OPEN ACCESS
Saudi Journal of Engineering and Technology
Abbreviated Key Title: Saudi J Eng Technol
ISSN 2415-6272 (Print) |ISSN 2415-6264 (Online)
Scholars Middle East Publishers, Dubai, United Arab Emirates
Journal homepage: http://scholarsmepub.com/sjet/

Original Research Article

An Overview of Basic Concepts for Advancements in Designs of Mechanical Agitators for Paint Mixing

T. N. Guma*, Anthony Agbata, T. Akor
Department of Mechanical Engineering, Nigerian Defence Academy, Kaduna, Nigeria

***Corresponding author:** T. N. Guma
| **Received:** 16.01.2019 | **Accepted:** 26.01.2019 | **Published:** 10.01.2019
DOI:10.21276/sjeat.2019.4.1.2

Abstract

Painting is recognized as the mainstay for preventing corrosion of structural components or systems and decorating objects. Paint is a heterogeneous liquid solution of many solid components that is daily needed to be blended in large quantities to requisite homogeneities and properties in many industries and units before application to ensure consistencies in the desired paintwork qualities and reliable effective corrosion protection at economical costs. Efficient and fast mixing of paint is done by mechanical agitation. Mechanical agitation also removes the drudgery of human folk in blending large quantities of paint and reduces exposure time of personnel to some paints that are toxic. No universal system till now has been found valid for agitating paint and other fluid quantities in different container sizes and shapes. For optimal functionality, efficiency, productivity, reliability, and economy agitators are usually not mass-produced and kept in storage but designed and developed to meet individual customer's requirements. Design specifications of agitators for mixing paint can be different from those of other liquid solutions for the same mixing quantities due to distinctiveness of paint properties such as viscosity, density, segmentation level, and environmental susceptibility. In this paper, some previous revolutionary works on means of agitating fluids are reviewed to provide a compendium of basic concepts that need to be understood for meaningful advancements in designs of mechanical agitators to optimally meet various paint mixing requirements with given equipment sizes and shapes. The review showed that the required mixing quantity per unit time, shape and size of paint container, impeller size and rotational speed, shaft strength, powering system, agitation time, and, structural anchorage system for the container are the basic design parameters for the agitators. These parameters along with basic considerations such as: ease of operation, operational efficiency and integrity, reduction of agitation time, cost reduction, reliability, durability, safety, reduction of paint exposure time to environment, ease of paint pouring in and out of containers and, easy means of loading heavy paint containers in place and unloading them were seen to be crucial in advancing the agitator designs.
Keywords: Paintwork quality, implications, paint mixing requirements, daily need, mechanical agitators, design variations, established basics, design advancements.

INTRODUCTION

Mixing is an essential operation in any process industry. All operations involving liquid phase reactions, blending homogenization, emulsion preparation, dissolution, extraction, etc., need mixing in one form or the other. Mixing of components in the production or usage of paints and many other products like powders, pastes, chemicals, foods, jellies, putties, chewing gum, soaps, grease, pulp, paper, etc is needed to be done in many industries or units. This is achievable by rigorous shaking and creating turbulence in them. The process is called agitation for which directionally reversible mixtures are utilized to create turbulence in them [1-3]. The energy required and ease of agitation of a fluid depends on its properties such as viscosity, density, and quantity. Mechanical agitation refers to the use of power operated machinery to force the required turbulent circulatory flow motion of a fluid to mix it inside a vessel. Mechanical agitators are used for fast efficient accomplishment of various mixing purposes in multi-phase liquids and solid-liquid solutions by suspending solid particles, blending miscible segments, improving efficiency of reaction through better contact between reactive components, dispersing a gas through the liquid in the form of small bubbles, and promoting heat transfer between different phases. There are so many mixing requirements in several quarters. Deciding whether a given agitator can perform a special mixing task can only be solved by comparing the new task with its previously solved mixing tasks. For optimal functionality, efficiency, productivity, reliability, and economy, agitators are usually individually designed and tailored to meet the special requirements of customer instead of mass -producing them to avoid little or no demand for them in many other requirement cases with losses [1, 4-6].

Corrosion is a notable environmentally inevitable costly natural process of material degradation which greatly impedes technological and economic achievements to optimal levels with a total estimated cost in the range of 2-4% of GNDP of the world's nations and needs to be managerially technologically controlled cost-justifiably to the barest level to minimize its consequences [7, 8]. Painting is recognized as the mainstay of protecting structural components or systems from corrosion, and decorating objects. About 90% of steel works, concretes, and wood works are corrosion-protected by painting [9]. Paint is however a heterogeneous liquid solution involving many solid components which if not mixed all the way, its components will not be blended and its true color, consistency, corrosion-protectiveness and economic viability will not be achieved in application due to various paintwork defects like flaking and peeling, absence of gloss, runs and sags, cracking in its coatings, etc [10, 11**].** Paint mixing to requisite blend homogeneities and properties before application is therefore a daily essential need to be done in many industries and at other entrepreneurial levels for ensuring consistencies in the requisite paintwork qualities with effective, reliable, and dependable corrosion protection at economical costs [12, 13]. Paints belong to higher viscosity solutions so they have to be agitatedly blended with component additives to lower their viscosities to acceptable level of about 100Centipoise for spraying, brushing or roll coating [14]. Over the years, different facilities have been developed to carry out mixing of paint and various other liquid solutions; each being improvement of some sort over the existing ones in terms of ease of operation, operational efficiency and integrity, reduction of agitation time, cost reduction, reliability, durability, safety, reduction of paint exposure time to environment, ease of paint pouring in and out of containers and, ease of means of loading heavy paint containers in place and unloading them. Yet no universal system till now has been found valid for agitating paint and other fluid quantities in different container sizes and shapes [1]. For examples, Plates I to III show three out of several contrasting versions of existing agitation paint mixers [15]. The motive in this paper is to review some previous important works on means of agitating/mixing liquids to provide a compendium of basic concepts that need to be understood by all that are concerned for meaningful advancement in designs of mechanical agitator to optimally meet specific paint mixing requirements with given equipment sizes and shapes.

