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NUMERICAL INVESTIGATION OF SILICON CARBIDE PARTICLE SUSPENSION BEHAVIOR FOR ENHANCING UNIFORM SUSPENSION IN EROSION WEAR TEST RIG

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Abstract: *Material removal due to erosion wear in components dealing slurry is an undesirable phenomenon. Various test rigs have been developed by researchers for estimating the erosion wear rate of components when exposed to angular impacts by particles. Researchers have reported errors in the wear rate estimation due to non-uniform particle suspension in the slurry pot tester. This study pertains to the numerical investigation of particle distribution in a slurry pot tester . Model of the subject was developed in CFD modeler Gambit. FLUENT was used as post processor for obtaining results. The results of the study portray particle suspension behavior at various cross sections in the tank.*

Keywords: *Slurry erosion, CFD, Simulation, Pot tester, Suspension*

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1. INTRODUCTION:

Erosion wear is the dominant process and can be defined as the removal of material from a solid surface due to mechanical interaction between the surface and the impinging particles in a liquid stream. Erosion involves the transfer of kinetic energy to the surface. This means that in erosion, material removal is a function of particle velocity squared to the higher power. Erosive wear depends on the predominant impact angle of particle impingement with the material surface. The material loss due to erosion increases with the increase in kinetic energy of the particles impacting at the target surface. The material removal due to erosion is caused by two dominant mechanisms namely brittle fractures and platelet deformations. In brittle type material, the solid particles impacting on the target surface forms cracks in longitudinal and lateral directions. These cracks propagate due to impact of succeeding particles and broken materials pieces will be carried out by flowing fluid. In Platelet mechanism, the impact of solid particles deforms the target surface to form hills and valleys. The repeated impacts of particles remove the material and forms crater at the surface.

Parameters affecting erosion wear:

The prominent parameters and their effect on erosion wear are as follows:

Impact angle:

Impact angle is defined as the angle between the target surface and the direction striking velocity of the solid particle.

Velocity of solid particles:

Velocity of solid particle strongly affects the erosion wear. As particle velocity increases there is a significant increase in erosion rate.

Hardness:

Surface hardness as well as hardness of solid particles has profound effect on the erosion wear mechanism. Hardness ratio has been defined as the ratio of hardness of target material to the hardness of solid particles [1].

Particle size and shape:

The erosion wears increases with increase in particle size according to the power law relationship. The effect of particle shape on the erosion is not very well established due to the difficulties in defining the different shape features. Generally roundness factor is taken into consideration. If roundness factor is one then the particles are perfectly spheres and a lower values show the particle angularity [1].

Effect of particle size:

Larger particles (greater than 500 microns) remove material by a combination of cutting and ploughing on a relatively macro scale. Commercial slurries are generally a broad mix of particle sizes. The wear caused by the larger particle sizes will always predominate.

Effect of particle shape on wear:

Particle shape is one of the most important variables in the erosion wear process. Sharp particles erode at a much faster rate than rounded particles because of the high contact stresses at the point of impact. Rounded particles are not able to erode between the carbides (if they are significantly larger than the inter-carbide spacing) and the resulting wear rate is influenced much more by the volume of carbides present than for sharp particles [1].

Solid concentration:

Concentration is the amount of solid particles by weight or by volume in the fluid. As concentration of particle increases, more particles strike the surface of the impeller which increase the erosion rate, the concentration of slurries can vary from 2% to 50% depending upon the type of slurry. However, at very high concentrations particle-particle interaction increases and this decreases the striking velocity of particle on the surface [1].

2. LITERATURE REVIEW

Moving particulate materials in slurry media can adversely affect their containers by erosion. Turbo machines are used extensively in industrial fields and are generally operated at higher rotational speed. Therefore, for improving performance, it is desirable to pay attention to the wear phenomenon. Erosive wear in centrifugal slurry pumps has motivated many researchers, due to its application in areas such as dredging, hydraulic transport etc.. A review of literature available in this area has been done in following section.

