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Development of Operating Model for the Design of Stirrer Arms of Slurries: Design and Fabrication of Stirrer Arms

Sunday Okerekehe Okpighe [a*], M. U. Shadrack [a] and H. U. Nwosu [a]

[a] *Department of Mechanical Engineering, University of Port Harcourt, Port Harcourt, Nigeria.*

Authors' contributions

This work was carried out in collaboration among all authors. Author SOO designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors MUS and HUN reviewed the manuscript and managed the analyses of the study. All authors read and approved the final manuscript.

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ABSTRACT

The "Development of Operating Model for the Design of Stirrer Arms of Slurries: Design and Fabrication of Stirrer Arms" is reported. In the previous research titled "Development of Operating Model for the Design of Stirrer Arms of Slurries: A Review", a research gap was identified to exist between the Two Z and TETE blade stirrer arms. The aim of this current research was to demonstrate a model/design and fabrication of the Two Z and TETE blade stirrer arms with the view of creating a platform for the future comparative tests of these stirrer arms. The specific objectives for this research include the identification and selection of all the materials needed to achieve the aim of the research (including the selection of the mixer that will host the stirrer arms); Design of the Two Z and TETE blades of the stirrer arms (with the application of the Solid Work software) in tandem with the selected mixer; Design calculations for the Two Z and TETE blades; Fabrication of the Two Z and TETE blades of stirrer arms in tandem with the selected mixer; Constitution of the slurry to be mixed and Calibration of the slurry viscosity. All the set objectives for this research were achieved and consequent on the foregoing, the theoretical (predicted or expected) mixing power consumption for the Two Z, TETE and hybrid Two Z – TETE blade stirrer arms were determined. The order of merit analysis for the theoretical (predicted or expected) power revealed the Two Z stirrer arm as the most efficient. Further future work should include empirical performance tests of

**Corresponding author: E-mail: eloziconsultants@yahoo.com;*

the Two Z, TETE and hybrid Two Z – TETE stirrer arms. This will establish/validate the level of degree of agreement between the theoretical (expected) and empirical (observed) mixing power consumption of the stirrer arms. Also such tests will highlight the comparative mixing power and energy efficiency of these stirrer arms hence the order of merit of being called to bar.

Keywords: Operating model; design; fabrication; slurries; stirrer arms.

1. INTRODUCTION

1.1 Statement of Problem

The work of [1] indicated that the Two Z stirrer arm gave the best mixing performance among the stirrer arms considered. This is duly reported in [3]. Also the work of [2] indicated that the TEET static stirrer arm gave the best mixing performance among the stirrer arms considered. This is also duly reported by [3]. As observed by [3], modeling of the TEET static blade into its dynamic equivalent will give an unstable dynamic stirrer due to imbalance of forces. Consequent on this, the TEET will be approximated to a TETE blade arrangement which will be dynamically stable in operation. The Two Z stirrer arm will therefore be modeled to [1] subject to the constraints of the selected mixer. Also the TETE stirrer arm will be modeled to [2] subject to the constraints of the selected mixer.

Performance information gap existed between the outcome of the works of [1] and that of [2]. Given the opportunity of choice of stirrer arms for the mixing process, the operator would be left in a state of dilemma as to which of the two types of stirrer arms he can deploy. This is so because each of these stirrer arms has been adjudged as best in their respective research outcomes. But these two have not been compared to evaluate relative performance efficiency. This information gap in comparative performance efficiency thereby stands as a wedge at point of decision making on which of the two types of stirrer arms could be deployed for process operations. For this information gap to be eliminated, there will be need to do comparative performance tests of these two types of stirrer arms.

1.2 Aim and Objectives of the Study

Aim: The aim of the study was to develop an operating model for the design of stirrer arms of slurries for a future comparative efficiency test of two- Z Stirrer and TETE geometry Stirrer Arm Mixers.

1.3 Objectives

The specific objectives were:

i) To select the mixer that will host the stirrer arms.
ii) To design the two- Z blade and TETE geometry Stirrer Arms in tandem with the selected mixer.
iii) To fabricate the designed Stirrer Arms in tandem with the selected mixer.
iv) To constitute the slurry to be mixed.
v) To calibrate the constituted slurry's viscosity.
vi) To do order of merit analysis for the theoretical (predicted) mixing power of the stirrer arms.

1.4 Literature

According to [4], the selection of mixer depends on:

i. The recipe
ii. Quality requirements.
iii. Batch.
iv. Size.
v. Reaction time.
vi. Material characteristics.
vii. Material charge in and discharge process from mixer.

In similar vein, [5] posited that mixer selection will depend on counter rotating flow and planetary motion among other factors.

According to [6], the flow pattern and power number in a vessel depends on:

i. Impeller blade angle.
ii. Number of blades.
iii. Blade width.
iv. Blade twist.
v. Blade thickness.
vi. Pumping direction.
vii. Interaction flow with the vessel wall.

Furthermore, [7] deposed that effectiveness of mixing depends on:

i. The state of mixed phases ,
ii. Temperature.
iii. Viscosity and density of liquid
iv. Mutual solubility of mixed fluid.
v. Type of stirrer.
vi. Shape of the impeller.

