

Erosion wear on centrifugal pump casing due to slurry flow



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ABSTRACT

Erosion wear is recognized as an engineering problem in slurry handling and transportation equipment such as centrifugal pumps, which are widely used in numerous industries for this purpose. The present work shows erosion damage predictions in lime slurry pumps in a process industry, Imperial Chemical Industries (ICI), Khewra, District Jhelum, Pakistan. Three-dimensional numerical analysis has been conducted for the prediction of erosion and its effect on the head and efficiency losses for lime slurry flow through centrifugal pumps. The tongue and belly portions of the volute casing are found to be the most affected regions of erosion damage. It has been found that erosion loss increases with impact velocity, concentration by weight, and diameter of the solid particles. The effect of temperature seems to be critical for erosion damage as it enhances the phenomenon of corrosion-erosion. The simulation results are compared and validated against both data provided by ICI and published experimental data. The results are found to be in good agreement.

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1. Introduction

Centrifugal pumps are widely used for transporting solid-liquid slurries. They find application in many process industries, coal industry, chemical industry, and metallurgical processes. Material loss by liquid flows usually occurs in two different ways—one is erosion caused by cavitation and the other is erosion caused by solid particles entrained in liquid flow, known as slurry erosion [1]. In typical slurries, solid particles vary in diameter and concentration depending on the type of slurry by usage. Erosion damage caused by lime slurry is a common and unique problem in soda ash-making industries, and it is a complex phenomenon that involves surface, erodent, and slurry properties.

Erosion of surfaces, especially in pumps and pump casings due to entrained particles, has been experimentally examined many times over the past years. Yuan et al. [2] measured erosion damage caused by particle impingements to express the wear coefficients based on Bitter's model. Pagolthivarthi et al. [3] made predictions and gained a physical understanding of the flow field of dense slurry in centrifugal pump casings subject to various working and geometric conditions. Solid concentration and solid wall shear stress increases gradually from upstream of the tongue region to downstream of the belly region. These quantities are considered critical in wear calculations along the casing wall. Kaushal et al. [4]

used the Eulerian model, which provides approximate estimates for pressure drop, concentration profiles at all efflux concentrations, flow velocities for pipeline flow, and flow through horizontal beds. Mesa et al. [5] studied Commercial AISI 410 and AISI 420 stainless steels and reported very high mass losses when tested in slurry composed of an acid solution comprising hard particles. Wood et al. [6] showed that pipes that support swirl could get particles into holdup. Lower pumping power is needed, and a lower pressure drop occurs when compared to a conventional round duct.

The present work shows the erosion loss predictions in lime slurry pumps at the Imperial Chemical Industries (ICI), Khewra, District Jhelum, Pakistan. It is one of the largest process industries in Pakistan, which produces Calcium hydroxide (Soda Ash) along with other products. Owing to impurities in Calcium Hydroxide, very small particles are suspended in liquid, making it a heterogeneous or settling slurry. The slurry is transported to the desired place using a centrifugal pump. The impact of small particles causes the surface of the volute casing to be eroded, reducing the life of the centrifugal pump. The pump casing needs to be replaced every three months for smooth running of the plant. The Eulerian two-phase model has been used to analyze erosion damage in volute casings [6]. Fig. 1 shows the wear damage due to impact and corrosion-erosion on the centrifugal pump casing at the actual site. A 3-D numerical analysis has been performed for the prediction of erosion and its effect on the head and efficiency losses for lime slurry flow through centrifugal pumps. The important parameters on which erosion loss depends are impact velocity, concentration, shape, and size of the lime slurry particles. The

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simulation results were compared and validated against the data provided by the ICI and with experimental data.

2. Theoretical aspects

Erosion wear occurs due to the interaction between solid particles in the fluid stream and the pump's surface, through sliding and impact mechanisms. It depends on surface, erodent, and slurry properties as shown in Table 1. The volute casing is made of gray cast iron. Impact wear is observed when particles repeatedly impact the casing at high impact angles and plastically deform the surface layers of the material ultimately causing material degradation through surface breakup. For standard cast iron products, highest erosion losses have been observed to occur for impact angles between 40–45° in most of the curved surfaces, indicating the domination of impact wear [7,8].

The solid particles are calcium carbonate granules, which mix with water, making it a settling or heterogeneous lime slurry. The slurry is transported to the desired place using a centrifugal pump. Fig. 2 shows the erosion modeling concept for the slurry flow.

