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The Effects of Impeller Blade Count on Centrifugal Pump Performance and Efficiency Under Different Operating Conditions: A Comparison of Numerical Prediction

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Abstract: Centrifugal pumps are widely used across various industries, such as water delivery, chemical processing, and HVAC systems, due to their efficiency and reliability in fluid handling. However, optimizing their performance remains a critical challenge, particularly in balancing head and efficiency under different operating conditions. This study explores the effect of impeller blade count on the performance and efficiency of centrifugal pumps using ANSYS 2024R1 computational fluid dynamics (CFD) simulations and polynomial regression models. Pumps with four, five, six, and seven blades were examined across flow rates (100–400 m³/h) and rotational speeds (1,500–4,500 rpm) to identify an optimal balance between performance and efficiency. The results reveal that increasing the blade count enhances fluid handling by reducing pressure fluctuations and creating more uniform pressure and velocity distributions. Among the configurations, the five-blade impeller at 2,500 rpm exhibited the best performance, achieving a head of 28.10 m and an efficiency of 91.9%. At higher speeds, efficiency peaked at specific blade counts but declined due to increased hydraulic losses. The seven-blade impeller produced the highest head of 64.1 m at 4,500 rpm, though efficiency dropped to 79.5%, highlighting the trade-off between head and efficiency. The regression models demonstrated high accuracy for each blade count. Notably, the four-blade configuration provided the most reliable predictions, with R^2 values of 0.9998 for the head and 0.9442 for efficiency. Similarly, the five-blade model showed strong performance, achieving R^2 values of 0.9972 for head and 0.7785 for efficiency. This study underscores the importance of selecting the optimal impeller blade count to balance performance and efficiency. Future work should investigate the influence of additional design parameters, such as blade angle and material composition, to further enhance centrifugal pump performance.
Keywords: Centrifugal Pump, Impeller Blade Count, CFD Simulation, Pump Efficiency, Fluid Dynamics

I. INTRODUCTION

Centrifugal pumps are critical in many industrial applications, such as water delivery, chemical processing, and HVAC systems, because of their effectiveness and dependability in fluid handling. The performance of centrifugal pumps can indeed be influenced by various geometrical parameters of the impeller blades, not just the blade count. Different blade shapes, angles, and lengths can significantly impact the pump's efficiency and head. Centrifugal pumps' performance and efficiency are critical in various industrial applications, but maximizing these parameters under varying operating situations is difficult. Preceding research has demonstrated that increasing the number of impeller blades may significantly enhance pump performance. It is widely employed in various applications, including industrial and residential buildings, power plants, agriculture, water supply, and transportation**.** The effects of blade count on total pump performance have been extensively studied, demonstrating that increasing the number of impeller blades can significantly enhance pump performance [1],[2, 3],[4]. In addition, research has shown that increasing the number of impeller blades improves efficiency, Head, and thrust, with stability achieved at 11 blades [5]. However, higher blade counts can lead to rotating stalls under part-load conditions and deteriorate inlet conditions during overload [[6]]. Besides, numerical modelling has been indicated as a method to optimize impeller blades to mitigate these issues [7]. The relationship between entropy generation and efficiency in pumps with varying blade counts has also been discussed [8]. Moreover, studies evaluating the effect of blade number on hydraulic efficiency conclude that increasing blade number enhances pump head and efficiency [9]. Additionally, investigations into cavitation properties related to different blade counts have been conducted [10], and the influence of inclined blade trailing edges on vortex-induced vibration has been studied [11]. Blade properties such as intake, number, and outlet angle significantly influence performance [12],[13]. The blade parameters include trailing edge angles (27, 30,33, 50 degrees), impact hydraulic efficiency, and Head for different working media (oil, water). Numerical investigations of geometric factors (tip clearance, blade arrangement) on pressure pulsation have been performed [14]. Also, computational Fluid Dynamics (CFD) is used to analyze the effects of outlet diameters and blade count on pump performance [15],[16].

Despite extensive research on centrifugal pump performance, critical gaps remain in understanding the influence of impeller blade count under varying operational conditions. Existing studies often rely on empirical data or computational fluid dynamics (CFD) simulations but lack robust predictive models to optimize blade configurations. Furthermore, the trade-offs between head and efficiency at higher rotational speeds, performance trends across different blade counts, and the effects of blade count on pressure distribution and flow patterns remain underexplored. This study addresses these gaps by analyzing the performance of centrifugal pumps with four, five, six, and seven blades using ANSYS CFD simulations and polynomial regression models. The objectives are to evaluate the effect of blade count on head, efficiency, and pressure fluctuations, develop predictive models for pump performance, identify optimal blade configurations, and provide design recommendations that balance performance and efficiency across various operating conditions.

II. NUMERICAL SIMULATION METHODOLOGY

A. Pump Design and Specification

The impeller blade operating parameters for the centrifugal pump employed in this study are as follows: the number of blades, the impeller blade angle, the flow rate, the Head, and the impeller's rotational speed (4 -7, 27-36^0, 100-400 m^3/h, 20-50m, 1500-4500 rpm). In this section, an original model of a centrifugal pump of the ANSYS 2024R1 Workbench platform is designed, meshed, and numerically simulated using the CFD approach. An input-output channel was created, and the impeller blade was also designed using Vista Centrifugal Pump Design (CPD), modelled using ANSYS Computational Fluid Dynamics (CFD). Figure 1 illustrates the 3D model of the centrifugal pump with a different impeller blade count.