Plate I

Plate II

Plate III

Plates I-III: Some versions of paint mixer designs [15]

METHODOLOGY

The information presented in this research work was got from literary sources both on the INTERNET and hard-copy sources and field discussions with other competent people on the subject covering basic design principles used in existing types of fluid agitators and, research works in mechanical agitator designs patterning to paint mixing and fine-tuned with our knowledge and experience gained over the years as engineers in the field, researchers and lecturers and industrial workers.

Principles used in existing types of agitators

Agitators come in many sizes and shapes and can be classified based on different criteria depending on the area of interest. The common and most important criterion used for classifying the agitator types is according to their mode of operations. By this agitators are classified as follows [1, 6]:`

- Impeller type agitator
- Static agitator
- Tumbling agitator.

Impeller Type Agitators

Impeller-type mixing equipment represents the largest category of general purpose mixing equipment for fluid processing applications. An impeller is usually composed of blades mounted to a central hub and rotated by a drive shaft to push and move the material to be mixed. The mixing action and the process results are primarily caused by the fluid motion [12]. For mixing to be effective, fluid circulated by the impeller must sweep the entire vessel in a reasonable time. In addition, the velocity of fluid leaving the impeller must be sufficient to carry material into the most remote parts of the container. Turbulence must also be developed in the fluid. Mixing is certain to be poor unless flow in the tank is turbulent. All these factors are important in mixing, which can be described as a combination of three physical processes; distribution, dispersion and diffusion [6]. Fig-1 shows the stirrer shaft and other components of a simple impeller type agitator [16].

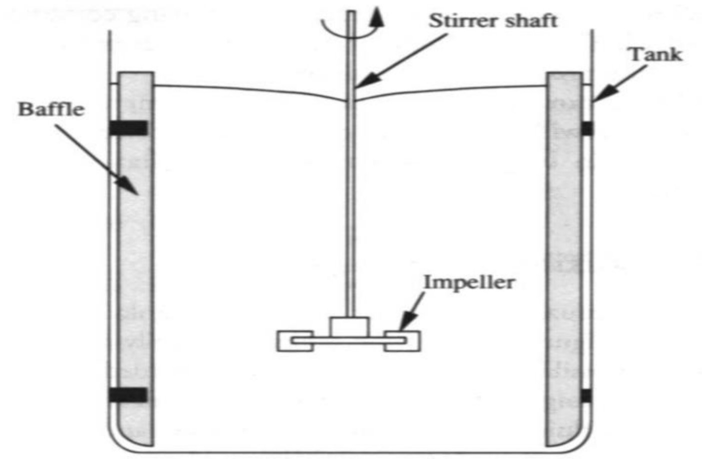

Fig-1: Components of a simple impeller type agitator [16]

Impeller agitators used in industrial environment are commonly further classified as anchor, propeller, turbine, paddle, gate anchor, and helical screw based on their impeller blade designs as shown in Fig-2. These different impeller blades generate different flow patterns leading to different hydrodynamics, thus affecting the energy efficiency of the system. The blades can be used individually or in combination to effect mixing in different ways so designers have to choose the blades or their combinations that most advantageously meet service needs [1, 12]. Most often the mounting positions of the impeller blade on the mixing vessel determine the generic name given to the agitator. Impeller type agitators can be operated by electric power, pneumatic power, or manually.

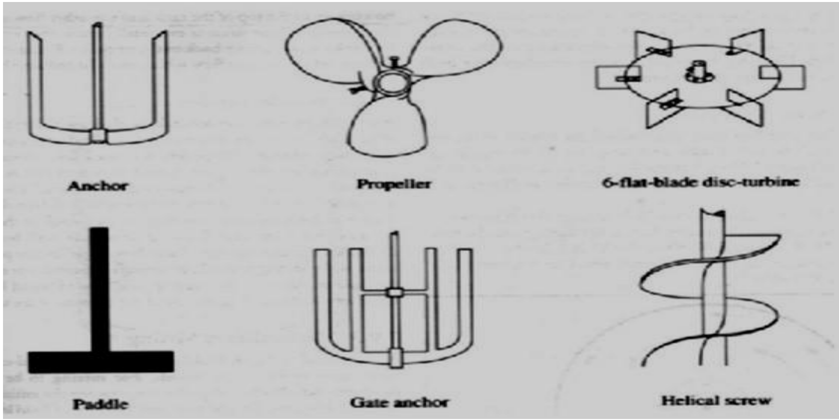

Fig-2: Some of the impeller blade designs frequently used on various types of impeller mixers in industrial environment [12]

