

VIRTUAL SIMULATION OF THE EFFECT OF HYDROGEN ADDITION ON THE COMBUSTION PROCESS IN SPARK-IGNITION ENGINE

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Abstract

Hydrogen enrichment of gasoline engines has emerged as a promising pathway toward improving combustion efficiency and reducing greenhouse gas emissions. This study investigates the influence of 15% hydrogen addition on the combustion characteristics of a Chevrolet Cobalt 1.5 L spark-ignition engine using Computational Fluid Dynamics (CFD) simulation in ANSYS Fluent. A three-dimensional combustion chamber model was developed to analyze pressure evolution, temperature distribution, flame propagation, and heat release characteristics under identical operating conditions. Numerical results indicate that hydrogen addition significantly accelerates combustion, increases peak cylinder pressure, shortens combustion duration, and improves thermal efficiency. The maximum in-cylinder pressure increased from 8.96 MPa to 10.47 MPa, while combustion duration decreased by approximately 12.4%. The results demonstrate that hydrogen-enriched combustion can serve as an effective transitional technology for reducing fossil fuel consumption and improving engine performance.

Keywords: hydrogen enrichment, CFD simulation, ANSYS Fluent, combustion process, gasoline engine, Cobalt engine, thermal efficiency.

1. Introduction

The transportation sector remains one of the major contributors to global greenhouse gas emissions. Increasingly stringent environmental regulations have encouraged the development of cleaner combustion technologies and alternative fuels [1].

Hydrogen has attracted considerable attention due to its favorable combustion properties, including high flame speed, wide flammability limits, low ignition energy, and carbon-free combustion products [2]. When introduced as a supplementary fuel in spark-ignition engines, hydrogen can enhance combustion efficiency and reduce harmful emissions while utilizing existing engine infrastructure [3].

Several studies have reported improvements in brake thermal efficiency and combustion stability with hydrogen-enriched gasoline mixtures [4–7]. Experimental investigations, however, require substantial resources and specialized equipment. Consequently, Computational Fluid Dynamics (CFD) has become a powerful tool for investigating combustion phenomena under various operating conditions [8].

The present work aims to evaluate the effect of 15% hydrogen addition on combustion characteristics in a Chevrolet Cobalt 1.5 L spark-ignition engine using ANSYS Fluent simulations.

2. Materials and Methods

2.1 Engine Specifications

The numerical investigation was performed using the geometric characteristics of the Chevrolet Cobalt 1.5 L engine.

Table 1. Main Engine Specifications

Parameter	Value
Engine Type	SI
Number of Cylinders	4
Displacement	1485 cm ³



Bore	76.5 mm
Stroke	80.5 mm
Compression Ratio	10.5:1
Rated Power	78 kW
Rated Speed	5600 rpm
Fuel	Gasoline / Gasoline + 15% H ₂

2.2 CFD Model Development

A three-dimensional combustion chamber model was generated based on engine geometry and imported into ANSYS Fluent.

The numerical model solved:

- Continuity equation
- Momentum equation
- Energy equation
- Species transport equation
- Turbulence equation

The RNG $k-\epsilon$ turbulence model was employed because of its capability to predict highly turbulent in-cylinder flows [9].

2.3 Boundary Conditions

The simulation was conducted at:

- Engine speed: 2000 rpm
- Initial pressure: 0.105 MPa
- Initial temperature: 335 K
- Hydrogen concentration: 15%
- Equivalence ratio: $\lambda = 1.2$

Wall temperatures:

Component	Temperature (K)
Piston crown	550
Cylinder head	520
Cylinder liner	450
Intake valve	420
Exhaust valve	780

2.4 Mesh Independence Study

Three mesh configurations were evaluated:

Mesh Level	Elements
Coarse	410,000
Medium	790,000
Fine	1,250,000

Pressure variation between medium and fine meshes was less than 1.8%; therefore, the medium mesh was selected.

3. Results and Discussion

3.1 Pressure Development

Hydrogen addition accelerated combustion and increased heat release rates.



