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Studying the Effect of Splitter Blades on the Performance of a Centrifugal Pump with Two-Phase Flow

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ABSTRACT

Slurry flow, a solid-liquid two-phase flow, has long been one of the most challenging industrial processes. The existence of the solid phase in centrifugal pumps decreases the pump efficiency and output head as well as increases the consumed power. Furthermore, it increases the pressure fluctuations inside the pump resulting in increased vibrations, noise, cavitation vulnerability, and abrasion of the pump components. Accordingly, in the present study, the effect of splitter blades on the performance and pressure fluctuations of a centrifugal pump handling solid-liquid two-phase flow is numerically investigated. The proposed splitters have the same profile as the impeller blades and are 50% of the impeller blades' length. Each splitter is placed at the centre of the impeller blades' passages, and consequently, the splitter blades have the same number as the main blades. The numerical simulations are carried out based on the three-dimensional, incompressible, turbulent, and unsteady Reynolds-Average Navier-Stokes (URANS) equations along with the k-ε turbulence model. In this study, experimental results from the literature are used to validate the results predicted by the current numerical model. Predicted results revealed that using splitter blades has a positive effect on the performance of the pump handling two-phase flow by increasing the net pump head by 11.8 % at the design point compared with the original impeller. Moreover, the fluctuation in pressure within a whole impeller cycle is significantly reduced by utilizing the proposed splitters.

Keywords: *Centrifugal pump; Two-phase flow; Splitter blades; Performance enhancement; CFD.*

1. Introduction

Centrifugal pumps handling solid-liquid two-phase (slurry) flow are extensively utilized in different fields including dredging industry, agriculture, petrochemicals, mining, and sewage handling. Since the centrifugal pumps are not designed to handle solids, the solid phase not only decreases the pump efficiency and output head but also increases the consumed power. Furthermore, the pressure fluctuations inside the pump increase, leading to increasing vibration, noise, cavitation vulnerability, and abrasion of the pump components. The experimental studies that investigated such types of flow are limited due to their complicated nature. With the development of computational fluid dynamics (CFD) tools, that have better accuracy and reliability, the numerical simulation has been used widely to predict pump performance and precisely describe the flow field inside it. Several research have been implemented to study the performance of centrifugal pumps while handling slurry flow; however, the improvement on the pump performance remains a concern. Selim et al. [1] showed that adding the solid phase decreases head, efficiency, and increases consumed power and cavitation. The study also proposed an empirical correlation to predict the reduction in pump head due to the insertion of the solid phase. Khalil et al. [2] indicated experimentally that the presence of solid phase causes degradation in the pump performance as the head and efficiency were decreased and the power consumption was increased. Their results also revealed that the degradation of the pump performance rises with increasing the solid phase volumetric concentration. Jiang, et al. [3] reported that with increasing the solid phase volumetric concentration, the impeller inlet velocity increases thus, the pressure decreases which in turn increases cavitation. Several studies were implemented to investigate the effect of solid particles on the performance of the centrifugal pump. Peng et al. [4] studied the effect of solid-liquid mixture with high solid concentration (laden flow) on a large-scale centrifugal pump using the Eulerian-Eulerian method. The study has revealed that increasing the solid phase concentration leads to an increase in flow viscosity and the flow resistance which in turn increases the backflow and makes a serious pre-whirl at the impeller inlet. Wang et al. [5] studied numerically the effect of

Solid-Liquid Two-Phase flow on a centrifugal pump and concluded that the increase of particle size causes the suction pressure at inlet to intensify causing higher cavitation probability and the same effect for increasing the particles volume fraction. Yang et al. [6] used a new technique of image processing to use the PIV method to measure the flow of a mixture from solid and liquid. New software was used to separate between solid particles and parcels. Based on this new technique, the effect of multi-sized concentrated slurries has been studied.

Sellgren and Addie [7] studied the effect of solid particles on the performance in terms of head and efficiency of the large centrifugal pumps. They concluded that the insertion of the solid particles decreased the pump efficiency and the drop in the pump head was even more. Walker and Goulas [8] investigated the performance of centrifugal pumps while handling fine homogenous and non-Newtonian mixture of (coal/water and kaolin/water) using two different pumps. The results of the study showed that there is a correlation between the drop in pump head and efficiency and Reynolds number. Ni et al. [9] studied the effect of handling high volumetric concentrations (up to 42%) of sand on head, efficiency and consumed power. The study also included the influence of fine, medium and coarse sand, and it showed that the slop of the head ratio (head in slurry/head in water) increased with increasing the sand size. Only the medium sand had a critical value, above which both head and efficiency ratios dropped faster. Kazim et al. [10] studied the influence of particle size, particle size distribution, specific gravity and concentration of solids on the head and efficiency of centrifugal pumps. They found that, the drop in efficiency is lower than in head at any flow rate and any concentration of solid. Due to the complexity of the solid-liquid two phase flow, it was required to determine how the solid particles influence on flow structure, unsteadiness, noise and induced vibration, erosion on the impeller blade and volute wall and generally the total performance of this pump. With the development of Computational Fluid Dynamics (CFD), such type of flow was analyzed and understood well.

