Effect of Flow Parameters on Pelton Turbine Performance by Using Different Nozzles

Talib Z. Farge, Abdul Jabbar Owaid. H., Mohammed Abdul Khaliq Qasim

***Abstract*—The aim of this paper is to investigate experimentally the effect of different nozzles, water head and discharge on the performance of Pelton turbine system. The effect of five different nozzles with outlet diameters of (3.61, 5.19, 8.87, 12, and 14.8) mm has been studied. The tip and hub diameter of the Pelton wheel of (269.89, 221.29) mm has been used with different nozzles. A water pump was used to generated the pressure head and volume flow rate. The results show for every certain nozzle that when decreasing the water head lead to reduction in water discharge and this caused reduction in the torque, brake power, efficiency and the rotational speed. In addition, the results show that when increasing in nozzle diameter lead to increasing the discharge and reduction water head. While in the case of constant head of 15 m, the results show that the nozzle with diameter 8.87mm give the best the performance than the others, where the percentage increase in torque, brake power, efficiency and the rotational speed of the turbine are (62.2%, 66.48%, 60%, and 15.35%) respectively with the second nozzle with diameter of 5.19 mm.**

***Index Terms*—Pelton turbine, water pump, electrical power, torque, brake power, nozzle.**

I. Introduction

The Electricity power considered as very important in Iraq country. In Iraq during summer, the outer temperature, sometimes, exceeds 50^0C [1], and this will increase the electrical demand by costumer. The country has several problems, electricity, which obstructs its development, despite the availability of natural resources in the country. The hydropower energy is one of the most important sources of the renewable energy of the world to supply the electricity. The percentage of hydropower energy was of 86.31% of the renewable energies were tapped as of 2008 [2].

The Pelton turbine is one of the most important part of the hydropower plants, which a type is of impales water turbine. In the 1870, the Pelton turbine was invented by luster Allan Pelton [3]. The Pelton turbine is kind of impales turbine that convert the gravitation potential energy into the kinetic energy, which the velocity of water jet increases and hitting the blades of the turbine converting to a mechanical energy (shaft rotation), which inanimately convert to electrical energy. There a lot of papers have been published in the last decades about numerical and experimental analysis and design of Pelton turbine [4-16] to improve the performance and development of Pelton turbine. In addition, there are of papers have been published to study experimentally and numerically the performance of the nozzle used in the hydro-turbine [17]-[28].

In the present work the experimentally investigation the effect of water head and volume flow rate on the performance of a Pelton turbine by using different size of nozzles to perform the performance of Pelton turbine system.

II. Experimental Work

A test rig of a Pelton turbine system was designed and implemented as shown in Fig. (1). Where the experimental works were carried on it with five different nozzles have outer diameters of (3.61, 5.19, 8.78, 12, 14.8) mm, the dimensions of the different nozzles as shown in Table I. The system consists from Pelton turbine with 24 cup buckets (material Glass filled Nylon) and the tip diameter of (269.89) mm and hub diameter of (221.29) mm as shown in Fig. (2), digital flow meter, water pump with head of (46) m, tow tension scale gauge connected by smooth belt to be used as a variable brake load and a tachometer to measure the rotational speed. A water pump was used to provide the pressure head and volume flow rate.

Fig. 1(a). Pelton turbine system.

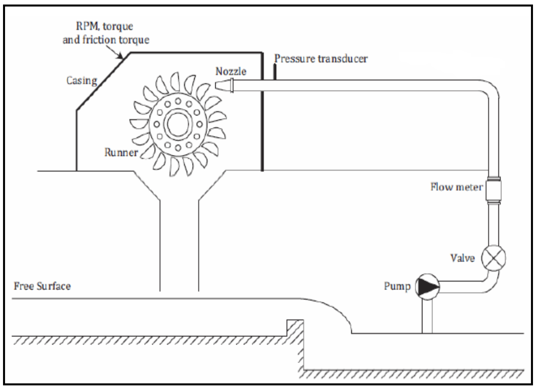

Fig. 1(b). Pelton turbine system diagram.

