
Effects of Varied Impeller Blade Exit Angle on the Parameters of Flow Through a Multistage Centrifugal Pump

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ABSTRACT

The blade exit angle of an impeller plays a crucial role in the performance of a multistage centrifugal pump. In this study, the effect of varied blade exit angle of impellers of a multistage centrifugal pump on flow parameters were analyzed. The results of the study showed that as the impeller blade exit angles increased from 20° to 35°, the pressure increased from 24687.94N/m² to 32427.96N/m², the velocity increased from 29.94m/s to 30.19m/s, the manometric head increased from 2.52m to 3.31m and the efficiency increased from 36.26% to 47.62%. The results have revealed that impeller with larger blade exit angles enhances a multi stage centrifugal pump performance.

Keywords: Impeller blade exit angle, centrifugal pump, pressure, velocity, discharge, head, efficiency.

INTRODUCTION

Centrifugal pumps are used to transport fluids by the converting rotational kinetic energy to the hydrodynamic energy of the fluid flow. The rotational energy typically comes from an engine or electric motor. The fluid enters the pump impeller along or near to the rotating axis and is accelerated by the impeller, flowing radially outward into a diffuser or volute chamber (casing), from where it exits (Ajinkya et al, 2017). According to Patel and Doshi (2013), in recent years, centrifugal pump has been increasingly utilized for various purposes, such as irrigation, water supply, steam power plants, oil refineries, air conditioning systems. Due to the vast application, it is very important that centrifugal pump should work efficiently. Vasava and Patel, (2015) opined that in the process industries more

than 90% of pump applications has been covered by centrifugal pumps because they have very few moving parts and are available in wide range of flow rates and pressure differential.

Djerroud et al (2011) stated that at the present time, single and multistage centrifugal pumps are widely used in industrial and mining enterprises. One of the most important components of a centrifugal pump [Peng,2008] is the impeller. The performance characteristics related to the pump comprising the head, the brake horsepower, and the overall efficiency rely a great deal on the impeller. To achieve better performance for a centrifugal pump, design parameters such as the number of blades for the impeller and the diffuser, the impeller blade angle, the blade height for the impeller and the diffuser, the impeller blade width,

the impeller diameter, and the volute radius must be accurately determined, due to the complex liquid flow through a centrifugal pump. Khalifa (2014) opined that the blade outlet angle is one of the most important design parameters which can affect centrifugal pump performance. Changing some geometric characteristic of the impeller in centrifugal pumps improves their performance. It is known that blade exit angle plays very important role in the performance of a centrifugal pump (Patel and Doshi, 2013)

The following researchers have expressed their findings, opinion and remarks based on their works on the effect of impeller blade exit angle on the performance of a centrifugal pump: Meakhail and Park (2004) discussed a developed model for pump characteristics and stated that the developed model yielded results that are in good agreements with the experimental results. Moreso, the new model showed that the side-blade exit angle has a major effect on the performance of regenerative pump, which has not been accounted for in the previous theory. Babayigit *et al.* (2015) carried a numerical study with a view to analyzing the effect of blade exit angle on the performance of multistage centrifugal pump impeller for the blade exit angle values of 18°, 20°, 25°, 30° and 35°. In their study, they found that the most convenient blade exit angle was 18°. Shojaeefard *et al.* (2012) numerically and experimentally investigated the effects of blade outlet angle and passage width on the performance of a centrifugal pump. Their study revealed that the optimum centrifugal pump performance was obtained with the blade discharge angle of 30° for 21 mm blade exit width. Korkmaz *et al.* (2017) stated that impellers with splitter

blades are used for pumps and compressors in the design of turbomachines. Design parameters such as the number of blades, blade discharge angle and impeller discharge diameter impact affect pump performance and energy consumption. They therefore studied the effect of the number of blades ($z=5, 6, \text{ and } 7$), blade discharge angles ($\beta_{2b}=25^\circ, \text{ and } \beta_{2b}=35^\circ$) and splitter blade lengths (40, 55, 70, and 85% of the main blade length) on Deep Well Pump (DWP) performance experimentally. The result of their study showed that the highest efficiency of all the impellers for best efficiency point (b.e.p) was the impeller with the number of blades $z=6$, blade discharge angle $\beta_{2b}=25^\circ$ and 85% splitter blade addition compared to impellers without splitter blades.