The anchor agitator is simple and consists of a shaft and an anchor type propeller and can be mounted centrally or at an angle. It is mainly used in reactors. A propeller agitator is shaped with blades tapering towards the shaft to minimize centrifugal force and produce maximum axial flow. Propeller agitators are popular for simple mixing jobs. Turbine agitators can create a turbulent movement of the fluids due to the combination of centrifugal and rotational motion. A paddle agitator is one of the most primary types of agitators with blades that reach up to the tank walls. Paddle agitators are used where a uniform laminar flow of liquids is desired. Radial agitators consist of propellers that are similar to marine propellers. They consist of two to four blades that move in a screw like motion and propel the material to be agitated parallel to the shaft. Helical agitators have blades with a twisted mechanism, just like the threads of a screw. The curves result in a vigorous motion of the fluids to be agitated. Helical agitators are most useful for mixing viscous liquids [12].

Impeller type agitators are sometimes classified based on the type of flow generated by the impeller blade as radial flow impeller and axial flow impeller. Some examples of impeller type agitators are: portable mixers, top-entering mixers, turbine mixers, side-entering mixers, bottom-entering mixers, high viscosity mixers, high-shear mixers, double-motion mixers (combination of a high viscosity, close-clearance mixer and high-shear mixer), and differential agitator [17].

Static Agitators

A static mixer is a precision engineered device for continuous mixing of fluid materials [12, 18]. Normally the fluids to be mixed are liquid, but static mixers can also be used to mix gas streams, disperse gas into liquid or blend immiscible liquids [18]. Fig-3 shows the basic components of a continuous process inline static mixer for creating homogeneous mix in a short length. Pumps or blowers are used instead of impellers to deliver the components to be mixed at the desired volumetric flow rates and to also supply the pressure energy required for mixing [19].

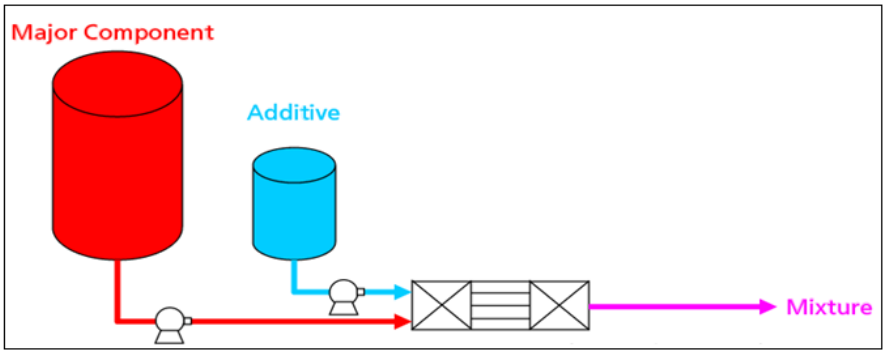

Fig-3: The main component parts of a static agitator [19]

A static mixer achieves it mixing objective by manipulating fluid streams to divide, recombine, accelerate or decelerate, spread, swirl or form layers as they pass through control surfaces of the mixer. As a result of these alterations in the fluid flow, mixture components are brought into intimate contact. Static mixers are therefore utilized not only for strictly mixing requirements but also reaction processes. Different designs of static mixers are available, typically consisting of plates or baffles positioned in precise angles in order to direct flow, increase turbulence and achieve mixing [19]. Static mixer size can vary from about 6 mm to 6 meters diameter. Typical construction materials for static mixer components include stainless steel, polypropylene, Teflon, PVDF, PVC, CPVC and polyacetal. The latest design involves static mixing elements made of glass-lined steel [18, 20].

The mechanical design of static mixers is unique compared with other types of mixing equipment. Most other mixers involve some type of rotating equipment. Static mixers have no moving parts so their design methods resemble those of piping and pressure vessels. The mixing elements of a static mixer can take many forms, but the most common is the twisted element style, shown in Fig-4. Most elements are merely inserted and fixed into a section of pipe, although some are designed to be removable for cleaning and others are sealed to the wall of the pipe. Design of the elements themselves is largely proprietary, although the pipe sections in which the elements fit are designed to piping standards for dimensions and end connections. Most static mixers are housed in the same size or one-size-larger pipe than the adjacent runs of piping and are of the same material and schedule (wall thickness) [17].

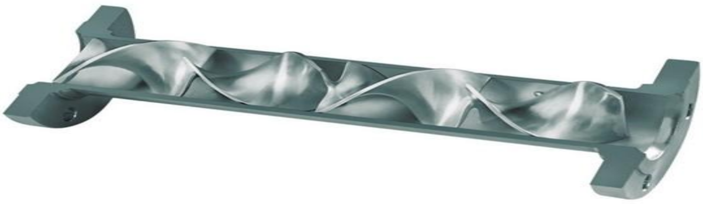

Fig-4: Twisted mixing element of the static mixer [12]

The number of mixing elements required for a specific application is a function of the customer's process and system requirements with consideration for the degree of mixing required, pressure drop limitations and fluid properties such as flow rate, viscosity, density, etc [19].

