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Numerical Investigation of Effect of Nozzle Diameter on the performance of Pelton Turbine

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ABSTRACT

A Pelton wheel, also known as a Pelton turbine, is a type of water turbine used for generating mechanical power from the energy of flowing water. Its performance has been investigated on the basis of various factors include nozzle diameter, Head, Bucket angle and many others but, we have investigated the performance of Pelton turbine by experimental analysis, by changing its nozzle diameter which effect the performance of turbine. We have selected different nozzle diameters to perform our experiment. By changing the nozzle diameter of the Pelton wheel, the performance of the turbine changes non linearly. We have increased diameter from 150 mm to 200 mm then absolute velocity decreases from 26.03 m/s to 14.65 m/s similarly shaft power decreases from 1323 KW to 415 KW and efficiency remains constant about 78 %. It causes the effect on the efficiency of the Pelton turbine, work done, shaft power and its absolute velocity. When the diameter of jet increases then absolute velocity of the blades decreases similarly, work done and Head also decreases. The hydraulic efficiency increases with an increase in nozzle diameter up to a certain point, beyond which it starts decreasing. We have concluded that nozzle diameter has effect on different parameters of the Pelton wheel that discussed above.

Keywords: Numerical Investigation, Nozzle Diameter, Pelton Turbine

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Introduction

Hydropower has long been recognized as one of the most sustainable and reliable forms of renewable energy, with a significant contribution to the global electricity mix. Among the various hydraulic turbines employed in power plants, the Pelton turbine occupies a distinct position due to its suitability for high-head and low-discharge conditions. It operates on the impulse principle, where the entire energy of the water jet is transformed into kinetic energy before striking the runner buckets. This feature allows Pelton turbines to achieve high efficiencies, often above 85%, making them ideal for mountainous regions where steep gradients provide large water heads.

The performance of a Pelton turbine is not determined by a single parameter but rather a combination of design and operating factors. Parameters such as jet velocity, bucket angle, speed ratio, and nozzle diameter collectively govern the turbine's output power and efficiency. Among these, nozzle diameter is particularly significant as it directly influences the velocity of the water jet and, consequently, the momentum transfer to the buckets. A smaller nozzle diameter generates a high-velocity jet, leading to greater power transfer, while a larger diameter allows for greater discharge but at reduced velocity. Understanding this trade-off is vital for optimizing turbine performance and adapting designs to varying site-specific requirements.

Although Pelton turbines have been studied for more than a century, most research efforts focus on efficiency improvements through bucket geometry optimization, material design, and flow interaction analysis. Comparatively fewer studies have isolated the effect of nozzle diameter on performance under controlled conditions. This research seeks to address that gap by providing a systematic investigation of the role of nozzle diameter on turbine characteristics such as jet velocity, shaft power, work done per second, head, and efficiency. The insights gained will be valuable for engineers and designers seeking to maximize power generation in high-head hydropower projects.

Objectives

The primary aim of this study is to investigate the effect of nozzle diameter on the performance of a Pelton turbine under controlled discharge conditions. To achieve this aim, the research is guided by the following specific objectives:

To evaluate the impact of nozzle diameter on jet velocity and effective head. Since nozzle size directly governs the jet velocity, this objective focuses on quantifying how velocity varies with different diameters.

To analyze the influence of nozzle diameter on work done per second and shaft power. These parameters provide insights into how nozzle design affects the mechanical output of the turbine.

To examine changes in overall turbine efficiency across varying nozzle diameters. This will determine whether efficiency remains stable or fluctuates with nozzle variations.

To identify the optimal nozzle diameter, range for balancing efficiency and power output. This objective is crucial for providing practical design recommendations for Pelton turbines in high-head hydroelectric projects.

Literature Review

The Pelton turbine was invented in the late 19th century by Lester Allan Pelton, who revolutionized hydropower by designing a turbine capable of extracting almost all the kinetic energy from a water jet. His design, which utilized double-cupped buckets to split and deflect

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the jet, minimized energy loss and set a new benchmark for turbine efficiency. Since then, researchers have devoted significant attention to improving Pelton turbine design and performance.

