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Analysis of Spiral Pump Head Based on Water Wheel Parameters

Hengky Luntungan[1*], Stenly Tangkuman [1], Benny L. Maluegha[1]

[1]*Mechanical Engineering Department, Sam Ratulangi University, Jl. Kampus Unsrat, Bahu, 95115, Indonesia*
[*]*Corresponding Author: st75@unsrat.ac.id*

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Abstract
Water supply is a crucial factor for farmers in managing agricultural land, especially those relying on river water sources. The lower position of rivers and the considerable distance from the fields often pose challenges, making water pumps powered by electricity or fuel a common choice, despite their high operational costs. To address this issue, the utilization of renewable energy through the use of a spiral pump powered by a water wheel is proposed. The spiral pump is considered an environmentally friendly technology as it does not require electricity or fossil fuels. This study aims to analyze the head of a spiral pump based on the parameters of an undershot water wheel as preparation for the design of the spiral pump. In this study, a significant decrease in discharge value was observed from a head of 0.5 m up to a head of 3 m; in contrast, from a head of 3 m to 10 m, the discharge value decreased gradually. For small agricultural land or household needs, this spiral pump water wheel would be suitable at a maximum head of 5 m with a discharge value of 0.53 L/s. The results show a negative correlation between the head of the spiral pump and the discharge produced, where an increase in head results in a lower discharge.

Keywords: fluid flow, head pump, spiral pump, water discharge, water wheel

1 Introduction

The spiral pump is a type of water pump that operates without electricity or fossil fuels, making it often considered environmentally friendly. The spiral pump consists of two main components: a spiral pipe (or spiral hose) and a driving mechanism, which is generally a water wheel [1]. The spiral pipe is placed in the water and rotates with the wheel, transporting water into the spiral. The spiral pump utilizes the kinetic energy of the water that drives the wheel, so it does not require additional energy. For this reason, the spiral pump is ideal for areas far from power sources or where fuel resources are limited.

The spiral pump, initially invented by H. A. Wirtz in 1746 [2], was originally powered by horses. This invention remained largely forgotten for approximately 240 years until it was revived and advanced by Peter Morgan, who transformed it into an eco-friendly technology by using a water wheel instead of horse power to drive the pump. Spiral pumps offer valuable support to communities, particularly in agriculture, as they operate without needing electricity or fuel.

The water wheel converts the kinetic energy of the water flow into mechanical power to rotate the spiral pump [3]. The higher the speed and volume of the water flow hitting the wheel, the greater the power generated, which then increases the spiral pump's rotation and its efficiency in raising water. A well-designed water wheel can maximize the use of energy from the water flow, thereby optimizing the spiral pump's performance [4]. Factors such as wheel size, number of blades, and blade angle affect how efficiently the water flow energy is transferred to the spiral pump. Overall, the performance of the spiral pump largely depends on the design and performance of the water wheel [5]. For the spiral pump to operate optimally, the water wheel should be designed to match the flow conditions and energy needs at a specific location [6].

Therefore, it is necessary to conduct research on the water wheel of the spiral pump. This study aims to analyze the head of a spiral pump based on the parameters of an undershot water wheel as preparation for the design of the spiral pump.

2 Theoretical Background

The wetted cross-sectional area refers to the area of the blade or paddle cross-section of the water wheel that is in direct contact with or submerged by the water flow. This area is important because it indicates how much of the wheel is receiving pressure or force from the water flow, which affects the efficiency and power generated by the wheel. For d as the water depth on the wheel and w as the width of the wheel, the wetted cross-sectional area (A) can be calculated using the following equation (Equation 1).

$$A = d.w \tag{1}$$

The input power of the water wheel is influenced by the density (ρ), wetted cross-sectional area (A), and water flow velocity (V). The following equation (Equation 2) can be used to calculate the input power of the water wheel [7][8].

$$P_{in} = \tfrac{1}{2}.\ \rho.\ A.\ V^3 \tag{2}$$

Only about 30% - 50% of the water power calculated above can be converted into the output power of the water wheel. This value is known as the water wheel's efficiency. In this study, the midpoint value of 40%, or 0.4, is used. The choice of 40% efficiency is also based on three main considerations. First, in practice, even under good conditions, there are unexpected losses due to turbulence, friction, misalignment, and non-ideal flow. Choosing 40% instead of assuming a higher 50% helps account for these typical inefficiencies without requiring complex adjustments. Second, selecting a slightly conservative value like 40% ensures that the system is more reliable. It prevents overestimating the pump’s capability, which is important if the water flow rate or environmental conditions change. Finally, since this study did not engage in detailed optimization (such as adjusting blade shapes or angles), assuming a moderate efficiency like 40% simplifies the calculations while maintaining a realistic approach. Therefore, the output power of the water wheel P_{out} can be calculated using the following equation (Equation 3).

$$P_{out} = \eta.\ P_{in} \tag{3}$$

The power generated is also directly proportional to the density (ρ), gravitational acceleration (g), water discharge (Q), and pump head (H), which can be formulated as follows.

