac{(D_L - D_S)^2}{4x} \quad (6)$$

Where,

$x > 2(D_L + D_S)$

i.e. $x > 2(160 + 68)$
∴ $x > 456$ mm

Hence, let x = 500 mm (it is assumed that space is available)

Thus, to determine the belt length, we have that

$$L = \frac{\pi}{2}(160 + 68) + 2(500) + \frac{(160 - 68)^2}{4 \times 500}$$

= 1362.37 mm

As a guideline, to take into consideration the initial tension, the belt length is shortened by 1%. Hence, the required belt length,

L_o = 1348.75 ≅ 1350 mm

Angle of wrap:

$$\alpha = \sin^{-1}\left(\frac{D_L - D_S}{2x}\right) \quad (7)$$

$$\alpha = \sin^{-1}\left(\frac{160 - 68}{2 \times 500}\right)$$
= 5.28°

Now, from the relation below

$$\theta = (180 - 2\alpha)\frac{\pi}{18\ 0} \quad (8)$$

We can therefore determine the angle of wrap as

$$\theta = [180 - 2(5.28)]\frac{\pi}{180}$$
= 2.96 rad

Design power:

$$P_d = C_s \times P_o \quad (9)$$

Where,

P_o = 391 W

For agitators for liquids, blowers, exhausters etc. The service factor for the belt for normal service is taken as 1.1 i.e. C_s = 1.1

Thus, the design power becomes,

$P_d = 1.1 \times 391$
= 430 W

Width and thickness of belt:

$$P_d = bt(\sigma_d - \rho v_s^2)\left(1 - \frac{1}{e^{\mu\theta}}\right)v_s \quad (10)$$

Where,

P_d = 430 W

The design stress for a rubber belt may be considered as 1.7 MPa. Similarly, density of belt is 1000 kg/m^3. Also, for a rubber belt, the coefficient of friction may be taken as 0.42.

i.e. σ_d = 1.7 MPa and
ρ = 1000 kg/m^3
μ = 0.42

Thus

$$430 = bt\left(1.7 - \frac{1000 \times 4.985^2}{10^6}\right)\left(1 - \frac{1}{e^{0.42 \times 2.96}}\right)4.985$$

∴ $bt = \frac{430}{5.94}$

= 72.39 ≅ 72 mm^2

From Table 1, a type A belt of standard thickness, t = 8 mm, and width, b = 13 mm is selected as its area is the closest to the calculated area.

Thus, a type A leather belt of 8 mm thickness, 13 mm width, and 1350 mm length satisfy the design condition.

2.1.5 Design of the agitator shaft

Diameter of the shaft:

The turbine shaft is subjected to twisting (torque) moment only due to the shaft rotation. As a result, the shaft is designed based only on the twisting moment.

In actual sense, the shaft is subjected to fluctuating torque, and one must take into account the combined shock and fatigue factors for the computed torque [8]. Table 2 below shows recommended values for combined shock and fatigue factors for shafts subjected to torsion. Thus, to design the shaft, subjected to fluctuating torque, we use the following relation.

$$T = \frac{\pi}{16} \times \tau \times d_s^3 \quad (11)$$

Where,

T = 2560 N-mm
τ = 40 MPa (for commercial steel shafting with keyway)

Thus, to determine the shaft diameter, we have

$$2560 = \frac{\pi}{16} \times 40 \times d_s^3$$

$$\therefore \quad d_s = \sqrt[3]{\frac{2560 \times 16}{40\pi}}$$

= 6.88 mm ≅ 7 mm

From Table 2, taking the torsion factor to be one for a rotating shaft subjected to heavy shock due to the vibration created by the rotary speed of the electric motor, the diameter of the shaft then becomes

$d_s = 7 \times 3.0$ = 21 mm

This is the calculated shaft diameter. The actual shaft diameter used for the design is taken above the calculated shaft diameter to be 30 mm

i.e. Actual diameter of shaft, d_a = 30 mm

i. Weight of the shaft:

