Experimental Investigation of Agitator to Optimize Performance & Cost

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Abstract- **Mixing is one of the most primary operations in industries like chemical, Biochemical, paper, food, cosmetic, and pharmaceutical applications. Though the customer have standard sized agitator with standard parameters but this method is time consuming as well as it consumes the more power for a batch type process. So the customer needs to design optimum agitator which runs with optimum power and time to perform its function. Further he requires small sized agitator which runs continuously without interruption the process flow. In this work the power requirement for small size agitator to mix two fluids are analyzed with optimum time. This paper describes the mechanical design of agitator to mixing polyectrolyte having viscosity 1.5cp considering the fluid forces that are imposed on the impeller by the fluid. The analysis shows that the forces are a result of turbulent flow of fluid and static fluid forces. The loads are dynamic and are transmitted from the impeller blades to the agitator shaft and then to the gear box. Agitator design is often though as the application of two engineering disciplines. The first step is process design from a chemical viewpoint and involves the specification of the impeller pattern, speed, temperature and blade angle etc. The next step in the design sequence is the mechanical design of the agitator component. The approach is straight forward design for the power (torque & speed) then shaft loads. The experiment is carried out for agitator 500 liter of capacity. Drawback of the old agitator is removed. The old agitator does not gives homogeneous mixing.**

The next objective is to Design of Bi-Directional Agitator using Scotch Yoke Mechanism. In this objective it is required to blend the weighty density metal powder in the paint. 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 only possible by creating vigorous shaking in the content. To create high instability in fluid and powder mixture the impeller should rotate in ahead and reverse direction. This bidirectional Agitator gives more effective agitating turbulence.

***Index Term*-Agitator shaft,Design of agitator,Homogeneous Mixture,Unidirectional,Impeller blades,Oscillating Motion, Polyelectrolyte,Rack And Pinion,Scotch Yoke Mechanism,Staticfluid forces,Turbulent flow**

I.INTRODUCTION

IN this age, mixing is one of the most fundamental operations in industries like paper, food, cosmetic, and chemical, biochemical and process industryapplications. Agitator is one of the important parts in the mixing process. Agitation refers to force a fluid by agitating and to flow in a circulatory motion. Agitator has various purposes such as suspending solid particles, coming together miscible liquids, dispersing a gas through a liquid in the form of small bubbles, and promoting heat transfer between the water and coil or jacket. There are some factor affecting the efficiency of agitating, some are linked to the liquid characteristics such as viscosity and densities as well as some are related to geometry such as the tankdiameter (D), impeller length (L), revolving speed (N), an height of impeller from bottom of the container other distinctiveness of mixing include the liquid the necessity of performing the process to make the liquid experience all kind of movement inside tank. There is no universal system

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till now that is valid for all liquids and all tanks. Mixing is a significant unit operation in many industries like cosmetic, chemical, bio-chemical and applications dairy and food process industry. For instance, all operations involving blending homogenization, emulsion preparation, suspension, crystallization, liquid phase reactions, etc., need mixing in one form or the other.

In this work two objectives are discussed first one is to design small size agitator to mix polyelectrolyte and second one is to design & develop Bidirectional agitator to mix paint. For the first objective a tank of size 500 liter capacity is selected. Then the calculation for power number, fluid forces, power requirement for agitation are carried out. For the second objective design of scotch yoke mechanism is carried out. In this case to achieve the forward and reverse direction employed Scotch Yoke device with proper arrangement of rack & pinion. Scotch yoke mechanism converts a constant rotational motion into to and fro motion known as simple harmonic motion. In present case a rectangular cross- section bar is attached to the yoke as shown in Fig.12 .For this bar a rack is attached to rack is a spur gear. As the rack moves back and forth it drives the pinion attached to it. Again to and fro motion converted into rotational motion. This rotational motion is then transfer to the bearing and then to impeller shaft. For 0^0 to 180^0 revolution of the disk the impeller moves in back and forth direction and 180^0 to 360^0 the impeller moves in reverse direction. Hence the high vigorous action is created in the paint and help to exploit the Agitating performance. It is easilyachievable to manage the degree of rotation of impeller just by changing the pitch circle diameter of pinion attached to the impeller shafts.

