Investigation of conical draft tube of Kaplan turbine with spiral liner and without spiral liner using CFD simulation

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Abstract. The draft tube is a component in the Kaplan turbine to create positive suction pressure using kinetic energy that is not used when leaving the turbine runner and increasing turbine power efficiency. This research aimed to find out the highest efficiency of variant geometries of a conical draft tube with spiral liner and without the spiral liner. The design geometry was processed using 2D software and 3D using Inventor and simulated in CFD software. The inlet water discharge was 0.1 m³/s with head 5 m and theoretical turbine power 4.9 kW. Based on the simulation results showed that the spiral liner draft tube variant was the best power and efficiency.

Keywords: draft tube, efficiency, Kaplan turbine, kinetic energy, spiral liner

1. Introduction
Kaplan turbines are known as axial flow reaction turbines that use large amounts of water and low head [1]. The draft tube is one of the significant components in the reaction turbine. Without this, the pressure at the outlet can drop due to a lack of water, which can affect plant efficiency and may even fail to produce the desired power [2]. Investigation of the effect of the inlet nozzle shape on the performance and internal flow of cross-flow turbines for hydropower by modifying the diffuse length and angle using CFD shows the results that the narrow and convergent shape of the inlet nozzle gives a better effect on turbine performance [3]. Another simulation of the conical draft tube with different lengths and diffuser angles by calculating the head loss, head recovery coefficient using CFD and ANSYS CFX 13.0. The results showed that the maximum efficiency was achieved at a diffuser angle of 5 degrees with \( \frac{L}{D3} = 19 \) [4]. Design Optimization of the elbow draft tube model with multiple diffuser angles for the same or increased diffuser angle to resolve the problem of draft tube design and reduce prototyping costs using CFD and analysis in ANSYS 14.0 [5]. In this paper, the CFD analysis of the Mixed Elbow draft has been performed, and results for the same are compared with experimental reading. From results were found within limits and to compare the results of experiments and CFD with a simple elbow draft tube. [6]. The efficiency and losses of draft tube are calculated from the pressure and velocity distribution to determine the effect of geometric parameters on the draft tube performance to obtain the best results. The best performance is achieved with a height ratio close to 2.24 and a length ratio \( \frac{L}{D1} \) of 6.0 [7].

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In another study investigated the hydraulic performance of the Francis turbine at a 15 MW hydroelectric power plant. The design parameters used were the thickness of the guide vane, three types of draft tubes, and the characteristics of the cord using three-dimensional numerical methods with SST turbulent models. The vortex and flow field results are depicted using different design parameters and operating conditions [8]. An experimental study of draft tubes in crossflow turbines found that the correct shape and size of the draft tubes can have a positive effect on improving turbine performance at each turbine head. The result showed that the 300 mm draft tube variant has the highest output [9]. In the present work, there were three types of conical draft tubes with a length of 22.45 m, 30.4 m and 38.4m and were modelled using a diffuser angle of 4°. The results showed that the draft tube with a length of 30.4 m is the most suitable where the efficiency is 22.7% [10].

The objective of this study was to investigate draft tube with spiral liner and without spiral liner against the efficiency of power generated by the Kaplan turbine.

2. Materials and Methods
This study consisted of 3 variations of the draft tube with the same height and diffuse angle but the number of different spiral liner, namely DT-1 without spiral liner, DT-2 with 6 spiral liner, and DT-3 with 12 spiral liners. The parameters and dimensions of the turbine used are 0.1 m³.s⁻¹ discharge and 5 m head and can see in Table 1. The 2D geometry using AutoCAD, 3D model using Inventor software, and water flow using flow simulation of CFD software. The boundary conditions can see in Table 2. The results of the pressure and velocity can see in Figure 1 and Figure 2. Theoretical power is calculated by the formula:

\[ P_{th} = \dot{m} \cdot g \cdot H = \rho \cdot g \cdot Q \cdot H \]  

(1)

Where \( P_{th} \) is theoretical power (Watt), \( Q \) is water discharge (m³.s⁻¹), \( \rho \) is density of water (kg.m⁻³) and \( H \) is head (m).

