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SELF-PRIMING CENTRIFUGAL CHEMICAL PUMPS: A REVIEW

Samuel Chukwudi Okafor

Department of Mechanical Engineering, University of Port-Harcourt, Nigeria

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Abstract: This paper gives a thorough examination of the literature of self-priming centrifugal chemical pumps, focusing on their design, operational principles, and applications in various industries. They render surpassing advantages, including improved efficiency in handling liquids containing air or gas, and reduced maintenance requirements. The paper analyzes the fundamental mechanisms that enable self-priming capabilities, including positive displacement elements and impeller design. An analysis of different self-priming centrifugal pump innovations is presented, emphasizing developments in materials and engineering that improve performance and reliability. Examines and also illustrate the practical applications of these pumps in food and beverage processing, chemical processing, wastewater management, and other sectors. Furthermore, the review reveals current challenges and future directions for research, such as development of more energy-efficient designs and innovations in smart pump technologies. This paper serves as a helpful resource for researchers, practitioners and engineers seeking to optimize the use of self-priming centrifugal pumps in the industry for aquous chemicals and other hazardous liquid applications.

Keywords: Self-priming; Centrifugal pumps; Chemical Pumps; Self-priming mechanisms; displacement elements.

Introduction

Pumps are devices that are used to move fluid (liquid or slurry) from one point to another by mechanical action commonly driven by steam turbines, diesel engines or electric motors. They are categorized as dynamic and positive displacement pumps. Whereas positive displacement pumps move a liquid by repeatedly enclosing a fixed volume and moving it mechanically through the system, Dynamic pumps impart velocity and pressure to the liquid as it moves past or through the impeller and subsequently, convert some of that velocity into additional pressure [1]. Centrifugal pumps are of the Dynamic category and are the most used pumps in the world. Mostly used in the industry to move aqueous chemicals from one point to the other due to their proven reliability, energy efficiency, smooth flow, low maintenance and corrosion resistance.

A pump is regarded as self-priming if it can evacuate air from the suction side at start up before commencing its pumping mode. As the pump evacuates air from the suction side, liquid is forced into the suction line by the pressure of the surrounding air. The self-priming process occurs automatically once the pump is started with the initial quantity of liquid. Without operator involvement, the pump can prime itself with the liquid and begin pumping. If vacuum is broken, the pump is able to re-prime and continue pumping.

Self-priming centrifugal chemical pumps are indispensable equipment in industrial applications as they are mostly used in water treatment, pharmaceuticals, chemical processing, food and beverage production, providing effective and efficient fluid transfer solutions [2]. They are made to automatically remove entrained air from their casing, creating a vacuum that allows them to pull liquid without the need for priming manually [3]. This design and capability greatly enhance efficient operations and reduces downtime, making self-priming pumps very attractive option for many fluid handling operations and applications. Again, self-priming centrifugal chemical pumps' ability to handle diverse range of liquids, from water-like fluids to more complex chemical and mixtures, makes them indispensable in applications where reliability and safety are prioritized. Contemporary designs and advanced materials of construction has further improved their reliability and resilience against corrosion and wear, mitigating to the barest minima specific challenges posed by aggressive chemicals.

A common design on self-priming centrifugal pump has two phases of operation: priming mode and pumping mode. In its priming mode, the pump essentially acts as a liquid-ring pump. The rotating impeller generates a vacuum at the eye of the impeller which draws air into the pump from the suction line. At the same time, it also creates a cylindrical ring of liquid on the inside of the pump casing [4]. This effectively forms an air-tight seal, stopping air returning from the discharge line to the suction line. Air bubbles are trapped in the liquid within the impeller's vanes and are transported to the discharge port. There, the air is expelled and the liquid returns under gravity to the reservoir in the pump housing [2]. Gradually, liquid rises up the suction line as it is evacuated. This process continues until liquid replaces all the air in the suction piping and the pump. At this stage, the normal pumping mode commences, and liquid is discharged. When the pump is shut off, the design of the priming chamber ensures that enough liquid is retained so that the pump can self-prime for the next occasion it is to be used. Thus, for a centrifugal pump that has not been in use for a while, it is important to check for losses from the casing due to leaks or evaporation before starting it. Figure 1 is a Self-Priming Centrifugal Pump and sectioned view of its pump casing.

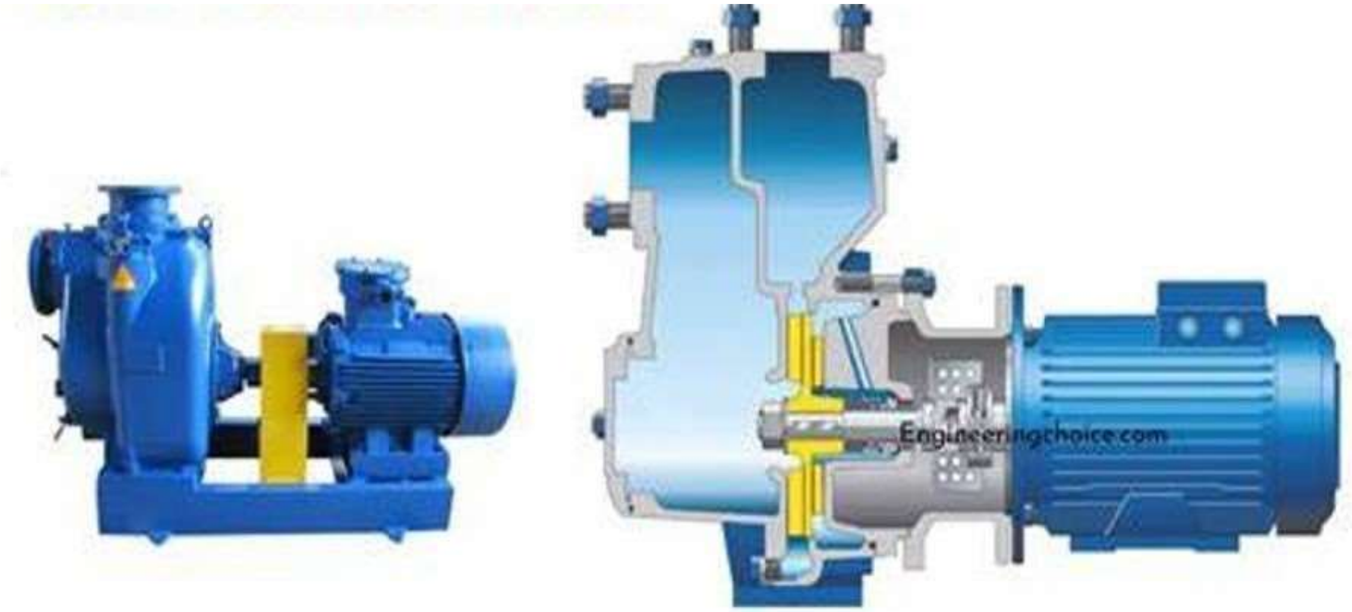

Figure 1. Self-Priming Centrifugal Pump and sectioned view of its Casing [5].

