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# Centrifugal Slurry Pumps Design & Selection for Sustainable Mining Industry – A Review

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***Abstract***— **Centrifugal Slurry Pumps are the heart of wet process operations in mineral processing plants and for hydro-transport duties. Sustainable mining industry is driven by technological innovation to minimize environmental impact and slurry pumps are strategic and critical assets in this process. Hence the importance of their optimisation, innovation and continuous improvement. Designing efficient and durable slurry pumps will not only reduce the operations costs but will have significant environment impact by reducing energy consumption during pumps operation and during the pumps manufacturing process. Having durable and long lasting pumps contribute considerably to resource conservation by reducing the need for frequent manufacturing which reduce energy consumption, minimise industrial waste and conserve raw materials.**

**Unlike site-specific machinery such as the hydraulic turbines, which are custom designed for specific site conditions (head, flow, and water properties) allowing specific optimization of their geometry and blade angles to operate under steady and controlled conditions, the centrifugal pumps use standard designs to handle different operating conditions which limits their efficiency. In addition, slurry centrifugal pumps are required to operate under severe conditions involving solid particles, high densities and viscosities. These factors increase internal hydraulic losses and accelerate wear of the slurry pump's wet end components, which introduces major constraints and pose significant challenges for achieving cost-effective optimisations.**

**This paper is aimed to categorise slurry pumps design and optimisation considering applications and material selection. The review of numerical and experimental studies undertaken in this field have been summarised to develop a simplified flowchart as guide for centrifugal slurry pumps selection, while future improvements depend on continued CFD researches and composite material innovations.**

***Keywords***— **Slurry, Centrifugal Pumps, Wet end, Impeller, Volute, Wear Rate, Erosion, Abrasion, Flow, Head, Efficiency, BEP, CFD.**

## I. Introduction

Centrifugal slurry pumps are the most common type of slurry pumps in mining industry thanks to their flexible performance, suitability for wide range of applications and their ability to perform reliably across varied process conditions. They are required to handle solid-liquid mixtures with solid particles extending from fine sediments to large and coarse gravels.

For centrifugal pumps design, the Navier–Stokes equations are extensively used to predict fluid flow behaviour, to optimize energy transfer, and to improve efficiency by enabling accurate assessment of velocity profiles, pressure distribution, and force interactions. These equations consist of continuity and momentum conservation laws and are formulated as follows :

Momentum equations : $\rho\left[\frac{\partial \boldsymbol{V}}{\partial t}+(\boldsymbol{V}.\nabla)\boldsymbol{V}\right]= -\nabla p+\boldsymbol{F}+ \mu\nabla^2 \mathrm{V}$

Continuity equation : $\nabla.\mathbf{V}=0$


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Where :

- ρ : fluid density
- V : velocity vector
- t : time
- p : pressure
- $\nabla p$ : gradient of pressure
- F : body forces (gravitational weight ρg)
- μ : dynamic viscosity ($\nu = \frac{\mu}{\rho}$ : kinematic viscosity)
- $\nabla^2$V : Laplacian of velocity
- $\nabla.$V : Divergence of velocity

While Navier–Stokes equations are applied in CFD modelling (Computational Fluid Dynamics) for detailed flow simulations, Euler's equations provide a simplified approach for calculating pump performance during the design by linking the specific work and energy delivered to the fluid with the geometry of impeller and the velocity distribution.

It is essential to understand the velocity triangle in centrifugal pumps because it illustrates the different velocity components that govern how kinetic energy is transferred to the fluid. Velocity triangles enable designers to determine head, efficiency, and power requirements while ensuring that impeller vane angles are optimized for smooth fluid flow and reduced energy losses.