In order to achieve the homogeneity of products, stirring and stirrer arms have to be used. Hence the design of stirrer arms is of paramount importance [8]

The achieving of the desired homogeneity of product depends on the:

i. Properties of the mixer machine.
ii. Characteristics of materials to be mixed [9].

Also for the paint mixing applications, the limitation of the conventional mixer and that developed by the Schatz geometry theory was investigated. The exceptional efficiency of the Schatz geometry shake mixer arose from a design based on the use of rotation, translation and inversion principles [10].

While reporting on two unsteady stirring approaches, namely, co – reverse periodic rotation and time – periodic fluctuation of rotation speed (which were adopted to enhance global mixing in a stirred tank with high viscosity materials), the findings were:

i. That mixing time can be significantly reduced in stirred tanks when unsteady stirring approaches are used.
ii. That for the method of co-reverse periodic rotation, only when Re is larger than a critical value, can significant enhancement in mixing be obtained.
iii. For the case of time periodic RPM, fluctuations such a critical value is not easy to define.
iv. That the higher the frequency of periodic co-reverse rotation and the larger of time-periodic fluctuation, the shorter is the mixing time.
v. That in both cases, after Re becomes larger than a certain value, further increase in Re yields relatively small returns [11].

The ingredient being mixed directly influenced the equipment type that should be used depending on the mixing scenario. It is therefore important to consider a balance between the equipment and ingredient properties in order to obtain an effective size of production without using a large quantity of time and energy consumption [12].

The influence of stirrer blade design on the dispersion of reinforcement particles in the Aluminum metal matrix through experiments and also simulation using Computational Fluid Dynamics (CFD) method was investigated. Experimental results validated the CFD recommendation on the blade design. The four-blade flat stirrer design achieved the highest compressive strength (642 MPa), highest hardness (45 HRB), and highest tensile strength (206 MPa) among the five different blade designs investigated [13].

A low cost technology of a mixer was constructed to homogenously mix the premix (Super cereal plus) together with maize flour of ratio 0.00525:15 kg respectively. The machine was efficient at 300 to 360 revolution of the crank lever [14].

The mechanical design of agitator to mixing polyectrolyte having viscosity 1.5cp considering the fluid forces that were imposed on the impeller by the fluid was undertaken. The analysis showed that the forces were as a result of turbulent flow of fluid and static fluid forces. The design approach entailed designing for:

i. The power (torque and speed).
ii. Shaft loads [15].

So the selection of the mixer will be guided by the parameters as enunciated by [4], [5], [8],[11] and [12] among others. And the design of the stirrer arm will be modeled to [1] and [2] respectively (and be guided by [6], [7], [8], [10], [12] and [15] subject to the constraints of the selected mixer.

In the design of the blades of the stirrer arms, it is to be noted that warping of cross sections can occur under the action of a torque. For rectangular and square sections, the maximum shear stress is found to occur at the midpoint of the longer side. For dimensions t and h, where h is greater than t, the maximum shear τ according to [16] is as expressed in equation (1).

$$\tau = \frac{(1.8t+3h)T}{t^2h^2} \quad (1)$$

Where, t = thickness of blade.

h = height of blade (subject to mixer constraints).
T = applied torque
τ = maximum shear stress.

For the designed and fabricated stirrer arms (Two Z, TETE and hybrid Two Z – TETE), the theoretical (Expected) power could be computed and the Order of Merit ascertained according to [3] using Equation (2).

$$\frac{Merit\ of\ A}{Merit\ of\ B} = \frac{O_{A1}}{O_{B1}} * \frac{O_{A2}}{O_{B2}} * \ldots * \frac{O_{An}}{O_{Bn}} = M_{A/B} \quad (2)$$

$$If\ M_{\frac{A}{B}} > 1\ Select\ B$$
$$If\ M_{A/B} < 1\ Select\ A$$

Where: $M_{A/B}$ is the merit of stirrer arm A over B. if the Two Z stirrer arm is considered as A, the TETE stirrer arm can be considered as B, vice versa.

2. MATERIALs AND METHODS

2.1 Materials

The materials needed for this investigation are :Slurry Mixer, Stirrer Arms, Solute (Akamu also called Pap 16.68 Kilogramme), Solvent (Water 63 Litres), Digital AC/DC Clamp, Digital Stop Clock, Photo/Contact Type Digital Tachometer, Gas Cooker, Boiling pot, Digital weighing scale, Portable Generator, Cylindrical measuring jar, Colorant (Milo 1.2 Kilogramme), Viscometer and Food Grade Thermometer. The specifications of the key measuring instruments are as shown on Table 1

2.1.1 Selection of the mixer

Four makes of mixers namely Kenwood, China B30, Philips 1 and Philips 2 were considered for comparison in line with:

i. Number of stirrer arms at a time.
ii. Rotation mode.
iii. stirrer arm eccentricity.
iv. Planetary motion.
v. Operability.
vi. Quality rating.

The details are as shown in Table 2.

Plates 1 to 4 show the images of the mixers so appraised.

2.2 Design Models (Design of the Two Z Blades and TETE Geometry Blades of the Stirrer Arms in Tandem with the Selected Mixer)

The assumptions, input data, important equations used and references for the design are as detailed below:

Basic assumptions: The shape and configuration of Two Z was subjected to [1]] and to the constraints of the Philips 2 mixer as shown in Table 2.