2.1. Pump performance parameters

Industry data shows that pump performance declines for heavier fluids like lime slurry. It is important to account for pump head losses and power losses that occur as the slurry is transported through the pump.

Head and efficiency ratios are defined by the ratios of the head and efficiency when pumping slurry to the head and efficiency when pumping water, respectively.

$$HR = H_s/H_w \quad (1)$$



Fig. 1. Erosion wear on centrifugal pump casing at actual site.

Table 1
Data obtained from ICI.

Parameters	Description
Slurry (working fluid)	Milk of lime Ca(OH)_2
Density of slurry	1281 kg/m^3
Temperature of slurry	70–90 °C
Volute casing material	Gray cast iron
Solid particles	Calcium carbonate CaCO_3
pH of slurry	12.4
Density of particles	2710 kg/m^3
Mean diameter of particles	1.20 mm
Particle Reynolds number	72,056
Pump suction head	1.52 m
Pump discharge head	10.60 m

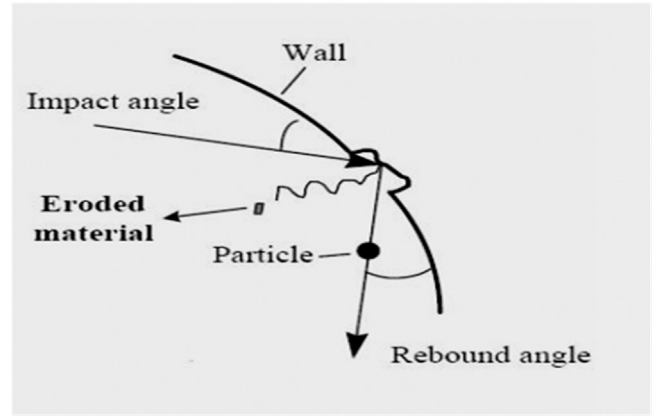


Fig. 2. Schematic for the erosion modeling concept.

$$ER = \eta_s/\eta_w \quad (2)$$

HR and ER depend on the specific gravity of the solids (SG_s), volumetric concentration (C_v) of the solid particles, particle diameter (d_{50}), and impeller diameter (D_i).

The magnitude of efficiency ratio is usually smaller than the head ratio. The reason for this is that the efficiency ratio includes the effects of both head losses as well as power losses [9,10].

Detailed readings are taken and analyzed for the effect of head ratio and efficiency ratio with and without slurry flow through a centrifugal pump casing in ICI for comparison at room and elevated temperatures.

2.2. Mathematical formulation

In the Eulerian or continuum approach, steady continuity, momentum, and energy equations are presented for both solid and liquid (carrier) phases.

2.2.1. Continuity equation

$$\nabla \cdot (\alpha_t \rho_t v_t) = 0 \quad (3)$$

where t is either solid phase s or fluid phase f .

2.2.2. Momentum equations

Separate momentum equations are used for liquid and solid phases.

Momentum equation for fluid phase:

$$\begin{aligned} \nabla \cdot (\alpha_f \rho_f v_f v_f) = & -\alpha_f \nabla P + \nabla \cdot \tau_f + \alpha_f \rho_f g + K_{sf}(v_s - v_f) \\ & + C_{vm} \alpha_f \rho_f (v_s \cdot \nabla v_s - v_f \cdot \nabla v_f) \\ & + C_L \alpha_s \rho_f (v_f - v_s) \times (\nabla \times v_f) \end{aligned} \quad (4)$$

Momentum equation for solid phase:

$$\begin{aligned} \nabla \cdot (\alpha_s \rho_s v_s v_s) = & -\alpha_s \nabla P + \nabla \cdot \tau_s + \alpha_s \rho_s g + K_{sf}(v_f - v_s) \\ & + C_{vm} \alpha_s \rho_f (v_f \cdot \nabla v_f - v_s \cdot \nabla v_s) \\ & + C_L \alpha_s \rho_f (v_s - v_f) \times (\nabla \times v_f) \end{aligned} \quad (5)$$

where α_f , ρ_f , v_f , and $\nabla \cdot \tau_f$ and α_s , ρ_s , v_s , and $\nabla \cdot \tau_s$ are the volumetric concentrations, densities, velocities, and viscous terms of fluid and solids respectively. ∇P is the static pressure gradient, C_{vm} is the coefficient of virtual mass force, C_L is the lift coefficient, and K_{sf} is the inter-phase drag coefficient.

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