Detection of Failure mode of Pressure Vessel Agitator due to variable load

[1]Shivam M Shukla, [2]Prashant S Bajaj,

[1]Master's of Engineering Student, [2]Associate Professor Mechanical Engineering Department,
[1]Mechanical Engineering Department,
[1]Shree Sant Gadge Baba College Of Engineering & Technology, Bhusawal,India

Abstract-In this era, mixing is one of the most fundamental operations in industries like paper, food, cosmetic, chemical, biochemical and pharmaceutical applications. Pressure vessel agitator is one of the important parts in the mixing process. Proper and uniform mixing gives improved quality of the product. In this paper, we have mainly focused on detection of failure mode of Pressure Vessel agitator for variable load. Reactor Pressure for variable viscosity loads. The design of agitator affects on the mixing process as proper design can increase the mixing and uniform distributions of all additives, chemicals, raw materials present in the fluid. The review helps us to design an error prone model for agitator blade which will increase the mixing percentage avoiding the deflection of the blades. The dimensions calculated by the theoretical formulas may lead to high dimensions along with more thickness of the Blades being sized. In order to avoid these troubles the approach of Design by analysis or FEA must be adopted, where stimulation of the Agitator model being developed & being analyzed using the various loads being applied for different speeds of rotation. The result of the analysis will help to figure out optimum size of the Blades along with the trouble of bending of the blades can be avoided.

Keywords-Agitator,deflection

I. INTRODUCTION

1.1 Pressure Reactor Vessel

Pressure reactor vessel is one kind of Pressure vessel which is used for mixing of various process fluids, at various operating conditions. Process of mixing is done for considerable amount of time and at the end of cycle mixed product is being taken out. In most cases to have a proper mixing of the process components a device called as 'Agitator' is been used. The preferred type of Reactor is Vertical type, in order to have better mixing output & spacing for the Blades of Agitator for complete revolutions. The process of agitation itself starts from zero RPM, and the initial torque required must be sufficient, to overcome the Inertia forces due to stagnant fluids and also the stage wise addition of different fluids in the reactor. These fluids may have various viscosities, and over a period of time may create problems to the blades of Agitator, such as bending. This problem is observed in some of the reactor vessels where mixing is done at various speeds.The earliest documented design of pressure vessels is described in the book Codex Madrid I, by Leonardo da Vinci, in 1495, where containers of pressurized air were theorized to lift heavy weights underwater. The need for high pressure and temperature vessels for petroleum refineries and chemical plants gave rise to vessels joined with welding instead of rivets. Generally they are also used to carry out reaction, distillation, boiling, condensation, crystallization, heat transfer, flashing and decantation.

1.2 Agitators

Industrial agitators are machines used in industries that process products in the chemical, food, pharmaceutical and cosmetic industries, in a view of mixing liquids together, promote the reactions of chemical substances, keeping homogeneous liquid bulk during storage, increase heat transfer, to stir or mix fluids, liquids specifically.

1.3 Types of Agitator

Mainly Five types of Agitators are used in Pharmaceutical reactors, they are viz.,

i. **Paddle Agitators:** This is one of the most primary types of agitators with blades that reach up to the tank walls. Paddle agitators are used where an uniform laminar flow of liquids is desired.

ii. **Anchor Agitators:** This simple agitator consists of a shaft and an anchor type propeller and can be mounted centrally or at an angle. It is mainly used in reactors.

iii. **Radial Propeller Agitators:** Radial agitators consist of propellers that are similar to marine propellers. They consist of two to four blades that move in a screw like motion, propelling the material to be agitated parallel to the shaft.

iv. **Propeller Agitators:** A propeller agitator is shaped with blades tapering towards the shaft to minimize centrifugal force and produce maximum axial flow. Propeller agitators are popular for simple mixing jobs.

v. **Turbine Agitators:** Yet another type of process agitator is the turbine agitator. Turbine agitators can create a turbulent movement of the fluids due to the combination of centrifugal and rotational motion.

vi. **Helical Agitators:** These agitators have blades with a twisted mechanism, just like the threads of a screw. The curves result in a vigorous motion of the fluids to be agitated. Helical agitators are most useful for mixing viscous liquids.