II. MECHANICAL DESIGN

A. Existing agitator specifications

Capacity = 3000 Liter, Dimensions of Tank length = 2m, Height = 1.5, width = 1m

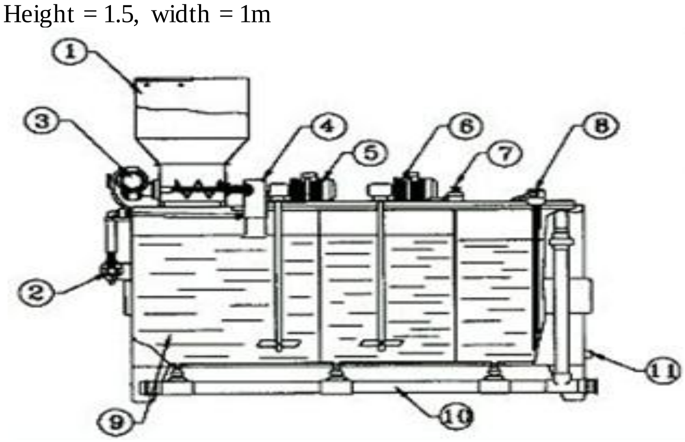

Fig. 1.Existing Agitator with Hopper

1. Hopper 2. Power feeder and Breaker
3. Power feeder4. Pre-dilution Chute
5. Stirrer 6.Stirrer
7. Emergency stop 8. Pump
9. Tank 10. Drain 11. Outlet Connection

The Fig 1Shows the Agitator uses the Solid polyectrolyte kept into the hopper. The Hopper motor is 0.25 HP. The two impeller motor are of capacity 1 HP. The space requirement for rectangular agitator is 7 m^2.

The hopper motor runs for 24 Hrs during the all working shift.Fig.2

Power consume for one month = 0.18 * 24 * 30

= 129.6 kWh.(1 Unit= 6.89 Rs)

Electricity bill for one month = 129.6 * 6.89 = 892.9 Rs (1)

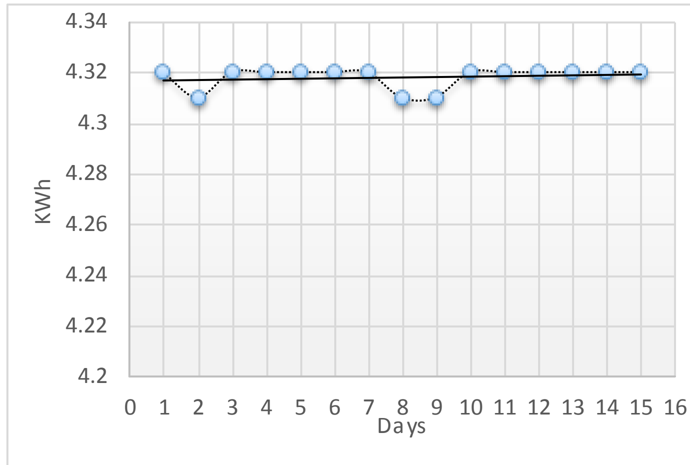

Fig. 2. Power consume by hopper motor (kWh) Vs Days

Power consumed by **two** impeller motors. Fig 3

= 1.492 (kw) * 24 * 30 * 2 = 14803 Rs (2)

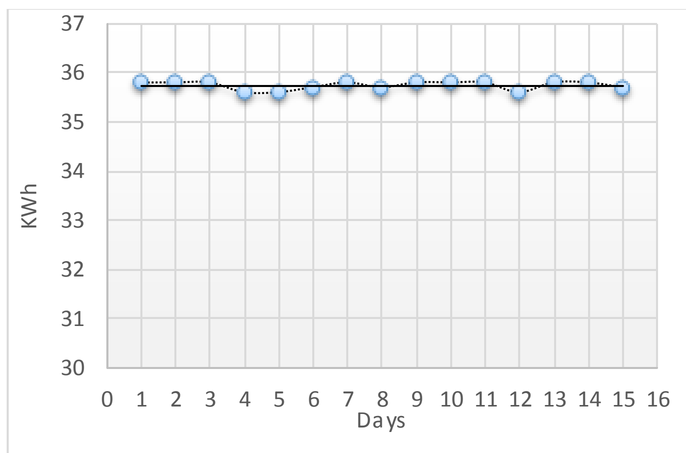

Fig.3.Power consume by impeller motors (kWh) Vs Days

Total Electricity bill Equation 1 + Equation 2

= 892.9 + 14803

= 15695.92 Rs.

B. New Agitator Design to Optimize the Cost

To determine power require running the agitator. Impeller Reynolds No[22] $N_{Re} = \frac{\rho N D^2}{\mu}$(3)

N= Impeller rotational speed = 103 RPM = 1.72 RPS

ρ = Fluid Density = 1250 Kg/m^3

μ = Viscosity of Fluid = 0.0015 Pa-s

Po = Impeller Power Number

$N_{Re} = \frac{1250*1.72*0.318^2}{0.0015}$ = 144944.4 > 10000

Hence flow in the tank is turbulent and mixing possible.