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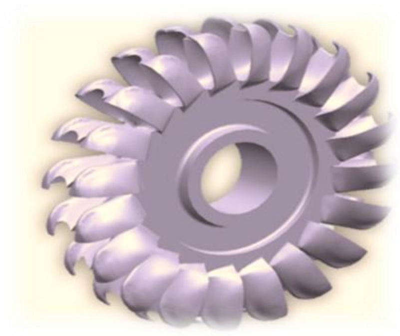

Fig. 2. Pelton turbine wheel.

TABLE I: THE DIMENSION OF THE FIVE NOZZLES

Nozzle no.	Length (mm)	Inlet diameter (mm)	outlet diameter (mm)
1	3.61	10.5	48.5
2	5.19	10.19	30
3	8.87	18.13	70.5
4	12	18.13	47.8
5	14.8	18.13	22.5

III. PERFORMANCE CALCULATION

The main parameters that effect on the Pelton turbine performance are (discharge of water, water head, and the torque applied on the turbine shaft).

To calculate the performance of the Pelton turbine by using the experimental readings starting with calculating the discharge (volume flow rate) of water the fallowing equations used. [28].

$$Q = \frac{V}{t} \tag{1}$$

To find the power proved to the Pelton turbine (water power) the following equation was used:

$$Ph = \rho \; g \; H \; Q \tag{2}$$

To find the torque applied on the shaft of the Pelton turbine from the water jet the following equation was used:

$$T = (F_1 - F_2)\; R \tag{3}$$

To find the brake power produced by the turbine (power available at Pelton turbine shaft) by using the following equation:

$$Pb = T \times \omega \tag{4}$$

To find the efficiency produced by the turbine using the following equation:

$$\eta = Pb/Ph \times 100\ \% \tag{5}$$

To find the rate of circumference blades velocity of rotational bucket of Pelton turbine (U) at reference diameter to the jet velocity at the nozzle outlet C_j the following were used: [28]

$$\frac{U}{C_j} = \frac{\frac{\pi D_{ref}}{60} N}{\frac{Q}{A_j}} \tag{6}$$

$$D_{ref} = \frac{D_{tip} + D_{hub}}{2} \tag{7}$$

$$A_j = \pi \left(\frac{d_j}{2}\right)^2 \tag{8}$$

IV. RESULT AND DISCUSSION

The experimental data were collected during the experiment for different type of nozzles as shown in the table (1). A water pump was used to generate the volumetric flow rate and water head, where as they are function of nozzle diameter. When the nozzle diameter increase, the volumetric flow rate will increase and the water head will decrease as shown in following figures. In addition, the volumetric flow rate and head can be controlled by using valve, when the valve fully opened; the maximum volumetric flow rate and maximum head were obtained. Figs. (3, 6, 9, 12, 15, 18, 21, and 24) show the relationship between the torque applied on the shaft of the Pelton turbine and the rotational speed of the turbine. The figures show the maximum rotational speed of Pelton turbine at zero torque applied on the shaft and the rotational speed decrease when the torque increase until reached the maximum torque the rotational speed becomes zero. In addition, the figures show that the maximum limits of rotational speed of the turbine and the maximum limits of torque increase when the water head and volumetric flow rate increased for every nozzle. This is because the potential energy converted to the kinetic energy, which increase the velocity of the water jet strike the bucket of the turbine causing the rotary motion of the turbine and produce the power output.

Figs. (4, 7, 10, 13, and 16) show the relation between the brake power produced by the Pelton turbine and the rotational speed of the turbine for different nozzles. The figures show that for every nozzle the values of brake power were increased at increased the water head and water discharge (volume flow rate) increase till reach the maximum values of water head and water dis charge for full open valve. In addition, the range of rotational speed increased as water head and water discharge increased. The figures show that the brake power equal to zero at zero and maximum rotational speed of Pelton turbine and increase towards the middle range of the rotational speed, which it's value reach the maximum value. This because the brake power is a function of torque and rotational speed, and for maximum torque the rotational speed equal to zero and for maximum rotational speed the torque equal to zero and the brake power increase toward the mean values of rotational speed and torque. Also the figures show that the peak value of brake power increases gradually with increasing the water head and water discharge due to increasing in the applied torque, where the brake power was a function of torque and rotational speed of the turbine.

