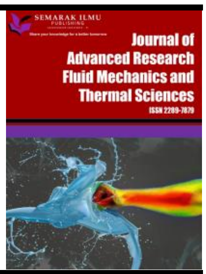
Journal of Advanced Research in Fluid Mechanics and Thermal Sciences

Journal homepage:
https://semarakilmu.com.my/journals/index.php/fluid_mechanics_thermal_sciences/index
ISSN: 2289-7879



Impact of Different Blade Counts on In-Pipe Drag-Type Water Turbines

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ARTICLE INFO

Article history:
Received 28 December 2022
Received in revised form 4 April 2023
Accepted 12 April 2023
Available online 29 April 2023

Keywords:
In-pipe turbine; drag-type; fluid dynamic; turbine blades; simulation

ABSTRACT

Hydropower is a low-cost, well-developed renewable energy source. Since hydropower relies only on the energy from moving water, instead of replacing pressure-reducing valves, the in-pipe turbine might be employed to create electricity. Hence, the purpose of this study is to investigate the performance of the output velocity and pressure using the designated blade of an in-pipe drag-type turbine. Several configuration sets based on fixed turbine design and pipe diameter are considered. By adjusting the number of blades and the angle of the deflector, the flow is analysed to improve the performance of an in-pipe turbine. A computational fluid dynamic simulation known as ANSYS Fluent software is employed, and a 3D simplified model is designed using SolidWorks software. The results indicate that the in-pipe drag-type water turbines with five blades perform better in terms of flow efficiency since their output velocity is slightly higher but more stable than that of the turbine with only two blades.

1. Introduction

For many years, in-pipe turbine power has been regarded as a potential alternative energy source. It is not only an economic way to generate electricity, but it is also a renewable source of energy. According to Muhsen *et al.,* [1], the energy created within the pipeline can be used to develop in-pipe turbines. The in-pipe turbines may operate in a variety of flow patterns, volumes, and velocities. It generates energy by eliminating excessive head pressure from huge diameter pipes, gravity-fed water pipelines, and effluent streams (a stream fed directly by groundwater) [2]. Designers in the renewable energy industry must recognise the relevance of shape in all aspects in order to grow or change their existing designs, particularly when in-pipe turbines are involved. The key problem with in-pipe turbines is determining the appropriate design to maximize their efficiency. The performance of water turbines is studied by some researchers using computational fluid dynamics (CFD) while others also run experiments to learn more about the technology and mechanism of the system [3-6].

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https://doi.org/10.37934/arfmts.105.2.6877

Many researchers have proposed Pump as Turbines (PATs) on behalf of a pressure regulator and power source for municipal water pipelines [7,8]. However, due to the lack of comprehensive knowledge regarding PATs performance, further challenges may arise under multiple water pipeline operating conditions [9]. In another study, an analysis of a micro-tubular hydro propeller turbine's performance was conducted by Ramos *et al.,* [10]. Nevertheless, even if these turbines have suitable efficiency, the passage flow rate and scale size have a big impact on how much power they can produce. Also, the assembly of propeller-type turbines would change the flow pattern, which caused installation difficulties [11]. Oladosu and Koya [12] conducted a numerical analysis of a lift-based in-pipe turbine to forecast the potential for harvesting hydropower in certain water distribution networks for the improvement of waterlines. They concluded that the amount of power available was influenced by the pipe diameter, flow rate, and material density of the turbine blades. The aforementioned concept has piqued researchers' interest in using the free-stream hydraulic turbine for in-pipe applications. However, for pipelines with small diameters, vertical-axis turbines have not yet been widely developed [13]. In this regard, it is noted that a proper study to examine the impact of design variables on the performance of a certain type of in-pipe turbine is crucial.

A reliable approach for the prediction and improvement of the efficiency of the installed in-pipe turbines is still debatable, despite the fact that various studies have been conducted to boost the effectiveness of the system [7]. Prior research clearly shows that the performance of the water turbine system is primarily influenced by the design of the turbines. It is noted that poor in-pipe water turbines contribute to low output velocity and pressure, which result in incompetent practice. Hence, this study aims to design and investigate the flow analysis of the in-pipe drag-type water turbines with various specifications and model development. Using the computational fluid dynamics software, the design and simulation of the selected model are carried out. Following that, variations in turbine performance related to the parameters used in turbine design are evaluated, and the ideal conditions are then offered for each of the contributing factors. The results of this study are anticipated to be useful in studies on in-pipe drag-type water turbines for the best power generation and energy efficiency in water transmission pipelines.

