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DEVELOPMENT OF A 50-LITRE BATCH CAPACITY INDUSTRIAL MIXER

Ikechukwu Celestine Ugwuoke
Department of Mechanical Engineering,
Federal University of Technology, P.M.B 65,
Minna, Niger State, Nigeria.

Abstract— **This work focused on the development of a 50-litre batch capacity industrial mixer using locally sourced material. The essence is to produce an industrial liquid mixer that is relatively cheap and easily affordable. The design is simplified in such a way that limits operational hazards. The development of the machine involved the use of simple fabrication techniques and methods for each component part so as to eliminate unnecessary complexity, for ease of maintenance. The electric motor capacity is 0.5hp. Calculation results gave the volume of vessel as 70.372litres, the total tension on the belt as 1033.063N, the force acting on the impeller as 197.867N, the power required to drive the 2 impellers as 22.694Watts (0.0304hp), the belt length as 254.435mm, the minimum length of the shaft as 760mm, the equivalent bending moment acting on the shaft as 142.603Nm, the equivalent twisting moment acting on the shaft as 71.371Nm, the shaft diameter as 20.5mm. Performance testing shows that the machine performed well as expected. The highly homogeneous product obtained during testing proves the viability of the machine and is indicative of the overall efficiency of the machine.**

Keywords— **Development, Batch Capacity, Industrial Mixer, Locally Sourced Material, Relatively Cheap, Easily Affordable**

I. INTRODUCTION

Mixers are equipment's used to prepare a uniform combination of two or more substances. Mixers are used in mixing operations which is a common operation in processing and production industries. It may involve the mixing of solids, liquids or gases in any possible combination involving two or more of the above. Mixing is an operation carried out to bring about homogeneity, reduce non-uniformities and gradients in properties such as concentration, color, texture or taste between different parts of a system. The mixing or agitation of liquids, solids and to a lesser extent, gases is one of the commonest of all operations in processing industries. Of the possible combination of these states, those of principal interest are liquid-liquid mixtures, solid-solid mixtures and liquid-solid mixtures or pastes. There are two types of patterns produced by a typical mixer simultaneously: radial mixing and flow division. In the first case, rotational circulations of a processed material around its own center causes the radial mixing. Processed material is inter mixed to reduce or eliminate radial gradients in temperature, velocity and material composition. In the case of flow division, a processed material divides at the leading edge of each element of the mixer and follows the channels created by the element shape. This work focused on the development of a 50-litre batch capacity industrial mixer with the following objectives:

1) To design, fabricate and test a portable 50-litre batch capacity industrial mixer
2) To fabricate the industrial liquid mixer using locally sourced materials.
3) To produce an industrial liquid mixer that is relatively cheap and easily affordable.

The market today has seen most manufacturing industries demand for industrial mixers that possess improved efficiency, faster operation and availability. There has also been a need for Industrial mixers that have been seamlessly designed with characteristic smooth surfaces that not only prevent batch contamination, but also support increased mixing efficiency.

II. REVIEW OF RELATED LITERATURE

A. Background to the Study

Mixing is one of the most common operations carried out processing and allied industries. The term mixing is applied to the process used to reduce the degree of non-uniformity or gradient of a property, such as concentration, viscosity, temperature etc. in a system. It is a critical process because the quality of the final product and its attributes are derived by the quality of the mixer. Improper results in a non-homogenous product that lacks consistence with respect to the desired attributes like chemical composition, color, texture, reactivity and particle size. The wide variety and ever increasing complexity of mixing processes encountered in Industrial applications require careful selection, design and scale up to ensure effective and efficient mixing. Improved mixing efficiency leads to a shorter batch cycle time and operational costs. Today's competitive production line necessitates robust equipment's that are capable of fast blend times, lower power consumption, equipment flexibility, ease of cleaning and a gamut of customized features. In addition to blending components, many moderate mixers are designed to combine different process steps in single equipment. Examples include coating, granulation, heat transfer, drying, etc. The type of operation and equipment used during mixing depends on the state of materials being mixed (liquid, semi-solid or solid) and the miscibility of the materials being processed. In this context, the act of mixing may be synonymous with stirring or kneading processes.

Liquid-Liquid mixing occurs frequently in process engineering. The nature of liquids to blend determines the equipment to be used. Single phase blending or mixing tends to involve low-shear, high flow mixers to cause liquid engulfment, while multi-phase mixing generally requires the use of high-shear, low –flow mixers to create droplets of one liquid in laminar, turbulent or transitional flow regimes, depending on the Reynolds's number of the flow. Turbulent or transitional mixing is frequently conducted with turbines or impellers; laminar mixing is conducted with helical ribbon or anchor mixers. Mixing of liquids that are miscible or at least soluble in each other occurs frequently in process engineering (and in everyday life). An everyday example would be the addition of milk to coffee. Since both liquids are water-based, the dissolve quickly and easily in one another. The momentum of the liquid being added is sometimes enough to cause enough turbulence to mix the two, since the viscosity of both liquids is relatively low. If necessary, a spoon or paddle is used to complete the mixing process. Mixing in a more viscous liquid, such as honey, requires more mixing power per unit volume to achieve the same homogeneity in the same amount of time. At an industrial scale, efficient mixing can be a bit more difficult to achieve. A great deal of engineering effort goes into designing and improving mixing processes. Mixing at industrial scale is done in batches, inline or with the help of static mixers.

Adejobi and Achoga [15], designed and built a paint mixer. In this design a 2hp electric motor running at 1430rpm was employed as the prime mover. Power from the motor is transmitted to a 30mm mild steel shaft to rotate the impeller by a v-belt drive with a velocity ratio of 1:1. One pulley is mounted on the motor while the other is mounted on the shaft. With an optimal capacity of 136 kg/hr. This design has an efficiency of 97.2% when producing emulsion paint with the stirrer running at 1430 rpm. All materials used in the fabrication of this machine were sourced locally. The vessel was made from galvanized steel and is supported by a frame built from 3mm thick angle iron.

