Experimental Investigation on Impact of Bottom Propeller Height on Slurry Erosion Wear of SS-316 Specimen in a Slurry Pot Test Rig

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Abstract: **Slurry Erosion is a material removal process by fast moving solid particles suspended in a fluid stream i.e. the slurry. Slurry erosion limits the useful life and reliability of the equipment handling solid-liquid mixtures such as pumps, turbine, boilers plates, heat exchanger tubes etc. Hence it is of vital importance to study the wear rate and erosion characteristics of the material of equipment which aresubjected to slurry erosion and to investigate the possibilities of enhancement of their life. The aim of the present study is to find the effect of height of bottom propeller (with reference to the base of the pot) on the erosion wear of the SS-316 material subjected to sand-water slurry. The main purpose of changing the bottom propeller height from the base is to obtain different turbulence conditions and varying distribution of sand particles in water which in turn affect the erosion wear rate.**

Experiments are conducted at five bottom propeller heights with six impact angles varying from 15º to 90º at each height. Other parameters such as velocity of bottom propeller, solid concentration, velocity of top shaft are kept fixed for every position of bottom propeller. Maximum erosion wear is observed at a particular angle for each propeller height. Also, the erosion wear increases with increase in propeller height and starts decreasing after a certain height. Scanning electron Microscope (SEM) analysis is also employed so as to observe the pattern of erosion wear at different propeller heights.

Keywords: Slurry Erosion, SS316, Propeller height

1. INTRODUCTION

Slurry Erosion is the gradual material removal from a surface by solid particles suspended in a fluid rubbing against the surface with appreciably high velocity. This rubbing action happens repeatedly for short periods of time and results in the erosion of material from the surface. The material removal takes place by a combination of mechanisms such as ploughing, cutting, fragmentation etc. It is a widely encountered phenomenon in industry. Failure due to slurry erosion can have detrimental consequences. For instance, in dams, sand laden water can have a maximum acceptable sand concentration of 0.5% by wt. or 5000ppm. Above this threshold value, there can be significant damage to the turbine blades due to erosion wear.[1-12] Hence it is vital to take erosion wear into consideration before design and selection of such equipment where the material and slurry

Table 1 :Composition of SS 316

SS 316	
Element	**%**
Fe	70.1000
Cr	16.4000
Ni	9.5667
Mo	2.1000
Mn	1.1667
Cu	0.2667
Sb	0.2000
Nb	0.1999
V	0.0000

1. EXPERIMENTAL DETAILS

The experiments for present study are conducted in a 7- liter capacity slurry pot test rig. The experimental setup used is shown in Fig. 1. The test rig consists of a pot of 240 mm diameter and 7 liters capacity.

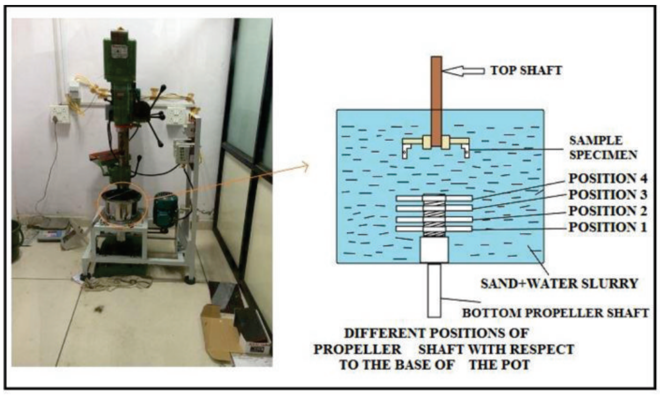


Fig.1 Slurry Pot Test Rig (Left) and the pot (Right)

The propeller shaft is inserted from the bottom of the pot and a mechanism is provided to vary the height of the propeller shaft with respect to the base of the pot. The propeller used is of PTB (Pitched Turbine Blade) type as better suspension of solid particles is obtained with it as compared to that of marine or butter fly type blade. The function of propeller is to achieve a uniform distribution of sand particles in water which is desired to avoid any discrepancies in test results. Four baffles of dimension are provided at the inner side of the pot along two planes perpendicular to the circumference of the pot. The prime objective of providing baffles is to direct the flow upwards near the pot walls and prevent the rotational movement of sand particles near the walls else the distribution of sand particles in water will not be uniform enough. The propeller shaft is supported by two bearings and the leakage from sideways of the shaft is prevented by using an oil seal. A dc motor of 1.5 hp with variable frequency drive(VFD) is provided to rotate the bottom propeller shaft through a beltpulley drive. Another VFD motor of same rating is provided at the top to provide rotation to the shaft on which the samples are attached. The velocity of rotation is measured by using a tachometer.