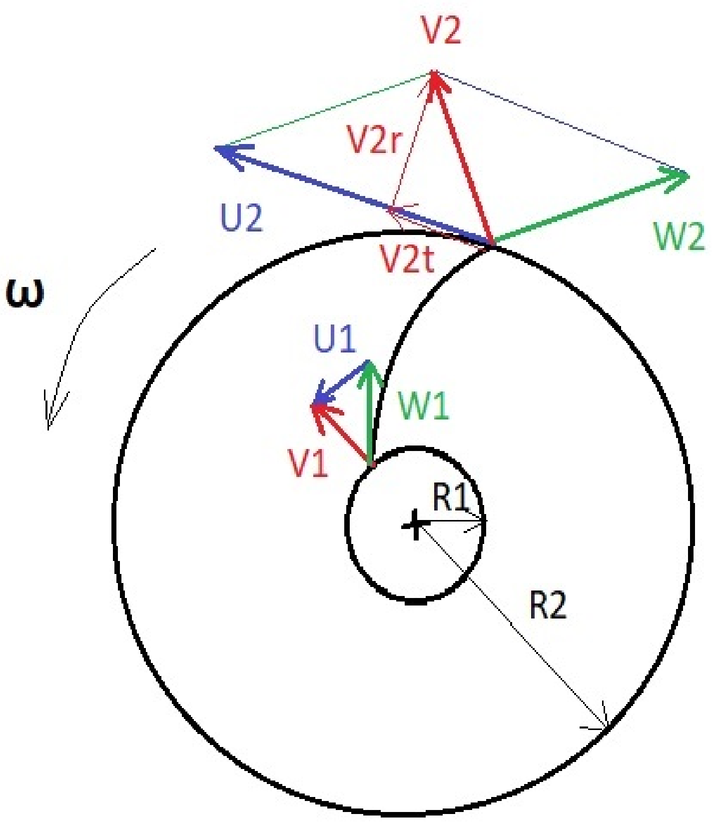


Fig. 1 Velocity Triangle for Centrifugal Pumps V = U + W


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Euler's equations for centrifugal pumps are formulated as follows :

Shaft torque : Tshaft = ρ*Q*(R2V2t – R1V1t)
Power : Pw = ρ*Q*(U2V2t – U1V1t)
Pump Head : H = (U2V2t – U1V1t)/g
The head formula can be simplified to H = U2V2t/g by assuming that the fluid enters the impeller radially, eliminating the inlet tangential velocity component (V1t = 0).

**Nomenclature**

ω : Angular Speed
R1 : Eye Radius (Inner Radius)
R2 : Outer Radius
U : Circumferential Velocity (U = R*ω)
U1 : Circumferential Velocity Inlet (U1 = R1*ω)
U2 : Circumferential Velocity Outlet (U2 = R2*ω)
W : Relative Velocity
W1 : Relative Velocity Inlet
W2 : Relative Velocity Outlet
V : Absolute Velocity
V1 : Absolute Velocity Inlet
V2 : Absolute Velocity Outlet
V1t : Tangential Component of Absolute Velocity Inlet
V1r : Radial Component Absolute Velocity Inlet
V2t : Tangential Component of Absolute Velocity Outlet
V2r : Radial Component Absolute Velocity Outlet
T : Torque
ρ : Fluid Density
Q : Volumetric Flow Rate
g : Gravitational Acceleration
Pw : Power
H : Head

Hydraulic Institute (ANSI/HI 12.1-12.6-2011) defines slurry as a mixture of solids with specific gravity typically greater than 1 in a liquid carrier, usually water. The pumps suitable for pumping this mixture are defined as slurry pumps [1].

Many scientific researches has been conducted to improve and developpe the performances of centrifugal pumps using numerical and experimental methods, advanced data acquisition, machine learning, and artificial intelligence techniques. Different results confirmed that design improvements, material upgrades and optimised operation can significantly enhance the efficiency, reduce running cost and extend service life [2]–[10].

Centrifugal slurry pumps exist in a wide range of materials and their selection is primarily guided by the operational conditions and the resulting performance impacts, as well as the type of wear caused by the handled product.

Because centrifugal slurry pumps experience significant wear over their operational lifetime, the geometry of pump's wet end can change substantially leading to altered pump performance and operating characteristics from the initial to advanced worn state. This highlights the importance to consider these factors when designing and selecting these machines.


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## II. Wear Mechanism & Wear Modes in Centrifugal Slurry Pumps

Wear refers to the deterioration of a solid surface, typically characterized by the progressive loss of material resulting from relative motion between the surface and a contacting substance. Wear mechanisms are generally categorized into mechanical, chemical and thermal, while wear modes are abrasive, adhesive, flow, fatigue, corrosive, melt and diffusive wear to describe and illustrate material degradation processes [11].