B. Simulation Setup

Following its design in Blade-Gen, the model is transferred to ANSYS Turbo-grid. This software achieves full automation while ensuring superior mesh quality for complex blade geometries. The final mesh parameters are meticulously defined to produce a high-quality mesh, with subsequent operations executed automatically.

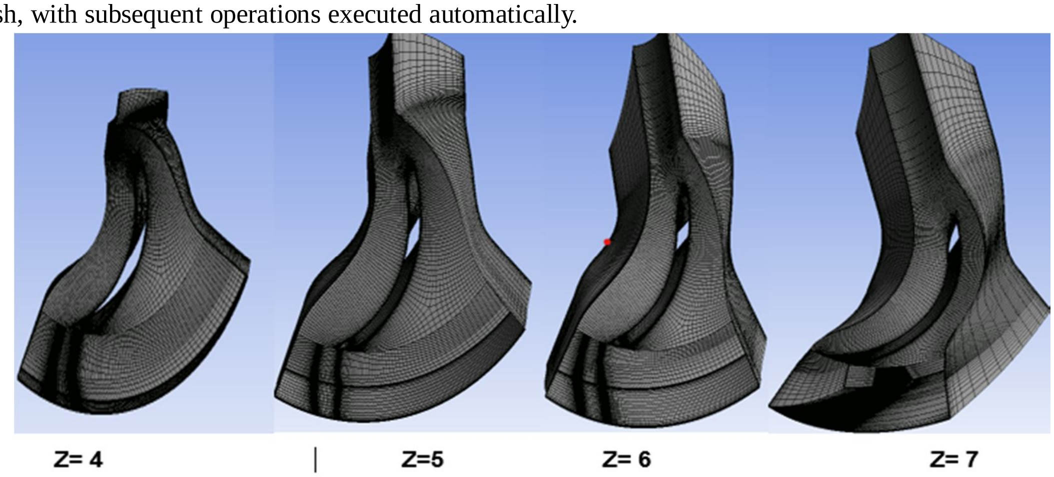

Figure 1: Mesh Generation for Impeller Blades (z= 4,5,6,7)

1) Boundary Conditions

The boundary conditions for the CFD simulations of the centrifugal pump are centred on varying impeller blade counts, as detailed in Table 2. The working fluid is water, with a mass flow rate of 77.8 kg/s. The simulations employ the Shear Stress Transport (SST) turbulence model, with flow direction averaged at the boundary. The reference pressure is set to 0, and the static pressure is maintained at 1 bar. The impeller's rotational speeds are set at 1500 rpm, 2500 rpm, 3500 rpm, and 4500 rpm. The wall surfaces are assumed to be smooth, with a no-slip condition applied. Turbulence intensity is fixed at 5%, as indicated in Table 2.

Table 1: Boundary Conditions

Inflow boundary condition	**Mass flow inlet**
Type of Fluid	Water
Turbulence Model Used	Shear Stress Transport (SST)
Flow Direction	Normal to Boundary
Reference Pressure	0 [atm]
Static Pressure	1 [atm)
Mass flow rate	77.8 kg/s
Wall roughness	Smooth Wall
Wall influence on the flow	No Slip
Turbulence intensity	5 %

2) Governing Equations

The pump's performance (η) Additionally, the Net Positive Suction Head (NPSH) [[17], which defines the efficiency of an ideal mixed-axial flow pump, was an essential objective for quick optimization in the designated pumps$N_s = \frac{\omega N\sqrt{Q}}{gH^{0.75}}$ (1),

The performance of the pump is evaluated using key governing equations. The efficiency (η) is determined as:

$$\eta = \frac{P_{in}}{P_{out}} \times 100 \quad (2),$$

where P_{out} the output power and P_{in} is the input power. The Net Positive Suction Head (NPSH) is calculated as:

$$\text{NPSH} = \frac{P_{atm} - P_{vapor}}{\rho g} \quad (3),$$

where P_{atm} is atmospheric pressure, P_{vapor} vapour pressure, ρ is the fluid density, and g is the gravitational acceleration. The head (H) developed by the pump is given by:

$$H = \frac{(P_2 - P_1)}{\rho g} + \frac{(V^2{}_2 - V^2{}_1)}{2g} \quad (4),$$

where P_2 P_1 are inlet and outlet pressures, and V_2 V_1 are inlet and outlet velocities.
The Reynolds number (Re) for flow characterization is:

$$(R_e) = \frac{\rho V D}{\mu} \quad (5),$$

V is velocity, D is characteristic length, and μ is dynamic viscosity.
The energy equation for computational fluid dynamics (CFD) simulation follows:

$$\nabla \times (\rho VE) = \nabla \times (k\nabla T) + \Phi \quad (6),$$

where E is total energy, k is thermal conductivity, T is temperature, and Φ represents viscous dissipation effects

C. Grid Independence Study

A Grid Independence Study was conducted to ensure that simulation results were independent of mesh resolution. The Richardson Extrapolation and Grid Convergence Index (GCI) method assessed numerical accuracy [18, 19]. Three mesh configurations were tested: Fine (857,205 elements), Medium (682,480 elements), and Coarse (606,097 elements). The y+ method was maintained at 1.5 across all meshes for near-wall treatment, ensuring accurate turbulence modelling. The GCI values for Fine-Medium and Medium-Coarse meshes were 0.58% and 0.089%, respectively, confirming that mesh refinement had minimal impact on pressure and efficiency variations (<0.6%).

