*Nanotechnology Perceptions*
*ISSN 1660-6795*
*www.nano-ntp.com*

# A Review on Hydraulic Losses in the Centrifugal Pumps

**Castro Owusu- Manu Kwabena[1], S Yamoah[2], Alexander Fordjour[3], C.P.K Dagadu[4]**

*[1]Ho Technical University, Faculty of Engineering Department of Mechanical, Ho, Volta Region, Ghana. Ghana atomic energy commission, University of Ghana (SNAS).Email:castroowusumanu@yahoo.com.*
*[2]School of Nuclear and allied Sciences (SNAS), University of Ghana, P.O. Box AE1, Kwabenya, Legon, Accra. Email: s.yamoah@gaecgh.org.*
*[3]Research Centre of Fluid Machinery Engineering and Technology, Jiangsu University, Zhenjiang, China. Department of Civil Engineering, Koforidua Technical University, Koforidua, Eastern Region, Ghana. Email: fordjouralexander27@yahoo.com*
*[4]Nuclear Power Ghana, c/o Bui Power Authority, KD PMB 62, Kanda Accra, Ghana. Email: dagadukofi@yahoo.co.uk*

Mechanical and hydraulic losses are a major factor impacting the pump's efficiency since they can make other process system components slow down or behave strangely. The objective of the review was to identify hydraulic losses in centrifugal pumps and propose mitigations' measures to address these issues. A wide range of studies are presented to give the reader a thorough understanding of the key strategies used and outcomes attained by scientists across the globe. In this study, the different losses in volute, impeller, recirculation and disk friction were highlighted. New emerging technology developed by various researchers for minimizing such challenges are discussed, proposed measures and future work are identified in the study.
**Keywords:** Centrifugal Pump; impeller; volute; hydraulics losses; review.

## 1. Introduction

The centrifugal pump serves a variety of purpose in addition to pump. By creating pressure energy from liquid and gas—all of which are referred to as fluids—the activities are carried out Khan et al., 2024. Pumping with centrifugal pumps is accomplished by centrifugal action. Water in a container, such as a glass, may attempt to rise above the glass wall if it is rotated quickly. Centrifugal pumps operate on the same basis Gou et al., 2023; Yuan et al., 2019: Keller et al., 2014. The eye refers to the center of the pump impeller. A suction pipe is used to connect it to the water supply. The impeller is rotated at a high speed, typically 1440 rpm, by one engine or motor. The water from the eye is forced toward the outer edge of the casing by the impeller's high speed, which is connected to vanes Dong et al., 2014. Pressure builds up close to the pump's exit. A delivery pipe connects to the output. When water begins to flow through this delivery pipe, the pressure is released. A centrifugal pump's casing and suction line need to be filled with water before it is turned on. This is referred to as priming, without which the pump cannot function. When the impeller rotates and water moves from the eye to the periphery, negative pressure builds up at the eye following priming, causing water to rush from the source to the eye Chalghoum et al., 2016. Pumping systems are among the largest energy consumers. According to the International Energy Agency and the European Commission Kye et al., 2018, pumping systems consume more than 22% of the energy provided by electric motors, which provide 46% of the world's power. Pump units have a practical efficiency of 40–90% Li et al., 2016 : Khoeini et al., 2017, and because of energy transformation process losses, ultra-low specific speed centrifugal pumps operating at part-load conditions may have an efficiency of less than 20 percent Baun et al., 2000. With the world's energy demand expanding at an accelerated rate, there is an increasing need to save energy and minimize consumption in pump units and pumping systems. The hydraulic loss in the various hydraulic components of the pump, particularly in the impeller, accounts for a substantial amount of the total loss of the pump units. It is essential to look into losses and understand the related energy conversion processes in the pump impeller in order to create high-performance pump models and reduce energy consumption in pumping systems Alemi et al., 2015: Zhang et al.,2009: Allali et al., 2015. Centrifugal pumps may have the following problems while operating. These problems, which include both mechanical and hydraulic problems, have been discussed for many years in a variety of industries in the literature. The objective of the review was to identify hydraulic losses in centrifugal pumps and propose mitigations' measures to address these issues.

## 2. Literature review

### 2.1 Hydraulic looses

Changes in temperature, fluid flow velocity, and fluid volumetric flow rate can cause hydraulic losses by changing the pressure inside the volute and the pipes that connect to the pump. Because of the complex internal flow of centrifugal pumps, calculating their hydraulic loss has proven to be a difficult problem. Hydraulic loss occurs in the volute, impeller, and suction room of centrifugal pumps. Figure 1 presents hydraulic losses in centrifugal pumps

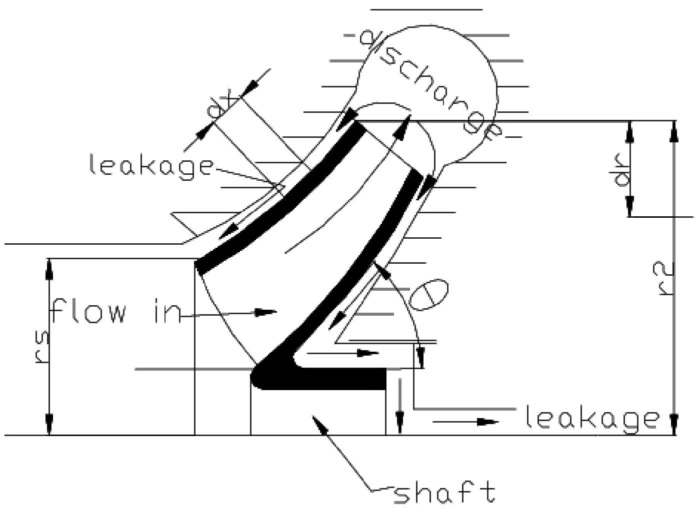


Figure 1 disk friction losses in centrifugal pump [15]