With the shaft diameter already determined and given that the length is known to be 1040 mm, the weight of the shaft can be calculated as

$$v = \frac{\pi d_a^2 L}{4} \tag{12}$$

Where d_a = 30 mm = 0.03 m
L = 1040 mm = 1.04 m

Therefore, $v = \frac{\pi \times 0.03^2 \times 1.04}{4}$
= 0.000735 m^3

Now, from the expression below

$$m_s = \rho_s v \tag{13}$$

Where, ρ_s = 7700 kg/m^3 for stainless steel

Thus, mass of shaft $m_s = 7700 \times 0.000735$ = 5.66 kg

Now, the weight of the shaft is obtained as

$$W_s = m_s g \tag{14}$$

$= 5.66 \times 9.81$

= 55.53 N

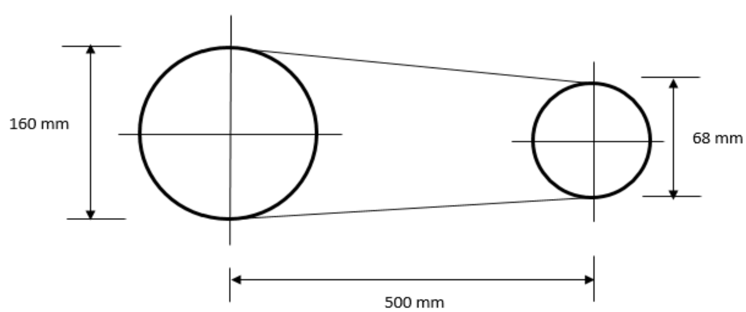

Fig. 1. Length of an open belt drive

Table 2. Recommended values for combined shock and fatigue factors for shafts subjected to torsion

Nature of load	**Combined shock and fatigue factors for torsion**
1. Stationary shafts	
a)Gradually applied load	1.0
b)Suddenly applied load	1.5 to 2.0
2. Rotating shafts	
a)Gradually applied or steady load	1.0
b)Suddenly applied load with minor shocks only	1.5 to 2.0
c)Suddenly applied load with heavy shocks	2.0 to 3.0

Source: (Khurmi and Gupta, 2015)

2.1.6 Design of the mixing disc

Area of disc:

$$A_a = \frac{\pi d_a^2}{4} \quad (15)$$

Where d_a = 160 mm = 0.16 m

Thus, to determine the area of the disc, we have

$$A_a = \frac{\pi \times 0.16^2}{4}$$
$$= 0.0201 \text{ m}^2$$

Volume of disc:

$$V_a = A_a \times t_a \quad (16)$$

Where,

A_a = 0.0201 m^2
t_a = 2 mm = 0.002 m

Therefore, the volume of the disc is gotten to be

$$V_a = 0.0201 \times 0.002$$
$$= 6.03 \times 10^{-5} \text{ m}^3$$

Design specifications:

The paint mixing machine was to be powered with a three phase (3∅) electric motor of 550 W (0.74 hp), 220 V, and 2.8 amps. rating, and an engine speed of 1400 rev/min. The speed of the mixing disc (blade) is 595 rev/min, and the equipment was to have the capacity to produce 30.6 L of paint in a single mix.

2.2 Material Selection and Construction Details

The selection of materials for the different parts of the paint mixing machine depends on the strength or tension/compression the components can withstand [9]. Table 3 below shows the materials chosen for each component of the paint mixer, and their fabrication methods. The estimated cost for each component are as well shown below in Table 4.

Table 3. Material selection and the fabrication methods for the components of the paint mixer

S/N	Components	Material(s) used	Fabrication method
1.	Impeller shaft	Stainless steel	Machining
2.	Pulleys	Cast iron	Cast
3.	Belt	Rubber	–
4.	Frame	Galvanized mild steel	Cutting & welding
5.	Mixing drum	Plastic	–
6.	Agitator	Stainless steel	Cutting & welding
7.	Pillow block bearings	Cast steel	–

Table 4. Bill of engineering measurements and evaluation for the paint mixer

S/N	Component description	Cost (₦)	Cost ($)
1	Belt	250	0.65
2	Electric motor	8000	21.00
3	Hydraulic system	33000	85.00
4	Hydraulic oil	1500	4.00
5	Hydraulic cylinder	9000	23.10
6	Bolts, nuts, and washers	750	2.00
7	Control box	6000	15.50
8	Bearings	3000	8.00
9	Stainless steel shaft	11000	28.50
10	Mild steel sheet	4000	10.30
11	Others	38200	98.00
	Total	**114,700**	**296**