The Medium mesh was chosen as the preferred resolution, balancing computational expense and precision. The simulations were conducted at a Reynolds number of 1.141643×10^5, validating that turbulent flow conditions were present. This research verifies that the CFD outcomes are independent of the grid and guarantee numerical precision in assessing pump performance. The main parameters analyzed were efficiency and pressure, with the findings outlined in Tables 4 and 5.

Table 2: grid independence results.

Mesh Type	Elements	Efficiency (%)	Pressure (Pa)	GCI (%)
Fine	857,205	93.6	327,061	0.58
Medium	682,480	93.8	327,314	0.089
Coarse	606,097	93.4	327,295	

The Medium mesh (682,480 elements) was selected as the optimal resolution, as further refinement yielded negligible improvements. The GCI values for Fine-Medium and Medium-Coarse grids were calculated using the formula**:**

$$GCI = \frac{1.25\times|f_2-f_1|}{r^p-1} \times 100 \quad (7),$$

Where, f_2 and f_1 Represent the simulation outcomes for two adjacent meshes: r The refinement ratio is denoted by the symbol, and p signifies the assessed order of accuracy. The y+ value was kept at 1.5 to ensure precise near-wall treatment with a Reynolds number of $Re = 1.141643 \times 10^5$, to create a 3D mesh.

III. REGRESSION MODEL DEVELOPMENT

The regression equation for efficiency with Z= 4 impeller blades. The efficiency regression polynomial equation for the configuration with four impeller blades is presented. As the mass flow rate increases, efficiency decreases. The quadratic term, characterized by a negative coefficient for $\dot{m}^2$), indicates substantial efficiency losses, resulting in a parabolic decline. The high R^2 value of 0.9442 demonstrates that the model accurately captures the trend and fits the data well the Efficiency with Z=5 Blades. Efficiency is relatively consistent across varying mass flow rates, with slight changes. The coefficients for $\dot{m}^2$ and $\dot{m}$ are significantly less than those for the four-blade model, showing a less noticeable influence of mass flow rate on efficiency. The R^2 value of 0.7785 indicates a moderate fit, as projected values nearly match CFD calculated values. Figure 6. shows the Regression polynomial equation for efficiency with Z=6 blades. Efficiency increases significantly as the mass flow rate increases, as seen by the negative coefficient for $\dot{m}^2$ and the positive coefficient for $\dot{m}$. The predictable efficiency values exhibit a steady trend and line well with the CFD estimated values, indicating a solid fit with an R^2 value of 0.8498, as seen in Figure 6. Figure 7. shows the Regression Polynomial Equation for Efficiency with Z= 7 Blades. Efficiency usually stays steady, with fair, modest changes. The coefficients are minor, implying a less significant influence of mass flow rate on efficiency. The R^2 value of 0.6217 indicates a weaker fit than other models, with expected values near CFD-determined values but considerable inconsistencies at higher mass flow rates,

A. Regression Model Formulation

Regression Equation for Efficiency and Head with Z=4 Impeller Blades

$$\eta_t = -0.087\dot{m}^2 + 10.985\dot{m} - 249.99 \quad (8)$$

$$H = -0.0015\dot{m}^2 - 0.0286\dot{m} + 16.871 \quad (9)$$

Regression Equation for Efficiency and Head with Z=5 Impeller Blades

$$\eta_t = -0.0007\dot{m}^2 + 0.0934\dot{m} + 87.357 \quad (10)$$

$$\eta_t = -0.0019\dot{m}^2 + 0.48\dot{m} + 54.015 \quad (11)$$

Regression Equation for Efficiency and Head with Z=6 Impeller Blades

$$\eta_t = -0.0054\dot{m}^2 + 1.2777\dot{m} + 15.432 \quad (12)$$

$$H = 0.0013\dot{m}^2 - 0.4106\dot{m} + 69.64312 \quad (13)$$

Regression Equation for Efficiency and Head with Z=7 Impeller Blades

$$\eta_t = -0.0019\dot{m}^2 + 0.48\dot{m} + 54.015 \quad (14)$$

$$H = -0.0013\dot{m}^2 - 0.1831\dot{m} + 76.004 \quad (15)$$

B. Residual Analysis

$$Residual = CFD\ Value - Predicted\ Value \quad (16)$$

Mean Absolute Error (MAE)

$$MAE = \frac{1}{n}\sum_{i=1}^{n}[CFD_i - Predicted_i] \quad (17)$$

Root Mean Squared Error (RMSE)

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$$\text{RMSE} = \sqrt{\frac{1}{n}\sum_{i=0}^{n}\left(CFD_i - Predicted_i\right)^2} \quad (18)$$

Mean Absolute Percentage Error (MAPE)

$$\text{MAPE} = \frac{100}{n}\sum_{i=0}^{n}\left[\frac{CFD_i - Predicted_i}{CFD_i}\right] \quad (19)$$

IV. RESULTS AND DISCUSSION

A. CFD Performance Results

[6] investigated the performance of centrifugal pumps with varying impeller blade counts (Z=4, Z=5, Z=6, and Z=7). The study presents key performance metrics, including Head (m) and Efficiency (%). At 1500 rpm with four blades, the pump achieves a head of 5.81 meters and an efficiency of 76.5%. As the rotational speed and blade count increase, the Head and efficiency generally improve, peaking at 2500 rpm with five blades, where the Head reaches 28.10 meters and efficiency hits 91.9%. However, at the highest speed of 4500 rpm with seven blades, the Head is 64.1 meters, with a blade angle of 36^0 and a flow rate of 400 m³/h, but efficiency drops to 79.5%, indicating a trade-off between speed and efficiency. The study also inspects how a centrifugal pump's pressure and velocity distributions change with different impeller blade counts (Z=4, Z=5, Z=6, and Z=7). Table 3 presents the centrifugal pump's baseline design simulation performance results at various rotational speeds (1500, 2500, 3500, and 4500 rpm).