2.1 Loss modeling for pump

Through the procedure of fluid motion inside the pump, the impeller does work to produce energy, but various energy losses are produced during energy transfer and internal flow. Thus, research on various energy losses should be the first step to predict the performance of the pump. The energy loss of the pump consists of hydraulic loss, volumetric loss, and mechanical loss. Hydraulic loss, accounting for the large proportion of the total loss, and it has a direct relationship with the geometrical shape of flow channel, structure, flow field distribution and size. Volumetric loss directly relates to sealing and fluid leak at the interface between the impeller and the volute casing. Mechanical loss directly relates to mechanical friction at the bearing, the seal. Lin et al., 2020 studied the effect of an inlet guide vane installed at the inlet of a centrifugal pump and found to reduce the hydraulic losses and improve the hydraulic performance. Litfin et al., 2014 used ANSYS and NX software to design a special forward-curved blade impeller. The comparison between the two impellers shows that the new impeller can significantly improve the hydraulic losses.

2.2 Loss in impeller

Impeller losses are due to loss of liquid from the pump and recirculation of the liquid in the impeller. The pressure difference between impeller tip and eye can cause a recirculation of a small volume of liquid, thus reducing the flow rate at outlet of the impeller. Li et al. [18] studied the effects of flow structures in the impeller on the performance of a low-specific speed centrifugal pump by PIV technique and computational fluid dynamics (CFD) simulation. The results showed that recirculation on the pressure side (PS) and suction side (SS) of the blade rotate oppositely. The PS recirculation enhances the hydraulic performance of the impeller, while the SS recirculation has a negative impact. Thin et al., 2008 compared the performance of centrifugal impellers with different blade leading-edge shapes, and found that optimized blade leading-edge could reduce the range of low-pressure zone caused by the recirculation at the inlet of the impeller passage and improve the efficiency of the pump. Although abundant research results have elucidated the flow features of centrifugal pump impellers, the links between the losses and the flow structures have still not been deeply analyzed Achour et al., 2021.The designed flow rate usually provides the flow angle of the blade inlet with the blade angle that can satisfy no incidence entrance design requirements. Under off-design conditions, the direction of flow at the inlet of the impeller will deviate from the angle of the blade and result in loss of incidence as:

$$\Delta h_{inc,p} = f_{inc} \frac{\Delta w_{1,p}{}^{2}}{2g} \tag{1}$$

where $f_{inc}$ is the incidence loss coefficient with a value of 0.5-0.8 Gou et al., 2023. In Fig. 1 the relative velocity under the off-design flow rate $W$ is decomposed into two components $w_{10}$ and $w_1$. $w_{10}$, has the same direction of current from no incidence entrance under the designed flow rate. $w_1$ , is along circumference direction, representing the inlet incidence level.

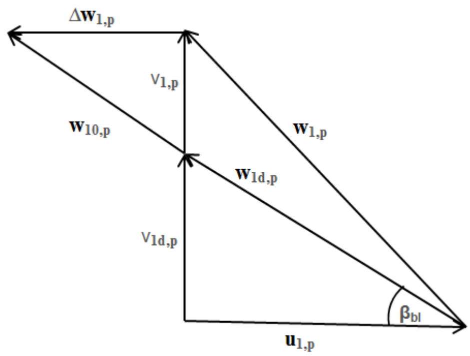


Figure 1: velocity triangle at impeller inlet under off-design condition (pump-mode) Kim et al., 2023.

The value of $w_{1,p}$ can be obtained by applying the triangle similarity theory with the velocity triangle in . Where the absolute velocity $v_i$ is proportional to the flow rate in Eq. (xx)

$$\Delta w_{1,p} = u_{1,p}\left(\frac{v_{1,p} - v_{1d,p}}{v_{1d,p}}\right) = u_{1,p}\left(\frac{Q - Q_{d,p}}{Q_{d,p}}\right) \tag{2}$$

(a) Surface frictional loss

In the internal flow field of the impeller, the loss of friction of the skin is defined as the linear loss caused by the wall boundary layer of the blade, the impeller chamber, and so on, under the effects of fluid viscosity:

$$\Delta h_{sfl,p} = \frac{b_{2,p}\,(D_{2,p} - D_{1,p})(v_{r1,p} + v_{r2,p})^2}{2\sin\beta_{2,bl}\, H_{r,p}\, 4g} \tag{3}$$

$$H_r = \frac{b_2\left(\frac{\pi D_{2,p}}{z}\right)\sin\beta_{2,bl}}{b_2 + \left(\frac{\pi D_{2,p}}{z}\right)\sin\beta_{2.bl}} \tag{4}$$

where $H_r$ is the hydraulic radius of the impeller.

