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Detect and treatment cavitation in centrifugal hydraulic pumps: A Review

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Abstract

Centrifugal pumps play an important role in engineering applications due to their wide use in both industrial and domestic systems and their versatility in handling a wide range of flow rates. However, the turbomachinery of these pumps often exhibit cavitation and irregular turbulent flow, and their performance can be difficult to improve. Cavitation is a complex phenomenon that reduces the efficiency and performance of centrifugal pumps. It is one of the most common causes of pump performance degradation. The severity of cavitation and its diagnosis affect pump reliability. This study reviews several experimental methods and control systems produced so far and highlights the area of future research on the topic of cavitation to extend pump operating life, save maintenance costs, and improve pump reliability. The results show that cavitation detection is possible, but in order To improve the reliability of the pump, a large number of sensors should be used to increase data accuracy, along with advanced data processing software. Additionally, methods of redundancy and double-checking should be applied, as well as leveraging modern artificial intelligence techniques for early detection.

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1. Introduction

Pumps are a common type of fluid machinery found in both industry and daily life. In the past, they provided the power needed to move fluids, and are essential for agricultural and domestic uses. However, during real operation, a number of errors can occur, causing a complex flow process, including phase change and cavitation. Cavitation occurs when the internal static pressure of the pump drops below the vapor pressure of the liquid at the operating temperature. When the liquid reaches the high-pressure region, a large number of bubbles are generated in this case, and these bubbles will burst [1]. They also vibrate the pump body and produce noise. Resonance may develop when the frequency approaches the original frequency of the pump, and it may even stop working normally. Therefore, cavitation is a problem of current importance and interest from a scientific point of view regarding pumps. The determination of cavitation is now a very important issue that must be solved immediately for safety reasons. Economic importance [2].

To avoid cavitation effects, a group of researchers have proposed a number of methods for detecting cavitation in centrifugal pumps. In particular, recently developed numerical techniques for modeling turbulent fluid flows with cavitation, developments in complex flow characteristics detected using optical, noise and vibration techniques as well as acoustic methods, factors affecting cavitation, such as temperature and oil viscosity, and optimal design methods for centrifugal pumps to increase pump performance and reliability.

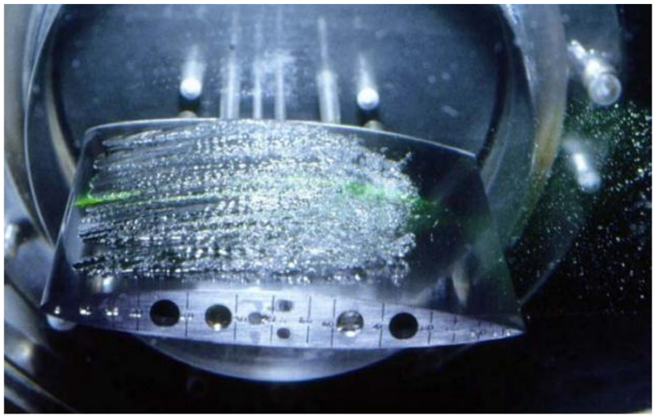


Figure 1. bubble causes cavitation [1].

2. Material and Methods

2.1. Cavitation

Cavitation is the term used to describe the barely perceptible early stages of cavitation. When cavitation arises and when it disappears, the conditions are different. Generally speaking, cavitation cannot be eliminated without a pressure increase above the point at which it first manifests. Vapor bubble creation might have two negative outcomes. First of all, it might be enough to obstruct the piping system, which would drastically lower the hydraulic performance. Second, there's a chance that noise and surface erosion of the waterways will result from the vapor bubbles collapsing as they travel to a higher pressure area [3]. The disintegration of vapor bubbles can result in extremely high local pressure and shock waves, which can severely erode the metal surface and obliterate any surface film that shields the metal from corrosion. No substance is impervious to cavitation-related damage in its entirety. Because of the collapsing vapor bubbles' water-hammering effect, erosion symptoms manifest as pitting [4]. There are different types of cavitation Incipient such as :-

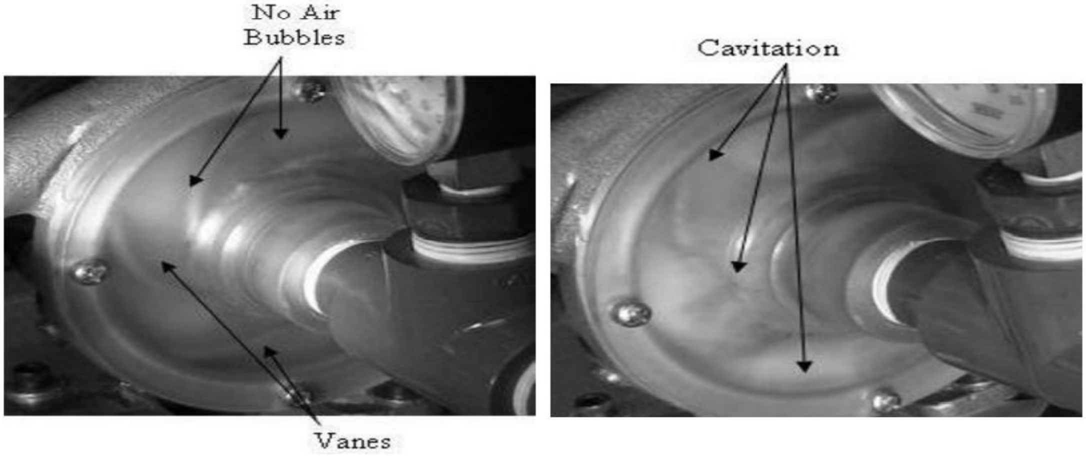


Figure 2: Cavitation and Non in centrifugal pump [3].

- Individual bubbles that emerge in the fluid and travel with it until they vanish are represented by traveling cavitation. Bubbles typically form at the low pressure point in turbulent flow or at the low pressure point on solid barriers [5].

- A cavity that is fixedly attached to the edge of a rigid body submerged in a fluid-flowing medium is referred to as fixed cavitation. When the flow separates from the stiff body, it happens. The definition of stable in the context of quasi-steady cavitation is this kind [4].

- When the cores of vortices created by turbulence have a high shear area, vortex cavitation happens. There are two types of cavitation: traveling and stationary [6]. The very low flow velocity causes vibratory cavitation, which causes the pump to recirculate. Since every component of the fluid may experience several cavitation cycles, this kind of cavitation is unique. In contrast, any fluid element only passes through the cavitation area

Figure 3: Worn impeller due to cavitation [6].

2.2. Common Cavitation Detection Methods

One of the components of fault detection is cavitation detection. Cavitation detection has been achieved by the use of energy methods, high-speed photography, surface coating methods, resistance methods, ultrasonic detecting methods, and optical methods. Nevertheless, the aforementioned techniques have certain limits due to the ongoing development of technology and the ongoing complexity of pumps. In the realm of cavitation, signal-based fault detection has demonstrated certain advantages recently [1]. The reference materials currently available for cavitation detection study in pumps state that noise, vibration, acoustic emission, temperature and optimal design methods for centrifugal pumps.