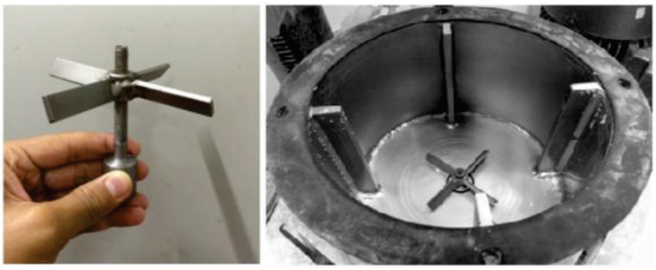


Fig.2 Bottom Propeller shaft with a PTB type propeller (b) Inside View of Slurry pot

At the bottom of the pot a hole of diameter 20 mm is provided so as to facilitate the slurry removal after experiment. A sample holder is attached to the bottom of the top shaft. It consists of two horizontal arms diametrically opposite to each other at 180° on which the test fixtures can be attached as shown in Fig 3. A slot of size 30 mm x 5mm x 2mm, rounded at both ends is provided in the test fixture to hold the test specimen inside it. The sample holder is provided with index plates by which test fixture can be made to orient at different angles from 15° to 90° in steps of 15°, along the direction of peripheral velocity.

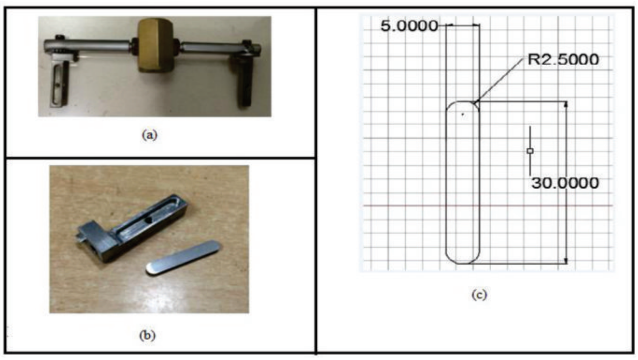


Fig.3 Sample Holder with test specimen (b) Test Fixture and Test Specimen (c) CAD drawing of test specimen

The test fixtures are made of high carbon steel and quenched in oil bath to achieve a high hardness. As a result, the wear on fixture surface is negligible as compared to wear on specimen. The test specimen is properly glued inside the fixture slot and it is ensured that the top surface of specimen is in line with the fixture surface. The arm lengths of the sample holder are of 66 mm. So, the radius of rotation of sample specimens is 66 mm.

3. EXPERIMENTAL PROCEDURE

Before conducting the experiments, sample specimens were prepared on a similar scale so as to maintain uniformity in every experiment. 60 test specimens of dimensions 30mm x 5mm x 2mm are cut from a SS316 sheet. After the samples have been cut, the next step is to polish the surface of the samples and give it a mirror finish. The prepared specimens have rough surfaces that need to be finished for accurate results else discrepancies will arise in test results. The finishing of surfaces is done by emery papers of mesh sizes #600, #1000, #1200, #1500 in increasing order of fineness. After finishing, the test specimens are cleansed with water, rinsed with acetone and dried before and after each experiment. To overcome the attrition effect of sand particles, the slurry is replaced every 45 minutes. Tests are conducted in five sets A to E by changing the bottom propeller height at intervals of 10mm i.e 0mm(bottom position), 10 mm, 20 mm, 30 mm, 40 mm. For each height, experiments are conducted for six impact angles ranging from 15° to 90°. The mass loss of samples after each experiment is measured in grams upto four decimal places. The average value of the mass loss of samples is used to calculate the erosion wear rate by using standard equations[13].

