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Erosion wear studies on high concentration fly ash slurries

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ABSTRACT

Erosion is an unavoidable phenomenon in the pipelines transporting bulk solids in both hydraulic and pneumatic conveying modes. Erosion wear depends on a number of factors like hardness of the material, size and shape of the solid particles, solid concentration, velocity of particles, impact angle of solids on the target material surface etc. Several investigators have made systematic studies to establish the functional dependence of erosion wear on various parameters. In the case of hydraulic conveying of the solids in slurry form, most of these studies are limited to low and medium solid concentrations only. But with the advent of new economical, environment friendly and water saving technology of solid conveying in the form of high concentration slurries (HCSD) the study of erosion wear at these concentrations becomes necessary. Hence, in the present study a modified pot tester capable of operating at high concentrations ($C_w > 60\%$ by mass) has been designed and fabricated. Measurements have been made with fly ash slurries at various concentrations (in the range 50% to 70% by mass) and relative velocities (in the range 1 to 4 m/s). It is observed that the parametric dependence of erosion wear at high solid concentrations is at variance with that observed at lower concentrations. The erosion wear was found to have a stronger dependence on concentration as compared to relative velocity. Studies are also conducted to investigate the effect of variation of angle of impact on the erosion wear at a solid concentration of 65%(by mass) and it is noticed that erosion rate shows a maximum at an angle of 45°.

1. Introduction

Disposal of coal ash in the form of slurry through pipelines in most of the thermal power plants has been at low or medium concentrations until very recently. Wear in pipeline is reasonably well understood for low and medium concentration slurries. Many empirical correlations are reported in literature which highlight the dependence of wear on velocity, concentration and particle size [11,14] etc. The shift towards high concentration ($C_w \geq 60\%$) is fairly a recent phenomenon in thermal power industry. Very few studies have been conducted for wear in high concentration slurry flows and it is not clear whether the empirical relations developed for low and medium concentrations will be applicable at high concentrations.

Erosion wear studies at in-situ conditions or in the pilot plant test loops are cumbersome, time consuming and expensive. Over the years, alternate approaches have been developed to simulate the erosion mechanism at the laboratory scale by using various test rigs like pot tester [22], Coriolis Wear Test Rig [4], Jet Impingement Tester [16] etc.

Tsai [22] reported an indigenously developed erosion wear test rig and carried out accelerated erosion wear tests on various steel alloys using silica, carbon and coal particles in kerosene oil at two concentrations (by mass) namely, 30% and 50%. Lynn et al. [17] conducted erosion wear studies using pot tester on cylindrical steel work pieces at 1.2% suspension of Si-C in oil. Gupta et al. [14] have presented a systematic study on a pot tester for establishing the effect of flow velocity, solid concentration (15–45% by mass), and particle size on erosion wear using copper tailing slurry. They proposed two relationships of erosion wear for the two materials namely brass and mild steel and found that functional dependence of erosion wear on velocity was very strong as compared to that on particle size and concentration.

Similarly Gandhi et al. [11] used the pot tester to study the phenomenon of erosion wear in the solid concentration (by mass) range of 20 to 30%. They designed a special fixture for the pot tester to conduct extensive parallel wear studies using pot tester. On the basis of extensive experimentation with zinc tailings slurry on brass material they concluded that the wear in parallel flow increases with solid concentration, particle size and velocity. Gandhi et al. [13] have also studied the effect of angle of impact of solid particles on the erosion wear taking brass as target material and slurry of water and zinc tailings at two concentrations namely 20% and 40% (by mass) using the pot tester. Further, Gandhi et al. [12] using narrow sized sand slurry also established the effect of

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Nomenclature

A_{wp}	wear piece Surface area which is subjected to erosion (mm^2)
C_w	solid Concentration by mass, %
E_W	erosion Wear (mm/year)
WL	measured weight Loss (gm)
d	weighted mean particle size in mm
t	time period over which the weight loss of wear piece has been measured (hours)

Greek symbols

ρ_{wp}	Mass density of the wear piece material (Kg/m^3)

particle size on erosion wear, in the solid concentration range of 20% to 40%(by mass). Subsequently they added fine particles to the coarse particles in the range of 5 to 25% keeping the overall concentration same. They observed that the presence of fine particles (< 75 µm) in relatively coarse particulate slurry reduces the wear up-to 50% if the percentage of fine particles added is 25% (w/w) of coarser particles.