There are several benefits to a self-priming centrifugal pump. Firstly, is getting the pump running and up to full speed. Rather than manually priming the pump and ensuring it is completely filled with water (chemical as in the case centrifugal chemical pump), the pump can be run with some air and water mixed together. This gets the pump up to speed quicker, though it is important to note that there must be some liquid in the pump; it should never be started completely dry. The wide variety of materials a self-priming pump can handle is also a distinct advantage. Self-priming pumps do well with corrosive fluids and slurries. Another advantage of the self-priming pump is the ability to pump fluid while the pump is not submerged. This allows greater flexibility than a submersible pump that has to stay underwater to stay primed and function correctly [6]. Again, self-priming pumps can handle a variety of liquids, work well with slurries, corrosive liquids, and suspended solids. Ideal for frequent and intermittent pumping operations, as the steps involving pump priming on start-up are eliminated.

This review is aimed at providing a thorough overview of self-priming centrifugal chemical pumps, encompassing their design principles, operational mechanisms, and outstanding advantages. Thus, the research is categorized into key areas, such as self-priming mechanisms, application of self-priming centrifugal chemical pumps in the industry and challenges/limitations of self-priming centrifugal chemical pumps. This work will throw more light on the current state of knowledge in the field of self-priming centrifugal chemical pumps. It will further identify gaps in the literature and propose potential avenues for future research, with a drive to contributing to the ongoing development in the area of self-priming centrifugal chemical pumps' technology. Various configurations and technologies that have emerged in recent years will be explored, along with their performance characteristics and suitability for different applications. Additionally, the review will highlight challenges associated with self-priming pumps, such as efficiency losses during operation and limitations in handling certain fluids, while also discussing potential solutions and innovations. The work will further analyze recent research and developments in the field of self-priming centrifugal chemical pumps, emphasizing innovations in pump design, materials science, and control systems. By consolidating existing knowledge and identifying trends, this review seeks to serve as a helpful resource for researchers, engineers, and professionals in the industry looking to enhance their understanding of self-priming centrifugal chemical pumps and their applications in modern industrial processes

There is substantial literature surrounding self-priming centrifugal pumps which goes across a wide range of topics such as design principles, operational characteristics, performance metrics, and material of construction. Studies have addressed diverse aspects of these self-priming centrifugal chemical pumps, including the impact of design modifications on performance and advancements in materials technology to improve corrosion resistance. Though, an extensive body of research has been made, there is a need for a thorough review that will harmonize these findings, challenges, and future course in the development of self-priming centrifugal chemical pumps.

2.0 Self-priming Centrifugal Chemical Pumps' Indispensability in the Chemical Industry

Self-priming pumps have been providing economical and reliable service to their owners in the industry for many years. They offer an alternative to vertical or submersible pumps in sump applications, and can help where overhead space is limited and can be found in virtually every industry, from farms to petrochemicals [2]. They solve the very basic problem of how to get liquid to the pump. The process of self-priming occurs automatically once the pump is started with the initial quantity of liquid. Without operator involvement, the pump primes itself with the liquid to be transferred and begin pumping. If vacuum is broken, the pump is able to reprime and continue pumping. The savings in time, effort and cost are substantial, especially in dewatering applications such as in mining where pumps often run dry for brief periods.

Self-priming centrifugal chemical pumps are essential in various industries due to their unique ability to handle fluids containing gases or air without requiring manual priming. Their indispensable advantages include:

i. Efficiency: They can quickly start pumping without lengthy setup, saving time and reducing operational costs through prompt delivery and reduced energy consumption.

ii. Versatility: Suitable for handling a wide range of corrosive and viscous chemicals, making them ideal for chemical processing, wastewater treatment, mining applications, food and beverage processing, pharmaceutical biochemicals, and cooling systems.

iii. Reliability: Designed to maintain consistent performance even in challenging conditions including fluctuating flow scenarios and reducing the risk of downtime.

iv. Safety of personnel, equipment and the environment: Minimize the risk of spills and leaks by efficiently managing chemical transfer.

On the whole, self-priming centrifugal chemical pumps play a significant role in improving productivity and safety of equipment, personnel and environment in industrial operations.

Numerical study on hydraulic and self-priming performance of a new double-stage self-priming pump was proposed. The performance prediction and flow analysis carried out using Computational Fluid Dynamics method [7]. From the findings, two-stage form in high-head self-priming pump can optimize the design parameters of each impeller through rational redistribution of head despite the structure and its complexity. The designed impellers and matching structures between hydraulic components in the study achieved a good result in the application and also met the requirements for the work. The agreement between simulation results and experimental data confirmed that optimization with Computational Fluid Dynamics method in complex structural self-priming pump was practicable. Under the design flow rate of 370 m3/h, the result from CFD method and experiment obtained minimum error, which was 8% in head and 5% in efficiency. Unsteady two-phase simulation can effectively reveal the mixing and separating process of air and water after start-up. The correlation between void fraction and generation of vortex in the impeller inner flow field was presented. The air void fraction reached 9.7% and 4.7% respectively in two impellers at some time of the early stage. In first impeller, the increase of air void fraction and deterioration on performance ability change steadily. Whereas in second impeller, the performance ability and air void fraction were influenced by the condition of first impeller which showed a more complex fluctuation.