Zhang et al. [11] studied the three-dimensional, incompressible and turbulent solid-liquid two-phase flow in centrifugal pump using the mixture model for the two-phase and RNG k -ε turbulence model. The results showed that the pump performance (head and efficiency) was reduced with increasing solid concentration or particles size. Cheng et al. [12] used CFX to model solid-liquid flow in three-dimensional back-swept centrifugal pump. Both phases were considered continuous (Eulerian–Eulerian flow) and the study demonstrated that the particles tend to gather close to the suction surface depending on the solid volumetric concentration. Moreover, the particles move to shroud side because of the large swept-back angle and wrap angle. Wu [13] simulated the unsteady, 3D, two-phase flow inside the centrifugal pump using ANSYS Fluent software. Using RNG k-ε turbulence model and mixture model for two-phase flow, the study showed the clocking effect (position of impeller relative to volute tongue) has a great effect on the pump specially while handling single phase. In addition, the solid-phase influences on the jet-wake structure. The variation of relative velocity of solid-phase flow was 7.6% smaller than clear water flow at impeller outlet.

Li et al. [14] implemented a numerical and experimental study of different solid particles diameter and their effect on the centrifugal pump performance. Using the mixture model, the study showed that, the experimental values are close to the simulated values (but smaller). Also, the effect of solid particles is small at flow rate smaller than design ($Q < 0.24\ Q_{design}$). It was noted that the particle volumetric concentration has a greater influence than the particle diameter. Gandhi et al. [15] performed an experimental study to the centrifugal pump characteristics at different speeds and concluded that the affinity laws that apply on the clear water condition can be applied also while handling solid-liquid flow but at low solid weight fraction (less than 20%) and for higher concentrations the affinity laws need to be corrected by taking into consideration the solid phase. The Solid particles also tend to increase the centrifugal pump susceptibility to cavitation. Roundnev [16] studied the suction performance of a slurry pump handling solids with diameters of 0.2, 0.96, 1.8 and 6.15 mm respectively. The study showed the variation of the required pump net positive suction head compared to single phase condition. Although there are many studies of the slurry flow through a centrifugal pump, the studies that introduce design modifications to enhance the pump performance are limited. Bozorgasareh et al. [17] introduced a new impeller configuration with innovatively designed shrouds. Experimental and numerical investigations were achieved to explore the new design effect on the pump head and efficiency. The proposed design involves attaching specific plates, called bladelets, to a semi-open impeller to reduce secondary flows over the blades, thereby increasing pump head and efficiency. Experimental and numerical investigations were conducted on a centrifugal pump with three different bladelet angles (30°, 60°, and 90°), showing acceptable agreement. Flow analysis reveals that impellers with 90° bladelets enhance hydraulic performance almost to that of a closed impeller configuration. The reduction in losses from secondary flows and eddy generation contributes to the improved hydraulic performance of the suggested design. Gu et al. [18] attempted to study the impact of solid-phase particle concentration on centrifugal pump characteristics and the drag reduction effects of an impeller with a non-smooth surface. Using an Eulerian model, numerical simulations were conducted by incorporating pit-type non-smooth surfaces on the impeller blades. Findings indicate that the pit-type non-smooth surface demonstrates superior drag reduction compared to other configurations. The shear stress within the pit is significantly lower than on a smooth surface, thereby enhancing the operational efficiency of solid-liquid two-phase flow in centrifugal pumps. One of the most studied modifications on the centrifugal pump impeller while handling clear water is splitter blades. Kergourlay et al. [19] studied the influence of adding splitter blades on the performance of a hydraulic centrifugal pump whose impeller is designed with and without splitter blades. Analysis of flow morphology reveals that the addition of splitter blades to the impeller leads to more uniform peripheral velocities and pressures. Pressure fluctuations were assessed at four locations during the best efficiency point (BEP) using dynamic pressure sensors. Experimental findings align with numerical predictions, confirming the impact of adding splitter blades on pump performance. Adding splitters has a positive effect on the pressure fluctuation. Yuan et al. [20] implemented an investigation to study the effects of splitter blade on the pump performance and flow characteristics in a high-speed centrifugal pump. Harnessing of splitter blades resulted in an approximate 10m increase in pump head and nearly 4% enhancement in operating efficiency. Additionally, the outflow jet-wake structure from the impeller showed significant improvement. There was a notable increase in jetting flow and a reduction in flow separations within the blade passage. Furthermore, the presence of splitter blades led to a more balanced distribution of turbulence kinetic energy, reducing turbulent kinetic energy dissipation and enhancing flow stability. Frequency domain analysis demonstrated a more even distribution of pressure fluctuations within the impeller with splitters, thereby promoting steady flow in the pump.

Patil et al. [21] used a numerical approach by using CFD to investigate Effect of Splitter Blades on Centrifugal Pump Performance. The study findings indicated that splitter blades decrease fluid clogging at the impeller inlet, thereby enhancing pump performance. Additionally, splitter blades reduce pressure fluctuations, leading to decreased vibration and noise, and increased pump head for the same power input. Furthermore, some research suggests that using splitter blades positively impacts suction performance, thereby reducing cavitation. Cavazzini et al. [22] compared between centrifugal pumps impeller with and without splitter blades in terms of suction performance experimentally and numerically. During the study, the same number of blades, meridional shape and volute casing to describe accurately the role played by the splitter blades in cavitation inception and development. The study showed a remarkable improvement with the usage of splitters at high flow rates while the suction performance deteriorates at low flow rates.