In similar vein, the TETE stirrer arm was designed in tandem to [2] subject to the Philips 2 mixer as shown in Table 2.

Input data:

Blade height (h) = 0.075m (7.5 cm)
Blade width = 0.05 m (5 cm).
Length of stirrer arm spindle = 0.216 m (21.6 cm).
Diameter of stirrer arm spindle = (0.005 m) (5 cm).
Mixer power = 350 Watt.

Plate 1. Kenwood model 8F19A mixer

Parameters to be determined:

i) Appropriate stirrer arm material based on shear strength and non-contamination of products.

ii) Thickness of stirrer arm blade (t)
iii) Materials shear stress validation for the stirrer arm spindle.
iv) Angular speed of mixer and stirrer arms (ω).

Important equations used: Among the equations used were equations (1), (3), (5), (6), (7), (14) and (22).

Key references for the design: Key references that supported the design are [1], [2], [3] and [8] among others.

Table 1. Measuring instruments

S/No	Instrument	Rating	Accuracy
1.	Digital AC/DC Clamp Meter (MASTECH MS2001)	20A/200A	± (2.0% +5)
2.	Digital Stop Clock (Samsung A 10S)	99 Hours.	± 0.01 Second
3.	Photo/Contact Type Digital Tachometer	2.5 to 99,999 RPM	± (0.05 + 1 digit)
4.	Digital Weighing Scale (SF400)	10 Kilogramme	± 1g
5.	Cylindrical Measuring Jar	250 ml (EX 20^{O}C	± 2 ml
6.	Food Grade Thermometer	360^{O}C	± 2^{O}C

Table 2. Selection of mixer

Make	Kenwood Mixer	China B30 Mixer	Philips 1 Mixer	Philips 2 Mixer
Model parameters	Model 8F19A HB150 220-240V 50-60Hz 300W CE Single Elliptical Blade	Model B30 308/136/83RPM Volume = 30 Litres 220V 50Hz 1.25KW 7.0AMP 1 Phase 58X45X84CM 95KG Manufactured November 2016. Serial no. B1611N085	Model HR 145673 AD. 5 Speed 175W 50-60Hz Philips NL9206AD-4 Drachten. Made in China	Model HR 1565 21AH 220-240V 50-60HZ 350W 13161 Mixer 3 Speed. Planetary: Driver Spline= 9 Teeth Bowl =139 Teeth Bowl Depth = 11.5cm Bowl Effective Depth = 7.5cm From Stirrer Arm to Bowl= 45mm Bowl Top Inner Dia = 192mm Philips NL9206AD-4. Drachen
Number of Stirrer Arms	1	1	2	2
Rotation Mode	Clockwise	Clockwise	Clockwise Co-current	Counter-Current
Stirrer Arm Eccentricity	Nil	Yes	Yes	Yes
Planetary Motion	Nil	Nil	Nil	Yes
Operability	Hand Held	Operation Base	Hand Held	Table Base
Overall Suitability Rating	1	3	3	5
Hence based on the Overall Suitability Rating, Philips 2 was selected as the Mixer for this Research.				