2. Methodology

The major concern of this study is to propose a new design for the in-pipe drag-type water turbines. Initially, the design features are examined based on the previous study. After finalizing and prioritizing some contributing factors, for example, the number of blades, aspect ratio, and angle of the reflector, the proposed design is created in a 3D CAD Model using SOLIDWORKS 2021 software. The flow and simulations analysis of the final design of in-pipe drag-type water turbines is conducted at various velocities and pressure conditions by setting up the boundary conditions and meshing process. Here, the ANSYS Workbench 2022 is employed to observe the flow analysis of the in-pipe drag-type water turbines. By comparing the proposed design with the prior design in terms of flow analysis, the validation process is carried out. Figure 1 shows the process flow of the overall methodology process, while details on the contributing factors that affected the design of the in-pipe drag-type water turbines are discussed in the next sub-topic.

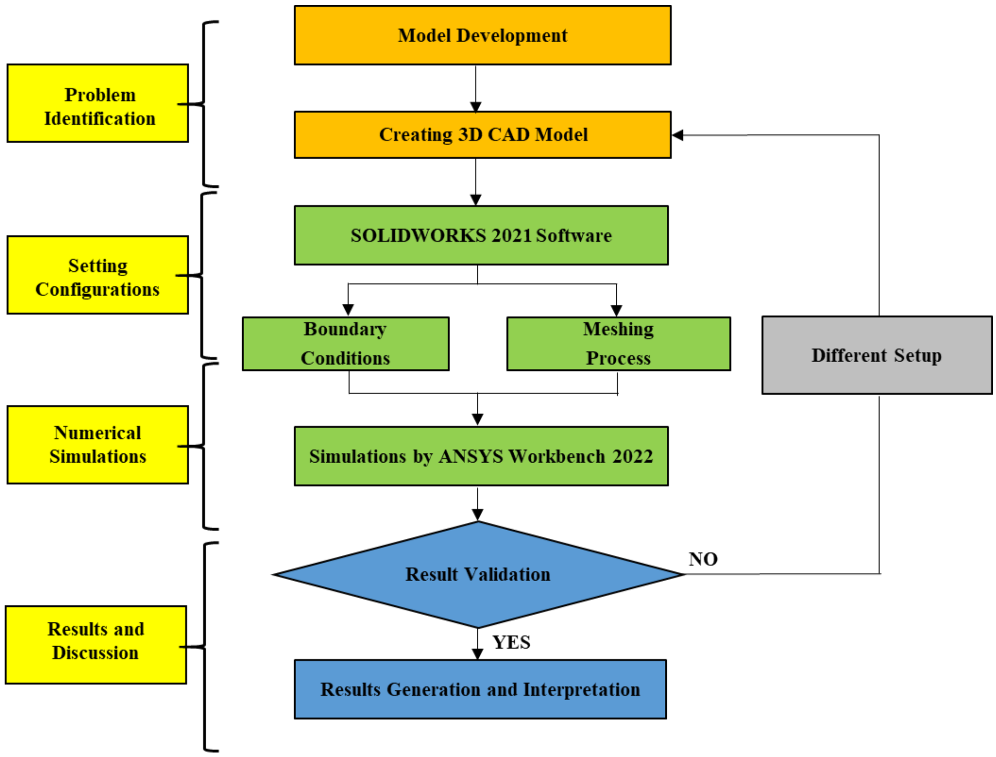


Fig. 1. Flow chart of the methodology process

2.1 Contributing Factors

Some of the contributing factors that have affected the design of the in-pipe drag-type water turbines are pointed out in this study and are listed in the following sub-section.