$$P_{out} = \rho.\ g.\ Q.\ H \tag{4}$$

If the desired pump head value has been determined, the pump discharge can be calculated using Equation 4, with slight adjustments to the formula. Therefore, the pump discharge can be calculated using the following equation (Equation 5).

$$Q = \frac{P_{out}}{\rho . g . H} \quad (5)$$

3 Method

The analysis of the spiral pump head based on the parameters of the water wheel consists of five steps: measuring the water flow velocity, modeling the water wheel, calculating the wetted cross-sectional area of the wheel, calculating the input and output power of the water wheel, and analyzing the head relative to the pump flow rate. These five sections will be explained further in sections 4.1 to 4.5. Through these steps, the head of the spiral pump can be analyzed by utilizing the performance of the water wheel as the driving mechanism. The numerical software used in this study was Solidworks.

4 Application and Results

4. 1 Measurement of Water Flow Velocity

The measurement of water flow velocity in this study is relatively simple. The tools used include a cylindrical float made of wood and a stopwatch to measure the time [9]. The procedure involves releasing the float over a distance of 10 meters, then measuring the time it takes to travel that distance using the stopwatch. From this measurement, the average flow velocity of the river water was determined to be 0.896 m/s.

4.2 Water Wheel Modeling

Creating a model of the spiral pump for this study provides an understanding of the behavior and performance of the spiral pump. Through this model, researchers can identify influencing factors such as efficiency, design more optimal configurations, and develop performance prediction methods for real-world applications [10]. Specifically, in this study, the pump head analysis was conducted using the spiral pump model as shown in Fig. 1.

4.3 Calculation of Wetted Cross-Sectional Area of the Water Wheel

The wetted cross-sectional area can be calculated using Equation 1. For a water depth on the wheel (*d*) of 0.3 m and a wheel width (*w*) of 0.6 m, the wetted cross-sectional area (*A*) is:

$$A = 0.3m.\ 0.6m = 0.18\ m^2. \quad (6)$$

4.4 Calculation of Input & Output Power of the Water Wheel

If the density (ρ) is known to be 1000 kg/m³, the wetted cross-sectional area (*A*) is 0.18 m², and the water flow velocity (*V*) is 0.896 m/s, then using Equation 2, the input power of the water wheel (P_{in}) can be calculated as follows.

$$P_{in} = ½.\ 1000\ kg/m^3.\ 0.18\ m^2.\ (0.896m/s)^3 = 64{,}738\ Watt. \quad (7)$$

Meanwhile, the output power of the water wheel can be calculated using Equation 3 by assuming the wheel's efficiency to be 40%. The output power of the water wheel (Pout) is then calculated to be 25.895 watts.

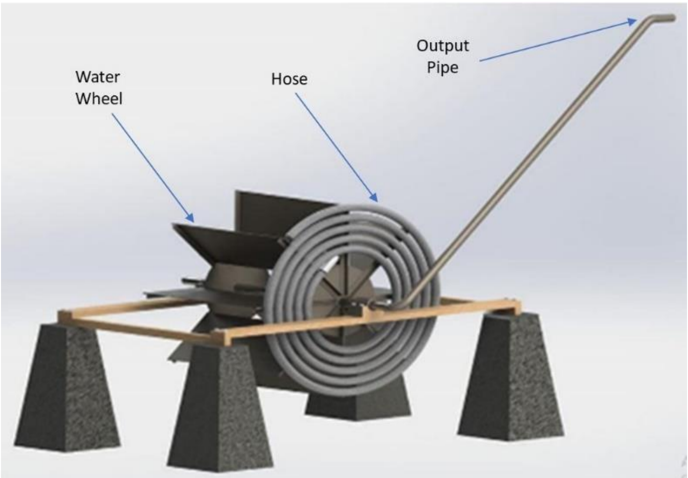

Figure 1. The spiral pump model under study

4.5 Spiral Pump Head Analysis

By determining the desired pump head, the pump discharge can be calculated using Equation 5. For example, if the pump head is set to 0.5 m, the pump discharge is:

$$Q = \frac{25.895\ \text{Watt}}{1000kg/m^3.9.81m/s^2.0.5m} = 0.00528\ \text{m}^3/\text{s} = 5.28\ \text{L/s}. \quad (8)$$

Based on the data from the calculation of the water discharge against the head, a graph is then created to facilitate the interpretation of the change in water discharge with respect to the head. Below are the Table 1 and Fig. 2 showing the relationship between the head and water discharge of the spiral pump.

In Fig. 2, the head of the spiral pump is varied from 0.5 m to 10 m with an interval of 0.5 m. A significant decrease in flow rate occurs until the head reaches 3 m, whereas from 3 m to 10 m, the flow rate decreases gradually. For small agricultural land needs or household purposes, a pump with a minimum flow rate of 0.5 L/s is required. Based on Fig. 2, the maximum head that meets this requirement is 5 m. Overall, the highest discharge (5.28 L/s) occurs at a head of 0.5 m, while the lowest discharge (0.26 L/s) occurs at a head of 10 m.