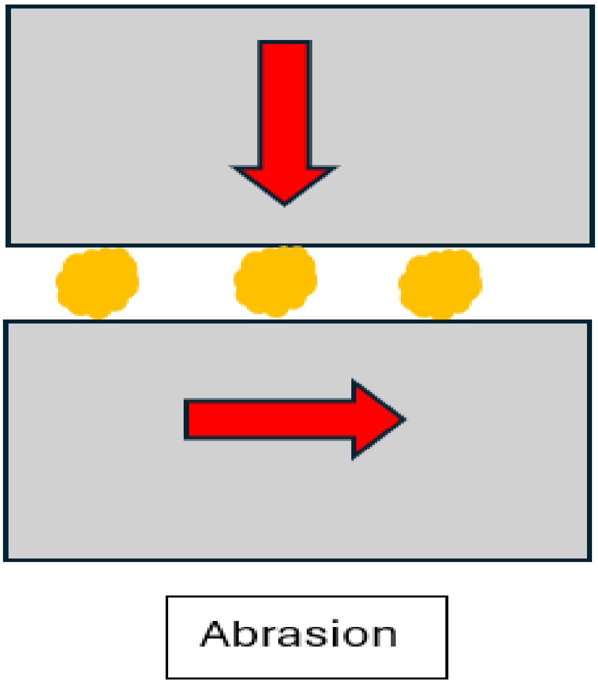


Fig. 2 Abrasion wear in slurry pumps

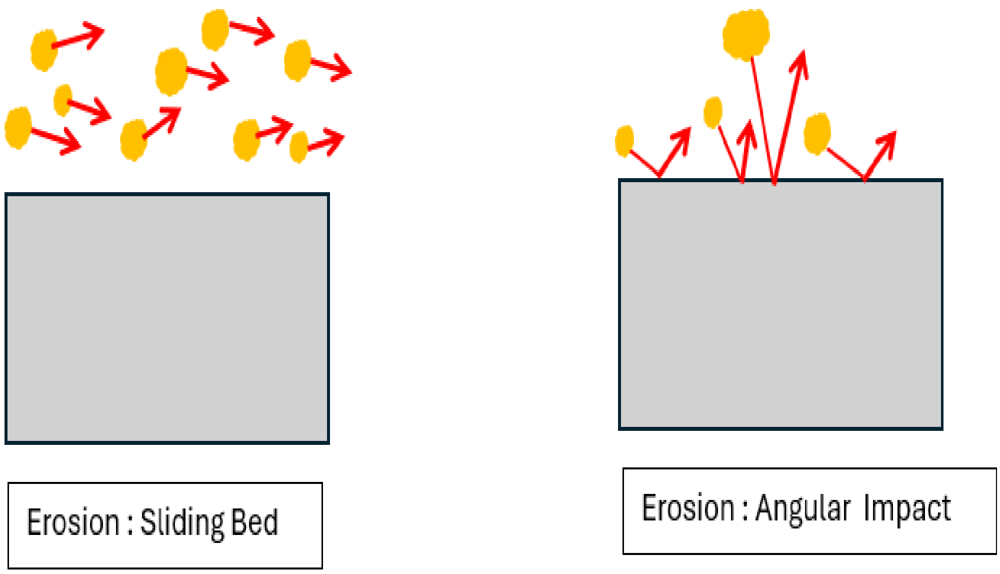


Fig. 3 Erosion wear in slurry pumps


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In centrifugal slurry pumps the dominant wear modes are Erosion and Abrasion with possibility of combination with Cavitation and Corrosion. During slurry pumps operation one or more of the wear modes can occur and affect the pumps components. These wear modes can be described as follow :

Erosion : It is a form of wear characterized by the removal of surface material as a result of kinetic energy transfer between particles entrained in the fluid and the eroded surface.

Abrasion : This wear process is generated when particles are driven in contact against a solid surface while maintaining relative motion with respect to that surface.

