Original Research Article

DESIGN OF CURVED-TYPE IMPELLER FOUNDRY SAND MIXER

Abstract

This paper is concerned with design and modeling of a sand mixer with an arrangement of curved-type impeller, driven by a geared motor using the dynamic simulation environment in Autodesk® Inventor® 2015. The study highlights the high demand for foundry sand and need for efficient and cost effective designs. Furthermore, it describes the various types of foundry sand, their importance and objectives of sand mixers. The methodology employed involves the design of geometrical parameters of the cylindrical stirred tank, the torque exerted on the shaft of the gearbox of radial flow impellers and driving mechanism. A simulated torque of 206.861Nm was achieved and used to determine the actual power required by the electric motor and mixer efficiency to be 1.5HP and 64.45% respectively. The results showed that the design of highly efficient mixers to achieve homogeneous mix of foundry sand for assured mold can be accomplished using computational analysis.

Key words: curved-type impeller, Autodesk® Inventor®, sand mixers, geometrical parameters, and torque.

1. Introduction

In recent years, the global increase in the number of foundries as a result of high level industrialization has created an auspicious demand for foundry sand, which has also necessitated the need for an improved casting quality sand mixer. No doubt, this trend has mounted more pressure on design experts cum researchers globally to come up with efficient and cost effective designs in order to achieve uniform distribution of foundry sand grains as it affects not only the permeability of foundry sand, but also their surface fineness, flowability and strength properties of bonded mixtures. Foundry sand refers to the various kinds of sand used in the foundry for casting, they differ in texture and nature; such as green, core and molding sands [1]. Green sand is an aggregate of sand, bentonite clay, pulverized coal and water. It is principally used in making molds for metal casting. On the other hand, core sand is very clayey while molding sand is very loamy, and is also known as foundry sand; when moistened or oiled tends to pack well and hold its shape, also used in the process of sand casting [2]. The high demand of foundry sand over time has led to the depletion of areas with large deposits of appropriate sand for casting operations and in turn gave rise to the production of synthetic sands [3]. Synthetic sand is artificially produced foundry sand, where the materials are carefully selected, sorted and blended together at designed proportions to meet the desired requirement for the metal to be poured in; therefore, foundry sand is categorized either as natural sand or synthetic sand. The demand for foundry sand is based on the composition, texture and its ability for reuse [4]. The resulting shaking off of lumped/coagulated sand from the cast requires further processing via thorough mixing. Hence, to achieve quality cast products and for proper admixture of foundry sand before use/reuse, it is imperative to use sand mixers. Mixers are an important integral in the synthetic/artificial sand production, they are described by [5] as mechanical attrition machines which stir the sand mix to proper uniformity and texture before using as molding sand. The mixer ensures the intimate and uniform mingling of clay and sand. Even though there are different types of mixers, the commonly used ones in foundry operations are sand mixers and sand mullers [6]; with much attention given to sand mixers due to their increasing use in foundry operations, based on reduce operational issues, low capital/maintenance cost as well as high efficiency.

No doubt, lots of attention has been focussed on sand mixers in recent times; [7] performed a design analysis and testing of sand muller for foundry application, while [8] produced a dough mixing machine. Sothea, *et al* [9] developed a crush and mix machine for composite brick fabrication and Sekar, *et al* [10] designed and constructed multiple casting machine which is a foundry equipment. Osarenmwinda and Iguodala [11] designed and fabricated a foundry sand mixer with rapped attention on the use of locally fabricated materials.

The objective of sand mixers is to achieve uniform mixture of moulding sand by using rotating blades driven by an electric motor. [12] A suitable design of sand mixer will facilitate continuous metering and blending of the constituents and rapid delivery to point of use [13]. Sand with a uniform bond coating and complete absence of uncoated grains will be more thermally stable than poorly mixed sand [7, 11,14 – 15]. These designs consider the use of flat blade which has a reduced mixing effect. Furthermore, the torque used were theoretically determined which does not represent the actual required torque.

