

A Review on Optimizing Centrifugal Pump Selection for Fixed Fire Water System: Performance and their Applications

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Abstract: *In this review article optimization of centrifugal pumps is studied as most of the conditions centrifugal pumps are operated under partial load and makes this study essential for the pump to operate under ideal conditions. Excess energy which is not utilised during operations is dissipated as vibrations and heat overall reducing the life of the pump itself. For fixed fire water systems, which are normally operated at huge volumes compared to domestic centrifugal pumps, as operated at reduced load, it makes initial pump investment of higher capacity than actually required capacity making as a huge investment. This makes studies related to optimization of these pumps an interesting area of research so conditions and performance improvement in such centrifugal pumps in fire application makes it ideal to reduce cost and operational efficiency when required . Optimization methods and techniques such as Turbulent Flow of Water Optimization (TFWO) algorithm, Reynolds Stress Models (RSM) , Large Eddy Simulation (LES), Shear Stress Transport (SST) , Detached Eddy Simulation (DES) along with CFD analysis and current integration of Artificial Intelligence (AI) and machine learning techniques in turbulent flow analysis were investigated in this article.*

Keywords: *Optimizing centrifugal pumps, Fixed fire water system, pump performance, centrifugal pump applications, Optimizing algorithm for pumps.*

1. INTRODUCTION

In this review, optimization of centrifugal pumps is essential for improving energy efficiency, operational reliability, and overall performance of the pump is studied . Optimization of the pump mostly depends on the guiding parameter such as operating the pump near its Best Efficiency Point (BEP), which significantly reduces energy consumption and mechanical stress. Common optimization methods such as impeller trimming, implementation of variable frequency drives (VFDs), and hydraulic system redesign are commonly employed to match pump output with system requirements. Also, minimizing head losses and integration of advanced monitoring and control systems facilitates real-time performance adjustments and long-term operational optimization. A centrifugal pump has been optimized by developing a mode of hydraulic loss based on the impellers (Rajesh, P et al.,2024). This model works on the functional relationship between impeller hydraulic losses and hydraulic efficiency, forming the basis for constructing an objective function. Hydraulic losses, primarily caused by flow separation, friction, and secondary flows within the impeller passages, are quantified as a function of key geometric and operational parameters. By expressing hydraulic efficiency as inversely proportional to these losses, the model enables systematic evaluation and optimization of impeller design (Wang et al., 2023).

Table 1. Showing types of fire fighting high pressure pump in market

S.no	Model	Flow rate (LPM)	Power (KW)	References
1.	Gorman-Rupp T Series	1,892 - 9,463 LPM	37.3 kW - 298.3 kW	grpumps
2.	Aurora 340 Series	757 - 11,356 LPM	22.4 kW - 223.7 kW	aurorapump
3.	Pentair Myers H Series	946 - 18,927 LPM	37.3 kW - 298.3 kW	Pentair aurora
4.	Firetrol FTA Series	1,892 - 13,248 LPM	37.3 kW - 186.4 kW	Firetrol pump
5.	Sundyne API 610	757 - 15,141 LPM	22.4 kW - 261.5 kW	Sundyne
6.	Peerless 8190 Series	1,892 - 5,678 LPM	55.9 kW - 111.8 kW	Peerless pumps
7.	KSB Etanorm Pumps	378 - 9,464 LPM	14.9 kW - 186.4 kW	KSB pump
8.	Xylem Goulds 3196	757 - 7,571 LPM	29.8 kW - 186.4 kW	Xylem pump

9.	Kirloskar KOS Series	757 - 9,463 LPM	14.9 kW - 186.4 kW	Kirloskar pumps
10.	Shakti Fire Fighting Pumps	378 - 7,571 LPM	11.2 kW - 149.1 kW	Shakti pumps
11.	Crompton Greaves GSP Series	1,136 - 11,356 LPM	18.6 kW - 261.5 kW	Crompton Greaves
12.	Texmo Fire Fighting Pumps	378 - 5,678 LPM	11.2 kW - 149.1 kW	Texmo
13	Sulzer Fire Fighting Pumps	946 - 18,927 LPM	37.3 kW - 373.5 kW	Sulzer India
14	BHEL Pumps	1,892 - 13,248 LPM	29.8 kW - 261.5 kW	BHEL
15	Atlas Copco Fire Pumps	757 - 9,464 LPM	18.6 kW - 223.7 kW	ATLAS India