2.2.1 Assembly details of the paint mixer

The components of the paint-mixing machine were assembled as follows:

- The electric motor was mounted to its seat prepared at the top of the machine frame
- The bearings were bolted in position at the top of the frame
- The mixing shaft was then force fitted into the selected bearing
- The small and large pulleys were fitted to the shaft of the electric motor and the mixing shaft respectively
- The constructed mixing disc was welded to the terminal end of the mixing shaft
- The V-belt was connected to the pulleys (to transmit rotary motion from the electric motor to the mixing shaft), and tensioned accordingly
- The top frame housing the belt and pulley components, on which the electric motor is mounted, was bolted to the female shaft of the hydraulic cylinder, which is attached to a hydraulic motor with a lever connected to it that allows for the upward and downward movement of the top frame
- All sharp edges of the machine were grounded and smoothened before the machine was finally painted.

3. RESULTS AND DISCUSSION

The test performed on the machine was done by mixing separately 25%, 50%, and 75% of the total mixing capacity of the mixing drum of the machine, and the time taken for the constituents to be thoroughly mixed in each mix was recorded. This was done to study the reliability of the machine as well as how long it takes the machine to achieve thorough mixing of the paint components. The paint components used for this test are for the oil-based (or enamel) paint, which is one of the two classes of paint; the other being the water-based (or emulsion) class of paint. The oil-based paint is slow drying and highly viscous compared to the water-based paint. Table 5 shows the test results obtained from each mix.

Table 5. Test results obtained from the running test

Test	Volume of constituents (L)	Time of mixture (min)
1	10.2	35
2	20.4	66.5
3	30.6	102

A graph of Volume of paint constituents v against Time t can be plotted below as follows Fig 2.

The table of results (Table 5) shows that the time taken for each test only increases exponentially, which clearly is as a result of the increase in the volume of the paint constituents. In the first test, it took 35 minutes to achieve a thorough mix, while almost doubling that amount in the second test. The third test brought the time taken for a thorough mix to 102 minutes (1 hour and 40 minutes). This continuous increase in the time taken due to the similar increase in the volume

