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Experimental Investigation of Jet Erosion Wear for Copper IS 191 due Solid-liquid Mixture

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Abstract: Erosion wear is a serious problem for slurry transportation and slurry handling equipment's. It plays an important role in design and operational conditions of slurry transportation system. This paper shows the experimental investigation of weight loss in copper material due to solid-liquid (slurry) impact by using different operating conditions and the validation of the readings using regression and Adaptive Neuro-Fuzzy Inference system (ANFIS). For the experimental investigation, Jet Erosion pot tester is fabricated by using propeller for uniform distribution. Special arrangement is made for angular movement of test carrying fixture in which it can move from 15° to 90°. Different experiments are carried on copper material for repeatability. For experimental study, different parameters like solid-liquid (slurry) concentration, particle size, variable angles (from15° to 90°) and time variable are used. These experimental repeatability readings are then validated by using Regression analysis and Adaptive Neuro Fuzzy Inference system (ANFIS). During this, it is observed that the erosion wear of copper (Ductile material) is maximum at 30° and also the percentage of accuracy in ANFIS is better than regression analysis.

Keywords: Erosion wear, Slurry containing Pot tester, Slurry flow, Repeatability, Adaptive Neuro-Fuzzy Inference System, Regression.

I. INTRODUCTION

Slurry erosion is happen because of the interaction of solid particles suspended in a liquid and a surface which experiences loss of mass by the repeated impacts of particles. It is one of the major sources of mass loss and failure of several slurry equipment and hydraulic components used in many industrial applications. Therefore, there is need to solve or minimize effect of mass loss. The slurry erosion is a difficult phenomenon and it is not fully understood because it is influenced by different parameters, which act simultaneously. These factors include flow field parameters, target material properties and erodent particle characteristics and its size distribution, velocity of slurry.

Among these parameters, the impingement angle and microstructure of the target material play an important role on the material removal process [1]. Erosive wear is the dominant process which can be say as the removal of material from a solid surface. It is due to mechanical interaction between the surface and the impinging particles in a liquid stream. In Erosion process there is a transfer of kinetic energy to the surface. With the increase in kinetic energy of the particles impacting at the target surface, it leads to increase in the material loss due to erosion. [2-3].

II. LITERATURE REVIEW

Erosion wear is classified due to solid particle, liquid impingement and cavitations erosion. This classified erosion effect on slurry containing equipment, pumps, fittings, pipes etc. Where Slurry erosion is a serious problem may lead due to the impingement of solid-liquid (slurry) mixture on the surface of target material. This slurry erosion may vary due to its impingement factors such as velocity of slurry, solid-liquid concentration, particle size, material properties of target surface, different operating angles, viscosity of slurry. During this experiments with different percentage of solid-liquid concentration(10%, 30%), angle of inclination(15°, 30°, 45°, 60°,75°, 90°), particle size(455 µm, 650 µm) and time dependency, it seem that the erosion in the form of weight loss for copper (Ductile) material is maximum at 30° and weight loss reduces, if angle of degree increases.

Many researchers have been trying to reduce the wear through various techniques but it has been difficult to find out the common cause and remedy of this problem due to its variation and dependency on large number of parameters. G.R. Desale[1], studied the erosion-corrosion wear of aluminium alloy composites. The LM13 alloy and LM13-Sic composites were taken to study the effect of sand concentration on the wear behavior in acidic and marine environment for a traversed distance of 763km and a rotational speed of 900rpm. They observed that the wear rate increase with increasing sand concentration irrespective of the material. This is because as the concentration of sand in the slurry increases the severity of erosion /abrasive attack increase because a greater number of particles are impinging on the surface. On the other hand, the slurry of corrosion attack may decrease because the effective volume of the corodent decreases. The alloy

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exhibited higher wear rate compared to the composite as sand concentration increased from 0% to 40%. It was concluded that all the material exhibited higher wear rate in the acidic media as compared to NaCl at 0% and 20%sand concentration. However at 30% and 40% sand concentrations the material posses lower wear rates in acidic media. Dalbir Singh Dhindsa [2], this report concludes that erosion wear is a function of velocity of slurry, as velocity increases erosion wear rate proportionally increases. 16Cr-5Ni stainless steel has the least erosion wear compared to other selected materials Mild Steel, Grey Cast Iron, 13Cr-4Ni Stainless Steel and grey cast iron erosion wear is found maximum. Maximum erosion wear rate is found at impact angle 300 and minimum at impact angle 900 . Erosion wear weight loss is the function of time. The materials 13Cr-4Ni Stainless Steel and 16Cr-5Ni Stainless Steel shows similar behaviour towards erosion and Mild Steel and Grey Cast iron also shows identical behaviour.

