EXPERIMENTAL INVESTIGATION OF EROSIVE WEAR ON THE HIGH CHROME CAST IRON IMPELLER OF SLURRY DISPOSAL PUMP USING RESPONSE SURFACE METHODOLOGY

Sunil Kumar[1,*], Jasbir Singh Ratol[2]

[1] Department of Mechanical Engineering, Chitkara University, Rajpura, District Patiala, Punjab, 140401 India.
[2] Department of Mechanical Engineering, Baba Banda Singh Bahadur Engineering College, Fatehgarh Sahib, Punjab, 140407 India.
[*] corresponding author: e-mail: sunil14478@yahoo.co.in

Resume

Erosive wear occurs on the impeller and volute casing of the slurry disposal pump due to the impact of the ash particles on the impeller with a high velocity. Due to erosive wear, pump life become very short. The service life of centrifugal pump, handling slurry can be increased by reducing the erosive wear.

In the present work, the experimental investigation of erosive wear has been carried out on the high speed slurry erosion tester to understand the effects of the ash concentration in slurry, rotational speed of the pump impeller and ash particle size on erosive wear. The erosive wear behaviour of high chrome cast iron was investigated by Response surface methodology (RSM). Analysis of variance (ANOVA) was used for statistical analysis and the modeled values for the response were obtained with the help of modeled equation. The result shows that the ash concentration in slurry and kinetic energy of the moving particles highly contributes to erosive wear of pump impeller as compared to the ash particle size.

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1. Introduction

Centrifugal pumps are used for the transportation of coal ash slurry (coal ash + clean water) from the thermal power plant to the ash pond which is located at a distance of about 3000 meters to 8000 meters from the power plant. These pumps are arranged in series (usually 2 to 4) to obtain a large pressure head. Erosive wear is a function of particle velocity and is more significant on impeller and volute casing in slurry pumps. The material of impeller and casing is usually high chromium cast iron due to its wear resistance property. The factors responsible for erosive wear are the rotational speed of the pump impeller, hardness of the target material, ash concentration in slurry, ash particle size and angle of impingement.

Erosive wear is recognized as serious problem in coal based power generation plants in India. The coal used in Indian power stations has large amounts of ash (about 50 %) which contain abrasive mineral species such as hard quartz (up to 15 %) which increase the erosive wear propensity of coal. An understanding of these problems and thus to develop suitable protective system is essential for maximizing the utilization of such components [1]. A variety of methods were adopted to protect materials from damage due to wear, by the use of efficient materials [2], processing techniques [3], surface treatment [4] of the exposed components and use of engineering skills leading to less impact of wear on the material, such as appropriate impingement angle of erodent and velocity of slurry. Investigations provide information about the mechanisms of material removal during the erosive wear [5]. There are a number of methods to test the erosive wear of materials using equipment, such as small feed rate erosion test rig [6], particle jet erosion test rig [7], coriolis erosion tester [8] and slinger erosion test rig [9]. Study has been carried out for various slurries and found that none of the correlation is universally applicable for modeling slurries for well graded particle size distribution [10]. Mechanical ash handling system and vacuum ash handling system are used to handle dry ash whereas hydraulic ash handling system is used to handle wet ash in thermal power plants. In hydraulic ash handling system, ash is carried with flow of water with high velocity through a pipeline and finally dumped in the sump. It can discharge large amount of ash at large distance from the power plant, therefore is suitable for large thermal power plants.

2. Experimental investigation-slurry erosion testing

2.1. High speed slurry erosion tester

Experimentation was performed on the High Speed Erosion Tester (DUCOM Bangalore Make, TR-401). In slurry erosion tester, a specimen, fixed to the specimen holder, is rotated in a circular container (slurry pot) filled with the slurry which is made homogeneous. In slurry erosion test, the amount of material removed from the specimen is determined by the weight loss. The samples are weighed before and after the tests.