Figs. (5, 8, 11, 14, and 17) show the relation between the overall efficiency and the rotational speed of the Pelton turbine system. The figures show that the variation of the efficiency at the same miner of those of the brake power except for the peak values of the efficiency, where they the at the same value approximately especially for the nozzles two and three. This is because the efficiency function of brake power and water power provide to the Pelton turbine, and the last one is constant at given water head and water discharge for each curve.

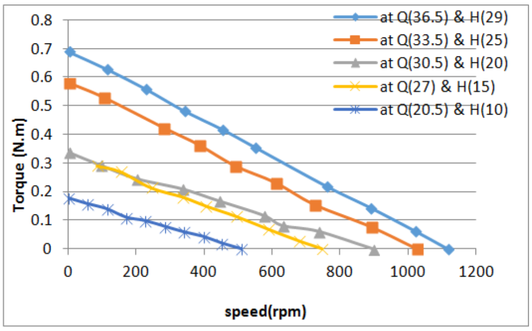

Fig. 3. The relationship between the applied torque and the rotational speed of Pelton turbine by using nozzle (1).

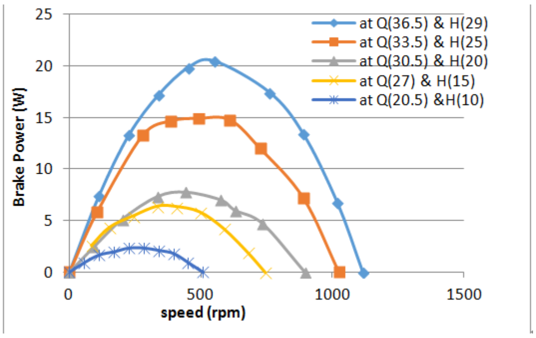

Fig. 4. The relationship between the brake power and the rotational speed of Pelton turbine by using nozzle (1).

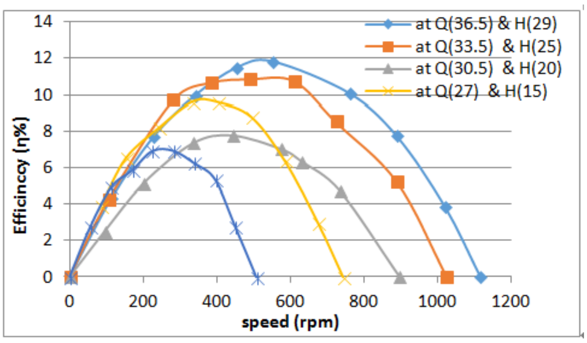

Fig. 5. The relationship between the efficiency and the rotational speed of Pelton turbine by using nozzle (1).

Figs. (18, 19, and 20) show the comparison result for different five nozzles at the maximum values of torque, brake power and the overall efficiency at full opening valve. The figures show that the nozzle 3 with outer nozzle diameter of 8.87 mm give a better performance than the others due to higher range of rotational speed of Pelton turbine, highest value of torque, highest value of brake power and the higher efficiency, which is a suitable to generated electricity.

Figs. (21, 22, and 23) show the comparison result of torque, brake power and efficiency respectively with the rotational speed of Pelton turbine for constant water head at 15 m for the different water discharge. The figures show the torque, brake power, and efficiency produced by the Pelton turbine with the nozzle number three give the highest value than the with other two nozzles. This is because the third nozzle has a higher water discharge firstly as shown in Fig. (24) and secondly due to the ratio of circumference blade velocity of rotational bucket of a Pelton turbine to the jet velocity of the value at 0.5 as in table 2 at maximum value of brake power and efficiency. The value of U/Cj =0.5 give the optimum design of the ratio of nozzle diameter to the Pelton wheel diameter [28].