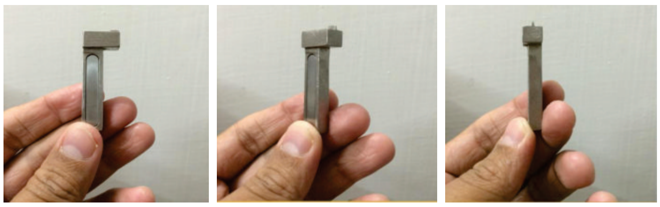


Fig.4 Different orientations of test specimen

Table 2 Operating Parameters

Solid Particle	Silica
Specific gravity of particle	2.64
Particle Concentration	10% by wt in 7 liter water
Average Particle Size	655 μm
Stirer Speed	720 rpm
Bottom Porpeller Speed	360 rpm
Particle Impact Velocity	5m/s
Sample Specimen hardness (HV)	147-149
Average roughness of sample Surface	0.126 μm
Erodent Particle Shape	Subangular
UTS of SS-316	579 MPa

The slurry is prepared by mixing Indian standard sand with water. Operating parameters are shown in Table 2. The sand is sieved between two successive sieves of mesh size 600μm and 710μm to collect particles of mean size 655μm. 700g of sand i.e. 10% by concentration is taken in the pot and the rest is completely filled with water. The pot is then covered by an acrylic lid and completely tightened to ensure the slurry does not spill out. Now, the propeller is rotated in a down-pumping mode with desired speed. The top shaft is rotated at 720 rpm so that the average peripheral velocity of samples is 5m/s. The bottom propeller shaft is rotated at 360 rpm in a direction opposite to that of the top shaft.

Up-pumping and Down-pumping

In the down-pumping mode, the impeller generates one circulation loop n lower part of the vessel. It was observed that the liquid in the upper part of the vessel was poorly circulated and the random motion between the solid particles is minimal. So, that place can be considered ideal for sample placement to study its erosion behaviour characteristics. But in up-pumping mode, the impeller induces two circulation loops, one in the upper part of the tank and one in the lower part. The PBT pumping upwards is observed to consume more power than down-pumping, Also up-pumping results in better mixing in upper region and higher turbulence levels which may not match practical situations.

4. RESULTS AND DISCUSSION

Loss of mass due to erosion wear of SS-316 samples in sand –water slurry has been measured at different propeller heights with six impact angles at each height. *Scanning electron microscope (SEM) study of the eroded surface has also been employed so as to analyse the microstructure of the eroded surface at different impact angles and propeller heights.

The erosion rate of SS-316 is calculated in the pot tester at 5m/s(720 rpm) for a particle size of 655μm with a sand concentration of 10% by wt and the time duration for one experiment is taken as 45 min. The bottom propeller is rotated at 360 rpm in a direction counter to that of the top shaft. The average value of surface roughness of the test specimens at four different angles (15°,30°,45°and 90°) at each propeller height are measured before and after experiments and depicted in bar graph shown in fig 5.

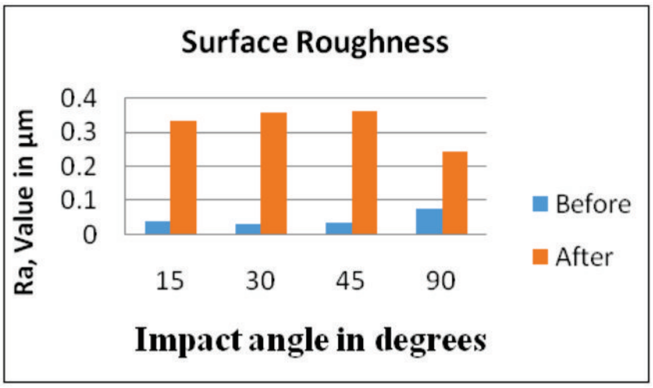


Fig.5 Average surface roughness values of test specimens before and after experiments at all propeller heights

Change in average surface roughness values of the test specimens before and after the experiments confirms that there is considerable wear of the samples due to the sandwater slurry. Analysis of the wear pattern of the test specimens shows that at a particular bottom propeller height the erosion wear reaches a maxima at 30° and decreases onwards up to 90°. This phenomenon is attributed to the ductile behavior of SS-316. It is observed that for ductile materials, the erosion wear first increases with increase in impact angle and reaches a maximum value in the range of 20° to 40° and starts decreasing afterwards[14].