Namazizadeh et al. [23] attempted to optimize the centrifugal pump impeller by adding splitters. A numerical and experimental study was carried out to obtain the pump characteristic curves. The results showed that incorporating splitters can enhance total head by approximately 10.6%, and through geometric modifications using the Design of Experiment (DoE) technique, this improvement could further increase by 4.4%, with minimal impact on the overall efficiency of the pump. In their study, Shigemitsu et al. [24] utilized a three-dimensional steady numerical flow analysis to examine rotor performance, volute efficiency, and vortex-induced losses. Experimental findings demonstrate that the presence of splitter blades enhances the performance of the miniature centrifugal pump. With splitter blades, flow uniformity improves at the rotor outlet, while backflow regions are mitigated. Additionally, there is an increase in volute efficiency and a decrease in vortex-induced losses. Ke et al. [25] studied the performance of a Low specific speed centrifugal pump and the results showed that the splitter blades not only solved the backflow of the flow channel and compressed the range of the trailing vortex, but it also alleviated the cavitation at the inlet of the main blade.

There are several research studied the effect of adding splitter blades on centrifugal pump performance while handling clear water. However, there is a lack in the studies related to centrifugal pump performance with solid-liquid two-phase flow. Accordingly, in the present study, the effect of splitter blades on the performance and pressure fluctuation of centrifugal pump handling solid-liquid two-phase flow is numerically investigated. The proposed pump design has a 177 mm impeller with 8.2 liter/sec flow rate and 30.5 m head. The proposed splitters have the same profile as the impeller blades and are 50% of the impeller blades' length. Each splitter is placed at the center of the impeller blades' passages, and consequently, the splitter blades have the same number as the main blades.

2. Physical Model

In the present study, the pump tested by Teaima [26] is adopted. The pump has single-stage, single-suction and untwisted blades in shrouded impeller. The pump specifications are given in Table 1. Splitter blades are proposed to be utilized between the main impeller blades to provide guidance to the flow and mitigate the negative effects due to the existence of solid phase aiming at enhancing the pump performance. Figure 1 shows the original impeller blades as well as the proposed design with splitter blades.

Table 1**:** Pump specifications [26]

Inlet pipe diameter	54 mm
Duct width or pipe outlet diameter	50 mm
Inlet impeller diameter	54 mm
Outlet impeller diameter	177 mm
Blades number	6
Blades thickness	5 mm
Inlet blade height	10.5 mm
Outlet blade height	5 mm
Inlet blade angle	21.5°
Outlet blade angle	28°
Operation rotational speed	2900 rpm
Design flow rate	8.2 Lit/s
Design pressure head	287013.5 N/m^2

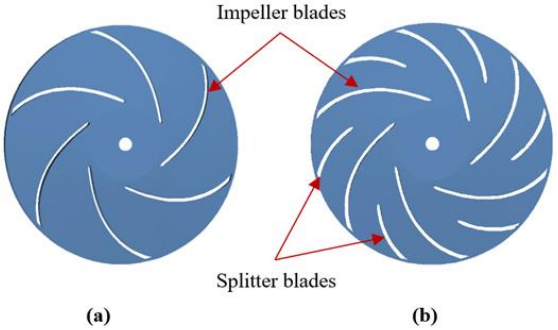


Fig. 1: (a) Original impeller blades and **(b)** Proposed design with splitter blades

3. Theoretical Analysis

In the present work, a three-dimensional, unsteady, incompressible, and turbulent flow inside a centrifugal pump handling single (liquid) and two-phase (solid/liquid) flows is developed. The model includes the Unsteady Reynolds-Averaged Navier-Stokes (URANS) equations in conjunction with the k-ε turbulence model. The flow governing equations including continuity and momentum equations represented in absolute velocity formulation and Cartesian tensor can be presented in a general form as follow:

$$\frac{\partial}{\partial t}(\rho_l)+\frac{\partial}{\partial x_j}(\rho_l u_j)=0 \tag{1}$$

$$\frac{\partial}{\partial t}(\rho_l u_j)+\frac{\partial}{\partial x_j}(\rho_l u_i u_j)=-\frac{\partial p}{\partial x_j}+\frac{\partial}{\partial x_j}\left[(\mu_l+\mu_t)\left(\frac{\partial u_i}{\partial x_j}+\frac{\partial u_j}{\partial x_i}\right)\right]+Su_{ip}+\rho_l g_i \tag{2}$$

Where $u_i$and $u_j$is the liquid velocity component at i direction and j direction, ρ_l is the liquid density, μ_t is the turbulent viscosity, μ_l is the fluid viscosity, and p is the mean pressure. The phase interactions are considered by the additional source term Su_{ip}, which is incorporated in the Navier-Stokes equations and calculated implicitly.

The basic equation of particle motion can be expressed as:

$$\frac{dx_{pi}}{dt}=u_{pi} \tag{3}$$

$$\frac{du_{pi}}{dt}=\frac{3c_D\rho_l}{4\rho_p D_p}|u_s|u_s \tag{4}$$

where, u_s is the slip velocity between particles and liquid, c_D is the drag coefficient related to the Reynolds number, ρ_p is the particle density, D_p is the particle diameter and x_{pi} is the geometric coordinate position of particles.