Rayan and Shawky (1989) presented some experimental results of erosive wear in a centrifugal slurry pump. The objective of their investigation was to study the relation between erosive wear in a centrifugal pump impeller and solid particle concentration. Desai et al. (1990) studied the erosion wear of centrifugal slurry pumps primarily governed by the particulate motion, concentration and physical properties. Clark (1993) carried out study to explain the importance of knowledge of flow field surrounding impinging particles and target is emphasized for an understanding of slurry erosion. Steward and Spearing (1992) emphasized on the pipeline wear and conducted accelerated wear test and actual pipeline tests. Postelhwaite and Neseic (1993) evaluated erosion rates along the length of a tubular flow cell of stainless steel carrying dilute slurries of silica sand and smooth glass beads. Gupta et al.(1995) conducted a systematic study on a pot tester to investigate the effect of velocity, concentration and particle size on erosion wear. Minemura and Zhong (1995) have followed a Lagrangian approach to predict the erosion wear on a pump casing wall due to striking of solid particles They have also analyzed the effect of mutual collision among the particles. Gandhi and Borse (2001) studied that the performance of pumps decreases for increase in solid concentration, particle size and specific gravity

3. METHODOLOGY

For numerical investigation of the suspension of silicon carbide particle for suspension behavior, the fluid volume of the slurry pot has been modeled in GAMBIT. The basic components of slurry pot are cylindrical flat bottom tank, 4 Baffles, Impeller inserted through bottom and impeller Shaft. In order to do the CFD analysis on the suspension system, basic fluid domain consisting of all the components were modelled. The procedure followed to model the domain is follows:

Cylindrical tank

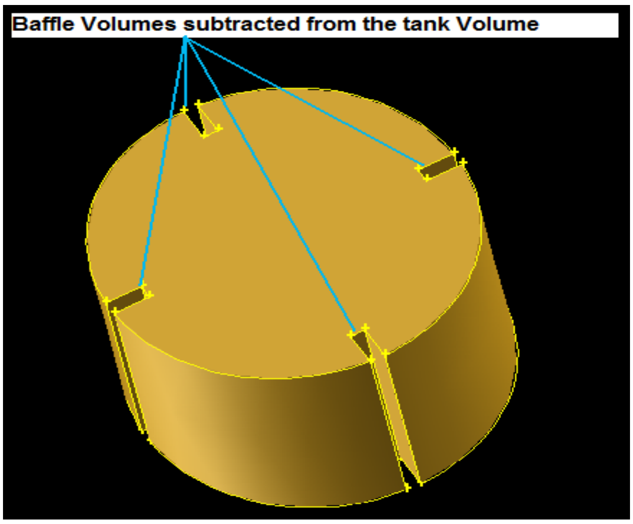

Figure 1: Fluid Volume excluding baffle space

Fluid volume of cylindrical tank was generated by taking cylinder diameter as 240 mm and the height equal to 225 mm. Four rectangular baffles with dimensions 25mm x 10 mm x 225

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mm were created and moved to the tank walls with 25mm side along the radius of the tank. All four baffles were then subtracted from the tank volume in order to obtain the desired fluid volume (as shown in figure 1).

Impeller

In order to model the impeller with shaft, the first step followed was to create a shaft volume and then each impeller blades were modeled one by one. A local coordinate axis was created in order to rotate the impeller blades at 45 degrees on their respective axis. All the impellers were modeled by following the same procedure but by only changing their dimensions. All the blade volumes and shaft volumes were united to create one impeller volume which was then subtracted and retained from the cylinder tank fluid volume (figure 2).

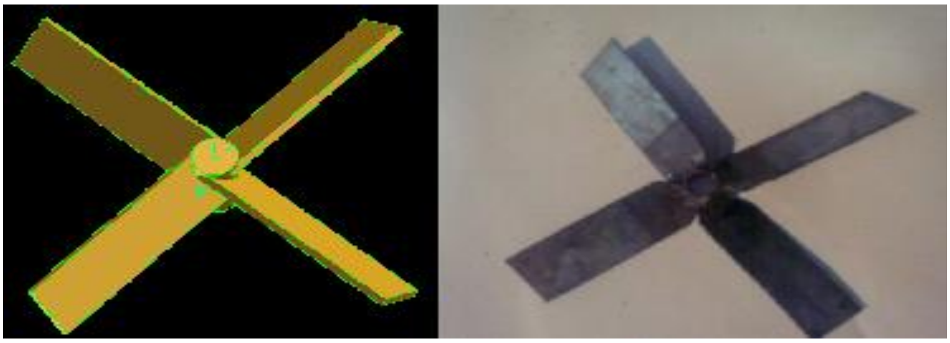

Figure 2 : a) CAD model of the Impeller, b) Impeller

The retention of the impeller volume after subtraction from the tank fluid volume was done because the same volume would be required for boundary conditions. Figure 3.a shows the CAD model and the original model after insertion of the impeller in the tank. CAD model generated is the fluid volume of the tank shown in figure 3.b.

Figure 3: a) CAD model of fluid volume with propeller b) Cylinder with propeller

Rotating Frame

To apply Multiple Reference Frame method, rotating cylinder was created which was of size equal to the impeller diameter and placed on the axis of rotation of the impeller.