Early studies primarily examined the basic energy transfer mechanisms in impulse turbines, focusing on velocity triangles and the impact of bucket deflection angles. More recent investigations, however, have applied computational fluid dynamics (CFD) and experimental methods to analyze jet behavior, bucket surface interaction, and the influence of various design parameters. For instance, Kumar et al. (2018)

Demonstrated that nozzle geometry plays a critical role in maintaining jet coherence and minimizing energy dissipation. Similarly, Singh and Saini (2020) emphasized that variations in nozzle size affect jet velocity distribution, which in turn governs the magnitude of force applied on the runner buckets.

Patel et al. (2022) presented findings indicating that an increase in nozzle diameter, while improving discharge capacity, results in reduced shaft power due to the inverse relationship between velocity and flow area. Other studies have noted that turbine efficiency generally remains stable across a range of nozzle diameters, as the energy conversion ratio does not change drastically, but the absolute power output may decline. This suggests that nozzle optimization is not merely about maximizing efficiency but balancing efficiency with achievable power output under site-specific conditions.

Despite these valuable insights, comprehensive evaluations that analyze nozzle diameter effects across a controlled range while keeping discharge constant are relatively limited. Most available studies either consider nozzle effects alongside multiple other variables or focus on specific case studies without broader generalization. This work attempts to fill this research gap by systematically varying nozzle diameters between 150 mm and 200 mm and observing their effect on turbine performance metrics under a constant discharge condition.

Methodology

- The purpose for these calculations is to determine the performance of Pelton wheel by taking nozzle diameter as variable. We provided the constant data for the calculations: Total
- discharge (Q) = 1 m^3/s Cv = 0.98, u = $0.46\sqrt{(2gH)}$, angle of deflection (θ) = 160°, mechanical efficiency = 85%.
- Then considered the value of nozzle diameters (d) as 150 and calculated the results and then varied the range of nozzle diameter 150 mm to 200 mm, with intervals of 5 mm.
- Then we calculated absolute velocity at inlet V by using the formula of discharge.
- From the velocity triangle diagram we concluded that absolute velocity at inlet is equal to whirl velocity at inlet
- Then we calculated the relative velocity at inlet.
- Then we calculate whirl velocity at outlet by using angle and value of absolute velocity
- We calculated relative velocity at outlet as it is equal to relative velocity at inlet.
- We applied work done formula and calculated its value.
- We calculated shaft power using mechanical efficiency formula.
- Then we calculated head (H) as it is compulsory to find overall efficiency.
- At the end, we calculated the value of overall efficiency using its formula.

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For Diameter d=150mm
Given Data:
Q = 1 m3/s, Cv = 0.98,
u = (0.46) V1
φ = 180° – 160° = 20°
ηmech = 85%
ρ = 1000 Kg/m3. g = 9.81 m/s2

Required Data:
ηtotal =?

Formulae Used:
Q=(a1)(v1)
W.D/s = ρav1[vw1 + vw2}(u)
ηmech = S.P / W.D/s ηtotal= S.P / ρQgH **Solution:** CASE:01
D=0.150m

$a1 = \frac{\pi}{4} d^2$

$a1 = 0.018 m^2$
Q=(a1)(v1)
v1=56.59m/s u = (0.46) V1
u=26.03m/s
From Velocity triangle v1=vw1=56.59m/s u1=u2=26.03m/s
vr1=vr2= vw1-u1=30.56m/s As we know
vw2=vr2 Cosφ-u2=2.66m/s
W.D/s = ρav1[vw1 + vw2}(u) = 1570994.707 Nm/S AS
ηmech = S.P / W.D/s S.P=13235345.5W
For H
V1 = Cv√2gH
H=170m
ηtotal= S.P / ρQgH = 80%

For Diameter d=160mm
Given Data:
Q = 1 m3/s, Cv = 0.98,
u = (0.46) V1
φ = 180° – 160° = 20°
ηmech = 85%
ρ = 1000 Kg/m3.
g = 9.81 m/s2

Required Data:
ηtotal =?