Cavitation : It is typically defined as the formation of cavities or vapour bubbles when the pressure of liquid has been reduced to its vapour pressure and that occurs where the liquid has been accelerated to high velocities.

Corrosion : It is the progressive degradation and decomposition of a material resulting from chemical and electrochemical reactions.

## III. Construction Material of Internal Hydraulic of Slurry Pumps

Material of construction for centrifugal pumps can include multitude of metallic, elastomer and composite materials. Care need to be taken for slurry pumps material selection due to presence of solids and sometimes combined with corrosive handled product and presence of air bubbles required in minerals processing such as flotation.

### *A. Metallic*

Metals and alloys used in centrifugal slurry pumps are selected for their high resistance to abrasion and corrosion. A wide range of High-Chrome White Iron is used for wet end part when abrasion is dominant while Duplex Stainless Steels are used when a combined resistance to abrasion and to chemical attack is required.

In their study Xie et al. [12] confirmed that material selection for slurry transport should be based on the dominant wear mode and operating conditions.

Robert and Dan [13] concluded that large particle impact wear affects significantly slurry pumps life, especially at impeller leading edges and volute cutwater. They deduct that hardness contributes to better wear resistance in metal alloys, but it can also make them more brittle. They found also that some materials perform differently under sliding versus impact wear, highlighting the need for application-specific selection.

### *B. Elastomer*

While metal alloys achieve wear resistance through microstructure matrix and hardness, elastomers wear resistance is primarily attributed to their resilience to absorb solid particles impacts.

Craig [14] deducted that rubber is preferable for fine particle slurries and that high chrome is better for coarse particles. He found also that wear performance is strongly influenced by impeller geometry and particle size.

The wear resistance of rubber lies in its resilience and its ability to absorb solid particles impact. Rubber deforms under load and re-transmits the majority of kinetic energy to the solid particles with negligible wear. The resilience of elastomers enables efficient energy restitution to the solid particles, inducing rebound with minimal wear and no permanent deformation. A range of parameters and factors need be considered when selecting elastomer for slurry pumps impeller and liners such as solid particle size, weight and shape, velocity, angle of impact and sliding wear, elastomer hardness and its physical properties, slurry temperature and chemical properties of carrier fluid.

Xie & Co [15] found in their study that all elastomers showed excellent resistance to small, rounded particles. Natural rubbers offer strong abrasion and erosion resistance but have comparatively poor resistance to hydrocarbons and solvents when compared to synthetic elastomers such as, Nitrile, Hypalon, and Butyl and Neoprene. In particular, nitrile demonstrated superior energy absorption and reduced surface stress compared with polyurethane. They found also [16] that elastomers and plastics outperform steels in resisting slurry-induced erosion, especially under conditions involving fine and rounded particles.

### *C. Ceramic*

Ceramic have high hardness and high wear resistance but their brittleness makes them unsuitable for most slurry pumps applications where impact resistance is critical. Due to this limitation, it is recommended to


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combine ceramics with other materials to form composite structures that enhance durability and performance of centrifugal slurry pump.

*D. Composite*

Composite materials offer enhanced performance by integrating the beneficial properties of distinct base materials, consequently using them in slurry pumps is strongly recommended to achieve even wear and durability.

Wang et al. [17] demonstrated the importance of developing composite materials with enhanced wear resistance as they offer superior strength, toughness, and higher resistance to wear. However, their fabrication is challenging because of materials physical and chemical compatibility, bonding issues and high cost of production.

## IV. SLURRY PUMPS HYDRAULIC DESIGN

In addition to wear resistant materials optimal selection for wet end parts, hydraulic design requires increased attention in slurry pumps development due the challenges of solid-liquid mixtures pumping. Particular attention must be given to excessive wear and clogging which are linked to internal velocities and turbulent flows.

Critical components for optimal hydraulic design are impeller (shape, size, number of vanes) and volute (shape, geometry, cutwater) in addition to the throat bush (suction) as it controls flow entry (inlet design) which is a key element design.