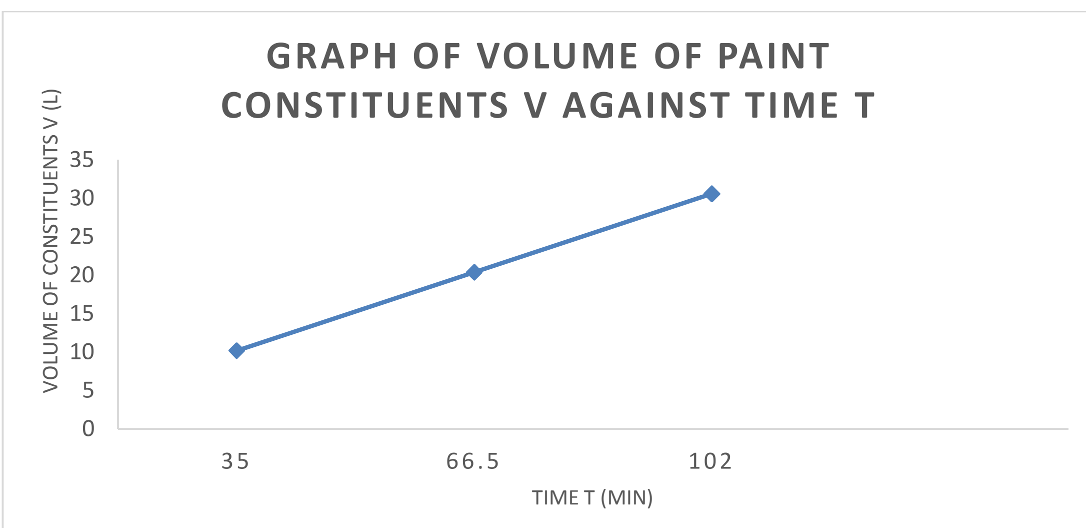

Fig. 2. Performance curve

of the paint constituents resulted in a straight line curve (Fig. 3), while also revealing a factor which is the constant rotational speed of the machine, although this was not an issue as all the paint constituents were thoroughly mixed within a not so long period. Dividing the test into three sections gave an idea of how long it takes to mix specific volumes of the paint constituents. In conclusion, the results obtained show that at a mixing speed of 595 rev/min, the paint mixing machine takes about 102 minutes to mix thoroughly 30.6 L of the paint constituents which is the mixing capacity of the drum.