Therefore, the choice of blade geometry that guarantee improve mixing effect and actual torque is crucial to the development of a foundry sand mixer. In this work, a foundry sand mixer with curved blades was considered and used for simulation to produce the actual simulated torque.

2. Principle of Operation of Sand Mixer

The sand mixer being described is an arrangement of curved-type impeller, driven by a geared motor. The impeller is usually composed of blades mounted to a central hub and rotated by a drive shaft in one direction (charge direction) that pushes and moves the material to be mixed inside a stirred tank with a closed discharge opening (Fig. 5). When foundry sand lumps are finally broken down and homogeneous mixing achieved by agitation of the sand within the stirred tank, the final product is released through the discharge opening.

The mechanical design of curved-type impeller sand mixing equipment is responsible for the process by which some form of energy, such as electricity, is converted into fluid motion and ultimately dissipated as heat. In order to achieve an efficient mixer design, there is need to determine the torque exerted on the shaft of the gear box of a radial flow impeller with two curves and a coupling force exerted on it using the weight of the bulk foundry sand which represent a key design factor for maximum performance and reliability and is the main focus of this paper.

2.1 Design parameters of sand mixer

The design of the sand mixer considers the geometrical parameters of the cylindrical stirred tank, the torque, shaft and driving mechanisms. In this paper, it was assumed that the mixer stirred tank was designed such that the height (H_t) is 15% higher than the maximum material height of sand poured in the tank (H_1) with H_2 representing the allowable height for proper agitation and prevention of material flight outside the stirred tank.

$$H_t = H_1 + H_2 \quad (1)$$

$$H_2 = 0.15H_1 \quad (2)$$

A geometric diameter to maximum material height ratio of 1:1.5 was assumed with a bulk density (ρ_b) of foundry sand of 1600kg/m^3 [15] respectively. The sand mixer is intended for use in a small scale foundry hence the geometric considerations.

$$\frac{D_t}{H_1} = \frac{1}{1.5} \quad (3)$$

The required material volume of the cylindrical stirred tank (V_t) is given by:

$$V_t = \pi\left(\frac{D_t^2}{4}\right)H_1 \quad (4)$$

In order to design for bulk mass (m_b) of foundry sand,

$$m_b = V_t \times \rho_b \quad (5)$$

2.1.1 Gearbox and motor selection

In the course of developing the theoretical design for this work, the gear unit selection was made by comparing actual transmitted loads (simulated torque) with the nearest output torque on the Table 2 for catalogue ratings based on standard set of loading conditions for the application. [16] Therefore, a gear reduction ratio of 30:1 was chosen to be the appropriate standard required to reduce speed (in rpm) of the electric motor. Using gear speed ratio, the speed of the shaft in rpm was determined using:

$$\frac{N_1}{N_2} = {}^{30}\!/_{1} \quad (6)$$

Where, the gearbox input speed (N1) is 1500 rpm and shaft output speed (N2) is evaluated. Furthermore, it is important to realize that catalogue ratings are based on a standard set of loading conditions which change depending on application. Therefore, a service factor must be used to calculate the equivalent output power, before comparing with catalogue ratings and is given by [16]:

$$\text{Equivalent Output Power} = \text{Input Power} \times \text{Service Factor} \quad (7)$$

Electric motors convert electric energy into mechanical energy (rotation of the shaft) and are manufactured with standard rotational speed (rpm) ratings and input power required to drive the gearbox. The selected motor for this design followed the standard rating procedure and a 1.5 HP, 3 phase electric motor running at a speed of 1500rpm was selected.