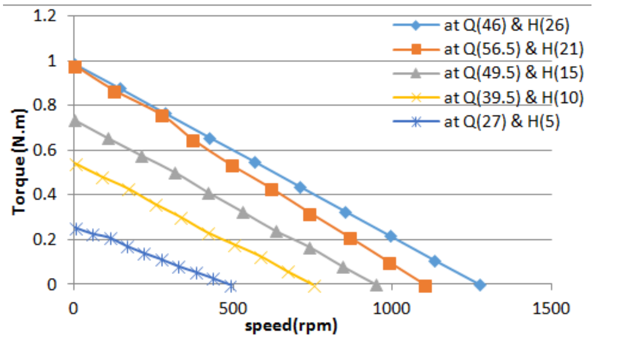

Fig. 6. The relationship between the applied torque and the rotational speed of Pelton turbine by using nozzle (2).

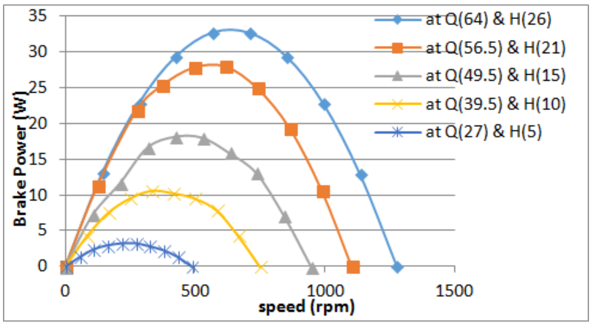

Fig. 7. The relationship between the brake power and the rotational speed of Pelton turbine by using nozzle (2).

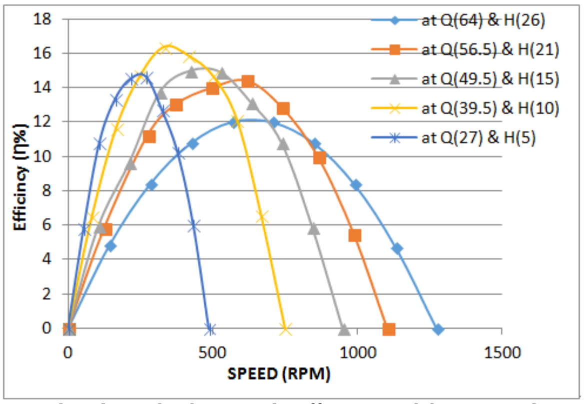

Fig. 8. The relationship between the efficiency and the rotational speed of Pelton turbine by using nozzle (2).

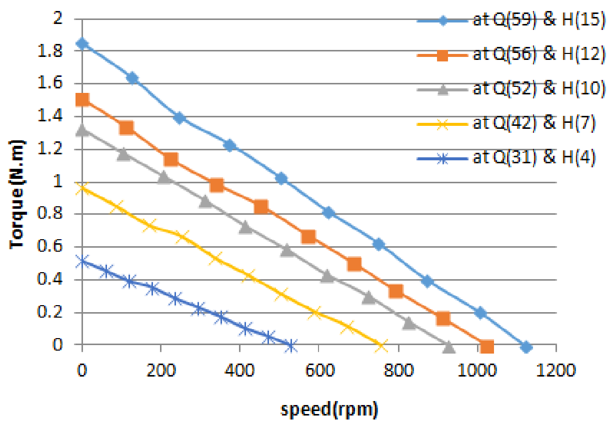

Fig. 9. The relationship between the applied torque and the rotational speed of Pelton turbine by using nozzle (3).

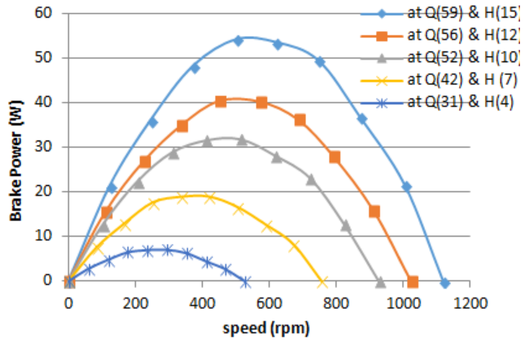

Fig. 10. The relationship between the brake power and the rotational speed of Pelton turbine by using nozzle (3).