Plate 2. China B30 mixer

Plate 3. Philips Model HR1456 Mixer

Plate 4. Philips model HR1565 mixer

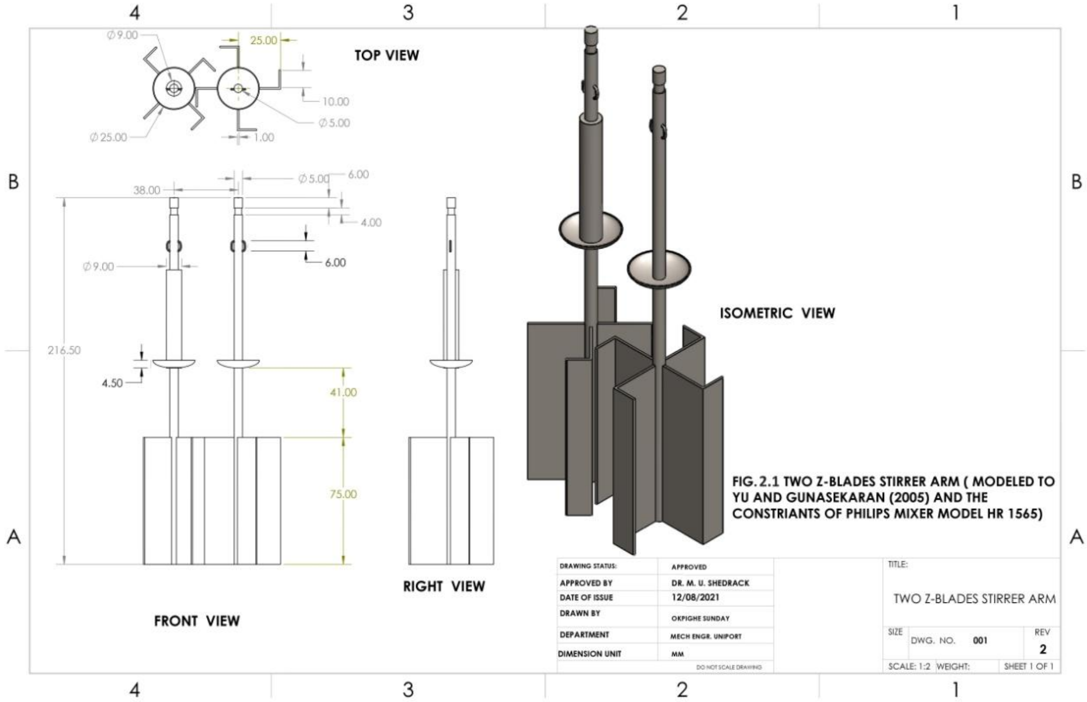

Fig. 1. Two Z-Blades Stirrer Arm (Modeled to Yu and Gunasekaran (2005) [1] and the Constraints of Philips Mixer Model HR 1565)

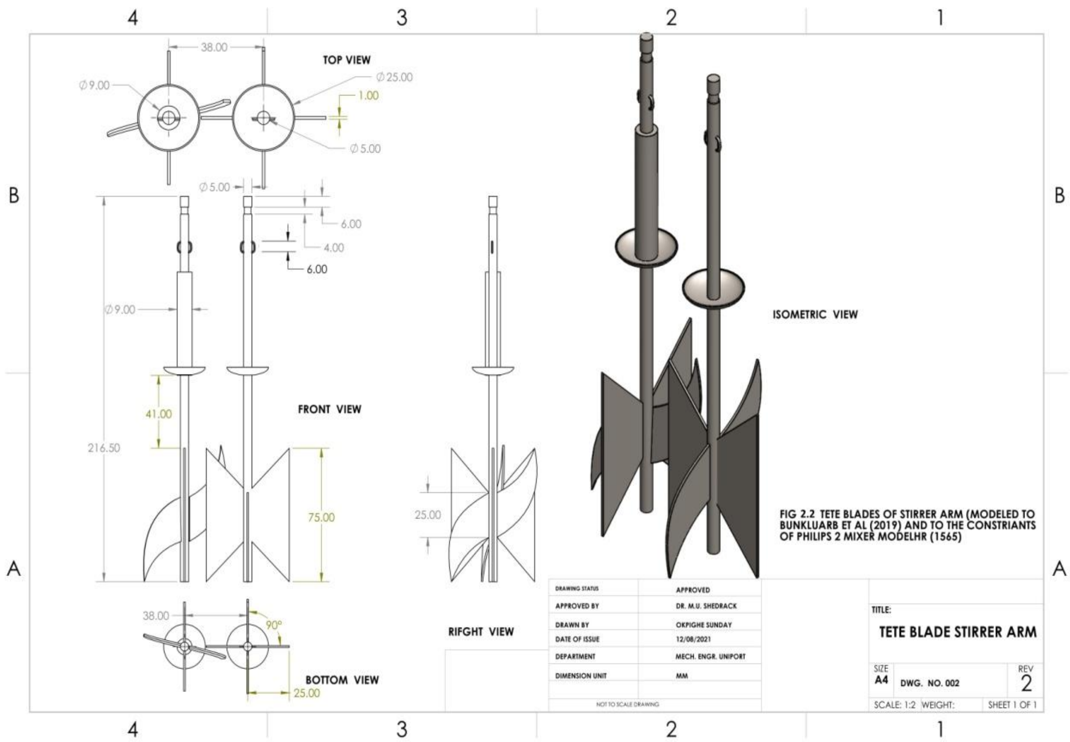

Fig. 2. TETE Blades of Stirrer Arm (Modeled to Bunkluarb et al. (2019) [2] and to the Constraints of Philips 2 Mixer Model HR 1565)