2.1.1 Number of blades

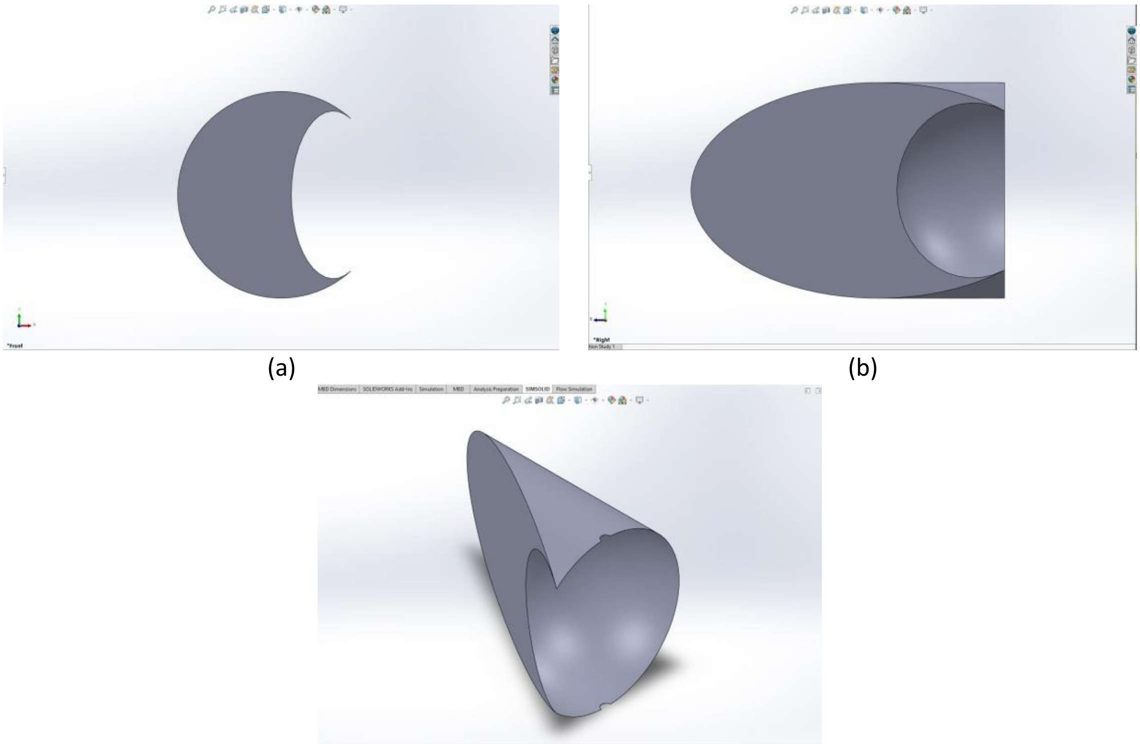
According to the previous study, increasing the number of in-pipe blades to five (5) enhances the efficiency of the water turbine [14,15]. However, the turbine's efficiency is reduced when it has more than five blades because of hydraulic resistance and lack of fluid impacting the blades. This is also applicable when fewer blades (less than 5) are set up since the flow capacity is not utilised to its maximum potential. Henceforth, this study considered increasing the number of blades to five compared to the two blades.

2.1.2 Aspect ratio

Based on the previous study, increasing the aspect ratio from 0.4-to-0.7 turbine should enhance the volume of water flowing through the gap between the tube and its blades (clearance) [16,17]. As a result, it is noted that the peak local flow velocity around the turbine rises, significantly. Therefore, having a higher aspect ratio means that a larger area of the returning blade is subjected to high pressure. Due to this finding, the aspect ratio of the proposed in-pipe drag-type water turbines is set to 0.7 in this study.

2.1.3 Angle of deflector

The deflector system has a positive influence on the flow field surrounding the Savonius rotor in terms of velocity magnitude when all configurations are compared. Increasing the advancing blade's contribution to torque generation helps the deflector system function better. For simplicity, only the deflection angle is changed in the deflector system's geometrical characteristics of this study. Hence, it is foreseeable that an increase in the deflection angle increases the expected net torque. Considering the prior discoveries, a deflection angle of α = 30° is employed in this study which results in the largest gain of the system [18-20]. The considered design for the deflector angle is presented in Figure 2.



