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Research Article

THE EFFECT OF ROTATIONAL SPEED VARIATION ON THE PERFORMANCE IN THE CENTRIFUGAL PUMP

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ABSTRACT:
The current study aims to investigate the effect of rotational speed on the performance characteristics of a centrifugal pump. The experimental test section consists of one horsepower (hp), motor-driven centrifugal pump, and impeller. The impeller has eight blades which are accomplished by the installation of a torque and pressure gauge for collecting data of flow rate and pressure. The pump's operating speed was varied at 1500, 2000, 2500, and 3000 revolutions per minute (rpm), respectively. The effect of speed diversity on centrifugal pump performance was investigated in terms of the total head (H), Water horsepower (Nu), Input horsepower (Na), and efficiency (η).The results obviously show that rotational speed has a significant impact on centrifugal pump performance. All performance parameters are sensitive to changes in rotational speed. The flow rate at which the pump operates has a significant impact on the performance of the head, power, and efficiency.

Keywords: *Centrifugal pump, Efficiency, Head, Rotational speed*

1. INTRODUCTION

A pump is a device that uses external force to lift fluid such as gas, slurries, or water from a lower level to a higher level. Actually, a pump is a hydraulic machine which is designed to raise or transfer fluids. It primarily consists of a moving piece in a cavity or a piston working in a cylinder, with valves appropriately positioned to admit or hold fluid as it is pulled or propelled through them by the piston's motion. The pump functions as a mechanical energy converter; it converts mechanical energy into pressure energy. One of the first applications was the use of a windmill or a watermill to pump water. Nowadays, the pump is widely used in all industrial fields, as well as the chemical and petroleum industries, pharmaceutical, aviation, metallurgy production, etc. [1], because of its uncomplicated design, high efficiency, large capacity, smooth flow rate, generous maintenance, and ease of operation. Pumps come in a variety of shapes and sizes to accommodate a wide range of applications, ranging from very small to very large, low pressure to high pressure, low volume to high volume capacities, handling liquids or gases. There are many types of pumps available, each with its operating principle, discharge, head, flow direction and specific discharge, etc. [2]. A centrifugal pump is a pump that uses centrifugal motion to convert mechanical energy into hydraulic energy. It is a rotor-dynamic pump that uses a rotating impeller to increase the pressure of a fluid. The fluid enters the pump impeller along the rotating axis and accelerates before flowing radically outward into a diffuser and leaving into the downstream piping system. Centrifugal pumps are the most common type of modern pump use in transportation, sewage services, and other applications [1]. Several studies have found that design parameters such as the impeller,

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volute, and diffuser affect the fluid flow behavior inside the turbo machines system, that affect the performance of a centrifugal pump. The impeller design is primarily determined by the number of blades, the blade angle setting, and the blade width.