1.1 Optimizing centrifugal pump

Meta-heuristic demonstrated to be performing superior optimization algorithms addressing both single and multi objective optimization limitations. These are used in selection of the optimal sizing of hybrid renewable microgrids. These algorithms are used to generate Pareto optimal solutions, which were used to represent various limitations between competing objectives. Single objective optimization addresses minimizing or maximizing a single objective function. Turbulent Flow of Water Optimization (TFWO) algorithm techniques were inspired by the natural phenomenon of whirlpools formed in water turbulence (Novara, D., & McNabola, A. (2021). The midpoint of the whirlpool functions as a suction region, drawing fluid around inwards due to centripetal force. This technique has been reported to have one of the fastest convergence rates among existing optimization algorithms. Neural Networks (NN) were integrated with FIS to optimize the pump performance which provides fault tolerance and adaptability of the system. These algorithms can be used in operational principle for VFD (Zwane, T et al., 2022). This works on the principle of varying the speed of the impeller by altering the voltage supplied to the motor; this variable AC voltage on demand helps to achieve VFD. These varying signals can be achieved using these algorithms. This system provides overall reduction in pump design and size and eventually helps in energy efficiency as centrifugal pumps are optimised to operate when there is a demand in the system.

1.2 The Fire Fighting High-Pressure Centrifugal Pump

High pressure centrifugal pumps are designed for fire fighting applications which are focused on sustained delivery of the fluid medium over the period of time at an elevated pressure. These pumps operate by the principle of centrifugal force which converts rotational energy from the motor to high pressure fluid flow as kinetic energy by the help of specifically designed impellers which helps to achieve high flow and head. Multi stage type centrifugal pumps are generally used in fire fighting applications which can generate 1000 Kpa to 2500 Kpa of pressure depending on the infrastructure they are deployed in. Centrifugal pumps of horizontal

or vertical split case end suction configuration were used. Multi stage impellers along with split case configuration, provide high pressure and head due to multiple impellers which generates high pressure at every stage.



Fig.1. Fire Fighting High-Pressure Centrifugal Pump (source : enggcyclopedia)

1.3 Optimization model

Optimization of a fixed fire station centrifugal pump is a critical parameter to operate in an effective manner preventing the fire accident. Effective minimizing models aims in minimizing energy consumption, reducing maintenance costs, maximizing the reliability of the fire safety system by rapid response and optimization based on fire levels and integrating smart sensor systems which regulate the water needed in specific areas when there is a crisis situation. The model also validates the critical factors such as flow rate, pump head, speed of the pump, pump input and maintenance intervals. Optimization of fire pump is focused on pump with flow rate or necessary head, it is also more focused on operation at BEP and able to deliver as per varying demand, key parameters such as impeller geometry, casing shape and CFD analysis which ensures the optimal performance of the system.

Table 2. Optimization Techniques in Fixed Fire Water System

S. no	Methodology	Definition	Optimized parameter	References
1.	Genetic Algorithm (GA)	Multi-objective optimization	Flow rate, head, power, maintenance interval, reliability	Kheirdast, A., et al. (2024)
2.	Particle Swarm Optimization (PSO)	optimal performance parameters	Pump speed, impeller diameter, efficiency	Kheirdast, A., et al. (2024)
3.	Linear/Nonlinear Programming (LP/NLP)	optimization for energy and cost	Energy input, operating cost, maintenance scheduling	Janus, T., et al. (2023).
4.	Multi-Objective Evolutionary Algorithm (MOEA)	Optimize trade-offs	Reliability, cost, energy use, redundancy level	Ni, Q., & Kang, X. (2023).