(b) Recirculation loss

The appearance of inlet recirculation results in parasitic power demand. Impellers with relatively large inlet diameters; the most likely to recirculate are usually found in high specific pumps. The recirculation head loss is given as, Lin et al.,2023: Recirculation usually occurs during reduced flows, and is the flow of some fluid around the impeller to the suction side. If this is found in the inlet of the impeller, then it is known as suction recirculation. If this is found at the outlet of the impeller, then it is known as discharge recirculation Shamsuddeen et al., 2022. Recirculation is inevitable in every impeller design. The discharge recirculation can be reduced in design, but this would result in a reduction in the rated efficiency of the pump. The suction recirculation can likewise be reduced, which would result in an increase in NPSHR (Li et al.,2020). In order to avoid recirculation, the recommendation is not to exceed certain suction specific speeds (a dimensionless ratio describing operating conditions in a pump). Although useful, this advice cannot be applied blindly to all cases. During recirculation, heat is added to the fluid being pumped due to the pump losses. As a result, if the pump operates in this mode for an extensive period of time, temperatures may increase leading to vaporization and potentially an explosive and dangerous condition may exist. This may result in a limiting the flow through the pump (Lin et al., 2021). During suction recirculation, a loud crackling noise is produced around the suction of the pump, for discharge recirculation, at the discharge volute or diffuser. Noise produced by recirculation has a greater intensity than that produced by cavitation, and is normally characterized by a random, knocking sound Jia et al., 2023. Suction or discharge recirculation can be determined by monitoring the pressure pulsations found in the suction and discharge of the pump. Piezoelectric transducers are normally placed close to the impeller on either the suction or discharge side of the pump. Data obtained may be analysed using a spectrum analyser to generate a plot of the pressure pulsations versus the frequency of selected flows. On this plot, a sudden increase in the magnitude of the pressure pulsations would represent the beginnings of recirculation. Pitot tubes installed at the eye of the impeller can also help determine the onset of suction recirculation. With the pitot tube directed into the impeller eye, suction recirculation will occur when the flow reversal from the eye impinges on the pitot tube with a rapid rise in the gauge reading Lu et al., 2024.

$$\Delta h_{rec,p} = \frac{k\omega^3 D_{1,p}^2}{\gamma Q}\left(1-\frac{Q}{Q_0}\right)^{2.5} \tag{5}$$

where $Q_0$ is the design flow rate. The recirculation loss coefficient $k$ depends on the piping configuration upstream of the pump in addition to the geometrical details of the inlet. A default value of 0.005 for the loss coefficient is taken.

(c) Disk Friction loss

Disk friction losses and the flow in the impeller side rooms have therefore found considerable attention in the literature; comprehensive lists of relevant publications are given in Deng et al., 2021: Akdemir et al.,2006. Only a fraction of the work can be quoted subsequent. Earlier experiments on disk friction losses were done with a simple disk rotating in a cylindrical casing, Li et ai.,2020: Pandey et al., 2012, and empirical correlations of disk friction factors as function of Reynolds-number (Re) and equivalent sand roughness were derived from such tests. Later it was recognized that any leakage flow through the side room can influence significantly the pressure distribution on the impeller shrouds and the disk friction itself Shadab et al., 2022 : Chen et al., 2012. These investigations demonstrated that disk friction and the flow in the impeller side room depend on the following parameters: (1) Reynolds)number Re; (2) surface roughness e; (3) direction and rate of (leakage) flow through the side room; (4) the circumferential absolute velocity in which the leakage enters the side room; and (5) geometry. While some aspects of these parameters have been treated in numerous publications, a generic procedure was lacking which allows to account, in a rational way, for all of these effects when calculating disk friction losses. Comparison of calculated and measured axial thrust confirms the validity of these procedures. When pumping highly viscous liquids the power absorbed by the pump increases compared to service in water. This is essentially due to disk friction only. The disk friction power is divided by the rate of flow and the head to be added to the theoretical head when calculating the shaft power demand. Yang et al., 2012 formulated the disk friction loss as:

$$\Delta h_{df,p} = \frac{f_{df,p}\rho\omega^3 r_2^5}{10^9 Q} \tag{6}$$

where the $\omega$ is the angular velocity and the loss coefficient of the disk friction $f_{df,p}$ is assumed as 0.005.

## 2.3 Volute loss

The volute casing collects the fluid from the impeller and leads it into the outlet flange, converting the dynamic pressure rise in the impeller to static pressure Barrio et al., 2008. The flow enters the volute with a through velocity $v_3$ , which is decomposed into a velocity parallel to the direction of a volute $v_{3p}$, and another one in the tangential direction of the impeller $v_{3d}$ . Then the flow exits the volute with a velocity $v_4 = Q/A_{th}$ Chen et al., 2023 which is given as:

$$v_4 = \frac{\eta_v \varepsilon_2 d_{2,p} b_{2,p} v_{r2,p}}{\tan\alpha_v d_{3,p} b_{3,p}} \tag{7}$$

