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Computer Simulation of Optimization Models for the Determination of Optimal Power Requirement for Liquids-Solute Mixer During Mixing Action

Tobinson A. Briggs[a*], Shadrack Uzoma Mathew[b]

[a,b]*Department of Mechanical Engineering, University of Port Harcourt, Port Harcourt, Rivers State, Nigeria*
[a]*Email: matshadrack@yahoo.com*
[b]*Email: tobinson.briggs@uniport.edu.ng*

Abstract

The study deal with the development of optimization models for the determination of the optimal power requirement for liquids mixers during mixing action. The impeller in question for mixing action is of the most straightforward geometrical configuration being cylindrical. The computational-algorithmic coding culminated in the determination of more or less accurate numerical values of the drive shaft optimal diameter and optimal values of the following parameters: mixing rod diameter, mixing rod length, clearance space between mixing rod end and the internal drum surface, the power required for mixing action. Analysis of the computational results confirmed that the clearance space of 0.05m and 0.15m produced the best optimal results for design and process variables for the determination of optimum power required for mixing action. The optimum power for mixing action increases as the clearance between the end of the mixing rod and the drum internal surface decreases. The mixing drum diameter is a composition of the clearance space, mixing rod diameter and the mixing rod length. The analytical value of the mixing drum diameter is all-inclusive at the clearance space of 0.05m and 0.15m.

Keywords: optimal power requirement; mixing action; impeller; cylindrical; algorithmic coding; accurate numerical values; and mixing drum diameter.

1. Introduction

Fluid mixer mechanical design and process parameters concepts have been an age-long area of study.

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* Corresponding author.

The technical configuration of a fluid mixer is (i) the installation structure, (ii) reducer gearbox, (iii) driveshaft, (iv) impeller blade or mixing rod and (v) mixing drum [1, 2, 3 4]. The geometrical configuration of the mixer vis-à-vis the shearing forces and bending moments is as shown in Figures 1, 2, and 3.