In the same vein, Li (2011) investigated the effect of various blade angles of an industrial centrifugal oil pump and remarked that the blade exit angle has equal effects on head, power and efficiency. Shigemitsu *et al.* (2011) performed experiment and numerical analysis on a mini turbo-pump and asserted that the flow rate of the maximum efficiency shifts to a large flow rate as a result of increase of the blade exit angle. Bellary and Samad (2016) asserted that centrifugal pumps are extensively used in the oil and gas industries and the impeller design parameters have significant effect on the pump performance. They investigated the performance of the centrifugal pump by considering different blade angles and impeller surface roughness to pump crude oil, kerosene, gasoline, saline-water and water. Their investigation showed that the blade angles have significant influence on the head, input power and efficiency of the impeller for different liquids.

More so, Nejadrajabali, et al (2016), carried out a numerical study in order to investigate the effect of blade angle on the performance of a regenerative pump. Two groups of impellers were employed by the researchers. The first type has symmetric angle blades with identical inlet/outlet angles of $\pm 10^\circ$, $\pm 30^\circ$, and $\pm 50^\circ$ and the second group has nonsymmetric angle blades in which the inlet angle was set to 0° and six different angles of $\pm 10^\circ$, $\pm 30^\circ$, and $\pm 50^\circ$ were designed for the outlet of the blades. They found that the maximum efficiency occurred at angle of $+15.5^\circ$ by curve fitting to the data obtained from numerical simulations for symmetric angle forward blades. According to Wen-Guang (2011) and Fard and Boyaghchi (2007) stated by Hassan et al (2016), the pump geometrical parameters remain the greatest interest of all researchers looking for improving the centrifugal pump performance. Some authors made optimization on the blade exit angle and they found that with increasing the blade exit angle the head increases but the efficiency decreases. Fard and Boyaghchi (2007) investigated the performances of a centrifugal pump with different blade outlet angles both experimentally and numerically. Their results showed that when the outlet angle increases, the centrifugal pump performance handling viscous fluids improves. Bacharoudis et-al (2008) studied the effect of various geometrical parameters of centrifugal pump with a view to improving the performance. They found that performance curve becomes flatter and smoother for the entire range of the flow rates as outlet blade angle increased. Patel and. Doshi (2013) investigated the effect of blade exit angle on the head and efficiency of the pump by comparing various head-flow

and efficiency-flow curves for different blade exit angles with the manufacturer's curves. They concluded that the head and the efficiency of the pump significantly increased with the increase in the blade exit angle. Gölcü and Pancar (2005), studied the effect of different number of blades and low outlet angle on the performance of centrifugal pump equipped with and without splitter. They found that splitter blade has no positive effect on the performance of the pump but useful when discharge blade angle is low.

From known literature of this study, more emphases have been on single stage pump. It should be noted that when fluid is to be conveyed at high pressure, velocity, head, flow rate and efficiency, it becomes necessary to increase number of stages of the centrifugal pump or use a multistage centrifugal pump. However, it should be noted that as the number of stages increases, the cost of the pump increases. So, there is need to have fewer number of stages with the modification of the pump parameters such as the blade exit angle in order to improve the efficiency of the pump at a minimal cost. So, knowledge about the effect of varied blade exit angle on the flow parameters through multistage centrifugal pump has become imperative. So, the effect of exit blade angles of a close type impeller in a multi stage (3 stages) centrifugal pump by experimentation is the focus of this research work.

MATERIALS AND METHOD

Test rig that was designed and fabricated by Odili (2015). The test rig comprises of a multistage (3-stage) vertical centrifugal pump of a model AS 71B14F85 manufactured in USA by Grundfos Pump

Industry, fitted with a single-phase motor of 50 Hz and 220Volts and has a speed of 2900rpm and power rating of 0.75kW. Valves, pressure gauges, flowmeters and pipe fittings. The schematic diagram is shown in figure 1.