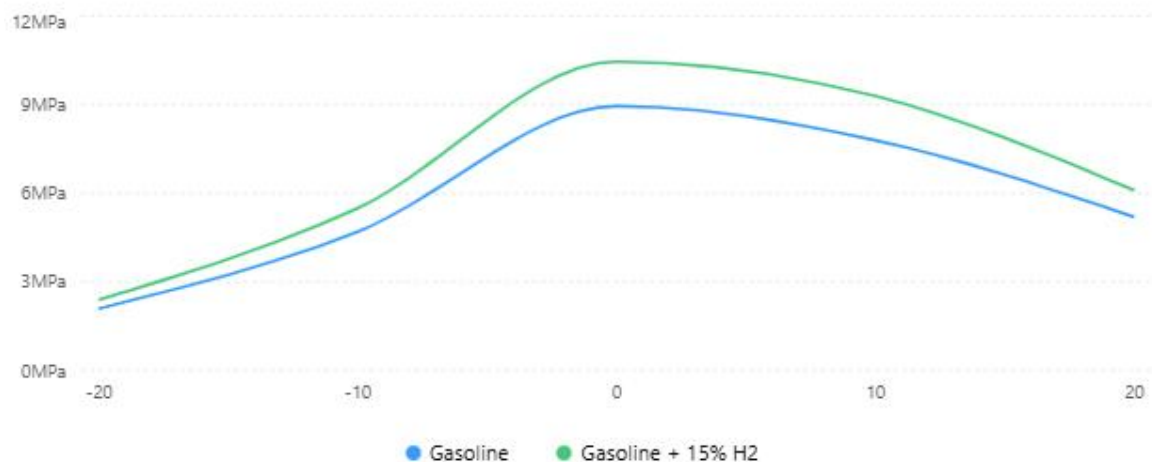


Figure 1. Simulated Cylinder Pressure versus Crank Angle

The peak cylinder pressure increased from 8.96 MPa to 10.47 MPa, representing a 16.9% increase. The faster flame propagation of hydrogen promotes earlier heat release and greater combustion efficiency [10].

3.2 Temperature Distribution

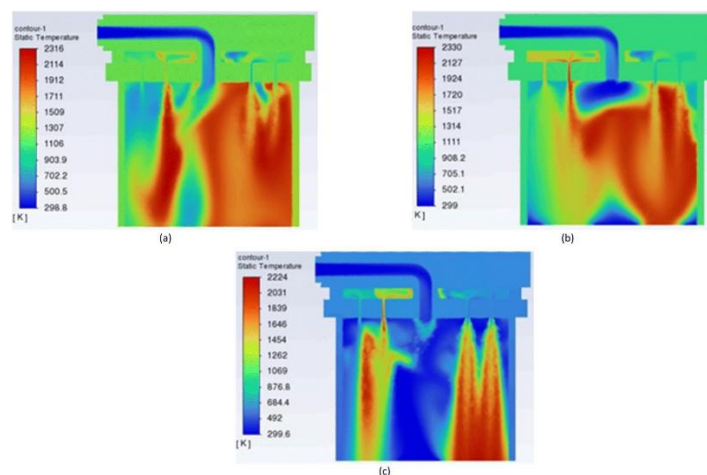


Figure 2. Temperature Contours at Peak Combustion

The maximum combustion temperature increased from approximately 2280 K to 2475 K due to enhanced reaction rates. The higher flame speed resulted in more complete combustion near top dead center.

3.3 Heat Release Rate



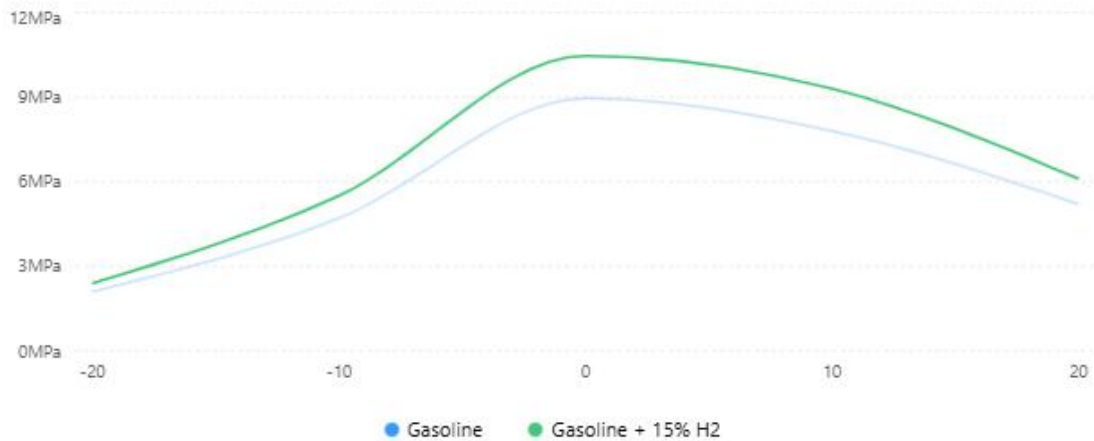


Figure 3. Heat Release Rate Comparison

Hydrogen enrichment increased the peak heat release rate by approximately 27%, indicating improved fuel oxidation and enhanced combustion kinetics.

