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EXPERIMENTAL ANALYSIS OF EROSION WEAR IN MULTI-SIZE PARTICULATE FLOW USING POT-TESTER

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Abstract- *All industries like thermal power plant, petroleum industries, mining industries etc. use simple as well as complex pipeline structure along with centrifugal pumps for the transportation of slurry and these slurry transportation equipments suffer from erosion wear. Erosion wear is a very crucial parameter for selection and design of slurry transportation system, as it affects directly to the economy of hydraulic conveyance of solids. The service life of equipment handling solid-liquid mixture is limited due to wear. Present work is focusing on erosion wear, as conditions of erosion wear i.e. high velocity and low impact angle mostly occur in practice while transportation of slurry. It is difficult to observe the types and rates of deformation in operating condition. Thus an attempt has been made in current study to do a parametric study of wear at high concentration using pot tester and test specimens of two different materials. Experimental results obtained from different test conditions may help in identifying the time for replacement of piping in long slurry fluid flow and also in centrifugal slurry pump impeller blade. The experimental method determines the effect of slurry velocity, solid concentration and impact wear angle on erosion wear. Current work also attempts to validate the calculated values from experimental setup(pot tester) against established relations in the literature, by plotting graph using R software.*

Keywords- *Slurry; Erosion wear; Impact angle; Centrifugal Pump; Pot tester;*

I. INTRODUCTION

India's electricity sector is dominated by fossil fuels and in particular coal because it's the most abundant fossil fuel, easily available at relatively low cost. At present 59.9% or 314642.32 MW (Data Source CEA, as on 31/01/2017) of total installed capacity of power stations in India is from Coal Based Thermal Power Station. Handling of coal and fly ash are a major challenge to the engineers in the thermal power plants, as large amount of ash is produced in central stations, as much as 10 to 20% of the total quantity of coal burnt in a day. To handle huge amounts of ash per day, mechanical means are employed. Slurry mixture impeller is a rotating device that mixes ash and water in the ash hopper. Impeller damage is a major problem that constantly accompanies the operation of the system for hydraulic transportation of solid material. Many organizations have been working in the field of slurry transport system since 1960's. The transportation of fuel like ash in the form of slurry through pipeline is a safe process in terms of causing environmental hazards. Ash is the residue remaining after the coal is incinerated. Ash is produced in large quantity from boilers and to utilize it completely converting into useful products is not always possible. In this condition ash is required to be dumped in ash pond which are usually far away from the plant area. The effective method of disposing ash is by pumping it in form of slurry through ash hopper. Slurry can be classified in low /high density depending on slurry concentration. The carrying medium is always water. Ash generated in power plant is about 30-40% of total coal consumption and hence the system is required to handle ash for its proper utilization or disposal.

Erosion wear is very common phenomenon in transportation of slurry flow. Centrifugal pump (like HCSD pump) impeller and piping system of slurry flow has affected by erosion wear. The Selection of material as well as the dimensioning of impeller blade are very important at the time of designing. Wear allowances is considered for designing of slurry transportation system. Centrifugal pumps are used to disposal of fly ash and transportation of coal dust in Thermal power plant. The impeller blades eroded during working of pump. Various parameters affect the erosion wear of pump material and long range piping system. Slurry velocity, Impact angle and Density of solid particle are the factors which affect the slurry erosion wear.

II. LITERATURE REVIEW

Many investigators have performed the various experiments to establish the relationship between erosion wear and different operational conditions.

Desale(2009) has performed an experiment on aluminum alloy (AA6063) in a slurry pot tester. Multi-size particle of quartz varying from 37.5µm to 655µm are used with velocity 3 m/sec. inside the pot tester. Solid concentration is 20% by weight and impact angle varies 30^0 to 90^0 in this pot tester. By taking the mean particle size 200µm the kinetic energy of solid particle which impact the wear piece is deciding parameter to find wear rate. Threshold kinetic energy is determined by using different operating conditions and different wear mechanism. Mass loss due to the particle impact decreases with decrease in particle size. At an angle of 30^0 and 90^0 for the particle size of 200µm to 256µm, the wear rate approximately constant. For constant slurry velocity the K.E. of a particle varies as cube of the particle size. By using the pot tester the mass loss of wear specimen of aluminum alloy (AA6063) has been determined for narrow sized particle with orientation angle of 30^0 and 90^0. No. of particles swept per hr. with collision efficiency of 100%. The particle size and orientation angle are main parameter to analyze the particle swept. Particle swept is directly proportional to orientation angle and inversely proportional to the particle size. The kinetic energy of the particle have relationship with particle size with power law relationship. At the different orientation angle particles which have K.E. lower than minimum have exponent value is 1 and for higher K.E. the exponent value is more than 1.