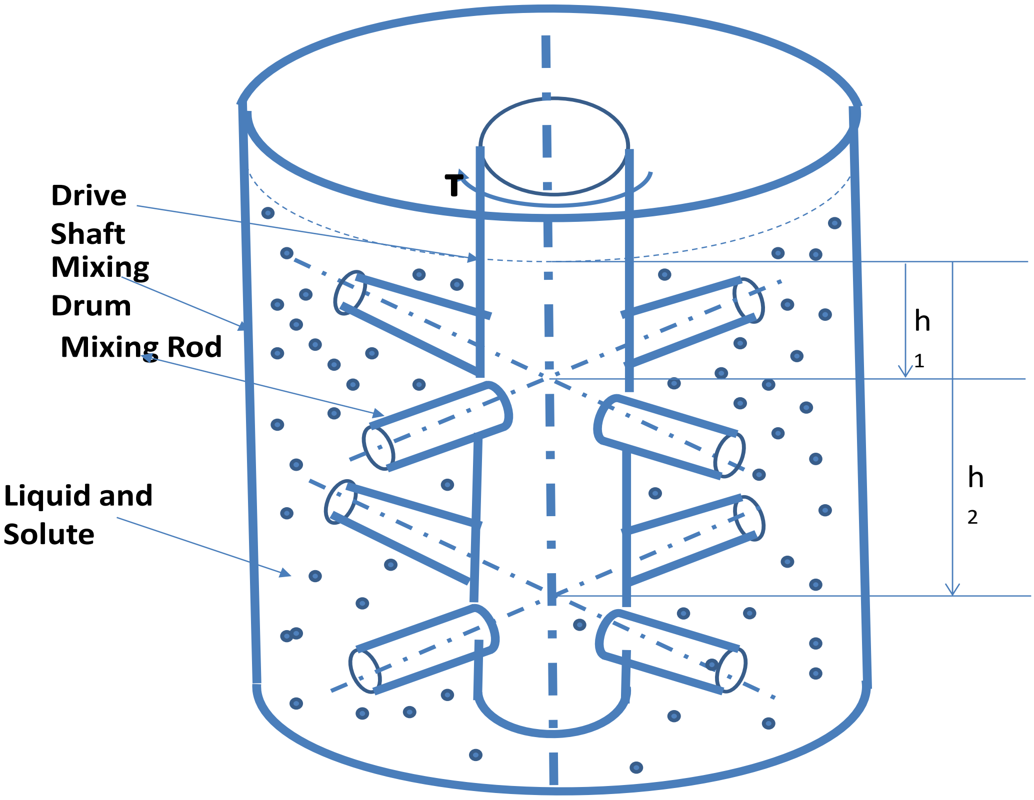

Figure 1: Isometric View of the Mixing Drum

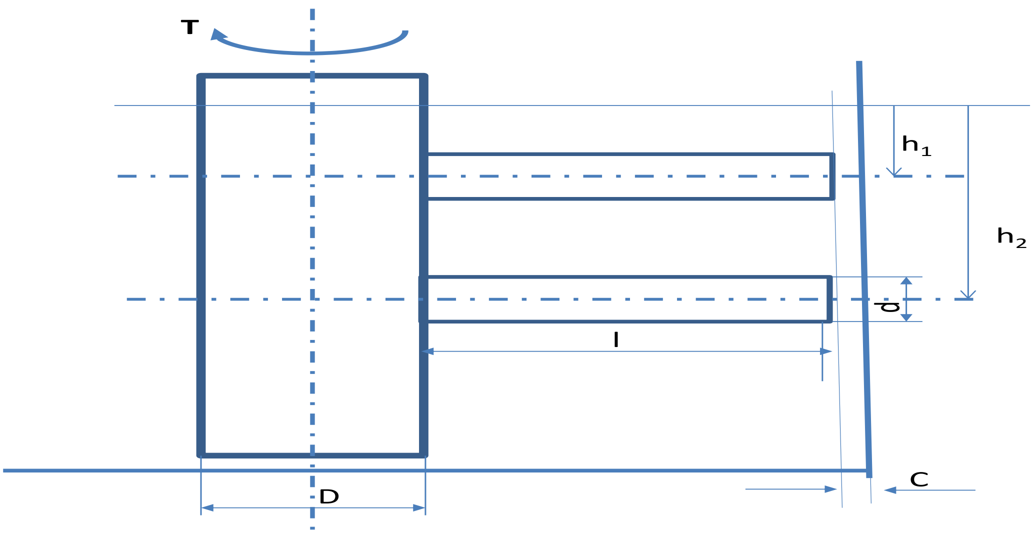

Figure 2: The Drive Shaft-Mixing Rod Configuration

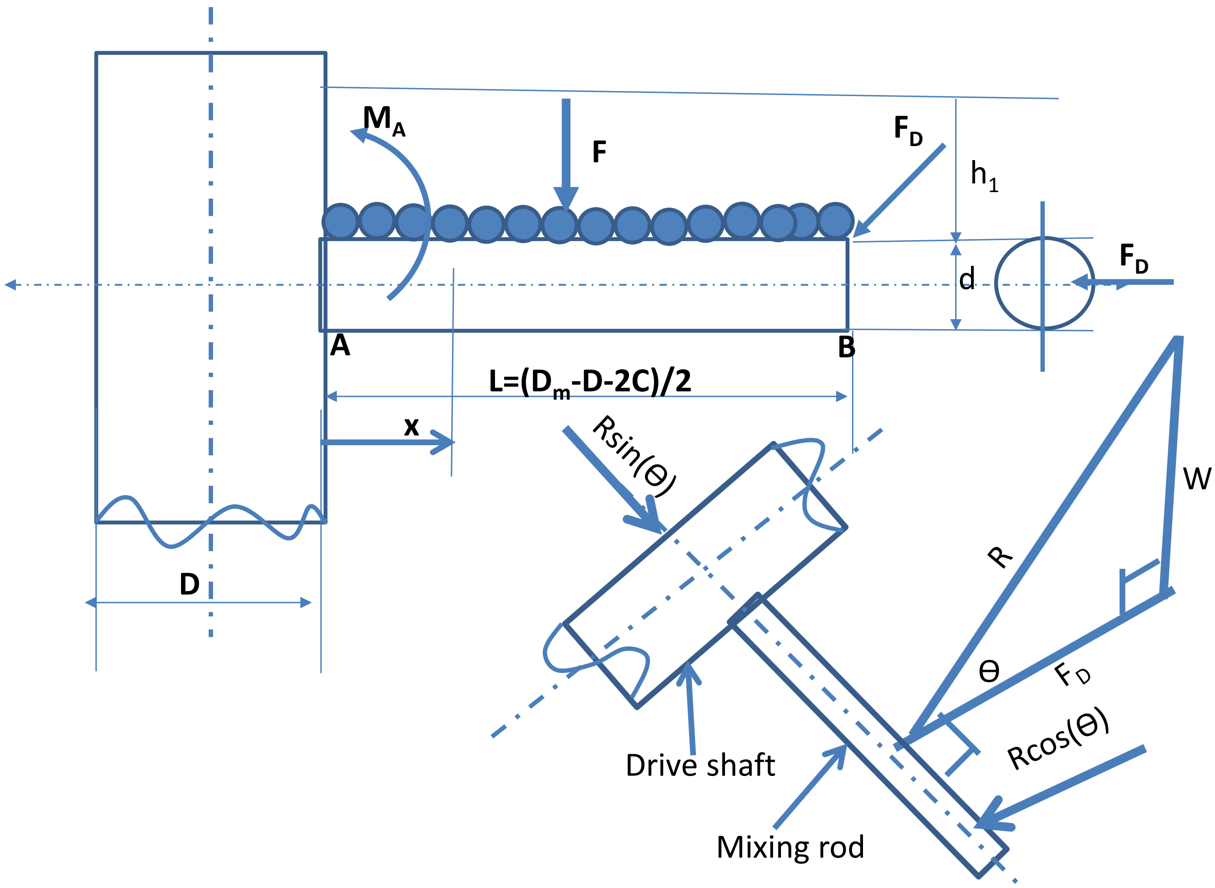

Figure 3: Forces and Moments Acting on the System

This paper shows how to compute main hydrodynamic characteristics and mixing parameters (the mixing time, circulation flow rate, etc.), and how to use computer simulation to advance the system design, in this case, to decrease the mixing time and power consumption.

Primarily a fluid mixer should function to achieve the following objectives:

(i) The blending of miscible fluids with less stringent considerations on power requirements.

(ii) The blending of high density and viscosity fluids whereby the power the requirement is a critical issue for effective and homogeneous mixing

(iii) Effectiveness in mass and heat transfer in the exothermic mixing process.

(iv) The high degree of dispersion of colloidal particles, most especially if the fluid the medium is a lubricant.

It is noteworthy that fluid mixers impeller design **is** of multiple configurations, subject to the process and mechanical design overview of the mixer that is the case problem. All in all, the benchmark in achieving durable, efficient, and high-quality mixer in operation with long service life. Mathematical models had been developed to enable the determination of the exact values of particular paramount design and process parameters for efficient mixing action by the fluids mixer by computational approach.

2. Study Significance

The study has provided a broad base fundamental concept for the determination of mixers design and process parameters. This paper shows how to calculate main hydrodynamic characteristics and the mixing parameters (the mixing time, circulation flow rate, etc.). The computational results had been proven to be quite intensive and satisfactory

3. Computational Analysis of the Model