Where:

$$\tan\alpha_v = \frac{A_c}{\pi d_{2,p} b_{2,p} (d_{3,p}/d_{2,p})(b_{3,p}/b_{2,p})} \tag{8}$$

$$v_{3p} = \frac{v_4}{\cos\alpha_v} \tag{9}$$

$$v_{3d} = v'_{\theta 2,p} - v_4 \tag{10}$$

Table 1 Summary of studies reviewed on impeller losses in centrifugal pumps

| Authors | Study focus | Main results achieved |
|---|---|---|
| Jingze et al.,2020 | Numerical Investigation of Flow Field and Energy Loss in a Centrifugal Pump as Turbine | The losses in the impeller are mainly due to flow separation and wake. |
| Win et al., 2019 | Performance Prediction of Centrifugal Pump | The major loss considered is shock losses at the impeller inlet caused by the mismatch of fluid and metal angles. Shock losses can be found everywhere in the flow range of the pump. |
| Han et al., 2018 | Impeller Optimized Design of the Centrifugal Pump: A Numerical and Experimental Investigation | The results demonstrated that optimized impeller, head and efficiency were higher than that of the original pump. With low flow rate (0.8 $Q_d$), the head and efficiency increased by 3.76 m and 3.84%. |
| Zhou et a., 2024 | The optimal hydraulic design of centrifugal impeller using genetic algorithm with BVF | Uniform distribution on the blade surface of optimal designed impeller confirms that the desired object function optimization is realized and this optimal hydraulic design method is available. But it may be due to an insufficient consideration on head estimation to care about all losses; the head of optimal designed impeller is not as good as expected. |
| Wen-Guang Li, 2011 | Effect of exit blade angle, viscosity and roughness in centrifugal pumps investigated by CFD computation | It was shown that a large exit blade angle resulted in an increase in the hydraulic loss over the entire flow rate range in the volute. |
| Gu et al.,2023 | Transient numerical investigation on hydraulic performance and flow field of multi-stage centrifugal pump with floating impellers under sealing gasket damage condition | Among the various loss ratios, the hydraulic loss ratio exhibits the highest magnitude, followed by the leakage loss ratio, with the shroud friction loss ratio being the smallest. |
| Gu et al.,2017 | Effects of the impeller–volute tongue interaction on the internal flow in a low-specific-speed centrifugal pump with splitter blades | Both the large energy loss and vorticity arise at each trailing edge due to flow separation and blade wake, also inducing huge values on the volute wall. However, the impeller–volute tongue interaction had lesser influence on the upstream flow of impeller. |
| Gamal et al., 2019 | Effect of impeller blades number on the performance of a centrifugal pump | Increasing the blades number decreases the pitch ratio and result in more guidance of the flow inside the channels with lower tendency of building energy stratification and the formation of the so-called Jet/Wake. |

| | | |
|---|---|---|
| Varley, 1961 | Effects of Impeller Design and Surface Roughness on the Performance of Centrifugal Pumps | Analysis of the test results with artificially roughened impellers demonstrated that current conceptions of disc friction and the energy balance sheet for a pump are untenable. |
| Xiao et al. 2016 | Effects of Impeller Trimming Methods on Performances of Centrifugal Pump | The results showed that impeller trimming can improve pressure distribution of the impeller outlet, decrease shaft power, and increase energy saving. |
| Tao et al. 2022 | Numerical study on hydrodynamic characteristics of a centrifugal pump influenced by impeller-eccentric effect | The results demonstrated that the eccentric impeller will deteriorate the hydraulic performance of the pump, nonetheless the influence is limited. |
| Sakran et al, 2022 | Effects of Blade Number on the Centrifugal Pump Performance | It is clarified that the performance of the centrifugal pump was significantly affected by the number of blades. With increasing blade numbers head, and efficiency would increase until specific values. |
| Weisheng et al, 2023 | Understanding of energy conversion and losses in a centrifugal pump impeller | Results show that the turbulent loss supplied by TKE production is the main part of the total loss in all investigated cases. The mean-flow viscous dissipation related loss decreases significantly under part-load conditions. |
| Yang et al, 2021 | A Numerical Analysis of the Effect of Impeller Rounding on Centrifugal Pump as Turbine | Internal flow results showed that the efficiency increases along with the decrease in impeller inlet resistance and the flow separation region in the impeller. |
| Shadab et al. 2021 | Effect of impeller shroud trimming on the hydraulic performance of centrifugal pumps with low and medium specific speeds | The results show that the shroud trimming reduces the produced head and efficiency at the design points. Examination of the radial force, which is applied on the rotating parts, shows that shroud-trimmed impellers experience higher radial forces than closed impellers in both pump types owing to the lack of a uniform pressure distribution around the impeller outlet. |
| Barrio et al. 2008 | The Effect of Impeller Cutback on the Fluid-Dynamic Pulsations and Load at the Blade-Passing Frequency in a Centrifugal Pump | For a given impeller diameter, the dynamic load increases for off-design conditions, especially for the low range of flow rates, whereas the progressive reduction of the impeller-tongue gap brings about corresponding increments in dynamic load. |
| Liu et al, 2013 | Experimental, Numerical, and | Experimental results show that PAT flow |