2.2.1 Noise and Vibration Methods

The stable efficiency of centrifugal pumps is negatively affected by cavitation, so it is necessary to detect cavitation and avoid unexpected results. These studies focus on the characteristics of cavitation and noise-induced vibration during the breakdown process. Zhang, et al 2015 [7] analyzed the energy of accelerometer signals, in the frequency range of 10-25 kHz, to determine the critical cavitation point. Gao, et al 2017 [8] studied the vibration energy of cavitation in the frequency range of 10-500 Hz through visual inspection. Jiaxing, et al 2017 [9] studied the vibration characteristics and instability caused by cavitation formation in centrifugal pump. The internal flow parameters of the impeller and the vibration signal were studied at four different locations of a closed hydraulic test bench, and then the experiments and numerical calculations were applied to the pump. Al-Hashemi, et al 2017 [10] discussed the effectiveness of vibration technology to diagnose and detect spectral cavitation in centrifugal pumps. presented the experimental results of cavitation observation in centrifugal pumps using vibration approach. Moreover, Gao et al. 2017 [11] studied the vibration characteristics of cavitation, and special attention was paid to the vibration energy in the low frequency range, 10-500 Hz. Through visualization analysis, the relationship between cavitation growth and the related vibration energy in the frequency range of 10-500 Hz was examined.

The results showed that unlike the high frequency range, the trend of fluctuating vibration energy in the low frequency range was distinctive. The vibration energy reached a local maximum at a cavity number significantly larger than the 3% head drop point with the decrease of the cavity number.

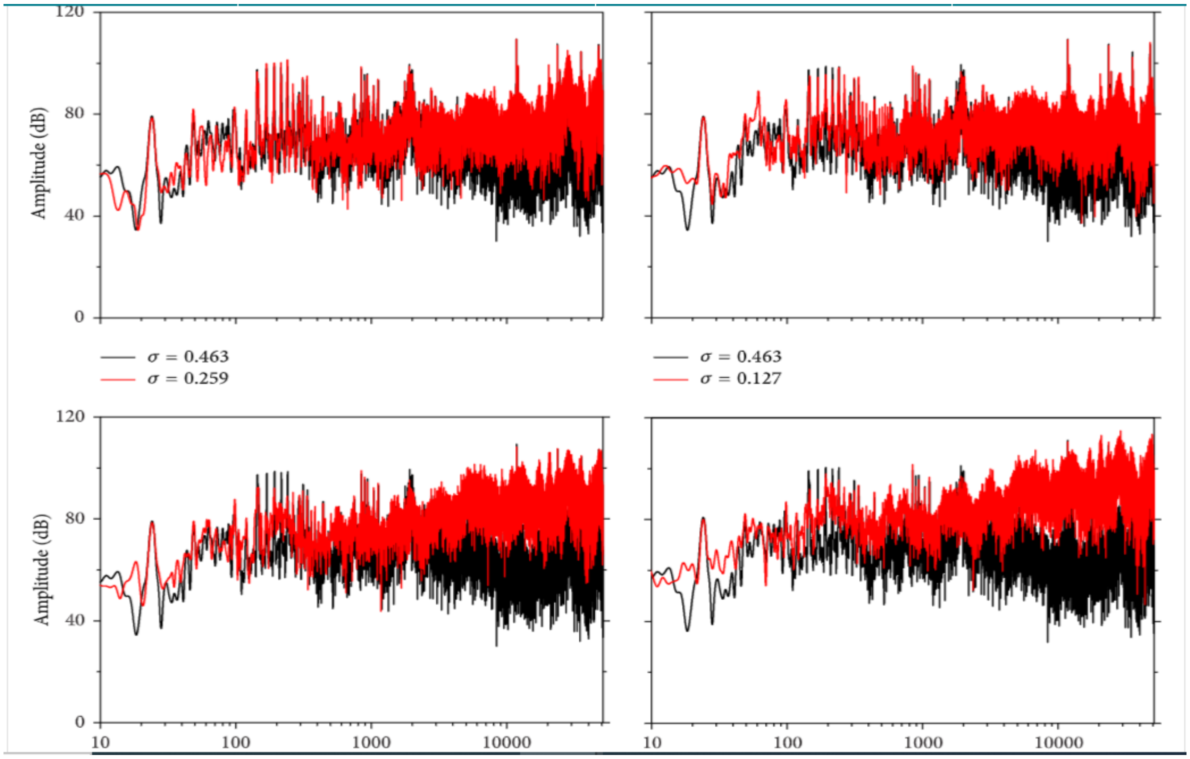


Figure 4: Vibration spectra at cavitation number [11].

Shervani et al. 2018 [12] explored the cavitation performance of centrifugal pump on vibration signals. Experimental data were collected for five different levels of cavitation. Administrative tasks were applied to the statistical behavior of ideal behaviors. Active component removal technique was applied. Multi-class support was trained to classify different areas of dark spots. The test results of the technical support vector algorithm showed that the developed model is associated with effective monitoring of surgery during on-site operation with high accuracy. Ramadan et al. 2020 [13] discovered that cavitation was inside the centrifugal pump using vibration and acoustic techniques. This was done by analyzing the acoustic signals in time and frequency domains. Cavitation was studied using several statistical features when performing time domain analysis (TDA). The fast Fourier transform (FFT) method was also used for frequency domain analysis (FDA). Karagiovanidis et al. 2023 [14] presented methods for early detection of cavitation phenomenon in centrifugal irrigation pumps by analyzing vibration and acoustic signals and produced a low-cost data collection and sensing system and compared different computing techniques. The smartphone's integrated accelerometer sensor was used to collect vibration data. The analysis was based on comparing signals under different operating conditions.