Emezora [16], designed and built a manually powered liquid industrial mixer for small scale liquid mixing. In this design, a stainless steel impeller is keyed to a solid shaft which was axially mounted in a vertical cylindrical tank and rotated by a bevel gear keyed to the other end of the shaft. This meshes with another bevel gear which transmit the motion produced by the manual rotation of an attached handle with a speed ratio of 1.63:1. The mixing vessel was made from galvanized sheet of 3mm thick and has discharge spout located at its base for easy discharge of the homogeneous liquid.

Uhi and Gray [13], proposed a design for a 300-litre batch capacity industrial mixer in which a centrally mounted agitator was employed. In this design, a sprocket is keyed to the upper end of the impeller shaft. The prime mover is an electric motor mounted adjacent to the shaft with a sprocket keyed to it. A high steel roller chain transmits rotary motion from the electric motor to the impeller shaft through the sprocket. The mixing chamber is mounted on another prime mover (a geared electric motor), responsible for rotating the drum in a direction opposite to the direction of impeller rotation. A couple transmits rotary motion from the reduction gear system to the mixing chamber. The ratio of the sprocket mounted on the impeller to that of the electric motor is 1:2. The speed of the electric motor is 1380rpm and that of the impeller shaft was 690rpm. Galvanized sheet of 2.5mm thickness was used for the drum, for the structural frame "I" beam rods, "U" channel rods and an angle iron was used. The shaft is solid and made from mild steel while the impeller is made from 4mm thick galvanized steel. The design has an efficiency of 80%.

PRODA (Projects Development Institute, Nigeria.) designed a 500litre batch mixer model with paddles staggered at different distances and angles on a solid shaft which is mounted vertically at the center of the mixing chamber. The clearance between the paddles of the impeller and the chamber wall was 3mm. a pulley is keyed to the prime mover which was mounted adjacent to the drum and the shaft. The power of the electric motor is 4hp and the speed is 1400rpm. A pulley ratio of 1:2 was employed to reduce the shaft speed to 700rmp. The discharge spout was located at the bottom end of the mixing chamber for releasing the product. A mild steel rod was used to produce the solid cylindrical shaft, a stainless steel sheet of 10mm thickness was used to produce the mixing chamber, a "U" channel rod and angle channel was used to fabricate the frame. The mixing time of 15 minutes and an efficiency of 87% was achieved.

Chukwudebelu and Chuka [17] designed and built an industrial liquid mixer. In this design an anchor impeller mounted centrally in a 250litres mixing tank was employed for industrial mixing. The clearance between the anchor impeller and the tank wall is 2mm. A flange couple was used to transmit rotary motion from a 1.5hp electric motor to the mild steel shaft. The shaft rotates with the same speed of the motor at 930rpm. A spout located at the center of the tank bottom facilitates product discharge. The tank was made from 3mm thick galvanized steel sheet. The design has an efficiency of 75% with a mixing time of 12 minutes.

Morka [18] designed and built a 50 litres double shaft rotary mixer for liquid mixing using a 0.35hp electric motor as its prime mover. Each shaft was mounted on a bearing mm apart. A spur gear mounted on the electric motor shaft with a flange couple, drives the two impeller shafts through a configuration of two other spur gears with an equal speed reduction ratio of 1:1 in opposite directions. The motor speed is 910rpm. The drum is made from a 3mm galvanized steel sheet and mounted on a frame built from mild steel angle rods. The mixing time of 12 minutes with an efficiency of 75% was achieved.

Mohtasim, Prasad, and Shreyans [12] built a 200litre portable industrial mixer; each component of the set-up was designed and analyzed using the finite element analysis (FEA) software packages, Solidworks and ANSYS workbench. In this design, a 0.35hp electric motor drives a hollow shaft and dual 45° pitch blade turbine impellers assembly at a speed of 400rpm. The electric motor was axially mounted and secured to a support frame built from 1.5′ × 1.5′ mild steel box pipe using 4×M10 bolts and 4×M8 bolts. Aluminum 6063 T3 alloy was selected as the shaft material.

B. Types of Liquid Mixers

Agitators

A common example is the central agitating blade in a top-loading washing machine. It remains stationary on its center axis, agitating water and cloths with its paddles as it turns. Agitators in food and industrial product processing may have similar configurations, or they may be removable agitating rods which are placed in a substance only long enough to properly agitate it. Agitators are used in liquids, as agitation is not as effective with thick, highly viscous materials.

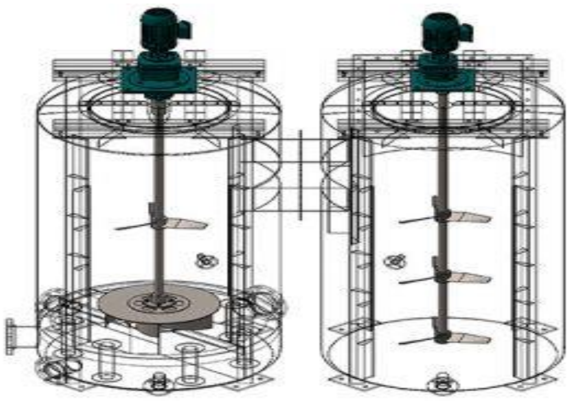

Fig. 1. Agitators

Static/Inline Mixers

These smart piece of equipment have no moving parts. Carefully designed ribbon-like obstructions are placed inside a cylinder through which liquid flows. As the liquid flows through, the obstruction inside cut the flow of the liquid, forcing it to mix and blend together. Inline mixers may be attached to flow tubes to enhance a liquid’s homogeneity without requiring power or servicing to moving parts.

Fig. 2. Static Mixer

Homogenizers

Homogenizers aim to produce a homogenous substance out of mixing a heterogeneous liquid with another liquid. They do this by impingement-radical force and strong pressure. Materials are broken down and blended completely afterwards. Homogenizers contain shearing blades positioned at a vertical axis that work rapidly inside an enclosed container.