The study is to scrutinize the main mixing characteristics and mixing conditions. We are to determine the mixing regime in the system, to evaluate the axial circulation and mixing time, and in order to improve the mixing and decrease the power consumption with the simplest technical means possible. The general, the sequence of computation, is as follows: enter the initial data for the mixing the system requested by the program, and then select the parameters to calculate the desired parameter, the required parameters for calculations are Power and forces, Flow characteristics and Blending, Uniformity of mixing.

(I) Input Data

Drum diameter, Dm=1m

Average absolute dynamic viscosity of the blends, μ=20Pas

The average density of Glycerine-Castor Oil, ρss=1500kg/m3

Clearance space, C=0—0.15m

Mixing rod immersion depth, h1=0.6m

(II) Core Mathematical Models

The dead load, F, on the mixing rod expressed as:

$$F = W = \rho_{ss} d l h_1 g \tag{1}$$

The diameter of the mixing drum, D_m expressed as:

$$D_m = D + 2l + 2C \tag{2}$$

The length of the mixing rod, l, is given as :

$$l = (D_m - D - 2C)/2 \tag{3}$$

The angle of inclination, Θ, of the resultant force, R, given as:

$$\theta = \sin^{-1}\left(\frac{\rho_{ss} h_1 g}{\sqrt{(\rho_{ss} h_1 g)^2 + (\pi \tau_{ss})^2}} \right) \tag{4}$$

Force component, $R_{l,}$ to shear the mixing rod expressed as:

$$\begin{aligned} R_l &= R\cos(\theta) \\ &= \sqrt{(\rho_{ss} dl h_1 g)^2 + (\pi dl \tau_{ss})^2}\ \cos(\theta) \end{aligned} \tag{5}$$

Force component, $R_{D,}$ to shear the drive shaft expressed as:

$$\begin{aligned} R_D &= R\sin(\theta) \\ &= \sqrt{(\rho_{ss} dl h_1 g)^2 + (\pi dl \tau_{ss})^2}\ \sin(\theta) \end{aligned} \tag{6}$$

The diameter of the mixing rod given as;

$$d = D/\tan(\theta) \tag{7}$$

The shearing stress of the liquids shown as:

$$\tau_{ss} = \mu \frac{dV}{dl} \tag{8}$$

At the optimal value of the drive shaft diameter, dP/dD=0.