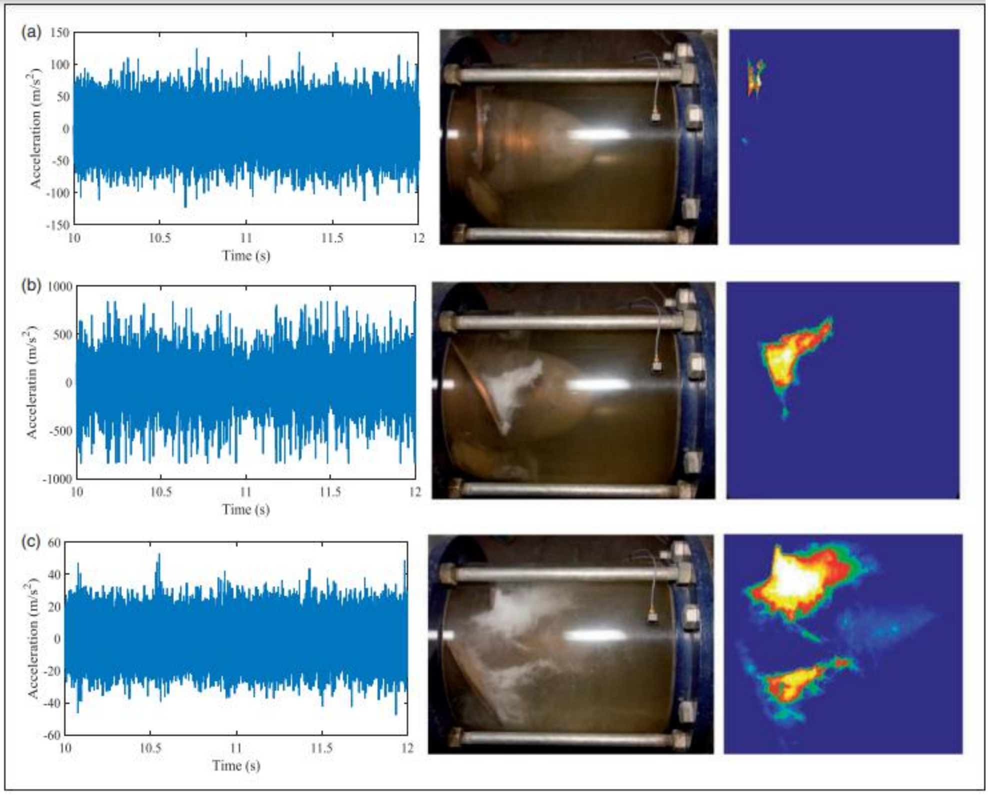


Figure 5: Acceleration signals and digital camera recordings [14].

2.2.2. Acoustic Emission Method

The occurrence of cavitation can be inferred from typical parameters of the acoustic emission signal, such as resonance number, center frequency, and power [15]. The difference between normal and cavitation can also be visualized using the waveform and spectrum of the signal. [16]. Early detection of cavitation can be achieved using several methods, as described in the studies cited below. Čudina 2012 [17] applied experimental work in a pump using audible sound. According to his report, there is a characteristic frequency band or narrow-band frequency range located within the audible noise spectra, which shows a strong relationship with the cavitation development process inside the pump. The results indicated that the amplitudes of the narrow-band frequency range increase by up to 15 dB(A) or more when the cavitation reaches its full potential. He concluded that: This characteristic tone of the specific frequency or using the narrow-band frequency spectrum, one can determine the onset and progression of cavitation.

Hosien et al. 2017 [18] measured the noise in a water tunnel under different operating conditions to determine the onset of cavitation of a centrifugal pump. The noise generated by different designs was measured in a water tunnel under different operating conditions. One-third octave bands spanning the frequency range from 31.5 Hz to 31.5 kHz were used for the measurements. The working section of the Plexiglas's side of the water tunnel was used to visually measure the onset of cavitation.

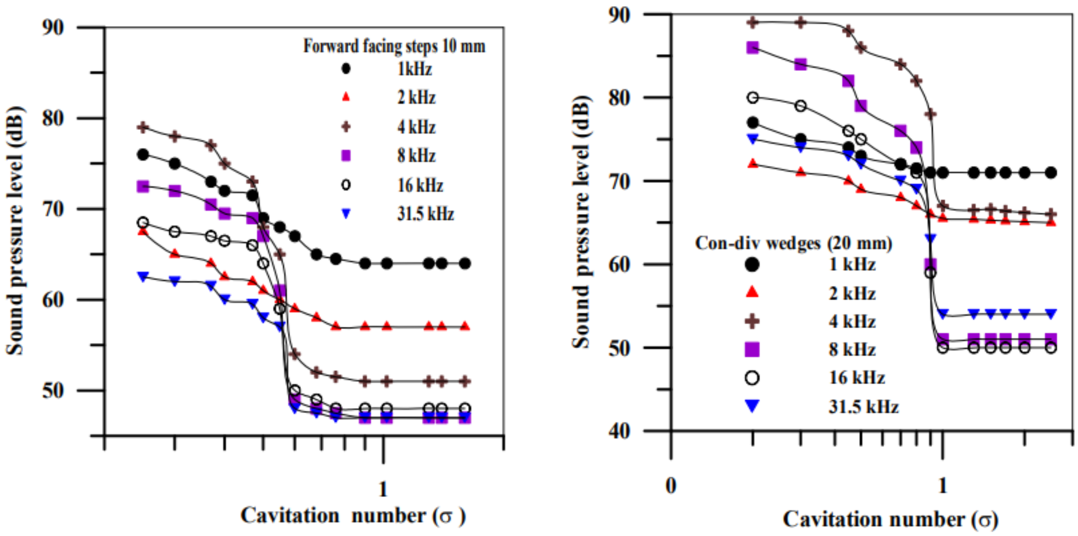


Figure 6: Variation of sound pressure & cavitation number at frequencies (1) for 20 mm con-div wedges. (2) for 10 mm forward facing steps [18].

Al Obaidi. et al 2019 [19] investigated the effect of different suction valve orifices on cavitation in a pump and used FFT technique to analyze the acoustic signal over a wide range of operating conditions. Using this experimental setup, the effect of reducing the suction pressure at the inlet of a centrifugal pump was explored by adjusting the suction valve orifice at the inlet in order to analyze different levels of cavitation under different operating conditions. Thus, pressure and acoustic signals were collected at different inlet valve orifices and flow rates - 103, 200, and 302 L/min.

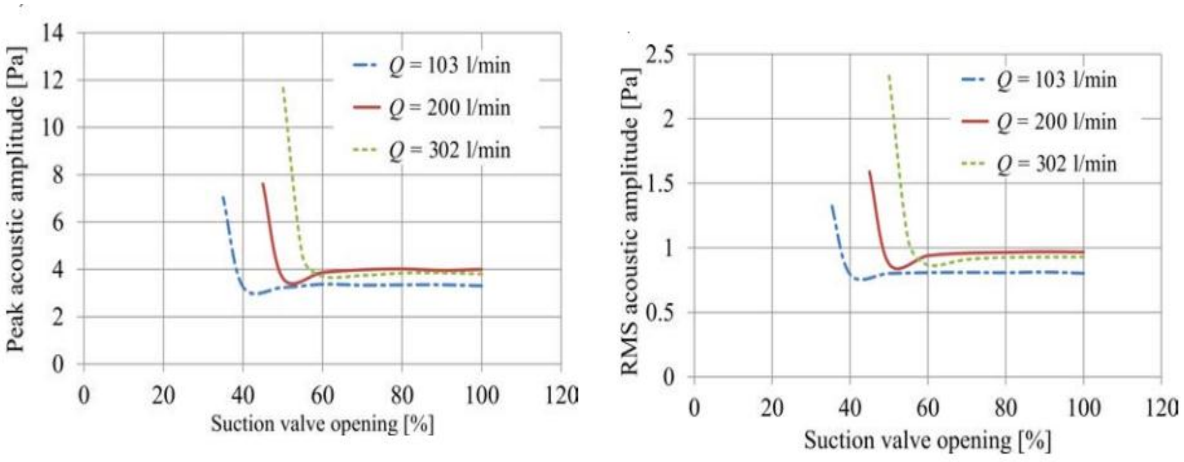


Figure 7: Comparing various acoustic signal statistics [19]

Ylönen et al 2020 [20] investigated the relationship between the diameter of the holes caused by cavitation on the surface of the material and the distribution of the peak voltage value AE. In addition, the relationship between the intensity of cavitation and the acoustic emission signal was indirectly investigated, AL-OBAIDI et al 2023 [21] used acoustic waves to consider the effects of different mass flows. The experimental results of the study showed that the acoustic method is a reliable method for determining different cavitation levels.

