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Design of a batch plastic mixer capable of mixing a 50 kg of thermoplastic materials and addictives

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Abstract
A batch plastic mixer was designed for the thorough mixing of thermoplastic pellets and additives (Master batch) in order to solve the problem of colour streaks and uneven wall-thickness normally encountered in the plastic end-products of poorly mixed materials using engineering solid works. The mixer was designed to be able to thoroughly mix a 50 kg of plastic materials at a time. The batch mixer has been designed to have 4 baffle points with an impeller diameter of 27.33 cm, impeller blade of 5.44 cm, impeller width of 3.87 cm and impeller of height of 9.33 cm. To avoid vortex formation, which could cause poor mixing point in the mixer, the impeller angle returns to 90^o, with the shaft having a motor speed of 7460 rpm and a power rating of 10 hp. The designed mixer has a shaft diameter of 2.5 cm, while the depth and volume of the cylindrical tank were 70 cm and 500 litres respectively.

Keywords: Design, material selection, batch plastic mixer and mixing efficiency

Introduction

In polymer processing, perfectly homogenized melt plays a decisive role in achieving high quality plastic end-products [3, 15]. To maintain high quality end-products that meet consumers' satisfaction, material mixer machines, also known as plastic blender mixers, are used to thoroughly mix and blend plastic materials and additives together prior to any production process [4, 16]. According to [6, 9], in industrial and engineering processes, mixing is a unit operation that involves the manipulation of a heterogeneous physical system with the intent of making the system more homogeneous. Mixing is carried out to allow heat and or mass transfer to take place between one or more streams, components or phases.

A mixer is a vital equipment used in a variety of industries and applications to combine two or more substances uniformly into a homogeneous mixture. The process of mixing involves the integration of different components, such as solids, liquids, powders, or gases, to achieve a desired outcome [1, 14]. Mixers find extensive use in chemical, pharmaceutical, food and beverage, cosmetic, and other industries where product quality and consistency are of utmost importance [1, 2, 5]. Achieving efficient and effective mixing is essential to ensure product quality, uniformity, and reproducibility. Consequently, researchers and engineers continually strive to develop innovative mixer designs and fabrication techniques that enhance mixing performance while minimizing energy consumption and production costs [15]. The success of many process operations depend on the effective agitation and mixing of the materials involved in the production. Agitation refers to the induce motion of a materials in a special way, usually in the circulatory pattern inside some sort of container. The term mixing can be applied to a variety of operations, differing widely in the degree of homogeneity of the mixed materials and for an effective agitation and mixing to take place, an impeller must be present [10]. This impeller is mounted as an overhung shaft supported from above and it is driven by a motor. The impeller creates a flow pattern in the system, causing the fluid to circulate through the vessel and return eventually to the impeller. Proper agitation and mixing of materials is a function of the position of the installed impeller in an agitated vessel during a process performance [10]. The design and fabrication of a mixer encompasses a range of considerations, including the mixing mechanism, geometry, material compatibility, energy input, and operational parameters [3, 6-8]. According to [8, 14], both batch and industrial mixers are effective equipments that efficiently enables the necessary interaction between mixed elements in order to get a high quality end- product. These equipments ensures a thorough and consistent mixing of all plastic granules, flakes and powders in order to guarantee a reliable and high quality end -product. In order to eliminate faults such as colour streaks, flow lines and uneven wall thickness in plastic end-products and at the same time improve its colour homogeneity, uniformity and plasticity, the design of a batch (static) plastic mixer came about.

Methods
The batch plastic mixer was designed using engineering solid-works with certain considerations in mind.

Factors/Design Considerations
For the design of the batch plastic mixer, the following factors were taken into consideration in the development of the machine parts:

- Minimum energy requirement
- Simplicity in design to ease fabrication
- Cheap source of raw materials
- Layout and material selection.
- Cutting of materials
- Forming
- Fastening
- Testing
- Finishing.