3.1 Computational Domain and Boundary Conditions

Figure (2) presents the computational domain of the present study along with the adopted boundary conditions. The computational domain consists of 4 sections, including the inlet pipe, impeller, volute and extension pipe after the volute. The boundary conditions were selected as mass flow rate at the pump inlet and the static pressure at the pump outlet. The impeller (original or Splittered) is considered as a moving wall with no slip boundary condition whereas all other solid walls are taken as stationary walls with no slip boundary condition. To minimize the influence of perturbations in boundary conditions, ensure a stable flow at the inlet, and achieve fully developed flow at the outlet, the lengths of the inlet pipe and outlet pipe are chosen to be five times the diameter of the inlet and 2.5 times the diameter of the volute outlet, respectively.

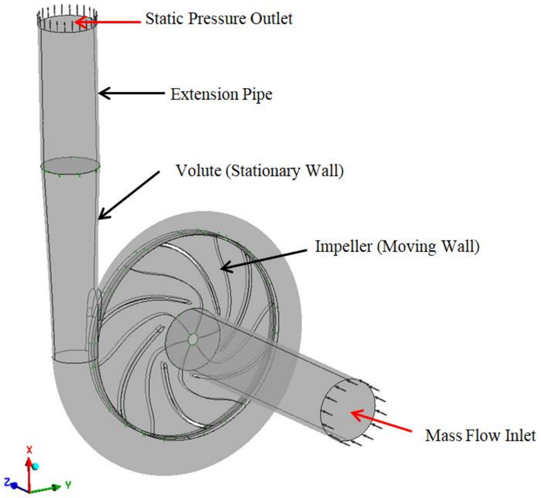


Fig. 2: Computational domain along with the adopted boundary conditions

4. Numerical Solution

In the present work, ANSYS-CFX software is utilized to solve the developed 3D, unsteady, incompressible, and turbulent flow inside a centrifugal pump handling single (liquid) and two-phase (solid/liquid) flows. The Eulerian-Lagrangian approach is used to simulate the two-phase flow. The simulation is performed for water as a continuous phase together with sand solid particles as a dispersed solid. The sand particles are assumed to have a spherical shape with density ρ_s =2520 kg/m^3 and a concentration of 20 % on mass basis. In order to facilitate the numerical simulation, the measured size distribution is fitted according to Rosin-rammler equation, Ref [27]. The mean diameter of particles is found to be 0.28 mm. However, the spread parameter (n) is found to be equal 3.

Regarding the convergence criteria of the numerical simulation, the numerical solution has two conditions to converge; the residuals to become less than 10^{-4}, and the pump head value remains constant for the single phase. While handling two-phase flow, another condition is added to the convergence criteria of the single-phase which is the mass flow rate of the solid particles to be almost constant.

4.1 Grid independence Study

In the current study, an unstructured grid with tetrahedral elements is considered to generate mesh for the complete flow domain as shown in Fig. 3. Fine mesh has been created in the rotating region and compared to the stationary zone. A grid independence study was performed utilizing the unstructured mesh of suitable grid sizes. Thus, three different grid numbers of 1.0, 1.8, and 4.5 million cells are tested as shown in Fig. 4. It is found that there are no remarkable variations in all computed parameters with increasing grid numbers over 1.8 million cells. Hence, the 1.8 million cells are retained for all presented computations.

Fig. 3: Grid generation for the computational domain

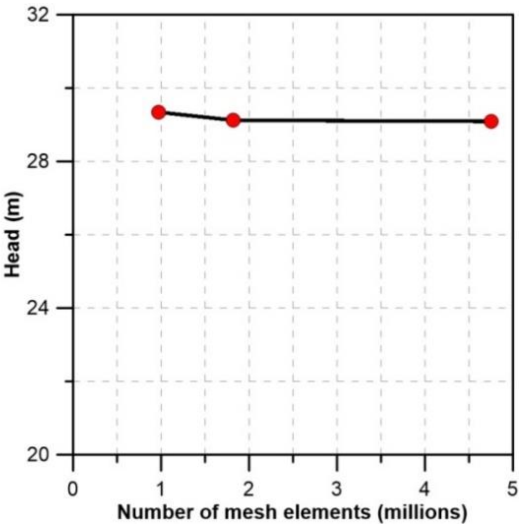


Fig. 4: Grid independence study

5. Results and Discussion

In this section, the current simulation is validated using the available measurements from literature. Moreover, the numerical results of the effect of the proposed design with splitters on the performance of the centrifugal pump with two phase flow are also presented.

5.1 Model Validation

The Experimental data of Teaima [26] was used to validate the numerical data for the single phase as well as the two-phase with concentration of 20% of the solid particles. Figure 5 presents the variation of the pump head with different flow rates for single-phase flow condition. From Fig. 5, it can be seen that there is good agreement between numerical results and measurement results for single phase flow.

The effect of the solid phase on the performance characteristics was emphasised in literature review section as it causes degradation of the pump performance. Moreover, it increases the flow disturbances which in turn increase vibration and noise compared to single-phase condition. Accordingly, the experimental results from ref. [26] are used as another validation for two-phase flow condition. The utilized concentration of solid phase is considered as 20%. Figure 6 depicts a ccomparison between the predicted H-Q curve and experimental results of Teaima [26] for two phase flow. According to Fig. 6, the current numerical are in good agreement with the available experimental data for two phase flow condition.