| | | |
|---|---|---|
| | Theoretical Research on Impeller Diameter Influencing Centrifugal Pump-as-Turbine(PAT) | versus head curve is lessened; its flow versus efficiency and flow versus power curves increased after the best-efficiency point in accordance with increasing impeller diameter. |
| Chen et al. 2012 | Simulation and experiment of the effect of clearance of impeller wear-rings on the performance of centrifugal pump | As the clearance value of wear-rings declines, the turbulent kinetic energy and energy dissipation decrease within the impeller, and the impact of secondary flow at the inlet of impeller on the mainstream weakens slowly, which leads to a lower hydraulic loss, thus a higher hydraulic efficiency. |
| Shadab et al. 2022 | Effect of impeller shroud trimming on the hydraulic performance of centrifugal pumps with low and medium specific speeds. | The results show that the shroud trimming reduces the produced head and efficiency at the design points. Examination of the radial force, which is applied on the rotating parts, showed that shroud trimmed impellers experience higher radial forces than closed impellers in both pump types owing to the lack of a uniform pressure distribution around the impeller outlet. |
| Chakraborty et al. 2011 | Numerical Studies on Effects of Blade Number Variations on Performance of Centrifugal Pumps at 4000 RPM | With the increase in blade number, the limitation of space between blade and flow stream increased. The area of low-pressure region at the suction of the blade inlet grows continuously and the static pressure is gradually increasing with the increase in blade numbers. |
| Li at al. 2020 | Effects of a Combination Impeller on the Flow Field and External Performance of an Aero-Fuel Centrifugal Pump | The hydraulic losses inside the impeller and volute can be decreased when the pump is equipped with the combination impeller. In particular, the flow instabilities in the impeller inlet, impeller outlet, and volute tongue are significantly regulated. |
| Akdemir et al. 2006 | Effect of Impeller Materials on Centrifugal Pump Characteristics | Reduction of impeller surface roughness positively affected the pump efficiency and power requirement. The cast brass impeller was more efficient than the cast iron impeller because of the surface roughness of the cast brass was reduced by machining. Total pressure head and flow rate of the cast brass impeller were also higher than cast iron. |
| Kurokawa et al. 1989 | Performance Prediction of Centrifugal Impellers and Scale Effects | The quasi-three-dimensional flow analysis combined with the rough assumption of the reverse flow region at the impeller |

| | | |
|---|---|---|
| | | entrance gave stable and satisfactory results to the impeller outlet flow characteristics for a wide flow-rate range. |
| Deng et al. 2021 | Energy Loss and Radial Force Variation Caused by Impeller Trimming in a Double-Suction Centrifugal Pump | The empirical equations used to predict pump performance after impeller trimming did not accurately predict the head in the investigated pump. The deviation between the tested and predicted head curves was large at overload. The predicted power was consistent with the tested values at all the flowrates studied. Thus, the load on the shaft and the capacity of the conserved energy could be predicted after impeller trimming. |
| Acosta et al. 2022 | An Experimental Study of Centrifugal-Pump Impellers | The Francis-impeller performance agreed better with potential theory than that of the two-dimensional impellers, and it is concluded that the different loss distributions of the two types are responsible. |
| Yamgping et al. 2024 | Design Method for Impeller of Centrifugal Pump With Guide Vanes Based on Oseen Vortex | Results showed that the average efficiency of redesigned pump under the working conditions is 1.04% higher than that of baseline pump, which validates the reliability of proposed design method by theoretical prediction based on Oseen vortex. |
| Yan et al. 2023 | Flow State at Impeller Inlet: Optimization of Conical Frustum Section of Elbow Inlet Conduit in Large Low-Lift Pump Station | The results indicated that the axial velocity distribution at the impeller inlet conforming to the cascade high-efficiency characteristics will achieve a better pump performance compared with a uniform distribution. |
| Yanpi et al. 2021 | Influence of Impeller Sinusoidal Tubercle Trailing-Edge (STTE) on Pressure Pulsation in a Centrifugal Pump at Nominal Flow Rate | Results show that a reasonable design of STTE can effectively eliminate the high-frequency pressure pulsation in the rotor–stator interaction region of the centrifugal pump. The use of STTE2 and STTE3 profiles affect the amplitude reduction of pressure pulsation at the blade passing frequency (fBPF). Compared with the impeller without the STTE profile, the amplitudes of pressure pulsation with STTE2 and STTE3 profiles decreased by 47.10% and 44.20% at the pump discharge, while the decrease, at the volute throat is 30.36% and 25.97%, respectively. |

| | | |
|---|---|---|
| Hyeon-Seok et al. 2020 | Design Optimization of the Impeller and Volute of a Centrifugal Pump to Improve the Hydraulic Performance and Flow Stability | The representative Pareto-optimal solutions obtained by the multi-objective genetic algorithm (MOGA) show enhanced objective function values compared to the baseline design. The results of unsteady calculation show that the flow instability of the centrifugal pump was successfully suppressed by the optimization. |

Table 2 Summary of studies reviewed on volute losses in centrifugal pumps

| Authors | Study focus | Main results achieved |
|---|---|---|
| Jingze et al.,2020 | Numerical Investigation of Flow Field and Energy Loss in a Centrifugal Pump as Turbine | The loss in the volute was mainly composed of friction loss and impact loss at the tongue. The loss in the guide vanes was due to the flow separation in the flow channel. |
| Mohamed et al., 2022 | Numerical investigation of losses in a double suction multistage centrifugal pump | The stage-to-stage analysis showed the loss mitigation at the second stage by the installation of the baffle plates in the first stage. The stage head loss decreased by 63.7%, 57.3%, and 76.75% while stage efficiency rose by 26.1%, 29.13%, and 22.84% for baffle plate designs 1, 2, and 3, respectively. |
| Gou et al., 2023 | Analysis and Comparison of Two Kinds of Design Approaches for Volutes of Centrifugal Pump | These findings demonstrated that the lengths of perimeters of volute cross-sections and inlet widths of volutes were considered two important geometrical parameters related to hydraulic losses in volutes |
| Khin Cho et al., 2008 | Design and Performance Analysis of Centrifugal Pump | The impeller friction losses, volute friction losses and disk friction losses are considered to less than the friction effect on centrifugal pump. Moreover, recirculation losses are also considered. |
| Achoura et al., 2021 | Numerical study of the performance loss of a centrifugal pump carrying emulsion | Since the emulsion viscosity is higher than that of water, the pump head decreases, which is caused by an increase in hydraulic losses. |
| Bowerman et al. 2022 | Effect of the Volute on Performance of a Centrifugal-Pump Impeller | The results showed that at their respective design flow rates, the influence of the volutes is least and the deviation of performance from the free-impeller operation was found to be small. |
| Worster et al. 1963 | The Flow in Volutes and Its Effect on Centrifugal Pump Performance | The pump casing determines much of the environment in which the impeller works and sometimes it has a profound effect on impeller performance: it can cause the impeller to work very inefficiently and it can destroy a large part of the energy given to the flow by the impeller: |