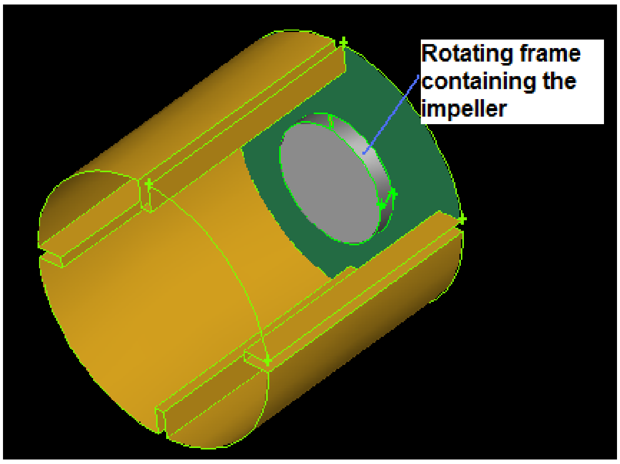

Figure 4: Slurry pot model with rotating frame

4. MESH GENERATION

All the three Volumes; Cylindrical Tank, Rotating frame and Impeller were meshed with meshing schemes as shown in Table 1. Cylindrical tank (slurry pot) was meshed with interval count of six whereas, Rotating frame and Impeller were meshed with interval counts 4 and 2 respectively. This was done as these parts were small and was the main area of focus. By increasing the number of elements we can improve the accuracy of the results but, that will be at the cost of computational efficiency. The elements created in meshing (as shown in table 1) are nearly a best fit between solution accuracy and computational time. Figure 5 shows the mesh geometry for each volume i.e., cylindrical tank, Impeller and the Rotating frame.

Table 1: Meshing scheme and number of elements

Volume	Meshing Scheme	No. of Elements
Cylinderical Tank	Tet/Hybrid, Hexcore	66333
Rotating Frame	Hex/Wedge, Cooper	5475
Impeller	Tet Hybrid,T-Grid	6809

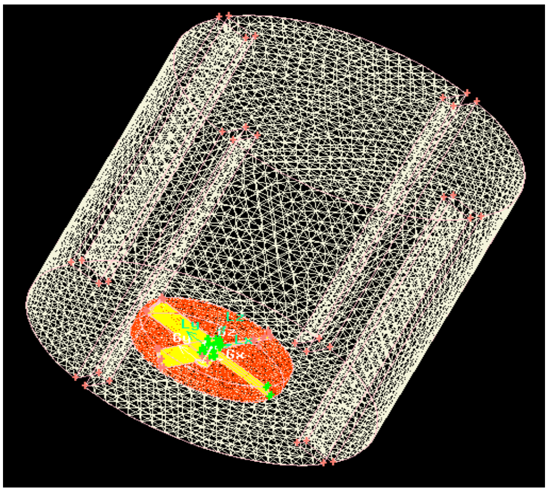

Figure 5 : Mesh of Tank, Impeller and Rotating Frame

5. BOUNDARY CONDITIONS:

As the fluid is not moving out of the tank volume, all the boundary condition would be of wall type. Under tab specific boundary types, boundary conditions for Cwall, Pwall and Mframe were declared in GAMBIT. All the outer, bottom & upper and wall faces of tank were set as wall type and named Cwall. Similarly Pwall for impeller and Mframe for moving frame were created. Under tab specific continuum types, initial sand and water zones were defined.

6. SIMULATION:

After meshing of the slurry pot assembly in GAMBIT, commercial CFD code FLUENT is used for simulation purpose. The boundary conditions moving wall or stationary wall are given at tank, moving frame and impeller. In the rotating frame containing an impeller, the impeller is at rest. In the stationary frame containing the tank walls and baffles, the walls and baffles are at rest. The performance results are obtained at different concentration and rotational speed for different types of propellers.

Assumptions

The following assumptions were taken for simulation:

1. The walls of the casing were assumed to be smooth hence any disturbances in flow due to roughness of the surface were neglected.
2. The friction co-efficient for all surfaces were set to 0, hence friction between the walls and fluid was neglected.
3. No leakage losses.