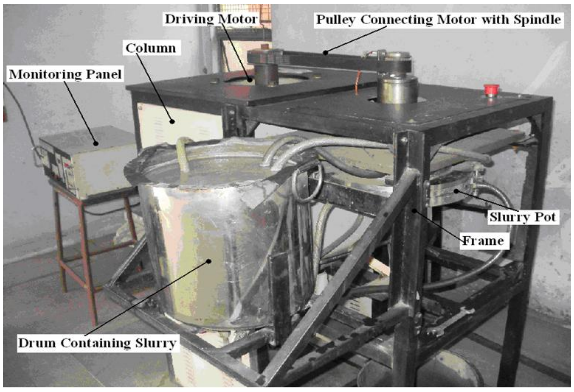

Fig. 1. Set-up of high speed slurry erosion tester

Slurry pot tester is simple in design and easy to operate. In a slurry pot tester, generally two specimens have been rotated in solid-liquid mixture. The rotational movement of specimens keeps the ash particles suspended in the water. The rotating test specimens move at a velocity relative to the solid-liquid suspension. The set-up of high speed slurry erosion tester during experimentation is shown in Fig. 1 and the test specimens are shown in Fig. 2.

Fig. 2. Test specimens of pump material

2.2. Procedure

The fly ash collected from thermal power station was used as the erodent. Sizing of the ash particles was done by sieve analysis and the average particle size was 75 μm. The test specimens of impeller material (High Chromium Cast Iron) were prepared and cut into pieces of OD 12 mm × ID 6 mm × Length 10 mm and polished using emery paper (200 μm grit size). The hardness of the specimen was measured to be 500 BHN. The rotation per minute maintained as 1200, 1400 and 1600. Specimens were ultrasonically cleaned with acetone and weighed before and after the experimentation. The weight of the specimen material is reduced due to erosion. The chemical composition of the material used was checked with the help of spectrometer. The detail is given in Table 1.

Table 1
Chemical composition of test specimens

Material	C	Mn	Si	S	P	Cr	Ni
High chrome cast iron	3.01	1.12	0.39	0.006	0.02	14.64	0.42

Rotations of specimen, ash concentration in slurry and particle size were considered as prominent factors. Three levels were taken for each factor as shown in Table 2. Two test specimens were tightened opposite to each other with the help of the screws. There was a drum of water carrying capacity of 30 liters was properly cleaned and slurry was prepared and drawn into the drum. The specimens were rotated in the slurry for 30 minutes. The slurry was made homogeneous in the drum by rotating it continuously during experimentation.

The total numbers of runs were 17 for the given values which were determined with the help of Box-Behnken design for Response Surface Methodology (Table 3). Table 4 shows the analysis of variance (ANOVA) for response surface linear model.

Table 2
Factors affecting Erosive Wear with levels

Sr. No.	Factors	Level 1	Level 2	Level 3
1	Rotation of specimen (rpm)	1200	1400	1600
2	Ash concentration (ppm)	$100x10^3$	$200\ x10^3$	$300\ x10^3$
3	Particle size (μm)	50	75	90

2.3. Observations and calculations

ANOVA (Analysis of variance) for response surface linear model

The Model F-value of 17.10 implies the model is significant. There is only a 0.01 % chance that a "Model F-Value" this large could occur due to noise. Values of "Prob > F" less than 0.0500 indicate model terms are significant at the confidence level of 95 %. In this case A, B are significant model terms. The Lack of Fit is consisting of the sum of squares for the interactions that were dropped from the model. The "Lack of Fit F-value" of 2.12 implies the Lack of Fit is not significant relative to the pure error. Non significant lack of fit is good. Pure error is arising from the replications. There are 05 replicates having 04 degree of freedom (df). The value of pure error is very small as one should expect. Regresion Analysis for Response Surface Linear Model is shown in Table 5.