Tumble/Diffusion Mixer

Diffusion mixer also known as tumbling mixer/blender is a powder/solid and liquid mixing equipment that consists of a closed metallic vessel usually stainless steel that rotates about an axis either manually or with the help of a motor at an optimum speed. Diffusion is the main mechanism of mixing in tumbling mixer. The materials to be blended are loaded into the blender container and the movement of the material occurs by tilting the material beyond angle of repose using gravity to impel flow. Different shapes of the diffusion mixer, results in the movement of the material in various planes, which is necessary for rapid mixing [21]. The degree of mixing/blending achieved by tumbling mixer in carrying out a mixing operation is dependent on [21]:

- The fill up volume, which should not be more than 50-60% of the total blender volume.
- The residence time.
- The rotation speed since increasing the speed above the optimum level causes adhesion of the material on the walls of the mixer.
- The method used in charging the powder.
- Inclination angle of the mixer.

There are several subclasses of tumbler but the popular and commonly used ones are the V-blenders, and the double cone blenders. Others include slant cone blenders, cube blenders, bin blender, horizontal/vertical/drum blenders, static continuous blenders, and dynamic continuous blenders. They are primarily distinguished by geometric shape and the position of the axis of rotation. The uniqueness of the tumbling agitators is that they do not necessarily utilize a stirrer for agitation therefore reducing the exposure of the products they mix to contaminations from the environment and contact with other foreign bodies [21].

The V-blender also known as twin-shell mixer consists of two hollow cylindrical vessel/container that are joined at an angle of 75^o to 90^o which is mounted on trunion to allow it tumble as shown in Fig-5. The free fall of the material within the vessel, and the repetitive converging and diverging motion, coupled with increased frictional contact between the material and the vessel's long, straight sides as the mixer tumbles, splits the material and recombines them continuously resulting in a homogenized blend. Removal of the blended material from the V-blender is normally through the apex port which is fitted with a discharge tube [21].

Fig-5: A view of a V-blender [17]

A V-blender can be modified by providing it with a high-speed intensifier bars also known as lump breaker running through the trunion into the vessel along with a spray pipe for liquid addition. This modified V-blender is called V-Blender with intensifier bar. Modifications make V-blender broaden its application in the pharmaceutical industries due to the following factors [21]:

- Ability to accomplish wet blending in addition to the normal dry blending that the V-blender is known for.
- It makes it suitable for mixing fine powders as well as coarse powders.

Provision of intensifier bar to a V-blender is not devoid of some short comings. These disadvantaged include:

- V- Blender with intensifier bar, unlike V-blender has cleaning problems after use.
- It causes intensifier bar shaft problems.
- It causes undesired particle attrition.

The double cone blender is an efficient and multipurpose tumbler blender for mixing dry powders and granules homogeneously. It is made of two conical shaped stainless vessels (available in different capacity ranging from 5kg-200kg or even more) that are separated by a cylindrical section. It is mounted at the centre of the container between two trunnions that allows the blender to turn end over end. Double cone blender has no dead spots mixing and it is easily cleaned after use. Double cone blender is not a suitable blender choice for very fine particles and particles with greater particle size difference due to fewer shears. A view of double cone mixer is shown in Fig-6 [21].

Fig-6: A double cone mixer [21]

Types of Paint Mixing Machines

Generally there are various kinds of paint mixing machines available in the market. Tapas Rajashirvad Jena [22] laid it out that they vary in their size, shape, technology and methodologies. Some of the common types he discussed included

i. Laboratory mixers

These are lab grade machines which are commonly used in laboratories nowadays. It depends on high shear lab mixing ideal for research and developmental works. These are used for various kinds of applications such as mixing, emulsifying and dissolving with great precision. Their capacity can vary from 1 ml to 12 liters and offer excellent reproducibility. These are used where process validation is required.

ii. Ultramix mixers

These are designed for applications which are beyond the capabilities of conventional mixers. They also require a lower shear. These are designed for clean in place and sterilize in place options. The dynamic mixing head provides excellent in tank movement. The large volume of materials is incorporated by a large vortex. This requires low maintenance with robust control process. Their design suits excellent chemical services and sanitary requirements.

iii. Inline mixers

These mixers are highly efficient and capable of reducing the mixing time up to a great extent. These can be modified by rapidly interchangeable work heads. This helps to mix, emulsify, homogenize and disperse the colors. The features include aeration free, self-pumping, no bypass, and rapid dissolving.

iv. Flash band mixers

These disperse powders into liquids and create a near-perfect consistent homogeneous mixture. This has one of the complex applications. It is a high shear system. It incorporates a wide range of powders. This design helps to incorporate powders on a continuous and semi-continuous basis. This system can also handle a wide range of viscosities. This design is suitable for large production and also is an agglomerate free process.

v. Bottom entry mixers

These are a series of high shear mixers designed to fit into the bottom of the mixers and sometimes the sides also. These are used coaxially with a slow speed stirrer anchor for high viscous products. The mixer distributes the homogenized output throughout the vessel. This is an ideal option for high viscous products like cosmetics and pharmaceuticals. These can also be used on low viscosity products to wet out powders. It uses a double mechanical shaft for operation.

vi. Dissolver mixers

It uses a powerful and unique mixer present at the bottom of the custom-built vessel. The mixer impales a great amount of suction force downwards the liquid surface pulling down the buoyant fluids. These are ripped apart and dissolved throughout the liquid.