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Formulae Used:
Q=(a1)(v1)
W.D/s = ρav1[vw1 + vw2}(u)
ηmech = S.P / W.D/s ηtotal= S.P / ρQgH

Solution:
CASE:01 D=0.160m
$a1 = \pi d^2$
4
$a1 = 0.02m^2$
Q=(a1)(v1)
v1=49.73m/s u 1= (0.46) V1
u=22.88m/s
From Velocity triangle v1=vw1=49.73m/s u1=u2=26.03m/s
vr1=vr2= vw1-u1=26.86m/s As we know
vw2=vr2 Cosφ-u2=2.36m/s
W.D/s = ρav1[vw1 + vw2}(u) = 1185383.376Nm/S AS
ηmech = S.P / W.D/s S.P=W =1007575.87
For H
V1 = Cv√2gH
H=131.29
ηtotal= S.P / ρQgH = 78%

For Diameter d=170mm
Given Data:
Q = 1 m3/s, Cv = 0.98,
u = (0.46) V1
φ = 180° – 160° = 20°
ηmech = 85%
ρ = 1000 Kg/m3. g = 9.81 m/s2

Required Data:
ηtotal =?

Formulae Used:
Q=(a1)(v1)
W.D/s = ρav1[vw1 + vw2}(u)
ηmech = S.P / W.D/s ηtotal= S.P / ρQgH **Solution:** CASE:01
D=0.170m
$a1 = \pi d^2$
4

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$a1 = 44.08m^2$
Q=(a1)(v1)
v1=44.08m/s
u = (0.46) V1
From Velocity triangle v1=vw1=56.59m/s u1=u2=26.03m/s
vr1=vr2= vw1-u1=23.81m/s As we know
vw2=vr2 Cosφ-u2=2.10m/s
W.D/s = ρav1[vw1 + vw2}(u) = 949023.87 Nm/S AS
ηmech = S.P / W.D/s S.P=806670.3
For H
V1 = Cv√2gH
H=103.2
ηtotal= S.P / ρQgH = 79%

For Diameter d=180mm

Given Data:
Q = 1 m3/s, Cv = 0.98,
u = (0.46) V1
φ = 180° – 160° = 20°
ηmech = 85%
ρ = 1000 Kg/m3. g = 9.81 m/s2

Required Data:
ηtotal =?
Formulae Used:
Q=(a1)(v1)
W.D/s = ρav1[vw1 + vw2}(u)
ηmech = S.P / W.D/s ηtotal= S.P / ρQgH **Solution:**
CASE:01 D=0.150m

$a1 = \frac{\pi}{4} d^2$

Q=(a1)(v1)
v1=39.32m/s u = (0.46) V1
From Velocity triangle v1=vw1=56.59m/s vr1=vr2= vw1-u1=21.2m/s As we know
vw2=vr2 Cosφ-u2=1.82m/s
W.D/s = ρav1[vw1 + vw2}(u) = 731975.22 Nm/S AS
ηmech = S.P / W.D/s S.P=622175.6W
For H
V1 = Cv√2gH
H=82.5
ηtotal= S.P / ρQgH = 77.2%

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For Diameter d=190mm

Given Data:
Q = 1 m3/s, Cv = 0.98,
u = (0.46) V1
φ = 180° – 160° = 20°
ηmech = 85%
ρ = 1000 Kg/m3. g = 9.81 m/s2

Required Data:
ηtotal =?

Formulae Used:
Q=(a1)(v1)
W.D/s = ρav1[vw1 + vw2}(u)
ηmech = S.P / W.D/s ηtotal= S.P / ρQgH

Solution: CASE:01
D=0.190m

$a1 = \frac{\pi}{4} d^2$

Q=(a1)(v1)
v1=35.28m/s u = (0.46) V1
From Velocity triangle v1=vw1
vr1=vr2= vw1-u1=19.05m/s
As we know
vw2=vr2 Cosφ-u2=1.67m/s
W.D/s = ρav1[vw1 + vw2}(u) = 599698.5 Nm/S AS
ηmech = S.P / W.D/s S.P=509743.7
For H
V1 = Cv√2gH
H=66m
ηtotal= S.P / ρQgH = 78.6%

Results and Discussion
We will discuss about the results obtained in our observations and investigations. We will discuss how different parameters in performance of Pelton wheel changes by changing jet diameter. We will discuss it by using graphs of different parameters (that remain constant or change) with diameter of the jet. Also, we make a table of different parameters that change during varying jet diameter.