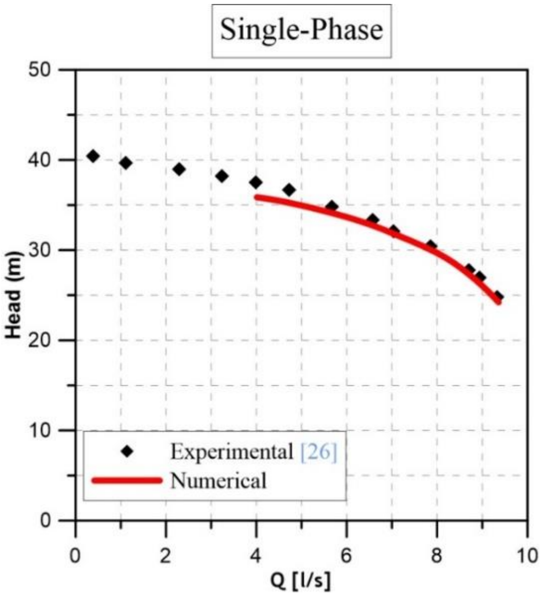


Fig. 5: Comparison between the predicted H-Q curve and experimental results of Teaima [26] for single phase flow.

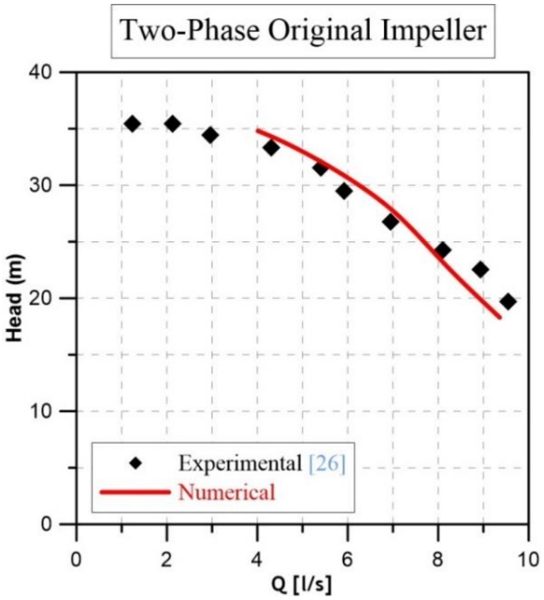


Fig. 6: Comparison between the predicted H-Q curve and experimental results of Teaima [26] for two phase flow.

5.2 Effect of Splitters

In this study, splitter blades having the same profile as the impeller blades and are 50% of the impeller blades' length are proposed. The effect of introducing the proposed splitters on the performance of a centrifugal pump handling solid-liquid two-phase flow is numerically studied. Figure 7 presents the predicted H-Q curve for the original impeller and the proposed impeller with splitters for two-phase flow condition. It can be observed that the pump head increased with adding splitter blades and the effect of splitters is more effective around the design point (Q=8.2 Lit/s).

To further explore the performance enhancement achieved by the proposed impeller with splitters for two-phase flow, the pressure and velocity distributions are presented. Figure 8 depicts sectional pressure contours for the proposed impeller with splitters (two-phase), original impeller (two-phase), and original impeller (single-phase). It can be noticed that the transition between single and two-phase caused the pressure to increase inside the pump, hence increasing the stresses inside it. However, the outlet pressure from the pump is decreased. By using splitter blades, the pressure inside the pump decreases, hence decreasing the stresses.

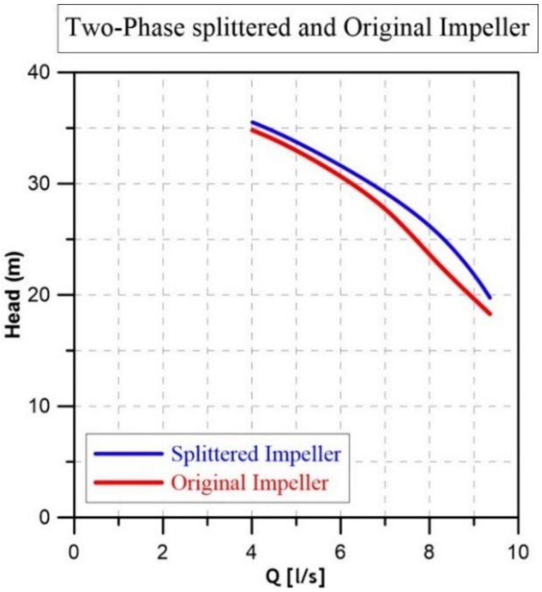
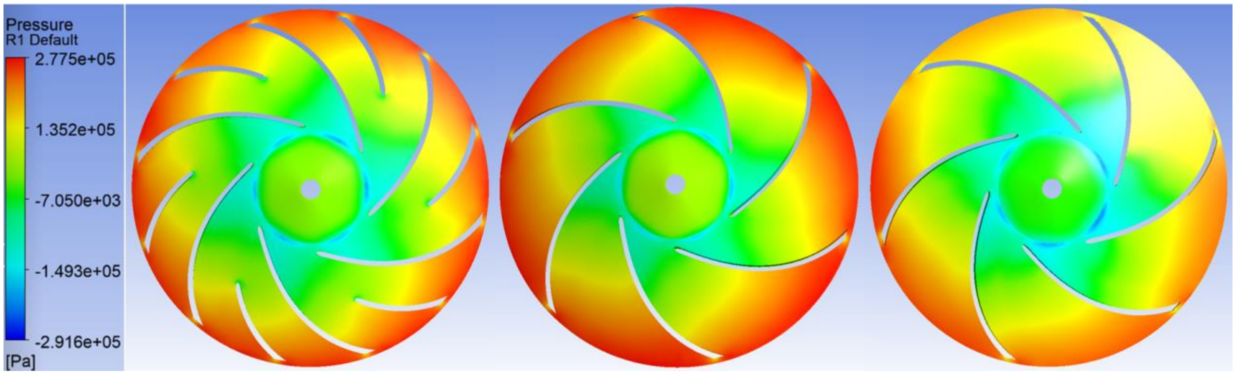