3.0 Self-Priming Mechanisms

Self-priming mechanism in a pump allows the pump to draw liquid into itself and develop the necessary pressure to trigger flow without requiring external or manual priming methods. This feature is particularly useful for applications where the pump may be located above the liquid source and where it is not practical to fill the pump with liquid promptly. Self-Priming Mechanisms features include special pump casing and impeller designs that help create vacuum to draw liquid into the pump. They can hold some amount of fluid to facilitate the priming process [8]. Their Priming process is such that when the pump is started, air within the pump is expelled, and liquid is drawn in. Designed to allow the pump to handle both air and liquid, making it effective in situations where the pump may encounter a mix of air and liquid. Once the pump is primed, self-priming pumps can operate continuously without needing to be re-primed, even if there occurs fluctuation in the liquid level.

Centrifugal pumps are traditionally not self-priming. Thus, it is normal that the pump casing is filled with the liquid before starting. However, there are contemporary designs where centrifugal pumps are self-priming using specific designs and mechanisms that enable centrifugal pumps to achieve self-priming capability.

3.1 Types of Self-Priming Mechanisms

A number of self-priming mechanisms exist in the pump manufacturing industry and as it suits the designer. These include:

i. Check valves or back flow preventers: Addition of a check valve or back flow preventer being placed at the bottom of the suction pipework ensuring that the pump casing is filled with water on startup. Thus, prevent the liquid from draining out of the suction pipework.

ii. Positive Displacement Element: Some self-priming centrifugal pumps often integrate a positive displacement element, which include diaphragms as in diaphragm pumps, set of impellers or a small chamber that can capture a certain amount of liquid. This captured liquid is pushed into the pump's suction line to help establish a vacuum that pulls more liquid when the pump starts.

iii. Vortex Chambers: Some self-priming pumps are incorporated with a vortex chamber, that helps in developing a low-pressure region that enables pulling liquid into the pump. This is so made to ensure that air is separated from the fluid, assisting in the priming process.

iv. Special Impeller Design: Some self-priming centrifugal pumps employ uniquely shaped impellers that are so designed to move liquid and air together, thus enhancing the pump's capability to self-prime by collapsing the air bubbles as while as creating a flow of liquid.

v. Air Separation Devices: Some self-priming pumps use air separation mechanism to remove trapped air. They are specific mechanism that aid in venting the system or separators that help in expelling air from the pump as the liquid enters the casing. vi. Built-in Priming Pump: There are self-priming centrifugal pumps designed with builtin priming pump, which operates briefly to fill the main pump casing with liquid before transiting to the normal pumping mode.

vii. Dual Impeller Configuration; Some self-priming pumps adopt dual impeller configuration in a design where one impeller is responsible for pumping, while the other assists in creating a priming effect by pumping air and liquid, assisting to create a liquid column.

On the basis of ensuring that the self-priming mechanism of a self-priming pump is consistent, a visual self-priming pump experimental bench was constructed. The flow pattern of the gas–liquid two-phase flow in the pump during the self-priming process under different structures was captured by changing the location and diameter of the reflux hole of the experimental pump and the influence rule and mechanism of the reflux hole on the functionality of the self-priming pump were unfolded [9]. It was a study that provides clear advice and experimental support for the selection of reflux hole position and diameter in the design process of self-priming pumps. The following explicit conclusions were drawn: The research fully proved that the change of the reflux hole structure parameters affects the self-priming performance of the self-priming pump by affecting the gas–liquid two-phase backflow rate during the self-priming process. Again, for the fact that the outlet of the volute was not vertically upward, there was a lateral component velocity when liquid flowed out of the volute, which led to fluctuating distribution of the pump body velocity. Therefore, the reflux hole in different positions will lead to change of gas–liquid two phase back flow rate in the pump chamber, thereby affecting the self-priming pump performance. It was revealed that, the self-priming performance was best when reflux hole was at +15°, and worst when reflux hole was at −30°. In addition, the area of the reflux hole mainly affected the formation of the backflow gas–liquid mixture in the pump. The self-priming time of the centrifugal pump first decreased and then increased with the increase of the area of the reflux hole; an overwhelming large reflux hole increased the gas flow back, while a minimal reflux hole limited the liquid flow back hole. The highest diameter of the reflux hole is 10mm in the study.

It was observed that with an increase in the impeller trim quantity, the maximum efficiency point of a two-stage self-priming pump moves to the small flow rate condition a hydraulic performance and self-priming experiment was carried out numerically [10]. The unsteady performances of pressure fluctuation and radial force in the pump were also analyzed at the same time. When the two stages of impellers were trimmed by 6%, head of the pump dropped by 13%, and efficiency of the pump decreases by only 1.69 percentage points, while the high-efficiency region was still relatively wide under the design flow rate. Therefore, the two-stage self-priming centrifugal pump in the head range of 94 to 107meters can meet the operating requirements using impeller trim. But with an increase in impeller trim quantity, the radial forces on the wall of radial guide vane and volute were smaller, and the pressure fluctuation in the positive guide-vane outlet flow channel of radial guide vane and the volute flow channel was smaller. Under the design flow rate, when the impeller outlet diameter trims by 6%, the radial forces on the wall of radial guide vane and volute dropped by 70% and 12.8% each. The monitoring point pressures in the radial guide vane and that in volute reduced by 14.2% and 8.4% each. And the pressure fluctuation coefficients reduced by 9.1% and 25% each. The gaps between the first-stage impeller and the radial guide vane, and the second-stage impeller and the volute increased with the increase in the impeller trim quantity. The self-priming time increases when the self-priming height is 4m. The self-priming time of the pump increased by 27seconds after the two stages of impellers were trimmed by 6% each.