Four sets of three closed type impellers. The parameters of all the impellers are: Outlet diameter = 95mm, inlet diameter = 30mm, blade thickness =

3mm, blade number = 6, shaft diameter = 15mm. The first set of the three-closed type impeller was the set that was originally fitted to the pump by the pump manufacturer. The second, third and fourth sets of three closed type impellers were manufactured in Kaduna, Nigeria by Critall Hope Ltd. The blade angles of the four sets of three closed type impellers used are depicted in Table 1.

Table 1: Blade angles of the set of three impellers used

S/N	Sets of Three Impellers	Blade Inlet Angle	Blade Exit Angle
1	1 st Set	20°	20°
2	2 nd Set	20°	25°
3	3 rd Set	20°	30°
4	4 th Set	20°	35°

3. 130 litres of water and
4. Stop watch

Mathematical modeling of parameters of flow through the multistage centrifugal pump

Consider, the schematic diagram of the Test Rig designed and fabricated by Odili (2015) as shown in figure 1.

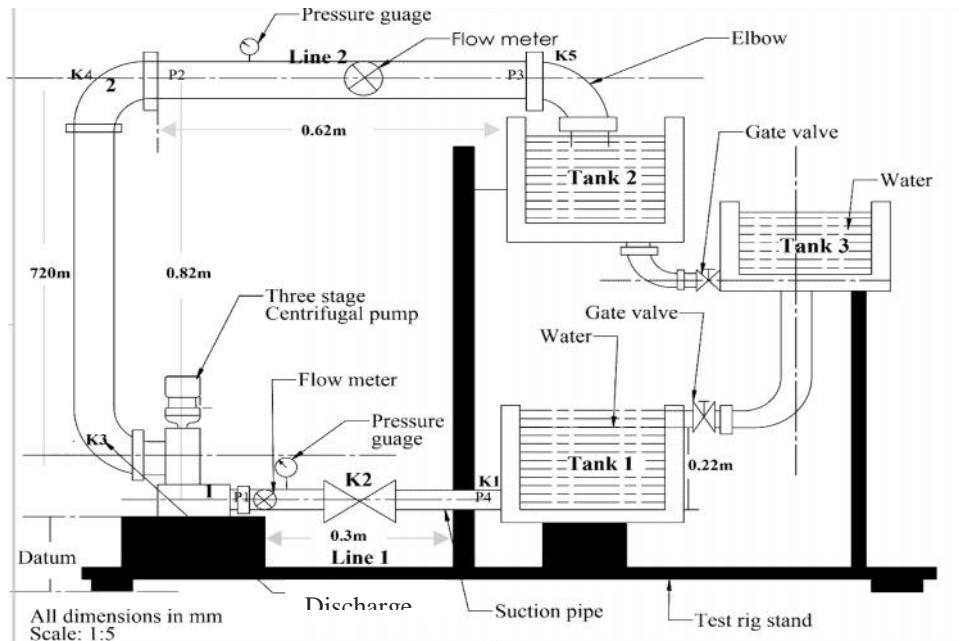


Figure 1: Schematic diagram of The Test Rig that was designed and fabricated by Odili (2015)

From continuity equation, the flow rate of water through the suction side of the pump,

$$Q_s = A_1 V_1 \quad (1)$$

$$\text{and the flowrate of water through discharge side of the pump, } Q_d = A_2 V_2 \quad (2)$$

Where, A_1 and A_2 are the cross-sectional areas of suction and discharge pipes respectively, V_1 and V_2 are the inlet and outlet velocities or velocities of water at the suction and discharge pipes respectively.