Furthermore, the major volute design parameters are the base diameter, volute width, vane setting angle of the volute tongue, and throat area. The energy loss in the volute section is significantly reduced. The reducing of vane height at the partial flow rate increases the output work of the impeller, and reduces the effect of rotor-stator interaction. Lowering the diffuser vane height at the design flow point can reduce energy loss in the diffuser zone. [3]. Other studies have discovered that the geometrical parameters of the impeller, which can vary in terms of blade number [4, 5], blade wrapping angle [5, 6], blade width, blade inlet angle 1 [6, 7], and blade outlet/exit angle 2 [7, 8], have a significant influence on overall performance. The number of impeller blades influences the high-speed centrifugal pump head, efficiency, and cavitation [9]. Three-dimensional developed structures, turbulence, secondary streams, and unsteadiness all have a significant impact on the complexity of centrifugal flow behavior. Other research has discovered that the flow behavior of turbomachinery is most prospective connected to pump geometry [10], suction pressure, rotational speed [11, 12], inlet gas volume fraction (IGVF) [13], and initial liquid flow rate [5, 6]. Centrifugal pump design is generally based on experimental experience and analytical correlation, which comprises a combination of model testing and industrial engineering expertise. For a proper design, a detailed perspective of the internal flow for design and off-design operating situations is now necessary. The complicated internal flow at the discharge section of the impeller emerges circumferential distortion, primarily at off-design operating points, due to the asymmetric shape of the spiral volute and tongue. The interaction of the rotor and the volute causes in the appearance of dynamic impacts, which have an impact on the overall centrifugal performance. Unbalanced radial growth is common in non-uniform flow conditions, particularly in pressure fields. All of these parameters have an impact on pump performance and should be considered when designing a pump. The interactions between the volute and the impeller have a significant impact on unsteady flow losses, particularly in off-design situations. To address appealing research of flow behavior in turbo-machines, including cavitation, pump performance prediction has been developed in conjunction with the study of the multifaceted internal flow via the impeller. To achieve the best possible design of centrifugal turbo-machines, various researchers have made major contributions to understand the flow mechanisms inside centrifugal impellers with spiral volutes and/or vane diffuser volutes. The pump flow field has been analyzed experimentally and numerically, involves both impeller flow structures and impeller-volute interaction [14]. However, researches on the important manufacturing parameters that affect pump performance are infrequently available in the open literature. Other experimental study looked at the effect of different blade outlet angles on the pump's characteristics. It is a crucial centrifugal pump design parameter that influences the internal flow field and overall pump performance. It has a significant impact on both the efficiency of the pump and the head. The greater width of the blade exist angle, the better the overall pump performance [7]. In addition, the inlet angle of the blade has a significant impact on the performance of the pump. As the blade inlet angle increases, the efficiency at the best efficiency point (BEP) improves [6]. Pumps with large wrapping angles have a large surface area, which improves efficiency and immovability. Researchers [15] discovered that all performance parameters are more sensitive to changes in rotational speed than to changes in blade number. The head, power, and efficiency of a pump are all affected by the flow rate at which it operates. Furthermore, cavitation is one of the most important issues related to increasing the rotational speed of a centrifugal pump, where it occurs as a consequence of the low-pressure level the pump may encounter at the impeller inlet; static components at the pump inlet, such as inducers or pre-swirl, are used in order to reduce the fluid vaporization. Moreover, the number of blades maximizes pump performance. It can be concluded that the performance of the centrifugal pump is more sensitive to changes in rotational speed than to changes in the number of blades [16, 17]. Inner flow and pump performance were evaluated experimentally with varied rotating speeds in this study.

2. EXPERIMENTAL SETUP

The experimental test rig for this work was a small centrifugal pump with a perpendicular impeller inside a closed impeller case, as shown in Fig 1. A horizontal drive shaft from a (1) hp electric motor used as a power unit was directly coupled with the pump to drive the impeller. Flow rate Q =6.6 m3 /h, head H=10 m, and rotational speed N=3000 RPM were the original design parameters. The pump's inlet and outlet diameters were both 2.54 cm (1.0 inches). A switch valve in the piping system allowed for the use of a closed-loop circuit. To control the flow rate, a throttle device was used. As shown in Figs. 2-3, the performance of the impeller model was investigated one by one. The real-time rotational speed and torque was measured by the speed sensor, which was installed between the pump model and the motor. A flow meter was used to measure the flow rate of the centrifugal pump. The pressure sensor measured the pressure at the pump's inlet and outlet in real-time. Following the measurement of all parameters, the head, hydraulic power, and efficiency of the centrifugal pump were calculated using Eqs (2, 3, 4, and 5). After that, the performance curves were obtained.