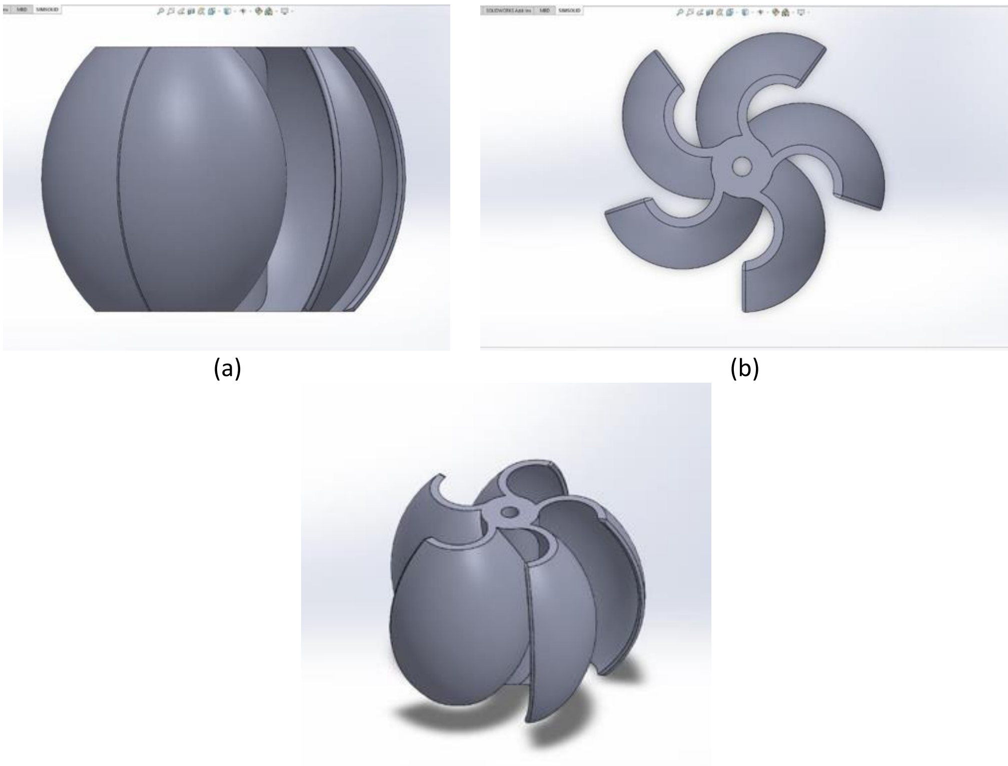
(a) (b)

(c)

Fig. 2. 3D design of the turbine reflector (a) front view (b) side view (c) isometric view

2.2 Final Design in 3D Model

Based on the above-mentioned parameters, the final design employed in this study is illustrated in Figure 3.



(a) (b)

(c)

Fig. 3. Final design of the in-pipe drag-type water turbines (a) top view (b) side view (c) isometric view

3. Results and Discussion

The computational fluid dynamic analysis is carried out using ANSYS Workbench 2022 R1. Based on the data collection and validation process from the previous study, the simulation of the proposed design is conducted. In this study, the boundary conditions are modified to meet the requirement of the analysis demand. The velocity and pressure settings are set to 16.27 m/s (367138 Pa), 15.21 m/s (327898 Pa), and 12.04 m/s (144346 Pa). Meanwhile, the diameter of the in-pipe drag-type water turbines is set to 1 meter. In order to demonstrate the efficiency of the proposed design, a comparison between the projected model (five-blade) and different numbers of in-pipe drag-type water turbine blades (two-blade) is carried out. However, an analytical method for the prediction of the performance of the in-pipe turbine is not feasible due to the complexity of the turbine geometry and the sensitivity of the turbine performance to the alteration of the effective parameters. Figure 4(a) and Figure 4(b) display the pressure contour and streamlines of the designated model on the ANSYS Workbench 2022 R1 software with five blades in-pipe drag-type water turbines, respectively.