Table 3: Pump Design & Specifications Simulation Performance Results at Various Rotational Speeds

Rotational Speed (rpm)	Head (m)	Number of Blades	Impeller blade Angle (^{0})	Flow rate (m^3/h)	Head (m)	Efficiency (%)
1500	20	4	27	100	16	77.2
2500	30	5	30	200	28.10	91.2
3500	40	6	33	300	48.30	82.2
4500	50	7	36	400	64.10	79.9

Figure 2 illustrates that as the number of impeller blades increases, the pressure distribution becomes more uniform, suggesting enhanced fluid handling and reduced pressure fluctuations. This observation aligns with the findings of [20]. The study examines a centrifugal pump's pressure and velocity distributions with varying impeller blade counts (Z=4, Z=5, Z=6, and Z=7). Figure 4 demonstrates that higher blade counts result in more evenly distributed velocities across the impeller, improving overall pump performance. The findings in Figures 2 and 3 corroborate previous studies on the impact of impeller blade count on the performance of mixed-flow and centrifugal pumps**.**

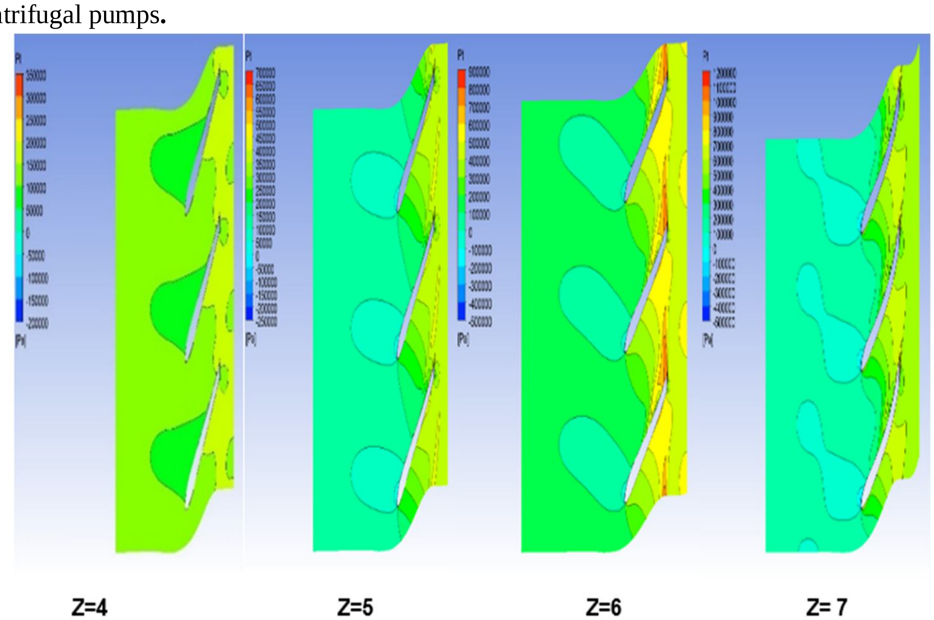

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Figure 2: Pressure distribution for impellers with different blade counts (Z=4,5,6,7)

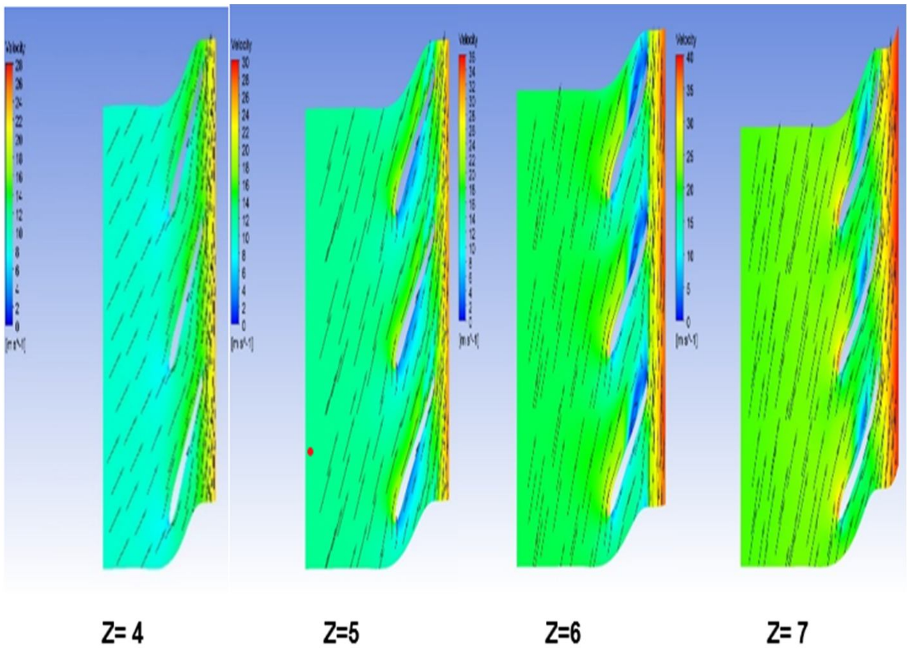

Figure 3: Velocity Distribution Across Blade Counts (Z=4,5,6,7)

B. Regression Model Performance

Tables 4 and 5 present the CFD calculations and regression polynomial predictions for efficiency and head of the centrifugal pump with varying mass flow rates for impeller blade counts of four, five, six, and seven, respectively.