The self-priming process of a centrifugal pump with double blades was numerically and experimentally investigated. One of the findings presented was that the self-priming process is divided into three stages according to a gas discharge method and liquid level state in the test pump [11]. In the initial stage of self-priming process, the liquid contents of different parts were divided into three periods. The liquid phase in the inlet pipe increased to 81% from 31%, and the liquid phase in impeller decreased from 100% to about 2% in the initial stage. The liquid in the impeller was discharged into chamber and volute by the centrifugal force due to the impeller rotation, and the negative pressure in impeller inlet and inlet pipe was formed. Therefore, the faster impeller rotating speed led to a lower pressure, and it benefited self-priming performance. The middle stage of self-priming process was a steady gas discharging process. There were three key points which affect the self-priming performance of the pump in the middle stage: the mixing rate of gas and liquid phases in the impeller, the transport rate of gas-liquid mixture to chamber, and the separated rate of gas from liquid phase in the chamber. The liquid level in inlet-pipe fluctuated and rosed to the peak of the pipe in 24seconds. In the last stage of self-priming process, the liquid phase entered into the test pump to add to the liquid phase fraction in the chamber, increased reflux rate, and keep saturated liquid phase fraction in impeller. This helped the mixing of the gas and liquid phases in impeller. Eventually, the outlet pipe was full of liquid, and the gas was discharged by the bubbly and slug flow. Also, the gas-liquid mixing and separation processes were revealed. The bubbles were broken-up into several small bubbles by the force from blade, and small bubbles were discharged with liquid. The reflux liquid was pressed by blade and fully mixed with gas to form the gas-liquid mixture. Furthermore, the numerical techniques established in the study have reference value to predict the time of self-priming process, and the methods are useful for the other gas-liquid two-phase flow scenarios.

4.0 Applications of Self-priming Centrifugal Chemical Pumps in the Chemical Industry

Self-priming centrifugal chemical pumps are widely used in the chemical industry due to their efficiency and versatility. Here are some key applications:

i. Food and Beverage Processing: Often used in Pumping food-grade chemicals and additives, guaranteeing compliance with safety standards.

ii. Transfer of Chemicals: Different chemicals are often moved as process fluids between tanks, reactors, and other equipment as needed in the production chain in the industry. Also effect transfer of ingredients for batch production processes in batch processing. iii. Pharmaceuticals and Biochemicals: Often employed in the transfer of pharmaceutical ingredients during production without losing touch of safety and ensuring hygiene as well as handling delicate bio-chemicals that require conscientious processing conditions.

iv. Wastewater Management: Effluent Handling to pump wastewater containing chemicals and other solids from production facilities to treatment facilities. Also, in sludge removal for handling thick sludge and transfer sludge in treatment plants and facilities.

v. Cooling Systems: Circulating cooling fluids in chemical reactors, plants and processing units. In heat exchanger applications, movement of heat transfer fluids to and from heat exchangers.

vi. Recycling and Recovery: In solvent recovery, self-priming centrifugal pumps are used to pump solvents for recovery and reuse, contributing to enduring innovations. Restoring valuable chemicals from waste streams for reuse in production.

vii. Pumping Viscous Liquids: Viscous Fluids/chemicals are efficiently handled viscous chemicals, which may be challenging for standard pumps.

viii. Abrasive and Corrosive Fluid: Corrosive Chemical are often handled safely by self-priming centrifugal chemical pumps due to their design; they are made of special materials that withstand chemical attack. Also, suitable for transferring slurries or fluids with solid particles.

ix. Agricultural Chemicals: In fertilizer and pesticide application, self-priming centrifugal chemical pumps are employed to efficiently deliver agricultural chemicals for crop protection and nutrition.

Centrifugal pumps are identified as the most popular type of pump for transporting fluids in several industries [12]. The work described centrifugal pumps as pumps that employ centrifugal force to transport fluids through a revolving impeller. And that, this is a preferred method, precisely for transporting fluids from one area to another in many industrial applications, including municipal (water and wastewater treatment plants), agriculture, power production plants, mining, petroleum and chemical industries, and others. The article added that centrifugal pumps can handle massive amounts of fluid at very high flow rates. Furthermore, their flow rates can vary over a large range. Centrifugal pumps are typically designed to handle fluids with low viscosity, such as water or light oil. They require greater horsepower to operate in viscous fluids. It should be noted that, positive displacement pumps are more energy efficient than centrifugal pumps for fluids with higher viscosities. Many fluid transport tasks adopt the use of centrifugal pumps. Thus, they are more popular in a variety of sectors. The study revealed also, that centrifugal pumps are most commonly used for pumping water, managing hot water, water supply and supporting fire safety systems.

With the many varieties of the pumps that are available, proper design is the most important requirement for any facility. Generally, ensuring the absence of cavitation and a proper flow. A single stage centrifugal pump design was analyzed in the study, the numerical relationship between head H, flow rate Q, rotational speed and power P was successfully obtained [13]. The work was designed with the hope that it is very much economical and will help obtain variable rate of discharge in variable speed when fabricated and tested in further research. In addition, a centrifugal pump was analyzed using a single-stage end suction centrifugal pump. The centrifugal pump was chosen for design and performance study because it is the most versatile mechanical rotodynamic equipment in fluid operations, with applications ranging from residential to agricultural to industrial. As a result, the design parameter, operating circumstances, and maximum efficiency with the least amount of power consumption were all determined. The work presents the design and model of a single stage centrifugal pump. The design specifications include a head, (H) of 10m, flow rate, (Q) of 0.00083m^3/s and velocity of 2800 rpm for an input power of 1.0HP. An electric motor powers the centrifugal pump, and does the function of transferring fluid to an elevated storage tank via a flow control valve.

A detailed study was made on performance improvement in centrifugal pump by changing some design parameters, such as blade angle, number of blades, micro grooved impeller, grove thickness in a review to increase the efficiency of the pump [14]. It was revealed that, with the change of design parameters a considerable amount of increase in efficiency was established. The significance of efficiency in pump is selecting a proper pumping system which will minimize fuel or electricity consumption and decrease the annual pumping costs. Inefficient and poorly chosen pumping systems can increase annual costs substantially.