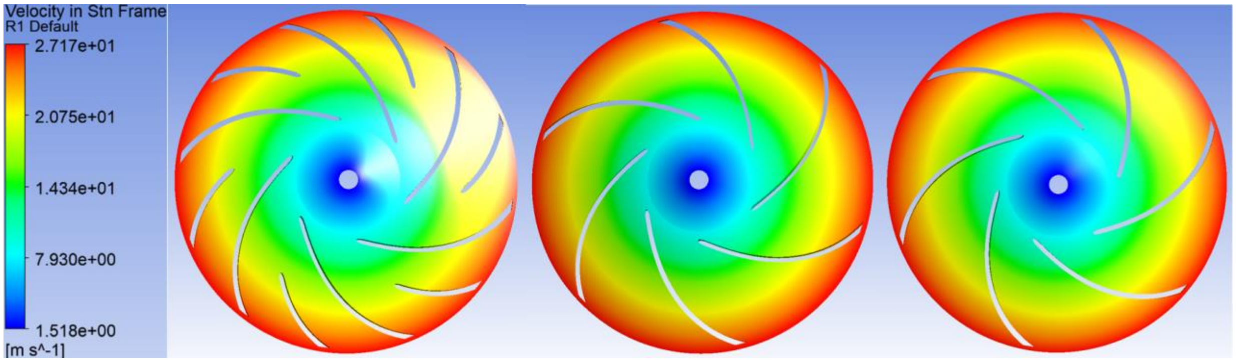
Fig. 7: The predicted H-Q curve for the original impeller and the proposed impeller with splitters.

However, the pressure at pump outlet was increased. Using splitters enhanced the pump head compared with the case of two-phase without splitters. The pump net head at the design point in single phase condition is (29.117 m), while in two-phase original impeller the head is (22.795 m). This means a reduction of (21.7 %) that happened due to the insertion of the solid phase. By using the modified impeller with splitters that only are half the length of the main blade in order not to cause any clogging at the impeller eye, the pump net head has increased to (25.481 m) with an increase of 11.8 %. The enhancement of the pump head is not the only advantage of using splitters, as shown in figure 9 which presents the sectional absolute velocity contours for the proposed impeller with splitters (two-phase), original impeller (two-phase), and original impeller (single-phase). It can be observed that the splitter blades were used to provide guidance to the flow in the blades passages which in turn will minimise the separation zones and consequently, raise the flow velocity. This is more obvious in figure 10 that describes the Path lines along with velocity for the three cases. At the beginning of the blade passage towards the pressure side of the blade, there is high separation zone. The effect of splitter blades is obvious by reducing these separation zones relative to the original impeller in the other two cases. To emphasis this observation, the velocity vectors inside an impeller blades passage is presented in Fig. 11 for the three cases. The observation from this figure confirms the effect of splitters in guiding the flow.



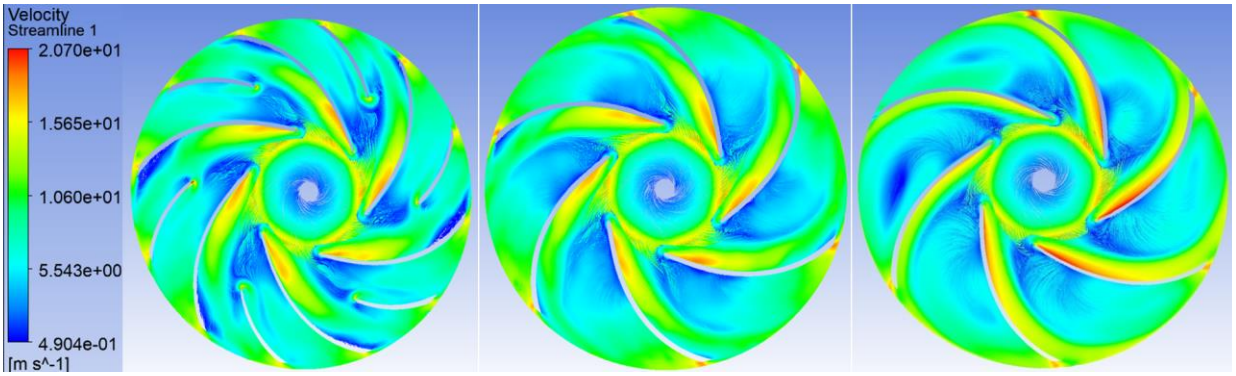
(a) **(b)** **(c)**

Fig. 8: Sectional pressure contours for **(a)** impeller with splitters (two-phase), **(b)** original impeller (two-phase), and **(c)** original impeller (single-phase)