Some Previous Recent Research Works with Applicable Information to Designing Agitators for Paint Mixing

Saeed Asiri [23] designed and implemented a new kind of agitator called differential agitator. The agitator was an electro-mechanic set with two shafts. The first shaft was the bearing axis while the second shaft was the axis of the quartet upper bearing impellers group and the triple lower group which were called as agitating group. The agitating group was located inside a cylindrical container equipped especially to contain square directors for the liquid entrance and square directors called fixing group for the liquid exit. The fixing group was to be installed containing the agitating group inside any tank whether from upper or lower position. The agitating process occurred through the agitating group bearing causing a lower pressure over the upper group leading to withdrawing the liquid from the square directors of the liquid entering and consequently the liquid moved to the denser place under the quartet upper group. Then, the liquid moved to the so high pressure area under the agitating group causing the liquid to exit from the square directors in the bottom of the container. For improving efficiency, he carried out parametric study and shape optimization. He also conducted numerical analysis and manufacturing and laboratory experiments to design and implement the differential agitator. Knowing the material prosperities and the loading conditions, he used the Finite Element Method (FEM) with ANSYS11 to get the optimum design of the geometrical parameters of the differential agitator elements. He performed experimental test to validate the advantages of the differential agitators to give a high agitation performance of lime in the water as an example. In addition, he did experimental work to express the internal container shape in the agitation efficiency. He ended up his study with conclusions to maximize agitator performance and optimize the geometrical parameters to be used for manufacturing the differential agitator.

E. Rajasekaran and B. Kumar [1] noted that mixing is a very important unit operation in any dairy and food process industry. To attain uniform mixing with the optimal product preparation time for the desired quality and remove the drudgery of human folk, they developed and suggested a new automated agitator in their project about a dynamic mixer for a food processing industry particularly about milk making process. They considered the existing agitator not suitable for comfortable working condition to the workforce thus creating problems in the output of the different parameters of the organization efficiency like quality, quantity, delivery schedule and work force satisfaction. Their work suggested a new design for the agitators by careful study of three different models in all aspects, one of which was to be taken for the final fabrication. To finalize the best design, they used simulation to conduct required experiment. They took required inputs from different literature surveys and the discussion with the experts who were on the field and conducted real time study to get the exact requirement of the customer.

Dattatrava *et al.,* [24] developed bidirectional stirrer mixer by doing many changes in conventional design of mixer. They reported the results of their work as encouraging and giving better agitating performance over conventional method. They found that their bi-directional mixer rotated in both directions and gave better agitation effect resulting in more uniform mixture of product, and observed that the quality of mixture was very high. They also found that the production cost of the mixer was very low as compared to the conventional mixture as it required no gear box. The cost also reduced due to compact size of mixture which led to low space requirement. In overall their new developed mixer had low cost, high performance and structural simplicity.

Gaikwad Prasanna *et al.,* [4] designed, produced and tested a chemical agitator. The machine consisted of two main groups of which the first one was power transmitting group and second one was agitating group. The power transmitting group consisted of electric motor, gear box, bearing etc, while the agitating group consisted of impeller shaft, impeller blades and mixing chamber carrying chemicals that were continuously in contact with it. They supplied electricity to power the electric motor to run at 1440 rpm and achieved the desired 50-rpm speed of impeller in the mixing chamber using gearbox for speed reduction. They used bearing to hold the gearbox and the impeller shaft directly connected to the worm gear with the help of rectangular key arrangement to eliminate coupling. Due to their type of arrangement, they found that the cost of their unit was reduced up to 25% to 30% and its efficiency increased as compared to old type of agitators.

In their work, Sumit *et al.*, [25] emphasized the importance agitator shaft as component of agitation system used in reactor pressure vessel. They pointed out that failure of agitator shaft leads to breakdown of whole plant, and the existing agitator undergoes deflection that is not suitable for uniform mixing of fluid and increases the time required for agitation. They asserted that one of the major parameters to increase the overall performance of agitator shaft is to reduce deflection, and carried out their work to reduce deflection by optimizing the design or by using different materials like SS, SS304 and SS305. They redesigned existing single impeller agitator shaft by using SS316 material with double impeller and found that this improved overall performance by minimizing deflection of the agitator. They modeled their redesigned impeller agitator shaft using CAD modeling software. They also conducted stress analysis of the shaft subjected to combined loading using FEA software and compared their results with experimental values observed by company and wrote that the deflection of redesigned agitator was 0.8375 mm with a reduction of 14.997 % over that of the exiting agitator.