For a steady flow,

$$Q_s = Q_d \quad (3)$$

$$A_1 V_1 = A_2 V_2 \quad (4)$$

Applying Bernoulli's equation between point 1 on the suction line and point 2 on the discharge line of the centrifugal pump, we have

$$\frac{p_1}{\gamma} + \frac{v_1^2}{2g} + Z_1 = \frac{p_2}{\gamma} + \frac{v_2^2}{2g} + Z_2 \quad (5)$$

Where γ = the specific weight of the fluid

$\frac{p_1}{\gamma}$ and $\frac{p_2}{\gamma}$ = Pressure heads at the inlet and outlet of the pump respectively

$\frac{v_1^2}{2g}$ and $\frac{v_2^2}{2g}$ = Velocity heads at the inlet and outlet of the pump

Z_1 and Z_2 = datum head and vertical height of the pump outlet from the datum line.

The head against which a centrifugal pump has to work is known as manometric head and it is denoted by H_{mano} (Rajput, 2008). According to (Rajput, 2008), it is expressed as

$$H_{\text{mano}} = H_{\text{static}} + \text{losses in pipes} + \frac{V_d^2}{2g} = (h_s + h_d) + (h_{fs} + h_{fd}) + \frac{V_d^2}{2g} \quad (6)$$

Where h_s = Suction head

h_d = Delivery head

h_{fs} = Frictional head loss in the suction pipe

h_{fd} = Frictional head loss in the delivery pipe

$V_d = V_2$ = Velocity of liquid in the delivery pipe

Moreso,

H_{mano} = Total head at the discharge of the pump – total head at the suction of the pump

$$= \left(\frac{p_2}{\gamma} + \frac{v_2^2}{2g} + Z_2 \right) - \left(\frac{p_1}{\gamma} + \frac{v_1^2}{2g} + Z_1 \right) \quad (7)$$

Power input to the pump is denoted by P_i and the power output of the pump or useful power denoted by P_o is expressed as

$$P_o = \gamma Q H_{\text{mano}} \quad (8)$$

$$\text{The efficiency of the pump, } \eta = \frac{\text{power output}}{\text{power input}} = \frac{\gamma Q H_{\text{mano}}}{P_i} \quad (9)$$

EXPERIMENTAL METHOD

The Three stage centrifugal pump was fitted with the first set of three closed type impellers and mounted on the test rig. The

test rig tanks were filled with water and allowed to fill the suction line of the pump. The pump was switched on and allowed to run for five minutes to ensure that there

were no leakages from pipe fittings. After another five minutes, the inlet pressure of water into the pump was read off from the pressure gauge and the flowrate of water into the pump was read off from the flowmeter fitted to the suction line and noted. The inlet velocity of water into the pump or velocity at the suction line was computed using equation 1. The outlet pressure of water out of the pump and discharge were read off from the pressure gauge and the flow meter fitted to the discharge line of the pump respectively and noted. The outlet velocity or velocity of discharge was determined by using equation 2. The manometric head, power output from the pump and the efficiency of the pump

were determined using equations 7, 8 and 9 respectively.

After the use of the first set of three closed type impellers, the multistage centrifugal pump was dismantled and the impellers were removed. The second, third and fourth set of closed type impellers were individually fitted in turn to the pump and mounted on the test rig and carried out the same process of experimentation.

RESULTS AND DISCUSSION

The variation of outlet pressure of water from the centrifugal pump with impeller blade exit angles is shown in figure 2.