BArch Mixer Operating Parameters

- Operating pressure = 1 atm
- Operating temperature = 40 °C
- Internal surface area = 8780.52 cm^2
- Volume of tank = 50620.70 cm^3
- Operating volume = 24000 cm^3
- Volume clearance = 105470.60 cm^3

Vessel design

- Depth of tank = 70 cm
- Depth of polymer material = 50 cm
- Number of baffles = 4 pcs
- Number of vessel = 40 cm
- Width of baffle = 7.88 cm

Impeller Data

- Diameter of impeller = 27.33 cm
- Diameter of disk = 10.40 cm
- Length of the blade = 5.44 cm
- Width of the blade = 3.87cm
- Height of the impeller above the bottom level = 9.33 cm
- Angle of the blade = 60^o
- Impeller type = Disk flat blade turbine with six blades.
- Angle of agitation = 90^o
- Number of blades = 6

Motor Rating Type
Power = 10 hp
Speed = 7460 r.p.m

Shaft Diameter: Diameter of shaft = 2.5 cm

Material selection
Vessel = Mild steel
Impeller = Mild steel
Shaft = Steel

Volume and Capacity
Since the tank is cylindrical, the volume was arrived at as described by [3, 9, 16] in the given equation;

$V = \pi r^2 h$ (1)

Given π 22/7
r = 0.5m
h = 0.101m

Substitution
$V = \pi \times (0.5)^2 \times 0.101$
V= 0.05062070 M^3
V= 500litres

Torque Transmitted by Electric Motor
According to [11], the torque transmitted by an electric motor can be given by:

$T = 9.55\ P/N$ (2)

Where, T is the torque transmitted (Nm)
P is the power of the electric motor (watt)
N is the number of revolution per minute of the electric motor (rpm)

Recall
1Hp = 0.7457 kw
10Hp = xkw
Xw = 10 x 0.7457
Xw = 7.457 kw
X = 7457 w
T = 9.55 x 7457/7460 = 9.546 Nm

Isometric view of the batch plastic mixer with baffles and agitators
An agitator and its surrounding are a mechanical system of mounding and fixed point in which binding, torsion shear and fatigue stresses are encountered. Bearing supports, shifts, couplings, impeller hubs, impeller blades, baffles and supporting structural parts have been designed according to their stress experiences during operation.
If an impeller is mounted centrally, and there are no baffles in the tank, there is a tendency for the higher fluid or material mixture to be drawn in to form vortex, and for the degree of agitation to be reduced.

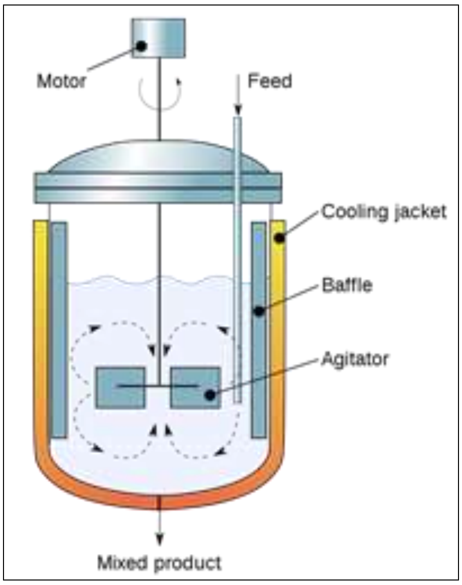

Fig 1: An isometric view of the batch plastic mixer

To improve the rate of mixing, and to minimize vortex formation, baffles are usually filled in the tank, and the resulting flow pattern is shown below:
Axial flow impeller (left) and flow impeller (right)

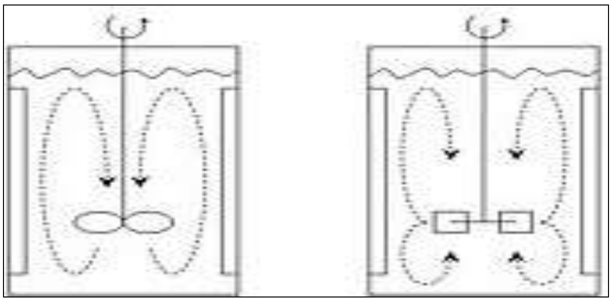

Fig 2: Flow pattern of materials under impeller agitation

The power requirements are, however considerably increased by the incorporation of baffles. Another way of minimizing vortex formation is to mount the agitator, off-center, where the resulting flow pattern is depicted below.