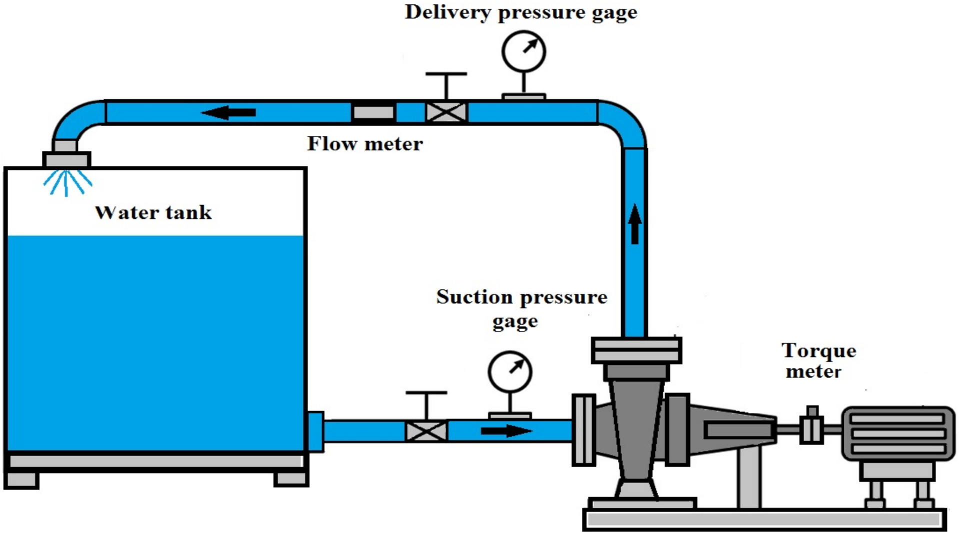

Fig. 1. Schematic diagram of the experimental setup.

Fig. 2. A photograph of the test rig.

Fig. 3. A photograph of delivery suction

3. Theoretical and Equations

3.1 Pump discharge

The discharge of a pump is the amount of water pumped per unit time. Discharge is also referred to as capacity or flow rate (Q). The discharge or capacity of the pump is calculated by using the following formula:

$$Q = \frac{\mathrm{V}}{\mathrm{time}} \tag{1}$$

Where, V, volume of water store in the discharge tank (litter); t, time which is require to fill that volume (sec).

3.2 Total head

Total head or the system head (H) is defined as the sum of total delivery head, the total suction head.

$$H = \frac{P_D - P_s}{\gamma} \tag{2}$$

Where, $P_D and\ P_s$ the dynamic and static pressure respectively.

3.3 Water horse power

The theoretical horse power which is required for pumping is referred to as water horse power. It is the pump's head and capacity expressed in horse power. The water horse power is calculated as follows:

$$Nu = \gamma \times Q \times H \tag{3}$$

Where, Nu, Water horse power. H, total head (meter). Q, discharge (litter/sec).

3.4 Input horse power

The power which is required by the pump shaft is referred to as shaft horsepower. The input horsepower is the amount of horsepower that is required by the electric motor to drive the pump. In the case of a direct-driven pump, as the one used in this study, the brake horsepower equals the shaft horsepower. The brake horsepower could not be measured separately in this study. A torque meter was used instead to measure the motor's input power. The shaft horsepower of the pump was calculated by the following formula:

$$Na = C \times \pi \times \frac{N}{30} \tag{4}$$

Where, C, Torque, N, rotational speed (RPM).

3.5 Efficiency of the pumping unit

The efficiency ratio is the power output to power input ratio. The combined efficiency of the pump and motor is given in percentage by the following formula:

$$\eta = \frac{\text{output}}{\text{input}} = \frac{\text{Nu}}{\text{Na}} \tag{5}$$

4. Results and Discussion

The purpose of this research was to assess the characteristics of a centrifugal pump with varying rotational speeds. The research was carried out in the fluid mechanical laboratory of the Department of mechanical engineering, Faculty of Technical Sciences – Sebha- Libya.

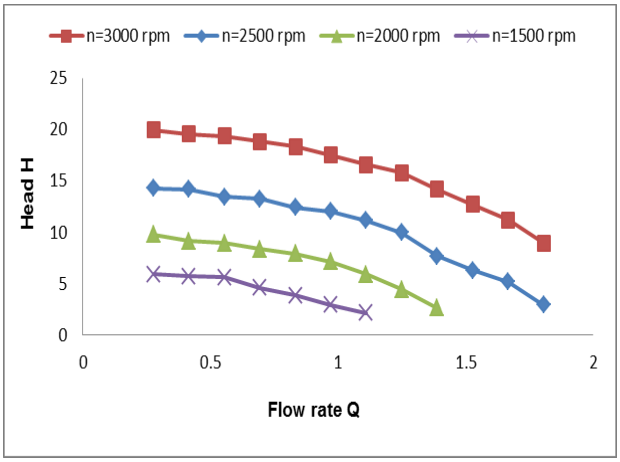

Fig. 4. Shows the curve Result of Head vs Discharge at different rotational speed.