Fig. 3. Homogenizer

C. Components of the Liquid Mixer

The liquid mixer basically consists of the following:

1) The shafts
2) The impellers
3) The vessels or tanks

Liquid Mixer Shafts

These are the connecting rods that hold the electric motor with a belt. The diameter of the shaft varies with the point of attachment in the driving motor and the length of the shaft varies with the height of the vessel. Shafts are used to transmit an induced motion from the driving motor to the impeller arrangement.

Fig. 4. Liquid Mixer Shaft

Liquid Mixer Impellers

These are usually in form of flat blade turbine type either centrally located in the vessel, or nearer to the bottom entry of the required material. These can either be radial or axial depending on the angle of inclination of the impeller blade with the plane of the impeller rotation.

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Fig. 5. Liquid Mixer Impellers

Radial Flow Impellers-These types of impellers are typically available in 4 or 6 blade designs. They are known to provide more shear and less flow per unit of applied horsepower than axial flow designs, and in comparison, radial flow impellers do not have a high tank turnover flow. They are sensitive to viscosity, which makes them an excellent impeller in dispersion applications like pigment paste or caulking compounds.

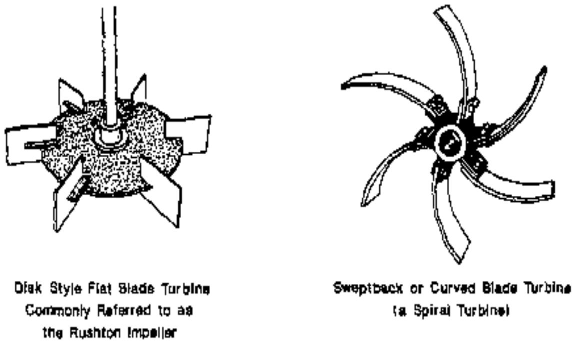

Fig. 6. Radial Flow Impellers

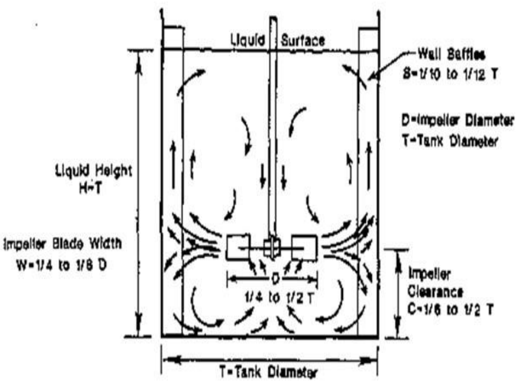

Fig. 7. Direction of Motion of Radial Flow Impellers

Axial Flow Impellers-They have an up and down flow pattern, ideal for applications where solid suspension or stratification is a challenge. The flow pattern produced by typical axial flow impellers produces an excellent top to bottom motion when the agitator is center mounted, and the vessel or tank is fully baffled. If the baffles are removed, the fluid in the vessel will swirl and vortex, resulting in a rather poor mix.

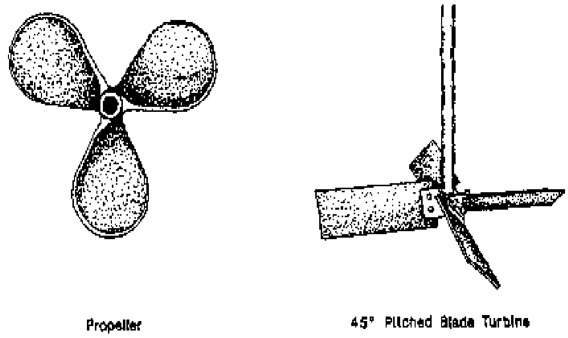

Fig. 8. Axial Flow Impellers

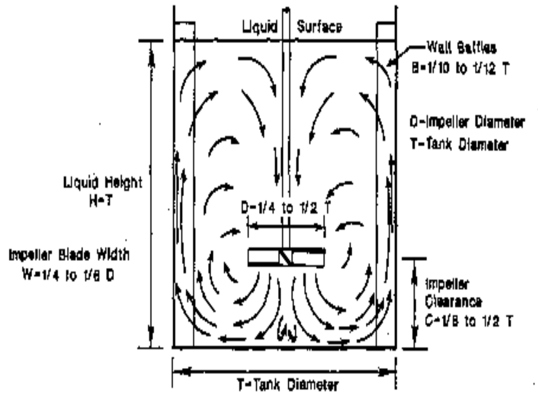

Fig. 9. Direction of Motion of Axial Flow Impellers

Liquid Mixer Vessels or Tanks

A mixing tank is a machine container that is used for blending different components together. Tanks are made up of different materials like glass, plastic, strong rubber and the most common one is the stainless steel. Stainless steel materials are used in fabricating tanks for smooth surfaces, easy cleaning, high corrosion resistance and convenience of use. The right kind of tank with the right features is crucial to the success of production. Industrial liquid mixing tanks can be general classified into; baffled and unbaffled tanks.

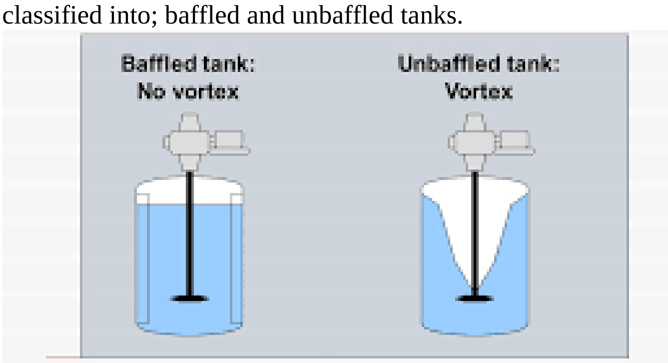

Fig. 10. Baffled and Unbaffled Tanks

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Baffled Tanks-Baffled liquid tanks have bulkheads in them with holes that let the liquid flow through. The baffles help to control the forward and backward liquid surge. Baffles are internals, generally flat plates, used in agitated vessels to optimize and stabilize the mixing flow pattern and minimize variation in agitator power draw.

