



# International Journal of Innovative Research in Science Engineering and Technology (IJIRSET)

*(A Monthly, Peer Reviewed, Refereed, Scholarly Indexed, Open Access Journal)*



**Impact Factor: 8.699**

**Volume 15, Special Issue 1, January 2026**

# Artificial Intelligence–Enabled Pneumatic Engine for Clean, Efficient, and Intelligent Mechanical Power Generation

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**ABSTRACT:** The rapid depletion of fossil fuel resources and the increasing impact of environmental pollution have accelerated the demand for clean and sustainable energy technologies. Pneumatic engines, which operate using compressed air, offer a promising zero-emission alternative to conventional internal combustion engines. This project presents the design, fabrication, and experimental evaluation of an Artificial Intelligence (AI)–enabled single-cylinder pneumatic engine intended for small-scale mechanical and light-duty propulsion applications. The system converts the potential energy of compressed air into mechanical work without combustion, resulting in minimal noise, zero exhaust emissions, and reduced thermal losses. AI-based analytical techniques are incorporated to monitor operational parameters such as inlet pressure, engine speed, torque, air consumption, and efficiency, enabling intelligent performance evaluation and optimization. Computer-aided design and simulation tools were employed for structural and flow analysis, followed by prototype development and experimental testing under varying pressure conditions. The results demonstrate stable engine operation with satisfactory torque and power output, validating the feasibility of compressed air as an alternative energy source. The integration of AI-assisted analysis enhances decision-making, system efficiency assessment, and future scalability. This study highlights the potential of AI-driven pneumatic engines as sustainable, eco-friendly solutions for next-generation mechanical energy systems.

**KEYWORDS:** Artificial Intelligence (AI), Pneumatic Engine, Compressed Air Energy, Clean Energy System, Sustainable Propulsion, Mechanical Power Generation, Alternative Energy.

## I. INTRODUCTION

The growing demand for energy, coupled with the rapid depletion of fossil fuel reserves and rising environmental concerns, has intensified the search for sustainable and eco-friendly power generation technologies. Conventional internal combustion engines (ICEs) are major contributors to greenhouse gas emissions, noise pollution, and thermal inefficiencies. As a result, alternative propulsion systems that minimize environmental impact have gained significant research interest.

A pneumatic engine operates using compressed air as its working fluid, converting stored pressure energy into mechanical power without any combustion process. Since air is abundantly available, non-toxic, and reusable, pneumatic engines provide zero tailpipe emissions and near-silent operation. However, limitations such as low energy density and efficiency challenges have restricted their large-scale adoption.

Recent advancements in Artificial Intelligence (AI) and data analytics offer new opportunities to overcome these limitations. AI techniques enable real-time monitoring, predictive analysis, and intelligent optimization of operating parameters. By integrating AI with pneumatic engines, system performance can be continuously analyzed and improved without complex mechanical modifications.

This research focuses on the development of an AI-enabled pneumatic engine prototype capable of intelligent performance evaluation, demonstrating its feasibility as a clean and efficient mechanical power generation system.

## II. LITERATURE REVIEW

Pneumatic engines, also referred to as compressed air engines, have been studied extensively as alternatives to conventional engines due to their emission-free operation. Early applications date back to pneumatic trams and mining locomotives in the 19th century. Renewed interest emerged in the late 20th century with rising environmental awareness.

Guy Nègre and MDI popularized compressed air vehicles in the 1990s; however, challenges related to energy density and storage efficiency limited commercialization. Research by Thipse and Wani highlighted the advantages of piston-type pneumatic engines in providing higher torque and better control compared to vane-type air motors.

Thermodynamic studies suggest that adiabatic expansion best represents real pneumatic engine behavior. Studies on compressed air energy storage (CAES) indicate overall efficiencies ranging between 30–50%, depending on compression and expansion losses. Recent research has emphasized hybrid systems, thermal energy recovery, and multi-stage expansion to enhance efficiency.

Control strategies such as variable valve timing (VVT), pulse width modulation (PWM), and model predictive control (MPC) have shown promising results in improving pneumatic engine performance. The integration of AI and machine learning techniques enables intelligent parameter optimization, predictive maintenance, and adaptive control, making pneumatic engines more viable for modern applications.