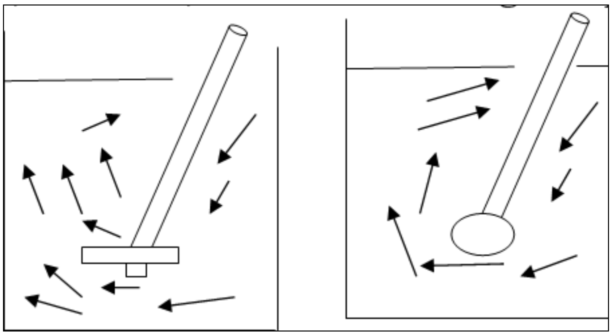

Fig 3: Flow pattern with agitator off center

Vessel Design
An open cylindrical vessel with flat bottom is recommended for this work. Mild steel will be used in the fabrication for its corrosion resistance, cleanliness and relative low cost. The design of the vessel involves consideration of details such as wall thickness, size and number of openings, shape of heads, necessary temperature and pressure controls and corrosive action of the contents. The necessary wall thickness for the vessel is a function of;

- The ultimate tensile strength or the yield point of the metal at the operating temperature.
- The operating pressure
- The diameter of the tank and the joint welding efficiencies.

Impeller Selection
Disk flat blade turbines are extensively employed in dispersion because of the high discharge velocities normal to the flow of the solid, which they maintain. They also have characteristics, which allow them to be operated in baffled tank over a very wide range of viscosity for the same power input, thus they can be used for a variety of operators involving liquids of different viscosity without fear of over loading the drive motor. These are desirable qualities for this agitator and are therefore chosen for the design. More so, this impeller is easier to fabricate when compared to shrouded propeller and paddle [10].

Fig 4: Isometric view of the impeller

Motor Rating (Power Required To Drive the Shaft)
The first fact of consideration here is the size of or horse power rating of the motor required to drive the shaft.
To produce the required flow pattern and flow velocity, it is necessary to move fluid against resistance heads. These resistance heads arise due to specific viscosity, eddy viscosity turbulence, and friction and solid surfaces. Power must be applied through the mixer to overcome these resistance. Motor is used as the prime mover in this research and it is located close to the supporting bearing to reduce the bending moment and hence the deflection and bending stress.

Shaft Selection
Shaft are usually subjected to torsion, bending and axial loads. Because the shaft is subjected to a torsion load, an axle shaft is recommended. Also for the fact that the lateral and torsional deflection of the shaft are held to close limits, the shaft is sized before the stresses. The shaft should be stiff enough in order to minimize deflection and be able to regulate stresses properly during operation.

Rate of Mixing
Once a suitable measure of mixing has been found, it becomes possible to discuss rate of mixing accomplishment. It has been assumed that the mixing index ought to be such that the rate of mixing at any time under constant working conditions, such as in a well-designed mixer working at constant speed, ought to be proportional to the extent of mixing remaining to be done at that time as described by [2, 9, 13, 14].

That is, $dM/dt = K[(1 - (M))]$ (3)

Where (M) is the mixing index and K is a constant, and on integrating from t = 0 to t = t during which (M) goes from 0 to.

$(M), [(1 - (M))] = e^{-Kt}$ or $(M) = 1 - e^{-Kt}$ (4)

This exponential relationship, using (M) as the mixing index, has been found to apply in many experimental investigations at least over two or three orders of magnitude of (M). In such cases, the constant K can be related to the mixing machine and to the conditions and it can be used to predict, for example, the times required to attain a given degree of mixing.

Discussion

The mixer has been designed to save cost, save energy (especially at power rating of 10 hp). With a motor speed of 7460 rpm, 4 baffle points, impeller diameter and height of 27.33cm and 9.33 cm respectively, the mixer would be able to ensure thorough mixing or blending together of the plastic materials to obtain a high quality end -product and in a timely manner too. These operating parameters would also ensure a near zero vortex formation that could initiate water or air voids, which could adversely impede production efficiency and quality of the final products as described by [3, 5, 10]. At a torque of 9.55 mm and a shaft diameter of 2.5 cm, the impeller would have sufficient power and force to efficiently mix a 50 kg of plastic materials in the 500 litre mixer tank.

Conclusion

Plastic products usually face rejection from customers due to colour streaks and uneven wall thickness or flow lines arising from poor mixing of the plastic materials involved in the production, hence the design and eventual fabrication of the 500 litre batch plastic mixer, would eliminate these defects in plastic end- products. Apart from ensuring a colour uniformity of the end-products, the service life of the products will be stretched further due to the enhanced homogeneity of the material blends and equally reduce the business operational cost due to fewer flash formation. Ultimately, the batch plastic mixer would be operated at no cost to the environment.

Conflicts of Interests

The authors declare that there are no conflicts of interests in carrying out this research and its publication.

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