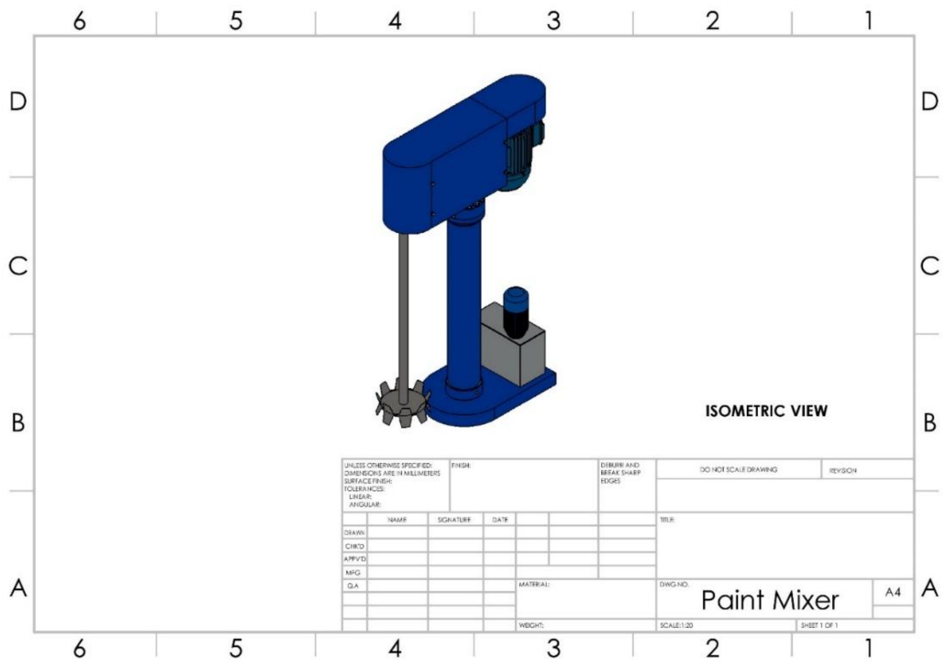

Fig. 3. Paint mixer assembly

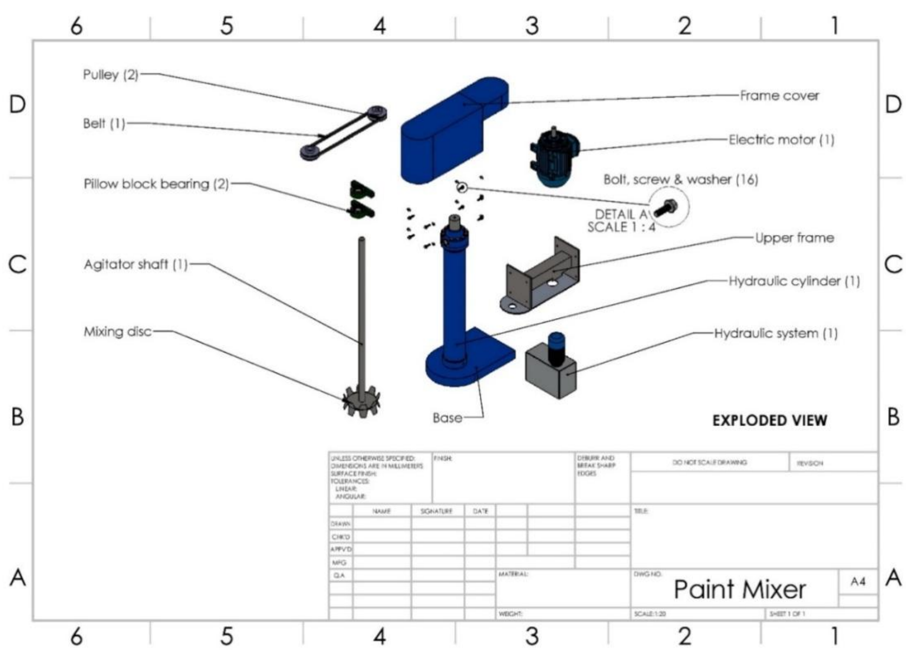

Fig. 4. Paint mixer (exploded view)

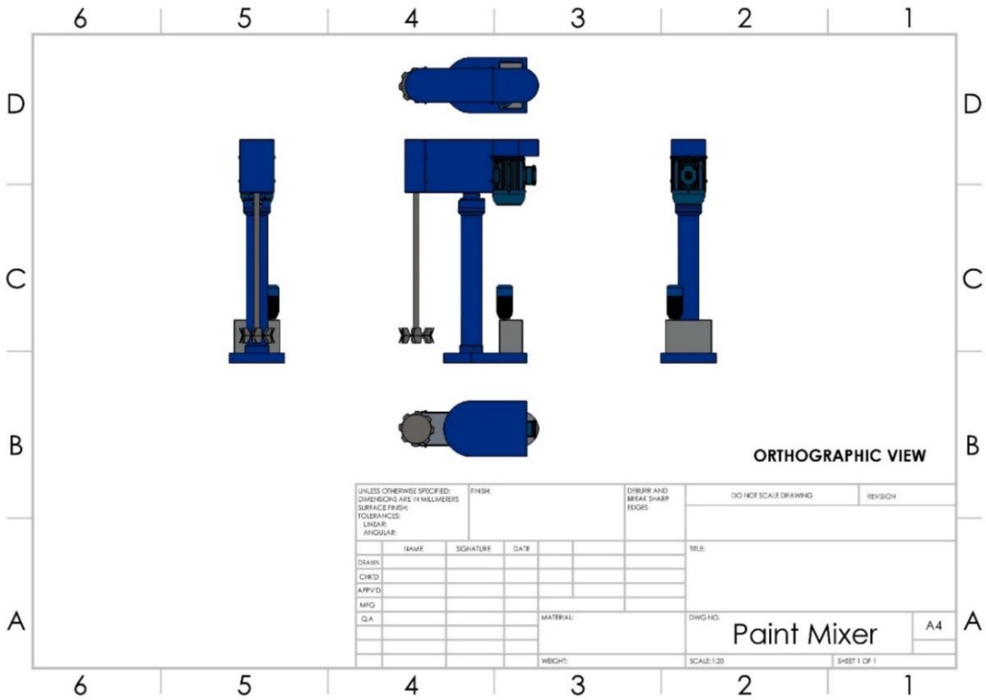

Fig. 5. Paint mixer (orthographic view)

4. CONCLUSION

An electrically operated paint mixing machine (or paint mixer, for short) has been designed and tested using Solid Works CAD software package. The machine was fabricated from mild steel and stainless steel, and the joining of metal to metal was purely by bolts and nuts, and welding processes.

The results obtained from the test carried out show that the machine takes about 102 minutes to thoroughly mix 30.6 L of paint constituents, and this is accomplished with a single push of a button.

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. The introduction of a hydraulic lift makes the design a unique one, making it relatively easy to mix paints like gloss (or enamel) paints with high viscosity by moving the mixing disc upward (up to a height of 19 cm above the drum) and downward (up to a height of 15 cm above the bottom of the drum) to prevent clogging and allow for easy mixing of the paint components. The hydraulic mechanism also allows the operator to remove the drum after mixing as well as to install the drum in place before starting the mixing operation.

The parts of the machine are readily available in the market. It is electrically safe and easy to operate. It is versatile, and thus can be used not only for paint mixing but also for mixing of other products like soap, beverages etc.

COMPETING INTERESTS

Author has declared that no competing interests exist.

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