| | | |
|---|---|---|
| Litfin et al. 2014 | The Effect of Volute Design on Unsteady Flow and Impeller–Volute Interaction in a Centrifugal Pump | As a result of the performed study, it can be seen how the different volute designs interact with the impeller depending on the operation point and how this affects the hydraulic performance of the pump. |
| Iversen et al. 1960 | Volute Pressure Distribution, Radial Force on the Impeller, and Volute Mixing Losses of a Radial Flow Centrifugal Pump | The resultant force from the integrated pressure distribution was found to give a reasonable design approximation of the radial force. |
| Gonzalez et al. 2002 | Numerical Simulation of the Dynamic Effects Due to Impeller-Volute Interaction in a Centrifugal Pump | 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 |
| Allali et al. 2015 | Numerical approach based design of centrifugal pump volute | The obtained results show that the form of the volute and the nature of fluid flow have a sensitive effect on the velocity, the pressure as well as on the shear stress. |
| Parrondo-Gayo et al. 2002 | The Effect of the Operating Point on the Pressure Fluctuations at the Blade Passage Frequency in the Volute of a Centrifugal Pump | The findings unequivocally demonstrated the tongue's dominant involvement in the impeller-volute interaction, as well as the marked rise in dynamic force magnitude and dipole-like sound generation under non-design conditions. |
| Atia, 2014 | Effect of Blade Exit Shape on Performance and Vibration of a Double Volute Centrifugal Pump | The impeller-volute interaction is an important design parameter and that design must be chosen carefully in each pump based on the pump design and operating conditions to minimize the flow induced vibration. |
| Zhang et al. 2009 | Effect of the Section Area of Volute in Low Specific Speed Centrifugal Pumps on Hydraulic Performance | It has been found that the uneven flow rate on different volute sections caused by the backflow between volute and impeller is one of the reasons for the efficiency decline of pumps at off-BEP conditions, especially in the low flow rate condition. It has also been found that the routine-designed impeller is more easily affected by the section area of volute than non-overloading designed impeller. |
| Hamed et al. 2014 | Effect of the volute tongue profile on the performance of a low specific speed centrifugal pump | The volute with short tongue provides lower radial force at lower capacity; however, the volute with sharp tongue was more efficient at off-design conditions. |
| Baun et al. 2000 | Effect of Relative Impeller-to volute Position on | At the optimum position the magnitude of the radial force characteristic for the |

| | | |
|---|---|---|
| | Hydraulic Efficiency and Static Radial Force Distribution in a Circular Volute Centrifugal Pump | circular volute is virtually identical to that of the spiral volute over the full flow range. |
| Khoeini et al. 2017 | Effects of Volute Throat Enlargement and Fluid Viscosity on the Performance of an Over Hung Centrifugal Pump | It was found that increasing the volute throat area, the head of BEP increased by 3.1% at 105% of the first volute throat area and eventually head enhancement by 6.4% achieved at 112% of the first volute throat area. |
| Shim et al. 2020 | Effects of the Cross-Sectional Area of a Volute on Suction Recirculation and Cavitation in a Centrifugal Pump | The results show that unlike the blockage, the hydraulic and suction performances were affected significantly by the volute shape. |
| Xiaojun et al. 2016 | Experimental and numerical investigations of head-flow curve instability of a single-stage centrifugal pump with volute casing | Results showed that the losses mainly focused on the blade suction surface and volute tongue, as well as in the region of the volute discharge at high flow rates. |
| Beomjun et al. 2018 | Flow characteristics in a volute-type centrifugal pump using large eddy simulation | It was found that vortices were shed from the blade trailing edge both at the design and off-design conditions. However, at the off-design condition, these vortices interacted with those from the following blade and leakage through radial gaps, causing broader areas of stronger vortices inside the volute. |
| Chalghoum et al. 2016 | Numerical Modeling of the Flow Inside a Centrifugal Pump: Influence of Impeller–Volute Interaction on Velocity and Pressure Fields | Results indicated that the experimental characteristic curves of centrifugal pump show good concordance with those obtained numerically by three turbulence models (kε, SST and SST-CC). At the design operating point, the SST model generally predicts the best result on the characteristic curve; its results are slightly better than those obtained using k-ε and SST-CC models. |
| Keller et al. 2014 | PIV measurements of the unsteady flow structures in a volute centrifugal pump at a high flow rate | The data obtained show that the fluid–dynamic blade–tongue interaction is dominated by high-vorticity sheets (positive and negative) being shed from the impeller channels, especially from the blade trailing edges, and their impingement on the tongue tip with subsequent cutting and distortion. |
| Yuan et al. 2019 | Numerical Investigation on the Mechanism of Double-Volute Balancing Radial Hydraulic Force on the Centrifugal Pump | The numerical simulations revealed that double-volute pump has smaller radial-force magnitude than single-volute pump on the abnormal conditions. |
| Qiuqin et al 2023 | Analysis and Comparison of | The numerical results show that the |