Gandhi et al. (2002) investigated about the Effects of particle size and size distribution on estimating erosion wear of cast iron in sand-water slurries by taking the median particle size and weighted mean particle size. He concluded that in sand water mixer the erosion wear increases when the particle size increases. For estimating the erosion phenomenon mean particle size diameter give the better result than weighted mean particle size.

Patil et al.(2011) have performed an experiment with sand water slurry mixture on aluminum wear piece to analyze the erosion wear rate. Various affecting parameters like impact angle, particle size velocity and solid concentration have been analyzed on this ductile wear piece. Experimental set up of pot tester has been fabricated. The analysis has carried out with different impact angle ranging from 150 to 900 and different solid concentration ranging from 20% to 40% and different particle size 225µm to 855µm and velocity ranging from 3.68 m/sec to 9.67 m/sec. The results which are obtained from the experimental investigations of aluminum wear piece in pot tester, conclusions are made that erosion wear depends upon the impact angle. Erosion wear increases with increase in impact angle up-to 45^0 and decreases at 90^0. Another conclusion are made that erosion wear increases with particle size increases. Increase in solid concentration is another parameter to lead the erosion wear. At very high concentration, the erosion rate get diminishes.

Ojala(2012) performed an experiment in pot tester to analyze the effect of slurry flow. Wear sample is attached in vertically rotating shaft on four levels in a pin mill configuration. Maximum speed up to 20m/s is achieved in this pot tester and large abrasive size material up to 10mm is used in this experiment. He concluded that abrasive size and shape affect the wear rate. The large and sharp particles cause more wear than small and round particles in the slurry-erosion. Two different material (Steel and Rubber) is used as wear piece.

Rawat(2017) has performed the experiment using pot tester for the high density ($C_w >$ 60%). Velocity ranges from 1to 4m/sec. has given. He concluded that during the parallel flow of slurry the erosion wear is more dependent on solid concentration than flow velocity. The value of power index of 3.41 is obtained for solid concentration and the value of 1.12 is obtained for the slurry velocity. He also concluded that the erosion wear is a function of impact angle. Wear increases up to an angle of 45^0 and than decreases up to 90^0 for the ductile material.

From exhaustive literature survey, it has been observed that most of the research work has been carried out using slurry with solid concentration (C_w) ranging from 30% - 50% and very few literature are available dealing with slurry of solid concentration more than or equal to 80%. Most of the studies in the literature are limited to equisized particulate slurries and very limited data related to multi-size particles are available. Literature also reveals that pot tester is the most common device for parametric study of erosion wear of different material.

III. EXPERIMENTAL SET UP FOR SLURRY(ASH+WATER)

The pot tester which is used for current study is the modification of the pot tester used by Rawat and Singh [12]. The modification which made is there are two independent rotating shaft, one shaft is connected to upper motor on which wear piece is mounted and another independent shaft which is connected to lower motor is used to avoid the settlement of solid particle. Upper motor of is of 1.5hp and lower motor is of 1 hp. Fig 3.1 shows the assembled diagram of pot tester. Fig 3.2 shows the diagram of the wear piece attachment. The dimensioning of this set up are mentioned in table 3.1.

Fig. 3.1 Assembled diagram of slurry pot tester

Fig 3.2 Wear piece with central shaft

Table 3.1 Dimensioning of cylindrical pot tester

Cylindrical tank	dia- 263mm, height-180mm
Test fixture shaft	dia- 20mm
Shaft of propeller	dia- 20mm
Propeller	2 blade, Bend at 45°(from Centre)
Test fixture	33.4mm×14.9mm×5mm
Transparent acrylic sheet	Dia-313mm, thickness15mm
Test specimen	27.8mm×6.4mm×2.12mm

3.1. Material composition

Two test specimens made up of brass and SS400 have been tested using experimental pot tester. Table 4.4 lists the composition as well as specific gravity of the material used in test specimen.