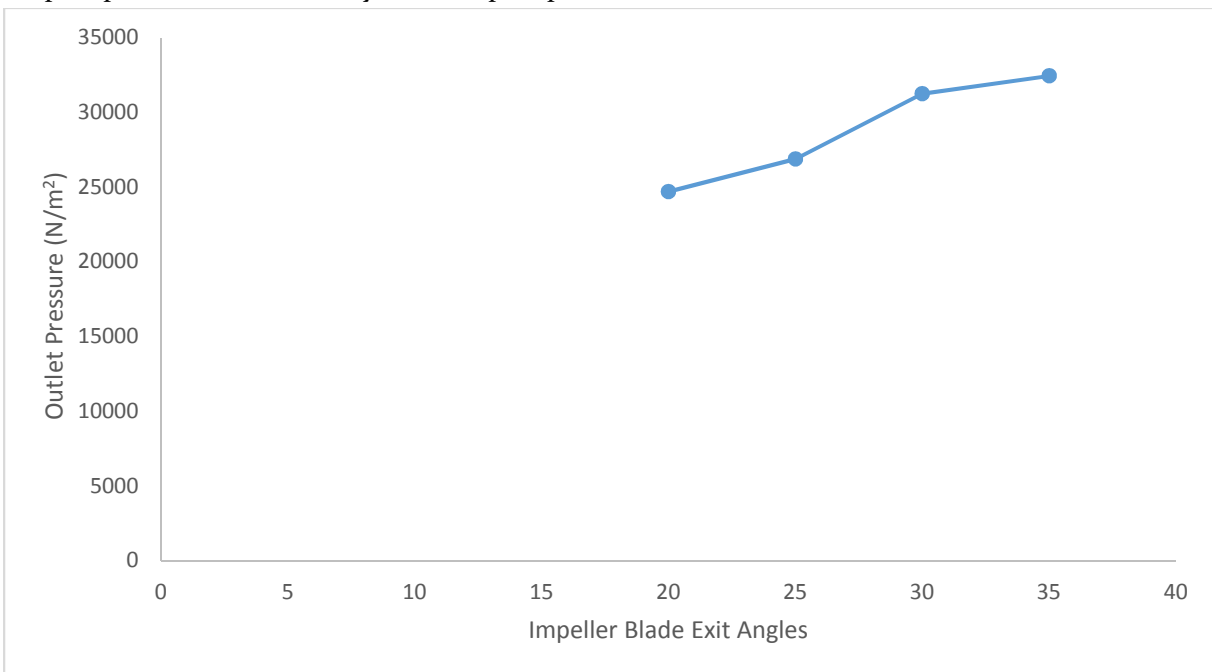


Figure 2: The variation of outlet pressure of water from the centrifugal pump with impeller blade exit angles.

It can be seen from figure 2 that the outlet pressure of the fluid flowing through the pump increased as the impeller blade exit angle increased. This finding is in line with the work of

Rehman et al (2015) that revealed that the total pressure is increasing from the inlet side to the outlet of the impeller the pressure increase across the impeller is increasing with increasing blade outlet angle.

The variation of outlet velocity of water from the centrifugal pump with impeller blade exit angles is shown in figure 3.

exit angles is shown in figure 3.

