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Optimising Diesel Engine Performance Using Double Shrouded Intake Valves

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Abstract*— Diesel engine performance and efficiency are greatly influenced by the air intake system, which also affects combustion characteristics [5]. Controlling airflow and increasing swirl, which have an impact on fuel-air mixing and combustion efficiency, are critical functions of the intake valve [8]. This work examines how airflow dynamics and swirl formation are affected by double-shrouded intake valves with different shroud angles. Utilizing various intake valve configurations, computational fluid dynamics (CFD) simulations are used to analyze swirl ratio, and velocity distribution. The findings suggest that optimal shroud angles improve fuel-air mixing and possibly increase combustion efficiency by intensifying air swirls while preserving adequate airflow. By shedding light on how valve shrouding affects intake flow characteristics, the study helps to direct future developments in diesel engine intake system.

***Index Terms*— Computational Fluid Dynamics (CFD), diesel engine intake, double-shrouded intake valve, swirl intensity.**

I. INTRODUCTION

In diesel engines, an efficient air intake system is crucial for optimal combustion. The amount and quality of air entering the cylinder directly influence key performance factors such as power output, fuel efficiency, and emissions [5]. Among the many components that contribute to this process, **the intake valve plays a vital role** in shaping airflow dynamics and creating swirl motion within the cylinder. Swirl helps improve fuel-air mixing, leading to more efficient combustion and lower emissions [2]. By enhancing turbulence, intake valves can contribute to better fuel atomization, reducing pollutants like unburned hydrocarbons, nitrogen oxides (NOx), and particulate matter [16].

To improve swirl intensity, **shrouded intake valves** have been widely studied [11]. These valves are designed with a physical obstruction that partially directs airflow into a swirling motion. While this can significantly enhance combustion efficiency, it also introduces a challenge—excessive shrouding can restrict airflow, reducing volumetric efficiency and potentially limiting engine performance [4], [5], [11]. Finding the right balance between generating sufficient swirl and maintaining adequate airflow is a key aspect of intake valve optimization.

Much of the existing research has focused on **single-shrouded intake valves**, demonstrating their effectiveness in enhancing swirl and combustion characteristics [20]. However, there is limited data on how **double-shrouded intake valves**, especially with different shroud angles, impact airflow and swirl intensity. The introduction of a second shroud could provide greater control over airflow dynamics, potentially improving engine efficiency while minimizing drawbacks.

This study explores the effects of **double-shrouded intake valves with varying shroud angles** using **Computational Fluid Dynamics (CFD) simulations**. By analyzing different configurations, we aim to identify an optimal design that balances swirl intensity with volumetric efficiency. The findings from this research could help refine intake valve designs for modern diesel engines, contributing to higher performance, lower emissions, and better fuel economy. Additionally, the results may offer insights for future advancements in intake system engineering, especially as emission regulations continue to become more stringent.

II. METHODOLOGY

A. Computational Fluid Dynamics (CFD) Analysis

A systematic CFD approach was employed to analyze airflow through different intake valve configurations. The methodology involves designing intake valves, setting up simulation parameters, and evaluating key flow metrics.

B. Valve Geometries

- Double-shrouded intake valves with shroud angle pairs:
  - 50°–90°
  - 30°–70°
  - 80°–100°
- Standard non-shrouded valve for baseline comparison

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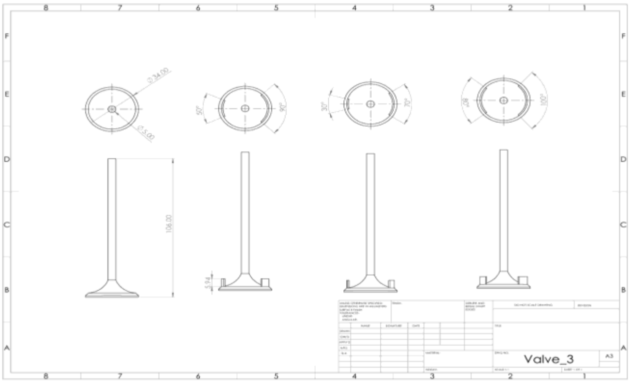


Fig. 1 Schematics of shrouded intake valve

- The CAD design drafts for the 4 valve geometries are shown in Fig. 1.