5.	Computational Fluid Dynamics (CFD)	Fluid dynamic optimization of pump geometry	Impeller shape, volute design, flow path	Kheirdast, A., et al. (2024)
6.	Life Cycle Cost Analysis (LCCA)	Economic optimization over the system's lifespan	Initial cost, operating cost, repair cost, downtime losses	Janus, T., et al. (2023).
7	Finite Element Analysis (FEA)	Structural optimization to minimize mechanical failure	Shaft alignment, bearing load, casing stress	Baranidharan, M et al (2022).
8.	Fuzzy Logic Control Optimization	Intelligent control	Start/stop thresholds, pressure control	Li, X., et al. (2020).

2. LITERATURE REVIEW

Reynolds-Averaged Navier–Stokes (RANS) model is the most commonly used approach for simulating turbulent flows. RANS models ignore certain parameters in the complex physical characteristics of turbulence and heat transfer, leading to the loss of critical information related to turbulent fluctuations. Researchers have proposed an alternative approach based on the partial averaging of turbulent fluctuation quantities (Yang, J et al., 2025). Unlike conventional statistical averaging techniques, this method employs a group averaging strategy. In fluid dynamics, machine learning models were used in the area of turbulence model research. With advancements in data analysis and prediction techniques such as artificial intelligence (AI), machine learning (ML) and deep learning (DL) techniques, large amounts of data are generated in turbulence analysis (Yadeta, L et al., 2023). These robust technologies are used to process complex fluid turbulence models to understand and predict the performance of the pump. Numerical simulations performed in this area provide significant research opportunities to further study and investigate the optimization techniques in centrifugal pumps. Decision support software was created to identify and aid designers selecting the most suitable configurations. These software process data specific to site requirements such as water flow rate and head based on site inputs providing a solution in selecting an optimised pump system which can be deployed. Low pressure regions normally observed at the leading edge of the impeller blades are vulnerable to the cavitation effect (Zhu, Y et al., 2023). Within the channel of the impeller, a pressure gradient is found providing higher pressure on the wheel side relative to the hub side. This pressure difference significantly leads to the increased loading on the outer edges of the inducer blades during operational conditions. Two-stage stochastic optimization models are used to determine energy efficient configurations for both centralized and decentralized booster pump stations in high-rise buildings . Models are validated using an available physical test rig incorporating system properties and topological decisions as constrained within the optimization framework.

The horizontal double suction pump is a centrifugal hydraulic device which is known for its efficient flow distribution and minimized hydraulic imbalance (Ni, Q., & Kang, X. 2023). These pumps work on the principle that fluid enters a semi-spiral inlet chamber, where it is flow of fluid divided and directed through dual intake pathways toward counter rotating impellers on both sides. The fluid is then accelerated by centrifugal force and discharged into the casing, generating high flow volume (Xu, M et al.,2025). Advantage of this type of pump is the symmetric axial force distribution, which enables the system to deliver approximately twice the volumetric flow rate compared to single-suction designs, while maintaining consistent head characteristics. The hydraulic reversibility of this machine allows it to function effectively as a water turbine, converting hydraulic energy back into mechanical power when operated in reverse flow conditions.

3. OPTIMIZING CENTRIFUGAL PUMP SELECTION

Optimizing the selection of a centrifugal pump requires the approach balancing the performance, efficiency, cost and reliability of the pumping system. The flow rate of the pump, fluid properties and pump head are the primary parameters to be determined before selection of the pump. A pump which operates at its BEP is an ideal choice for selecting an optimized centrifugal pump. This ensures the minimal losses, reduced vibration during operation and a longer life (Wuryanti, S., & Rizki, M. (2024). The choice of pump also depends on End suction which are commonly used centrifugal pump in industries, residential and commercial applications working principle of these pumps were the fluid entered horizontally towards the pump inlet suction and discharges vertically at desired velocity and pressure ensuring compact size, ease of installation and low cost maintenance , End suction pump provides balance in cost and efficiency which makes these kind of pump as a most reliable choice, split case is a type of centrifugal pump which provides medium to high head applications these pumps are designed by split opening partial horizontal casing allowing convenient access to internal components without impacting motor and piping system these pumps are ideally used in municipal water supply, HVAC application, fire protection pumping system, industrial cooling and power plant applications. Multi stage centrifugal pumps are the type of pump where 2 or more impellers are attached to a single motor shaft providing high pressure with moderate flow (Werbinska-Wojciechowska, S., & Rogowski, R. 2025). These kinds of pumps were used in high rise buildings, power plants such as boiler feed, and reverse osmosis (RO) plants. Vertical turbines typically work for underground wells and applications with high head; these pumps have bowl assemblies along with the impellers providing high flow high head over 100 meters depth creating high suction lift; these pumps are usually more expensive and complex than horizontal pumps . Depending on the application of flow and requirement using the software for optimal pump selection which are preferred accurately selecting based on performance curves, analyzing energy use and modelling installation constraints.