Sr. No	Diameter of	Absolute	WD/sec	Shaft power	Head (m)	Efficiency

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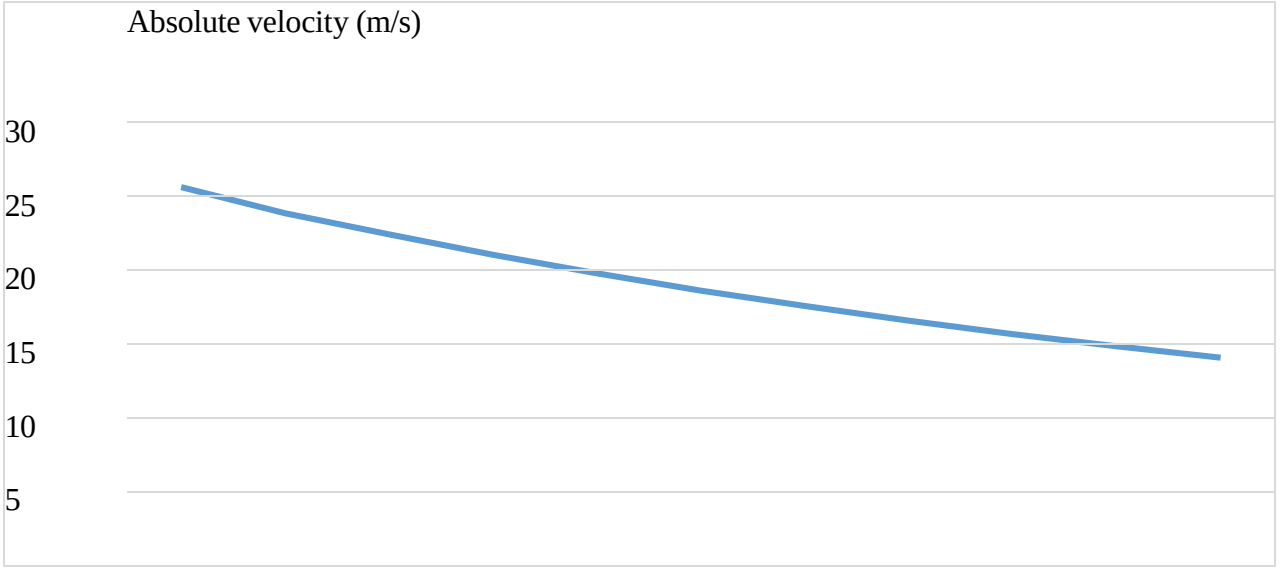
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	jet (m)	velocity (m/s)	(KW)	(KW)		(%)
1	0.150	26.03	1573	1323	170	80
2	0.155	24.28	1362	1158	149.05	79
3	0.160	22.88	1185	1007	131.29	78
4	0.165	21.51	986	838	116.14	77
5	0.170	20.27	949	806	103.2	79
6	0.175	19.13	832	707	92	78
7	0.180	18.09	731	622	82.1	77
8	0.185	17.11	644	548	73.5	76
9	0.190	16.23	599	509	66	78
10	0.195	15.41	540	459	60	78
11	0.200	14.65	488	415	54	78

Effect of Diameter of Jet on Different Parameters of Pelton Turbine

Effect on Absolute Velocity

When the diameter of jet increases then absolute velocity of the blades decreases. The absolute velocity is the velocity of the water relative to a fixed point.it varies inversely with the diameter of jet. When the diameter of jet increases then absolute velocity of the blades decreases. For example when the diameter of the jet is 150 mm then absolute velocity is 26.03 m/s similarly when the diameter increased to 155 mm then absolute velocity decreased which is 24.38m/s which is shown in the following graph.



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0	0.15	0.155	0.16	0.165	0.17	0.175	0.18	0.185	0.19	0.195	0.2

Effect on work done/second

The work done per second (power) of a Pelton turbine is a measure of the rate at which the turbine converts the kinetic energy of a fluid into mechanical work or electricity. It is inversely related to diameter of jet. When the diameter of jet increases then works done of the Pelton turbine decreases. For example, when the diameter of the jet is 150 mm then absolute velocity is 26.03 m/s similarly when the diameter increased to 155 mm then absolute velocity decreased which is 24.38m/s which is shown in the following graph.