Fig.1. Agitator Shaft with motor assembly

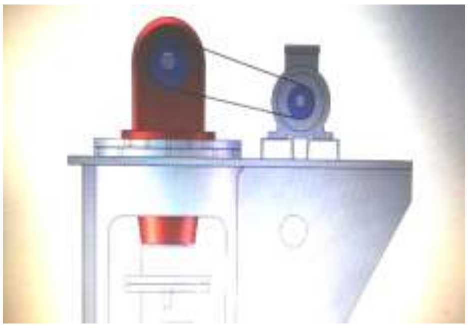

Fig.2. Motor assembly(2D View)

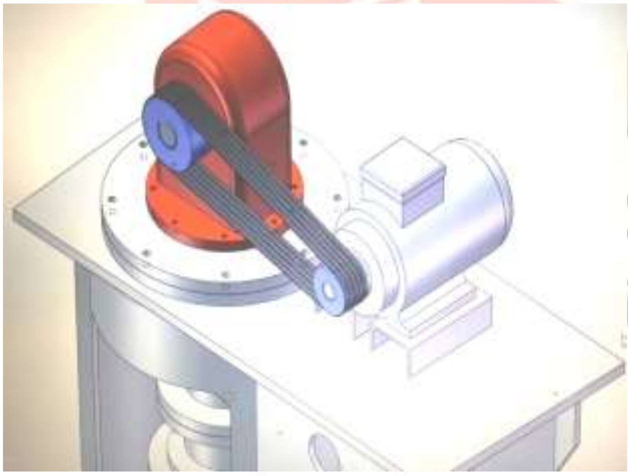

Fig.3. Motor Assembly(3D view)

The choice of the agitator depends on the phase that needs to be mixed i.e, Liquids only, liquid and solid, liquid and gas or liquid with solids and gas. Depending on the type of phase and viscosity of the bulk, the agitator can be named mixer, kneader, dough mixer, amongst others. The agitators use in liquids can be placed on the top of the tank on vertical position, or horizontally or less common, agitator is located on the bottom of the tank.

The agitation is achieved by movement of the heterogeneous mass, to the impeller. This is due to mechanical agitators, to the rotation of an impeller. The bulk can be composed of different substances and the aim of the operation is to blend it or to improve the efficiency of a reaction by a better contact between reactive product. Or the bulk is already blended and the aim of agitation is to increase a heat transfer or to maintain particles in suspension to avoid any deposit. The agitation of liquid is made by one or several agitation impellers. Depending on its shape, the impeller can generate the moving of the liquid which is characterized by its velocity and direction, Turbulence which is an erratic variation in space and time of local fluid velocity & Shearing given by a velocity gradient between two filets of fluids. An agitator is composed of a drive device, a guiding system of the shaft, a shaft and impellers .If the operating conditions are under high pressure or high temperature, the agitator must be equipped with a sealing system to keep tightened the inside of the tank when the shaft is crossing it. If the shaft is long (> 10m), it can be guided by a bearing located in the bottom of the tank.

II. PROBLEM DEFINITION

2.1. Reactor pressure vessel (Vertical):

Reactor pressure vessel (Vertical)is used to have better mixing, cyclic operation & even distribution of the Agitator Blades. The process of agitation starts from zero RPM requires initial high torque, to overcome the Inertia forces due to stagnant fluids and also the stage wise addition of different fluids in the reactor. These fluids may have various viscosities, and over a period of time may create problems to the blades of Agitator, such as bending or fatigue.

This problem is observed in one case of the reactor vessels where mixing is done at various speeds handling Emulsion polymer. The viscosity of the fluid does not remains the same during mixing period and keeps changing. These dimensions calculated by the theoretical formulas may lead to high dimensions along with more thickness of the Blades being sized. The case which is being handling in this report is of change in volume or Capacity of the reactor vessel. It is certainly that as per increase in volume the size and type of Agitator may also change. The previous type of Agitator was handling same fluid but only 5KL of capacity. As the capacity is now changed to 15KL the design of reactor and agitator has to be work on again. It will be also tested under ANSYS software to determined failure modes and to make a robust design.

III. PROPOSED METHODOLOGY

This problem is observed in Agitators of mentioned reactor vessels where **Emulsion polymer** is to be produced. The viscosity of the mixing fluid varies during mixing period. Due to which the calculated values using the theoretical formulas lead to a bulky design & failure because of bending as well as high stress concentration, also more load applied on the Motor. In order to avoid these troubles the approach of **Design by analysis or FEA** must be adopted, where stimulation of the existing Agitator model being developed & being analyze using the various loads and pressure being applied. The result of the analysis will help to figure out; optimum size of the failure loads acting on Blades, avoiding bending of the blades with new design Agitator with optimum dimensions.