3.1 Turbulence Models

Turbulence models significantly impact the simulations using CFD analysis which is used to analyse and optimize the pump performance and efficiency. In a centrifugal pump flow of fluid medium occurs around the impellers and the diffuser causing high turbulence in those areas therefore turbulent models are important to identify the head efficiency, cavitation and

recirculation zones during the pumping operation. Reynolds-Averaged Navier–Stokes (RANS) equations were widely used for its simplicity and accuracy in predicting turbulent flow patterns (Zwane, T et al., 2022). The $k-\omega$ SST model is also a preferred model in turbulence analysis as it combines near wall accuracy for the flow with strong curvatures and pressure gradients which are common in impellers. Reynolds Stress Models (RSM) which were used to analyse anisotropic turbulence, and Large Eddy Simulation (LES) analysis were more accurate for transient flows inside the pump and unsteady flow pattern. Shear Stress Transport (SST) also known as $k-\omega$ (k-omega) model is considered more suitable considering accuracy and computational cost, particularly for identifying pumping losses, optimizing impeller blade geometry, and improving overall hydraulic efficiency of the centrifugal pump (Wasim, M. S et al., 2022). Hybrid models like Detached Eddy Simulation (DES) combine RANS and LES models for more accurate turbulent flow models using CFD analysis.

3.2 Cavitation Mechanism

Cavitation is a negative phenomenon where local pressure in a liquid drops below the vapour pressure inducing the formation of vapour bubbles. These kinds of bubbles diffuse when they move to higher pressure regions causing noise, vibration and pitting damage on the impellers reducing the performance of the pump (Rajesh, P., et al 2022). This cavitation effect causes intense local shock waves and high temperatures. Cavitation effect caused by reduction in net positive suction head required by the pump. Understanding the effect of cavitation and its effect is crucial for efficient operation of a centrifugal pump. These can be prevented by minimizing the fluid temperature, maintaining the unobstructed flow of the medium. Prolonged operation under cavitation conditions can result in surface degradation of the impellers causing the overflow over the components (Wang, C et al., 2023). This kind of damage is primarily initiated over the inlet side of the impeller blade and is strongly correlated with the length of the cavitation cavity. The extent of the weak cavitation stage is based on the characteristics of the cavitation hole. Unstable cavitation stage where length of the cavitation zone reaches around 65% of the impeller channel area resulting in alternating cavitation effect on both the working surface and posterior region of the impeller, this effect contributing to the unsteady flow of the impeller channel.



Fig.2. Damage of impeller by cavitation (source: Wu, K. et al., 2019)

Figure 2 shows damage caused by the cavitation effect on the pump impeller blades. Flaky cavitation effect is often associated with minor pulsation effects which causes low instability

which usually results in lower risk in impeller damage, cloudy cavitation effect may cause significant instability leading to intense oscillations which leads to a notable cavitation, which usually leads to mechanical damage and vibrations and operational difficulties (Müller, T. M. et al., 2020). Partial cavitation is another type of cavitation where vapour bubbles collapse on the aerofoil surface and supercavitation where the cavitation region extends downstream of the impeller blade. Vortex cavitation arises when a low pressure region arises inside the vortex core region experiencing strong shear forces along the fluid (Sallam, M. E et al., 2022). Longer cavity timelines and slower collapse rate of vapour bubbles leads to sustained formation of the vortices.