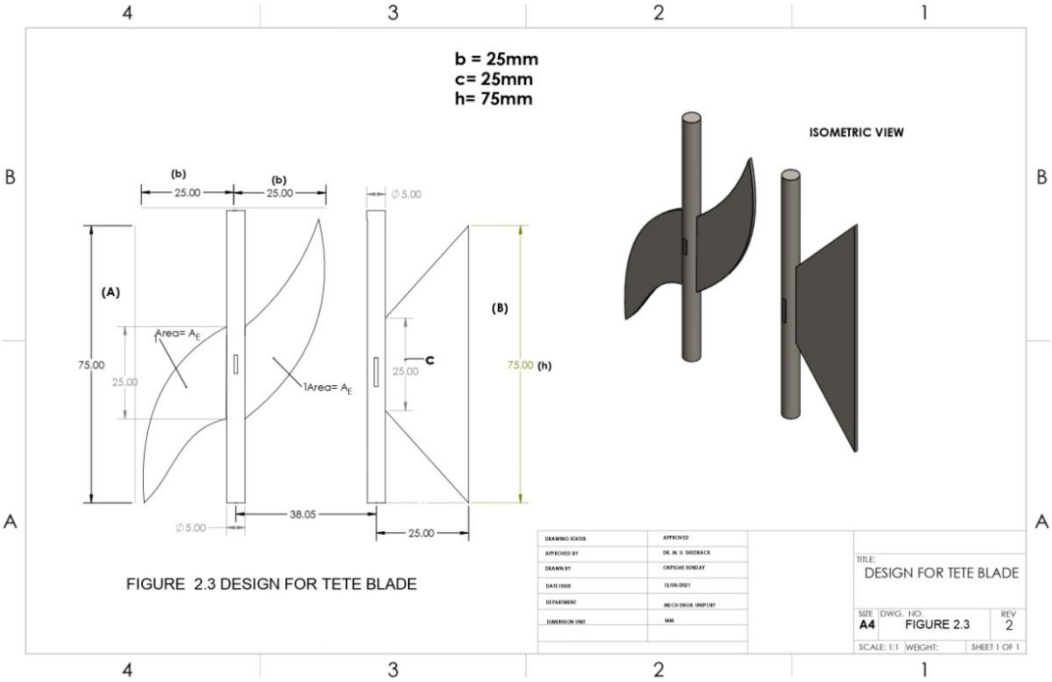

Fig. 3 Design for TETE Blade

2.2.1 Design for Two Z blade

The standard expression relating the power transmitted by a rotating shaft to the torque applied is given by equation (3).

$$Power(P) = Torque\ (T) * Angular\ speed\ (\omega) \qquad (3)$$

$P = T\omega$
and, $T = \frac{P}{\omega}$
Also, $\tau = KT$

where k is a constant.

$$T = \frac{KP}{\omega} \qquad (4)$$

$$\text{Also, } \tau = \frac{\mu\omega b}{h} \qquad (5)$$

Equating Equations (4) and (5), we get:

$$\frac{KP}{\omega} = \frac{\mu\omega b}{h}$$

$$\text{Therefore, } P = \mu\omega^2 \frac{b}{kh} \qquad (6)$$

$$\text{where, } K = \frac{1.8t+3h}{t^2h^2} \qquad h > t. \qquad (7)$$

For the selected Mixer, power, P = 350 Watts

From Table 4, average speed for Two Z Stirrer Arm, = 545.1 rpm

Hence, $\omega = \frac{2\pi N}{60} = \frac{2\pi * 545.1}{60} = 57.11$ rad.

and torque, $T = \frac{P}{\omega} = \frac{350}{57.11} = 6.129\ NM$.

From Table 4, average speed for TETE Stirrer Arm, = 816.3 rpm

Hence, $\omega = \frac{2\pi N}{60} = \frac{2\pi * 816.3}{60} = 85.52$ rad.

and torque, $T = \frac{P}{\omega} = \frac{350}{85.52} = 4.093\ NM$

From Table 4, average speed for Two Z – TETE Stirrer Arm, = 640.6 rpm

Hence, $\omega = \frac{2\pi N}{60} = \frac{2\pi * 640.6}{60} = 67.11$ rad.

and torque, $T = \frac{P}{\omega} = \frac{350}{67.11} = 5.215\ NM$

Considering the highest torque, for the Stirrer Arm of Two Z,

Maximum stress, $\tau = \frac{16T}{\pi D^3}$

where D is diameter of Stirrer Arm.

$= \frac{16*6.129}{\pi*0.005^3} = 249.617*10^6\ Nm^2 = 249.617\ Mpa.$

Now for AISI 1035 Steel shaft, Ultimate strength, S_u =550 Mpa.

Taking a factor of safety of 0.67,

Hence ultimate shear strength $S_u = 0.67*550\ Mpa = 368.5\ Mpa$

Since $368.5\ Mpa > 249.617\ Mpa,$

Therefore, the Stirrer Arm diameter of 5 mm is adequate.

$$F = AP_r = bhP_r \quad (8)$$

Moment about centre of shaft = $2bhP_r * \frac{b}{2} = T$ (9)

Therefore, $P_r = \frac{T}{b^2h}$ (10)

Slurry Shear $\tau_s = \mu\frac{du}{dy}$ (11)

As y tends to zero, du/dy tends to ω.

Hence, $\tau_s = \mu\omega$ (12)

Shear stress on blade $\tau = \frac{F}{ht} = bh\frac{P_r}{ht} = b\frac{P_r}{t} = \frac{bT}{htb^2} = \frac{T}{bht}$ (13)

From Equations (12) and (13), $\mu\omega = \frac{T}{bht}$

Therefore, $t = \frac{T}{\mu\omega bh} = \frac{P}{\mu\omega^2 bh}$ (14)

2.2.2 Design calculations for TETE

From Fig. 3,

A_T = Area of twisted blade. = 0.00125m^2

A_E Area of elliptical blade = 587.25 10^{-6} m^2

Force on twisted blade

$$F_T = A_TP_T = \frac{(c+h)b}{2}P_T \quad (15)$$

Moment about centre of shaft

$$= 2*\frac{(c+h)b}{2}P_T\frac{2}{3b} \quad (16)$$

Force on elliptical blade, $F_E = A_EP_T$ (17)

Moment = $2A_EP_T\frac{1}{2b}$ (18)

Therefore, total moment

$$= (c+h)b^2P_T\frac{2}{3} + A_EP_Tb \quad (19)$$

That is $T = \frac{2(c+h)}{3}b^2P_T + A_EP_Tb$ (20)