III.SLURRY EROSION

Slurry erosion is defined as type of wear or loss of mass that is caused by the impingement of slurry on targeted surface of material. This erosion occurs when the material moves at a certain velocity through the slurry or when the slurry moves past the material at a certain velocity. Slurries erode by the action of abrasive particles in the liquid which results in the failure of the surface of material in one or the other mode depending upon the conditions to which the system is exposed. Slurry erosion is a serious problem for the industries, which deals with the liquids having solid particles entrained in them. When such a mixture of liquid and solid particles termed as slurry come in contact with the machine element, the removal of material takes place from the surface making the component redundant from the surface.

IV.PARAMETERS AFFECTING ON EROSION WEAR

- Impact angle
- Velocity of solid particles
- Hardness
- Particle size and shape
- Solid concentration.

V. DEVELOPMENT OF JET EROSION TESTER

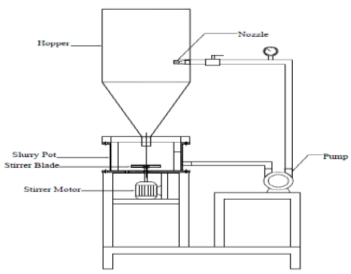

Fig.1 Schematic representation of jet erosion tester

Description of Jet Erosion tester:
This test rig consist of important part namely as slurry pot. This pot has 7.3 lit capacity similar to one which were developed by Desale et al (2005).the function of this pot is to prepare homogeneous mixture of Narmada sand and water for different particle sizes and different concentrations. To prepare the homogeneous mixtures of different combinations the pot has a stirrer which is to be rotated with the help of 3phase A.C. motor has maximum capacity of 1440 rpm. Rotational speed of a motor is controlled with the help of 3 phase dimmer stat (Transformer). This test rig also contains a centrifugal pump of 0.5Hp capacity made by Kirloskar Pumps. This pump sucks the slurry from slurry pot and supply the high pressure slurry to the converging section of the nozzle having 10 mm diameter where its pressure energy is converted into the velocity of fluid. There is one control valve also attached to control the mass flow rate of the mixture. It also has a specimen holder (Fixture), which has an arrangement to moves in different angular positions.
Slurry Pot: The slurry pot is the most important part of the project the function of this pot is to prepare the homogeneous mixture of Narmada Sand and Water. It has an 7.3liter volume it also has an provision for the propeller turbine blade similar to which developed by Desale et al. (2005).Height of the pot is 155mm.diameter the pot is 240mm.it also has a 4 baffles. The slurry pot is made up of stainless steel material [Fig2].

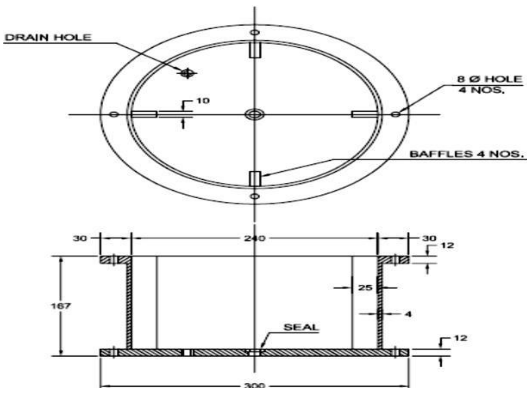

Fig.2 Slurry Pot

Propeller Blade: The turbine blade is fitted inside the slurry pot which helps to mix the sand and water and keep it in homogeneous form [fig3]

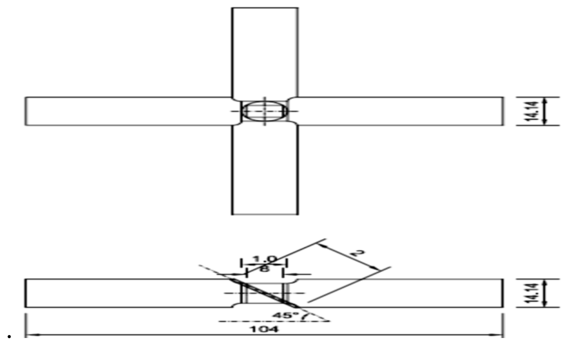

Fig.3 Details of Four Blade 450 Pitch Blade Turbine Propeller

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Base Stand: Main function of the base stand is to hold and support the hole assembly of jet erosion tester [Fig4].