Power Consumption = P = $\rho * N^3$ Po*D^5[22](4)

= 1250*18.03*1.72^3*0.318^5 = 373 Watt. = 0.5 HP.

Known Data

Cylindrical Tank Dimensions

Bottom Diameter(D_B) = 860 mm,Top Diameter (D_T) =910 mm

Height (h) = 810 mm, Viscosity of Fluid μ = 0.0015 Pa-s

Fluid Density = 1250 Kg/m^3

Location of Impeller h/6 = 135 mm from bottom side of tank.

Volume of Tank = (π/4) * Dt^2 * h = (π/4) * 885^2 * 810 (5)

= 498.26*10^6 mm^3 = 500 liter.

Maximum bending moment[23]M = $\frac{Pi*Li*fH}{N*Di}$

= $\frac{0.048*373*0.135}{1.72*0.318}$(6)

= 4.41Nm

Li = Distance from the bottom drive blade

fH = Hydraulic service factor = 1

Di = Diameter of i^{th} impeller = 0.318 m

Material Selection for shaft & Blade

Stainless steel 316L

$\sigma_{t} =$ 60 X 10^6 N/m^2, Ʈ = 35.9 x 10^6 Nm^2

According to Maximum Principal shear stress theory [19]

Te = $\sqrt{M^2 + T^2}$(7)

Power = $\frac{2\pi NT}{60}$ T = $\frac{373*60}{2\pi 103}$ = 34.58Nm

Te = $\sqrt{4.41^2 + 34.58^2}$ = 34.86 Nm.

(π/16) Ʈ d^3 = 34.86 (8)

d = 17.03 mm ≈ 25 mm.

According to Normal Stress theory [19]

Me = ½ [M+Te] = ½ [4.41 + 34.86] = 19.63 Nm(9)

π/32 * σ_t * d^3 = 19.63

d = 14.34 mm.

Select maximum diameter from both theories ie.25mm.Fig 4.

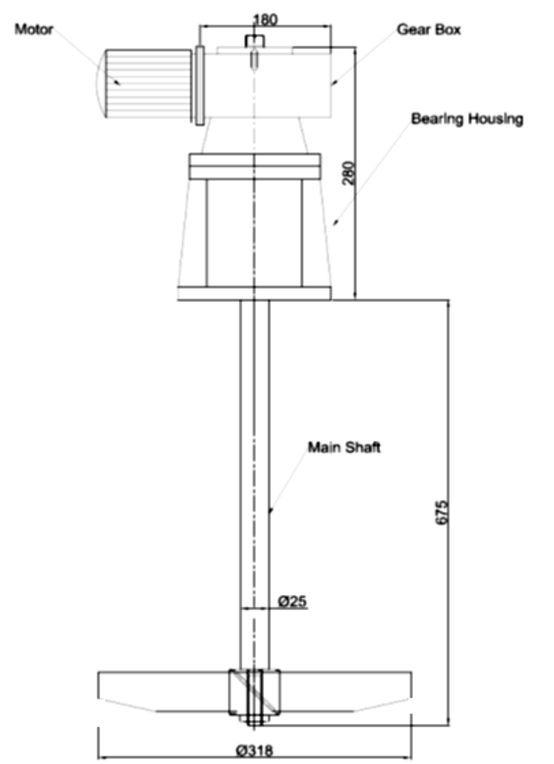

Fig. 4. Agitator Impeller detail dimensions

C. Impeller Blade Calculations[22]

1. Diameter of Impeller (d) = 360mm = 0.36 (0.3D to 0.6D) (Where D is diameter of tank)
2. Width of Impeller Blade (w) = 50mm =0.05m……(w = d/5) (Where d is diameter of Impeller)
3. Number of Blade (n) = 3……(Pitch Blade turbine Impeller)
4. Thickness of Blade (t) = 10 mm