Graph between diameter of nozzle and work done per sec

Effect on Shaft Power

Shaft power, also known as mechanical power, refers to the actual usable power output of an electric motor's shaft. It represents the mechanical work done by the motor and is a key parameter for assessing its performance. When the diameter of jet increases then shaft power decreases. For example when the diameter of the jet is 150 mm then shaft power is 1323 similarly when the diameter increased to 155 mm then shaft power decreased is 1158 which is shown in the following graph

Effect on Head

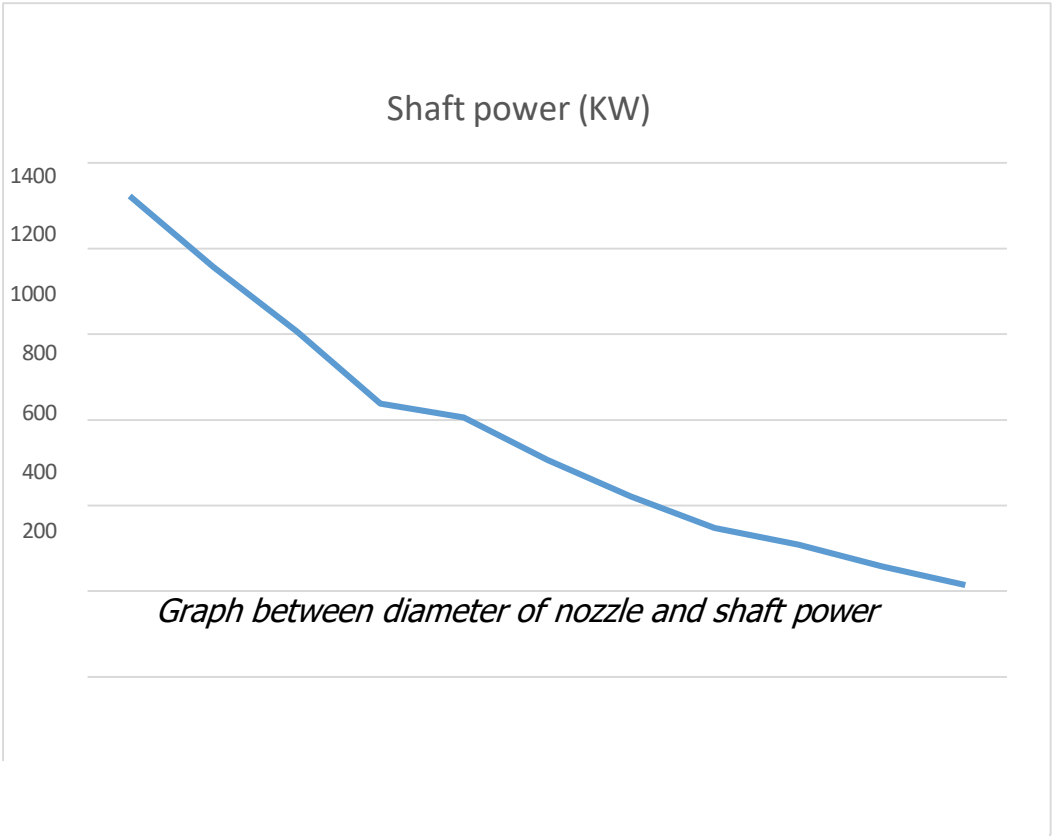
The head of water in a Pelton turbine refers to the height difference between the water source and the turbine. It is the amount of potential energy that the water possesses due to its position