R. H. Pardeshi and Prof. I. M. Quraishi [26] described the mechanical design of agitator to mixing polyectrolyte having viscosity 1.5cp considering its forces imposed on the impeller. Their analysis showed that the forces were a result of turbulent flow of fluid and static fluid forces. They found the loads to be dynamic and transmitted from the impeller blades to the agitator shaft and then to the gear box. They wrote that agitator design is often the application of two engineering disciplines of chemical and mechanical designs. The first step they used was process design from a chemical viewpoint and involved the specification of the impeller pattern, speed, temperature and blade angle etc. The next step in their design sequence was the mechanical design of the agitator component. Their approach was straight forward design for the power (torque and speed) and then shaft loads. They carried out experiment with agitator of 500-liter capacity and found that the drawback of the old agitator by not giving homogeneous mixing was removed.

Shivam M Shukla and Prashant S Bajaj [27] noted that in this era, mixing is one of the most fundamental operations in industries like paper, food, cosmetic, chemical, biochemical and pharmaceutical applications. They discussed pressure vessel agitator as one of the important parts in the mixing process. They argued that proper and uniform mixing gives improved quality of the product. In their paper they mainly focused on detection of failure mode of pressure vessel agitator for variable load. They reaffirmed that design of agitator affects the mixing process as proper design can increase the mixing and uniform distribution of all additives, chemicals and, raw materials present in the fluid. Their review helped them to design an error prone model for agitator blade which would increase the mixing percentage whilst avoiding the deflection of the blades. They opined that dimensions calculated by the theoretical formulae may lead to high dimensions along with more thickness of the blades being sized. In order to avoid these troubles they said the approach of Design by Finite Element Analysis must be adopted where simulation of the agitator model is being developed and being analyzed using the various loads being applied for different speeds of rotation. They said result of their analysis would help to figure out optimum size of the blades along with the trouble of bending of the blades be avoided.

Dr. T.N. Guma and Anthony Agbata [28, 29] presented the design and simulation integrity tests of a mechanical agitator for efficiently mixing paint to requisite consistent properties in sealed tank of total mass up to 200Kg without having any contact with the paint itself. Basically, they designed the agitator to consist of a steel supporting frame structure for the tank and a 50mm-diameter-90mm-long steel shaft gear-driven with a torque of 1800Nm by a 4-Hp electric motor for rotation of the tank carrier to continuously rotate the tank with angle inclination of 22° through 360° during the required agitation time to agitatedly mix the tank content. They selected three square hollow structural steel (SHSS) frame sectional profiles of 40x40mm, 50x50mm, and 60x60mm and 3mm wall thickness for the structural elements of the agitator. They then analyzed operational deflections and stresses in the frame structures using effective elasticity formulae with each SHSS section and repeated the same by simulation integrity tests with Solidworks under various static and operational design loads to assess the overall integrity of their designed agitator in service. The validated that the agitator was well designed to be structurally sound with the 60 x 60mm SHSS as the optimal profile by comparison of their obtained analytical and integrity test information with acceptable limits for structural deflection, strain and stress codes. In overall, they recommended their design to be used to develop the agitator by arc-welding the selected 60 x 60 SHSS components in place and used to remove the drudgery of human folk in mixing paint in massive tanks to desired consistent properties before blending it with additives in standard facility prior to painting to avoid inconsistencies in the requisite blend properties and consequent paintwork costs.

N. B. Jadhav, Prof. V. G Bhamre [30] designed a bidirectional agitator using scotch yoke mechanism with the objective to blend the weighty density metal powder in the paint. They noted that the automobile industries uses low density evaporative fluid which when mixed with metal oxide powder gives superior quality of paint. To ensure the good quality of paint it is necessary that the oxide powder is painstakingly mixed with low density fluid. The proper homogenization of paint is only possible by creating vigorous shaking in the content. To create high instability in fluid and powder mixture they designed a bi-directional agitator with impeller that rotated in ahead and reversed direction. They tested the agitator and found that it gave more effective agitating turbulence and was more energy efficient than the conventional one and saved 13845.55 Rs/Month because it uses only one motor to drive the impeller while conventional agitator uses 3 motors. They designed the impeller considering the bending moment, static forces, pressure on blades etc and explained the detailed design method of worm and worm wheel reduction gear box14:1. In the development of this agitator many changes were done in conventional design of mixer. The reported the results of their work as encouraging with better agitation with optimal time effecting in more uniform mixture of product over the conventional method.

Mr A. P Shastri and Prof. N. Borkar [31] conducted a review on nomenclature of agitator. They noted that in this era, mixing is one of the most fundamental operations in industries like paper, food, cosmetic, chemical, biochemical and pharmaceutical applications. Agitator is one of the important parts in the mixing process. Proper and uniform mixing gives improved quality of the product. In their review paper, they mainly focused on different types of agitator used to increase the mixing performance in industries. Different parameters for the design of good-performing agitator were reviewed. They wrote that the design of agitator affects the mixing process as proper design can increase the mixing and uniform distributions of all additives, chemicals, raw material present in pulp. Their review drove them to design an error prone model for agitator which will increase the mixing percentage, ultimately increase the gain of industry to get place into market with price for product. They, Sumit R. Desai *et al.*, [25] and Saeed Asiri [23] presented the review some parameters for the design of agitators as follows:

Standard Relation for the Agitator, Geometry

Equation (1) shows the standard relations in geometry of type and location of impeller, proportions of vessel and number of impeller blades.

$$\frac{D_a}{D_t} = \frac{1}{3}, \frac{W}{D_a} = \frac{1}{5}, \frac{L}{D_a} = \frac{1}{4} \qquad \text{. .... (.1)}$$

Where D_a is the impeller diameter, D_t is the tank or container diameter, W is impeller blade width, and L is impeller blade length.