3.1. *Design Procedure of Reactor Pressure vessel with Agitator*:

- **Procedure**

Detailing of complete procedure of problem which has to be sorted out, let us take a case study of Emulsion Polymer Vertical Reactor Pressure vessel, with a complete design & drawing based on the same being discussed below. The materials to be used in pressure vessels must be selected from Code-approved material specifications. This requirement is normally not a problem since a large catalogue of tables listing acceptable materials is available. Factors that need to beconsidered in picking a suitable table are:

- Cost
- Fabricability
- Service condition (wear, corrosion, and operating temperature),
- Availability Strength requirements.

- **Design Parameters & Materials**

1.Design code : ASME SEC VIII DIV.1 ,Edition 2010, Addenda-2011 & SMPV(U) Rule-1981
2. Service : EMULSION POLYMER
3. Type of vessel: Vertical, limpetted
4. Inside Dia: 2350 mm,Shell Length: 3700 mm
5. End closures type: 2:1 Ellipsoidal Dished Ends
6. Design pressure: [Vessel Side : 7.0 + 0.0955(Static Head) Kg/cm2 (g) Incl. Static Head] [Limpet Side: 10 Kg/Sq.cm(g)]
7. Design Temperature: -6 to +150 Deg.C
8. Operating Pressure: 3.00 Kg/cm2 (g)
9. Operating Temperature: 35 Deg.C
10. Gross Geometric Vol.: 0.41 m^3
11. Filling Percentage: 90%
12. Radiography: Shell: Full & Ends: Full
13. Joint Efficiency: Shell: 1 & Ends: 1
14. Corrosion Allowance: 0.0 mm
15. Material of construction shell: [Vessel Side: SA 240 Gr. 304L] & [Limpet Side: SA 312 TP 304-Limpet Coil]
16. Dished Ends: SA 240 Gr. 304L
17. Stiffeners: SA 240 Gr. 304L
18. Nozzle flanges: SA 182 F304L

19. Nozzle necks: SA 312 TP 304L
20. R.F Pad Plates: SA 516 Gr. 70
21. Lifting Lugs: SA 283 Gr.C or IS:2062 Gr.A
22. Pressure Bolting: SA 193 Gr.B8/SA 194 Gr.8,
23. Gaskets: SS-304 , Spiral wound.
24. Saddles: SA 283 Gr.C or IS:2062 Gr.A
25. Foundation Bolting: SA 307 Gr B / SA 563 Gr.A

3.2.*Volumetric, Static head & Hydro test Pressure Calculations for Flangeguard*

Volumetric calculations:
Shell Inside diameter, d = 2350 mm
Shell Length (T.L to T.L) L = 3700 mm
1) Vol. of the cylindrical shell = 0.7854 x d^2 x L= 16.048 m^3
Volume of 2 Nos. 2:1 Ellip. Dished Ends = 2 x 0.1309 x ID^3= 3.398 m^3
Total water filled capacity V = 19.446 m^3
2) Overall length of the Vessel: TL to TL Length = 3700 mm
Dished End Outside Height = 597.5 mm
Overall Tank length (Outside to Outside) = 3700 + 2 x 597.5 = 4895 mm
3) Calculation for static head :
Type of vessel = Vertical, limpetted
Specific Gravity of Liquid = 1.0
I.D of vessel, D = Shell diameter = 2350 mm.
Pressure due to static head, p = D x Density of Liquid x % Filling = 2350.000 kg/m^2= 0.235 kg/cm^2 (g)
Hence, pressure due to static head = 3.342 Psi
Total Design Pressure = Design Pressure + Static head = 56.89 psi (g) + 3.342 psi(g)= 60.30 psi(g)
Total Design Pressure = 4.24 kg/cm^2 (g)
4) Hydro static test pressure calculation:
Hydro test pressure = (1.3 x Design pressure x Max. allowable stress in ambient conditions)/ Max. Allowable in design conditions= (1.3 x 60.300 x 16700)/ 16700= 78.39 psi (g)= 5.51 kg/cm^2 (g)

IV. FEA ANALYSIS

The Old techniques of Design by formulae (DBF) methods were used to give design on safer side & thereby lead to more thick materials or rather more strong material selections. Because of which the overall cost of Vessels or Tanks etc., was too high & design used to be very Bulky & heavy. In any Process industry the Cost is more important & safety associated with the same.Here in this design the analysis are performed on ANSYS software & the Table given below shows how agitator is safe as the selected parameters is justifying the overall safety of Vessel. Material used for the agitator are having allowable stress value equal to that of the material in the Vessel wall, in case such material is unavailable lower strength material is used, provided with area or thickness of reinforcement is being increased.