*A. Impeller Design*

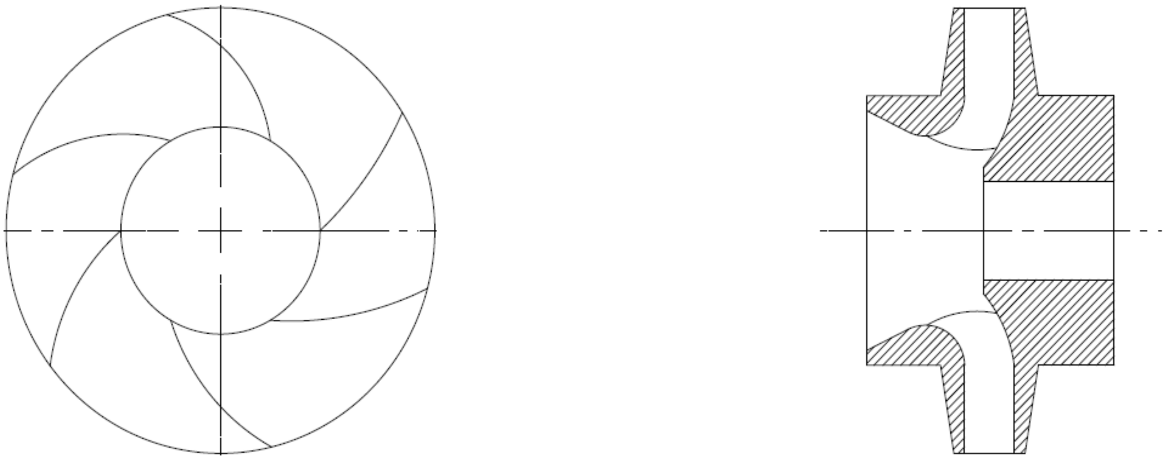

Fig. 4 Impeller

The impeller constitutes a key element in the operation of a centrifugal slurry pump as it transfers mechanical energy to the fluid. The design of a highly efficient impeller is just as crucial as maintaining its performance over time when handling abrasive slurry.

Peng et al. used computational fluid dynamics (CFD) and experimental validation in their study [18] to demonstrate that by improving impeller design they have achieved head and efficiency increase in addition to reduction of localised wear in critical areas.

The study of Wang et al. [2] provides a validated CFD-DEM framework for predicting and mitigating wear in slurry pumps as it offers practical design strategies to enhance pump durability and performance in slurries with high particle concentrations.

Cellek & Co found thar the number and geometry of impeller vanes significantly influence the pump's head and efficiency [19].

In slurry pumps, the impeller is continuously exposed to erosion, which accelerates surface degradation, causes a reduction in pump efficiency and considerable production losses. This highlights the importance of a


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proactive maintenance through wear prediction and condition monitoring using vibration-based diagnostics. Tse & Co. [20] have designed a prognostic method to evaluate impeller wear life and predict its Remaining Useful Life based on statistical data extracted from vibration signals collected during pumps operation.