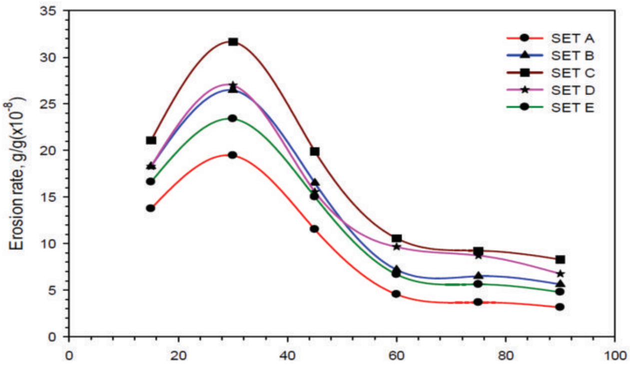


Fig.6 Variation of erosion wear with impact angle at different propeller heights

Similar trend is followed at all propeller heights as shown in fig 6. Abbade and Crnkovic[14] observed a similar trend for API 5L X65 steel in sand-water slurry with maximum wear rate at 30° impact angle.

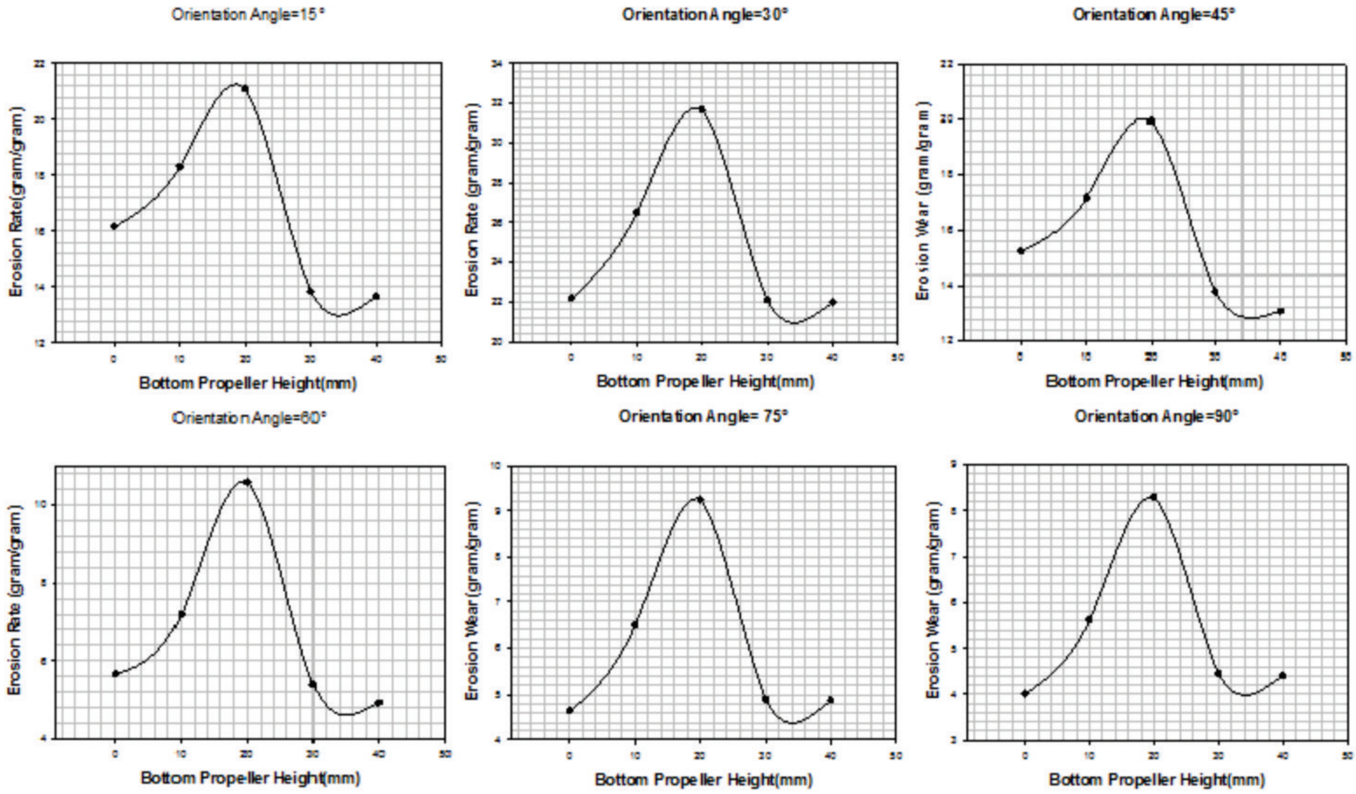


Fig.7 Variation Of Erosion wear with bottom propeller height at different orientation angles of sample specimen