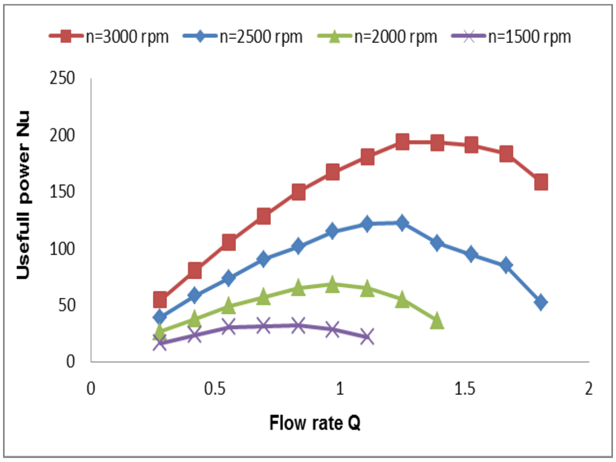

Fig. 5. Shows the curve Result of Water horse power vs Discharge at different rotational speed.

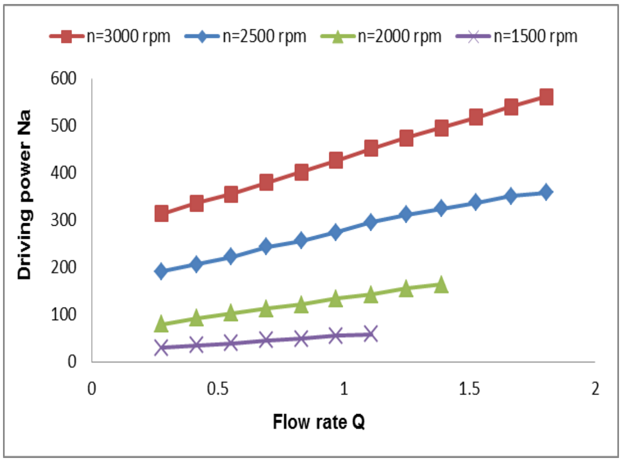

Fig. 6. Shows the curve Result of Input horse power vs Discharge at different rotational speed.

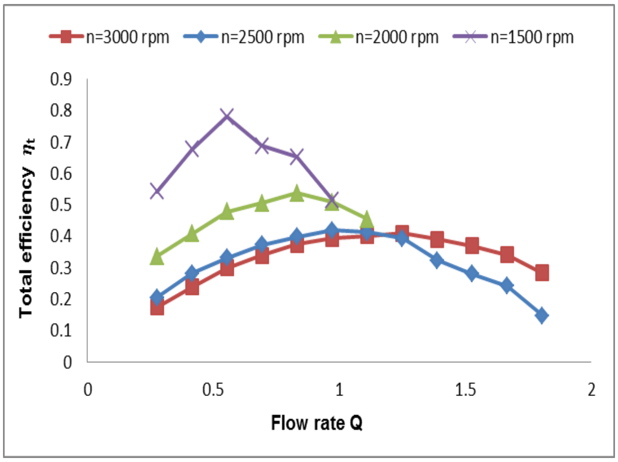

Fig. 7. Shows the curve Result of pump efficiency vs Discharge at different rotational speed.

Figure 4 depicts a centrifugal pump's head at various flow rates and rotational speeds. It has been discovered that as the flow rate increases, the head pump gradually decreases. As a result, the increase of flow rate at several rotational speeds follows a continuous downward trend in the head of the centrifugal pump. Moreover, it can be seen that the head is more sensitive to changes in rotational speed. It is clear that increasing the rotational speed causes a significant increase in the head, i.e., the value of the head increased from 2.14m at 1500 RPM to 16.6m at 3000 RPM. In terms of trend, these results are in agreement with Affinity Laws [18] and confirmed those obtained by [11], where an increase in rotational speed reasons a change in head pump level to be upper. The increase in the head is caused by a difference in pressures between the discharge and suction -regions under different operating conditions, which is more visible at higher rotational speeds. The suction pressure tends to increase as the pump capacity, whereas the discharge pressure tends to decrease. Therefore, when a pump operates at a high flow rate, the inlet suction pressure drops faster than when it operates at a low flow rate, so cavitation occurs further quickly [19]. Thus, from the above findings, it can be concluded that the rotational speeds of the pump are proportional to the occurrence of cavitation within the pump. That is, as the rotational speed of the pump increases, so does the occurrence of cavitation due to the decrease of pressure at the impeller inlet eye, which drops below the vapor pressure.