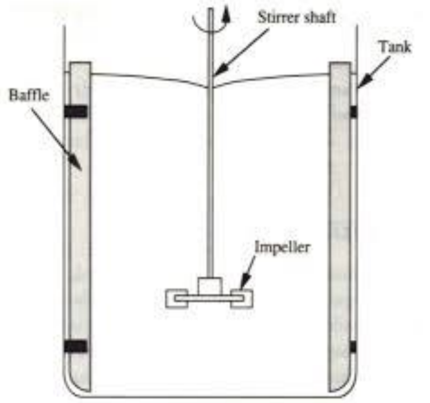

Fig. 11. Baffled Tank

Unbaffled Tanks-Unbaffled liquid tanks have nothing inside to slow down the flow of the liquid. Therefore, forward and backward surge is very strong. One of the main draw backs of unbaffled mixing tanks is the poorer mixing performance with respect to baffled vessels, due to the smaller pumping rate generated by the impeller.

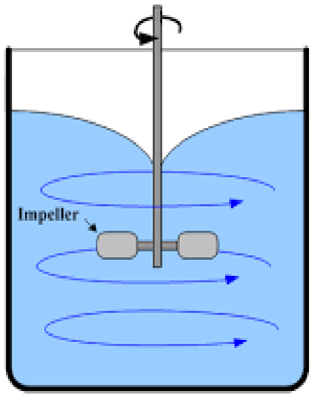

Fig. 12. Unbaffled Tanks

D. Installation and Maintenance of Liquid Mixers

To increase machine fatigue life and overall functionality, the mixer must be properly installed and maintained. Also, regular inspections decrease unexpected repairs and expenses and reduce downtime. Below is a checklist of steps to be followed.

Installation of Liquid Mixers

1) Check and ensure that the mixer is securely fixed to the floor or other holding base. This is because mixers operate at high speeds and use large amounts of power. Machinery that is not properly fixed to a firm base is a dangerous operating environment.
2) Electricity can be hazardous and must always be used with great care.
3) Check that all the electrical connections and cables are well connected and that there are no loose cables or wires.
4) The mixer must not be used by minors or anyone under the influence of drugs or alcohol.
5) Do not run the mixer without any liquid or without any other product in the unit. This is not only hazardous, but can cause damage to the mixer itself. Products serve to stabilize the impeller by acting as dampening medium.
6) Before starting the mixer, check that blades have been correctly fitted, and note the rotational marking on the blades if so marked. It is important to check that the indicated blade rotation matches the actual mixer shaft direction of rotation when the mixer is started.
7) When first commissioning the mixer, check that the unit operates with a clockwise rotation (normal), or as otherwise specified in the mixer instructions, by briefly switching on the mixer, and then immediately switching it off.
8) Mixers must always only be started when there is enough liquid added to the vessel.
9) Do not move the mixer while the tank is full.
10) Ensure that you have put on the prescribed personal protective equipment (PPE) for your plant. Eye goggles and safety shoes are the normal minimum requirement.
11) Never wear loose clothing, jewelry or hairstyles that may get caught in the mixer.
12) Do not put anything other than the mix in the mixer.
13) Do not put your hand or anything else than the mix into the drum, or tank while it is rotating.
14) Do not move the mixer while it is still connected to the power supply.

Maintenance of Liquid Mixers

Mixers and other mixing machinery require periodic inspection and maintenance. Timely maintenance and or well executed repairs with new parts keeps installations up and running in perfect condition. Besides equipment examinations, also lubrication and overhaul of machine components and units are also advisable when required.

1) Do not commence cleaning until the mixer is switched off.
2) Use only factory trained personnel. Do not attempt to repair internal components yourself.
3) Always unplug the mixer before cleaning, disassembling or reassembling.
4) Clean the mixer tank with mops and suitable rags.
5) Do not spray the mixer tank top with water to prevent water from getting into the motors, other electrical or control equipment.
6) Replace blades or impellers after not more than one third wear in thickness and no more than seven percent in diameter.
7) Use the proper type and also proper amount of lubricant to lubricate the mixer.

E. Mixing Mechanism

Mixing mechanisms for fluids fall essentially into four categories: bulk transport, turbulent_flow, laminar flow, and molecular diffusion. Usually more than one of these processes is operative in practical mixing situations.

Bulk transport–the movement of a relatively large portion of the material being mixed from one location in the system to another constitutes bulk transport. A simple circulation of material in a mixer may not necessarily result in efficient mixing. For bulk transport to be effective, it must result in a rearrangement or permutation of the various portions of the material to be mixed. This can be accomplished by means of paddles, revolving blades, or other devices within the mixer arranged so as to move adjacent volumes of the fluid in different directions, thereby shuffling the system in three dimensions.

Turbulent Mixing–the phenomenon of turbulent mixing is a direct result of turbulent fluid flow, which is characterized by a random fluctuation of the fluid velocity at any given point within the system. The fluid velocity at a given instant may be expressed as the vector sum of its components in the x, y, and z directions. With turbulence, these directional components fluctuate randomly about their individual mean values, as does the velocity itself. In general, with turbulence, the fluid has different instantaneous velocities at different locations at the same time. This observation is true for both, the direction and the magnitude of the velocity. If the instantaneous velocities at two points in a turbulent flow field are measured simultaneously, they show a degree of similarity provided that the points selected are not too far apart. There is no velocity correlation between the points, however, if they are separated by a sufficient distance. Turbulent flow can be conveniently visualized as a composite of eddies of various sizes. An eddy is defined as a portion of fluid moving as a unit in a direction often contrary to that of the general flow. Large eddies tend to break up; forming eddies of smaller and smaller sizes until they are no longer distinguishable. The size distribution of eddies within a turbulent region is referred to as the scale of turbulence. It is readily apparent that such temporal and spatial velocity differences, as a result from turbulence within a body of fluid produce a randomization of the fluid particles. For this reason, turbulence is a highly effective mechanism for mixing. Thus, when small eddies are predominant, the scale of turbulence is low.