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2.1.2 Shaft design

The rotating shaft is attached to the gear reduction system and the shaft diameter (d_s) used for this work is made from mild steel under torsion with a simulated torque of 206.861Nm and allowable bending stress (σ_s) of $48 \times 10^6\,\mathrm{N/m^2}$, therefore, to determine the required shaft diameter according to [7], is given as:

$$d_s = \left[\left(\frac{\tau_s}{\sigma_s}\right)\frac{16}{\pi}\right]^{1/3} \quad (7)$$

2.2 Efficiency of the Mixer

The efficiency ε, of a machine is given by a relationship between the output power (i.e. power required by the gearbox) and the input power (power supplied by the electric motor). Hence the efficiency for sand mixer is given as [17,18]:

$$\varepsilon = \frac{\text{Power Required}}{\text{Power Supplied}} \times 100\% \quad (8)$$

2.3 Description of the Dynamic Simulation

The dynamic simulation environment in Autodesk® Inventor® 2015 which constitute a part of an integrated design and analysis system has been used to perform dynamic analysis of a mechanical system for a mixer with curved-type impeller, driven by a geared motor. The process is based on multi-body dynamics theory. In this theory, the components of a mechanical system are modelled as rigid bodies interconnected by joints.

The software uses Gruebler's equation to establish the mobility of the planar mechanism for a mixer with curved-type impeller, driven by a geared motor (Fig. 4) and is given as [19]:

$$DOF = 3(b) - 2(r) - 2(p) - 3(g) \quad (9)$$

DOF represent the degree of freedom, b is number of bodies $(b = 2)$, r is the number of revolute joints $(r = 1)$, p is the number of prismatic joints $(p = 0)$ and g is the number of grounded bodies $(g = 1)$; which resolves to a single motion constraint.

The Constraint equation for the joint is used in conjunction with Lagrange's equation of motion to create a system of differential-algebraic equations. [19]. The torque exerted on the shaft of the gear box is determined by running the dynamic simulation of the designed model of a radial flow impeller with two baffles and coupling forces exerted on it using the weight of the bulk foundry sand. The solution of these equations solved by Newton Raphson's method provides the value of the torque exerted on the shaft of the gear box.

3. Simulation Result and Discussion

The parameters used for the implementation of the design of this study are shown in Table 1. It can be seen that the torque exerted on the shaft of the gearbox was simulated to be 206.861Nm for the design study of this particular work.

Table 1: Design parameters for the dynamic simulation study (the parameters are values taken from referenced standard tables and from calculations shown in equations 1-8)

Parameter,	Unit	Value
$\mathbf{D_t}$	m	0.394
$\mathbf{H_t}$	m	0.680
$\mathbf{H_1}$	m	0.591
$\mathbf{V_m}$	m^3	0.072
$\mathbf{m_b}$	kg	115.200
$\boldsymbol{\varepsilon}$	%	65.45
$\boldsymbol{\tau_s}$	Nm	206.861
$\boldsymbol{G_u}$		M237
$\mathbf{P}_{\boldsymbol{i}}$	KW	1.460
$\mathbf{P_a}$	KW	0.941
$\mathbf{d_s}$	m	0.028
$\mathbf{N_2}$	rpm	50