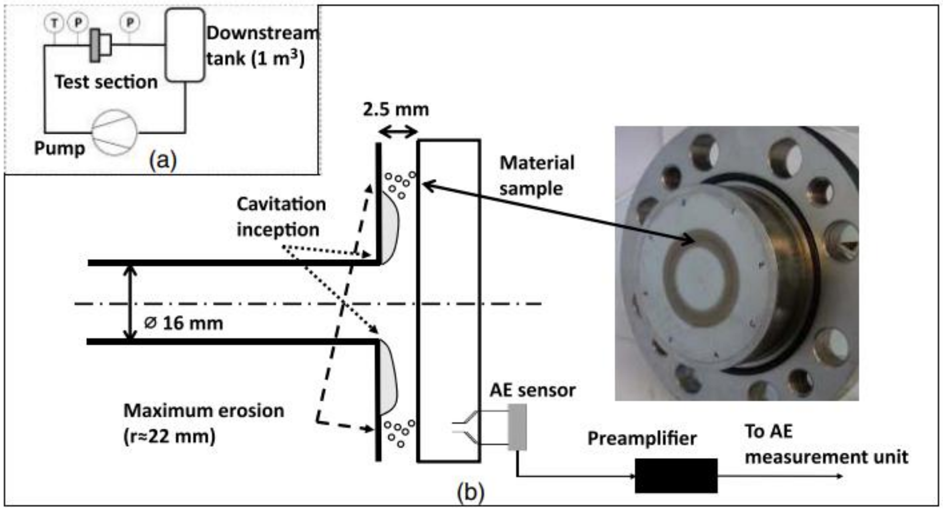


Figure 8: (a) PREVERO cavitation schematics; and (b) tunnel test sections details and material sample [20].

2.2.3. Effect Temperature on the Cavitation

Centrifugal pumps should not be operated at temperatures higher than ambient air, especially in industrial environments or for outdoor applications where they are exposed to high temperatures. As a result, great care must be taken to prevent any problems that may arise from increased fluid temperatures. Applications at high temperatures are becoming more common in the liquid handling sector. [22], Several researchers have discussed the effect of temperature on cavitation, including Al-Arabi 2008 [23] who experimentally investigated the effect of centrifugal pump performance and the onset of cavitation on water temperature. For this reason, a unique test setup was built using a centrifugal pump. The ability to adjust the rotation speed, water temperature, suction pressure and flow rate ratio were calculated independently. The results showed that cavitation accelerated with a 4° increase in water temperature. In addition, it was found that the temperature-related increase in the net positive suction head increased to a maximum value before decreasing again. Blist 2010 [24] investigated the effects of temperature on cavitation damage of various materials between 0 and 90°C for distilled water. The results showed that the damage rate peaked between 40 and 50 °C. The increase in damage at lower temperatures may be due to the increase in chemical activity with temperature, however this explanation is less certain. Lewitt et al. 2011 [25] modified the mass transfer equation considering all thermodynamic effects and physical properties. The modification focused on thermodynamic cavitation and was based on the Rayleigh-Blessed equation. The nozzle and hydrofoil NACA0015, which are examples of internal and external flow fields, were found to validate the updated model. They used the updated model to calculate the cavitation property of the hydrofoil NACA0015 at different temperatures. The experimental data were used to determine the pressure coefficient. The experimental results and the calculated results for nozzle cavitation under thermodynamic conditions were compared.

Tanaka et al. 2011 [26] used liquid nitrogen to examine the thermodynamic effect that affects the performance of an experimental cavitation centrifugal pump. Liquid nitrogen and cold water were used to test the pump cavitation performance in an experimental setup. The cavitation performance was measured by temperature, discharge flow rate, pump suction pressure and delivery pressure. The experimental results showed that liquid nitrogen produced superior cavitation effects than cold water. In addition, when the flow coefficient decreased, the estimated temperature depression caused by the thermodynamic effect also decreased. Moreover, it was shown that for the same flow coefficient, the estimated temperature depression of the low-performance cavitation impeller caused by the thermodynamic effect was larger than the estimated temperature depression of the high-performance cavitation impeller. Hosien 2017 [27] employed the Rayleigh-Blist equation to describe the bubble dynamics, and the model contained a number of critical elements that influenced the cavitation collapse process, including the gas pressure inside the cavity under operating conditions, the flow rate, rotation speed, temperature, and the thermodynamic properties of the water. Remarkably strong agreement was seen between the current results and previously published experimental data.

Abu-Rahmeh 2018 [28] investigated from the temperature and flow rate of the flowing water affecting the initiation of cavitation in the channels using pressure prediction and flow visualization techniques. The pressure, temperature and flow rates of the water flowing through the channels were controlled using a test device that included a heater, a pressure reducing valve and a variable flow meter. The temperature and flow rate ranges were 30°C to 40°C and 255 to 750 litres per hour, respectively. It was clear from all the experimental data that as the fluid temperature and flow rate increased, the propagation of cavitation increased. Jin Jiang 2019 [29] discovered that as the temperature rises above 90°C, the bubbles in the impeller channel will abruptly increase, and the rising trend will then begin to decline. Doria 2023[30] A computational fluid dynamics (CFD) model was developed to evaluate the cavitation phenomenon and its local effects on a centrifugal pump. The model incorporated fluid temperature, rotational speed and suction geometry. The model was validated using the manufacturer's pump characteristic curves with an error of 5%. Minimum pressure ratio and vapor volume lines were also plotted.