C. Software Used

- ANSYS Fluent for CFD simulations
- SolidWorks for 3D CAD modelling

D. Meshing and Grid Refinement

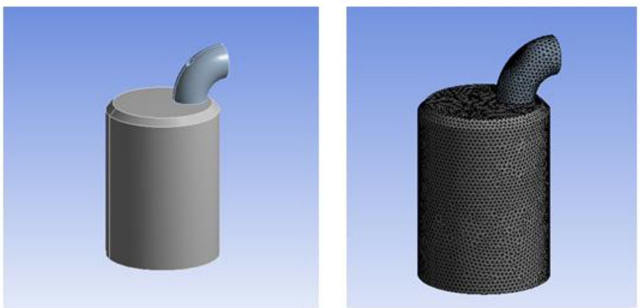
- High-resolution mesh applied using tetrahedral and hexahedral elements. The meshing view is shown in Fig. 2(b).
- Grid independence test conducted to ensure numerical accuracy.

E. Boundary Conditions

- Inlet: Ambient pressure of 101.3 kPa.
- Outlet: Mass flow outlet based on engine intake conditions.
- Turbulence Model: k-ε or k-ω SST model used for accurate swirl and turbulence prediction.

F. Evaluation Metrics

- Swirl Ratio: Indicates turbulence intensity within the cylinder.
- Velocity Contours and Streamlines: Visual representation of airflow patterns.



(a) **(b)**

Fig. 2 (a) Chamber design and **(b)** Refined Mesh view

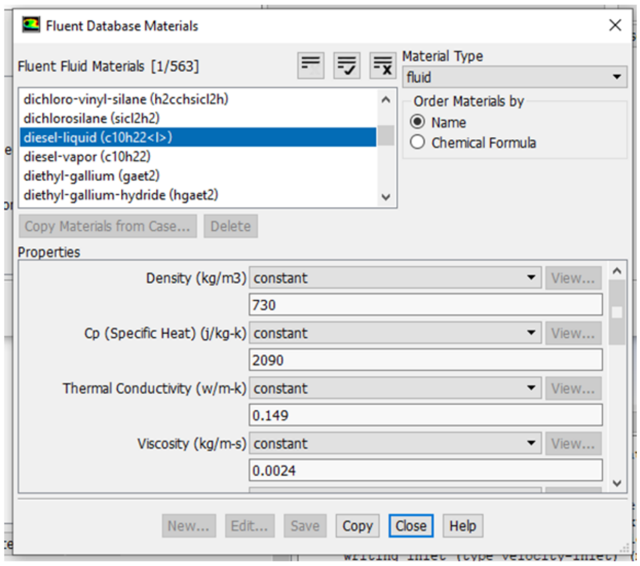


Fig. 3 Material Properties

III. FLOW ANALYSIS

Computational Fluid Dynamics (CFD) analysis was conducted to visualize and interpret the airflow characteristics around the double-shrouded intake valve. The simulations provide a detailed perspective on flow patterns, turbulence intensity, velocity gradients, and pressure contours within the intake manifold. The following subsections highlight the key observations from the CFD-generated images. The best results from the CFD-generated images are shown in Fig 4.

A. Velocity Contours

The velocity contour plots illustrate how air flows through the intake valve, highlighting regions of high and low velocity. Higher velocity regions are observed near the valve seat, where the intake air accelerates due to the pressure difference. The double-shrouded design ensures a smoother airflow transition, reducing stagnation zones and enhancing the volumetric efficiency of the engine.

B. Pressure Distribution

The pressure distribution plots reveal how pressure changes as air moves through the intake valve. A well-optimized intake valve should maintain a controlled pressure drop while ensuring efficient air entry into the combustion chamber. The results indicate that Valve 04 maintains a stable pressure distribution, minimizing energy losses and enhancing fuel-air mixture preparation.

C. Streamline Flow Visualization

The streamline plots provide a clear visualization of airflow direction and turbulence intensity within the intake port. The flow paths illustrate how effectively the intake valve directs air towards the combustion chamber. The double-shrouded valve structure minimizes flow separation

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and vortex formation, leading to a more uniform and predictable airflow pattern.