Table 4: Regression Polynomial Predictions for Efficiency

Regression Model for Four Impeller Blade (z=4)					
ṁ (kg/s)	Coefficient of $\dot{m}^2$	Coefficient of ṁ	Constant	CFD Efficiency (%)	Predicted Efficiency (%)
77.8	-526.6	854.63	- 249.99	77.0031	78.045
80.0	-556.8	878.8	- 249.99	88.9618	81.76
90.0	-704.7	988.65	- 249.99	87.5155	95.91
100.0	-870	1098.5	- 249.99	83.618	92.66
110.0	-1052.7	1208.35	- 249.99	74.5664	72.01
120.0	-1252.8	1318.2	- 249.99	50.8563	33.96
130.0	-1470.3	1428.05	- 249.99	-32.2265	-21.49
R^2 = 0.9442					
Regression Model for Five Impeller Blade (z=5)					
ṁ (kg/s)	Coefficient of $\dot{m}^2$	Coefficient of ṁ	Constant	CFD Efficiency (%)	Predicted efficiency (%)
77.8	-4.24	7.267	87.357	91.2059	90.355
80.0	-4.48	7.472	87.357	89.8898	90.317
90.0	-5.67	8.406	87.357	90.2929	90.057
100.0	-7.0	9.340	87.357	89.5082	89.657
110.0	-8.47	10.274	87.357	89.6901	89.117
120.0	-10.08	11.208	87.357	89.3663	88.437
130.0	-11.83	12.142	87.357	87.7488	87.617
R^2 = 0.7785					

Regression Model for Six Impeller Blade (z=6)					
ṁ (kg/s)	Coefficient of ṁ²	Coefficient of ṁ	Constant	CFD Efficiency (%)	Predicted efficiency (%)
77.8	-32.68	99.41	15.432	82.152	80.1959
80.0	-34.56	102.2	15.432	83.088	83.6905
90.0	-43.74	114.9	15.432	86.685	89.222
100.0	-54.00	127.8	15.432	84.202	87.9055
110.0	-65.34	140.5	15.432	90.639	89.4054
120.0	-77.76	153.3	15.432	90.996	90.3776
130.0	-91.26	166.1	15.432	90.273	90.4333
R^2 = 0.8498					
Regression Model for Seven Impeller Blade (Z=7)					
ṁ (kg/s)	Coefficient of ṁ²	Coefficient of ṁ	Constant	CFD Efficiency (%)	Predicted efficiency (%)
77.8	-11.50	37.34	54.015	79.858	79.8324
80.0	-12.16	38.40	54.015	80.255	80.2765
90.0	-15.39	43.2	54.015	81.825	81.3055
100.0	-19.00	48.0	54.015	83.015	80.3075
110.0	-22.99	52.8	54.015	83.255	84.6943
120.0	-27.36	57.6	54.015	84.255	84.9799
130.0	-32.11	62.4	54.015	84.305	82.4524
R^2 = 0.6217					

Table 5: Regression Polynomial Predictions for Head

Regression Model for Four Impeller Blade (z=4)					
ṁ (kg/s)	Coefficient of ṁ²	Coefficient of ṁ	Constant	CFD Head (m)	Predicted Head (m)
77.8	-9.08	-2.225	16.871	15.81258	15.567
80.0	-9.60	-2.288	16.871	11.8004	11.691
90.0	-12.15	-2.574	16.871	9.78425	9.755
100.0	-15.00	-2.860	16.871	7.6734	7.519
110.0	-18.15	-3.146	16.871	5.26884	4.983
120.0	-21.60	-3.432	16.871	2.31142	2.147
130.0	-25.35	1428.05	16.871	-0.67401	-0.989
R^2 = 0.9998					
Regression Model for Five Impeller Blade (z=5)					
ṁ (kg/s)	Coefficient of ṁ²	Coefficient of ṁ	Constant	CFD Head (m)	Predicted Head (m)
77.8	-0.030	-14.46	42.634	28.1004	28.140
80.0	-0.032	-14.87	42.634	27.1305	27.730
90.0	-0.041	-16.73	42.634	25.0974	25.863
100.0	-0.05	-18.59	42.634	23.5511	23.994
110.0	-0.061	-20.45	42.634	21.517	22.125
120.0	-0.072	-22.31	42.634	19.4235	20.254
130.0	-0.084	-24.17	42.634	17.3345	18.383
R^2 = 0.9972					
Regression Model for Six Impeller Blade (z=6)					