### *B. Casing or Volute Design*

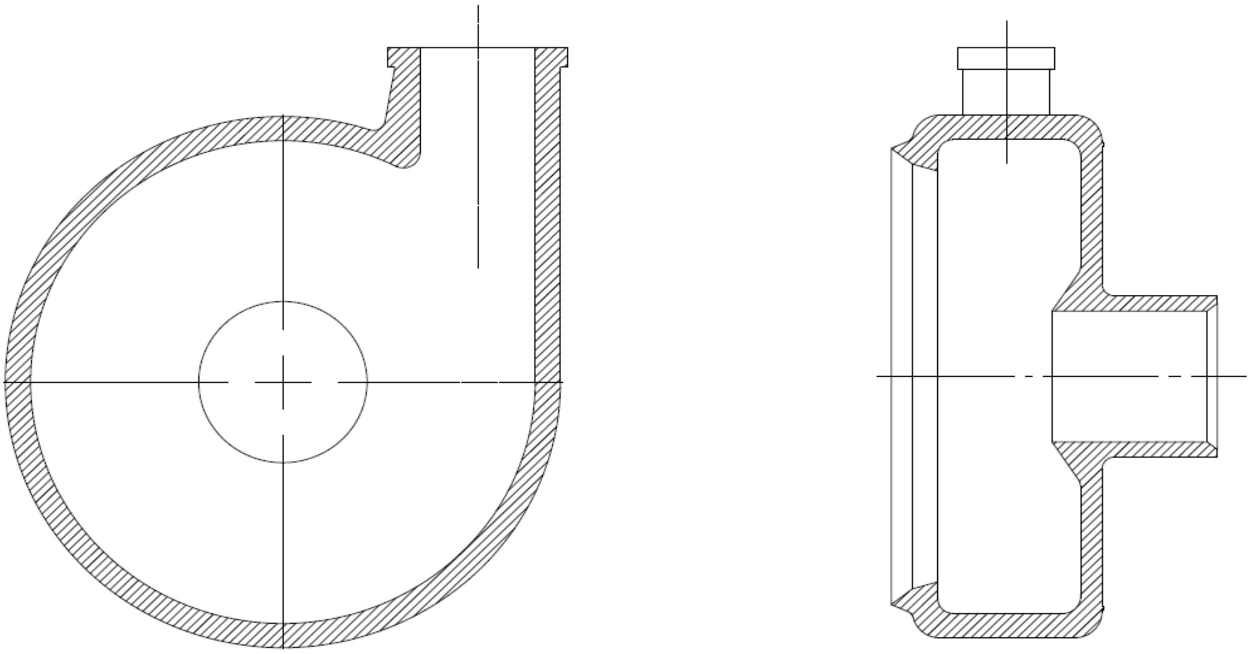

Fig. 5 Volute (Casing)

Pagalthivarthi et al. [21] conducted a study in which they confirmed the influence of casing or volute geometry such as volute width and cutwater (tongue) curvature on the pumps performance and wear pattern.

Alawadhi et al. [22] demonstrated that by using Response Surface Methodology (RSM) they were able to optimise the pump design to improve efficiency and reduce erosion rate. These results were achieved through optimization of key geometric parameters, including the number and shape of the vanes.

In their study Roudnev et al. [23] demonstrated the importance of using CFD simulations during the early design phases of slurry pumps to predict wear location, to support better pump design, longer service life, and lower maintenance costs.

## V. MAIN DESIGN PARAMETERS FOR SLURRY PUMPS :

The main design parameters and factors that need to be taken in consideration for design and selection of Centrifugal Slurry Pump are summarised as follow :

### *A. Applications and Handled Product Specifications*

Slurry pumps design and selection are based on type applications such as Hydraulic Transport, Mill Circuit, Flotation, Thickener UF and Leaching. Each of these applications involves different carrier fluids having distinct properties such as Chemical composition, PH level and Temperature.

The above mineral processing applications operate under distinct conditions using specific slurry characteristics and having critical parameters that guide the selection and design of centrifugal slurry pumps.

### *B. Particle size distribution, solids size, shape and abrasiveness*

Size and nature of solid particles such as hardness, abrasiveness, size, density, inertia and viscosity of solid liquid mixture, have a significant influence on wear in materials of construction in addition to alteration of pump performance. The abrasiveness of the particles in the slurry will determine the type of required pump with high wear-resistant components.


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Hao et al. in their study [24] demonstrated that larger particles tend to cause more severe wear due to higher inertia and slip velocity. Moreover, the wear is not even on all wet end components. This is also confirmed by Tarodiya & Co [25] who found that erosion varies along both the length and width of the pump casing due to differences in particles velocity, solids percentage by volume fraction and impact angles.

The particle size distribution in the slurry is a key parameter influencing slurry pumps selection, and careful consideration is required to determine whether the solid particles are widely graded sizing or closely graded sizing.

Deng et al. in their study [26] found that particles motion is governed by drag and collision forces, with pulsating transport and that at higher flow rates, the non-uniform transport of solid particles diminishes, resulting in steadier and more uniform particle transport.

This confirms that wear patterns are influenced by the operating point's position relative to the BEP (Best Efficiency Point), even when handling clear liquids, as high relative velocity gradients contribute significantly to increased erosion rates as demonstrated by Pokharel et al. in their study [27]. The presence of solid particles and air bubbles intensifies and accelerates the wear process and lead to pumps performance drop.