5.0 Challenges and Limitations of Self-priming Centrifugal Chemical Pumps

Self-priming centrifugal chemical pumps are beneficial in many applications, but they also come with several challenges and limitations. These include the following:

i. Self-priming pumps are designed to handle air but excessive air or vapor can lead to reduced efficiency, cavitation, and possible damage to the components of the pump. They may not maintain prime effectively if they experience frequent air pockets or vapors.

ii. Whereas self-priming pumps can lift fluid from below their installation point, there are limits to the suction lift capabilities, typically ranging from 10 (3.05m) to 25 feet (7.62m) [15]. Beyond this, they may struggle to remain primed.

iii. Self-priming pumps must be made from materials that can withstand corrosive or abrasive chemicals, which could limit options and increase in cost. Also, components can wear out more quickly when handling abrasive slurries or corrosive substances, which could lead to regular maintenance and replacement.

iv. Excessively thick fluids may hinder performance and lead to operational issues though designed to handle viscous liquids. Also, high temperatures can affect fluid viscosity and pump materials which could lead to thermal degradation.

v. As it applies to all pumps, self-priming pump models have seals and bearings that require maintenance and could result in replacement over time, particularly in harsh and corrosive chemical environments.

vi. In demanding operations characterized with variable flow conditions, guaranteeing that the pump remains primed can be very tasking.

vii. Self-priming centrifugal pumps are less efficient when compared to standard centrifugal Pumps as there exist a compromise of priming chamber in the pump casing by design to handle air. There could also be significant pressure losses while the pump is drawing in liquid and air, affecting overall functionality.

viii. Self-priming centrifugal pumps may need more space for their self-priming mechanisms, which can be a hindrance if to be installed in a limited space. For proper sizing, selecting the correct size and model for defined applications is indispensable as miscalculations could cause pump failure or inefficiencies.

No doubt self-priming centrifugal chemical pumps are effective and versatile for many industrial applications, having a knowledge of these challenges is crucial for choosing the right pump for a specific operation and guaranteeing long-term reliable performance. Careful operational practices and regular maintenance can check most of these limitations. Figure 2 shows a comparative picture of a traditional centrifugal pump casing internals and Figures 3 shows the internals of a self-priming centrifugal pump casing, obviously bigger due to incorporation of a priming chamber which is one reason self-priming centrifugal pumps are less efficient when compared to standard centrifugal pumps.

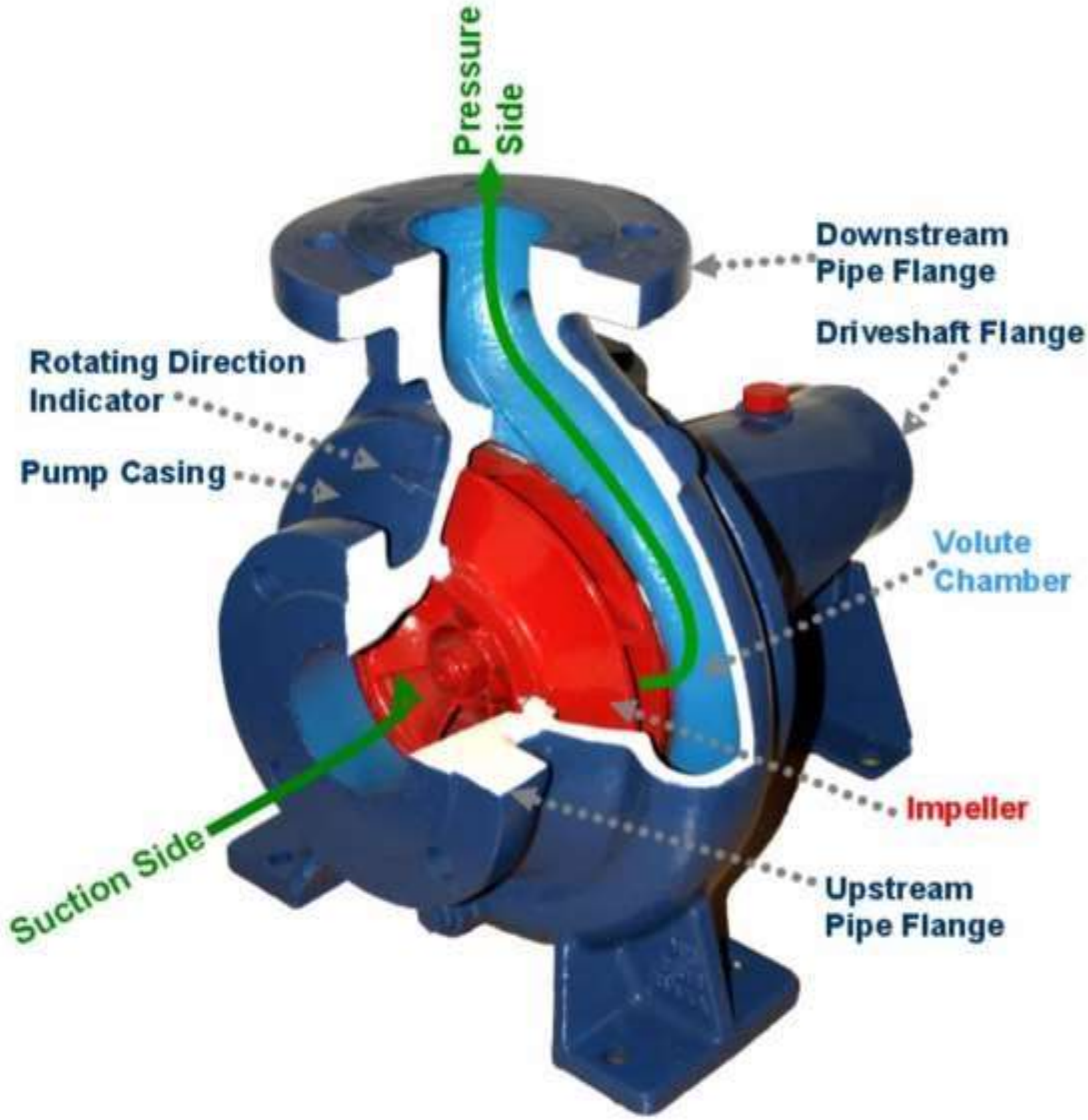

Figure 2. Internals of a traditional Centrifugal Pump Casing [5]