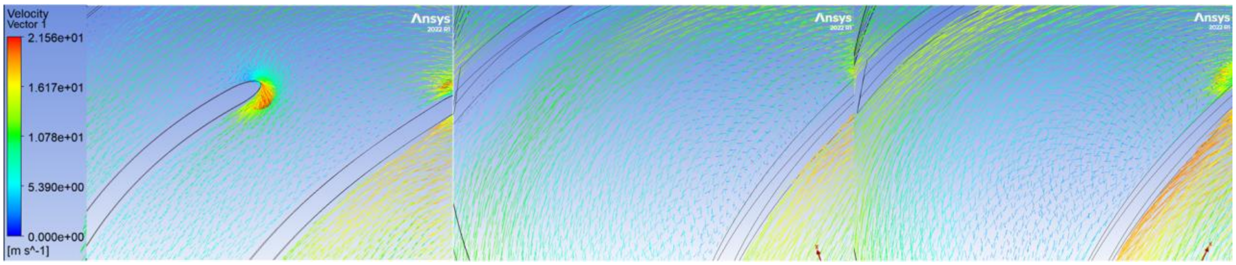
(a) **(b)** **(c)**

Fig. 9: Sectional absolute velocity contours for **(a)** impeller with splitters (two-phase), **(b)** original impeller (two - phase), and **(c)** original impeller (single-phase)



(a) **(b)** **(c)**

Fig. 10: Pathlines along with velocity for **(a)** impeller with splitters (two-phase), **(b)** original impeller (two-phase), and **(c)** original impeller (single-phase)



(a) **(b)** **(c)**

Fig. 11: Velocity vectors for **(a)** impeller with splitters (two-phase), **(b)** original impeller (two-phase), and **(c)** original impeller (single-phase)

The effect of splitter blades is not limited only in increasing head, but also decreasing the pressure fluctuations and hence vibration and noise. This is achieved by minimising the separation zones and guiding the flow at the high-pressure zone (the outlet) of the blade passage. Three monitoring point are used to monitor the pressure fluctuation at the design flow rate beside the head at the outlet. The first point P1 (coordinates: x=0.0328 mm, y=-0.106 mm, z=0.0243 mm) is located in the entrance of the volute spiral. It is worth mentioning that the origin of the domain is the impeller centre. The second point P2 (coordinates: x=0.04 mm, y=-0.0663 mm, z=0.0325 mm) is located on the impeller surface with a stationary frame. The third point P3 (coordinates: x=0.0847mm, y=-0.0432 mm, z=0.0319 mm) is located in the volute just after the impeller outlet. The position of these three points is kept the same for the original and splittered impeller as shown in Fig. 12.

At the first monitoring point P1, the pressure is plotted with the blade inclination angle (θ) in Fig. 1٣. During a full impeller cycle, the splitter blades were found to decrease the pressure difference between maximum and minimum pressure during the cycle from 0.051 bar to 0.04 bar, which represents 21.6% reduction. The second monitoring point P2, which is located at the impeller, also supports the same principle, as shown in Fig. 14. The pressure difference along the cycle is reduced from 0.84 bar to 0.69 bar. That represents 17.9 % reduction. At the third monitoring point P3, the pressure difference during the cycle in both impellers nearly remains the same, as shown in Fig. 15. However, the average pressure during the cycle was reduced by using splitter blades from 2.43 bar to 2.39 bar. The effect was not sensible at this point due to the effect of volute tongue as the point is located after it directly which provides a region of low pressure in both cases.

At the pump outlet, the head was monitored and plotted in Fig. 1٦. Using splitter blades not only mitigates the pressure fluctuation by decreasing the difference in head during the cycle, but also it increases the net produced head from the pump by nearly 11.8 % at the design point.

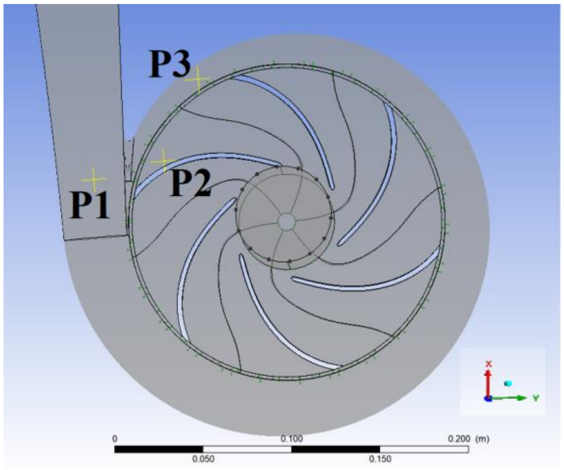


Fig. 12: Three monitoring points

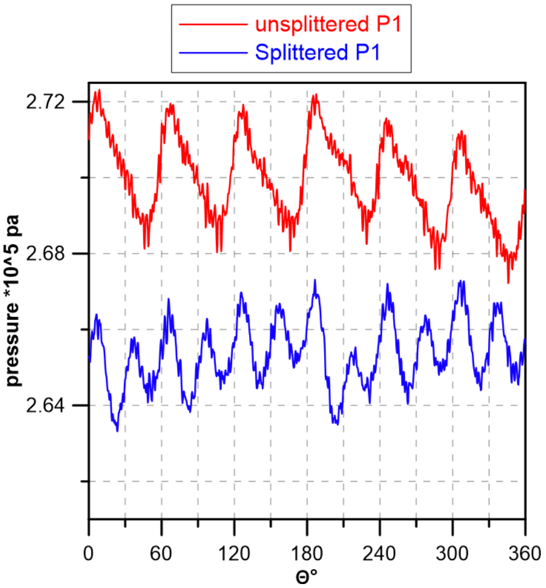


Fig. 13: Pressure fluctuations at point P1 within a whole impeller cycle for the proposed impeller with splitters and without splitters for two-phase flow condition