| Item                  | Unit                     |
|-----------------------|--------------------------|
| Operation pressure    | 101325 Pa                |
| Gravitation           | 9.81 m/s²(Y - Axis)      |
| System unit           | SI                       |
| Type of analysis      | Internal                 |
| Cavitation            | No                       |
| Reference axis        | Y                        |
| Fluid                 | Water ( O)               |
| Type of flow          | Turbulence and laminer   |
| Roughness             | 0.01                     |
| Wall thermal condition| Adiabatic wall            |
| Temperature           | 293.2 K                  |
| Turbulence model      | 2%                       |
| Turbulence length     | 0.003 m                  |
| Turbulence energy     | 1 J/kg                   |
| Turbulence dissipation| 1 W/kg                   |
| Rotation              | Assumption stop for a moment |

Turbine power (\( P_\theta \)) is obtained using the horizontal drag force approach (\( F_\theta \)) multiplied by tangential velocity (\( U_1 \)). Axial or vertical drag force (\( F_\theta \)) values are obtained from CFD analysis on the runner blade. Drag force and power are calculated by the following formula:
\[ F_{dh} = \frac{F_{dv}}{\tan \theta} \quad (2) \]

\[ P_d = F_{dh} \cdot U_1 \quad (3) \]

The calculation with drag force approach formulation on the blade surface is done because the calculation by velocity triangle cannot predict the force due to blade shape geometry. The result of efficiency can be seen in Table 3.

\[ \eta_h = \frac{P_d}{P_{th}} \times 100\% \quad (4) \]

\[ \eta_t = \eta_h \cdot \eta_m \quad (5) \]

Where the parameter \( \eta_h \) is hydraulic efficiency, \( \eta_m \) is mechanical efficiency = 95\%, and \( \eta_t \) is turbine efficiency.

3. Results and discussion

From the CFD simulation, are obtained the velocity and pressure contour as shown in figure 1 and figure 2, while the flow analysis to determine the power generated and efficiency in Table 2 and Table 3.

![Figure 1. Velocity contour of draft tube (a) DT-1, (b) DT-2, (c) DT-3](image1)

![Figure 2. Pressure contour of draft tube (a) DT-1, (b) DT-2, (c) DT-3](image2)
From figure 1, DT-1 has the bluest flow contour it means DT-1 has the highest average velocity. For DT - 2 and DT-3 it keeps going down. DT-1 has 1,885 m.s⁻¹, DT-2 has 1,880 m.s⁻¹, and the last one DT-3 has the lowest velocity with 1,862 m.s⁻¹. Then from figure 2, DT-3 has the highest pressure with an almost red contour on the flow simulation. DT-1 has the lowest pressure under DT-2 and DT-3. DT-3 has pressure 95552.08 Pa, DT-2 has 95529.52 Pa, and the last one DT-1 has 95362.93 Pa. It can be seen that the highest pressure has the lowest velocity, it keeps going down.

| Draft Tube Variant | DT -1  | DT -2  | DT -3  |
|--------------------|--------|--------|--------|
| Fd (N)             | 328.963| 341.28 | 349.407|
| Fdh (N)            | 375.4  | 461.2  | 472.2  |
| Pd (Watt)          | 4570.5 | 4741.1 | 4854.2 |

Table 2. Drag force and power of the draft tube

| Draft Tube Variant | Pth (Watt) | ηₘ (%) | ηₜ (%) |
|--------------------|------------|--------|--------|
| DT -1              | 4905       | 93.2   | 88.5   |
| DT -2              | 4905       | 96     | 91.2   |
| DT -3              | 4905       | 98     | 93.1   |

Table 3. Turbine efficiency

From Table 2 and Table 3, it can be seen the value of drag force and power of the draft tube of each variant. The DT–1 variant has a drag force of 328.963 N with a power of 4570.5 Watt, and a turbine efficiency of 88.5%. The DT–2 variant has a drag force of 341.28 N with a power of 4741.1 Watt, and 91.2% turbine efficiency. The DT–3 variant has a drag force of 249.407 N with a power of 4854.2 Watt, and a turbine efficiency of 93.1%.

4. Conclusions

From the results and discussion above can be found that using the spiral liner draft tube can increase the efficiency of the Kaplan turbine. The draft tube without spiral liner variant DT-1 produces an efficiency of 88.5%, the lowest efficiency. Variant DT-2 with 6 spiral liners produces an efficiency of 91.2% and variant DT-3 with 12 spiral liners produce 93.1%. It means that the best and the highest efficiency can be reached with 12 spiral liners.

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