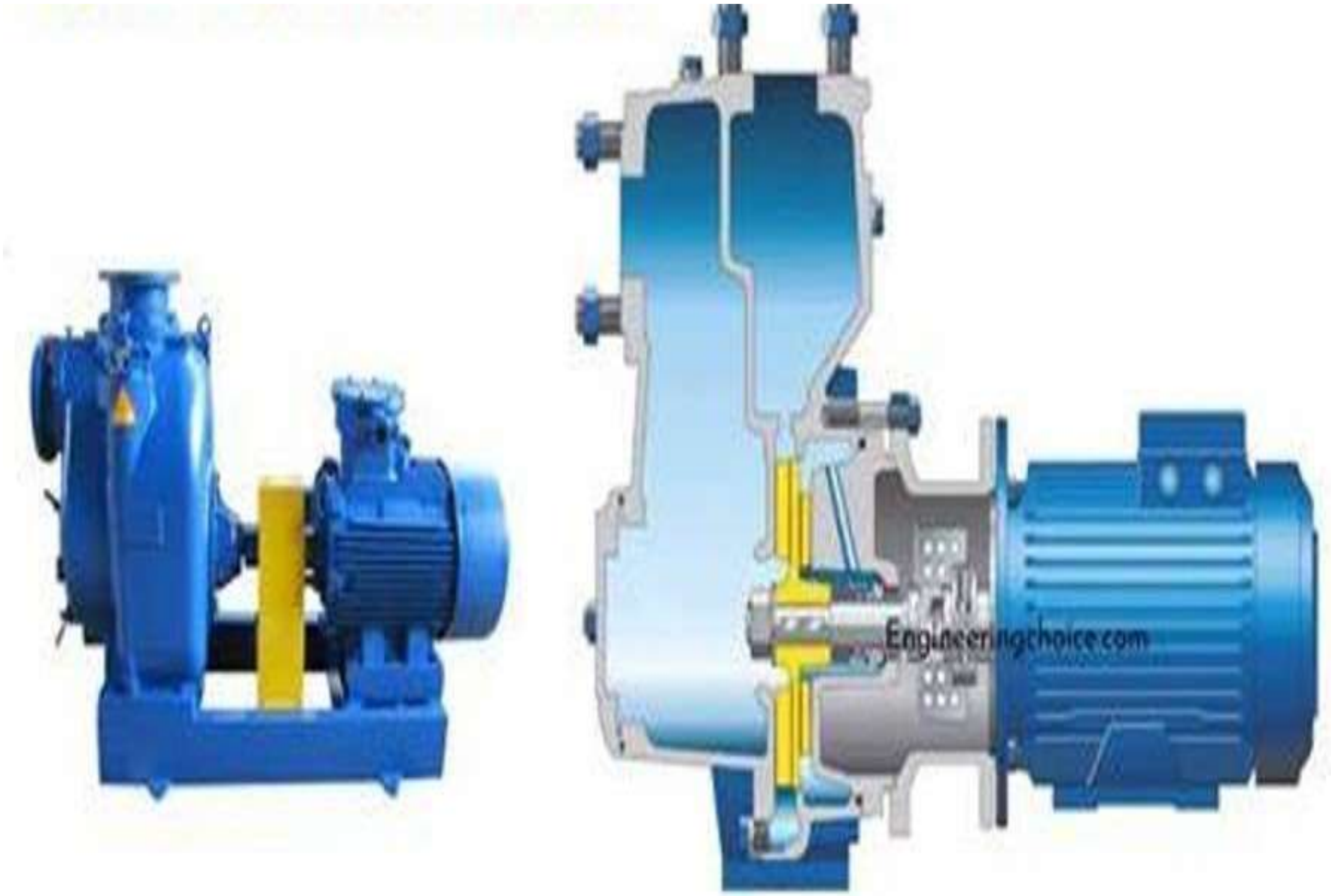

Figure 3. Internal view of a Self-Priming Centrifugal Pump Casing [5]

A set of experiments to determine the performance of a centrifugal pump was carried out at Reynolds number of $4x10^7$, $3.4x10^7$ and $2.7x10^7$ respectively [16]. The performance charts show that the maximum possible efficiency of the pump is less than 45% and the best efficiency point is around 42%. The maximum possible power coefficient is $2.48x10^{-4}$ at a corresponding flow coefficient of $3.2x10^{-3}$ giving a head coefficient of $7.8x10^{-2}$ at the best efficient point (BEP). It was realized that the pump has the capability of producing 5.6m head. A corresponding nondimensional analysis was done on a hypothetical pump with impeller diameter twice that under investigation. The flow rate was 9.93 liters/seconds as expected and the pressure difference 277.9kPa for the bigger pump. By increasing the pumping power, impeller diameter or pumping speed the volumetric flow can be increased. The choice of operating range should be away from the cavitation zone since cavitation represents a loss of useful power and can be harmful to the blades. The grove depth and the number of blades chances of having effect on formation of cavitation should be looked into in a further work, the study recommends.

Diverse issues and key technologies related to the CFD simulation of pump performance and cavitation was discussed in this work [17]. A contemporary pump simulation tool was outlined and demonstration cases presented. Detailed comparison between simulation results and experiment results were given for an axial flow model pump. Predicted pump performance and cavitation characteristics were found to match well with the test results. Transient simulations further improved the accuracy for both performance predictions and cavitation. Furthermore, a cavitation inception prediction method based on noticed bubble length was reviewed, with test results juxtaposed with simulation results. Considerable agreement between experiment and simulation outcome was found, with a chance for improvement. Computational Fluid Dynamics tools, including the one discussed here, assist the pump engineer in troubleshooting problems, improving existing designs, and developing entirely new pumps. However, it should be noted that such tools must be conversant and convenient to the engineer. The tools should be fast, easy-to-use, and produce reliable results. These outlined features will enable the CFD tool to be effectively used as a virtual test bed to either simply ascertain overall pump performance or study in detail the fluid dynamics inside a pump.