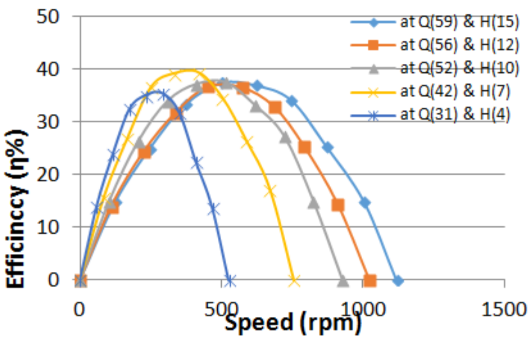

Fig. 11. The relationship between the efficiency and the rotational speed of Pelton turbine by using nozzle (3).

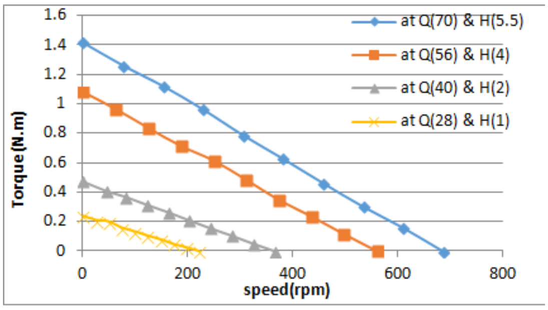

Fig. 12. The relationship between the applied torque and the rotational speed of Pelton turbine by using nozzle (4).

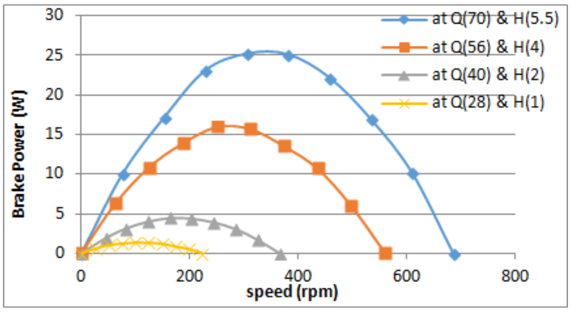

Fig. 13. The relationship between the brake power and the rotational speed of Pelton turbine by using nozzle (4).

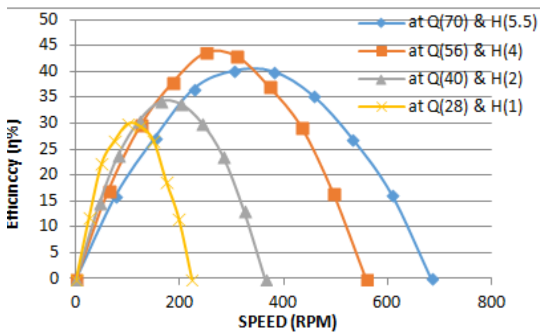

Fig. 14: The relationship between the efficiency and the rotational speed of Pelton turbine by using nozzle (4).

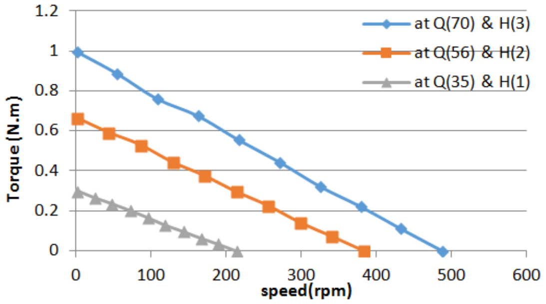

Fig. 15. The relationship between the applied torque and the rotational speed of Pelton turbine by using nozzle (5).

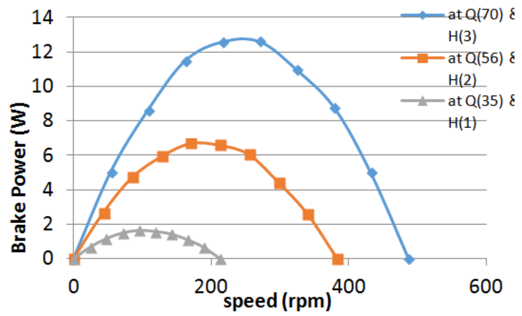

Fig. 16. The relationship between the brake power and the rotational speed of Pelton turbine by using nozzle (5).