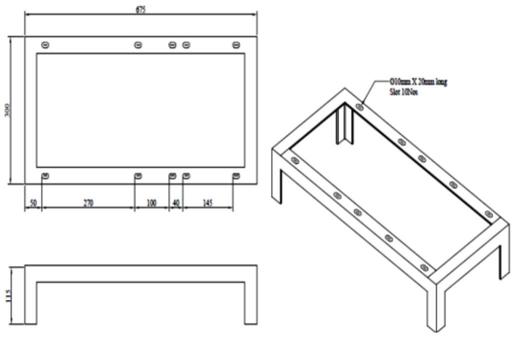
Fig.4 Base Stand

Motor Holder: Purpose of motor holder is to hold and support the stirrer motor in vertical direction and exactly at the centre of the pot where propeller blade turbine is situated [Fig5].

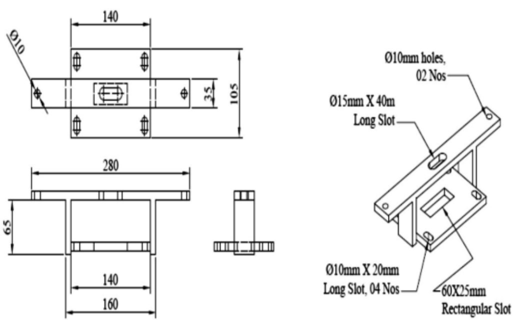

Fig.5 Motor Holder

Specimen Holder: This is the most important part of the test rig it has four holes drilled on it to clamp the specimen plate. It is made up of mild steel, one rectangular flat pate is welded to the bar which has threads at one end for tightening purpose and also marking on it, which coincides with the lines mark on a bar at different working angles [Fig6].

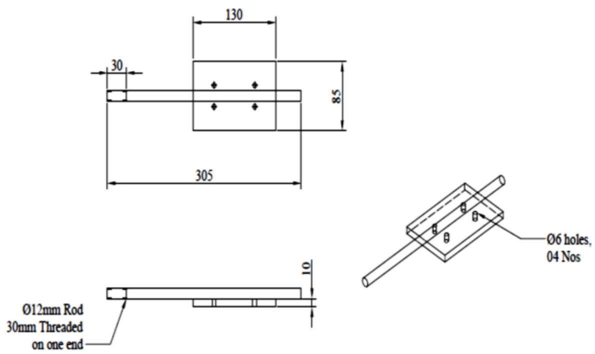

Fig.6 Specimen Holder

Particle size distribution:
Measurement of particle size distribution is essential to establish the variation in the particles in the solid sample and the percentage of particles present in different size ranges. For the coarser particles, sieve analysis can be used to determine the particle size distribution. This distribution has been obtained by dry sieve analysis method. A representative sample of the solid particle is taken and sieving is done with a set of sieves. Special care is taken to ensure that the sample is properly dried. The sample retained on each sieve is collected and its percentage is calculated following the standard procedure.
The particles of IS sand is selected as solid material for the present investigation and its physical properties are given in Table 1. It is not possible to collect identical size particles of the solid material. The particles are, therefore, sieved using successive sieves sizes and the particles collected between two successive sieves are designated by the mean sieve size.

TABLE 1.PHYSICAL PROPERTIES OF ERODENT USED

Solid Particle	Chemical Formula	Colour	Sp. Gravity (Kg/ m3)	Hardness VHN	Particle Shape
Quartz (IS Sand)	SiO2	Whitish	2652	1100	Sub Angular

TABLE II ELEMENTAL COMPOSITION OF TARGET MATERIAL USED

Target Materia	Element Composition (Wt. %)					
Copper IS 191	Cu%	Zn%	Pb %	Mn %	P%	Si%
	99.974	0.000	0.003	0.000	0.013	0.010

TABLE III RANGE OF PARAMETERS FOR THE INVESTIGATION ON EROSION BEHAVIOUR OF DUCTILE MATERIAL COPPER IS 191

Target Material	Impact angles	Particle Size (μm)	Solid particle	Solid Concentration % by wt.	Time
Copper IS 191	15°,30°,45°,60°,75°,90°	450	Quartz (IS sand)	10%	60 min

VI. EXPERIMENTAL PROCEDURE

The procedure has to be followed on erosion tester to calculate the erosion wear of different materials is as follow:
1. Firstly the specimen is cleaned properly.
2. Drying, if required.
3. Weighing the specimen (initial weight).
4. Clamp the specimen in fixture provided in test rig.

5. Setting the holder at required angle.
6. Weight the required sand as per concentration of slurry.
7. Mixing the proper amount of water and sand in tank.
8. Start the pump.
9. Adjust the flow rate to obtain desired value of mass flow rate and running the test for required time interval.
10. Removing the specimen from the fixture.
11. Cleaning and drying the specimen.
12. Weighing the specimen after erosion to measure the mass loss.
13. Repeat the steps.