3.3 Centrifugal Pump Design Method

Centrifugal pumps used in firefighting issues are generally designed for dewatering purposes and these pumps are operated at very high velocity around 700 rpm which causes stress over pump casing making material selection an important parameter during the design of a pump for these kinds of applications. Materials such as cast iron and steel are used. These have high tensile strength and due to debris during pumping operation impeller blades are generally designed to withstand high stress and due to operation at high rpm even material like cast iron which are usually prone to rusting but due to high velocity reducing the risk of corrosion (T. Zwane et al., 2022). One dimensional models were generally used for performance analysis and prediction as this gave accurate results and these analyses based on geometrical data of pump and losses occurred in various parts of pump design. Numerical models were used with one-dimensional analysis, providing fast and reliable results (T. Zwane et al., 2022). Centrifugal pumps are vertically constructed with suction acting downwards, which are electromechanically interconnected. Impellers in the pump are the main objective for any centrifugal pump design as the impeller part is a core part of the pump functioning: the suction, pump head, cavitation of the pump, flow rate and efficiency of the pump depends on the impeller design. Impeller geometry is usually complex in nature due to twisted design and projections based on fluid dynamics which needs to be optimized by meshing in software such as ANSYS which makes CFD analysis of the impeller blades more effective and reliable.

3.4 Performance Monitoring

Pressure losses due to friction are simulated using experimental outcomes and data for the literature were used to model the pump impeller to evaluate the efficiency during operational conditions (Tim M. Müller et al., 2020). Maximum pressure of all smaller pumps, its pressure head below required pressure even connected in series, unable to meet the required demand which makes importance in evaluating the performance of the pumps. Varying the degrees of freedom in water pumps in the supply system indicates the decentralised pumping system which can lead to cost savings of 25% using a booster station when compared to an optimal parallel pump system (Tim M. Müller et al., 2020). The power curve with respect to CFD in simulative and experimental data tends to steadily increase in flow rate until the overload threshold is reached (Wang, W et al., 2020). When analysis is conducted with mesh having higher grid numbers pump performance shows a change of 0.024% in head and 0.011% in efficiency (Wang, W et al., 2020). Performance of centrifugal pumps is usually monitored using efficiency of operation and various simulations and CFD analysis were performed before actual prototypes were made and tested experimentally. Results of actual performance and simulation results were compared and in trial and error methods pump configurations will be improved.

4. APPLICATIONS OF OPTIMIZED CENTRIFUGAL PUMP SELECTION

Optimization of pump selection can be applied across various industries based on the application

And purpose leading to the improved system performance, efficiency, reliability and cost effectiveness. Power plants, oil refineries usually select a reliable pumping system with required back up for sustainable operation. Optimized centrifugal pump selection improves overall system performance, reduces life cycle costs, and supports long-term operational efficiency (Mostafa, M et al, 2024). AI powered centrifugal pumps offer environmental and economic advantages. These types of pumps regulate and monitor energy consumption, reducing and optimizing the peak demand period. These pumps provide in-situ monitoring by finding and fixing the various malfunctions and identifying the preventive maintenance indications before actual damage occurs (Medina, R. et al 2022). This type of system analyzes large amounts of data to monitor, prevent and predict future failure of the system. These systems can be deployed with advanced algorithms such as Adaptive Neuro-Fuzzy Inference System (ANFIS), integrating with the Artificial Neural Networks (ANN). The reasoning methodology of Fuzzy Inference Systems (FIS). ANFIS helps to identify dynamic system behavior, high adaptability, and rapid development processes.