Table 3.2 Properties of test specimen

Material	Composition	Specific Gravity (g/cm^3)
Brass	70% copper, 30% zinc	8.5
SS-400	12% Ni, 17% Cr, 2.5%Mo	8.03

3.2 Rheological properties and physical specifications of wear piece

Fly ash which has been used in slurry, was collected from the Jhabua power plant (Seoni, M.P.). The physical and Rheological properties of the solid particles present in the slurry plays an important role for the determination of erosion rate, therefore established approaches are applied to determine it. Table 4.5 lists different approaches used to determine respective parameters for the current work

Table 3.3 Various methods for finding physical properties

Parameter	**Method**
Particle Size Distribution	Sieve Analysis
Specific Gravity	Pyknometer
PH value	Ph meter
Rheological Properties	Rheogonimeter (Oscillating Disc Rheometer)

Particle size distribution (PSD) in fly ash collected from the Jhabua Power Plant which has been used for experimental purpose mainly consists of 70% particle finer than 70µm and 30% particles are of ultra fine by weight. Maximum size of particle is 350µm and the weighted mean diameter is 55µm.

3.3 Experimental test conditions for pot tester (Ash + water)

Current research work attempts to establish the relationship of erosion wear with different parameters such as solid concentration, impact angle and velocity. Experimental analysis is done by taking Following three test conditions .

1) Solid particle concentration varies from 35% to 80% by mass at a rotating speed of 350rpm and the impact angle remains constant at 0^0.
2) Variation in Impact wear is observed by changing the impact angle from 30^0, 60^0 and 90^0 and taken the solid concentration 70% by mass and speed at 350rpm.

Average weight loss method is adopted for calculation of erosion wear in above mentioned three different conditions. After every 45 min. of motor run, reading is taken and mass loss is calculated by micro balance machine. by considering the erosion allowance the erosion wear is calculated in terms of mm/year, formula which is suggested by James and Broad has been used.

IV. RESULTS

This section describes the results obtained from experimental setup using Pot tester with ash water slurry and wear pieces of brass and SS400 to find the effect of various parameters like solid concentration, impact angle and slurry velocity.

4.1 Test Condition 1

This experiment has been carried out to evaluate wear rate on Brass and SS400 for total time run of 180min with experimental settings as impact angle 0^0, solid concentration C_w varying from 35% to 80%, velocity 4m/sec. Desired amount of slurry concentration is prepared with the mixing of solid particles into the water and then poured into the cylindrical pot. The settling behavior has not been considered in this experiment. Baffles are provided to avoid separation. Weight loss is calculated at different slurry density. Mass loss measurement in wear piece of brass have been tabulated in table 5.11 and the graphs between average weight loss(mg) with respect to solid concentration on different time run have been plotted using R software.

Table 4.1 Weight loss of Brass wear piece with variable density

Time (min.)	**Weight loss(mg)**			
	Cw(35%)	**Cw(55%)**	**Cw(65%)**	**Cw(80%)**
45	0.25	0.56	0.85	1.15
90	0.86	1.26	2.18	3.26
135	1.10	2.15	3.25	4.63
180	1.56	2.63	4.76	5.3

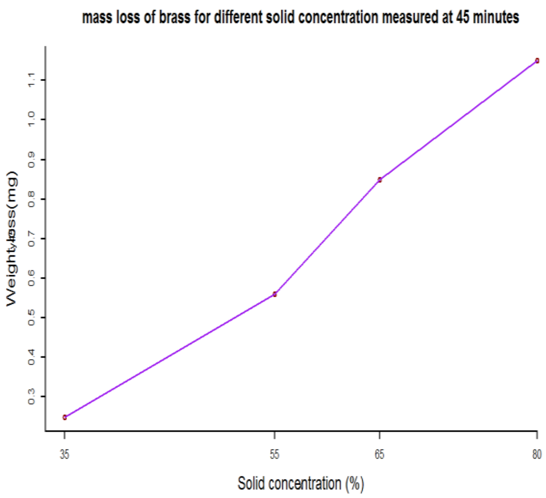

Fig. 4.1 Weight loss variation with variable density (Test duration 45 min.)