Therefore,

$$3D^2 + (8C - 4D_m) + (D_m^2 - 4CD_m + 4C^2) = 0 \tag{9}$$

The optimal value of the drive shaft diameter expressed as;

$$D_{opt} = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a} \tag{10}$$

Where,

$$a = 3, \quad b = (8C - 4D_m) \quad and \quad c = (D_m^2 - 4CD_m + 4C^2)$$

Power required to drive the mixer assembly for n number of mixing rods expressed as :

$$\begin{aligned} P &= nM_A\omega_D \\ &= \frac{n\pi Ndl^2}{30}\sqrt{(\rho_{ss}h_1g)^2 + (\pi\tau_{ss})^2} \\ &= \frac{n\pi N\cos(\theta)D(D_m - D - 2l)^2}{120\tan(\theta)}\sqrt{(\rho_{ss}h_1g)^2 + (\pi\tau_{ss})^2} \\ &= KD(D_m - D - 2l)^2 \end{aligned} \tag{11}$$

Where K expressed as:

$$K = \frac{n\pi N\cos(\theta)\sqrt{(\rho_{ss}h_1g)^2 + (\pi\tau_{ss})^2}}{120\tan(\theta)}$$

(III) Computational Algorithm Coding

```
% Computer simulation of the Optimum Power Requirement for Mixing Action

% Mixer for Liquids-Solute Blending

% N--Drive shaft speed, N, in rev/min

  N=60;

% Number of mixing rod, n

  n=4;

% Depth of immersion of mixing rods below the liquids surface

  h1=0.6;

  disp(' The value of k=')
```

```
  fprintf('% 12.7f\', k)
%   Mixing drum diameter, Dm((m)
  Dm=1;
%   Average density of the Glycerine-Castor Oil mixture, Dave (kg/m3)
  Dave=1500;
%   Acceleration due to gravity, g (m/s2)
  g=9.8;
%   Average absolute viscosity of Glycerine-Castor oil (Pas)
  Vgc=20;
 for C=0:0.05:0.15
  disp('The value of C=')
  fprintf('%8.4f\n',C)
  a=3;
  b=((8*C)-(4*Dm));
  c=(Dm^(2)-(4*C*Dm)+(4*C^(2)));
  D1opt=(-b+(b^(2)-(4*a*c))^(0.5))/(2*a);
  D2opt=(-b-(b^(2)-(4*a*c))^(0.5))/(2*a);
  disp('The value of D1opt, D2opt=')
  fprintf('%8.4f\n',D1opt,D2opt)
  %   Optimal mixing rod lenght, l (m)
  l1=((Dm-D1opt-(2*C))/2);
  l2=((Dm-D2opt-(2*C))/2);
```

```
   disp('  The value of l1, l2=')

   fprintf('% 12.7f\n',l1,l2)

%   Velocity at the tip of the mixing rod, V (m/s)

    V1=(((D1opt/2)+l1)*2*pi*N)/60;

    V2=(((D2opt/2)+l2)*2*pi*N)/60;

%   Shearing resistance of Glycerine-Castor Oil  (N/m2)

    Sgc1=((Vgc*V1)/l1);

    Sgc2=((Vgc*V2)/l2);

%   Determination of the optimal value of the mixing rod diameter, dopt(m)

   y1=((Dave*h1*g)/((Sgc1*pi)^(2)+(Dave*h1*g)^(2))^(0.5));

   y2=((Dave*h1*g)/((Sgc2*pi)^(2)+(Dave*h1*g)^(2))^(0.5));

   disp('  The value of   y1,  y2=')

   fprintf('% 12.7f\n',y1,y2)

   x1=asin(y1);

   x2=asin(y2);

   disp('  The value of   x1,  x2=')

   fprintf('% 12.7f\n',x1,x2)

   disp('  The value of   x1,  x2=')

   fprintf('% 12.7f\n',x1,x2)

   T1=tan(x1);

   T2=tan(x2);

   disp('  The value of   T1,  T2=')
```

```
fprintf('% 12.7f\n',T1,T2)

d1opt=((D1opt)/(T1^(0.5)));

d2opt=((D2opt)/(T2^(0.5)));

disp(' The value of d1opt, d2opt=')

fprintf('% 12.7f\n',d1opt,d2opt)

% Optimal Power to drive the drive shaft (Watts)

P1opt=(pi*n*N*d1opt*l1^(2)*(1/30))*((Sgc1*pi)^(2)+(Dave*h1*g)^(2))^(0.5);

P2opt=(pi*n*N*d2opt*l2^(2)*(1/30))*((Sgc2*pi)^(2)+(Dave*h1*g)^(2))^(0.5);

disp(' The value of P1opt, P2opt=')

fprintf('% 12.7f\n',P1opt,P2opt)

end
```