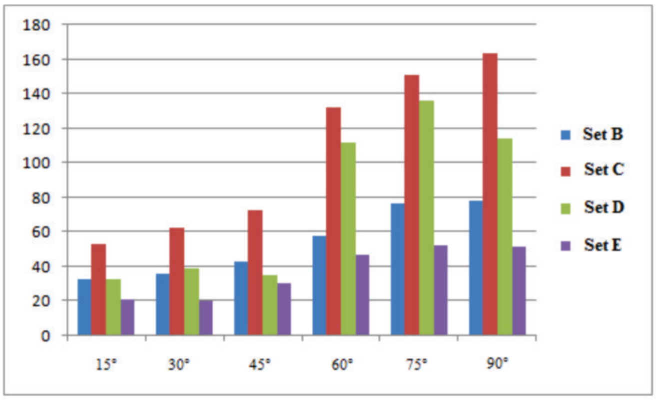
Table 3 % Change in erosion wear at different propeller heights w.r.t bottom propeller position

IMPACT ANGLE	At 10mm above bottom position	At 20mm above bottom position	At 30mm above bottom position	At 40mm above bottom position
15°	33.11% (↑)	53.37% (↑)	33.11% (↑)	20.95% (↑)
30°	36.05% (↑)	62.72% (↑)	38.77% (↑)	20.25% (↑)
45°	43.36% (↑)	72.86% (↑)	35.10% (↑)	30.38% (↑)
60°	57.92% (↑)	132.31% (↑)	112.19% (↑)	46.95% (↑)
75°	76.35% (↑)	150.67% (↑)	136.48% (↑)	52.70% (↑)
90°	78.63% (↑)	163.36% (↑)	114.51% (↑)	51.91% (↑)

Propeller height from bottom of the pot also has its effect on the erosion wear. The variation of erosion wear with propeller height is shown in Fig 6. For each of the six impact angles from 15° to 90°, the erosion wear values are plotted against bottom propeller heights. It is observed that the erosion wear increases with increase in propeller height from 0mm (the bottom position) till it reaches a maximum value at 30mm and declines sharply afterwards. Table 3 shows the average percentage variation of erosion wear at different impact angles at bottom propeller heights with respect to the bottom position. It can be seen that the maximum percentage increase in erosion wear occurs in 10 to 20 mm interval of bottom propeller height. From 0 mm to 10 mm interval, the wear rate increases by 33.11% for 15 and reaches 78.63% increment as the impact angle reaches 90.

The percentage increment in wear rate is maximum for 20mm at all impact angles. After that, the wear rate starts decreasing. At 30 mm propeller height, the wear rate decreases by 20.26% and 48.85 % points at 15° and 90° respectively. Further decrement is shown at 40 mm height. Also, the maximum wear rate occurs at 30 which decreases continuously afterwards till 90. Similar pattern is observed at all impact angles. The increase in wear rate upto a certain height (20 mm in our case) can be attributed to the improved ease of movement of solid particles as the propeller height is increased.

When the propeller is at bottom position, the space left between the propeller and the pot base is very small which obstructs the loop formation which is necessary for uniform distribution of sand particles.



*Set A- Bottom or Original position of propeller

Fig.8 Bar graph showing percentage change in erosion wear w.r.t original position of propeller for different sets at each angle

As the propeller height is increased, there is enough space left for the formation of particle flow loop which makes it easy for uniform distribution of sand particles in water. 30mm is the optimum bottom propeller position above which the erosion wear rate starts decreasing. This decrease in erosion wear occurs due to poor suspension of sand particles in water at increased propeller heights. As the propeller height is increased, the uniformity of sand particles suspension in water is affected as sand particles settle down to the bottom of the pot and the increased propeller height makes it difficult for the propeller to force these settled sand particles to form a uniform suspension.

5. CONCLUSIONS

The main objective of the presented research was to investigate the effect of impact angle and bottom propeller height from the base of the pot on erosion wear rate. The investigated material was SS-316. The results indicated that at a particular bottom propeller height the wear rate increases with increase in impact angle and reaches a maximum in the range of 20° to 40° and decreases afterwards. Also, the wear rate first increases with increase in bottom propeller height and reaches a maximum value at 20mm and declines sharply afterwards at increased propeller heights. The wear rate at heights above 20 mm increases with respect to that of the original position but decreases with respect to that at the 20 mm propeller height. This trend is observed at all impact angles. The study is intended to analyze the effect of turbulence level of slurry on erosion rate which indirectly is varied by changing the bottom propeller height in the pot.

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