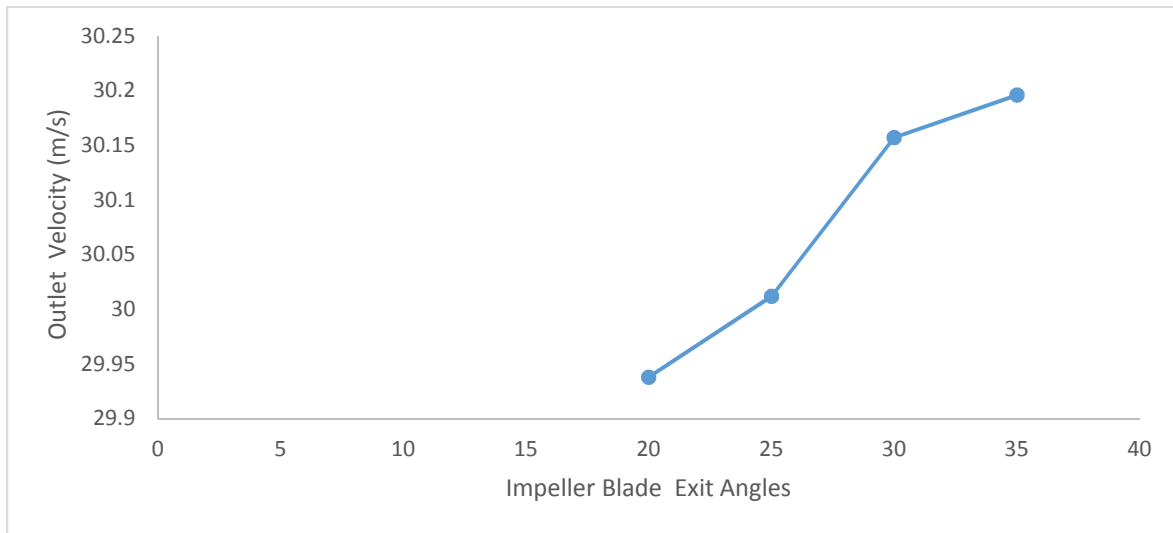


Figure 3: Variation of outlet velocity of water from the centrifugal pump with impeller blade exit angles

It can be seen from figure 3, that as the impeller blade exit angles increased from 20° to 35°, the outlet velocity of the fluid flowing through the pump also increased. This indicates that there is better pump

performance when the blade exit angles are increased.

The variation of Manometric Head of the pump with impeller blade exit angles is shown in figure 4.

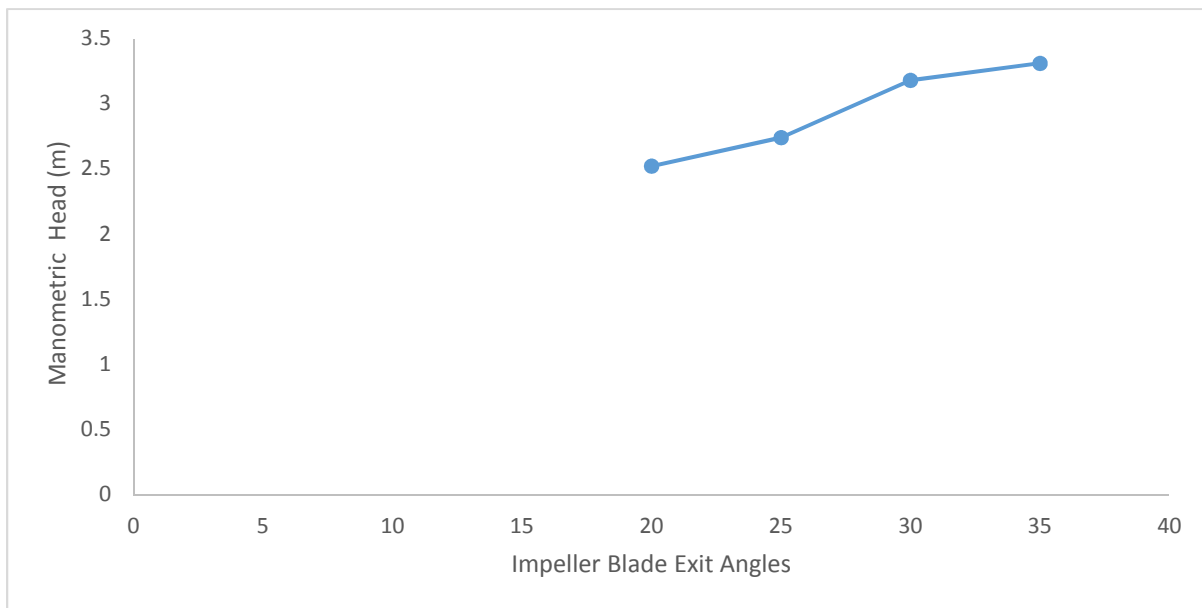


Figure 4: Variation of Manometric Head of the pump with impeller blade exit angles

It can be seen in figure 4 that as head of the fluid flowing through the impeller increased with increase impeller blades exit angles. The head at the discharge is higher when the impeller blade exit angles are higher which shows also that there is better pump performance when the blade exit angles are increased. This result is in line with the results obtained by Varley (1961) that demonstrated that the head increased with increasing discharge angle of a double suction centrifugal pump reported by Li (2011). Patel & Doshi (2013) who remarked in their work that the head of centrifugal pump

increases with increases in the blade exit angle. Also, in line with findings of Nishi.et.al (2012) who investigated the radial thrust acting on two kinds of single-blade centrifugal impellers having different blade outlet angles experimentally and numerically and found the total head of the impeller with a blade outlet angle of 16° increased more than the impeller with a blade outlet angle of 8° at a large flow rate. The variation of efficiency of the centrifugal pump with impeller blade exit angles is shown in figure 5.