4.1. FAILURE MODES OF AGITATOR: LOAD VALUES (40N, 45N & 50N):

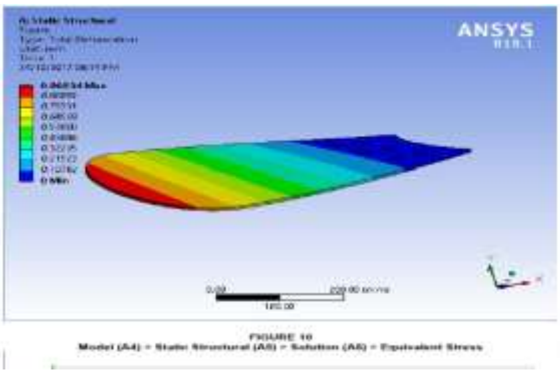

Fig. 4.Blade failure for 40N

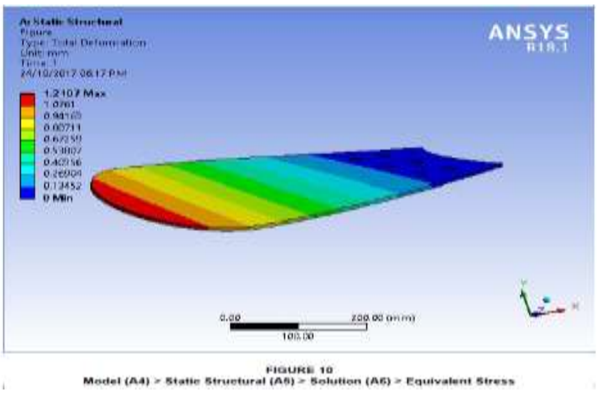

Fig. 5. Blade failure for 45N

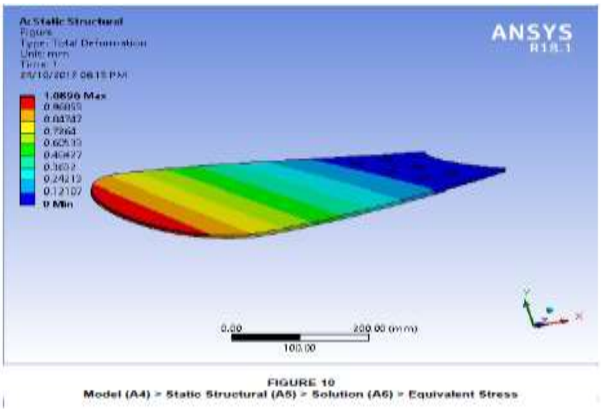

Fig.6. Blade failure for 50N

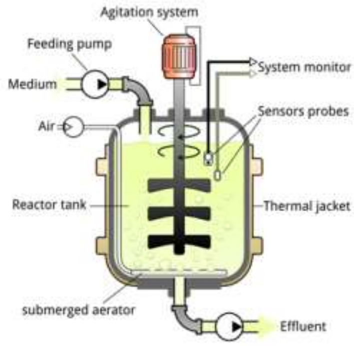

Fig.7.Schematic diagram of Pressure Vessel Agitator

V. CALCULATION RESULTS FROM ANSYS:

The Blade of Agitator having 8mm thick plate:						
Force (N)	**Area (mm^2)**	**Pressure (pa)**	**pressure (mpa)**	**Total Deformation**	**Equivalent (von-Mises) Stress**	**Maximum Principal Stress**
10	0.18196	54.95713344	5.49571E-05	0.24213 mm	2.8127 Mpa	3.2349 Mpa
15	0.18196	82.43570015	8.24357E-05	0.3632 mm	4.219 MPa	4.8523 Mpa
20	0.18196	109.9142669	0.000109914	0.48427 mm	5.6254 MPa	6.4697 Mpa
25	0.18196	137.3928336	0.000137393	0.60533 mm	7.0317 MPa	8.0871 Mpa
30	0.18196	164.8714003	0.000164871	0.7264 mm	8.4381 MPa	9.7045 Mpa
35	0.18196	192.349967	0.00019235	0.84747 mm	9.8444 MPa	11.322 Mpa
40	0.18196	219.8285337	0.000219829	0.96854 mm	11.251 MPa	12.939 Mpa
45	0.18196	247.3071005	0.000247307	1.0896 mm	12.657 MPa	14.557 Mpa
50	0.18196	274.7856672	0.000274786	1.2107 mm	14.063 Mpa	16.174 Mpa

Table.6.1- ANSYS results (for 8mm Thick Blades)

VI. CONCLUSION

The design techniques for Agitators are not being considered for various viscosity & effective load acting on same. In some cases design becomes bulky & loading of motors being increase, to have a perfect design if design & analysis runs simultaneously, more robust design can be produced. It will save the overall cost of production, material & Labour along with other reduced expenses.

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