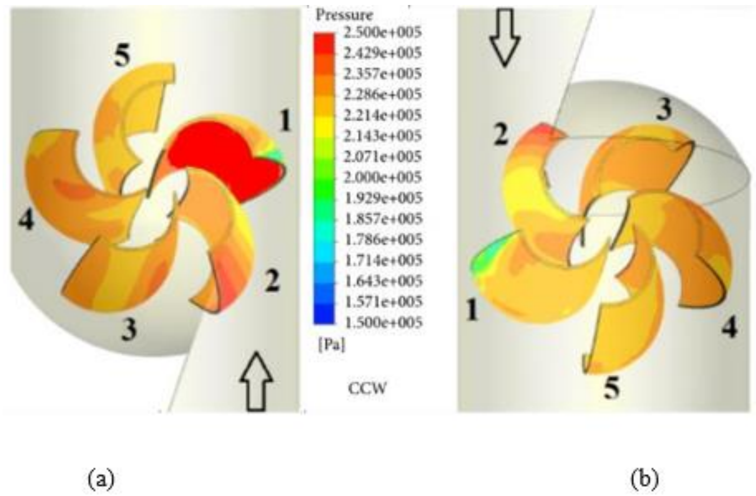
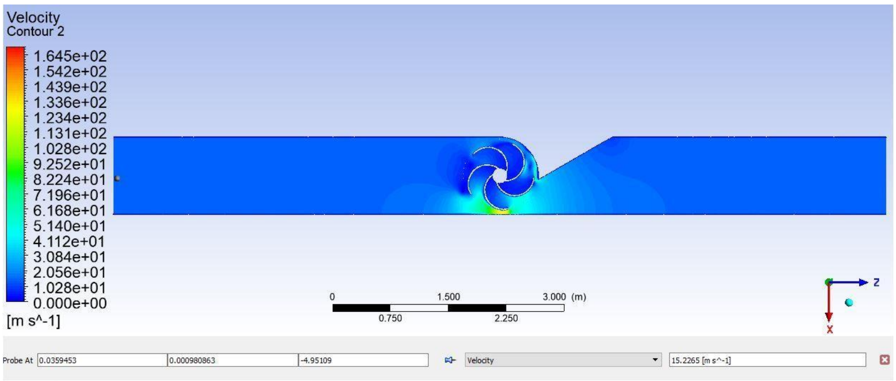


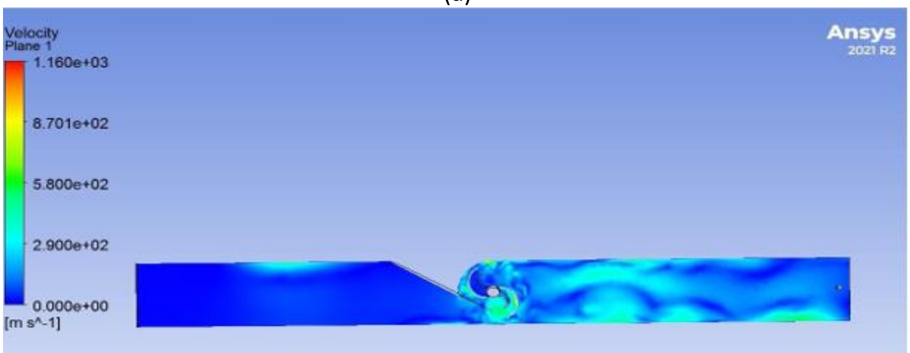
Fig. 4. Design of a five-blade in-pipe drag-type water turbine in (a) pressure contour (b) streamlines

Figure 5 exhibits the velocity contours between the five-bladed (refer Figure 5(a)) and the two-bladed in-pipe drag-type water turbine (refer Figure 5(b)). Meanwhile, Figure 6 shows a graph of outlet velocity corresponding to the number of blades. Noticeably, a five-bladed drag-type water turbine is more efficient, as can be seen from the data and graph (see Figure 6.) produced by the flow simulation. This is because an in-pipe drag-type water turbine with five blades has produced a slightly higher output velocity (16.41m/s) in the pipeline when compared to normal inlet velocity (16.27m/s) with means of no in-pipe turbine installation, as shown in Table 1. An increase of 0.9% in the outlet velocity is observed when the five-bladed in-pipe turbine is employed. As the turbine's efficiency depends on absorbing the force of the water's velocity whilst it strikes the blades, the increase in the outlet velocity of the five blades turbine is believed to be acceptable. It is obvious that the five-bladed in-pipe drag-type water turbine effectively absorbs the velocity force, which subsequently enhances the turbine’s performance.