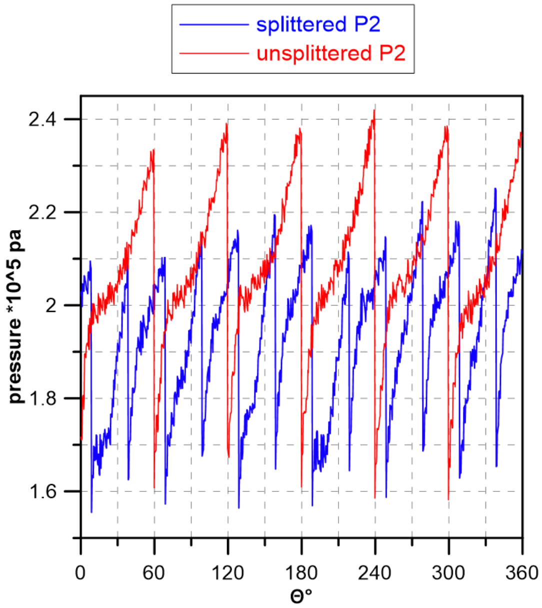


Fig. 14: Pressure fluctuations at point P2 within a whole impeller cycle for the proposed impeller with splitters and without splitters for two-phase flow condition

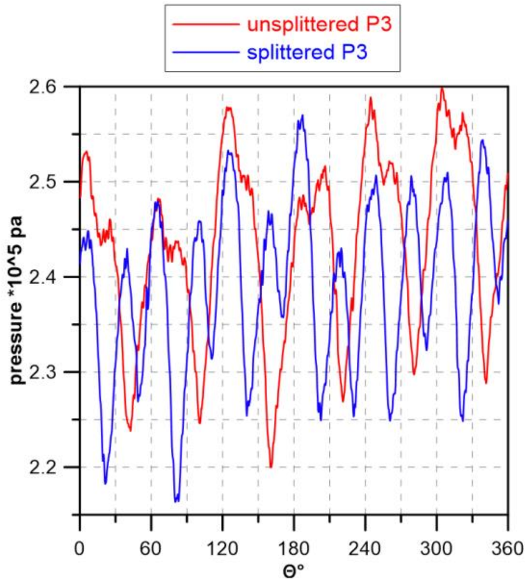


Fig. 15: Pressure fluctuations at point P3 within a whole impeller cycle for the proposed impeller with splitters and without splitters for two-phase flow condition

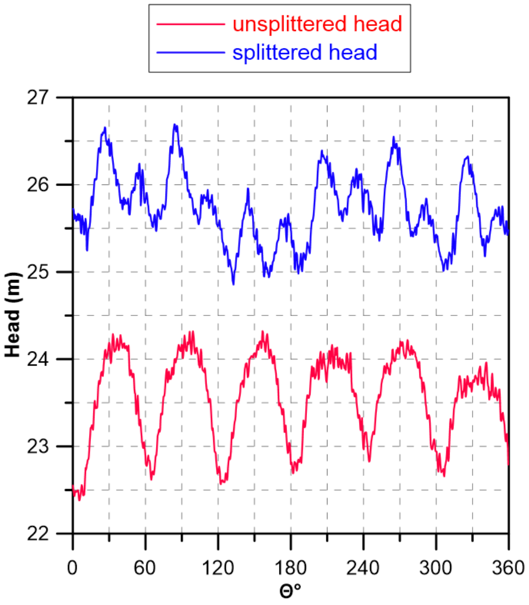


Fig. 16: Fluctuations of outlet pump head within a whole impeller cycle for the proposed impeller with splitters and without splitters for two-phase flow condition

6. Conclusion

The effect of splitter blades on the performance of a pump handling solid-liquid two-phase flow is numerically studied. The proposed splitters have the same profile as the impeller blades and are 50% of the impeller blades' length. Each splitter is placed at the center of the impeller blades' passages, and consequently, the splitter blades have the same number as the main blades. The numerical simulations are carried out based on the three-dimensional, incompressible, turbulent, and unsteady Reynolds-Average Navier-Stokes (URANS) equations along with the turbulent model of k-ε. The results predicted by the current numerical model are successfully validated with experimental data from the literature. Based on the current study, some significant findings can be derived. Using the proposed impeller with splitter blades increases the pump outlet head at all studied flow rates compared with the impeller without splitters. A percentage gain of 11.8% in the pump net head is obtained at the design point by using the splitters. The fluctuation in pressure within a whole impeller cycle is reduced by 21.6 % in certain locations and consequently reduces the vibration and noise from the pump as the splitters provides guidance to the flow at impeller outlet.

7. References

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