Power Consumed In Mixing And Agitation.

The power requirement (P) for mixing is a function of power number and Reynolds number which are depending on dimensions selected and is given by:

$$P = N_P {D_a}^5 N^3 \rho \qquad \text{…………………………….. ……… (2)}$$

Where, N_P is the power number. D_a is the impeller diameter (m), N is the impeller speed (m/s) and ρ is the fluid density(Kg/m^3). The power number depends on Reynolds number. Reynolds number can be determined as:

$$R_e = \frac{\rho N {D_a}^2}{\mu} \qquad \text{…………………………. (3)}$$

Where μ is the fluid viscosity$(N.s/m^2)$ Power number

$$(N_P) = \frac{Pg}{\rho n^3 {D_a}^5} \qquad \text{… … … … … … (4)}$$

Where g is the Newton's law proportionality factor

The minimum impeller blade thickness

The minimum impeller blade thickness (t) can be calculated as:

$$t = 0.981 \sqrt[2]{\left(\frac{PF_L\left(\frac{D_t}{2}\right) - \left(\frac{D_S}{2}\right)}{Nn_b Sin\alpha\left[F_L\left(\frac{D}{2}\right)\right]W\sigma_b}\right)} \qquad \text{…………… (5)}$$

Where:F_L is the location fraction for the flat blade turbine (FBT) and is equal to 0.8, W is the width of the blade (m), n_b is the number of blades, σ_b is the blade allowable stress, and α is the blade angle.

Shaft Torque

The maximum shaft torque will occur above the uppermost impeller. The maximum torque (T) for rotational speed of $\omega(rad/s)$ or n revolutions per second can be calculated as:

$$T = P/\omega = P/2\pi n \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (6)$$

Stresses and Shaft Diameter

The maximum operative bending moment(M) on the shaft is the sum of forces on the multiplied by the distance from the individual impellers to the bottom bearing in the mixer drive. The minimum shaft diameter (d) can be determined from the larger value of d_S or d_t from equations 7a and 7b respectively.

$$d_S = \sqrt[3]{\frac{16\sqrt{T_S{}^2 + M^2}}{\pi\tau_{max}}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (7a)$$

$$d_t = \sqrt[3]{\frac{32\left(M + \sqrt{T_S{}^2 + M^2}\right)}{\sigma_{max}}} \quad \ldots\ldots\ldots\ldots\ldots \quad (7b)$$

Where:τ_{max} = maximum allowable shear stress of the shaft material, and σ_{max} = maximum allowable tensile stress of the shaft material, T_S = maximum operative torque on the shaft, M = maximum operative bending moment on the shaft.

CONCLUDING REMARKS

Paint is a very important product that is commonly used worldwide for corrosion coat-protection of structural materials and enhancement of aesthetic values of objects. It is estimated that about 90% of all applied structural materials are decorated or corrosion-protected by paint coatings. Large quantities of paints are used daily in painting buildings, automobile bodies, aircrafts, ships, industrial systems, etc. Paint is however a highly heterogeneous liquid solution involving many solid components which if not mixed all the way, its components will not be blended and its true color, consistency, corrosion-protectiveness and economic viability will not be achieved in application due to various paintwork defects like flaking and peeling, absence of gloss, runs and sags, cracking in its coatings, etc. The most efficient, fastest, and labor- serving means of mixing paint is by mechanical agitation. Although there are different types of agitators in existence for mixing paint, no universal system till now has been found valid for agitating paint and other fluid quantities in different container sizes and shapes. For optimal functionality, efficiency, productivity, reliability, and economy, agitators are usually individually designed and tailored to meet the special requirements of customer instead of mass - producing them to avoid little or no demand for them in many other requirement cases with losses. Design specifications of agitators for mixing paint can be different from those of other liquid solutions for the same mixing quantities due to distinctiveness of paint properties such as viscosity, density, segmentation level, and environmental susceptibility. The paper has reviewed some revolutionary works in the area fluid agitation to provide a compendium of basic applicable information that need to be understood by those that care for advancements of agitator designs to optimally meet different paint mixing requirements. The review showed that the required mixing quantity per unit time, shape and size of paint container, impeller size and rotational speed, shaft strength, powering system, agitation time, and, structural anchorage system for the container are the basic design parameters for the agitators. These parameters along with basic considerations such as: ease of operation, operational efficiency and integrity, reduction of agitation time, cost reduction, reliability, durability, safety, reduction of paint exposure time to environment, ease of paint pouring in and out of containers and, easy means of loading heavy paint containers in place and unloading them were seen to be crucial in advancing the agitator designs.

REFERENCES

1. Rajasekaran, E., & Kumar, B. (2014). Agitator and wiper design modification for milk khoa machine. *Int J Innov Res Sci Eng Technol*, *3*(1), 1262-1267.
2. Wang, J. (2010). Suspension of High Concentration Slurry in Agitated Vessels, School of Civil, Environmental and Chemical Engineering. *RMIT University, Melbourne*.
3. Nienow, A. W. (1994). The Suspension of Solid Particles in Mixing in the Process Industries, 2nd ed., Harnby, N., Edwards, M. F., & Nienow, A. W. Eds. Butterworths, London, U.K., 364-393.