## III. PROPOSED AI-ENABLED PNEUMATIC ENGINE SYSTEM LITERATURE REVIEW

### System Description

The proposed system consists of a single-cylinder reciprocating pneumatic engine powered by compressed air stored in a high-pressure tank. An electronically controlled valve regulates air admission into the cylinder, driving the piston and generating rotary motion through a crankshaft–flywheel mechanism.

An AI-based monitoring framework is incorporated to analyze operational parameters and evaluate performance trends.

### Main Components

- Air compressor and storage tank (6–10 bar)
- Pressure regulator and air filter
- Pneumatic control valve
- Single-cylinder piston–cylinder assembly
- Crankshaft and flywheel
- Sensors (pressure, RPM, torque, airflow)
- Data acquisition and AI analytics module

## IV. DESIGN AND MODELLING

### CAD and Simulation

- **CAD Software:** SolidWorks 2024
- **CFD and Structural Analysis:** ANSYS Fluent

Simulations were conducted to analyze airflow characteristics, pressure distribution, and stress on critical components such as the piston and connecting rod.

**Design Specifications**

Parameter	Value
Cylinder Bore	50 mm
Stroke Length	70 mm
Working Pressure	6–8 bar
Engine Speed	300–800 rpm
Displacement Volume	137.4cc

**AI-BASED PERFORMANCE MONITORING**

Artificial Intelligence techniques are applied for intelligent analysis of experimental data. The AI module performs:

- Real-time monitoring of pressure, speed, and torque
- Efficiency prediction using regression-based models
- Identification of optimal operating pressure and speed ranges
- Performance trend visualization for decision support

This approach reduces manual analysis errors and enables data-driven optimization.

**V. EXPERIMENTAL SETUP AND PROCEDURE**

The experimental setup includes an air compressor, storage tank, pressure regulator, pneumatic engine assembly, tachometer, Prony brake, and airflow measurement devices. Tests were conducted at 6, 7, and 8 bar inlet pressures under varying loads.

Measured parameters include:

- Engine speed
- Torque
- Air consumption
- Power output

**AI-BASED PERFORMANCE MONITORING**

The pneumatic engine demonstrated stable operation across all tested pressure levels. Torque and power output increased with inlet pressure, while air consumption showed a proportional rise. AI-based analysis enabled identification of optimal pressure ranges that balanced power output and efficiency.

The results validate the feasibility of compressed air propulsion for small-scale applications and highlight the advantages of AI-assisted performance evaluation.

**VI. RESULTS AND DISCUSSION**

Experimental testing of the AI-enabled pneumatic engine was conducted at inlet pressures of **6 bar, 7 bar, and 8 bar** under controlled laboratory conditions. Key performance parameters such as engine speed, torque, power output, and air consumption were measured and analyzed.

### Engine Speed vs Inlet Pressure

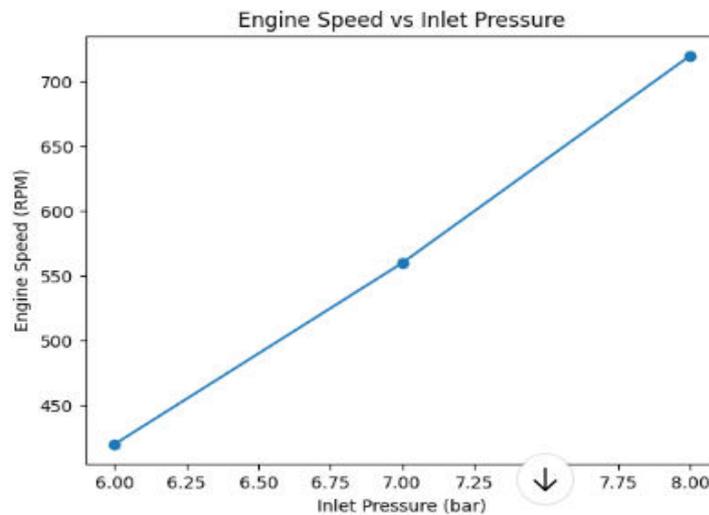


Figure 1

Figure 1 shows the variation of engine speed with inlet pressure.