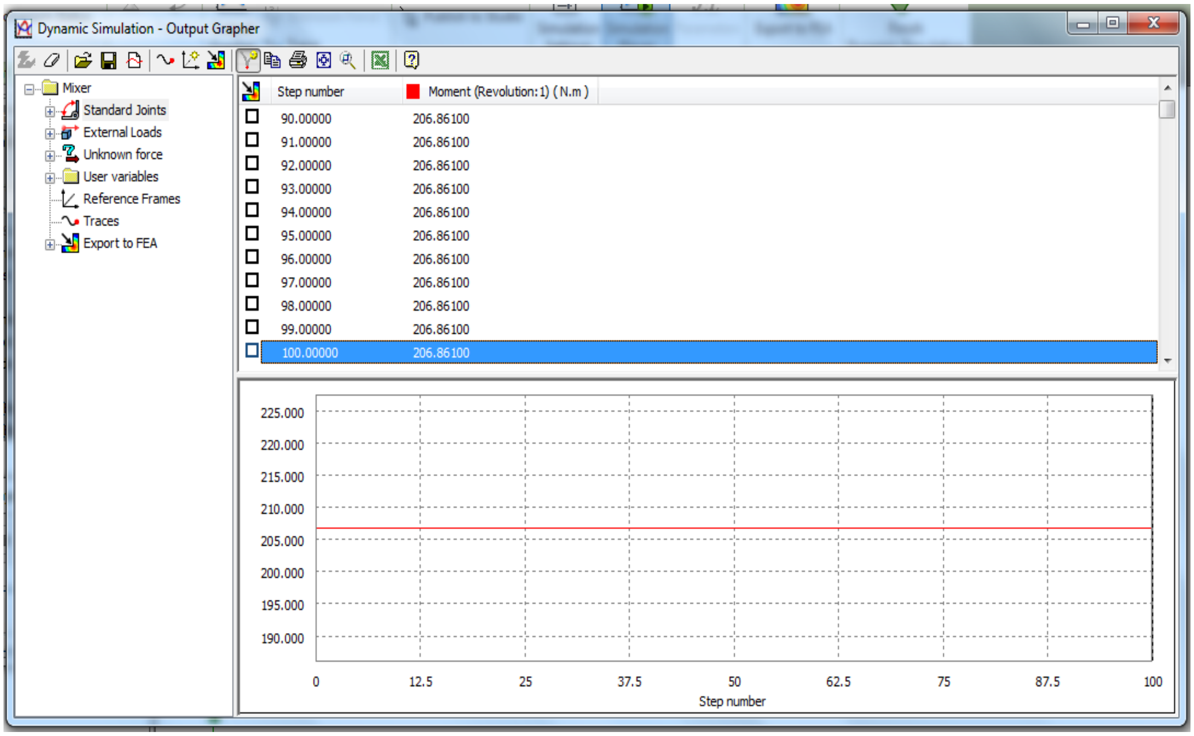
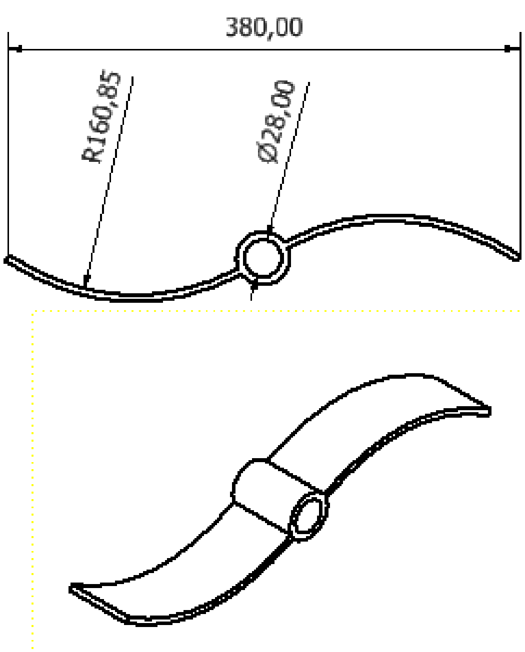


Fig. 1. Dynamic simulation analysis of torque exerted on the shaft



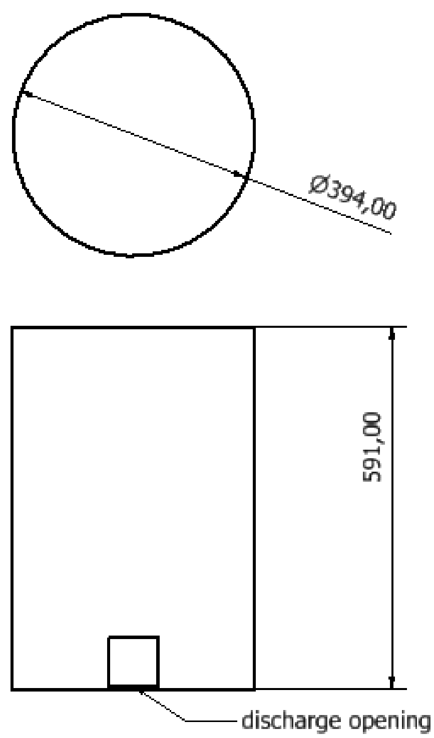


Fig. 2. Geometry of (a) Curved-type Impeller (b) Mixer tank

The iteration method used for the analysis converged at 206.861Nm after 100 iterations. From available ratings, the nearest output torque to that achieved by simulation was 214Nm, and the corresponding gear ratio is 30:1. Hence, the gearbox output speed (N_2) is determined using equation (6) as 50rpm by comparing the nominal unit ratio with the gear unit input and output ratio, therefore:

$$N_2 = {}^{1500}/_{30}$$

Using the ratings for M237 and nearest output torque to that obtained from simulation from Table 2, we got a corresponding input power (P_i) of 1.46KW and gearbox input speed of 1500rpm. Hence the actual power required (P_a) by the gear unit is calculated as:

$$\frac{206.861 \times 1.46}{214 \times 1.5} = 0.941kW$$

This is ideal to reach the required vortex levels for the bulk foundry sand. Recall that, 1HP = 0.746KW, therefore, the calculated power ratings for the electric motor is given as 0.941KW or 1.262Hp. Hence, the standard available power rating selected for the design of an electric motor for a curved-type impeller sand mixer is 1.50Hp.

shows the result of 100 iterations in a second for the torque exerted on the mixer shaft with a direct coupling on the gearbox. The value of torque obtained is required to rotate the shaft successfully despite the coupling force constraints. These applied constraints are used to determine the equivalent bulk mass of foundry sand as 115.2Kg. It can also be observed from the result for the simulated torque of 206.860Nm that the catalogue ratings for gearbox in that range gave an output torque of 214Nm and as such, the required input power is 1.5HP. This explains why when a gearbox unit transmit less than rated output torque, the input power is reduced.
Further analysis of the result on Table 1 with other experimental studies carried out by [7,11] on mixer designs revealed that with 115.2Kg of foundry sand, 0.072m^3mixer material volume and 206.861Nm torque, an electric motor of 1.5HP is sufficient to handle the sand mixer system

effectively with a mixer efficiency of 65.45% as against those designed at lower capacity and high power requirement. This shows clearly that a properly designed foundry sound mixer with the aid of Computer Aided Design (CAD) and Computer Aided Engineering (CAE) helps save costs to the barest minimum.

Table 2: Ratings at 1500RPM Input Speed [16]

Nominal Ratio RPM	Nominal Output	Capacity	Unit Size					
			112	162	200	237	287	337
5/1	300	Input Power KW Output Torque Nm	0.548 16.6	1.243 38.4	2.72 77.5	4.05 121	5.51 171	10.8 312
7.5/1	200	Input Power KW Output Torque Nm	- -	1.081 45.8	1.93 82.6	2.92 126	4.76 203	7.24 311
10/1	150	Input Power KW Output Torque Nm	0.432 24.6	1.052 61.8	1.88 112	2.60 146	3.82 228	6.29 354
15/1	100	Input Power KW Output Torque Nm	0.329 25.0	0.942 73.5	1.50 120	2.30 186	3.71 301	5.62 462
20/1	75	Input Power KW Output Torque Nm	0.300 28.3	0.655 67.1	1.40 142	2.30 233	3.71 294	5.62 447
25/1	60	Input Power KW Output Torque Nm	0.266 30.2	0.578 70.8	1.14 142	1.83 231	2.74 352	3.91 511
30/1	50	Input Power KW Output Torque Nm	0.217 28.5	0.515 73.0	0.94 137	1.46 214	2.31 348	3.50 537
40/1	37.5	Input Power KW Output Torque Nm	0.164 25.4	0.427 76.1	0.70 129	1.06 197	1.68 321	2.55 498
50/1	30	Input Power KW Output Torque Nm	0.112 20.9	0.309 65.0	0.53 115	0.820 180	1.31 301	1.91 446
60/1	25	Input Power KW Output Torque Nm	0.096 14.8	0.240 43.5	0.38 75.2	0.60 121	1.00 264	1.55 412
70/1	21.4	Input Power KW Output Torque Nm	0.090 14.6	0.206 43.7	0.35 74.0	0.53 118	1.81 198	1.18 305