Desale et al. [7] using a pot tester studied erosion wear of sand water slurries in the solid concentration range of 0–30%(by mass) by ensuring uniform distribution of solid particles. Desale et al. [6] also investigated the effect of properties of the target material on erosion wear by choosing two ductile materials namely, AA6063 and AISI 304 L steel and three solid materials namely; quartz, alumina and silicon carbide. They predicted that erosion wear increases with increase in density of the slurries. Desale et al. [8] have also established the effect of PSD on erosion wear of aluminium alloy (AA 6063) using a pot tester and sand slurry at 20% (by mass) solid concentration with wear material being placed at angles of attack of 30° and 90°. The erosion wear was found to increase with the increase in particle size (mean particle size).

Dube et al. [9] studied the erosion wear due to alumina and silica slurry in turbulent operating conditions in the solid concentration range of 15–50%(by mass) using a "counter rotating double disc erosion tester" manufactured by DUCOM Instruments (P) Ltd. Abouel-Kasem et al. [1] using paint erosion technique established a functional dependence of the erosion wear as a function of angle of attack, velocity, and time of erosion and found that this relationship was similar to the relationship obtained by previous researchers using other techniques.

Sapate & Raut [19] conducted a study related to Slurry abrasion in abrasion test apparatus (DUCOM make, India). They measured the abrasion rate of hard faced low alloy steel to establish the effect of normal load, sliding distance and solid concentration (by volume) in the range of 27.07–99.52(g/l) using silica sand as abrasive particles. Based on their measurements, the abrasion rate of hard faced alloy steel is directly proportional to sliding distance, normal load, slurry concentration, and particle size of the abrasive medium.

Ojala et al. [18] designed a sturdier pot tester suitable for high speed erosion wear for testing of wear resistant materials suitable for industrial applications. Wear tests in the pot tester resulted in different wear rates at different levels of samples due to large variations in concentration and leading to higher variation in experimental results.

Zhang et al. [24] predicted the position of puncture point in an elbow and U-shape bend by numerically simulating the fluid transportation. For discrete particles they tried to describe the kinematics and trajectory and the particle–particle interaction by discrete element method (DEM), whereas the hydrodynamic model of the fluid phase has been described by the volume-averaged Navier–Stokes equations. Further, for calculating the solid–fluid interaction force a fluid density-based buoyancy model has been used. Based on these and the wear pattern in the elbow and U-bend, the puncture point locations have been determined. Specifically they have discussed the effect of slurry velocity, bend orientation, and angle of elbow on the puncture point location.

Cenna et al. [3] conducted experiments in a pneumatic pipeline to analyse the critical wear patterns using fly ash. They found, using the Scanning electron Microscope (SEM) that there exist continuous wear channels at the bottom of the pipeline which can be attributed to the phenomenon of larger particles moving close to the bottom wall. Similar phenomenon is observed in slurry flows where the concentration gradient exists with larger particles moving close to the bottom.

Walker & Hambe [23] using a Coriolis wear tester have established the effect of particle shape on the wear rate. They found an inverse power law relationship between the circularity factor (CF) and the erosion rate of white iron. Other techniques used for doing erosion wear are ultrasonic wear meter which measures the loss in the wall thickness of the material due to solid particles directly [2] and erosion wear based on the tensile stress applied on the pipe materials. Sun et al. [20] using macroscopic and SEM based analysis determined how the tensile stresses affect the erosion wear.

The above literature survey reveals that a number of test rigs have been developed to conduct experimental studies to establish the dependence of erosion wear on different parameters. The most common device used to study erosion wear of different materials is the pot tester. Most of the studies done in a pot tester are restricted to a maximum concentration of 50% (by mass), and no systematic study to establish the dependence of erosion wear at higher concentrations [$C_w \geq 60\%$ (by mass)] is reported. Thus, an attempt has been made in the current study to do a parametric study of wear at higher concentrations using a modified pot tester. The parameters investigated experimentally to establish the erosion wear are: Solid concentration (by mass)(C_w), Relative velocity of particles (V) and Angle of impact of solid particles on the wear surface (θ).

2. Experimental setup and range of parameters

2.1. Details of the Pot Tester

The pot tester used in the current study is a modified version of pot tester used by Gupta et al. [14] and Gandhi et al. [11]. The modifications made in the pot tester keeping the needs of the high concentration slurry are: increase in the size of the pot and independent control on speed of wear piece and stirrer.

The pot tester consists of a cylindrical tank of aluminum having a capacity of 14.13 l as shown in Fig. 1. The Cylindrical tank diameter is 300 mm and its height is 200 mm. The full unit of pot tester consists of two motors of 1.5 HP and 2 HP capacities and