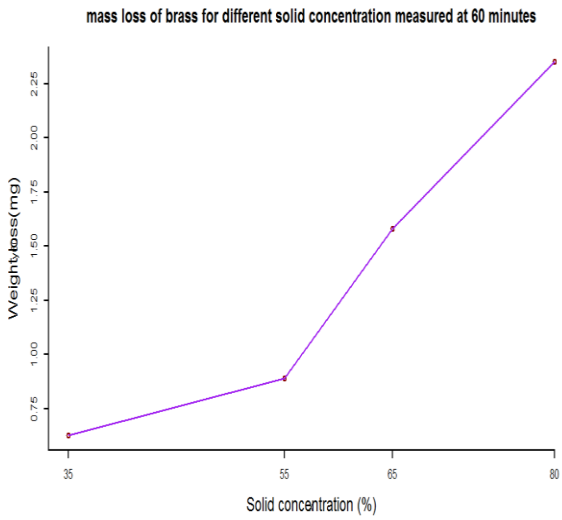

Fig. 4.2 Weight loss variation with variable density (Test duration 60 min.)

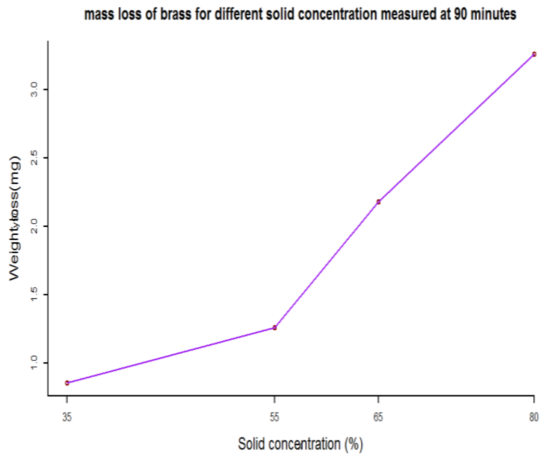

Fig. 4.3 Weight loss variation with variable density (Test duration 90 min.)

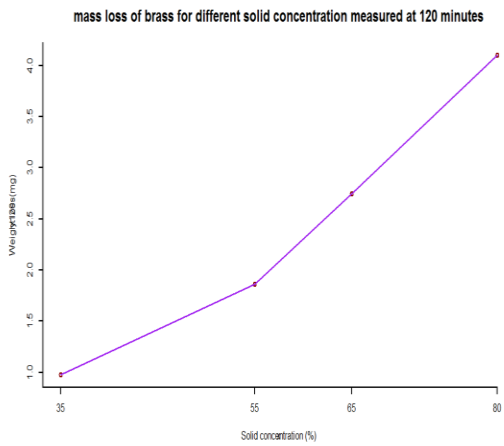

Fig. 4.4 Weight loss variation with variable density (Test duration 120 min.)

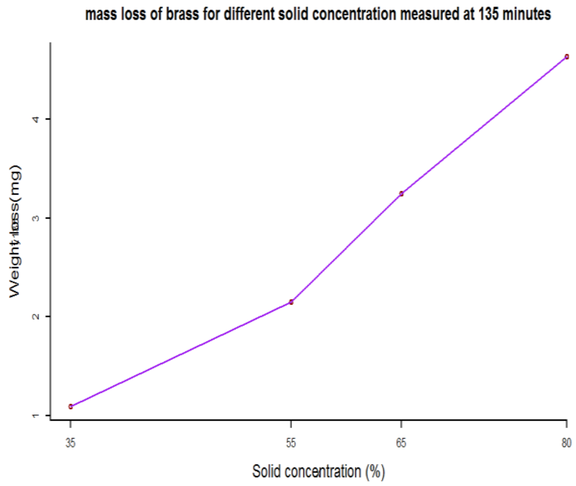

Fig. 4.5 Weight loss variation with variable density (Test duration 135 min.)