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ṁ (kg/s)	Coefficient of ṁ^2	Coefficient of ṁ	Constant	CFD Head (m)	Predicted Head (m)
77.8	7.87	-31.94	69.643	48.3036	45.567
80.0	8.32	-32.85	69.643	42.5513	45.115
90.0	10.53	-36.95	69.643	42.5301	43.219
100.0	13.00	-41.06	69.643	41.4946	41.583
110.0	15.73	45.17	69.643	41.1853	40.207
120.0	18.72	-49.27	69.643	39.4986	39.091
130.0	21.97	-53.38	69.643	37.8205	38.235
R^2 = 0.7563					
Regression Model for Seven Impeller Blade (Z=7)					
ṁ (kg/s)	Coefficient of ṁ^2	Coefficient of ṁ	Constant	CFD Head (m)	Predicted Head (m)
77.8	-7.87	-14.25	76.004	55.0689	53.890
80.0	-8.32	-14.65	76.004	52.9116	53.036
90.0	-10.53	-16.48	76.004	47.5756	48.995
100.0	-13.00	-18.31	76.004	44.7584	44.694
110.0	-15.73	-20.14	76.004	41.8457	40.133
120.0	-18.72	-21.97	76.004	35.6509	35.312
130.0	-21.97	-23.80	76.004	30.1905	30.231
R^2 = 0.9875					

The results show that the pump head decreases for all impeller configurations as the flow rate increases, which is expected due to increased hydraulic losses. Adding more blades improves the head, with the seven-blade impeller (z = 7) performing the best, followed by six, five, and four blades. However, the gains diminish at higher flow rates. The regression model does a great job predicting the head values and closely matching the CFD results, though slight differences appear at extreme flow rates. As such, a seven-blade impeller is the best choice, while a six-blade setup might offer a good balance between performance and efficiency.

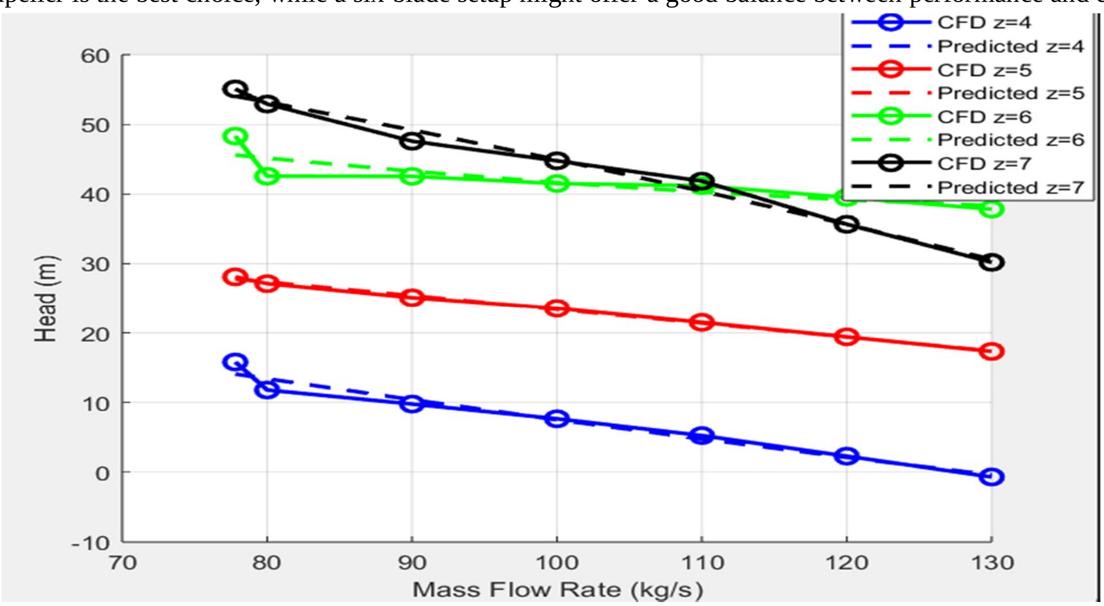

Figure 4: Comparison of CFD and predicted head and with Z= 4,5,6,7)

The efficiency trends reveal that all impeller configurations perform well at lower flow rates, maintaining efficiencies above 80%. However, the four-blade impeller (z = 4) shows a sharp decline in efficiency beyond 110 kg/s, even turning negative at 130 kg/s, indicating severe losses or possible operational instability.

In contrast, impellers with five or more blades sustain high efficiency across the flow range, with minimal deviations between CFD and predicted values. The seven-blade impeller (z = 7) provides the most stable efficiency, suggesting that increasing the blade count helps maintain performance, especially at higher flow rates. However, diminishing returns beyond six blades should be considered when optimizing for both efficiency and manufacturability.