2.2.4. Effect of Viscosity on the Cavitation

A centrifugal pump's NPSHr increases when it operates with viscous oils that have a viscosity greater than that of water. The pump will experience cavitation as a result of a higher NPSHr. As a result, the pump may experience unusual behaviors, like high noise, strong vibration, decreased performance, damage to the impeller or other components, and so forth. Naturally, when a centrifugal pump handles viscous lubricants, accurately anticipating its NPSHr at different operating circumstances is crucial for hydraulic design optimization and engineering applications. [31]. Many researchers have discussed the effect of viscousity on cavitation, including, Wen-Guang [2011][32] An experimental centrifugal pump was used and took advantage of numerically unsteady flow. The LDV measurement results were verified for water velocity profiles at impeller discharge. Quantitative evidence has been provided for the effect of viscosity on flow variability in the snail. It has been shown that when the fluid viscosity increases, the variable flow fluctuations become less significant and the tendency toward flow separation on the blade pressure side becomes less pronounced. Saleh et al. 2011[33] investigated how viscosity affected the wear particles in distilled water and glycerol-water solutions from vibration cavitation wear tests on Al-99.92. The wear particles during the incubation stage were shown in the scanning electron microscope images. Surface topography analysis showed that fatigue was the source of the wear particles. As the viscosity increased, the pressure generated by cavitation bubbles diminished. Li at el 2014 [34] used of CFD code, the hydraulic performance of the centrifugal pump in relation to water and viscous oils was quantitatively assessed. Higher viscosity and a certain degree of big surface roughness have been found to be associated with the presence of a "sudden high head effect." The effect can be attributed to viscosity and roughness, which cause the boundary layer flow pattern in the impeller and volute to transition from a fully rough regime to a hydraulically smooth one.

Wen-Guang 2015[35] predicted net positive suction head required (NPSHr) correction factor for viscosity oils was compared with the existing measured data and empirical correlation curve, and the factor is correlated to impeller Reynolds number quantitatively. A useful relation between the pump head coefficient and vapor plus non condensable gas-to-liquid volume ratio in the impeller was obtained. Vapor and non-condensable gas concentration profiles were illustrated in the impeller, and a “pseudo cavitation” effect was confirmed as NPSHa was reduced. The effects of exit blade angle on NPSHr were presented, and the contributions of liquid viscosity and noncondensable gas concentration to the increase of NPSHr at a higher viscosity were identified. Azad at el {2019[36] Using a viscous fluid, cavitation in a transparent centrifugal pump has been experimentally investigated. Aqueous solutions of polyacrylamide at different concentrations of 100, 200, and 400 ppm at room temperature are known as viscoelastic fluids. Using two distinct techniques: (a) counting the bubbles in the flow visually and (b) examining the pump's characteristic curves The findings demonstrated that the initiation and growth of bubbles can be strongly influenced by polymer content, cavitation number, and degradation. In comparison to water, the polymer solutions showed a considerable decrease in the number of bubbles under the same conditions, particularly at high concentrations. As the number of cavities decreased, this effect diminished. Furthermore, compared to tap water, new polymer solutions showed less crucial holes. This study also examined the degradation effect in addition to the fresh polymer solution. The findings demonstrated that bubble initiation accelerated and bubble quantity increased with breakdown. A noteworthy rise in comparison to fresh approaches.

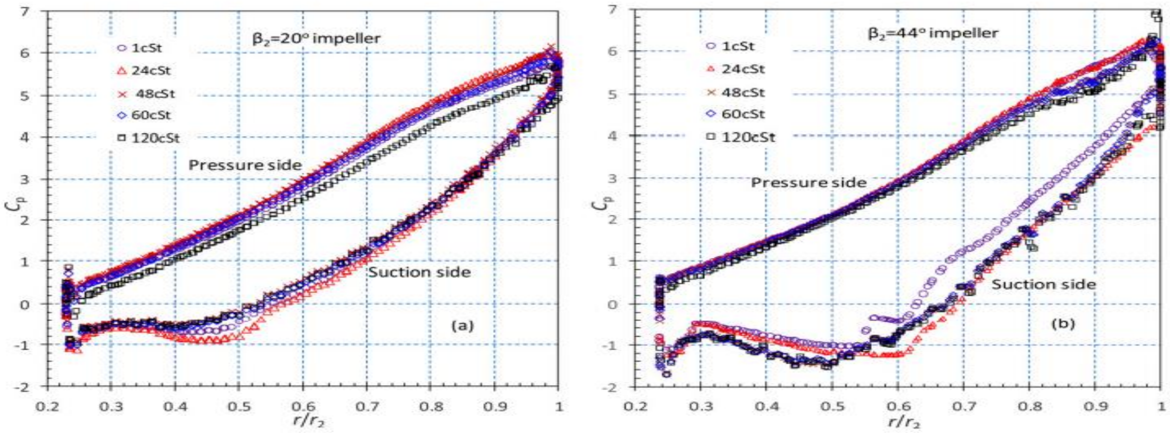
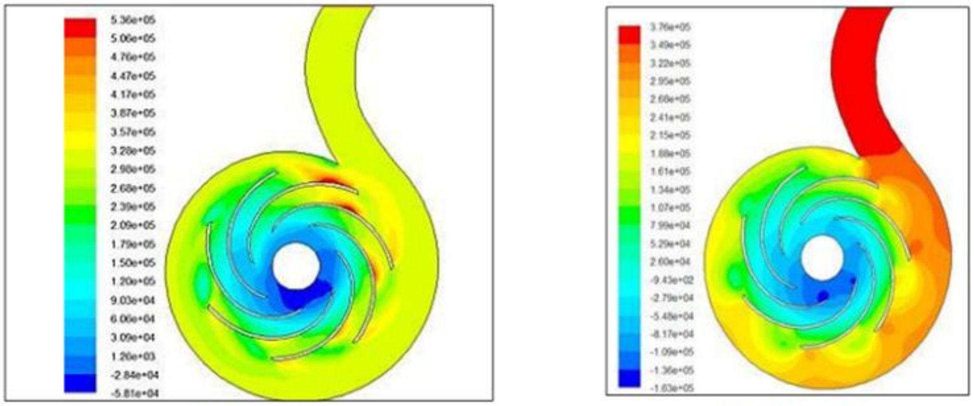


Figure 9: Pressure coefficient profile o at five viscosities and BEP(u 5 0.379) for two impellers with 20 deg and 44 deg blade angles under 3% head drop condition: (a) b2 5 20 deg and (b) b2 5 44 deg [35].

2.2.5. Numerical Analysis by ANSYS

The use of CFDs plays an important role in fluid mechanics. Improvements made Computer capabilities over the years have allowed for numerical methods Through CFD for use in improving the prediction of the performance of centrifugal pumps. Many researchers have used CFD code to perform transient numerical calculations under different operating situations, and vary the geometric parameters of the flow field inside the pump under single-stage and cavitation conditions, including, Houlin L.6 2010 [37] investigated the impact of the number of impeller blades on the pump's performance using experiments and numerical simulation using Ansys Fluent. The study examined the flow through model pumps including 4, 5, 6, and 7 blades at a specified speed of 92.7 using a comparing scheme between the two ways. For the head, net positive suction head, and efficiency, the greatest variance in the predicted findings was 3.9%, 0.36 meters, and 4.83%, respectively. The number of blades increased with the developing head, but the efficiency was complex. ns. Sujoy C.4 2012 [38] carried performed a numerical study on the impact of impeller speed and blade number on the performance of centrifugal pumps. Pumps with different impeller blade numbers, ranging from 4 to 12, were simulated at various speeds (2900, 3300, and 3700 rpm) utilizing the commercial program Ansys' CFD code Ultimately, it was discovered that the pump head increased as the number of blades and pump speed increased, while the efficiency was somewhat complex, with the 10 bladed impeller having the higher efficiency. Pandey K.M5 2012 [39] investigated the impact of varying the number of blades on the pump's performance while maintaining a consistent impeller diameter and speed across all versions. Ansys Fluent software was utilized to solve the RANS equations using the standard k-ε turbulence model and SIMPLEC method. The flow through impellers with six, eight, and nine blades at a speed of 2500 rpm was examined. The number of blades increased the static pressure and the pump head, but the efficiency variation was more complex, with different optimum values for each type.