Laminar mixing–Streamline or laminar flow is frequently encountered when highly viscous liquids are being processed. It can also occur if stirring is relatively gentle and may exist adjacent to stationary surfaces in vessels in which the flow is predominantly turbulent. When two dissimilar liquids are mixed through laminar flow, the shear that is generated stretches the interface between them. If the mixer employed folds the layers back upon themselves, the number of layers, and hence the interfacial area between them, increase exponentially with time.

Molecular diffusion–The primary mechanism responsible for mixing at the molecular level is diffusion resulting from the thermal motion of the molecules. When it comes in conjunction with laminar flow, molecular diffusion tends to reduce the sharp discontinuities at the interface between the fluid layers, and if allowed to proceed for sufficient time, results in complete mixing. The process is described quantitatively in terms of Fick's Law of diffusion:

$$\frac{dm}{dt} = DA \times \frac{dc}{dx}$$

Where, the rate of transport of mass, *dm/dt* across an interface of area **A** is proportional to the concentration gradient, *dc/dx*, across the interface. The rate of intermingling is governed also by the diffusion coefficient, D, which is a function of variables including fluid viscosity and size of the diffusing molecules. The concentration gradient at the original boundary is a decreasing function of time; approaching zero as mixing approaches completion.

F. Factors Influencing Mixing

Nature of the product-Rough surface of one of the components does not induce proper mixing. The reason for this is that the active substance may enter into the pores of the other ingredient. A substance that can adsorb on the surface can decrease aggregation, for e.g. addition of colloidal silica to a strongly aggregating zinc oxide can make it a fine dusting powder which can be easily mixed.
Particle size-Variation in particle size leads to separation as the small particles move downward through the spaces between the bigger particles. As the particle size increases, flow properties also increases due to the influence of gravitational force on the size. It is easier to mix two powders having approximately the same particle size.
Particle shape-For uniform mixing, the particles should be spherical in shape. The irregular shapes can become inter-locked and there are less chances of separation of particles once these are mixed together.
Particle charge-Some particles exert attractive forces due to electrostatic charges on them. This results to separation or segregation.

G. Applications of Liquid Mixers

Liquid mixers used for the mixing of various miscible/immiscible, low/high viscosity liquids has various industrial applications including:
Food industry-Liquid mixers are used in the production of edible fluids such as flavoring essence, beverages, flavored syrups, fruit tea, ice cream, butter, mayonnaise, etc.
Pharmaceutical industry-In the production of antacids, antibiotics, nutrition liquids, mineral oil emulsions, injectable, vaccines and others, etc.

Daily chemicals industry-Aerosols antiperspirants, toothpaste, detergents, shampoo, shoe polish, wax emulsions, etc.

Cosmetics industry-Hair gels, liquid make-up, lotions, shampoo, shaving cream, deodorants, ointments, cold creams, etc.

Chemical Industry-Paints, color dispersions, pigment coating, fertilizers, emulsified asphalt, lubricating grease, diesel, petroleum catalyst, etc.

II. MATERIALS AND METHOD

Design Considerations

The following requirements were considered in the design of the machine:

1. The equipment should be relatively cheap
2. The equipment should be able to mix efficiently
3. The equipment should be made with readily available materials
4. The load capacity of the machine was considered for low power requirement
5. The machine should be easy to operate (user friendly).

Machine Description

The machine is made up of five summarized parts which include the power supply system (electric motor), shaft and impeller assembly and the mixing drum.

1. ***The power supply and transmission system:*** The power supply system consists of a v-belt drive and a radial electric motor with a power rating of 550 watts running at1200rpm.Power from the prime mover is transmitted through the v-belt drive to rotate the shaft attached to the impeller blades in the mixing vessel.
2. ***The Agitator:*** This is the component that actualizes the aim of the design. The impellers are welded to the hollow shaft. The rotating shaft thus rotates the impellers at the same speed. The impeller blades stir and rake the materials to be mixed. The shaft and impeller are both made of stainless steel to reduce product fouling due to corrosion which can be caused by reaction with various chemicals during mixing. Each impeller is a 45° pitch-blade type with two blades each.
3. ***The mixing vessel:*** A flag stainless steel sheet of 3mm thickness was used for the construction of the vessel. The sheet was rolled and welded to specification to actualize the drum design. A discharge spout is welded to the vessel at the bottom along the wall to ease discharge of thoroughly mixed materials. The vessel has a total volume of 70.372litres.

Material Selection

The selection of materials was based on certain criteria such as:

1) Availability
2) Durability
3) Feasibility
4) Cost

The best material for each component is the one which serves the desired object at minimum cost. Taken into consideration the aforementioned criteria, the various materials used for each machine component and the reasons for such selection are summarized in Table 1.

Table 1. The materials selected for each component and the reasons for usage.

Machine component	**Material selected**	**Reasons for usage**
Shaft	Stainless steel	Heat-resistance, corrosion resistance, ductility, toughness, weldability,
Impeller blades	Stainless steel	Heat resistance, corrosion and oxidation resistance, ductility, toughness, weldability
Mixing vessel	Stainless steel	Corrosion and oxidation resistance, toughness, weldability, availability.
Mount for motor	Mild steel angle iron	Toughness, strength, weldability, availability and cost

Mild Steel-Mild steel (iron containing a small percentage of carbon, strong and tough but not readily tempered), also known as plain-carbon steel and low- carbon steel, is now the most common form of steel because its price is relatively low while it provides material properties that are acceptable for many applications. Mild steel contains approximately 0.05-0.30% carbon making it malleable and ductile. Mild steel has a relatively low tensile strength, but it is cheap and easy to form; also its surface can be further hardened by carburizing.