Therefore, $P_T = \frac{3T}{2[(c+h)b^2+A_Eb]}$ (21)

$$\tau = (4A_T + 4A_E)\frac{P_T}{h_1t} \quad (22)$$

i.e., $\tau = \frac{4A_T + 4A_E}{h_1t}*\frac{3T}{2}[(C+h)b^2 + A_Eb]$

$$\tau = \frac{4*0.00125 + 4*587.25*10^{-6}}{0.0582t} * \frac{3*6.029}{2}[(0.025+0.075)*0.025^2 + 587.25*10^{-6}*0.025]$$

i.e., $\tau = \frac{2.279866}{0.00007718t}$

Therefore t = $\frac{2.279866}{0.00007718\tau}$

If we take $\tau = 245.545*10^6\ N/m^2$

Then, $t = \frac{2.279866}{0.00007718*245.545*10^6}$

t = 0.12 mm.

where, t is the thickness of TETE Blade.

For τ = 368.5 Mpa

Recall Equation (1)

$\tau = \frac{(1.8t+3h)T}{t^2h^2}$

$368.5*10^6 = \frac{(1.8t+3*0.075)*6.129}{t^2(0.075)^2}$

That is, $\frac{368.5*10^6*0.075}{6.129} = \frac{1.8t+0.225}{t^2}$

That is, $338{,}197.504 = \frac{1.8t+0.225}{t^2}$

That is, $338{,}197.504t^2 - 1.8t - 0.225 = 0$

Recall Pythagoras Equation, $x = \frac{-b\pm\sqrt{b^2-4ac}}{2a}$

$t = \frac{-(-1.8)\pm\sqrt{(-1.8)^2-4*338{,}197.504*(-0.225)}}{2*338{,}197.504}$

$t = +0.818mm\ or -0.813mm$

For $\boldsymbol{\tau} = \mathbf{2}45.545*10^6\ N/m^2$ $245.545*10^6 = \frac{(1.8t+3*0.075)*6.129}{t^2*(0.075)^2}$

That is, $225{,}353.341t^2 - 1.8t - 0.225 = 0$

$$t = \frac{-(-1.8) \pm \sqrt{(-1.8)^2 - 4*225{,}353.341*(-0.225)}}{2*225{,}353.341}$$

That is, $t = +1.00mm \; or -0.995mm$

Hence, based on the forces at play, blade thickness of 1 mm for the Stirrer Blade is recommended.

2.3 Fabrication of the Mixing Blades of Stirrer Arms in Tandem with the Selected Mixer

Material for the fabrication of the blades was stainless steel sheet (304 Steel; AISI 1035) the fabrication process in line with Figs 1, 2 and 3 respectively entailed:

i. Marking out of blade shapes on sheet steel.
ii. Cutting out of shapes using power saw and shaping machine.
iii. Smoothening of the blade profiles.
iv. The blades were then fitted to the spindles through welding.

The fabricated stirrer arms are as shown on Plates 1, 2 and 3 respectively.

2.4 Constitution of the Slurry to be Mixed

The slurry to be mixed was Pap (Akamu). The Pap (Akamu) Slurry wias constituted by dissolving 0.0; 0.100; 0.200; 0.300; 0.400; 0.500 and 0.556 Kilogramme of Pap (Akamu) in two Litre of water respectively for each run. This solution was poured into a cooking pot and boiled on a gas cooker with stirring to a temperature of 100^{O}C and the slurry was maintained at a temperature range of 80 – 85^{O}C through the test. The colorant used was Milo solution (0.040 Kilogramme per 0.010 Litre of warm water).

3. RESULTS

The results of the research are as expressed below.

The Two Z blade stirrer arm was designed subject to Yu and Gunasekaran's work of 2005 and to the constraints of the Philips Mixer Model HR 1565 using the software Solid Works as shown by Fig. 1.

Also the TETE stirrer arm was designed subject to Bunkluarb et al. work of 2019 and the constraints of the Philips Mixer Model HR 1565 using the software Solid Work as shown by Figs. 2 and 3.

The Two Z and TETE stirrer arms were successfully fabricated as shown by Plates 1, 2 and 3.

The slurry for mixing was duly constituted and the viscosity calibration was done using Viscometer and results as indicated on Table 3.

Plate 5. Two Z Blade stirrer arm

Plate 6. TETE Blade stirrer arm

Plate 7. Two Z – TETE Blade stirrer arm

Table 3. Slurry viscosity versus mass of pap

S/No	Pap per 2 litre run(kg)	Pap per litre(kg)	Viscosity (μ) (NS/M^2)
1.	0	0	0.224
2.	0.100	0.050	0.239
3.	0.200	0.100	0.372
4.	0.300	0.150	8.494
5.	0.400	0.200	14.854
6.	0.500	0.250	362.285
7.	0.556	0.278	1,163.416

Source: Data from slurry calibration

Table 4. RPM and angular speed of blade stirrer arms

S/No.	Two Z blade stirrer arm		TETE blade stirrer arm		Two Z - TETE blade stirrer arm	
	RPM (N)	ω = 2πN/60 rad.	RPM (N)	ω = 2πN/60 rad.	RPM (N)	ω = 2πN/60 rad.
1.	566.8		800.8		661.7	
2.	560.5		824.2		567.1	
3.	567.3		830.4		651.9	
4.	500.9		816.1		651.7	
5.	530.0		810.0		670.7	
Average.	545.1	57.11	816.3	85.52	640.6	67.11

The RPM for the various types of stirrer arms was done using the Digital Tachometer (Microprocessor) photo/contact type Model DT-2236B and results obtained are as tabulated in Tables 4.