Blade no-7 **Blade no-7**

Figure 10: Total pressure distribution for different impellers at 2500 rpm [39].

Wei W.42 2012 [40] examined the impact of the incidence angle of the inlet flow on the cavitation performance of centrifugal pumps. Four distinct impellers (R1, R2, R3, and R4) were subjected to numerical modeling using the Mixture cavitation model and the SST k-ω turbulence model. Some impellers had varied inlet incidence angles at the blade hub, mid-span, and blade tip, while others had the same. Liu et al. 2013 [41] proposed a cavitation model that is frequently seen in hydrofoils and propellers and used a modified k-ω model to simulate the cavitation flow in a centrifugal pump.. The numerical analysis unequivocally shows that cavitation formation is the primary cause of the collapse of pump performances. The impeller tube is filled with vapor-filled cavities that attach to the blades; this causes the flow to separate from the blades and, as a result, the head coefficient to decrease. Ran .et al 2014 [42] changed the blade thickness and leading edge ellipse ratio on the leading 20% mainline using a genetic algorithm. The optimization process was finished with a noticeable improvement in the cavitation inception performance thanks to the use of CFD simulation. But as can be seen, these conclusions about the features of cavitation in centrifugal pumps are based on a single cause, whereas in real-world applications, cavitation results from the combined action of several elements. Ahmed A. 2014 [43] carried conducted a CFD numerical simulation to look into how the pump's performance is affected by the design of the volute. After comparing the simulation findings to the experimental data, it was possible to see that the outcomes of the two methodologies agreed. It was discovered that the pump head increased with the pump volute cross-sectional area. Rajiv Kaul . 2016 [44] Analyzed a centrifugal pump in 3D CFD modeling software. Centrifugal pump impellers are designed to have 6 blades and are semi-vaned with blade angles (15°-28°; 18°-30°). Korkmaz, et. al. 2017 [45] examined the impact of various blade counts on the deep well pump's performance. Several numbers of blades (z=5, 6, and 7) were employed. As a consequence, at z=6, the impellers had the best efficiency and performance at their Best Efficiency Point (BEP).Pei, Ji, et al 2017 [46] employed CFD technology to assess how the centrifugal pump's cavitation performance was impacted by the impeller inlet diameter D1, the inlet incidence angle Δβ, and the blade twist angle φ. In order to determine the ideal parameter sets for pump design, the cavitation characteristics of the pump are studied using orthogonal DOE. The improved impeller's internal flow was examined and contrasted with the original flow .Wang et al. 2018 [47] examined the relationship between the pressure fluctuation and vortex in a low specific-speed centrifugal pump both with and without cavitation. According to the findings, cavitation formation may come from a decrease in pump head. An enormous effect on the cranium will result from cavitation. After the cavitation coefficient falls to a particular value, the head would abruptly drop by Luo Xu et al.2018[48].

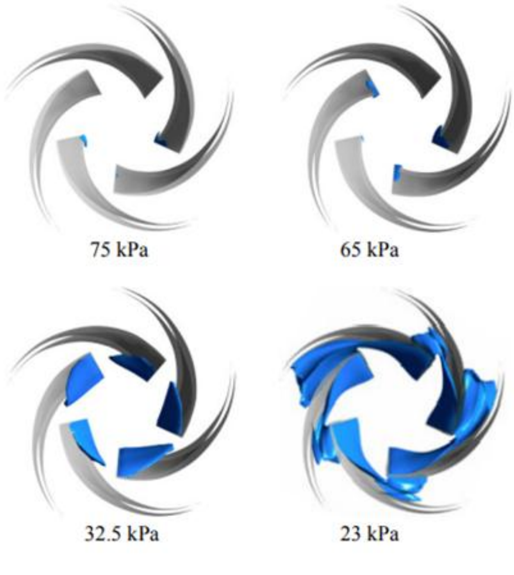


Figure 11: Vapor volume fraction distribution of original impeller (75, 65, 32.5 and 23) kPa [46].

Lal and Deshmukh, 2018 [49] investigated the performance of a centrifugal pump in a variety of operating situations when used as a turbine. The optimal efficiency of the pump at its intended flow rate was discovered to be about 2% less than pump mode. Additionally, for loading variations between 60% and 120%, the Net Positive

Suction Head was adjusted by ± 3%. In addition, the NPSHR-NPSHA disparity was at its lowest for 100% loading at 2.8%. (Al-Obaidi, 2019 [50] observed the centrifugal pump's performance with varying numbers of impeller blades while there was cavitation. The findings demonstrated that as the pump moved from its input to its output, its velocity and pressure increased. Additionally, the pressure in this area was higher than in other pump portions because of the strong interactions between the rotor and stator at the exit. Furthermore, the dispersion of the volume fraction first occurred at the suction impeller side, particularly in the inlet eye zone. The outcome also revealed that cavitation occurs more frequently as flow rate and impeller blade count rise,and Wu, Kaipeng, et al 2022 [51] By utilizing the CEL language, CFX analyzed the improved cavitation model. With the use of an automobile electronic water pump, a numerical simulation of the cavitation full flow field at three distinct temperatures—25, 50, and 70—was performed.

2.2.6. Optimal Design of Centrifugal Pump

Enhanced Centrifugal Pump Performance A collection of articles helped to improve centrifugal pump design so that it could operate better using different types. Improvements in pump performance have been observed when the intake, exit, and slewing angles of a centrifugal pump are adjusted to optimize the geometry of the impeller. Extending the blade's leading edge and applying a significantly greater blade angle will result in improved performance. According to studies, the increased inlet blade angle also enhances the pump's cavitation performance. Kim et al. 2009 [52] Enhanced performance of the centrifugal pump by response surface method optimization of the impeller. Safkhani .et al 2011 [53] Improved centrifugal pump by the use of multi-objective evolutionary algorithms and polynomial neural networks. Kim and Kim 2012 [54] Enhanced pump vaned diffuser design with radial basis neural network prototype. Derakhshan et al. 2013 [55] Centrifugal pump design optimized by artificial neural network and artificial bee colony algorithm. Zhang et al. 2014 [56] centrifugal pump vibration optimization using integration of FSI modeling, experimental testing, and Kriging surrogate model.