Stainless Steel-In metallurgy, stainless steel is an alloy of steel that contains a minimum mass content of 11% chromium and a maximum mass content of 1.2% carbon. Stainless steel are most known for their high corrosion resistance, which increases with increasing chromium content. There are various types of stainless steel with varying chromium and molybdenum contents tailor to fit the environment the alloy will be used in. The ability of stainless steel to resist corrosion, its low maintenance and its familiar luster make it an ideal material for many engineering applications where both its corrosion resistance and strength are required.

Design Analysis and Calculations

Fluid Selection Calculations

The basis for fluid selection is its Reynolds number. Reynolds number is a dimensionless quantity that describes the flow pattern of a fluid. It is given as [14]:

$$R_e = \frac{\rho N D^2}{\mu}$$

Where,
R_e= Reynolds number
ρ = Fluid density in kg/m^3
N =Impeller speed in rev/s
D =Vessel diameter=400mm
μ =Kinematic viscosity

For effective mixing, a turbulent flow ($R_e > 10^4$) is required hence fluids with viscosity of 1 to 3 centipoise with densities between 1000 to 1100 kg/m3 are usually selected.

Vessel Design Calculations

The dimensions of the mixing vessel determine the entire setup as impeller design and the nature of forces acting on the shaft depend on it. Vessel design is determined by the quantity of fluid to be mixed. Neglecting volume occupied by the shaft and impeller assembly, the volume of the vessel is determined as follows:

$$V = \frac{\pi}{4} D^2 H = \frac{\pi}{4} \times 400^2 \times 560 = 70.372 \times 10^{-6} \text{mm}^3$$
$$= 70.372 \text{litres}$$

Where,
H = Vessel height = 560mm

However, for the purpose of this design, fluid quantity for the vessel is set at a batch capacity of 50litres as the vessel should not be filled to the brim during mixing.

Baffle Design

For the elimination of swirls which will be developed during turbulent mixing, 3 baffles are positioned radially along the vessel wall 120° apart. Each baffle has a width of 20mm.

Impeller Design Calculations

Impeller design is based on three criteria: Reynolds number, power number and pumping number. These provide a basis for the comparison of different impellers and have proven to be reliable basis for predicting a number of process results of mixing operations. The power number gives the magnitude of power consumed by an impeller, while the impeller flow number suggests the impeller discharge or flow set up. The power number is given by the following formula:

$$N_P = \frac{P}{\rho N^3 d^5}$$

Where,
N_P = Impeller power number
P = Power consumed in watts
d = Diameter of impeller in meters

Pumping is the amount of material discharged by the rotating impeller [14]. It is calculated using the formula;

$$N_Q = \frac{Q}{N D^3}$$

Where,
N_Q=Pumping number
Q = radial discharge

Table 2. Pumping Number, N_Q, under Turbulent Conditions for Various Impellers [14]

Impeller Type	N_Q
Propeller	0.4-0.6
Pitch blade turbine	0.78
Hydrofoil impellers	0.55-0.73
Retreat curve blades	0.3
Flat blade turbine	0.7
Disk flat-blade turbine(Ruston)	0.72
Hollow-blade turbine (Smith)	0.76

Pitch-blade turbine has the highest pumping number of 0.78; it also possesses the least power number of 1.5 therefore it is selected as the impeller type for this design. From empirical relations;

$$d = 0.3D = 0.3 \times 400 = 120\text{mm}$$

The impeller width;

$$W = 0.2d = 0.2 \times 120 = 24\text{mm}$$

Impeller blade thickness is to be selected from a range of values from 3-10mm. a thickness of 3mm is selected. Considering ratio of vessel fluid height to tank diameter, double 45° pitch-blade impellers with dual blades are required.

Impeller Power Requirements and Motor Selection

The magnitude of power required to rotate each impeller for turbulent mixing is calculated using the formula:

$$P = N_p \times \rho \times N^3 \times d^5$$

Where,
P = Impeller power in watts

The power required to drive the 2 impellers is determined as:

$$P = 2 \times 1.27 \times 1100 \times 6.67^3 \times 0.12^5 = 20.631\text{Watts}$$

Assuming 10% gland losses;

$$P = 1.1 \times 20.63 = 22.694\text{Watts} = 0.0304\text{hp}$$

Therefore, an electric motor with a power rating of 0.0304hp with a minimum rotational speed of about 125rpm is required for turbulent mixing. A 0.5hp electric motor running at 1200rpm is selected.

Belt and Pulley Design Calculations

The belt is used to transmit power from the prime mover (electric motor) to the shaft. In this case, v-belts were selected because of its advantages over other belts which include the following [2]:

1) The V-belt drive gives compactness due to the small distance between centres of pulleys.
2) The drive is positive, because the slip between the belt and the pulley groove is negligible.
3) Since the V-belts are made endless and there is no joint trouble, therefore the drive is smooth.
4) It provides longer life, 3 to 5 years.
5) It can be easily installed and removed.
6) The operation of the belt and pulley is quiet.
7) The belts have the ability to cushion the shock when machines are started.
8) The high velocity ratio (maximum 10) may be obtained.
9) The wedging action of the belt in the groove gives high value of limiting ratio of tensions. Therefore the power transmitted by V-belts is more than the other belts for the same coefficient of friction, arc of contact and allowable tension in the belts.
10) The V-belt may be operated in either direction, with tight side of the belt at the top or bottom. The centre line may be horizontal, vertical or inclined.

Determination of Belt Length

The belt length in determined as follows [2]:

$$L = 2C + \frac{\pi}{2}(D_1 + D_2) + \frac{D_1 + D_2}{4C}$$

Where,
L = Belt length
C = Center distance between driving and driven pulleys
D_1 = Diameter of the driving pulley = 20mm
D_2 = Diameter of the driven pulley = 40mm

$$C = 2D_1 + D_2 = 2 \times 20 + 40 = 80\text{mm}$$
$$L = 2 \times 80 + \frac{\pi}{2} \times 60 + \frac{60}{4 \times 80} = 254.435\text{mm}$$

Determination of speed ratio of belt drive

The speed ratio of the belt drive is expressed as

$$\frac{N_2}{N_1} = \frac{D_1}{D_2}$$

Where,
N_1 = Speed of the driving pulley = 1200rpm
N_2 = Speed of the driven pulley

$$N_2 = \frac{N_1 \times D_1}{D_2} = \frac{1200 \times 20}{40} = 600\text{rpm}$$

Determination of peripheral velocity of the belt drive.