| | | |
|---|---|---|
| | Two Kinds of Design Approaches for Volutes of Centrifugal a Pump | head and efficiency can be improved using a shorter cross-section wet volute under the same impeller conditions. The influence of the wetted perimeters of the volute sections on the pump performances is more remarkable than that originating from the volute inlet width. |
| Khan et al 2024 | Impact of Volute Throat Area and Gap Width on the Hydraulic Performance of Low-Specific-Speed Centrifugal Pump | The results from numerical simulations revealed that the head–capacity curve becomes steeper and that the best efficiency point (BEP) becomes closer to the design point as the volute throat area is reduced. Efficiency also improves, especially at underload and design flow conditions. |

## 3. Future studies

The field of hydraulic losses in centrifugal pumps can progress toward more dependable, effective, and environmentally friendly pumping systems, which benefits numerous industries and applications, by concentrating on these possible study subjects. Computational fluid dynamic (CFD): Create more complex CFD models to simulate turbulence and complex flow patterns in centrifugal pumps. This will allow for a thorough analysis of hydraulic losses in a range of operating conditions. Advanced materials: Consider the ways that utilizing state-of-the-art materials with improved wear and corrosion resistance might reduce hydraulic losses and lengthen the life of pump parts. Smart pump technology: Consider the ways that utilizing state-of-the-art materials with improved wear and corrosion resistance might reduce hydraulic losses and lengthen the life of pump parts. Optimization algorithms: Develop advanced optimization algorithms to systematically identify optimal pump configuration and operating parameters that minimize hydraulic losses and maximize energy efficiency. Energy recovery systems: Examine whether it is possible to use energy recovery systems, like hydraulic turbines or regenerative brakes, to capture and utilize hydraulic losses and boost pump efficiency. Environmental Impact: Assess the environmental impact of hydraulic losses in centrifugal pumps and explore sustainable solutions to reduce energy consumption and carbon emissions associated with pump operation. Machine Learning Applications: Examine how hydraulic losses in centrifugal pumps can be predicted and optimized using machine learning techniques that account for both past performance and present operating conditions.

## 4. Knowledge gaps

Engineers and researchers may improve the performance, dependability, and efficiency of centrifugal pumps by filling in these knowledge gaps, which will help fluid handling systems across a range of sectors. Impact of Design Parameters: Further research is necessary to examine the impact of design parameters on hydraulic losses in centrifugal pumps, including impeller geometry, volute design, and clearance thickness. Optimization Techniques: There is a gap in knowledge regarding the development and application of advanced optimization techniques to minimize hydraulic losses and improve the overall efficiency of centrifugal pumps

Effect of Wear and Tear: Research focusing on the impact of wear, erosion, and corrosion on hydraulic losses in centrifugal pumps is necessary to develop effective maintenance strategies

Experimental Validation: There is a need for more experimental studies to validate theoretical models and simulations related to hydraulic losses in centrifugal pumps for real-world applications

Effect of Operating Conditions: To fully comprehend how changes in fluid characteristics, pressure, flow rate, and other operating parameters affect hydraulic losses in centrifugal pumps, more research is required. Transient Behavior: Understanding the transient behavior of centrifugal pumps and how it relates to hydraulic losses is necessary to improve their performance in dynamic operating conditions.

## 5. Conclusions

A number of crucial factors must be considered in order to lower centrifugal pump losses. These components are necessary to increase overall efficiency, minimize hydraulic losses, and maximize pump performance. Some of the most important factors to consider are.

- Pump components need to be regularly maintained and inspected in order to ensure optimal performance and minimize losses. Resolving issues such as wear, misalignment, and damage can help prevent efficiency losses.
- The impeller and casing should have enough clearance and tolerance to reduce leakage and recirculation. Put into practice strategies to stop cavitation, include enhancing impeller design, lowering operating speeds, and optimizing suction condition.
- It is necessary for further research to be performed on variables like the diameter, angle, number, inlet with, volute cross section and profile of the blades to reduce losses and enhance flow characteristics.

## References

1. Li, J., Meng, D., & Qiao, X. (2020). Numerical investigation of flow field and energy loss in a centrifugal pump as turbine. Shock and Vibration, 2020(1), 8884385.
2. Win, D. H. H., Htike, D. T. T., & MYO, M. (2019). Performance prediction of centrifugal pump. IRE J, 3(2).
3. Han, X., Kang, Y., Li, D., & Zhao, W. (2018). Impeller optimized design of the centrifugal pump: A numerical and experimental investigation. Energies, 11(6), 1444.
4. Zhou, X., Zhang, Y., Ji, Z., & Hou, H. (2014). The optimal hydraulic design of centrifugal impeller using genetic Algorithm with BVF. International Journal of Rotating Machinery, 2014(1), 845302.
5. Li, W. (2011). Effect of exit blade angle, viscosity and roughness in centrifugal pumps

investigated by CFD computation. TASK Quarterly. Scientific Bulletin of Academic Computer Centre in Gdansk, 15(1), 21-41.