4.1 Energy Savings

When it comes to energy saving the primary criteria is to understand the application and provide proper sizing of pumps based on flow rate and head as a deciding parameter. Pumps with variable speed drives are usually preferred, these pumps adjust the RPM based on the demand providing variable flow rate eventually reducing the overall power consumption. Optimizing the pumping system design is another key parameter when it comes to improving pump performance mainly by reducing frictional losses and reducing throttling. Pump maintenance also plays a vital role in energy savings by regular inspection checking worn out parts and checking clogging of pumps which saves most of energy and overall pump efficiency (Ma, Q et al., 2022). Keeping up with the technology is also important to reduce energy consumption, modern high efficient pumps often operate at lower energy consumption with high discharge compared to conventional pumps. Optimizing system pressure also plays an important role in the energy efficiency of pumps. Providing pressure relief valves reducing the building up of excessive pressure over the pump operation also plays a significant role in energy reduction. Monitoring the pump and setting governing parameters to ensure the pump operates at optimal conditions helps in identifying the problems during operation itself to eliminate the causes. Providing high energy savings, followed by a data analysis of those collected data during operation helps in understanding the variation and providing the necessary corrective measures (Liu, H et al., 2023). VFD models are currently used widely; these types of pump models provide a reduction in 25% of energy consumption enhancing the efficiency compared to conventional models. VFD are cost-effective, reliable and provide precision in applying to the pumping system. These models are also available in AC and DC and VFD is achieved by integrating AC-AC conversion and DC-DC conversion module to the motor which helps in varying the voltages to desired levels to achieve variable speed of the

impeller (Li, R et al., 2025). These systems support seamless integration across various operating RPM. VFDs not only facilitate variable RPM control but also improve motor performance by reducing current during pump startup and enhancing the overall power factor.

4.2 Reduced Maintenance Costs

Reducing the maintenance costs involves incorporating several practices, equipment upgrades and operational improvements (Guo, T et al., 2025). Preventive maintenance schedule includes regular inspections, lubrication for the required equipment, seal and gasket checks. Condition monitoring includes vibration analysis of the pumping system, thermography which detects overheating of the pumping system. Flow and pressure monitoring which indicates the internal wear and tear of the pump parts and blockages (Ji, Y et al., 2023). Training the operator ensures to operate the pump smoothly and identify early detection of failure. Documentation and implementation of standard operating procedures significantly reduces failure and maintenance expenses. Pump casing and impeller made from corrosion resistant alloys such as stainless steel alloys or bronze increases the lifespan of the pump. Using mechanical seals from traditional packing methods reduces the maintenance cost. Another key important method is prevention or avoiding the dry run, integrating the sensor system which shuts down automatically during the dry run avoiding the pump failure (Hong, D et al., 2024). Optimizing and correct sizing improves the pump function reducing the cost and energy efficiency.

4.3 Increased System Reliability

Redundant systems such as installation of jockey pumps to maintain the pressure and reduce main pump wear. Fire station pumps also need to be using backup power sources to operate during power failures. Ensuring the pump size correctly based on the fire protection system demand. Ensuring the alignment and installation of pumps also provides increased system reliability. Automatic controllers which were used to autostart during the emergency, also sensors to detect temperature, pressure and flow rate ensuring the increased system reliability. Compliance with standards such as NFPA 20 and NFPA 25 (Standard for the Installation of Stationary Pumps for Fire Protection) provides necessary guidelines and procedures for pump installation for fire protection ensuring the reliability of the system. According to incident reports of NEPA pump failure, it is considered to be a critical failure therefore ensuring its proper operation especially in aging infrastructure, is crucial, which involves public life and damage to the property (Ghali, G et al., 2022). Factors influencing the reliability include mechanical and hydraulic issues such as impeller erosion, cavitation, seal failures, shaft misalignment, bearing degradation, wear due to insufficient lubrication or wear due to dry operation. Electrical and power failures due to power improper backup, malfunctioning of controllers and sensors used in fire systems, battery or generator failure based on the fire system. Environmental and operational stress includes corrosion, scheduled operation and maintenance which reduces stiffness and blockages, fluctuating water supply pressure (Fan, Y et al., 2024). Human factors and non compliance of the standard protocols.