VII. REGRESSION

Since multiple regression is used to determine the correlation between a criterion variable and a combination of predictor variables, the statistical multiple regression method is applied. It can be used to analyse data from any of the major quantitative research designs such as causal-comparative, correctional, and experimental. This method is also able to handle interval, ordinal, or categorical data and provide estimates both of the magnitude and statistical significance of the relationships between variables Therefore, multiple regression analysis will be useful to predict the criterion variable of material erosion rate via predictor variables such as Angle, Time, Particle size, and solid concentration.

In which experiment 48 test reading are conducted with variable time, concentration, angle, and size. Ea= 0.00118 X $(C\wedge^{0.042})$ x $(T\wedge^{0.037})$ X $(S\wedge^{0.038})$ X $(A\wedge^{-0.27})$Where, Ea- Erosion rate of selected material, C- Solid concentration in percentage- Time in minute, S- Particle size in micron and A- Angle in degree. New empirical model Eq. (1) is developed for prediction of material erosion rate using Angle, Concentration, Time, particle size. It is observed that the proposed equation establishes relation among input variables and response variable. The average deviation observed in measured value and regression predicted value is 18.34 % at confidence level of 81.65%. These regression prediction models compare with ANFIS prediction model values to verify the accuracy of prediction models.

VIII. ADAPTIVE NEURO FUZZY INFERENCE SYSTEM

Adaptive Neuro Fuzzy Inference System (ANFIS) is a fuzzy inference system implemented in the frame work of adaptive networks. Using a given input/output data set, the ANFIS method constructs a fuzzy inference system (FIS) whose membership function parameters are tuned (adjusted) using a back propagation gradient descent and a least-squares type of method.

This allows fuzzy systems to learn from the data they are modelling. FIS structure is a network-type structure, which maps inputs through input membership functions and associated parameters, and then through output membership functions and associated parameters to outputs. ANFIS applies two techniques in updating parameters. For premise parameters that define membership functions, ANFIS employs gradient descent to fine-tune them. For consequent parameters that define the coefficients of each output equations, ANFIS uses the least-squares method to identify them. This approach is thus called hybrid learning method since it combines the gradient descent method and the least-squares method.

ANFIS modelling process starts by obtaining a data set (input–output data pairs) and dividing it into training and testing data sets.

The training data set is used to find the initial premise parameters for the membership functions by equally spacing each of the membership functions. A threshold value for the error between the actual and desired output is determined. The consequent parameters are found using the least-squares method. Then an error for each data pair is found. If this error is larger than the threshold value, update the premise parameters using the gradient decent method. The process is terminated when the error becomes less than the threshold value. Then the testing data set is used to compare the model with actual system. A lower threshold value is used if the model does not represent the system Jang (1993).

The adaptive network in the proposed fuzzy inference system was feed forward type. The membership function was Sugeno type triangular shape membership function. There are three input membership function for each input and 27 learning rules. The learning weight was set to 1 with linear input / output values and for the defuzzification that is to produce crisp output of the consequent part weighted average scheme was used. For simplicity, we assume the fuzzy inference system under consideration has two inputs X and Y and one output Z.

For the first order Sugeno fuzzy model a typical rule with two fuzzy if-then rules can be expressed as: Rule 1: If (X is A1) and (Y is B1) then (Z1 = p1X + q1Y + r1), Rule 2: If (X is A2) and (Y is B2) then (Z2 = p2X + q2Y + r2), Where, X and Y are the inputs, Ai and Bi are the fuzzy sets, Zi (i = 1,2) are the output within the fuzzy region specified by the fuzzy rules, pi, qi and ri are the design parameters that are determined during the training process.

XI. RESULTS AND DISCUSSION

In this experiment we can conduct 48 readings. The fuzzy inference system was trained up to 100 epochs. The experiment was conducted using Sugeno type fuzzy inference system with 27 rule, triangular membership function of each input parameter, hybrid of least square-gradient descent learning algorithm and linear output.

The analysis of experimental data was conducted on Mat Lab 7.6.0 workstation. The first four columns were treated as input and the last column as output data for the Fuzzy inference system (FIS). In which two tables are shown in

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below. First table shows the experimental readings validates with regression analysis and second table shows the experimental readings validates with Adaptive Neuro Fuzzy Inference System.

TABLE 1

It shows the experimental readings validates with Regression Analysis. And in between error is shown in percentage.