6. Gu, Y., Bian, J., Wang, C., Sun, H., Wang, M., & Ge, J. (2023). Transient numerical investigation on hydraulic performance and flow field of multi-stage centrifugal pump with floating impellers under sealing gasket damage condition. Physics of Fluids, 35(10).
7. Elyamin, G. R. A., Bassily, M. A., Khalil, K. Y., & Gomaa, M. S. (2019). Effect of impeller blades number on the performance of a centrifugal pump. Alexandria Engineering Journal, 58(1), 39-48.
8. Varley, F. A. (1961). Effects of impeller design and surface roughness on the performance of centrifugal pumps. Proceedings of the Institution of Mechanical Engineers, 175(1), 955-989.
9. Qu, X., & Wang, L. (2016). Effects of impeller trimming methods on performances of centrifugal pump. Journal of Energy Engineering, 142(4), 04016008.
10. Yu, T., Shuai, Z., Jian, J., Wang, X., Ren, K., Dong, L., ... & Jiang, C. (2022). Numerical study on hydrodynamic characteristics of a centrifugal pump influenced by impeller-eccentric effect. Engineering Failure Analysis, 138, 106395.
11. Sakran, H. K., Abdul Aziz, M. S., Abdullah, M. Z., & Khor, C. Y. (2022). Effects of blade number on the centrifugal pump performance: a review. Arabian Journal for Science and Engineering, 47(7), 7945-7961.
12. Chen, W., Li, Y., Liu, Z., & Hong, Y. (2023). Understanding of energy conversion and losses in a centrifugal pump impeller. Energy, 263, 125787.
13. Yang, H., Zhu, L., Xue, H., Duan, J., & Deng, F. (2021). A numerical analysis of the effect of impeller rounding on centrifugal pump as turbine. Processes, 9(9), 1673.
14. Shadab, M., Karimipour, M., Najafi, A. F., Paydar, R., & Nourbakhsh, S. A. (2022). Effect of impeller shroud trimming on the hydraulic performance of centrifugal pumps with low and medium specific speeds. Engineering Applications of Computational Fluid Mechanics, 16(1), 514-535.
15. Barrio, R., Blanco, E., Parrondo, J., González, J., & Fernández, J. (2008). The effect of impeller cutback on the fluid-dynamic pulsations and load at the blade-passing frequency in a centrifugal pump.
16. Yang, S. S., Liu, H. L., Kong, F. Y., Dai, C., & Dong, L. (2013). Experimental, numerical, and theoretical research on impeller diameter influencing centrifugal pump-as-turbine. Journal of Energy Engineering, 139(4), 299-307.
17. Chen, S. X., Pan, Z. Y., Wu, Y. L., & Zhang, D. Q. (2012, November). Simulation and experiment of the effect of clearance of impeller wear-rings on the performance of centrifugal pump. In IOP conference series: earth and environmental science (Vol. 15, No. 7, p. 072017). IOP Publishing.
18. Shadab, M., Karimipour, M., Najafi, A. F., Paydar, R., & Nourbakhsh, S. A. (2022). Effect of impeller shroud trimming on the hydraulic performance of centrifugal pumps with low and medium specific speeds. Engineering Applications of Computational Fluid Mechanics, 16(1), 514-535.
19. Pandey, K. M., Singh, A. P., & Chakraborty, S. (2012). Numerical studies on effects of blade number variations on performance of centrifugal pumps AT 2500 rpm. Journal of Environmental Research And Development, 6(3A), 863-68.
20. Li, J., Wang, X., Wang, Y., Wang, W., Chen, B., & Chen, X. (2020). Effects of a combination impeller on the flow field and external performance of an aero-fuel centrifugal pump. Energies, 13(4), 919.
21. Akdemir, B., Kayisoglu, B., & Kocoglu, S. (2006). Effect of Impeller Materials on Centrifugal Pump Characteristics. AGRICULTURAL MECHANIZATION IN ASIA AFRICA AND LATIN AMERICA, 37(2), 62.
22. Kurokawa, J., & Jiang, J. (1989). Performance prediction of centrifugal impellers and scale

effects. In Proceedings, International Symposium on Large Hydraulic Machinery & Associated Equipment: 28-31 May 1989, Beijing, China (Vol. 1, pp. 56-67). International Association of Hydraulic Research (IAHR).

23. Deng, Q., Pei, J., Wang, W., Lin, B., Zhang, C., & Zhao, J. (2021). Energy loss and radial force variation caused by impeller trimming in a double-suction centrifugal pump. Entropy, 23(9), 1228.
24. Acosta, A. J., & Bowerman, R. D. (1957). An experimental study of centrifugal-pump impellers. Transactions of the American Society of Mechanical Engineers, 79(8), 1821-1839.
25. Lu, Y., Liu, M., Tan, L., & Liu, D. (2024). Design Method for Impeller of Centrifugal Pump With Guide Vanes Based on Oseen Vortex. Journal of Fluids Engineering, 146(6).
26. Jia, X., Lv, H., & Zhu, Z. (2023). Research on the influence of impeller tip clearance on the internal flow loss of axial circulating pump under unpowered driven condition. Journal of Fluids Engineering, 145(2), 021202.
27. Lin, Y., Li, X., Li, B., Jia, X., & Zhu, Z. (2021). Influence of impeller sinusoidal tubercle trailing-edge on pressure pulsation in a centrifugal pump at nominal flow rate. Journal of Fluids Engineering, 143(9), 091205.
28. Shim, H. S., & Kim, K. Y. (2020). Design optimization of the impeller and volute of a centrifugal pump to improve the hydraulic performance and flow stability. Journal of Fluids Engineering, 142(10), 101211.