The theoretical (expected) power consumption was computed using Equations (6) and (7) and data from Tables 3 and 4 and we get Table 5.

Power economy: Based on the theoretical (Expected) slurry mixing power (E) on Table 5, the order of merit for the stirrer arms was computed applying Equation (2).

$$\frac{Merit\ of\ Two\ Z}{Merit\ of\ TETE} = \frac{0.006}{0.0134} * \frac{0.0064}{0.0143} * \frac{0.0099}{0.0223} * \frac{0.2270}{0.5090} * \frac{0.397}{0.891} * \frac{9.689}{21.727} * \frac{31.115}{69.772} = 0.0035$$

$$\frac{Merit\ of\ Two\ Z}{Merit\ of\ TwoZ-TETE} = \frac{0.006}{0.00827} * \frac{0.0064}{0.00883} * \frac{0.0099}{0.0137} * \frac{0.2270}{0.3136} * \frac{0.397}{0.5436} * \frac{9.689}{13.379} * \frac{31.115}{42.966} = 0.105$$

$$\frac{Merit\ of\ TETE}{Merit\ of\ TwoZ-TETE} = \frac{0.0134}{0.00827} * \frac{0.0143}{0.00883} * \frac{0.0223}{0.0137} * \frac{0.5090}{0.3136} * \frac{0.891}{0.5436} * \frac{21.727}{13.379} * \frac{69.772}{42.966} = 29.966$$

Hence order of merit analysis for the theoretical (Expected) Power (E) revealed the Two Z stirrer arm as the most economical to deploy, followed by Two Z – TETE and lastly TETE.

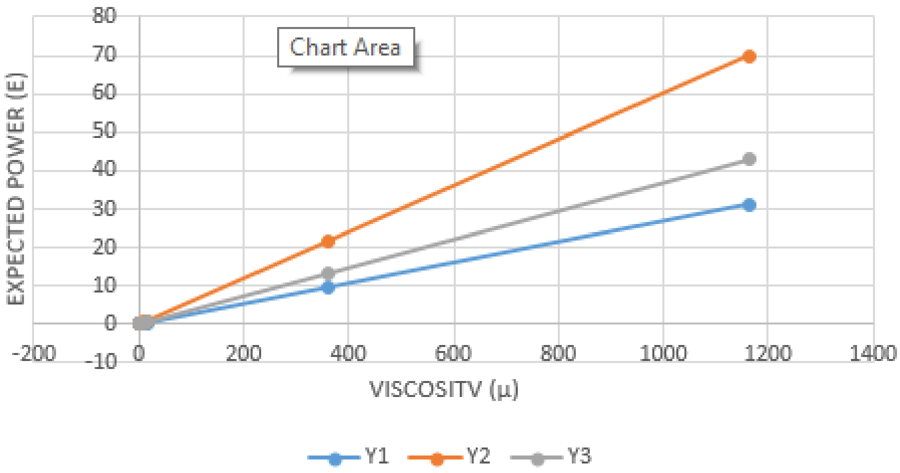

Fig. 4. Theoretical (Expected) stirrer arm mixing Power (E) versus Viscosity (μ)
Y1 = Two Z blade. Y2 = TETE blade. Y3 = Two Z – TETE blade
Source: Data from Table 5

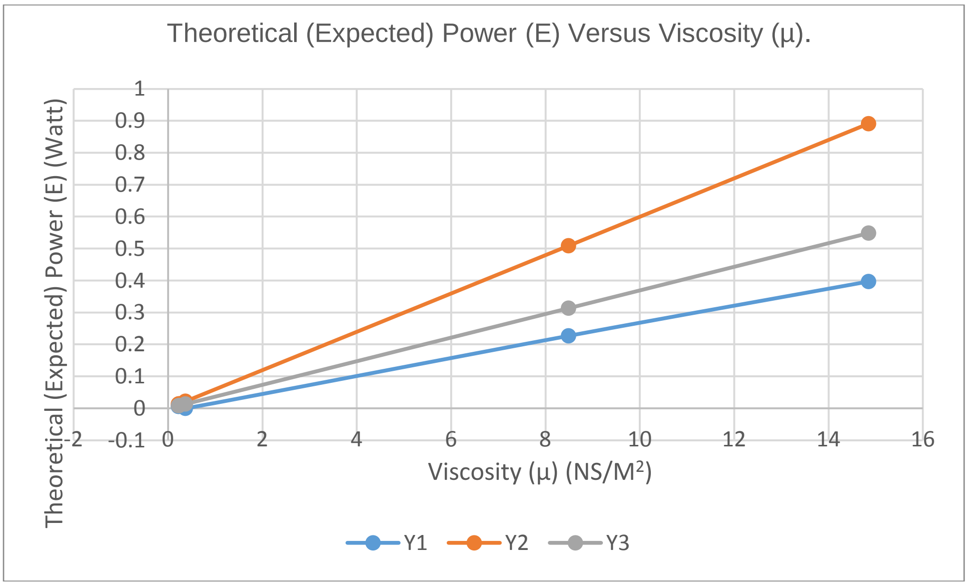

Fig. 5. Theoretical (Expected) stirrer arm mixing Power (E) versus Viscosity (μ).
For viscosity 0 – 15. Y1 = TwoZ blade. Y2 = TETE blade. Y3 = Two Z – TETE blade.
Source: Data from Table 5