Solution parameters:

1. 3-D solver used to solve for simulation.
2. Multiple reference frame technique used in the simulation of the suspension system.
3. Multiphase (two phases, silicon carbide sand and water) Eulerian-dispersed model was used in the simulation.
4. Standard K-Epsilon model is used for turbulence modeling.
5. Convergence criteria for the continuity, velocity and turbulence parameters were set to 10^{-3} .
6. First order scheme is used for pressure correction as well as for solving momentum, Turbulent kinetic energy and turbulence dissipation rate.
7. Shymlal-Obrien correction was used for drag coefficient.
8. Packing limit for sand was set at 0.60

7. RESULTS

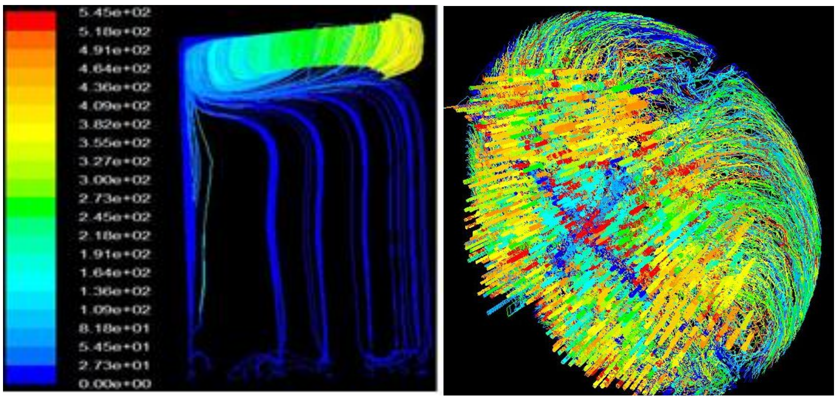

Figure 6 :Pathlines of fluid at bottom face inside slurry pot, shown in the left portion of the Y-Z plane

Contours:

The contour in figure 6 shows that the Volume Fraction of solids is maximum at the bottom of the tank. It is minimum at the top portion, colored blue, and uniform in the central part of the tank. Figure 6 show the path followed by the water particles in the tank. Water, as shown in the pathlines, move up towards the top periphery of the tank and then get diverted to the center of the tank. A pathline is the path traced by an individual particle in a given time interval. The pathlines shown above are of sand particles in the bottom part of the slurry tank. The particles, as shown in the figure above, move up after being swept by the impeller at the bottom of the tank. Figure 7 and Figure 8 show the pathlines at the bottom face and the top face of the slurry tank.

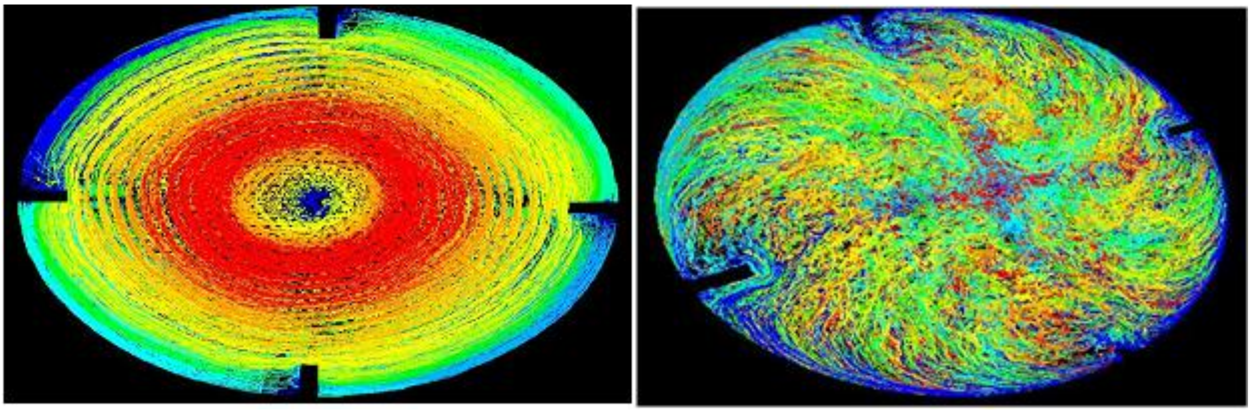

Figure 7: Pathlines at the top and bottom face of the slurry tank

The results of the simulation explain the importance of baffles in dispersing sand particles across the fluid volume. In figure 7, the particles show turbulent behavior. On the top face the particles are seen to follow a set path with minimum turbulence. In such a scenario, the particles will remain suspended in on a defined plane and will cease to strike the inserted specimen in the pot tester.

8. CONCLUSION & FUTURE SCOPE:

The above study show a methodology to model the fluid domain and test the two phase model for find out pathlines contours at various cross-sections of the fluid domain. The model gives step by step procedure for modeling two phase fluid domain mesh geometry with rotating reference frame. This methodology can be used to validate experimental results for weight fractions obtained at different planes in a slurry pot tester. The experimental results if validated through simulation can be used in estimating accuracy of the pot tester in estimating the wear rate.\

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