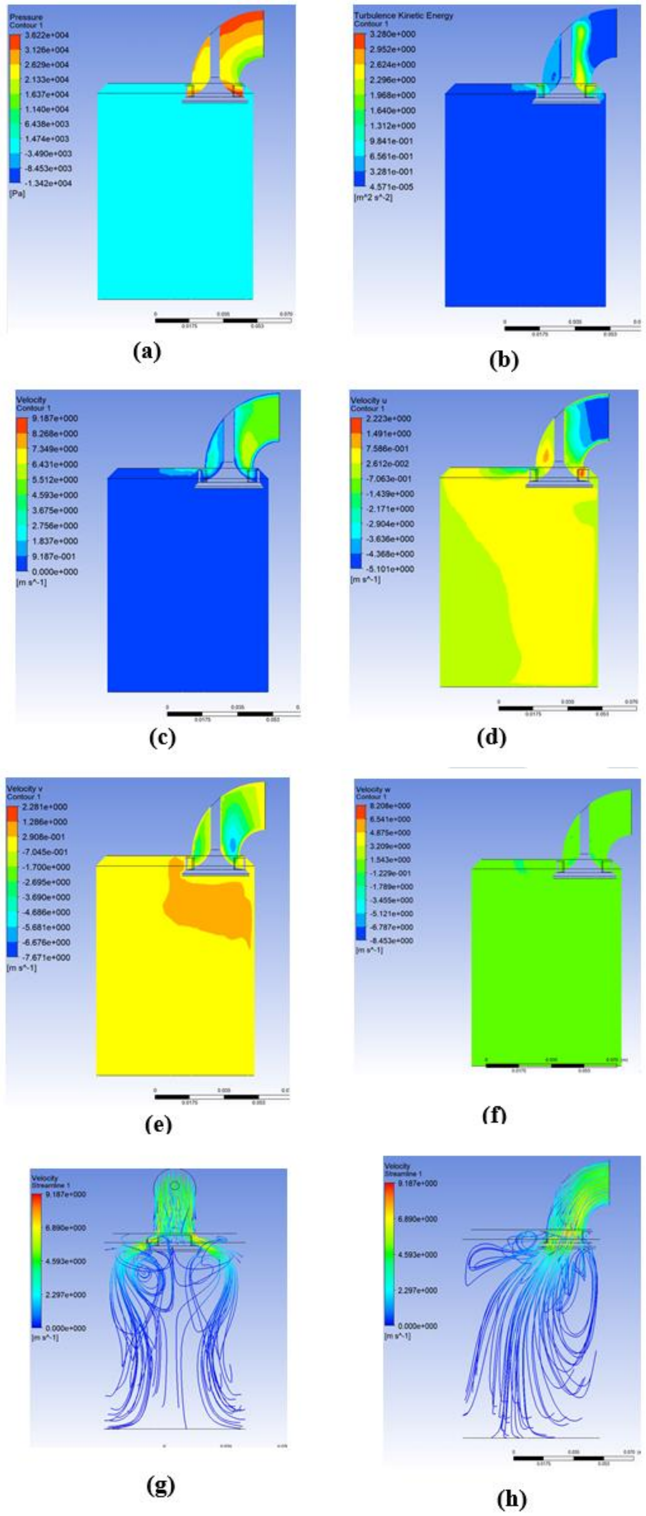


Fig. 4 CFD contours for **(a)** Pressure, **(b)** Turbulence Kinetic Energy, **(c)** Velocity, **(d)** Velocity u, **(e)** Velocity v, **(f)** Velocity w, and CFD velocity streamlines in **(g)** Front View, **(h)** Side View.

D. Vorticity and Turbulence Intensity

Vorticity plots depict the rotational motion of air as it interacts with the intake valve. High vorticity regions can indicate excessive turbulence, which may lead to unwanted energy dissipation. The analysis shows that Valve 04 maintains controlled turbulence levels, ensuring effective mixing without introducing unnecessary resistance to airflow.

IV. RESULTS AND DISCUSSION

The study aimed to optimize engine performance by investigating the impact of using a double-shrouded intake valve. The Ansys simulations provided comprehensive insights into various flow characteristics, including eddy viscosity, pressure distribution, turbulence kinetic energy, and velocity components. These numerical values derived from the CFD analysis can be seen in the Table. I. The findings have been analyzed and plotted in form of bar graphs as shown in Fig. 5. They are used to determine efficiency and combustion performance.