5. Impeller Speed (N) = 103 rpm

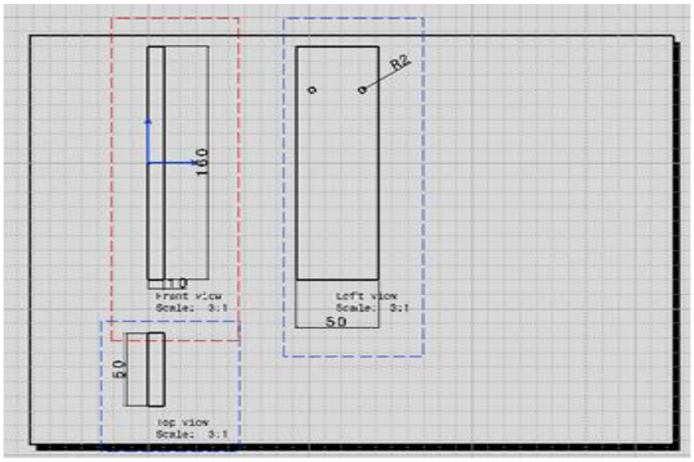

Fig. 5.Agitator Impeller blade dimensions 45^0 pitch blade

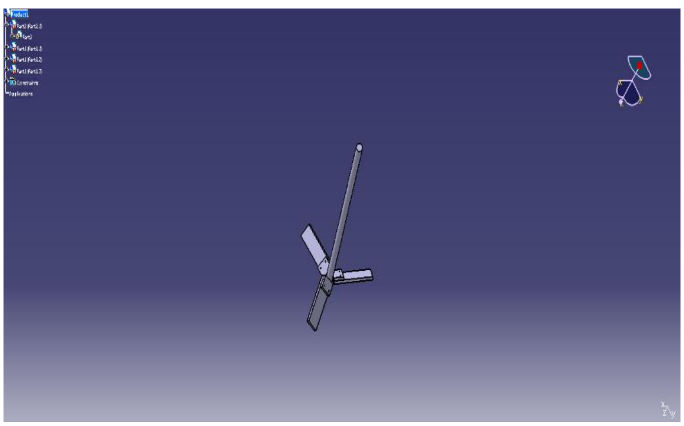

Fig. 6.Geometry of agitator impeller shaft and blade in Ansys 14.0

D. Design of Gear Box [19]

Known Parameters	
Centre Distance (X)	44 mm
Speed Reduction (V.R)	14 : 1
Power to Transmit (P)	0.5 HP or 373 W
Pressure Angle (α)	20^0

1. Design of Worm [19]

l_N = Normal Lead Angle, λ = Lead Angle

We have

$\mathrm{Cot}^3 \lambda = 14$» $\mathrm{Cot}\ \lambda = 2.4$ » $\lambda = \tan^{-1}[1 \div 2.41]$ » $\lambda = 22.5^0$(10)

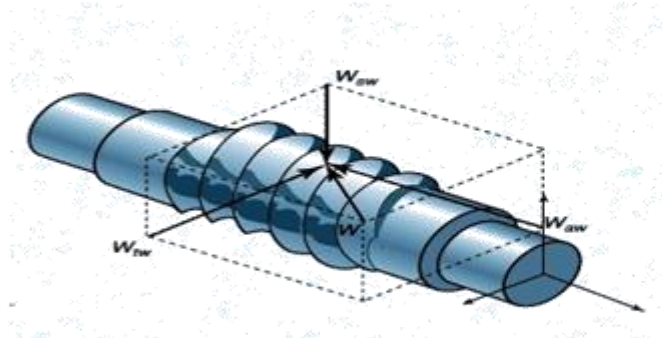

Fig. 7. Forces on Worm [14]

We know that

$\frac{X}{l_N} = \frac{1}{2\pi}\left(\frac{1}{\sin\lambda}\right) + \frac{V.R}{\cos\lambda}$ » $\frac{44}{l_N} = \frac{1}{2\pi}\left(\frac{1}{\sin 22.5}\right) + \frac{14}{\cos 22.5}$

» $\frac{44}{l_N} = \frac{1}{2\pi}(17.77)$» $\frac{44}{l_N} = 2.83$ » $l_N = 15.56$ mm

Axial Lead (l) $\frac{l_N}{\cos\lambda} = \frac{15.56}{\cos 22.5}$ » l = 16.84 mm

For velocity ratio of 14 the number of starts on the worm

n = Tw = 2

Axial pitch of the threads on the worm

$P_a = \frac{l}{n} = \frac{l}{2} = \frac{16.84}{2} = 8.42$ mm » $m = \frac{Pa}{\pi} = 2.6$ Take Standard module (m = 2.5) » $2.5 = \frac{Pa}{\pi}$

» $P_a = \pi * 2.5$ » $P_a = 7.85$ mm

$l = P_a * n = 7.85 * 2 = 15.7$ mm

Normal Lead of threads on the worm

$l_N = l \cos\lambda = 15.7 \cos 22.5$ » $l_N = 14.51$ mm

We know that centre distance[15]