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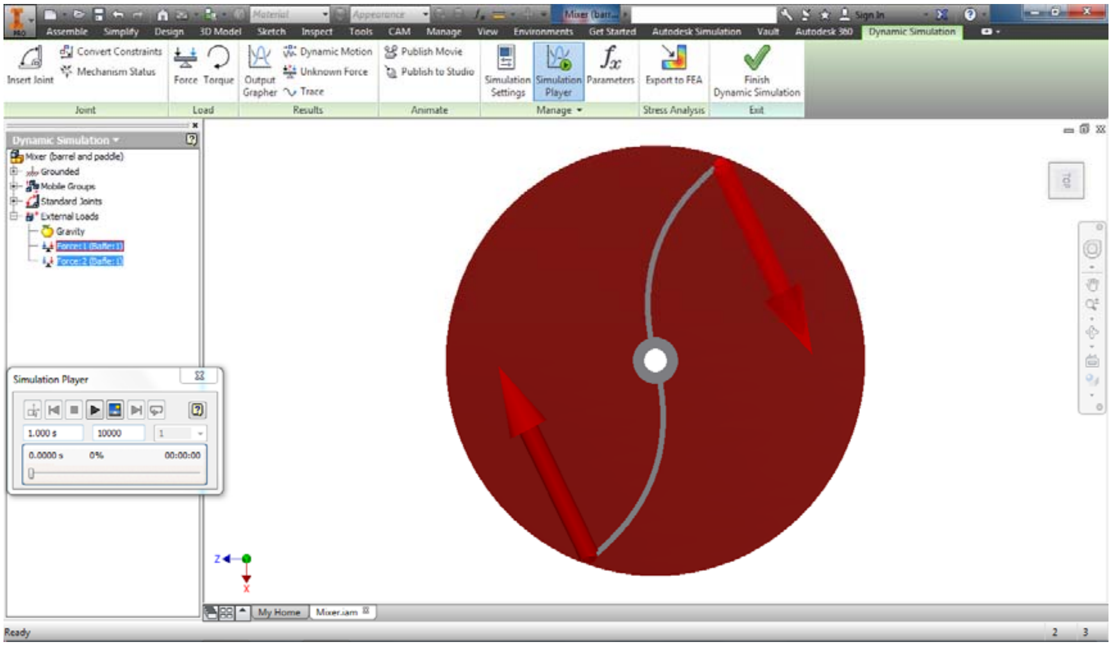