In the meantime, the reading velocity output for two blades in-pipe turbine is reported as 99.20m/s. The difference between output velocity and input velocity is about 82.93m/s. As shown in Figure 5(b), the two-bladed turbine creates an enormous and abrupt rise in velocity, which leads to an unstable flow into the pipe. The unstable output velocity consequently has the potential to harm the turbine blades. According to Du *et al.,* [21], a good match between the flow attack angle and the blade intake angle can reduce energy waste in the runner inlet and increase the stability of equipment operation. Also, the performance of the turbine is directly impacted by the runner's input width as well as its inlet and output diameters. Based on the findings in Figure 5 and Figure 6, it can be concluded that the performance of the turbine is affected by the number of blades in terms of velocity profiles and energy consumption.



(a)



(b)

Fig. 5. Velocity contour for different blades in-pipe drag-type water turbines (a) five blades (b) two blades

Table 1
Comparison of outlet velocity with different numbers of blades in in-pipe drag-type water turbines

Inlet velocity (m/s)	Five (5) blades	Two (2) blades
16.27	16.41	99.20

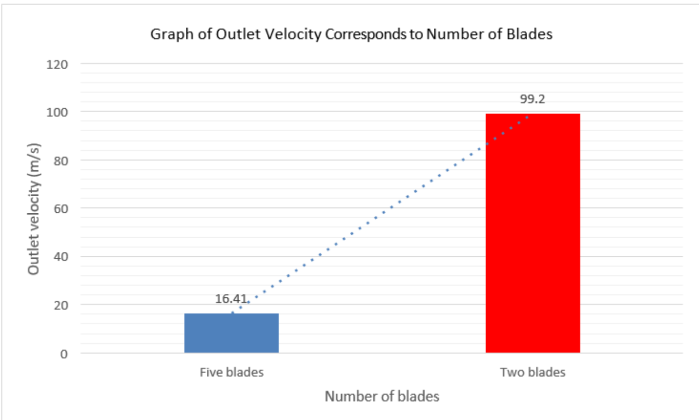


Fig. 6. Graph of outlet velocity corresponds to the number of blades

Figure 7 presents the pressure contours between the five-bladed (refer Figure 7(a)) and the two-bladed in-pipe drag-type water turbine (refer Figure 7(b)). On the other hand, Figure 8 shows a graph of outlet pressure corresponding to the number of blades. Noticeably, a five-bladed drag-type water turbine produced a lower output pressure (366292pa) in the pipeline when compared to normal inlet pressure (367138pa) with means of no in-pipe turbine installation, as revealed in Table 2. It is discovered that a significant pressure gradient forms as pressure progressively drop from the pipe's input to its outlet in the five-blade in-pipe turbine. Meanwhile, the reading of the pressure outlet in the two-blade in-pipe turbine is slightly higher (368411pa) compared to the five-blade turbine. Based on the data collection, an increase of 0.35% in the outlet pressure is observed when the two-blade in-pipe turbine is used. High pressure is created at the pipe's inlet by the collision of the water flow and the blades. The pressure area first declines from 367138pa to 366292pa and then increases as the number of blades drops. Thus, it can be observed that the pressure at the output pipe varies depending on the number of blades, suggesting that the pressure energy changes well. Consequently, it can be concluded that different blade numbers have an impact on both the pipe's capacity to convert pressure energy and the pressure gradient at the inlet pipe.