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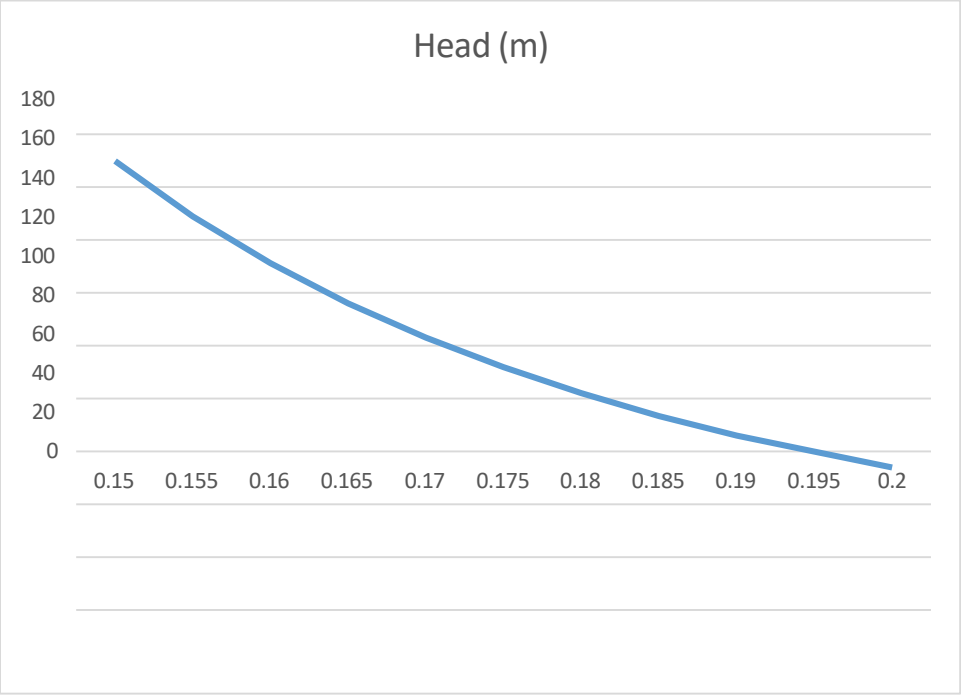
Graph between diameter of nozzle and shaft power

above the turbine. The head of water is used to calculate the amount of kinetic energy that can be generated by the turbine. When the diameter of jet increases then head decreases. For example when the diameter of the jet is 150 mm then shaft power is 170 similarly when the diameter increased to 155 mm then head is 149.5 which is shown in the following graph.

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Graph Between Diameter of Nozzle and Head

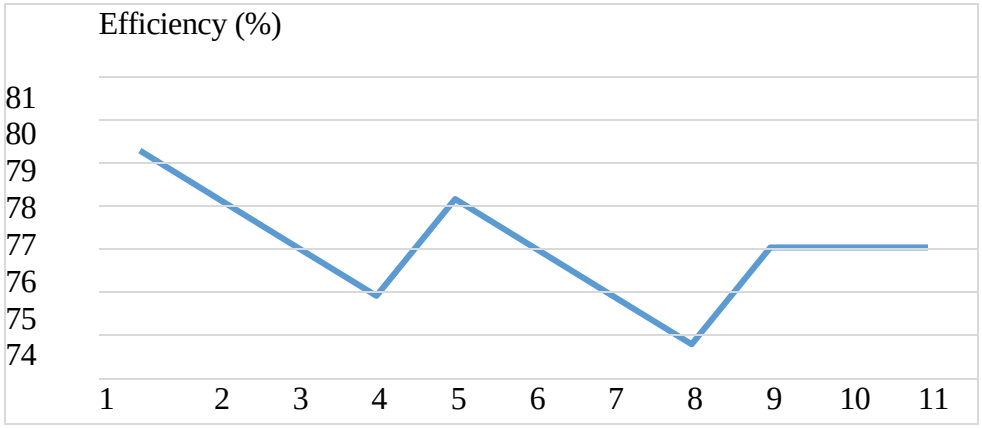
Effect on efficiency

The efficiency of a Pelton turbine is defined as the ratio of the power developed by the runner to the power supplied by the jet at the entrance to the runner. The efficiency of a Pelton turbine is affected by several factors, including the nozzle diameter. The hydraulic efficiency increases with an increase in nozzle diameter up to a certain point, beyond which it starts decreasing. The optimal nozzle diameter for maximum hydraulic efficiency depends on several factors such as the head, speed, and specific speed of the turbine

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Graph Between Diameter of Nozzle and Efficiency

Conclusions

We investigated the performance of Pelton turbine for different nozzle diameters (d) through detailed design calculations using a simplified mathematical model. We assumed the following data constant for our calculations. Total discharge: 1 m3 /s, Cv: 0.98, u=0.46V1, angle of deflection:160°,ηmech=85%.We changed the nozzle diameter in the range of 150 mm to 200 mm with an interval of 5 mm each time. We calculated the value of various performance parameters and constructed the graphs. An overview of results of calculations we made is given below:

When the diameter of jet increases then absolute velocity of the blades decreases. The absolute velocity is the velocity of the water relative to a fixed point.it varies inversely with the diameter of jet. When the diameter of jet increases then absolute velocity of the blades decreases. For example when the diameter of the jet is 150 mm then absolute velocity is 26.03 m/s similarly when the diameter increased to 155 mm then absolute velocity decreased which is 24.38m/s which is shown in the following graph.