Fig. 3. Coupling forces used for torque simulation

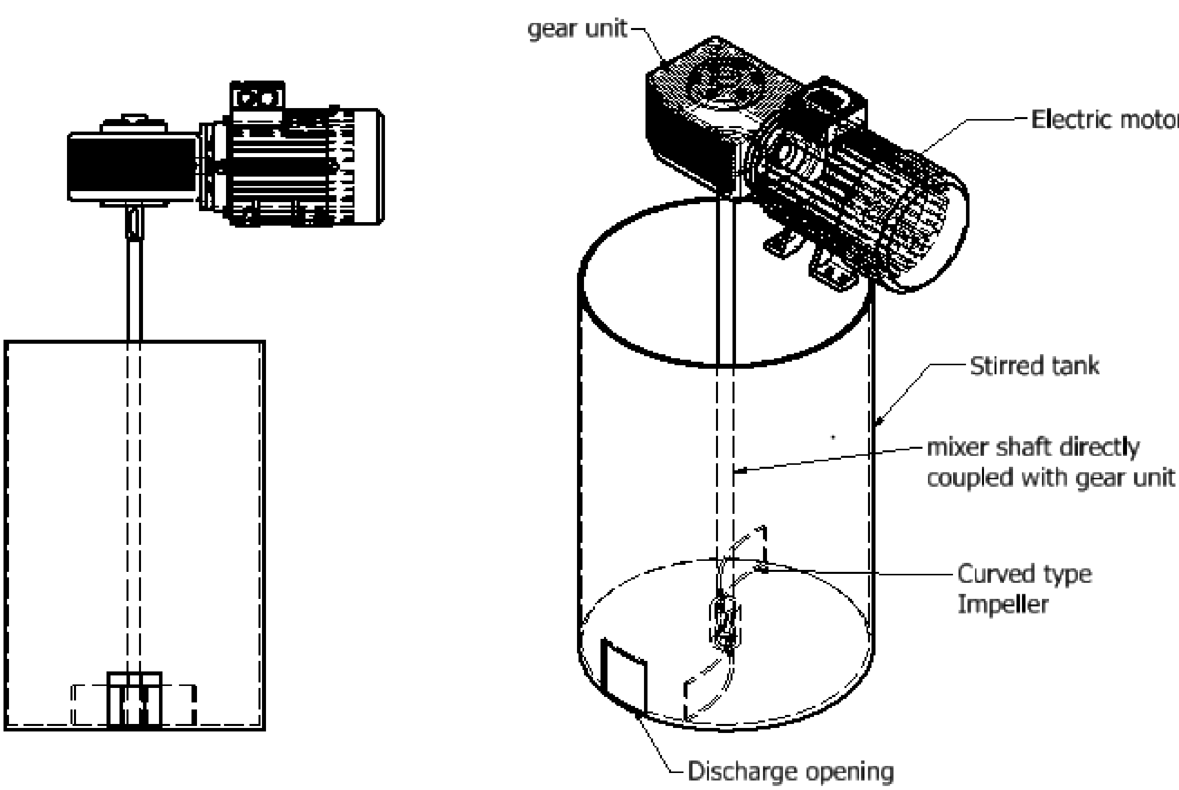

Fig. 4. Schemes of sand mixer showing: (a) front view (b) complete assembly

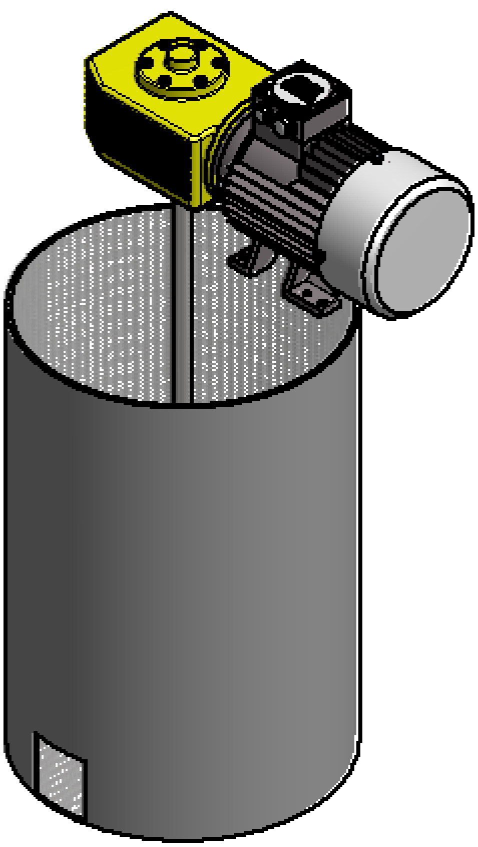

Fig. 5. Pictorial scheme of sand mixer

4. Conclusion

The application of CAE for the fabrication of foundry sand mixers is a rapid prototyping engineering method to quickly achieve product design and bridge the gap that exist in the local manufacturing of highly efficient foundry sand mixers. Design and simulation software has made it easy to obtain the required torque despite complex geometry of the curved curved-type impellers; and this gives an efficient and cost effective design over conventional models.

The adoption of CAE for design and fabrication works will eliminate the use of guess work and manual effort in computation which could be clumsy, costly and less efficient.

Competing Interests

Authors have declared that no actual or potential conflict of interest including any financial, personal or other relationships with other people or organizations that could inappropriately influence, or be perceived to influence this work exist.

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