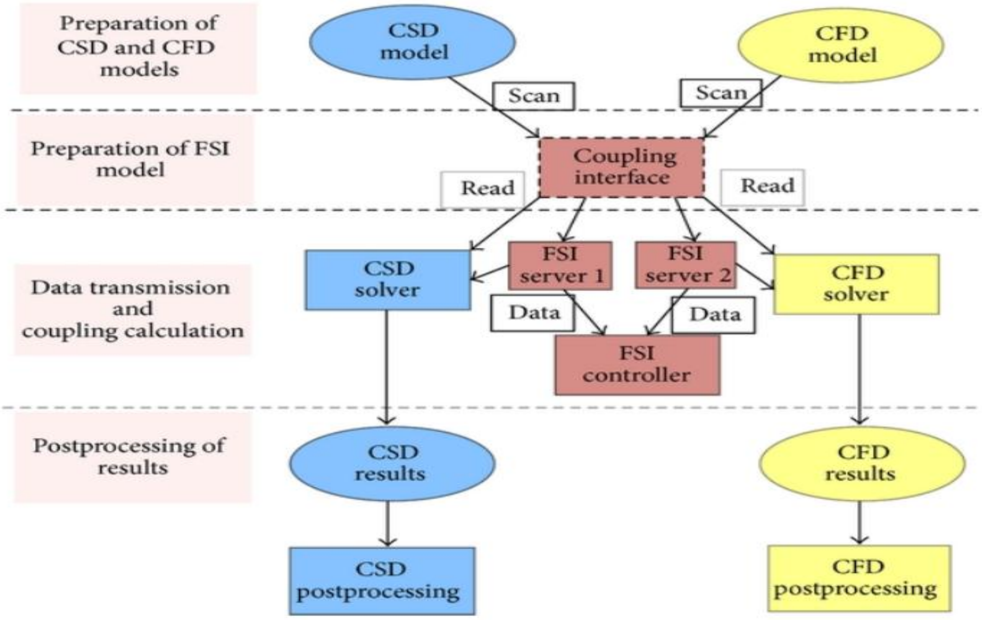


Figure 12: The process of FSI simulation [56].

siddique et al. 2016 [57] created method to improve the performance of two pumps—a centrifugal impeller and an ESP—by employing multiple-surrogate assisted multi-objective optimization. The CFD simulations were run in order to the values of the goal function at various stages, and using a genetic algorithm, a PoF was produced. The Points of View information from each surrogate was matched to identify a strong stand-in that works effectively in both situations. As an analysis of the findings and discussion section is included. substitute fidelity and pump flow physics. Bellary et al. 2016 [58] used many surrogate models to optimize two centrifugal pumps with disparate parameters. Zhang et al. 2017 [59] suggested a diffuser optimization technique that combines OEM, numerical simulation, RSM, and the multi-island genetic algorithm (MIGA) to produce the optimal pump performance. Using an RSM based on the quadratic fitting function, the ideal combination of four variables diffuser inlet diameter, diffuser inlet breadth, diffuser inlet angle, and diffuser wrap angle was discovered. Furthermore, the ideal and original pumps' speed and total pressure distributions were compared to show how much efficiency was gained. Wang et al. 2017 [60] provided a three-objective centrifugal pump impeller design that uses three-dimensional (3D) Navier-Stokes equations to reduce flow and cavitation recirculation. To simulate multiphase cavitation flow inside a centrifugal pump, use a cavitation model. Verify the numerical results for the critical cavity number and total head coefficient by contrasting them with experimental data. hydraulic efficiency at the design flow rate, clogging at 50% of the flow rate, and critical bore number for head drop of 3% at 125% of the design flow rate are selected as objective functions in order to meet the optimization goals. By utilizing the multi-objective genetic algorithm, Pareto optimum solutions were achieved (MOGA). Examine six exemplary Pareto optimum (POD) designs in order to assess the optimization outcomes. When compared to the baseline architecture, PODs' goal functions demonstrated notable gains. Consequently, optimization enhances the centrifugal pumps hydraulic performance and dependability.

shim, et al 2018 [61] provided a three-dimensional (3D) Navier-Stokes equation optimization of the centrifugal pump impeller's three-objective design to reduce flow and cavitation recirculation. Multiphase cavitation flow inside a centrifugal pump was simulated using a cavitation model. Tianxin, et al 2022 [62] suggested a genetic algorithm (GA) and artificial neural network (ANN)-based multi-objective diffuser optimization. First, modify the five geometric variables to create a parametric design for the diffusers. Assist publishers with multi-objective optimization design by employing minimal efficiency index (MEI) and header as optimization goals. The MEI is a thorough and formal indicator that assesses pump efficiency at three distinct flow rates: 0.75Qd, 1.0Qd, and 1.1Qd. In the interim, he presented the entropy production method as a tool for calculating the energy loss in the suggested ANN-GA approach, which will aid in the quantitative assessment of internal flux losses and the identification of their underlying causes. The outcome demonstrates that the multi-objective optimization technique is appropriate for diffuser design optimization at various flow rates. The optimized model decreased the CMEI by 1.89 and increased the head by 1.47 m at the specified location in comparison to the original model. Siddique. 2022 [63] Improved the head, reduce input power, and change pump design parameters - such as number of blades, splitter blade length, splitter blade angle at the axis, and twist angle. Use the surrogate-based internal optimization code to optimize the same impeller after simulating it using a computational fluid dynamics (CFD) analyzer and verify the accuracy of the CFD results. Improved pump performance by 8.2% in head and 3%.
Shi, Yifang, et al 2022 [64] discovered and modeled the plastic centrifugal pump's structural design parameters. Then, using the orthogonal design approach (or experiment), the flow field simulation of the model was examined using CFD. Utilize net positive suction head (NPSH) and efficiency as assessment metrics. The Taguchi method is used to re-optimize the pump impeller parameters while accounting for the maximum efficiency and least NPSH. The ideal combination is as follows: input diameter of 35 mm, entry angle of 26 degrees, exit angle of 27 degrees, and roll angle of 110 degrees. grades). It was discovered that the lowest NPSH and maximum efficiency were, respectively, 0.957% and 61.5%. Cancan, Peng, et al 2022 [65] Verify the pump performance by experiment and numerical simulation. conducted the Design of Experiment (DOE) using the sparse grid method, and built the approximate model using three distinct adaptive response surface (RSM) techniques. Use MOGA (Multi-Objective Genetic Algorithm) to perform multi-objective optimization of the ideal response surface model. An additional pressure of 38 kPa was applied to the optimized model.