$x = \frac{Ln}{2\pi}\left(\frac{1}{\sin\lambda}\right) + \frac{V.R}{\cos\lambda}$» $x = \frac{14.51}{2\pi}\left(\frac{1}{\sin 22.5}\right) + \frac{V.R}{\cos 22.5}$ » x = 41 mm

Let Dw = Pitch circle diameter of the worm

We know that - $\tan\lambda = [(l) \div (\pi * Dw)]$

$Dw = [(l) \div (\pi * \tan\lambda)]$ » $Dw = [(15.7) \div (\pi * \tan 22.5)]$

Dw = 12.06 mm

Since the velocity ratio is 14 and the worm has 2 threads

$T_G = 14 * 2 = 28$

Length of threaded portion is[19]

$Lw = Pc [4.5 + 0.02 \ Tw] = 7.85 \ [4.5 + 0.02 * 2] = 35.64$ mm

This length should be increased by 25 to 30 mm for feed marks produced by the vibrating wheel as it leaves the thread root $L_w = Pc [4.5 + 0.02 \ T_w] = 35.64 + 25 = 60$ mm(11)

Depth of tooth $h = 0.623 \ P_C$ » $h = 0.623 * 7.85$ » $h = 4.89$ mm

Addendum (a) = $0.286 * P_C = 0.286 * 7.8 = 2.25$ mm

Outside diameter of the worm, $D_{OW} = D_W + 2\,a$(12)

$= 12.06 + 2 * 2.25 = 16.56$ mm

2. Design of Worm Gear[19]

Pitch diameter of worm gear $D_G = m*T_G = 2.5*28 = 70$ mm

$D_{OG} = DG + 0.8903 \ P_C = 70 + 0.8903 * 7.85 = 77$ mm(13)

Throat diameter,

$D_T = D_G + 0.572 \ P_C = 70 + 0.572 * 7.85 = 74.4$ mm(14)

Face width (b),

$b = 2.15 \ P_C + 5$ mm (avoid allowance)= $2.15 \ P_C$(15)

$= 2.15 * 7.85 = 16.8$ mm

Fig. 8.Experimental Setup

Check the designed worm gearing from the stand point of tangential load, dynamic load, and static load, wear load and heat dissipation.

3. Check for the tangential load [19][15]

N_G = Speed of worm gear in rpm

$V.R = \frac{N_w}{N_G}$ » $N_G = \frac{N_w}{V.R} = \frac{1440}{14} = 102.8$ rpm = 103 rpm (appx.)

We have, $P = \frac{2\pi NT}{60}$(16)

$$T = \frac{60\ P}{2\pi N_G}$$

$T = \frac{60 * 373}{2\pi * 103} = 34.58$ Nm

Tangential Load acting on the gear

$W_T = \frac{2*\text{Torque}}{D_G} = \frac{2*34.58*10^3}{70} = 988$ N(17)

We know that pitch line velocity of worm gear,

$V = \frac{\pi * D_G * N_G}{60} = \frac{\pi * 70 * 103}{60} = 0.38$ m/sec

Velocity Factor $C_V = \frac{6}{6+V}$

$= \frac{6}{6+0.38} = 0.94$

Tooth Form Factor $y = 0.154 - \frac{0.912}{T_G} = 0.154 - \frac{0.912}{28} = 0.121$

Worm gear is made up of phosphor bronze

Static Stress for phosphor bronze $\sigma_0 = 84$ MPa

Tangential load $W_T = [\sigma_0 * C_V] * b * \pi * m * y$ (18)

$= 84*0.94*16.8 \ \ \pi*2.5*0.121 = 1265$ N

Since this is more than the tangential load acting on the Gear (988 N) therefore the design is **safe** from the standpoint of tangential load.

4. Check for Dynamic load

$W_D = \frac{W_T}{C_V} = \frac{1265}{0.121} = 10454.54$ N(19)

Since this is more than [W_T = 988 N] Therefore the **design is safe** from standpoint of static load.

The readings are taken for new agitator and electricity consumption over 15 days calculated. The designed agitator uses 0.5 HP motor to drive the impeller.Fig

Elecrticity consumption for month = 0.373(kw) * 24 * 30

= 268.56 kWh

Total Electricity Bill = 268.56*6.89 = 1850.37 Rs.