The work done per second (power) of a Pelton turbine is a measure of the rate at which the turbine converts the kinetic energy of a fluid into mechanical work or electricity. It is inversely related to diameter of jet. When the diameter of jet increases then works done of the Pelton turbine decreases. For example, when the diameter of the jet is 150 mm then absolute velocity is 26.03 m/s similarly when the diameter increased to 155 mm then absolute velocity decreased which is 24.38m/s which is shown in the following graph.

Shaft power, also known as mechanical power, refers to the actual usable power output of an electric motor's shaft. It represents the mechanical work done by the motor and is a key

parameter for assessing its performance. When the diameter of jet increases then shafts power decreases. For example, when the diameter of the jet is 150 mm then shaft power is 1323 similarly when the diameter increased to 155 mm then shaft power decreased is 1158 which is shown in the following graph.

The head of water in a Pelton turbine refers to the height difference between the water source and the turbine. It is the amount of potential energy that the water possesses due to its position above the turbine. The head of water is used to calculate the amount of kinetic energy that can

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be generated by the turbine. When the diameter of jet increases then heads decreases. For example, when the diameter of the jet is 150 mm then shaft power is 170 similarly when the diameter increased to 155 mm then head is 149.5 which is shown in the following graph.
The efficiency of a Pelton turbine is defined as the ratio of the power developed by the runner to the power supplied by the jet at the entrance to the runner. The efficiency of a Pelton turbine is affected by several factors, including the nozzle diameter. The hydraulic efficiency increases with an increase in nozzle diameter up to a certain point, beyond which it starts decreasing. The optimal nozzle diameter for maximum hydraulic efficiency depends on several factors such as the head, speed, and specific speed of the turbine.

References

Peng, W.W., Fundamentals of turbomachinery. 2007: John Wiley & Sons.
Williams, A., Pumps as turbines: a user's guide. 2003: ITDG Pub.
Khurmi, R. and N. Khurmi, Hydraulics, Fluid Mechanics and Hydraulic Machines. 1987: S.Chand Publishing.
Kumar, K., Engineering fluid mechanics. 2008: S. Chand Publishing.
Qasim, S.A.S.O.a.M.A.K., , Effect of Flow Parameters on Pelton Turbine Performance. p. Vol. 7, No. 3.. International Journal of Modeling and Optimization,, 2017. **p. Vol. 7** p. No 03n.
N Kholifah*, A.C.S., D S Wijayanto, I Widiastuti and H Saputro, Performance of Pelton Turbinefor Hydroelectric Generation in Varying Design Parameters. The 2nd Annual Applied Science and Engineering Conference (AASEC2017), 2018:p. 288.
In Chan Jo, J.H.P., Jeong-Won Kim, Youhwan Shin & Jin Taek Chung, Jet
quality characteristicsaccording to nozzle shape of energy-recovery Pelton turbines in pressure-retarded osmosis. http://www.tandfonline.com/loi/tdwt20, 2016: p. 1-10.
M.K. Padhy a, R.P. Saini b, Study of silt erosion on performance of a Pelton turbine. www.elsevier.com/locate/energy, 2011: p. 141-147.
Vashishtha, G. and R. Kumar, Pelton wheel bucket fault diagnosis using improved shannonentropy and expectation maximization principal component analysis. Journal of Vibration Engineering & Technologies, 2022: p. 1-15.
Gudukeya, L. and C. Mbohwa. Improving the efficiencies of Pelton wheel in micro-hydro power plants. in Proceedings of the International Conference on Industrial Engineering and OperationsManagement. 2017.
Zeng, C., et al., Hydraulic performance prediction of a prototype four-nozzle Pelton turbine byentire flow path simulation. Renewable Energy, 2018. **125**: p. 270-282.
Audrius1, Ž., et al., Parametric optimisation of two Pelton turbine runner designs using CFD*. Journal of Hydrodynamics, 2015: p. 403-412.
R Z Gong1, C.Y.S., H J Wang, D Y Li1, D Q Qin2, Solution of a kind of negative flow in a Pelton turbine. 29th IAHR Symposium on Hydraulic Machinery and Systems, 2019. **240**.