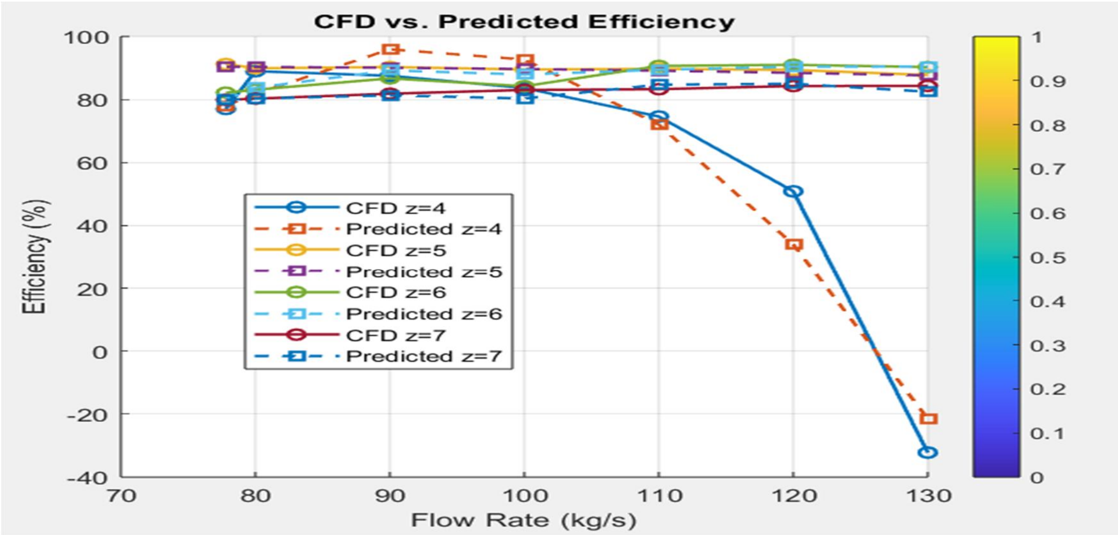

Figure 5: Comparison of CFD and Predicted Efficiency with (Z=4, 5, 6, 7)

C. Error Analysis and Residuals

The residual plot provides insight into the accuracy of the predicted efficiency values compared to CFD results. Ideally, residuals should be close to zero, indicating minimal deviation. The four-blade impeller (z = 4) shows the highest fluctuations, with significant positive and negative residuals at higher flow rates, revealing that the prediction model struggles to capture its performance accurately. Meanwhile, impellers with five or more blades (z = 5, 6, and 7) exhibit relatively stable residuals, mostly oscillating around zero, indicating better agreement between CFD and predicted values. The seven-blade impeller (z = 7) offers the most consistent predictions, reinforcing its suitability for efficient and predictable pump performance.

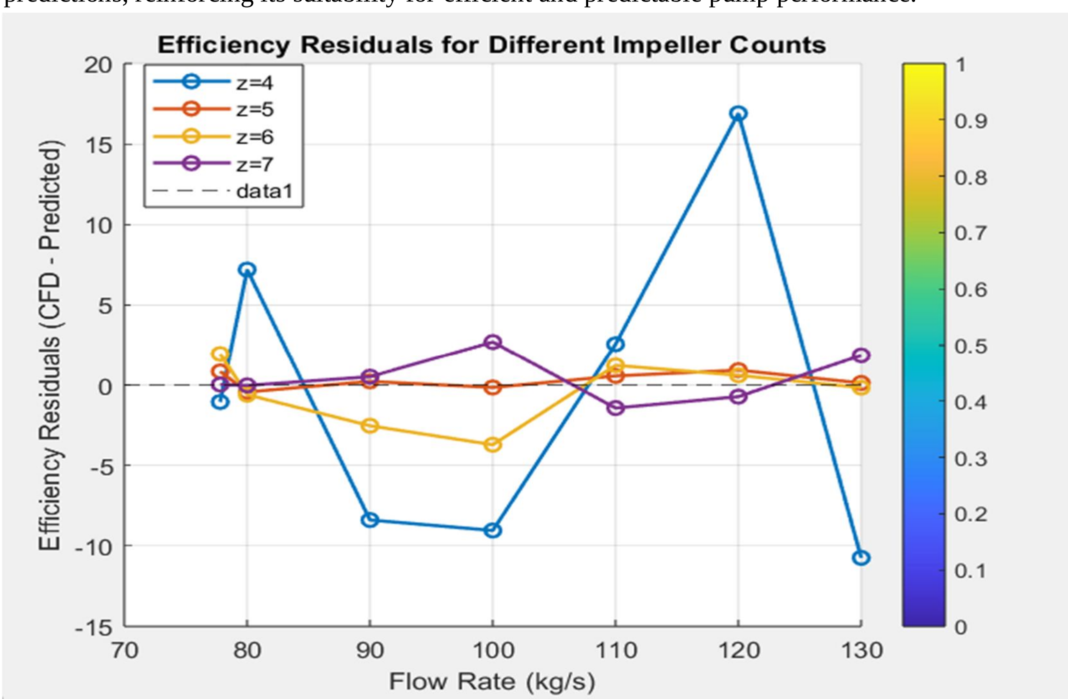

Figure 6: Efficiency Residual for Different Impeller Blade with (z= 4, 5, 6, 7)

The head residual plot shows the deviation between CFD and predicted values for different impeller counts across various flow rates. Ideally, residuals should be close to zero, indicating an accurate prediction model. The impellers with 4 and 5 blades (z = 4, 5) exhibit relatively stable residuals, shows better agreement between CFD and predicted values. However, the 6-blade (z = 6) and 7-blade (z = 7) impellers show more significant deviations, particularly at lower and higher flow rates, indicating potential inconsistencies in the prediction model for these configurations. The trend suggests that while higher impeller counts may improve head performance, their predictability requires further refinement.