4. Gaikwad, P. P., Gaikwad, P. N., Rathod, P. S., Muley, S. L., Deshpande, S. V. (2016). Design and manufacturing of chemical agitator. *IJARIIE*, 2(3), 3093-3098.
5. Bakker, A., & Gates, L. E. (1995). Properly choose mechanical agitators for viscous liquids. *Chemical engineering progress*, *91*(12), 25-34.
6. Brinkop, A., Laudwein, N., & Maasen, R. (1995). Routine design for mechanical engineering. *AI Magazine*, *16*(1), 74.
7. Guma, T. N., & James, A. (2018). A Field Survey of Outdoor Atmospheric Corrosion Rates of Mild Steel around Kaduna Metropolis. *SSRG International Journal of Mechanical Engineering*, 5, (11).
8. Shafiei, E., Zeinali, M., Nasiri, A., Charroostaei, H., & Gholamalian, M. A. (2014). A brief review on the atmospheric corrosion of mild steel in Iran. *Cogent Engineering*, *1*(1), 990751.
9. Guma, T., Aku, S., Yawas, D., & Dauda, M. (2014). An overview assessment of various surveyed corrosion protection approaches for Steel. *IOSR Journal of Engineering*, *4*(11).
10. Why we stir paints thoroughly before use? - Quora. https://www.quora.com/Why-we-stir-paints-thoroughly-before-use. Accessed 02/11/2018.
11. What will happen if a painter does not mix the paint before he uses it? *https://www.quora.com/What-will-happen-if-a-painter-does-not-mix-the-paint-before-he.* Accessed 15/9/2018
12. Paul, E. L., Atiemo-Obeng, V. A., & Kresta, S. M. (Eds.). (2004). *Handbook of industrial mixing: science and practice*. John Wiley & Sons.
13. Asiri, S. (2012). Design and implementation of differential agitators to maximize agitating performance. *International Journal of Mechanics and Applications*, *2*(6), 98-112.
14. Optimum Viscosity for Paint Application - American Coatings Association, https://www.paint.org/article/optimum-viscosity-paint-application/ Accessed 10/10/2018.
15. Images for types of Paint Mixing Machines. Accessed on INTERNET 27/10/2018.
16. Mixing process engineering https://en.wikipedia.org/wiki/mixing_(process_engineering). Accessed 23/07/2017
17. Dickey, D. S., & Fasano, J. B. (2004). Mechanical design of mixing equipment. *Handbook of Industrial Mixing: Science and Practice*, 1247-1332.
18. KLM Technology Group-Practical engineering guidelines for processing plant solutions www.klmtechgroup.com. Retrieved 12/01/2018
19. http://www.stamixco-usa.com/principles-of-operation, Principles of operation of static mixers. Accessed 12/01/2018
20. Albright, L. (2008). *Albright's chemical engineering handbook*. CRC Press.
21. Diffusion Mixers In Blending and Mixing Equipment by Calistus OziokoJanuary 11, 2016. Accessed 13/05/2018.
22. Raj, T., & Jena, A. (2014). *Design and development of an automated paint mixing machine* (Doctoral dissertation).
23. Asiri, S. (2012). Design and implementation of differential agitators to maximize agitating performance. *International Journal of Mechanics and Applications*, *2*(6), 98-112.
24. Patil, D. P., Patil, V. P., Shrotri, A. P., & Mane, N. S. (2015). Design and Development of a Special Purpose Bidirectional Mixer to Maximize Agitating Performance. *International Journal of Modern Studies in Mechanical Engineering (IJMSME)*, *1*(1), 1-7.
25. Sumit, R., Desai, S. Y., & Gajjal, K. (2016). Redesign and structural analysis of agitator shaft for reactor pressure vessel. *International Journal of Current Engineering and Technology*, (4), 268-273.
26. Pardeshi, R. H., & Quraishi, I. M. (2016). Design and development of vertical agitator. *International Journal of Engineering Research in Mechanical and Civil Engineering*, (1), 64-70.
27. Shivam, M. S., & nbspPrashant, S. B. (2018). Detection of Failure mode of Pressure Vessel Agitator due to variable load. *International Journal of Engineering Development and Research (IJEDR)*, *6*(1), 329-334.
28. Guma, T. N., & Agbata, A. (2018). Design of a mechanical agitator for supplementing paint mixing with standard facilities. *International Journal of Engineering Research and Technology*, 7(10), 130-139.
29. Guma, T. N., & Agbata, A. (2018). Simulation Integrity Test of a Designed Mechanical Agitator for Supplementing Paint Mixing with Standard Facilities. *International Research Journal of Engineering and Technology*, *5*(12), 1332-1344.
30. Jadhav, N. B., & Bhamre, V. G. Experimental investigation of agitator to optimize performance & cost. *International Engineering Research Journal*, 1154-1162.
31. Shastri, A. P., & Borkar, N. B. (2015). A Review on Nomenclature of Agitator. *International Journal of Research in Advent Technology. Special Issue on Special*, (1st), 435-439.