Table 3
Box-Behnken design matrix in terms of actual values

Run	Rotational speed (rpm)	Ash concenteration (ppm)	Particle size (microns)
1	1400	200000	75
2	1200	300000	75
3	1600	200000	90
4	1400	100000	50
5	1400	200000	75
6	1200	100000	75
7	1200	200000	90
8	1600	200000	50
9	1400	200000	75
10	1600	300000	75
11	1400	100000	90
12	1200	200000	50
13	1400	200000	75
14	1400	300000	50
15	1600	100000	75
16	1400	200000	75
17	1400	300000	90

Table 4

Analysis of variance (ANOVA)

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Model	0.083	3	0.028	17.10	< 0.0001	significant
A-rotation	0.040	1	0.040	24.96	0.0002	
B-ash concen.	0.041	1	0.041	25.58	0.0002	
C-particle size	1.243×10^{-3}	1	1.243×10^{-3}	0.77	0.3956	
Residual	0.021	13	1.610×10^{-3}			
Lack of Fit	0.017	9	1.923×10^{-3}	2.12	0.2434	Non-significant
Pure Error	3.621×10^{-3}	4	9.052×10^{-4}			
Cor Total	0.10	16				

Table 5

Regresion analysis for response surface linear model

Std. Dev.	0.040	R-Squared	0.7979
Mean	0.28	Adj R-Squared	0.7512
C.V. %	14.47	Pred R-Squared	0.6293
PRESS	0.038	Adeq Precision	14.656

PRESS stands for "prediction error sum of squares" and it is a measure of how well the model for the experiment is likely to predict the response in a new experiment. Small value of PRESS is desirable. C.V. is the coefficient of variation which measures the residual variability in the data. The "Pred R-Squared" of 0.6293 is in reasonable agreement with the "Adj R-Squared" of 0.7512. A difference less than 0.20 between the "Pred R-Squared" and "Adj R-Squared" indicates that there is no problem with model and/or data. "Adeq Precision" measures the signal to noise ratio. A ratio greater than 4 is desirable. The ratio of 14.656 indicates an adequate signal. This model can be used to navigate the design space. The modeled values for the response are calculated and tabulated in Table 6 along with the experimental values.

Table 6

Experimental and Modeled values of the response

Run	Rota-tion (rpm)	Ash-conc. (ppm)	Particle size (microns)	Experi. Values (gms.)	Modeled Values (gms.)
1	1600	300000	75	0.497	0.421
2	1400	200000	75	0.281	0.279
3	1200	200000	90	0.248	0.217
4	1400	200000	75	0.282	0.279
5	1600	200000	90	0.365	0.359
6	1200	100000	75	0.175	0.136
7	1200	200000	50	0.186	0.193
8	1200	300000	75	0.288	0.280
9	1400	200000	75	0.208	0.279
10	1600	200000	50	0.308	0.334
11	1400	100000	50	0.239	0.192
12	1400	100000	90	0.163	0.216
13	1600	100000	75	0.294	0.278
14	1400	300000	90	0.353	0.360
15	1400	200000	75	0.262	0.279
16	1400	200000	75	0.258	0.279
17	1400	300000	50	0.307	0.335

Regresion equation to calculate the modeled values:

$$WL = (-0.40687) + (3.54375 \times 10^{-4}) \times RS + (7.17500 \times 10^{-7}) \times AC + (6.13078 \times 10^{-4}) \times PS \quad (1)$$

where: *WL* is Weight Loss, *RS* is Rotation Speed, *AC* is Ash Concentration, *PS* is Paricle Size

3. Results

Graphs were plotted between the factors affecting erosive wear and the weight reduction of specimen. It has been found form these graphs that all the three factors behave linearly with the weight loss.

As the rotational speed of the impeller increases, the force with which slurry strikes the impeller increases which in turn increases the erosion rate (Fig. 3). It shows that at 1200 rpm rotational speed, 100000 ppm ash concentration and 50 μm particle size, the weight loss of the material due to erosive wear is very less.

The weight loss of the material increases linearly with the increase of ash concentration as shown in Fig. 4. It shows that at 100000 ppm ash concentration, 1200 rpm rotational speed and 50 μm particle size, the weight loss of the material due to erosive wear is very less.

The effect of particle size on the weight loss due to erosion is shown in Fig. 5. The behavior of particle size with erosive wear is linear. The particle size has low effect on erosive wear when other values are taken at lower level, but increase in wear is more by taking other parameter level at middle and higher. The particle size has very low effect on the metal removal rate for the value less than 100 μm as compared to other parameters [11].