Kumar et al. [28] have observed that both the head and efficiency ratios depend not only on solid concentration but also on slurry properties and characteristics, as it was noticed that mixing fly ash with bottom ash slurry enhances head and efficiency of the centrifugal slurry pump.

are influenced not only by the solid concentration but also by the properties of the slurry as adding fly ash into bottom ash slurry enhances head and efficiency of the centrifugal slurry pump.

Wang et al. [29] found that coarse particles caused more fluctuation and turbulence in the flow and that optimal particle size selection contribute to minimizing wear and improving pump performance. Unfortunately, this is not always possible as the particle side distribution is dictated by the mineral processing application.

### *C. Solids concentration*

Higher concentration of solid particles leads to more particle interactions, thereby increasing the total surface area exposed to wear. Kumar et al. confirmed in their study [30] that increasing solids concentration by weight of silica sand in slurry mixture leads to a higher wear rate across various pump components, with the extent of wear varying by components such as impeller and casing independently of selected material for these components.

The solids concentration in the slurry will also affect the type of the required pump. If the concentration is high, Head and Efficiency Ratios need to be specified carefully for accurate pump design and selection to handle the thicker slurry. In their study Peng et al. [31] have used CFD validated by experimental results to prove that high solids concentration and large particles size significantly impacted hydraulic performance (lower head and lower efficiency) and increased wear.

The study of Macia et al. [32] confirmed that reducing solids concentration and average particle size D50, reduced considerably the energy consumption which reflects the trend that reducing solid content and particle size improves slurry head and efficiency (Head and Efficiency ratios closer to the value of 1).

In their study Makwana & Co [33] confirmed that various researchers have attempted to predict the pump performance by proposing the correlation for Head and Efficiency ratios and that these ratios are influenced by multiple factors, including solid concentration, solid specific gravity, slurry specific gravity, weighted mean or average particle size. Their study confirmed that for slurry centrifugal pumps, the increase in slurry concentration and solid particle size results in a reduction in both head and efficiency.

Patel et al. [3] showed in their study that increased slurry concentration and coarser solid particle size reduce pump efficiency and head, in addition to increase of power consumption.

### *D. Specific gravity of the slurry*

The slurry density will affect the pump's ability to lift the slurry. A higher slurry specific gravity, requires a higher de-rating and a higher energy to lift the slurry.

Pagalthivarthi et al. [34] have used CFD modelling to simulate dense slurry flow within pump casing, aiming to optimize design for reduced wear and enhanced performance.

Tarodiya & Co demonstrated in their study [35] that handling slurry by centrifugal pumps leads to decreased pump head and efficiency, while energy consumption increases proportionally with the slurry's specific gravity.


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They found also that performance degradation depends considerably on specific gravity of solids and on particle size and concentration.

*E. Flow rate and Head*

The volume flow rate of the slurry will determine the size of the pump required. Higher flow rates require a larger pump to handle the slurry or even few pumps in parallel might be needed.

The Total Dynamic Head of the slurry will determine the size of the pump required. Higher heads require a larger impeller diameter or even few pumps in series might be needed especially for hydraulic transport and tailing applications.

## VI. Centrifugal Slurry Pumps Selection Flowchart

Based on insights from various research studies and practical application reviews, the below flowchart has been developed as a reference tool and guideline for selecting centrifugal slurry pumps. Selection criteria include particle size and shape, fluid temperature, PH level, presence of oils, solvent or strong acids in addition to impeller tip speed.