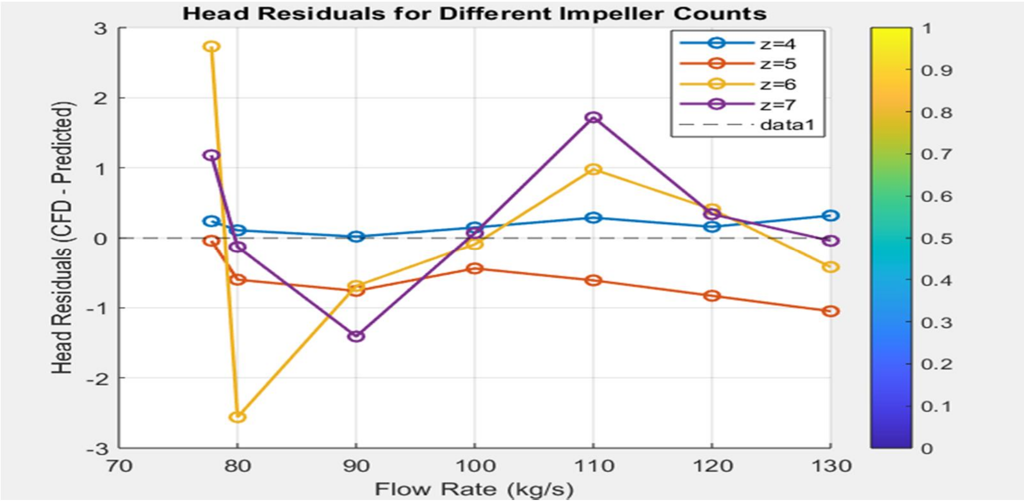

Figure 7: Head residuals for Different Impellers Blades Counts (z= 4, 5, 6, 7)

D. Comparison with Previous Studies

This study's results align with previous research on impeller blade count and centrifugal pump performance. [4] found that more blades improve performance by enhancing fluid handling and reducing pressure fluctuations. This study identified optimal performance with five blades at 2500 rpm, yielding a head of 28.10 meters and an efficiency of 91.9%. [6] also concluded that increased blade counts enhance energy characteristics and flow patterns, which this study supports by demonstrating better pressure and velocity distributions. [7] emphasized that optimizing blade shapes is crucial for hydraulic efficiency. Using CFD simulations and polynomial regression models, this study validated its findings with high correlation coefficients. [5] focused on optimizing blades for electric vehicle pumps, and this study's use of ANSYS CFD models aligns with that approach. Additionally, [8] identified the trade-off in blade count; seven blades at 4500 rpm achieved a head of 64.1 meters, and efficiency dropped to 79.5%. Finally, [10] noted that while more blades reduce cavitation, they can also decrease efficiency, a trend confirmed in this study with peak efficiency at five blades

The error metrics reveal how well the regression models predict efficiency and head. For efficiency, the 5-blade model (z = 5) is the most accurate, with the lowest MAE (0.47), RMSE (0.56), and MAPE (0.52%), meaning predictions are nearly perfect. The 7-blade model (z = 7) performs best for a head, with the lowest MAPE (1.53%), making it the most reliable for head estimation. In contrast, the 4-blade model (z = 4) has the highest errors, especially in efficiency (MAPE: 14.26%) and head (MAPE: 9.15%), indicating weaker predictive performance. A higher R^2 shows better model fit, but lower MAE, RMSE, and MAPE determine accuracy. More blades (z = 5, 6, 7) generally lead to better predictions, while z = 4 struggles the most.

Table 4: Error Measurement for Efficiency and Head

Impeller Blades (z)	MAE (Efficiency)	RMSE (Efficiency)	MAPE (Efficiency)	MAE (Head)	RMSE (Head)	MAPE (Head)	Efficiency(R^2)	Head(R^2)
4	7.98	9.35	14.26%	0.19	0.21	9.15%	0.9442	0.9998
5	0.47	0.56	0.52%	0.62	0.69	2.92%	0.7785	0.9972
6	1.54	1.94	1.81%	1.13	1.50	2.58%	0.8498	0.7563
7	1.04	1.40	1.25%	0.70	0.96	1.53%	0.6217	0.9875

V. CONCLUSION

This study analyzed the influence of impeller blade count on centrifugal pump performance using ANSYS 2024R1 CFD simulations and polynomial regression models. The findings reveal that the five-blade configuration at 2,500 rpm delivered the best performance, achieving a head of 28.10 meters and an efficiency of 91.9%. This balance highlights the configuration's suitability for efficient and stable fluid handling.

Increasing the blade count improved pressure and velocity distribution, reducing pressure fluctuations and enhancing fluid dynamics. However, this improvement reached diminishing returns beyond five blades, as higher blade counts increased hydraulic losses due to friction and turbulence. At 4,500 rpm, the seven-blade configuration achieved the highest head of 64.1 meters but with reduced efficiency at 79.5%, demonstrating a clear trade-off between head and efficiency at higher rotational speeds.

The regression models demonstrated high accuracy in predicting pump performance. Notably, the four-blade configuration provided the most reliable predictions, with R^2 values of 0.9998 for the head and 0.9442 for efficiency. Similarly, the five-blade model showed strong performance, achieving R^2 values of 0.9972 for head and 0.7785 for efficiency. Efficiency generally peaked with a five-blade count before declining at seven blades due to hydraulic losses. Flow rates significantly influenced head and efficiency, with lower flow favouring higher efficiency. Experimental validation, advanced turbulence models.

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A. CrediT Authorship contribution statement

Mohd Sayuti Ab Karim: Supervision, Writing – review & editing. Nik Nazri Nik Ghazali: Supervision, Writing – review & editing. Enemugha Emmanuel Ebikabowei: Conceptualization, Data curation, Writing – original draft. PTDF: Funding acquisition, Resources, Supervision, Writing – review & editing.

B. Data Availability Statement

The authors aim for transparency and will provide access to qualified researchers for verification and further research. For more information, contact the corresponding author at 22058411@siswa.um.edu.my.

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D. Conflict of Interest

The authors state they have no conflicts of interest regarding publishing this work

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