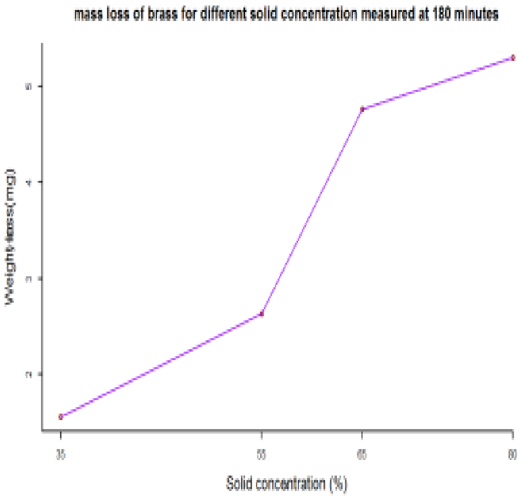

Fig. 4.6 Weight loss variation with variable density (Test duration 180 min.)

Average erosion wear (mm/year) for a fixed time run of 180 min with varying solid concentration (35%-80%) has been calculated and tabulated in table 5.12 and table 5.13 for brass and SS400 respectively, because of limitations of experimental setup, it is difficult to monitor the erosion of wear piece at frequent time intervals. Fig 5.64 and Fig. 5.65 shows the graph for the respective observations.

Table 4.2 Variation of erosion wear of Brass wear piece (mm/yr.)

Solid concentration	**Average Erosion Wear (mm/yr.)**
35%	3.51
55%	4.86
65%	8.3
80%	12.48

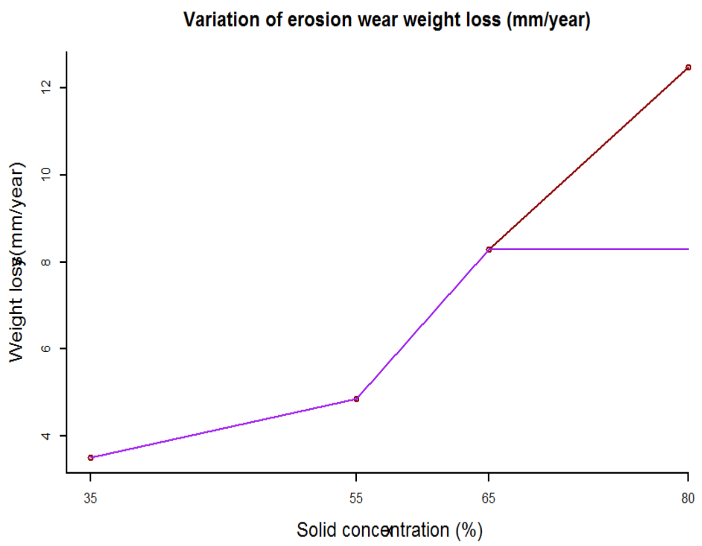

Fig. 4.7 Variation of erosion wear in (mm/yr.)w.r.t. solid concentration with best fit curve

The experimental results have been analyzed and compared with following established co-relation of erosion wear proposed by Elkholy[2]

$E_w = KV^aCw^bd^c$ (4.1)

Where E_w= Erosion wear in mm/yr.
V= Velocity of flow in m/sec.
C_w= Solid concentration in fraction
d= Mean Diameter of particle size
K, a, b, c are the constants depending upon the properties of wear surfaces

As per the test condition1 only concentration is varied while particle size and velocity remain constant resulting in following equation-

$E_w=AC_w^b$ (4.2)

Where $A= KV^ad^c$

By taking the log of both the side of equation (4.3)

$\log E_w=\log A + b \log C_w$ (4.3)

To evaluate the value of b the best fit curve is plotted. By using least square method proposed by Rawat[12] the dependency of erosion wear on solid concentration is non linear function. The empirical relation obtained from best fit curve method is $Ew \propto Cw^{3.23}$ for the wear piece of brass and $E_w \propto C_w^{3.41}$ for the wear piece of SS400. This correlation shows that at higher concentration flow the erosion wear is highly dependent on concentration. The power index lies between 3 and 4.

4.2 Test Condition 2

This experiment has been performed to evaluate wear rate on brass and SS400 for total time run of 180min with experimental settings as impact angle varying from 0^0 to 90^0, slurry velocity 2.5m/sec and solid concentration C_w=70%.