Total Saving = 15695.2 – 1850.37 = 13845.55 Rs/Month

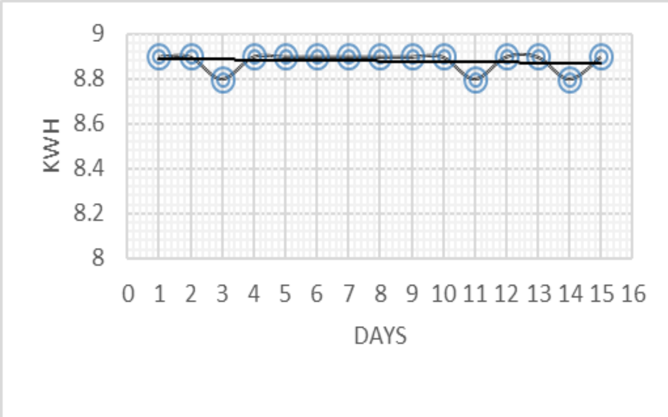

Fig. 9.Power consume by Impeller motors (kWh) Vs Days

III. DESIGN of BI-DIRECTIONAL AGITATOR [2][3][4]

A. Design of Rack and Pinion[14]

Materials for rack and pinion are Plain carbon steel [40C8]

Sut=600 N/mm2 ,

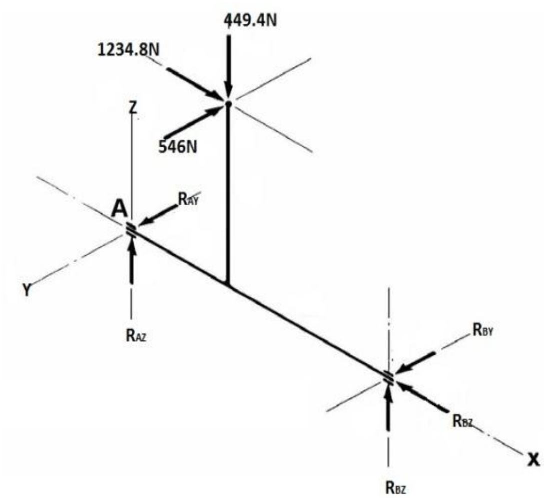

Fig. 10.Pictorial view of forces on Worm [19]

σb = 30 N/mm2
As the material for Rack & Pinion is same.
Therefore we assume Pinion is weaker than the Rack.
Zp (min) = 2/Sin2α = 17
Zp = 18

Lewis form factor (Y) for 18 teeth is 0.308.
From suggested series of module take m = 4

Face width is lies between
8m < b < 12m
(8*4) < b < (12*4)
32 < b < 48

Take b = 40 mm.(20)

The permissible bending stress is one third of Sut.
(600/3 = 200 N/mm2)

Sb = m*b*σ_b*Y = 4*40*200*0.30 = 9856 N

Static Load$P_t = \frac{2\,Mt}{d'_p} = \frac{2*60*10^6*kw*0.745}{m*Zp*2\pi*n_p}${$n_P$ = 280 RPM because rack moves forward and reverse in scotch yoke mechanism so 140*2 = 280}

$= \frac{2*60*10^6}{4*18*2\pi*280}$ = 705.44 N

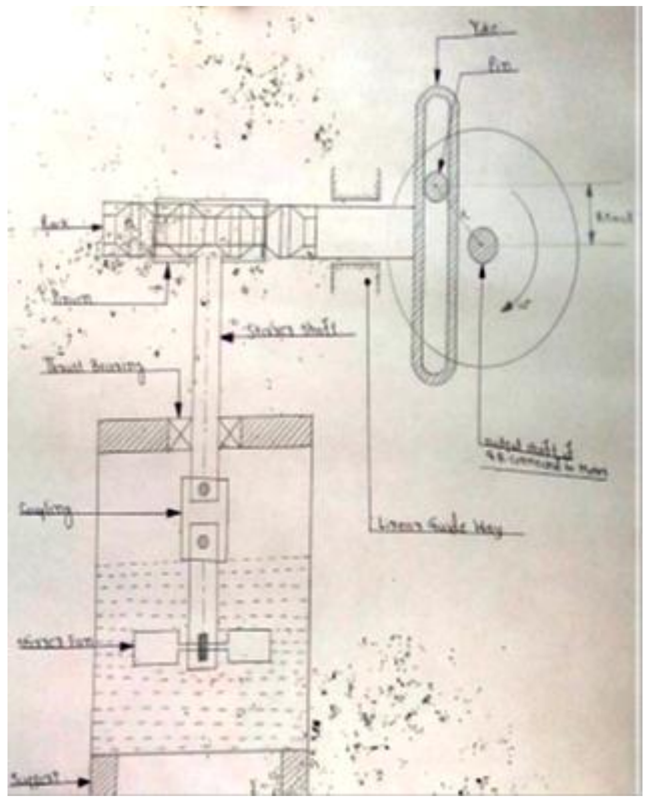

Fig. 11. Schematic of Bi-directional Agitator[4]