Table 1. Head versus discharge of pump

No	***Head (m)***	**Discharge Q (m^3/s)**	**Discharge (L/s)**
1	0.5	0.00528	5.28
2	1	0.00264	2.64
3	1.5	0.00176	1.76
4	2	0.00132	1.32
5	2.5	0.00105	1.05
6	3	0.00088	0.88
7	3.5	0.000754	0.75
8	4	0.00066	0.66
9	4.5	0.000587	0.59
10	5	0.000528	0.53

11	5.5	0.00048	0.48
12	6	0.00044	0.44
13	6.5	0.000406	0.41
14	7	0.000377	0.38
15	7.5	0.000352	0.35
16	8	0.00033	0.33
17	8.5	0.00031	0.31
18	9	0.00029	0.29
19	9.5	0.000278	0.28
20	10	0.000264	0.26

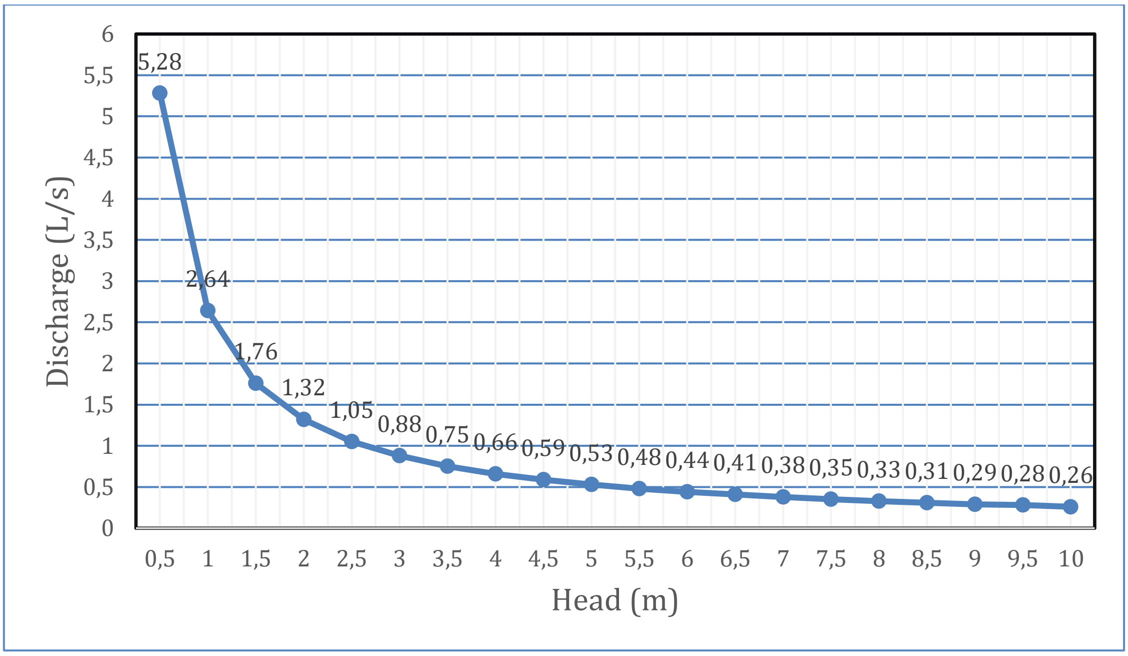

Figure 2. Head vesus discharge of pump

5 Conclusions

This study shows that a significant decrease in discharge occurs from a head of 0.5 m to a head of 3 m, whereas from 3 m to 10 m, the decrease in discharge is more gradual. For small agricultural land needs or household use, the water wheel pump for this spiral pump will be suitable for a maximum head of 5 m with a discharge of 0.53 L/s. Overall, the highest discharge (5.28 L/s) occurs at a head of 0.5 m, while the lowest discharge (0.26 L/s) occurs at a head of 10 m. The analysis shows that the higher the head of the spiral pump, the lower the discharge obtained.

Although this study identifies a maximum head of 5 meters as suitable for small-scale applications, examining the scalability of the spiral pump design is crucial to extend the applicability and impact of the findings. Adapting the spiral pump for larger capacities would involve modifications to key design parameters such as coil diameter, the number of turns, pipe size, and the driving mechanism (e.g., using larger water wheels or optimizing rotational speed). Increasing the pipe diameter and the overall scale of the spiral can enhance the volume of water transported per cycle, while adjustments to the number of turns can increase the achievable head. For instance, if a two-fold increase in head is desired, the pipe diameter and water wheel diameter may need to increase by a factor of approximately 1.5 times.

Furthermore, larger systems would need to address additional engineering challenges such as higher mechanical stresses, increased frictional losses, and the need for structural stability. Material selection becomes more critical to ensure durability under greater operational loads. By exploring these adaptations, this study could provide valuable insights into how the fundamental principles of the spiral pump can be applied not only to small-scale rural water supply projects but also to medium- to large-scale agricultural irrigation systems or decentralized industrial water distribution systems.

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