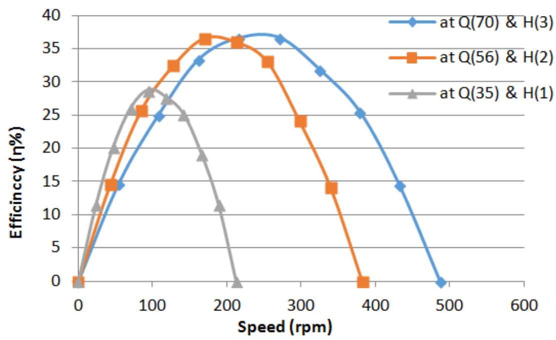

Fig. 17. The relationship between the efficiency and the rotational speed of Pelton turbine by using nozzle (5).

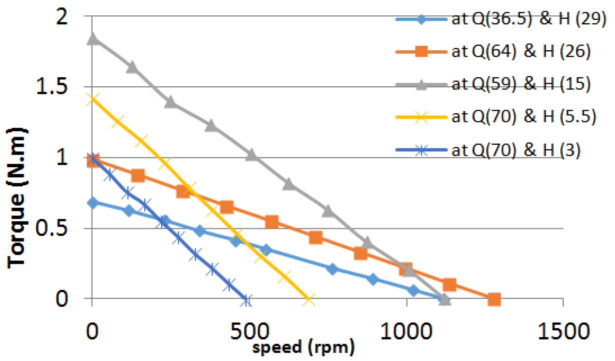

Fig. 18. Comparison of the torque for the all nozzles.

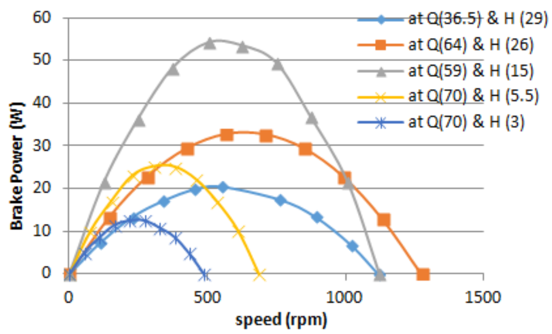

Fig. 19. Comparison of the torque for the all nozzles.

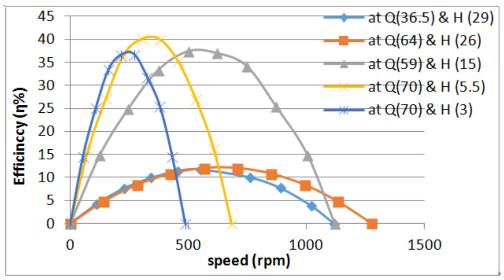

Fig. 20. Comparison of the torque for the all nozzle.

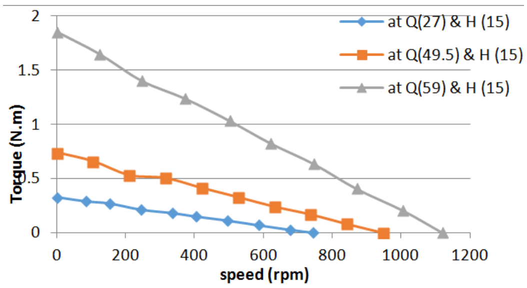

Fig. 21. The comparison of the torque for first 3 nozzles with head of 15 m (1, 2, and 3).

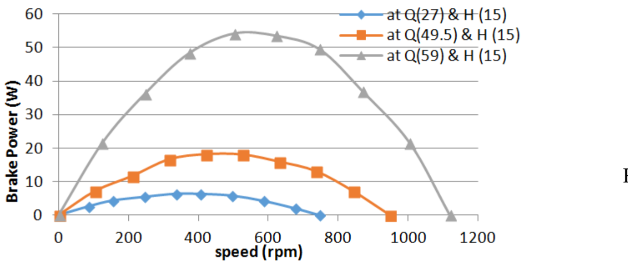

Fig. 22. The comparison of the brake power for first 3 nozzles with head of 15 m (1, 2, and 3).