Overall performance comparisons between two different centrifugal pump designs were presented under two-phase flow conditions for different inlet void fractions and rotational speeds., on the premises of an experimental investigation [18]. Complete 3D-URANS simulation using the Euler– Euler inhomogeneous two-phase flow model was carried out to ascertain the flow characteristics. The following outstanding conclusions were reached by analyzing the experimental and numerical results of the selected model pumps: (i). The second pump, pump#2 was less responsive to gas liquid two-phase flow than pump#1. For the rated rotational speed of 2900 rev/min, pump#2 was still able to deliver two-phase mixtures up to 10% before pump shut-off, whereas pump#1 was limited to 8%. The performance deterioration of both pumps was the same for equivalent impeller outlet rotational speed, but a greater rotational speed enhances the pump's ability to work for higher inlet air void fractions. For a given angular rotational speed, a greater impeller outlet radius allows the extension of the pump's ability to work at higher inlet void fractions. (ii). The generation of vortices intensifies the accumulation of air, and then affects the energy exchange and transfer of the rotating impeller, resulting in the degradation of pump performance. Bubbles always gather on the suction side of the blade surface at first, and gradually gather in the entire flow passage with the increase of inlet air void fraction. Some bubbles flow exiting from the impeller outlet moved to the volute, gather along the wall surface and finally are forced to the outlet pipe. The phenomenon of air-water separation begins when the inlet air content is 5%. (iii). The pump performance obtained by simulation under inlet air void fractions below 7% are consistent with the experimental ones, indicating that the selected Euler-Euler heterogeneous flow model can satisfy the calculation needs under low inlet air void fraction conditions. The degradation slope of the simulation curves increases more when the inlet void fraction increases with a negative sign of the decreasing head and efficiency. (iv). Pressure pulsation is mainly caused by rotor-stator interaction between impeller and volutes and vortices in the whole flow passage. The addition of air fraction in the flow-path leads to intensified degree of vortices. The time domain diagram of pressure for the monitoring points under different α_0 presents six 'peak-values' periodic variation rules consistent with the number of blades, and the pulsation pressure fluctuation near the volute tongue is greater than that far away from the tongue. The pressure pulsation amplitude at low frequency area gradually increases with the increase of α_0 and produces broadband pulsation. Its range gradually widens with the increase of α_0. The pressure pulsation amplitude at shaft passing frequency account for the main part, which is consistent with the test results when the void fraction, α_0 gets to 5%.

The viscous flow inside a backswept centrifugal impeller was solved by using the fully three dimensional N-S equations and standard two-equation k-ε turbulence model. The computed results were compared with experimentally measured values in detail and the comparisons showed good agreement [19]. It was also observed that the jet-wake structure still occurs despite the absence of flow separation. The present computation successfully predicts the formation of the jet-wake structure; however, the initial location and size of the predicted jet-wake structure differ slightly with the measured ones. The turbulence model could be improved to take the effects of rotation and curvature into account, in order to obtain better results.

Steady and unsteady diffuser vane pressure measurements were carried out for a two-dimensional test impeller. In addition, unsteady impeller blade pressure measurements were made for another two-dimensional impeller with blade number and blade geometry identical to the two-dimensional impeller used for the diffuser vane pressure measurements. Also conducted investigation for different flow coefficients and radial gaps between the impeller blade trailing edge and the diffuser vane leading edge (5 and 8 percent of the impeller discharge radius). The largest pressure fluctuations on the impeller blades diffuser vanes were found to be of the same order of magnitude as the total pressure rise across the pump [20]. On the impeller blades the highest fluctuations were noticed to occur at the blade trailing edge whereas the largest pressure variations on the diffuser vanes were noticed to occur on the suction side of the vane near the vane leading edge. However, the dependence of the fluctuations on the flow coefficient was found to be different for the diffuser vanes and the impeller blades; whereas at the blade trailing edge, the fluctuations were smallest for the maximum flow coefficient and increased with decreasing flow coefficient, on the vane suction side, the fluctuations were largest for the maximum flow coefficient and decreased with decreasing flow coefficient. Increasing the number of the diffuser vanes resulted in a significant decrease of the impeller blade pressure fluctuations. The resultant lift on the diffuser vanes was ascertained from the vane pressure measurements and the magnitude of the fluctuating lift was found to be more than the steady lift.

6.0 Performance and Maintenance of Self-Priming Centrifugal Chemical Pumps

Self-priming centrifugal pumps are vital in many industries, but they can face operational and maintenance challenges. Here are some common issues and solutions in each scenario:

i. Loss of Prime: The pump fails to maintain a prime, most times as a result of air leaks or inadequate liquid in the suction line of the pump. The way out is look out for leaks, seal all found leaks in the suction line, ensure that the pump casing is filled with liquid, and that the suction height is adequate.

ii. Cavitation: This occurs when the pressure in the pump drops below the vapor pressure of the liquid, giving rise to the formation of vapor bubbles in the pump casing. The solution could be to reduce the pump speed, increase the inlet pressure, or regulate the NPSH (Net Positive Suction Head) of the pump to guarantee adequate liquid supply.

iii. Overheating: Too much heat can damage components which as a result of running the at excessive speed or without liquid in the casing. The pump speed should be reduced and ensure proper priming of the pump.

iv. Reduced Flow Rate: Reduction in flow can be as a result of wear and tear, incorrect impeller sizing or blockages. The impeller should be Inspected and cleaned, be sure that the pump is correctly sized for the application and also, no obstructions in the piping.

v. Excessive Vibration: This could be as a result of imbalanced impellers, misalignment or cavitation. Perform balancing on rotating components, routinely check alignment, and monitor for signs of cavitation.

vi. Seal and Bearing Failures: Mechanical seals and bearings can wear out due to operational stress or chemical corrosion. Implement a routine maintenance schedule to inspect and replace seals and bearings as may be required, using compatible materials for the fluid being pumped.

vii. Corrosion and Erosion: Pumps can be damaged by corrosive or abrasive fluids. Use corrosion-resistant materials for pump components and consider protective coatings or liners.

viii. Clogging: Solids in the fluid can clog the impeller or suction line, disrupting flow. Ensure that strainers are installed in the suction line to prevent solid particles from entering the pump.

In attending to these common issues with appropriate solutions, the performance and longevity of self-priming centrifugal chemical pumps can be substantially improved, ensuring reliable operation in various applications.