4.4 Wastewater Treatment Plants

Application of centrifugal pumps in waste water treatment plants is important, as pumps are used in moving water and sludge removal at various stages. When it comes to waste water treatment often classified as Effluent treatment plant (ETP) and sewage treatment plant (STP) configuration and material selection may be different based on the water quality where ETP needs more corrosion protection as it usually contains corrosive substances. STP needs pumps

designed to operate without blockages or sludge handling capabilities (Ji, Y et al.,2023).. Influent pumping stations involved in pumping of sewage from low lying areas to treatment facilities. In primary treatment centrifugal pumps were used to transfer waste water in sedimentation tanks. In the secondary treatment process centrifugal pumps are commonly used to pump water through biological treatment processes, followed by specialized designed centrifugal pumps for sludge handling. Centrifugal pump for sludge handling involves specific requirements as this involves pumping of high viscosity, solid contents and abrasive in nature of those sludge materials. Non clog impellers such as semi open, vortex or channel impellers were used. Large passage sizes typically more than 3 inches were used for sewage sludge. Material selection is important in such applications materials such as hard iron, stainless steel and pumps with rubber lining or ceramic coating were used.(Ali, A et al.,2021), As sludge is usually non newtonian fluid, the shear effect may be lower therefore viscosity of the sludge increases with the concentration of the sludge therefore pumps with high torque will be recommended in these applications. Submersible pumps are often used in underground or confined environments. Variable frequency drives were used to optimize the performance and reduce energy consumption.

5. CHALLENGES AND RESEARCH GAP

Selecting centrifugal pumps for a fixed fire water system involves several challenges. These systems require the pumping unit which should operate at emergency or critical conditions reliable to start as normal operation but lack of inactivity for long periods may cause challenges during operational conditions. Therefore reliable operation and immediate start of the system is considered to be an important parameter. Designers usually consider the factor of safety. Overdesigning the fire pumping system with a higher rating to provide sufficient flow and pressure during demand often leads to inefficiencies and hydraulic instability subsequently undersizing of the fire pumping unit causes system failure during emergency(Abbassi, R., & Saidi, S. 2024). Lack of real time data for these applications limits validation of the performance of these pumps and matching the required Net Positive Suction Head Available (NPSHa) with the pump's requirements under variable site conditions. Research on environmental factors and parameters such as space constraints and corrosion of the pumping unit from stagnant water pose additional risks and challenges where researchers can work to overcome these constraints . Research gaps exist in areas such as modeling pump degradation over time during inactivity, understanding dynamic behavior during transients of fluid mediums, and developing predictive maintenance protocols using smart monitoring technologies such as internet of things (IOT) and artificial intelligence (AI). Standardized testing protocols may not actually consider real-life operational conditions and stresses and challenges to overcome during a crisis. Investigating these challenges through field-based studies followed by the simulation, and intelligent monitoring could lead to more reliable and efficient fire protection systems.

6. CONCLUSION AND FUTURE WORK

In conclusion this review article provides a structured approach in selection and optimization of fixed fire centrifugal pumps and water systems. Discussions on key parameters such as head, flow rate, efficiency and performance of various pump types and selection techniques were studied and found split type with multi blade impeller cut suction provides high water discharge achieving required pressure and head which is suitable for fire applications. Various optimizing

algorithms used in turbulent flow analysis and optimising pump operational conditions were discussed where hybrid models namely DES which combine RANS and LES models for more accurate turbulent flow models using CFD analysis were found to be effective compared to available models. In fire safety application selection of the hydraulic system and its compliance towards standards such as NFPA 20 and NFPA 25 were studied. Right pump sizing and available pumps and various optimizing algorithms were studied and tabulated which can be used depending on applications and conditions considering various infrastructural and operational parameters. Operational reliability and cost analysis were also discussed. Damage and cavitation effects and types of various cavitation effects on impeller blades and reduction of cavitation mechanisms were discussed and found effective methods such as minimizing the fluid temperature, maintaining the unobstructed flow of the medium helps significantly in cavitation reduction. Energy efficiency and optimising the pump performance based on energy efficiency were discussed and found selection of correct pump sizing with providing pressure relief valves, reducing building up of excessive pressure over the pump operation were the parameters to be monitored for efficient functioning of the pump. Other water applications of centrifugal pumps such as waste water treatment and sludge removal were also discussed in this article. Future research focuses on data collection and during real time operational conditions to optimize the centrifugal pump along with developing predictive maintenance protocols using smart monitoring technologies such as internet of things (IOT) and artificial intelligence (AI) having an area of interest for the researchers to further research in this area.

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