The peripheral velocity of the belt drive is determined as follows:

$$V_d = \frac{\pi D_1 N_1}{60} = \frac{\pi D_2 N_2}{60} = \frac{\pi \times 0.02 \times 1200}{60} = 1.257m/s$$

Determination of the lap angle of the belt drive

The lap angle of the belt drive is determined as follows [2]:

$$\alpha = 180 \pm 2\sin^{-1}\left(\frac{D_2 - D_1}{2C}\right) = 180 \pm 2\sin^{-1}\left(\frac{40 - 20}{80 \times 2}\right) = 2.891\text{rad}$$

Where,
α = Lap angle

Determination of the belt tension of the belt drive

The belt tension of the belt drive is determined as follows [2]:

$$2.3 \log\left(\frac{T_1}{T_2}\right) = \mu\alpha$$

Where,
μ = Coefficient of friction = 0.47
T_1 = Tension on the tight side of the belt
T_2 = Tension on the slack side of the belt

$$P = (T_1 - T_2)V_d$$
$$T_1 - T_2 = \frac{P}{V_d} = 296.738$$
$$2.3 \log\left(\frac{T_1}{T_2}\right) = 0.47 \times 2.891$$
$$\log\left(\frac{T_1}{T_2}\right) = \frac{0.47 \times 2.891}{2.3} = 0.591$$
$$\frac{T_1}{T_2} = e^{0.591} = 1.806$$
$$T_1 = 1.806T_2$$
$$T_1 - T_2 = 1.806T_2 - T_2 = 0.806T_2 = 296.738$$

Therefore,

$$T_2 = 368.162\text{N}$$
$$T_1 = 1.806T_2 = 1.806 \times 368.162 = 664.901\text{N}$$

The total tension on the belt T is expressed as:

$$T = T_1 + T_2 = 664.901 + 368.162 = 1033.063\text{N}$$

Determination of belt width of the belt drive

The belt width of the belt drive is determined as follows [2]:

$$b = \frac{B}{1.25} = \frac{13}{1.25} = 10.4mm$$

Where,
b = Belt width
B = Pulley width = 13mm

Shaft Design Calculations

Determination of the shaft twisting moment

The shaft twisting moment is determined as follows:

$$T = \frac{60P}{2\pi N_1} = \frac{60 \times 373}{2\pi \times 600} = 5.936\text{Nm}$$

Where,
T = twisting moment acting on the shaft (N/m)

To account for additional starting torque, a correction is made to the shaft twisting moment using a service factor of 1.5.
$T = 1.5 \times 5.936 = 8.904\text{Nm}$

Determination of the force acting on the impeller

The force acting on the impeller is determined as follows:

$$F_m = \frac{T}{0.75R_b} = \frac{8.904}{0.75 \times 0.06} = 197.867\text{N}$$

Where,
F_m = Force acting on impeller
R_b = Impeller radius

Determination of the shaft bending moment

The shaft bending moment is determined as follows:
For two impellers located at distances L_1 and L_2 respectively on the shaft the bending moment M is therefore expressed as;
$M = F_m(L_1 + L_2) = 197.867(0.30 + 0.42) = 142.464\text{Nm}$

Determination of the shaft diameter

The shaft diameter is determined from maximum shear stress theory as follows:

$$M_t = \frac{1}{2}\left(\sqrt{T^2 + M^2}\right) = \frac{1}{2}\left(\sqrt{8.904^2 + 142.464^2}\right) = 71.371\text{Nm}$$

$$Z_p = \frac{M_t}{\sigma_S} = \frac{\pi d^3}{16}$$

Where,
M_t = Equivalent twisting moment
σ_s = Permissible shear stress = 42MPa
Z_p = Sectional modulus of shaft
d = Solid shaft diameter

Rearranging, we get

$$d = \sqrt[3]{\frac{16M_t}{\pi\sigma_s}} = \sqrt[3]{\frac{16 \times 71.371}{\pi \times 42 \times 10^6}} = 0.0205\text{m} = 20.5\text{mm}$$

The shaft diameter is determined from maximum normal stress theory as follows:

$$M_b = \frac{1}{2}\left(M + \sqrt{T^2 + M^2}\right) = \frac{1}{2}\left(142.464 + \sqrt{8.904^2 + 142.464^2}\right) = 142.603\text{Nm}$$

$$Z_p = \frac{M_b}{\sigma_t} = \frac{\pi d^3}{16}$$

Where,
M_b = Equivalent bending moment
σ_t = Permissible tensile stress = 112MPa

Rearranging, we get

$$d = \sqrt[3]{\frac{16M_b}{\pi\sigma_t}} = \sqrt[3]{\frac{16 \times 142.603}{\pi \times 112 \times 10^6}} = 0.0186\text{m} = 18.6\text{mm}$$

Therefore, d=22mm was chosen as the diameter of the solid shaft

A hollow shaft will improve the stiffness and reduce the weight of mixer shaft thus improving the overall machine efficiency. The estimations for hollow shaft specifications are made and verified for safety by comparing computed shear and tensile stresses values with actual allowable stresses.

$$\sigma_s = \left(\frac{16\sqrt{T^2 + M^2}}{\pi}\right) \times \frac{d_o}{d_o^4 - d_i^4} = \left(\frac{16\sqrt{8.904^2 + 142.464^2}}{\pi}\right) \times \frac{0.028}{0.028^4 - 0.018^4} = 39.938\text{MPa}$$

$$\sigma_t = 16\left(\frac{M + \sqrt{T^2 + M^2}}{\pi}\right) \times \frac{d_o}{d_o^4 - d_i^4} = 16\left(\frac{142.464 + \sqrt{8.904^2 + 142.464^2}}{\pi}\right) \times \frac{0.028}{0.028^4 - 0.018^4} = 79.797\text{MPa}$$