A study where Hire CT (high-resolution gamma-ray computed tomography) was applied to study gas holdup and two-phase distribution within the rapidly rotating impeller wheel of a commercially available industrial centrifugal pump was carried out [21]. Time-averaging rotation-synchronized CT scanning mode was used. The pumping device was installed in vertical and horizontal positions and operated under two relevant inlet two-phase flow conditions, namely, disperse and swirling inlet flow, at various inlet gas volume fractions. Thus, untreated tap water was used as liquid phase and dry, de-oiled pressurized air as gas phase. Flow rate performance curves of the centrifugal pump were taken at various inlet gas fractions and showed decreasing liquid transfer efficiency for increasing inlet gas fractions in all the operation cases. While the flow rate decreases almost linearly for disperse inlet flow, an abrupt performance drop occurs for swirling inlet flow, because of a sudden increase of the amount of accumulated gas within the impeller. This behavior was found for both installation positions. Radiographic scans showed that the gas is primarily accumulated within the impeller region, again for both installation positions. However, an additional gas structure at the driving shaft sealing was found for the horizontal alignment, which led to a faster wear of the sealing. Moreover, the gas holdup and two-phase distribution within the impeller wheel was studied for various operating conditions for both installation positions of the pumping device. It was found that gas accumulates within each chamber of the impeller wheel depending on the inlet gas fraction. At low inlet gas fractions ($\varepsilon_{in} = 1\%$), an asymmetrical phase distribution occurs, which disappears at higher inlet gas fractions. It was shown that the gas buffers within the chambers are increasing constantly with growing inlet gas fraction. Thus, the effective conveying cross section is reduced, restricting the liquid flow path and therefore decreasing the liquid flow rate.

Exit flow field of a centrifugal pump impeller was measured when the circumferential pressure was distorted due to a non-uniform fence located at the vaneless diffuser outlet [22]. The mean flow parameters, such as static pressure, total pressure, and flow angles were strongly dependent on the circumferential position. The flow parameters plotted against the local flow rate at each circumferential position showed loops along the quasi-steady curves obtained from the result without the fence. Simple theoretical calculations were made and used, instead of more accurate but complex and unsteady CFD, to predict the velocity components at the impeller exit with imposed static pressure. The assumption of quasi-steadily varying relative flow angle at impeller outlet was more effective than that of constant relative flow angle for the velocity prediction. Another model in which the total pressure as a parameter was also evaluated. Good prediction of radial velocity was obtained with the assumption of quasi-steadily varying total pressure. A simple method was proposed to predict the impeller exit flow with downstream blockage in two-step sequence: the first step deals with the diffuser alone, while the second step deals with the impeller alone. This simpler method can be used as enough accurate alternative to the complex and unsteady CFD.

7.0 Advancements in Technology and Future Direction

The future of self-priming centrifugal chemical pumps is assured of compelling developments driven by evolving industrial needs, sustainability initiatives and technological innovations. The following are some important areas of advancement:

i. Advanced Materials: Increased use of advanced materials including composites and unique alloys, so made to enhance resistance to corrosive chemicals and guarantee longevity of pumps. Also, the use of lighter materials in design for easier installation and maintenance.

ii. Incorporation of sensors for prompt monitoring and predictive maintenance, which enables remote operation and diagnostics. Use of data Analytics to analyze pump performance and optimize operations, enhancing efficiency and reducing downtime. iii. Energy Efficiency Improvement including evolution of more efficient impeller designs to reduce energy consumption and increase flow rates. Adoption of variable frequency drives (VFDs) to regulate pump speed as the case may be, to further improve energy efficiency.

iv. Focus on sustainability: With a drive of designing pumps that minimize environmental impact, including lower emissions and reduced energy usage. Encourage the use of recycled materials in the construction of pumps to promote sustainability in manufacturing and waste disposal.

v. Improved Priming Mechanisms: Modernizations in priming chamber designs to improve air separation and reduce priming times. Evolution of pumps with multi-stage priming capabilities for handling wider scope of fluid types and applications.

vi. Smart Controls: The use of advanced control systems that automate operation, enhance efficiency, and drastically reduce the need for manual intervention. Seamless integration with plant-wide automation systems for optimized performance and monitoring.

vii. Enhanced Safety Measures: Utilization of advanced safety measures and features to comply with critical regulations in handling chemicals and environmental protection.

Paying attention to these future directions, the self-priming centrifugal chemical pump technology can enhance sustainability, reliability and performance, meeting the demands of modern chemical processing and beyond.
The impeller-volute interaction in a centrifugal pump was successfully predicted by a numerical model developed using a finite volume commercial code [23]. Both experiments and numerical prediction show the presence of a spatial fluctuation pattern at the blade passing frequency as function of the flow rate. That frequency is predominant in what refers to the dynamic effects inside the pump and conditions the possible limitations in what refers to the use of the dynamic data for design purposes. Unsteady forces were calculated using the numerical results. Considering the model results obtained, secondary flow pattern in the volute was numerically analyzed through the helicity magnitude, showing that the stronger effects of such secondary flow are concentrated in radial positions close to the impeller exit. The pressure fluctuations at the blade passing frequency reveal the blade tongue interaction with the flow at the impeller outlet plane. Such interaction clearly increases the fluctuation levels for off-design conditions, which produces other effects already studied (limiting operation ranges, increase of losses, etc.). The unsteady calculation combined with the sliding mesh technique was proven to be a useful tool to investigate the flow field inside a centrifugal pump including the dynamic effects. Altogether, the main goal was to gain a deeper knowledge of the flow dynamic variables inside a centrifugal pump (pressure and forces) which could be used in a design process. This was achieved.

Conclusions

The review of self-priming centrifugal chemical pumps buttresses their critical role in various industrial applications which is sequel to their efficiency, reliability, and versatility. Industries can better leverage the advantages of self-priming centrifugal chemical pumps, leading to enhanced performance and safety in chemical handling processes, food and beverage processing, waste water treatment processes, cooling systems, abrasive and corrosive fluids and pumping viscous liquids. Self-priming centrifugal pumps offer notable advantages in several industrial applications including chemical processing, specifically in applications where uninterrupted operation, safety of operation personnel, maintenance personnel, equipment and environment is critical. The review featured various operational principles, designs, and self-priming mechanisms, emphasizing their suitability for handling industrial fluids including viscous and abrasive fluids. Comparative analysis revealed that self-priming pumps can surpass traditional centrifugal pumps in specific scenarios, including where suction conditions are poor or unstable. Developments in technology and materials have improved the reliability and lifespan of these pumps, making them an indispensable choice in many industrial applications.

Not with sanding their advantages, self-priming centrifugal chemical pumps face challenges such as dealing with excessive air, limited suction lift priming capacities and the need for regular maintenance to ensure optimal performance. There are also, worries regarding efficiency losses during the priming process, which is bound to affect overall operational costs.

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