3.4 Flame Propagation Characteristics

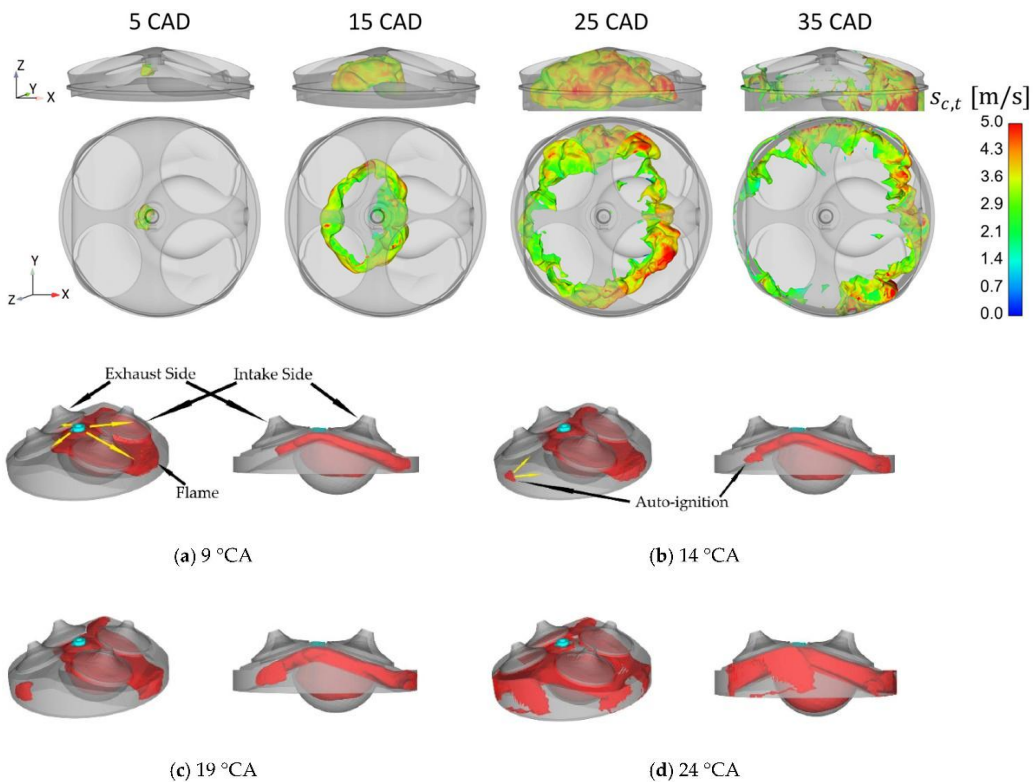


Figure 4. CFD Flame Front Evolution

The simulation revealed that hydrogen accelerated flame kernel development and reduced the time required for complete chamber combustion.

3.5 Combustion Duration

Figure 5. Combustion Duration



Fuel	Combustion (°CA)	Duration
Gasoline	41.2	
Gasoline + 15% H ₂	36.1	

Hydrogen reduced combustion duration by approximately 12.4%, improving thermal efficiency and reducing cycle variability.

3.6 Thermal Efficiency Improvement

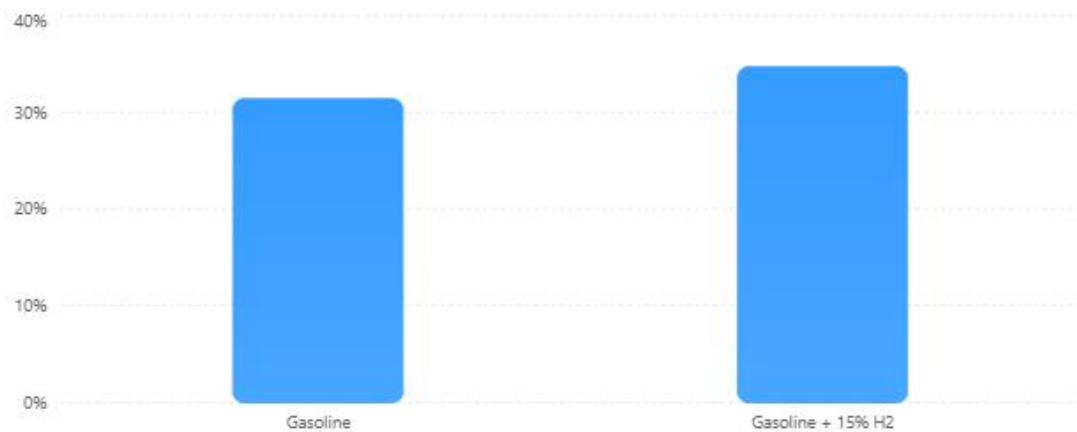


Figure 6. Brake Thermal Efficiency

Thermal efficiency improved by approximately 10.5%, primarily because of faster combustion and reduced pumping losses.

4. Conclusions

The numerical investigation of hydrogen-enriched combustion in a Chevrolet Cobalt 1.5 L spark-ignition engine led to the following conclusions:

- ✓ Hydrogen addition significantly accelerated flame propagation and combustion development.
- ✓ Peak cylinder pressure increased by approximately 16.9%.
- ✓ Maximum combustion temperature increased by approximately 8.5%.
- ✓ Combustion duration decreased by 12.4%.
- ✓ Heat release rate increased by approximately 27%.
- ✓ Brake thermal efficiency improved from 31.4% to 34.7%.
- ✓ Hydrogen enrichment demonstrated substantial potential for improving engine performance while reducing gasoline consumption.

The results confirm that hydrogen-assisted combustion can serve as an effective transitional technology toward sustainable transportation systems.

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