`	Input Parameter				Predicted Erosion		
Sr	Concentration	Time	Size	Angle	Erosion		Error
No	%	Min	µm	Degree	Experimental	Regression	%
1	10	60	455	15	0.057	0.070	22.01
2	10	60	455	30	0.090	0.058	35.91
3	10	60	455	45	0.065	0.052	20.46
4	10	60	455	60	0.050	0.048	4.33
5	10	60	455	75	0.042	0.045	7.23
6	10	60	455	90	0.032	0.043	33.98
7	10	90	455	15	0.065	0.081	24.31
8	10	90	455	30	0.095	0.067	29.45
9	10	90	455	45	0.075	0.060	19.91
10	10	90	455	60	0.065	0.056	14.49
11	10	90	455	75	0.057	0.052	8.19
12	10	90	455	90	0.040	0.050	24.53
13	10	60	650	15	0.06	0.080	32.74
14	10	60	650	30	0.082	0.066	19.44
15	10	60	650	45	0.068	0.059	12.93
16	10	60	650	60	0.055	0.055	0.4
17	10	60	650	75	0.045	0.052	14.61
18	10	60	650	90	0.04	0.049	22.74
19	10	90	650	15	0.064	0.093	44.58
20	10	90	650	30	0.098	0.077	21.69
21	10	90	650	45	0.074	0.069	7.04
22	10	90	650	60	0.068	0.064	6.4
23	10	90	650	75	0.06	0.060	0.12
24	10	90	650	90	0.054	0.057	5.63
25	30	60	455	15	0.088	0.110	25.37
26	30	60	455	30	0.15	0.091	39
27	30	60	455	45	0.107	0.082	23.35
28	30	60	455	60	0.09	0.076	15.68
29	30	60	455	75	0.062	0.071	15.23
30	30	60	455	90	0.05	0.068	36.02
31	30	90	455	15	0.098	0.128	30.8
32	30	90	455	30	0.131	0.106	18.84
33	30	90	455	45	0.098	0.095	2.77
34	30	90	455	60	0.081	0.088	8.84
35	30	90	455	75	0.068	0.083	22.07
36	30	90	455	90	0.06	0.079	31.7
37	30	60	650	15	0.098	0.126	28.92
38	30	60	650	30	0.132	0.105	20.62
39	30	60	650	45	0.102	0.094	7.92
40	30	60	650	60	0.092	0.087	5.54
41	30	60	650	75	0.084	0.082	2.6
42	30	60	650	90	0.07	0.078	11.26
43	30	90	650	15	0.122	0.147	20.32
44	30	90	650	30	0.168	0.122	27.53
45	30	90	650	45	0.144	0.109	24.22
46	30	90	650	60	0.116	0.101	12.96
47	30	90	650	75	0.098	0.095	3
48	30	90	650	90	0.08	0.090	13.11
Average							18.347

TABLE 2

IT SHOWS THE EXPERIMENTAL READINGS VALIDATES WITH ADAPTIVE NEURO FUZZY INFERENCE SYSTEM (ANFIS) AND IN BETWEEN ERROR SHOWN IN PERCENTAGE.

`	Input Parameter				Predicted Erosion		
Sr	Concentration	Time	Size	Angle	Erosion		Error
No	%	Min	µm	Degree	Experimental	ANFIS	%
1	10	60	455	75	0.042	0.0444	5.71
2	10	90	455	45	0.075	0.082	9.33
3	10	60	650	90	0.04	0.0352	12
4	10	90	650	30	0.098	0.0882	10
5	30	60	455	75	0.062	0.0644	3.8
6	30	90	455	60	0.081	0.0844	4.19
7	30	60	650	90	0.07	0.065	7.14
8	30	90	650	60	0.116	0.119	2.58
						Average	6.8437

CONCLUSIONS

Arrangements in the Jet Erosion Tester have been made to evaluate the effect of impact angle, concentration, velocity, particle size etc. on erosion wear. This design of jet erosion tester is intend to conduct wear tests at moderate solid concentrations and actual flow of velocities to simulate the wear conditions for pipeline, pipe and fittings, bend, pump etc. and may provide more realistic results. Finally, the contributions of jet erosion wear is find out in the form of weight loss for the series of different impact angles such as 150,300,450,600,750,900at 10% solid concentration of sand for 60 minutes for Ductile materials.

For different angular positions, it is observe that the weight loss decreases as the angle is increases from 30° to 900 the maximum weight loss is occur at 300 angle of impact and it decreases as angle is increases from 300 to 900respectively.

By completing the validation with ANFIS and Regression analysis, it is observed that the erosion wear of copper material by ANFIS with triangular membership function is 93.156%, with the error of 6.843% and by using Regression analysis is 81.65%, with the error of 18.34%.

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