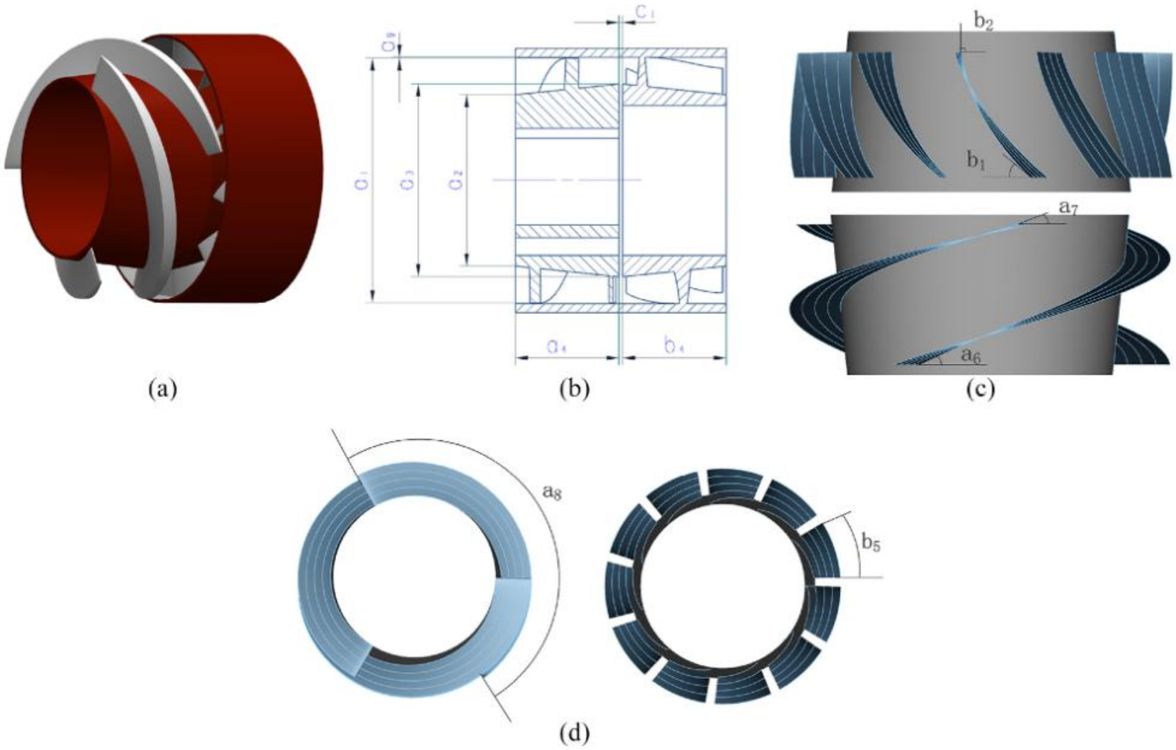


Figure 13: Diagram for a single-stage pump model: (a) 3D diagram, (b) dimensions of impeller & diffuser, (c) hub inlet and outlet flow of impeller and diffuser [66].

Fracassi, et al 2022 [66] suggested a code optimization for a pump similar to ERCOFTAC and assessed the resilience of ideal profiles by looking at the spread of uncertainty. The primary cause of uncertainty is the variation in operating conditions, specifically the pump shaft's rotating speed, which also has an impact on tidal rate.. Abdolahnejad. et al 2022 [67] Used numerical simulation tools, research on the effect of spacer blades on the slip factor distribution to optimize the pump head was presented and confirmed using data from experimental tests. Then, using a combination of surface response, genetic algorithm techniques, and experimental design, use an optimization process to determine trait features (i.e., length, number, and ecological location of traitors). It was found that the improved separation occurred at a relative circumferential position of 67.2% of the way from the suction surface of the main blade. The six separator blades, 62.8% of the length of the main blades, were the ideal number and length. The best efficiency point (BEP) of the slurry pump has shifted toward lower flow rates due to the addition of split blades and decreased flow passage. By enhancing the separator, it was possible to increase the pump head from 29.7 m to 31.7 m while maintaining efficiency at the starting points.

3. Comparison Among cavitation detection methods

Each cavitation detection method has its strengths and limitations. Vibration and acoustic detection are useful for real-time monitoring but can be affected by external noise and require calibration. Temperature and viscosity measurements provide indirect indications of cavitation effects but may not provide detailed insights into the cavitation process itself. Optical design methods provide detailed, direct observations but involve complex equipment and setup. The choice of method often depends on the specific application, the accuracy required, and the resources available.

Table 1: Overview of the experimental techniques detection for cavitation in centrifugal pumps

NO	Experimental Method	Experimental Set Up	Economic Cost	Capability of Detection
1	noise and vibration	• Simple to establish at the machine's casing	• High cost of sensors	• Able to detect the onset of cavitation

		• It is necessary to apply a high pass filter. • Useful for commercial and industrial settings	and high pass filters • No establishment cost	• Multidirectional monitoring • •Unsuitable for use in ultrasonic analysis
2	Acoustic Emission	• Adaptability to place sensors near the machine in different locations. • Applying high-pass filters • Practical for industrial applications	• Low cost of sensors • No establishment cost • High pass filter cost	• having the ability to recognize and track high frequency phenomena • The signal and low frequency analysis are impacted
3	Temperature	• Sensors found in the pump's rotational and stationary components, such as the casing and blades. careful consideration for the proper placement of the sensors • Locating the sensor in the pump's spinning components through the use of telemetry systems	• Low cost of sensors and their establishment • High cost in case of telemetry system or signal transmitting through hollow shaft	• Possible to detect the location of bubble implosion • Low frequency band is not affected from mechanical noise
4	viscosity	Easily established at the casing of the machine	No establishment cost	Able to detect and monitor high frequency phenomena
5	Optimal design	• • Near the transparent window are the stroboscope and high-speed camera. • The installation of transparent elements in industrial pumps is impractical.	• High cost of high speed camera sensors, amplifiers and high pass filters	• Explicit and trustworthy detection • It is feasible to locate the bubble implosion

4. Conclusion

The development of vapor bubbles in a fluid flow caused by a pressure drop under vapor pressure is the universal understanding of cavitation phenomenon. Cavitation detection requires advanced techniques because it is a rapid and complex process, which provides the importance of cavitation detection and treatment in centrifugal hydraulic pumps, emphasizing a comprehensive approach to achieve optimal pump performance. Effective management of cavitation in centrifugal hydraulic pumps requires a comprehensive approach that includes both detection and remediation strategies. Using a combination of detection methods allows for early identification and mitigation of cavitation, while targeted remediation strategies address the root causes and minimize the impact on pump performance. By proactively managing cavitation, operators can improve pump reliability, efficiency and longevity, resulting in more robust and cost-effective hydraulic systems. Therefore, extra care must be taken during the design phase so that centrifugal pump performance can be accurately predicted using computational and experimental methods and cavitation can be reduced to manageable levels, if not completely avoided.

5. Abbreviations

Time domain analysis	(TDA)
Frequency domain analysis	(FDA).
Fast Fourier transform	(FFT)
Computational fluid dynamics	(CFD)
Net positive suction head required	(NPSHr)
Net positive suction head avalible	(NPSHA)
Multi-island genetic algorithm	(MIGA)
Genetic algorithm	(GA)
Artificial neural network	(ANN)
Minimal efficiency index	(MEI)
Multi-Objective Genetic Algorithm	(MOGA)

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