A. Swirl Ratio Calculation

Swirl ratio is a key parameter in determining the rotational motion of the intake air within the cylinder [2], [8]. It is calculated using the following formula:

$$\text{Swirl Ratio} = \frac{\omega_{swirl}}{\omega}$$

$$\omega_{\,swirl} = \frac{VW}{r}$$

$$\omega = \frac{2\pi N}{60}$$

Where,

- ω = Engine Angular Speed
- r = Reference radius (usually half of cylinder bore) in m
- V_W = Tangential Velocity
- N = rotational speed of the engine in RPM.
- $\omega_{\,swirl}$ = Swirl angular speed in rad/s

The computed swirl ratios for the tested intake valves are as follows:

- **Valve 01**: 0.907
- **Valve 02**: 0.893
- **Valve 03**: 1.279
- **Valve 04**: 1.306

Inference from Swirl Ratio Analysis Swirl ratio plays a crucial role in enhancing fuel-air mixing, which directly impacts combustion efficiency [5], [15]. Among the tested designs, **Valve 04** exhibited the highest swirl ratio (1.306), indicating superior air rotation within the cylinder, which can enhance atomization and combustion efficiency. **Valve 03** also demonstrated a relatively high swirl ratio (1.279), suggesting effective turbulence generation.

Table 1

MODEL	EDDY VISCOSITY (M^2/S)	PRESSURE (PA)	TURBULENCE KINETIC ENERGY (M^2/S^2)	VELOCITY (M/S)	VELOCITY U (M/S)	VELOCITY V (M/S)	VELOCITY W (M/S)
Valve 01	5.48×10^{-1}	2.65×10^{4}	3.658	7.804	5.316	1.349	5.696
Valve 02	8.14×10^{-1}	5.32×10^{4}	1.31×10^{0}	9.01	6.81×10^{0}	1.82×10^{0}	5.61×10^{0}
Valve 03	5.13×10^{-1}	3.19×10^{4}	3.585	8.442	1.706	2.108	8.038
Valve 04	5.55×10^{-1}	3.62×10^{4}	3.28	15.366	9.187	9.187	8.2048

Conversely, **Valve 02** (0.893) and **Valve 01** (0.907) exhibited lower swirl ratios, which may result in reduced mixing effectiveness but potentially lower flow resistance [11], [19].

These findings confirm that a higher swirl ratio contributes to better fuel-air interaction, leading to improved combustion stability and efficiency [16], [3]. However, excessive swirl may also increase pressure drop and flow resistance, which must be optimized for overall engine performance [5], [18].

B. Eddy Viscosity and Turbulence Dissipation

Eddy viscosity plays a crucial role in determining turbulence dissipation within the intake valve [13]. Among the tested configurations, Valve 02 exhibited the highest eddy viscosity (8.14×10^{-1}), indicating better turbulence dissipation. In contrast, Valve 03 had the lowest eddy viscosity (5.13×10^{-1}), suggesting less effective turbulence control. Since excessive turbulence dissipation can reduce the energy available for air-fuel mixing, Valve 04's moderate eddy viscosity (5.55×10^{-1}) suggests an optimal balance between turbulence control and flow stability.

C. Pressure Distribution and Flow Resistance

Valve 02 recorded the highest pressure (5.32×10^4 Pa), indicating higher resistance to airflow. Meanwhile, Valve 01 exhibited the lowest pressure (2.65×10^4 Pa), suggesting lower resistance and smoother flow characteristics. Valve 04 maintained a balanced pressure level (3.62×10^4 Pa), ensuring an adequate compromise between pressure drop and efficient air intake. These results demonstrate that extreme pressure differences can either hinder or enhance flow performance, depending on their effect on air mass distribution within the combustion chamber.

D. Turbulence Kinetic Energy and Flow Stability

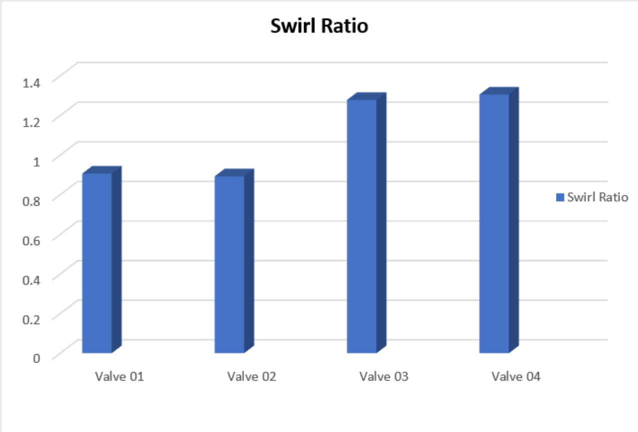
Turbulence kinetic energy (TKE) is indicative of airflow intensity and stability [16]. Valve 01 showed the highest TKE (3.658), which, although beneficial for mixing, might lead to increased pressure losses. On the other hand, Valve 02 had the lowest TKE (1.31×10^0), implying reduced turbulence but potentially at the cost of poorer air-fuel mixing. Valve 04 maintained a balanced TKE (3.28), suggesting a controlled level of turbulence that enhances engine combustion efficiency while preventing excessive energy loss.