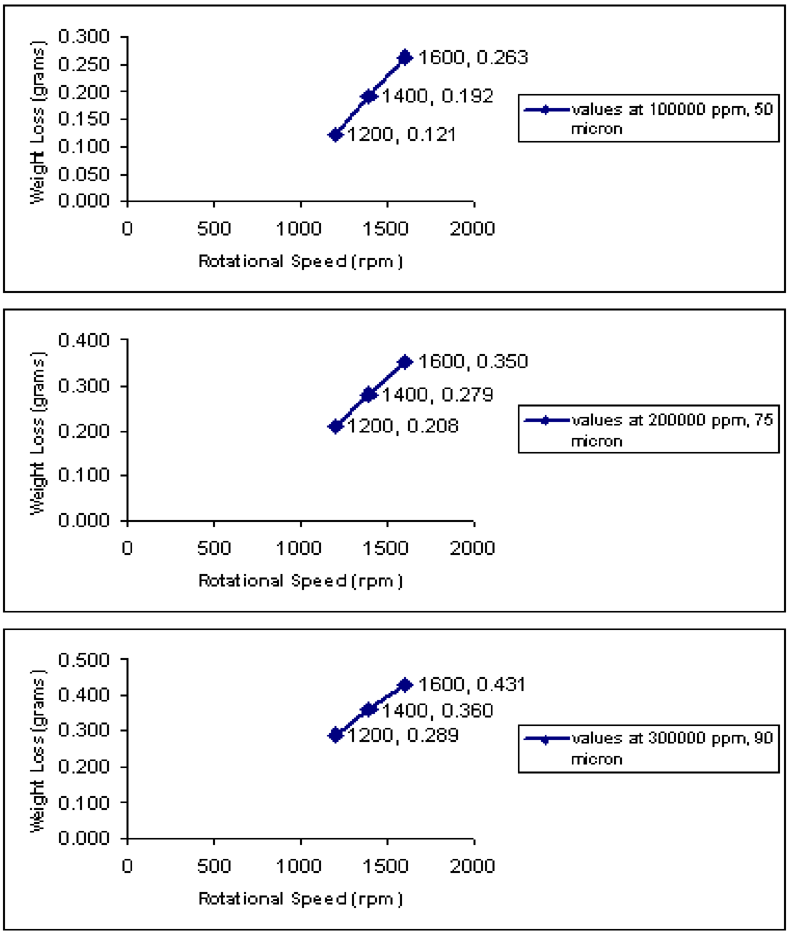

Fig. 3 Weight loss vs. rotational speed

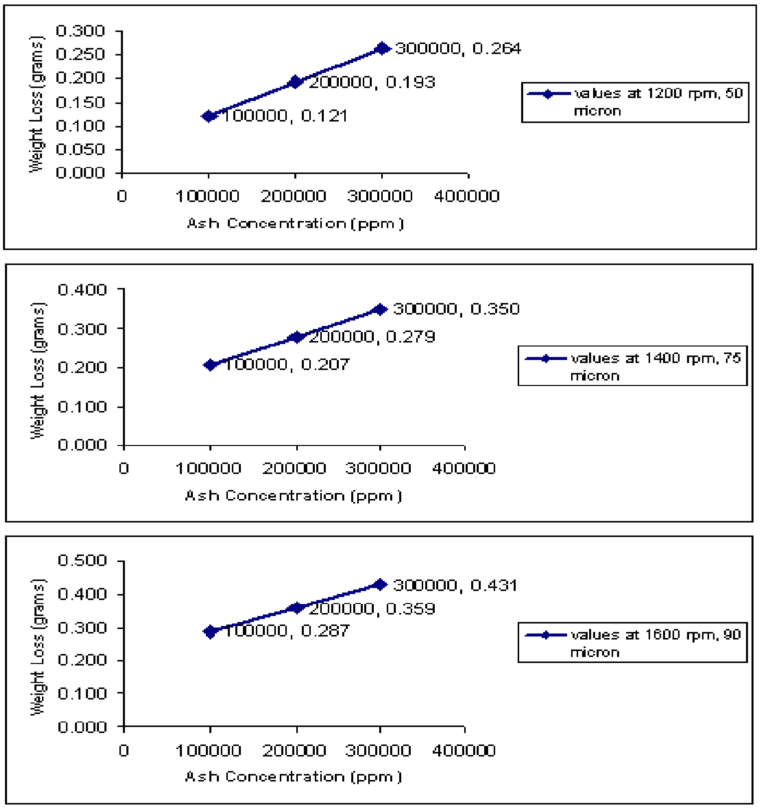

Fig. 4. Weight loss vs. ash concentration

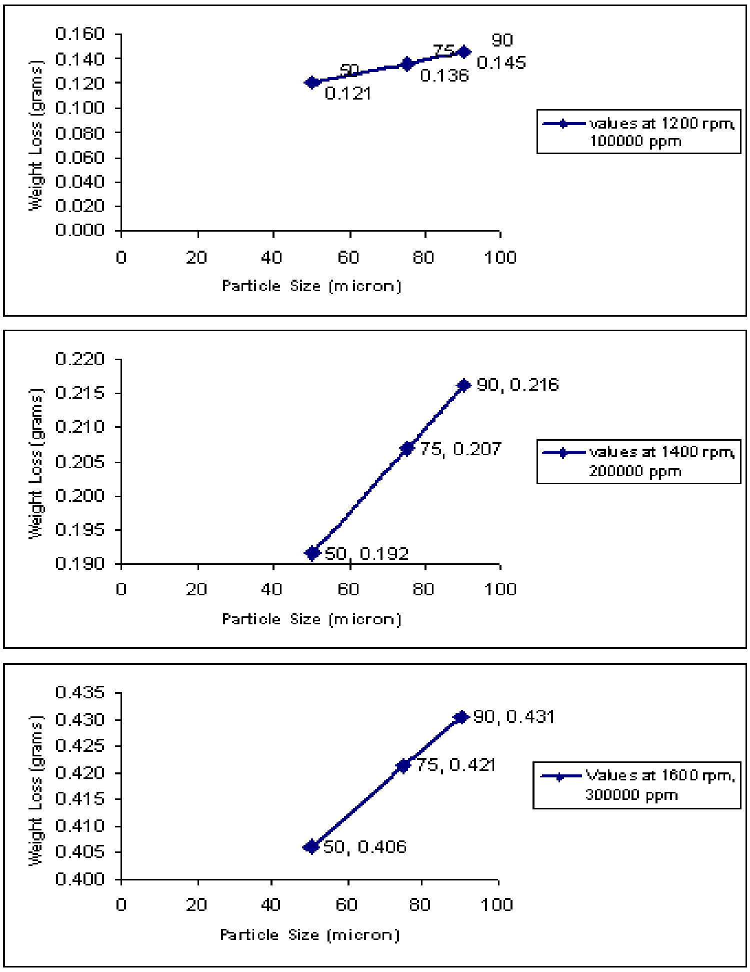

Fig. 5. Weight loss vs. ash particle size

4. Conclusions

Reduction in weight is primarily depends upon the ash concentration in the slurry followed by the rotational speed of the pump impeller and ash particle size as shown in Fig. 6. The conclusion is this that if the slurry pumps has to work the range where the erosive wear is less; the performance of the slurry disposal pump may be improved. Erosive wear of the pump impeller would decreases with decreasing ash concentration, rotation speed and particle size.

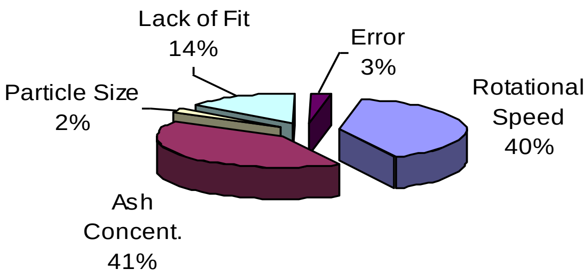

Fig. 6. Contributions of parameters for erosive wear

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