Effective load[14]

$V = \frac{\pi*d_p*n_p}{60*10^3} = \frac{\pi*4*18*280}{60*10^3}$= 1.055 m/s(21)

$C_V = \frac{3}{3+V} = \frac{3}{3+1.055}$ = 0.739

$P_{eff} = \frac{Cs}{Cv}*P_t = \frac{1}{0.739}$*705.44 = 954.87(22)

Factor of Safety [14]

$F_s = \frac{S_b}{P_{eff}} = \frac{9856.87}{954.87}$ = 10.32(23)

Surface Hardness

$S_w = P_{eff} * Fs = 954.87*10.32 = 9856.87$(24)

$Q = \frac{2Z_g}{Z_g+Z_P} = 1$(25)

$S_w = b*Q*d_P*\left[\frac{BHN}{100}\right]^2$(26)

$9856.87 = 40*1*4*18*\left[\frac{BHN}{100}\right]^2$

BHN = 185

Consider gears are manufactured according to Grade-6

For this grade -: $e = 8+0.63\Phi$

For pinion –: $\Phi = m+0.25\sqrt{dp} = 5.06$ (27)

$e_p = 8+0.63*5.06 = 11.188$

For Rack -: $\Phi = m+0.25\sqrt{d_R} = 5.06$(28)

$e_p = 8+0.63*5.06 = 11.188$

Total e = 11.188+11.188 = 22.38μm = 22.38*10^-3mm

Dynamic Load [14]

$P_d = \frac{21V\,[C*e*b+Pt]}{21V+\sqrt{[C*e*b+Pt]}}$(29)

$= \frac{21*1.055\,[11400*22.38*10^{-3}*40+706.44]}{21*1.055+\sqrt{11400*22.38*10^{-3}*40+706.44]}}$

= 1866.89{C= Deformation constant and for material 40C8 it is 11400}

$Peff = Cs*P_t + P_d = 1*706.44 + 1866.89 = 2573.33$(30)

$Fs = \frac{S_b}{P_{eff}} = \frac{9856}{2573.33} = 3.83$(31)

Design is Safe

Basic Dimensions of Rack

$d_R = 4*18 = 72$ mm

Length = $\pi*d_R$ or $(\pi*m*Z_R) = 226.19$ » L = 226.19 + 35 (Grinding Allowance)= 262mm

Mounting Distance (a) = Z*m/2+H+X*m(32)

=18*4/2+36+0.6*4 = 74.4 mm

B. Design of Scotch Yoke [2]

For complete revolution of pinion ie.0^0 to 360^0 the rack should move ‘L’.Hence the pin should be adjusted at R= 113 mm from the centre of motor shaft. The pin ‘P’ glides in the slot and Yoke oscillate up and down in vertical direction only. The motion of point P is SHM.

We have $V = \frac{dx}{dt} = \frac{d(Rsinwt)}{dt} = wRcoswt$ & $a = \frac{dv}{dt} = -w^2R\sin wt$

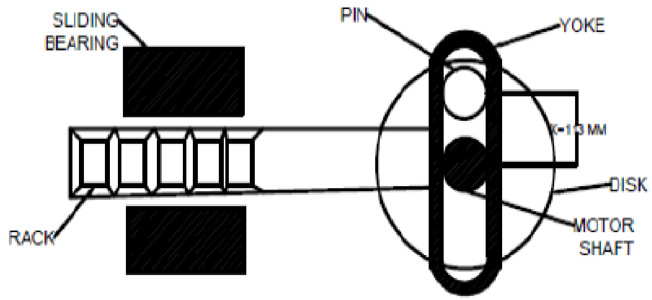

Fig. 12. Scotch Yoke Mechanism

C] Power Required Running the System[2][4][20]

Input Data

1] Kinematic viscosity of paint = 2.4 poise= 240 centipoise

2] Specific gravity for paint = 1.59 Kg/lit

It is required to calculate the torque which is necessary for the stirring and based on this torque selecting an appropriate motor after including a suitable factor of safety.

Total Torque Required = Torque overcome to viscous force + Torque overcome to static Pressure

A] Calculation of torque owed to viscous force [2][20]

(Diameter of blade = 10cm)

Actual motor speed 1400 rpm.[V.R.10 Hence N=140]

Tangential speed of shaft = $u=\pi*D*N/60$ (33)

$= \pi*0.10*140/60 = 0.733$ m/sec

Now Shear Stress = $\mu\,\frac{\partial u}{\partial y} = 0.24 * [0.733/0.01] = 17.592$ N/m^2

du = change in speed = u-0 = 0.733 m/sec

dy = Distance between shaft and journal = 0.01m.