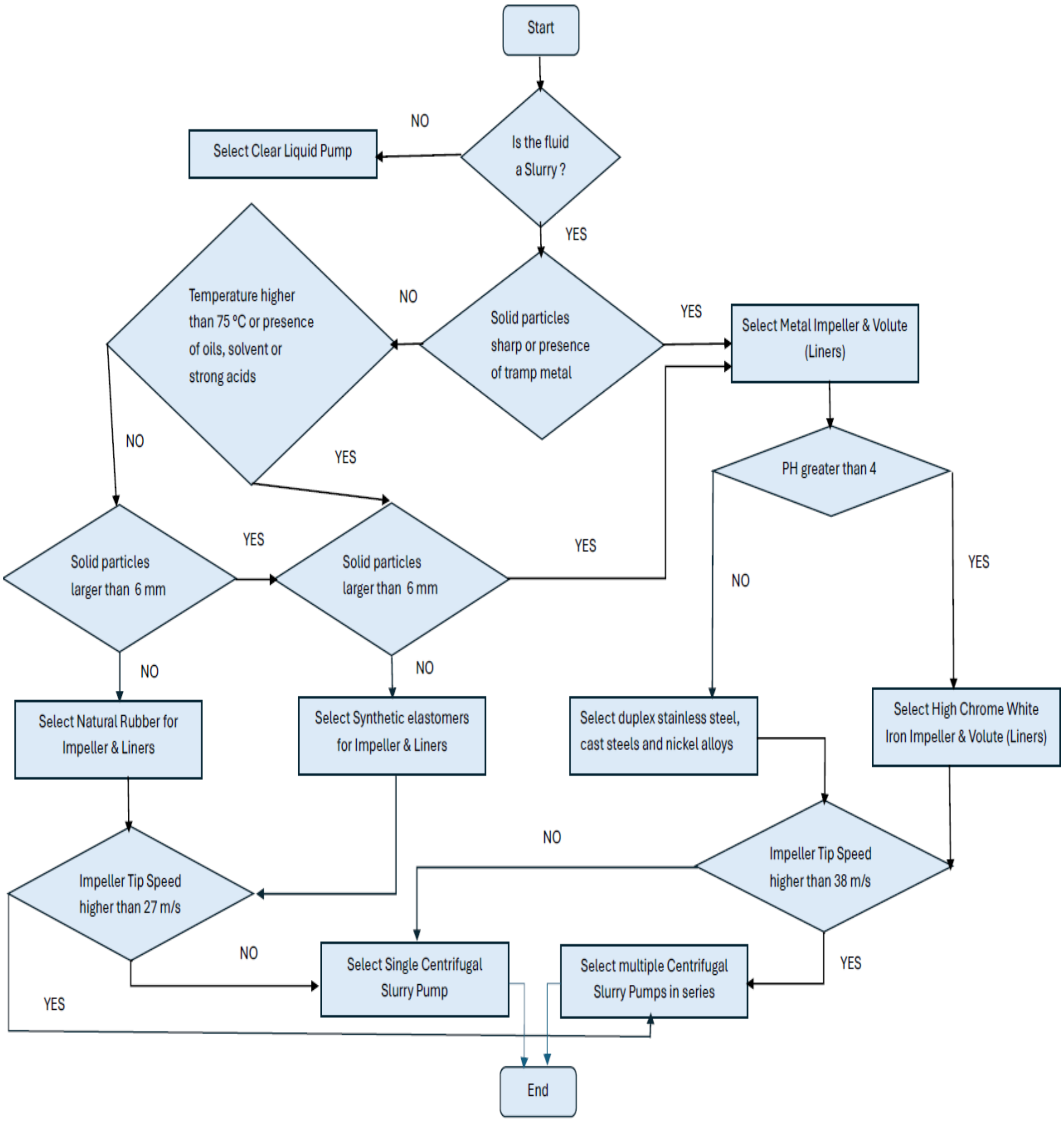


Fig. 6 Centrifugal slurry pumps selection flowchart


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## VII. CONCLUSIONS

In mining and wet mineral processing industry, the handled products by slurry pumps are process-driven, with the primary objectives being efficient liberation of valuable minerals from waste and maximizing recovery while minimizing energy consumption. As a result, slurry pumps are required to handle a wide range of slurry compositions across varying process conditions to comply with operational demands.

Wear phenomenon in centrifugal slurry pumps is correlated with fluid dynamics, abrasive particles interactions and behaviour, material properties, and operating conditions which is reflecting the depth of its complexity.

Researches and field experience in mining industry show that no single material nor hydraulic design can adequately address all challenges related to centrifugal slurry pumps. Therefore, addressing diverse applications and operational conditions requires a range of solutions, integrating customized hydraulic designs and combination of material selections.

Although the flowchart developed in this review is recommended for centrifugal slurry pump selection, future researches should focus on CFD simulations and advanced composite material technologies to improve predictive accuracy and optimize design for a sustainable mining industry

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