E. Velocity Analysis and Flow Efficiency

The overall velocity distribution across different valves highlights the effectiveness of air passage [10]. Valve 04 recorded the highest velocity (15.366 m/s), indicating excellent flow throughput. Valve 04 also demonstrated superior directional control with the highest velocity components in U (9.187), V (9.187), and W (8.2048) directions, ensuring efficient multidimensional airflow distribution. This suggests that Valve 04 offers optimized airflow dynamics, leading to improved volumetric efficiency and fuel atomization within the combustion chamber.

F. Final Comparative Analysis

Among all valve designs, Valve 04 emerged as the most balanced option. It maintained moderate pressure, controlled turbulence levels, and superior velocity components in multiple directions. These characteristics make Valve 04 the most suitable choice for optimizing intake efficiency in internal combustion engines. The findings suggest that employing a double-shrouded intake valve with optimized turbulence control and pressure management can enhance engine performance by improving airflow dynamics and combustion stability.



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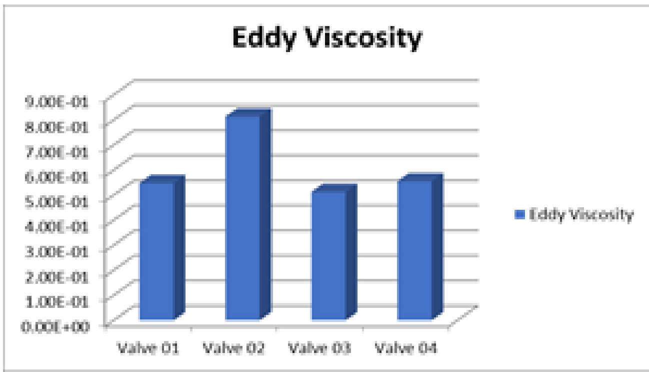

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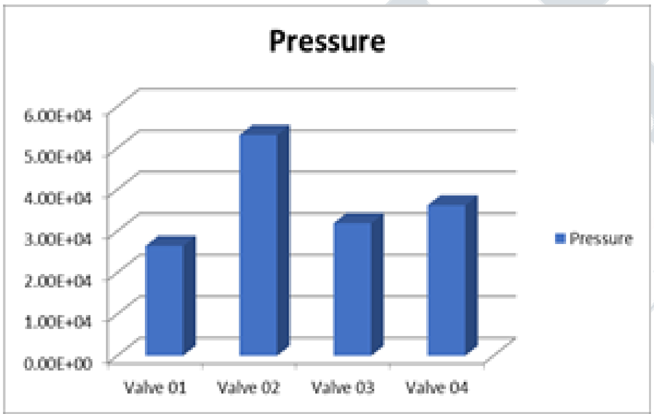

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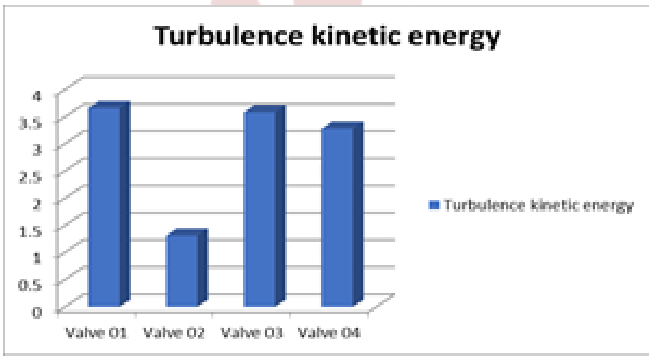