4. Analysis of Results

Computational results of the mathematical models, as shown in Table 1 below:

Table 1: Mixer Design Parameters

C (m)	n	D_{opt} (m)	d_{opt} (m)	l_{opt} (m)	P_{opt}
0.00	4	0.333	0.864	0.333	2132.124
0.05	4	0.0300	0.0777	0.300	1554.315
0.10	4	0.2667	0.06909	0.2667	1091.648
0.15	4	0.233	0.604	0.233	731.32

In the table above, shows that the optimum power to drive the mixer assembly increases as the clearance space decreases. This trend is expected, since the tighter configuration of the mixing rod end and drum surface would create more frictional resistance during mixing action, thereby leading to increased drive power. The geometrical configuration of the system demands that the sum of the clearance space, driving shaft diameter and mixing rod diameter should equate the drum diameter. Clearance space of 0.05m and 0.15m result in this accuracy. The power of the electric to drive the mixer sub-systems rated at one to two horsepower (1 to 2 hp). The optimum power for mixing action is expected to increase with the number of mixing rods and their depth of immersion below the liquids (blends) surface.

5. Recommendation for Future Research

The development of mathematical models and algorithmic coding for mixers of different impeller configuration and attainment of optimum power requirement for design and process variables order than optimal parameters of drive shaft diameter, mixing rod diameter, mixing rod length, and clearance space should be the future area that needs more essential details. This paper shows how to calculate main hydrodynamic characteristics and the mixing parameters (the mixing time, circulation flow rate, etc.), and how to use VisiMix to improve the system design, in this case, to decrease the mixing time and power consumption.

6. Conclusion

The development of the computational optimization models for liquids mixer during mixing action. The computational algorithm is straightforward to handle, and the generated results were close to exact practical expectation for the optimum performance of the mixer sub-systems. The computer simulation has thus shown that considerable process improvement can be achieved by quite simple means, without going into significant expenditures. However, you can also use the computer model for checking a lot of additional process parameters, for example, evaluation of the characteristic the function of tracer distribution in the Blending, and the dynamics of mixing/blending of the media that has not passed through the agitator zone a certain number of times.

Nomenclature

F, W—dead load acting on the mixing rod (N)

V_1—Volume of the fluids-solute medium on the mixing rod (m^3)

A—Surface area of the fluids-solute medium above the mixing rod (m^2)

h_1—the height of the fluids-solute medium above the mixing rod (m)

l—length of mixing rod (m)

D_m—diameter of mixing drum (m)

C—clearance space between the mixing drum walls and the ends of the mixing rod (m)

g—acceleration due to gravity (m/s^2)

μ—Average absolute viscosity of the blends (Pas)

τ_{ss}—shearing resistance of the blends (N/m^2)

τ_D—shearing resistance of the drive shaft/mixing rod (N/m^2)

ρ_{ss}—average density of the fluids-solute medium (kg/m^3)

ρ_D—density of the drive shaft material (kg/m^3)

d—diameter of the mixing rod (m)

D—diameter of the drive shaft (m)

x—coordinate axis locating the distribution of loads on the mixing rods referenced to the point of attachment of the mixing rods on the drive shaft (m)

M_A—restoring moments resulting from the interaction of all the external forces

on the drive shaft-mixing rod acting at the base of the mixing rod (Nm)

n—number of mixing rod

F_D—a shearing force to stir the fluids-solute medium (N/m^2)

R—resultant force influencing mixing action (N)

R_l—shearing force on the mixing rod (N)

R_D—shearing force on the drive shaft (N)

M_R—resultant restoring moment acting on the drive shaft (Nm)

ω_D—the rotational speed of the drive (rad/s)

V—linear velocity of the mixing rod (m/s)

P—power required to drive the drive shaft (Watts)

d—diameter of the mixing rod (m)

d_{opt}—optimal diameter for the mixing rod (m)

D—diameter of the drive shaft (m)

D_{opt}—optimal diameter for the drive (m)

P—power required to drive the mixer (Watts)

P_{opt}—Optimal power to drive the mixer (Watts)

Ɵ—the inclination of the resultant force to the horizontal

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