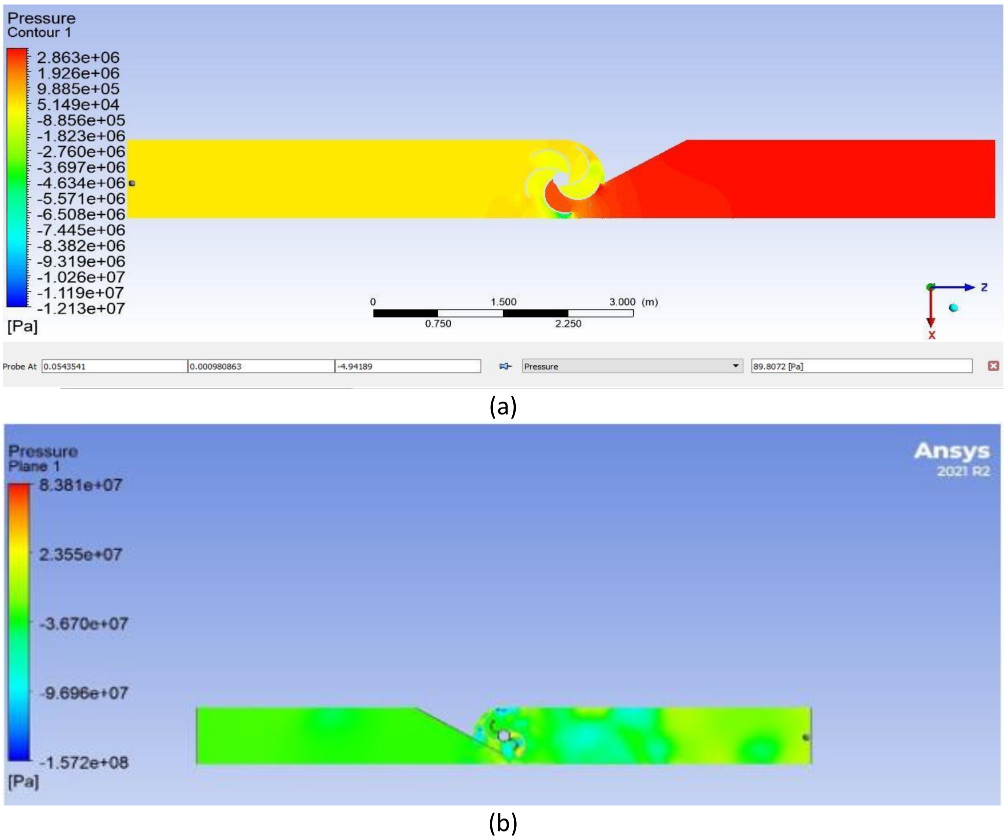


Fig. 7. Pressure contour for different blades in-pipe drag-type water turbines (a) five blades (b) two blades

Table 2
Comparison of outlet pressure with different numbers of blades in in-pipe drag-type water turbines

Inlet pressure (Pa)	Five (5) blades	Two (2) blades
367138	366292	368411

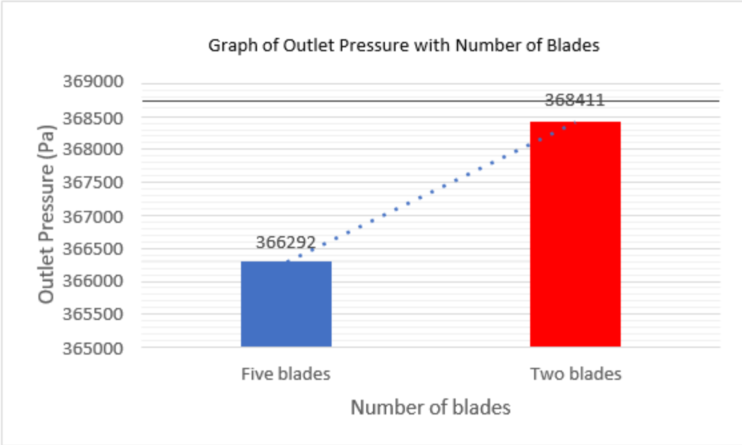


Fig. 8. Graph of outlet pressure with the number of blades

4. Conclusions

In this study, a new design for the in-pipe drag-type water turbines is proposed, and the flow analysis between the projected design and current practice is compared. On the basis of the prior research, the design criteria are first collected and analyzed. The final model is proposed based on some important criteria, such as the number of blades, aspect ratio, and angle of the reflector, which have been prioritized and determined. This proposed model is basically the combination of all contributing factors that have been selected from the previous study. The computational simulation is carried out to examine the flow of the in-pipe drag-type water turbines, hence several data on the output velocity and outlet pressure are collected. Based on the findings, it can be concluded that the in-pipe drag-type water turbines with five blades have better efficiency in terms of flow performance due to the output velocity that is slightly higher and more stable compared to the two-bladed design. Due to the increase in efficiency and power output, it is noted that the five-bladed model of the in-pipe drag-type water turbines is a better invention for sustainable and power-generating distributions when compared to the two-bladed model in terms of flow configuration. Follow-up studies are required in the future since there is still much that can be done to enhance the performance of the in-pipe drag-type water turbines, such as searching for a more efficient geometry of the turbine or angle deflector. Also, an experimental setup is encouraging to provide a better understanding of the in-pipe drag-type water turbines in real applications.

Acknowledgment
This research is supported by the Faculty of Mechanical and Manufacturing Engineering Technology, Universiti Teknikal Malaysia Melaka.

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