Figure 5 depicts the power versus flow rates at various rotational speeds. It was discovered that increasing the rotational speed significantly increases the water horsepower. By increasing the rotational speed from low 1500 rpm to high level, the water horsepower rapidly increases at 3000 rpm. Furthermore, as flow rates are increased, the increase in water horsepower becomes more visible. As a result, the water horsepower increased from 16W to 32W as the flow rate increased from 0.27 to 0.83 kg/s. Moreover, the increase is visible at 3000 RPM, where the water horsepower increased from 150 W to 193 W. These results are in agreement with those reported by [16].

Figure 6 shows that increasing rotational speed has a moral effect on input horsepower, as increasing rotational speed from 1500 to 3000 RPM resulted in an increase in input horsepower from 30 W to 562 W due to high discharge and pressure values. However, the input horsepower in these combinations decreases as the total head (H) value and discharge rate increase (Q). This has contributed to a decrease in pump efficiency. These findings are consistent with the theoretical pump's laws, which state that increasing rotational speed necessitates increasing input horsepower

Figure 7 depicts the efficiency of a centrifugal pump versus flow rates at various rotational speeds. Comparable to the head, the efficiency is more sensitive to changes in rotational speed. The increase in rotational speed contributes to a noticeable decrease in efficiency value. It becomes more noticeable as the flow rate increases. In the current study, speed is inversely proportional to pumping efficiency. In general, the speeds on the efficiency curve are similar in that they gradually increase until they reach their peak and then begin to decline. It should be noted that the highest value of pump efficiency, 0.77, was recorded at a speed of 1500RPM. In comparison, the lowest efficiency value recorded at 2000RPM is 0.22. The current results could be attributed to the proximity of the cavitation area when the rotational speed and discharge rate are increased. It agrees well compared to research by [12]. It is well understood that the best efficiency point (BEP) of a pump should, in theory, coincide with the design point. Actually, at the highest rotational speed and flow rate, the BEP of the concerned pump model deviates from the design point. The best efficiency point parameters at various rotational speeds are shown in Table 1.

Table 1: best efficiency point parameters by experiment at different rotational speeds.

Parameters	1500 RPM	2000 RPM	2500 RPM	3000 RPM
Q (L/s)	0.55	0.83	1.11	1.11
Head (m)	5.6	7.9	11.1	16.6
Na (W)	39	121	295	452
Nu (W)	30	65	122	181
η (%)	0.77	0.53	0.41	0.39

5. Conclusion

In this study, the effects of rotational speed on inner flow and centrifugal pump characteristics were investigated experimentally. Several flowing conclusions have been drawn based on the above results regarding the effect of different flow rates and pump rotational speeds on centrifugal pump performance.

- The performance of a centrifugal pump is more sensitive to changes in rotational speed. Whereas increasing the rotational speed from 1500 to 3000 RPM resulted in a moral increase in water horsepower, head, input horsepower, and amoral decrease in pump efficiency.
- The flow rate at which the pump operates has a significant impact on the performance of the centrifugal pump. The corresponding stable working point at a given rotational speed could be obtained by adjusting the discharge valve opening.
- The results have shown that when the pump works under unstable flow rate, it leads to change in the dynamic characteristics within a centrifugal pump.
- The trend for the head of the centrifugal pump gradually decreases when flow rate is increased due to the hydraulic and mechanical losses as well as different levels of cavitation occurrence within a pump.
- When the rotational speed exceeds the design point, the pressure in the suction side drops below the vaporization limits, which led to the occurrence of cavitation.
- The level of cavitation within a centrifugal pump has been directly linked with the pump flow rate and pump rotational speed.
- Many types of pumps, including centrifugal pumps, have been studied and developed. However, there isn't a typical pump which is perfectly suited for every application; there are still many issues that need to be addressed to improve performance and specific parameters for each case.

Nomenclature

H	Total head, m
C	Torque
N	Rotational speed, RPM
Nu	Water horse power, W
Na	Input horse power, W
P_d	Dynamic pressure, P_a
P_s	Static pressure, P_a
Q	Volume flow rate, L/s
γ	Specific weight, N/m^3
η	Efficiency of the pump

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