$A = \pi*D*w = \pi*0.1*0.04 = 0.012$ m^2

Power = F * u = 0.211 * 0.733 = 0.155 watt (34)

B] Calculation of torque owed to viscous force at top and bottom end of blades[2][4][20]

Thickness of blade = 40 mm

Length of blade = 1000 mm

Area of blade that is exposed to shear intensity will be

A= L * t = 1000 * 40

$A = 40 * 10^3 \ mm^2 = 0.04 \ m^2$.

Shear Force (F) = τ * Area 17.592 * 0.04 = 0.704 N.

Total shear force (F) = 3F = 3 * 0.704 = 2.111 N

Power = F * u = 2.11 * 0.73 = 1.55 watt (35)

C] Calculation of torque owing to static total pressure acting on the blades by benefit of stationary fluid [3][4][20]

Specific Gravity = 1.59 Kg/lit = 1.59 * 1000 Kg/m^3

Pressure = $\rho * g * h * A$

= 1590*9.81*1*0.04

= 623.91 N

Torque that each pinion has to overcome to rotate about its own axis is given by

T = F * Distance*Radius = 623.916 * 0.04 = 24.95 Nm

Power required at output shaft to overcome the static opposition of fluid is

$$Ps = \frac{2\pi * N * T}{60} = \frac{2 * \pi * 140 * 24.956}{60} = 365.883 \text{ watt} \quad (36)$$

The net power required at the output shaft is the addition of above three powers [Equation 34+35+36]

P_{NET} = 0.155 + 1.547 + 365.883 = 368 watt.

The scotch Yoke mechanism used for converting rotary motion into reciprocating motion is not tested for its efficiency so assuming only 50% efficiency. Some quantity power is loss in rubbing between Rack and Pinion assume it is 10%. So overall efficiency is 100 – 60 = 40 %

Total Power required for 40 % efficient mechanism is

P = 368 + 40 / 100 * 368 = 515 watt. = 690.626 watt » 1HP

VI. CONCLUSION

This paper presents the mechanical design procedure of an agitator capacity 500 liter based on the polyectrolyte fluid having viscosity 1.5 cp. It is observed that new develop agitator is energy efficient than conventional one. It saves 13845.55 Rs/Month because it uses only one motor to drive the impeller. While conventional agitator uses 3 motors. The dosing system not explained in this paper beyond the scope of the paper. The impeller is design considering the bending moment, static forces, pressure on blades etc. The detail design method of worm and worm wheel reduction gear box 14: 1 explained.

The development of this bidirectional agitator many changes are done in conventional design of mixer. The results of this work are encouraging and giving good agitating performance over conventional method. This bi- directional mixer rotates in both directions and it gives better agitating effecting in more uniform mixture of product. It is observed that the quality of mixture is very high. The cost also reduced by compact size of mixture which leads to low space requirement. This new developed mixer has low cost, high performance and structural simplicity. Mixing process has been accomplished which chase that the proposed mixing avoid the formation of segregated region hence optimize the mixing time than other mixing method. Also by using the bidirectional mixer in tank create turbulent flow of mixture and we get the homogeneous mixture.

NOMENCLATURE

d = Pitch circle diameter = mz
da = Addendumcircle diameter = m (z+2)
df = Dedendum circle diameter = m (z-2.5)
b = Face width
M_t = Transmitted torque (N-mm) (T)
σ_b = Permissible bending Stress
S_{ut} = Ultimate tensile stress
Fs = Factor of Safety
Z_P = No.of teeth on pinion
Z_R = No.of teeth on rack
Pt = Tangential component
Pr = Radial component
Y = Lewis form factor
Peff = Effective force
S_b = Beam strength of gear tooth
Cs = Service Factor
C_V = Velocity factor
α = Pressure angle
W_T = Tangential load on the gear
W_D = Dynamic load
D_T= Throat Diameter
Fs = Factor of Safety
N_{RE} = Reynolds Number
ρ = Fluid Density kg/m^3
N = Impeller rotational Speed RPM
μ = Viscosity of fluid Pa-S
Po = Impeller power number
D_B = Bottom diameter of tank mm
fH = Hydraulic service factor
Te = Equivalent twisting moment
Me = Equivalent bending moment
λ = Lead angle
Tw = Number of starts on worm
l_N = Normal lead.

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