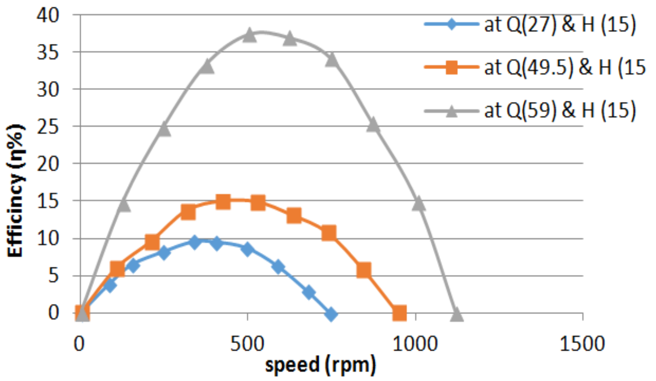

Fig. 23. The comparison of the efficiency for first 3 nozzles with head of 15 m (1, 2, and 3).

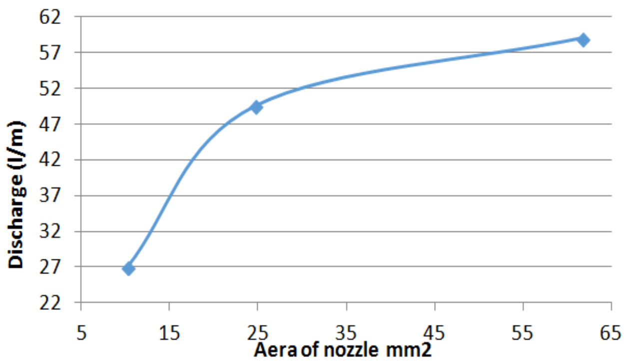

Fig. 24. The relationship between water discharge and the outer diameter.

TABLE II: SPEED RATIO OF THE FIRST 3 NOZZLES WITH HEAD 15 M

Nozzle no.	N	100	200	300	400	500	600	700	745	800	900	948	1000	1120
1	$\frac{U}{C_j}$	0.0292	0.05849	0.0877	0.11699	0.14622	0.01754	-	0.2179	0.1901	-	-	-	-
2	$\frac{U}{C_j}$	0.0329	0.06595	0.0989	0.1319	0.16487	0.19785	0.2308	-	0.26379	-	0.3125		-
3	$\frac{U}{C_j}$	0.0808	0.1616	0.2424	0.32323	0.4040	0.484	0.5656	--	0.6464	0.7272	-	0.8080	0.90505

V. CONCLUSION

The following remarks can be concluded from the experimental investigation

1- Increasing the nozzle diameter lead to increasing in the water discharge and decreasing the water head, where subjected to pump operating which boost the water flow through the nozzle to Pelton turbine.

2-The water discharge decreasing as the water head decreased for every certain nozzle size, which lead to decreasing the Pelton turbine performance (torque, brake power, efficiency and the range of rotational speed)

3- The best performance of Pelton turbine system was obtained by the nozzle number three with outlet diameter of 8.87mm, where the percentage increased in torque, brake power, efficiency and the rotational speed of 60.2%, 66.48%, 60% and 15.35% respectively comparing with the second nozzle with outer diameter of 5.19mm at the maximum values.

4- The optimum design for the Pelton turbine when choosing the nozzle outer diameter, which gives the ratio of circumferential blade velocity over rotating wheel to the jet velocity of water approaches from the value of 0.5.

NOMENCLATURE

Abbreviation	Manning of Abbreviation	Abbreviation	Manning of Abbreviation
A_j	Area of the nozzle (m2)	Ph	Hydraulic power(W)
Cj	Jet speed (m/s)	Pb	Brake Power (W)
D_{ref}	Reference turbine diameter (mm)	Q	Discharge (1/S)
D_{tip}	Tip diameter of the Pelton turbine (m)	R	Brake wheel radius 0.021m
D_{hub}	Hub diameter of the Pelton turbine (m)	t	Time (Sec)
d_j	Nozzle diameter (m)	T	Torque (N•m)
F1	Load reading on (N)	U	Bucket speed (m/s)
F2	Load reading on (N)	V	Volume of water
g	Acceleration m^2/Sec	ω	Angular speed (rad/S)
H	Head of water m H2O	η	Efficiency
N	Revolution per minutes (rpm)	ρ	Density of water (kg/m^3)

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