Mass loss measurement in wear piece of brass and SS400 has been tabulated in table 4.3 and table 4.4 respectively. Fig. 4.8 and Fig. 5.69 shows the graphs between average weight loss(mm/year) with respect to impact angle plotted using R software

Table 4.3 Variation erosion wear rate for brass with impact angle

Impact Angle	Erosion Wear (mm/yr)
0^0	12.1
10^0	13.6
20^0	16.3
30^0	15.7
40^0	16.1
45^0	16.8
60^0	15.9
70^0	15.1
80^0	14.8
90^0	13.8

Fig. 4.8 Variation of erosion wear in (mm/yr.) w.r.t. impact angle with best fit curve

Table 4.4 Variation of erosion wear rate for SS400 with impact angle

Impact Angle	Erosion Wear (mm/yr)
0^0	5.3
10^0	6.5
20^0	7.3
30^0	8.5
40^0	9.4
45^0	9.9
60^0	10.3
70^0	9.6
80^0	8.9
90^0	7.6

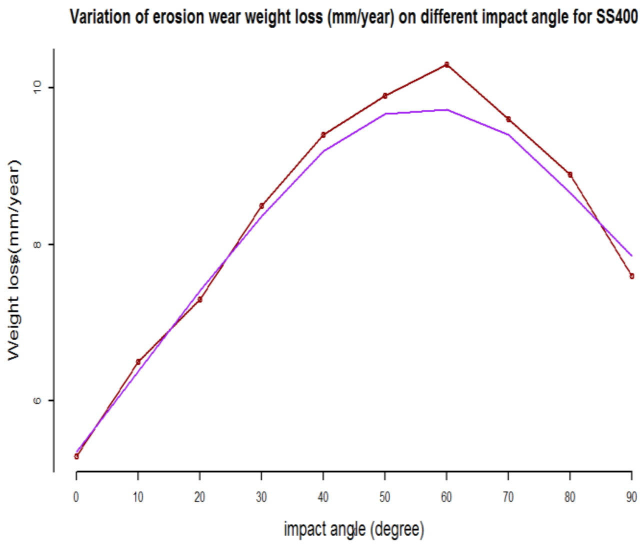

Fig. 4.9 Variation in of erosion wear in (mm/yr) w.r.t. impact angle with best fit curve

High concentration slurry flow, Clearly indicates that impact wear increases by increasing the impact angle at a certain angle 0^0 to 45^0. After 45^0 the wear loss will slightly be decreased. Cutting wear and deformation wear are the parameter to find the effect the of impact angle. Angle taken from 0^0 to 30^0 the cutting wear will be higher than the deformation wear. Up-to 45^0 the deformation wear increases as compared with the cutting wear. Beyond the 45^0 the cutting wear will get decrease. At an angle of 90^0 the impact increases but the cuttings wear decreases. Gandhi [4] has suggested the effect of impact angel on erosion wear. He suggested that erosion wear at an 90^0 is 3-4 times higher than that at 0^0, but in present experimental set up erosion wear at an 90^0 is 1.5times that 0^0, it is because of due to high solid concentration Cw=70% . In high density slurry the interaction between the solid particle increases so the viscosity of fluid also increases, which causes to restrict the erosion wear in due to high concentration.

V. CONCLUSIONS AND FURTHER SCOPE

Experimental data obtained from different test conditions help to identify the time for replacement of piping in long slurry fluid flow and also in centrifugal slurry pump impeller blade. The experimental method determines the effect of slurry velocity, solid concentration and impact wear angle on erosion wear. Pot tester used in (Ash + water) experimental set up, finds the effect of various parameters like solid concentration, velocity and impact angle on erosion wear by using two different materials Brass and SS400. Erosion wear mainly depends upon the velocity, and follows the linear pattern. Similar behavior has been observed in wear pieces of Brass and SS400 for the variation of impact angle. Erosion wears increase from 0^0 to 45^0 and slightly decreases up to 90^0. Erosion wear also depends on the density of solid particles in slurry flow, wear increases with increase in density of solid particle. During high density slurry transportation various problem arises.

5.1 Further Scope

Using various erosion wear tools, current work can be extended to find out erosion wear for larger range of variation in the identified parameters, affecting erosion wear in CFD modelling, As experimental setup has limitations while working with high density slurry and the effect of temperature can also be included to determine the erosion with high density slurry, as viscosity of slurry causes rise in temperature of slurry with time, which in turn may result in thermal wear.

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