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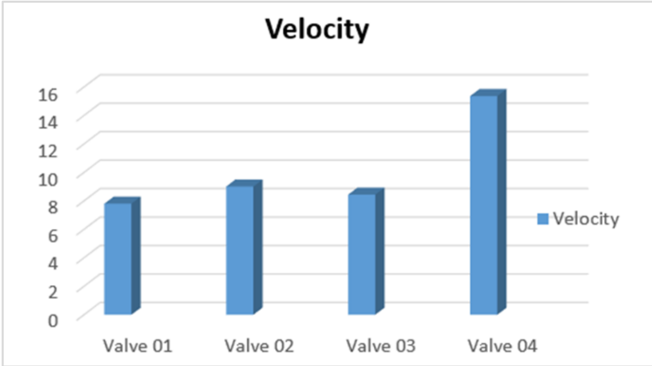

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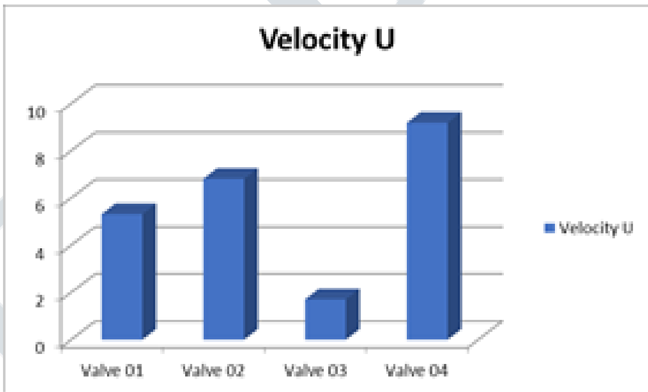

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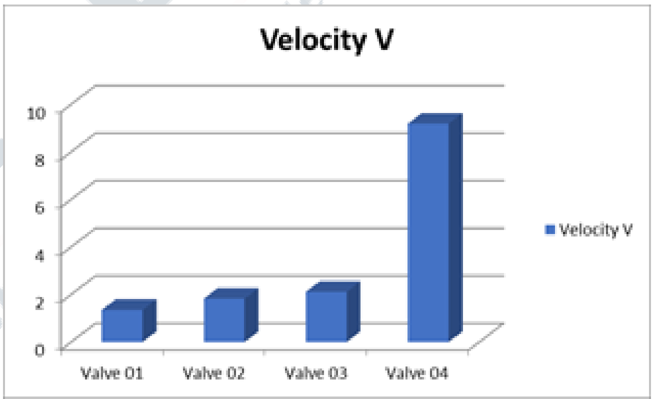

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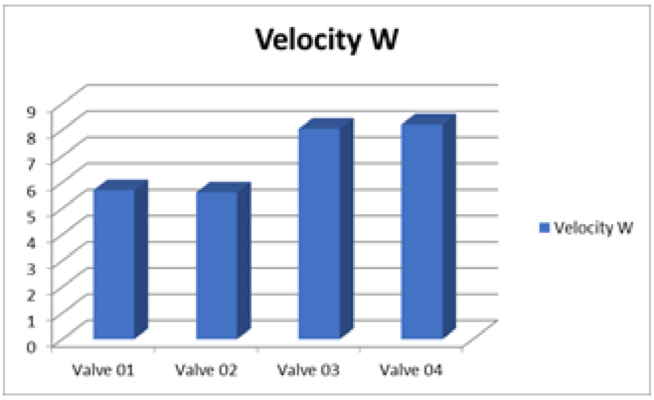

(h)

Fig. 5 Graphical representation of results

V. CONCLUSION

This study explored the influence of a double-shrouded intake valve on airflow dynamics and engine efficiency. Through Ansys simulations, various valve designs were analyzed based on key performance indicators such as eddy viscosity, pressure distribution, turbulence kinetic energy, and velocity components. The results revealed that while high turbulence dissipation improves stability, an optimal balance is required to ensure efficient fuel-air mixing and combustion.

Among the tested configurations, Valve 04 exhibited the most favorable characteristics, offering balanced turbulence dissipation, moderate pressure levels, and superior velocity components. These properties contribute to improved volumetric efficiency, reduced pressure losses, and enhanced directional airflow control, ultimately leading to better combustion and overall engine performance.

Implementing a double-shrouded intake valve with an optimized design can significantly enhance the efficiency of internal combustion engines, reducing fuel consumption and emissions while maximizing power output. Future research should explore experimental validation of these findings and consider real-world applications to further refine intake valve designs for advanced engine systems.

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