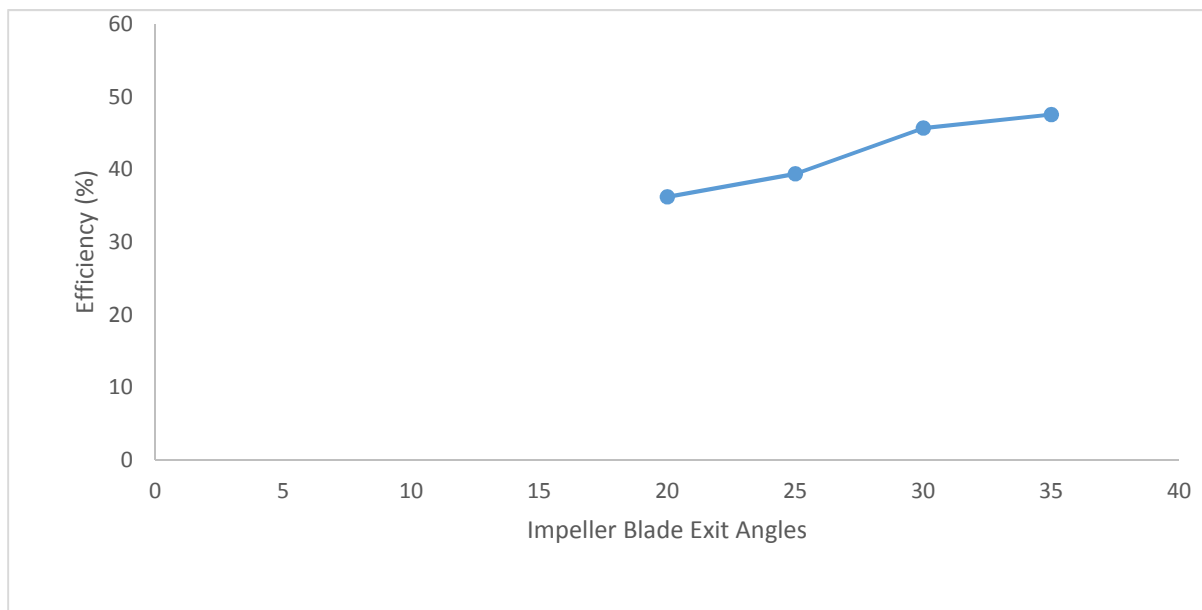


Figure 5: Variation of efficiency of the centrifugal pump with impeller blade exit angles.

It is evident in figure 5, that the efficiency of a centrifugal pump increased when the exit blade angle of impeller was increased. This result is in line with the results obtained by Ajinkya et al (2017), Moreso with Bacharoudis et al (2008) who concluded in their work that the increase of the outlet blade angle causes a significant

improvement of the hydraulic efficiency. More so in line with Patel & Doshi (2013) that remarked in their work that efficiency of a centrifugal pump increases with increase in the blade exit angle,

CONCLUSION

Experiments were carried out on a test rig to analyze and study the effect of varying the exit blade angles of a closed type impeller in a multistage centrifugal pump. The outlet pressure, outlet velocity, manometric head and efficiency were determined. The following conclusions can therefore be made.

1. With increase in impeller blade exit angles, the manometric head of the multistage centrifugal pump increases.
2. The efficiency of the multistage centrifugal pump also increases with increase in impeller blade exit angles.
3. Increasing impeller blade exit angle leads to increase in the pressure, velocity and discharge of liquid through the multistage centrifugal pump and
4. Higher pressure, velocity, head and efficiency of a centrifugal pump can be achieved by using impellers with higher blade exit angles instead of increasing the number of stages of the pump that would make the multistage centrifugal pump to be more robust thereby occupying more space and expensive.

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