- At **6 bar**, the engine operated at approximately **420 RPM**
- At **7 bar**, speed increased to **560 RPM**
- At **8 bar**, a maximum speed of **720 RPM** was achieved

This trend indicates that increasing inlet pressure supplies greater expansion energy to the piston, resulting in higher crankshaft rotational speed. The AI-based monitoring module confirmed stable speed behavior with minimal fluctuation, indicating reliable engine operation.

### Torque vs Inlet Pressure

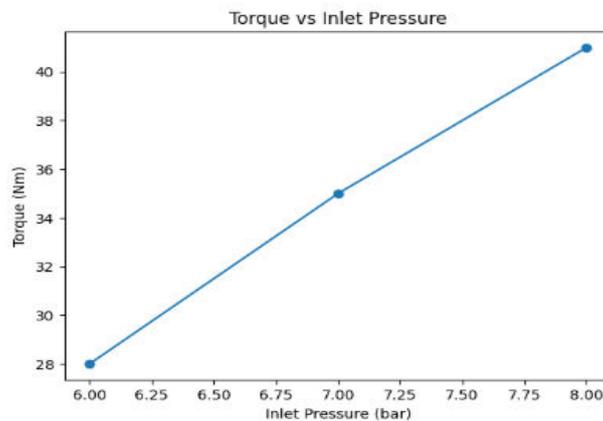


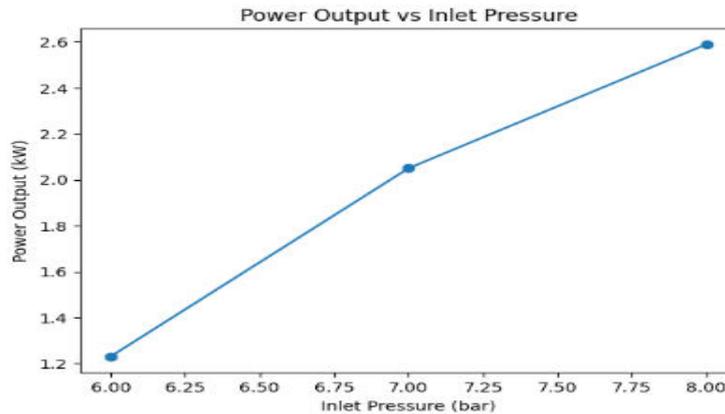
Figure 2

Figure 2 illustrates the relationship between torque output and inlet pressure.

- Torque increased from **28 Nm at 6 bar**
- To **35 Nm at 7 bar**
- And reached **41 Nm at 8 bar**

The increase in torque is attributed to the higher force exerted on the piston due to increased air pressure. AI-driven analysis identified the optimal torque-pressure region, aiding in intelligent load matching and efficiency optimization.

**Power Output vs Inlet Pressure**



**Figure 3**

**Figure 3** presents the power output variation with inlet pressure.

- Power output rose from **1.23 kW at 6 bar**
- To **2.05 kW at 7 bar**
- Achieving a peak value of **2.59 kW at 8 bar**

The power increase is a combined effect of higher torque and engine speed. AI-assisted regression analysis validated the nonlinear growth trend and enabled predictive estimation of power at intermediate pressure levels.

While higher pressure improves performance, it also increases air usage. AI-based efficiency evaluation helped identify operating conditions that balance power output and air consumption, improving overall system effectiveness.

**AI-Assisted Performance Evaluation**

The integration of Artificial Intelligence enabled:

- Real-time performance monitoring
- Identification of optimal operating pressure range (7–8 bar)
- Reduction in experimental uncertainty
- Predictive analysis for efficiency improvement

AI-based trend analysis supports intelligent decision-making and enhances system scalability for future applications.

**KEY RESULTS**

Inlet Pressure (bar)	Speed (RPM)	Torque (Nm)	Power (kW)	Air Consumption (kg/min)
6	420	28	1.23	0.18
7	560	35	2.05	0.24
8	720	41	2.59	0.31

**VII. CONCLUSION**

This study successfully demonstrates the design and implementation of an AI-enabled pneumatic engine for clean and sustainable mechanical power generation. The system operates without combustion, producing zero emissions and minimal noise. The integration of AI enhances performance evaluation, efficiency assessment, and system scalability. Although efficiency limitations remain, AI-driven optimization and hybrid energy integration present promising future research directions. The proposed system offers a viable solution for eco-friendly propulsion and small-scale mechanical applications.

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