Where,
d_i = Inside diameter of hollow shaft = 18mm
d_o = Outside diameter of hollow shaft = 28mm

The calculated stresses are within range of permissible working stress, hence the shaft design meets safety criteria.
Minimum length of shaft = Vessel height + Clearance from top of vessel − Off bottom clearance
$560 + 240 - 40 = 760\text{mm}$

Bearing Selection

A bearing is needed to support a shaft with the other shaft of the mechanism where reciprocating and rotary motion are required. The selection of bearings for application in this mixer demands a bearing type capable of;

1) Low starting friction
2) Carrying thrust components
3) Supporting loads inclined at any angle in the transverse plane
4) Easy maintenance and replacement.

Having satisfied this criteria, two available bearings of required specifications where selected for application in the mixer.

Degree of Turbulence

The degree of turbulence achievable during mixing under safe operating condition is given by the Reynolds number of the selected liquid. The Reynolds number is expressed as

$$R_e = \frac{\rho N D_V^2}{\mu} = \frac{1100 \times 10 \times 0.120^2}{0.003} = 5.28 \times 10^4$$

$R_e > 10^4$
Therefore, turbulence is verified and mixing is possible.

III. Fabrication and Testing

Fabrication

The development of the machine involved the use of simple fabrication techniques and methods for each component part so as to eliminate unnecessary complexity, for ease of maintenance. The liquid mixing machine was assembled with the required electric motor which is connected to the v-belt drive. The belt drive transmits the motion from the electric motor. The electric motor rotates the belt drive, which in turn drives the pulley attached to the shaft. The shaft is incorporated with stainless steel impeller blades used for the mixing operation inside the stainless steel tank. Fig. 13 shows the photograph of the developed industrial liquid mixer. Each component required a number of machining operations before final assembly. A summary of the fabrication procedure and machines employed for such fabrication operations for each of the developed mixer components are shown in Table 3.

Table 3. Summary of Fabrication Procedure and Machines Employed

Components	Materials	Procedure	Machine Tools
Vessel	Stainless steel	A 560mm x 1258mm stainless steel plate was measured out, cut and rolled into a cylinder. A circular flat cover of 400mm diameter was also cut and welded to one end of the cylinder to form the vessel bottom, another circular flat plate of 420mm diameter was cut and was used to cover the vessel using bolts and nuts; a hole was bored through it for the shaft bearing, allowance was made for the hopper too by cutting away a marked rectangular section of appropriate dimension on the plate..	Sheet metal rolling machine, Cutting machine, Welding machine, Drilling machine, Boring machine.
Impeller	Stainless steel	Marking out of impeller blade geometry on the stainless steel plate was carried out, it was then cut out and welded onto the shaft.	Cutting machine, Welding machine.
Shaft	Stainless steel	The shaft used in this fabrication was sourced for locally and on conformity to design specification. The appropriate shaft diameter and length was achieved by turning and cutting respectively.	Lathe machine, Cutting machine
Frame	Mild steel	A 3mm x 30mm Angle iron was measured out and cut into required lengths and welded together to support the axially mounted motor.	Cutting machine, Welding machine.
hopper	Stainless steel	Flat stainless steel plates were marked, cut to specified dimensions, and welded to form the hopper.	Cutting machine, Welding machine

The 70.372litres vessel is a cylindrically shaped tank made from stainless steel. The sheet was rolled into its cylindrical shape using a rolling machine and welded. Three baffles are welded onto the vessel radially along its inner surface. The vessel was bored close to its bottom for the discharge spout which was then welded to it. The impeller was cut from stainless steel plate and welded to the shaft at specified distances apart to form the agitator. The 50-litre batch capacity industrial mixer was developed from the initial design stage to its final form to provide an efficient solution to the financial consequences associated with poor mixing. The machine is economic, portable and is simple to operate and maintain. The highly homogeneous product obtained during testing proves the viability of the machine and is indicative of the overall efficiency of the machine.

Safety Consideration

The design is simplified in such a way that limits operational hazards however certain safety precautions are still to be observed during its operation these include:

1) Mixers must always only be started when there is enough liquid added to the vessel.
2) Do not move the mixer while the tank is full.
3) Ensure that you have put on the prescribed personal protective equipment (PPE) for your plant. Eye goggles and safety shoes are the normal minimum requirement.
4) Never wear loose clothing, jewelry or hairstyles that may get caught in the mixer.
5) Do not put anything other than the mix in the mixer.

6) Do not put your hand or anything else than the mix into the drum, or tank while it is rotating.
7) Do not move the mixer while it is still connected to the power supply

Fig. 13. Developed 50-litre batch capacity industrial mixer

IV.CONCLUSION

This work focused on the development of a 50-litre batch capacity industrial mixer using locally sourced material. The essence is to produce an industrial liquid mixer that is relatively cheap and easily affordable. The design is simplified in such a way that limits operational hazards. The development of the machine involved the use of simple fabrication techniques and methods for each component part so as to eliminate unnecessary complexity, and for ease of maintenance. The electric motor capacity is 0.5hp. Calculation results gave the volume of vessel as 70.372litres, the total tension on the belt as 1033.063N, the force acting on the impeller as 197.867N, the power required to drive the 2 impellers as 22.694Watts (0.0304hp), the belt length as 254.435mm, the minimum length of the shaft as 760mm, the equivalent bending moment acting on the shaft as 142.603Nm, the equivalent twisting moment acting on the shaft as 71.371Nm, the shaft diameter as 20.5mm. Performance testing shows that the machine performed well as expected. The highly homogeneous product obtained during testing proves the viability of the machine and is indicative of the overall efficiency of the machine.

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