Table 5. Viscosity (μ), angular speed (ω) versus power (P)

S/No.	Viscosity (μ)	ZZ blade		TETE blade		ZZ – TETE blade	
	NS/M^2	Angular speed (ω) (Rad)	Power = $82*10^{-7}\ \mu\omega^2$ (Watt)	Angular speed (ω) (Rad)	Power = $82*10^{-7}\ \mu\omega^2$ (Watt)	Angular speed (ω) (Rad)	Power = $82*10^{-7}\ \mu\omega^2$ (Watt)
1.	0.224	57.11	0.006	85.52	0.0134	67.11	0.00827
2.	0.239		0.0064		0.0143		0.00883
3.	0.372		0.0099.		0.0223		0.0137
4.	8.494		0.2270		.5090		0.3136
5.	14.854		0.397		0.891		0.5486
6.	362.285		9.689		21.727		13.379
7.	1163.416		31.115		69.772		42.966

4. DISCUSSION

4.1 Addressing Objectives

Objective (i): To select the mixer

An array of mixers namely Kenwood Model 8F19A Mixer (Plate 1), China B30 Mixer (Plate .2), Philips Model HR1456 Mixer (Plate 3) and Philips Model HR 1565 Mixer (Plate .4) were considered for selection. The Philips Model HR 1565 Mixer was eventually selected because of its comparative advantage due to overall suitability rating (see Table 2). Hence, the objective (i) was successfully achieved.

Objective (ii): To design the two Z blade and TETE geometry stirrer arms in tandem with the selected mixer

The stirrer arm shaft for the selected HR 1565 had constraints of a diameter of 0.005m and span of 0.2165m. The necessary requirement was to select materials of the required strength that can transmit the rated power of the mixer 350 watt safely to the stirrer arm blades. Material selected for the fabrication of the stirrer arm shaft is stainless steel (304 steel; AISI 1035). Also, the dimensions of the blades for the stirrer arms for the HR 1565 mixer were constrained to 0.075m height and 0.05m diameter respectively. The geometrical shapes were constrained to the test models:

Two Z modeled to [1]. TETE modeled to [2]. Using steel 304 (AISI 1035), the thickness of the stirrer arm blades was established at 0.001 m (see Figs. 1 to 3). Hence, objective (ii) was achieved.

Objective (iii): To fabricate the mixing stirrer arms in tandem with the selected mixer. This was done in line with Figs. 1 to 3 and Section 2.3. Hence, objective (iii) was achieved.

Objective (iv): To constitute the slurry to be mixed. The constitution of the slurry was done in line with Section 2.4. and data so obtained are as tabulated on Table 3.. Hence, objective (iv) was realized.

Objective (v): To calibrate the constituted slurry's viscosity. The slurry was calibrated in terms of mass of pap versus viscosity and data so obtained are as tabulated on Table 3. Hence objective (v) has been realized.

4.2 Summary

The selection of the Philips model HR 1565 was adjudged to be satisfactory as it met such requirements as counter flow and planetary motion. The use of Solid Works software added impetus to the quality of the blade design.

The fabricated blades of the stirrer arms met the compatibility of design requirements as precision processes were adopted at the machine shop.

The constitution of the slurry was done and the viscosity calibration revealed that the relationship between the mass of solute (Pap) and the slurry viscosity is not linear.

The angular speed of blade stirrer arms derived from their rotation per minute (as determined by the Photo/Contact Type Digital Tachometer showed that TETE had the highest speed. This appears to be so due to the lesser resistance to drag motion subject to its design constraints.

The theoretical (Expected or Predicted) power versus the slurry viscosity showed a fairly linear relationship for a given angular speed. The TETE appeared to have the highest power consumption for a given value of slurry viscosity.

The order of merit analysis for the theoretical (Predicted) power clearly gave the comparative advantage of call to bar to the Two Z stirrer arm. However, further work by determining the empirical (Observed) value of order of merit analysis will corroborate this assertion. The empirical value will be achieved by test running the Two Z, TETE and the hybrid Two Z – TETE with the calibrated slurry viscosities.

5. CONCLUSION

The Philip model HR 1565 so selected has the most suitable parameters to meet counter – rotating flow and planetary motion. The Solid Works design software gave compatibility advantage to the blades design. The fabrication of the stirrer arms in tandem with Yu and Gunasekaran and Bunkluarb et al. and subject to the mixer constraints have been exact. The relationship between solute mass and slurry viscosity do not appear to be linear. The relationship between slurry mixing power and viscosity appear to be linear for a given angular speed. The order of merit analysis for the theoretical (Expected) power revealed Two Z as the most power efficient to call to bar. Further work will need to be done to get the empirical (Observed) data to validate the findings of this report.

COMPETING INTERESTS

Authors have declared that they have no known competing financial interests or non-financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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