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Enhancement Of Engine Performance & Efficiency by Replacing Existing Cavity Piston to Flat Top Piston

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Abstract

This document synthesizes research findings regarding the impact of piston crown modifications, specifically top bowl geometries, on the performance of Compressed Natural Gas (CNG) engines. It presents a detailed analysis of the enhancement of engine performance by replacing cavity pistons with flat-top piston geometry in CNG engines. The study discusses combustion characteristics, thermal efficiency, brake power, emissions, turbulence generation, flame propagation, and fuel economy.

It highlights how variations in tumble flow, turbulence kinetic energy (TKE), and air-fuel mixing, driven by geometric constraints, lead to significant improvements in thermal efficiency and power output.

1. Introduction

The increasing demand for cleaner fuels and stringent emission regulations have accelerated the development of alternative fuel engines. Compressed Natural Gas (CNG) is considered one of the most promising alternative fuels because of its high-octane number, low carbon content, and reduced exhaust emissions.

In CNG engines, combustion chamber design significantly affects engine performance and emissions. The piston crown geometry controls air-fuel mixing, turbulence intensity, swirl motion, and flame propagation characteristics. Traditionally, cavity or bowl-type pistons are used in diesel engines to promote turbulence and mixing. However, when diesel engines are converted into spark ignition CNG engines, flat-top pistons are often investigated due to their simpler geometry and improved flame travel characteristics.

This review paper focuses on the effect of replacing cavity pistons with flat-top piston geometry on the performance enhancement of CNG engines.

2. The CNG Challenge: Flame Speed and Mixing

Compressed Natural Gas (CNG) presents a unique challenge in internal combustion engines due to its gaseous state and relatively slow laminar flame speed. To compensate, high-intensity turbulence is required. Flat top pistons provide a shorter jet impingement distance, which accelerates the development of TKE during the late compression stroke.2. Properties of CNG as an Engine Fuel

3. In-Cylinder Mixing Performance

Recent numerical studies indicate that flat top designs significantly improve mixing uniformity. In Direct Injection (DI) gas engines, a flatter crown architecture allows the gaseous jet to interact more effectively with the bulk air motion (tumble/swirl), preventing the formation of overly rich zones near the piston walls.

The high-octane number allows CNG engines to operate at higher compression ratios without knocking. However, CNG has a lower flame speed compared to gasoline, leading to slower combustion and lower thermal efficiency if combustion chamber design is not optimized.

4. Literature Review

- ✓ **Studies on Flat-Top and Bowl Pistons in CNG Engines**

A study titled *"Investigations with bowl-in-piston and flat-piston geometries to study engine characteristics of a CI engine retrofitted for SI operation with CNG fuel"* reported that bowl-in-piston geometry achieved approximately 2.58% higher efficiency than flat pistons due to stronger turbulence generation. However,flatpistons showed improved flame front propagation and stable combustion behavior.

Another investigation on retrofitted CNG engines with different piston-top shapes showed that piston geometry significantly affects brake thermal efficiency, power output, and emissions. Flat-top pistons reduced combustion duration and improved combustion stability under lean conditions.

Experimental studies on converted diesel-to-CNG engines found that torque and brake power were influenced by compression ratio and piston bowl geometry. Flat-top pistons demonstrated improved power output at moderate compression

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ratios because of reduced heat losses and improved flame travel.

Research on turbulence-enhanced piston designs for natural gas engines concluded that combustion speed and thermal efficiency improve with optimized turbulence intensity. Excessive bowl depth may increase wall heat losses and negatively affect emissions.

Comprehensive reviews of CNG combustion strategies also highlighted that combustion chamber optimization is essential for improving brake thermal efficiency and reducing NOx emissions in CNG engines.

5. Effect of Flat-Top Pistons on Engine Performance

✓ Brake Thermal Efficiency (BTE)

Flat-top pistons can improve combustion uniformity and reduce heat transfer losses due to smaller surface area. Improved flame travel contributes to better thermal efficiency under spark ignition operation at higher engine RPM.

✓ Brake Power and Torque

Flat-top pistons provide improved volumetric efficiency because of reduced obstruction in the combustion chamber. Studies reported improved torque and power at medium engine speeds, leading to 3–10% performance improvement under certain conditions.

✓ Combustion Characteristics

The flat piston geometry allows smoother flame propagation and reduced combustion duration. Faster flame speed improves pressure rise characteristics and combustion completeness.

6. Conclusion

Piston crown geometry plays a crucial role in determining the combustion and performance characteristics of CNG engines. Replacing cavity pistons with flat-top pistons can improve flame propagation, reduce combustion duration, and decrease heat losses. Flat-top pistons also simplify manufacturing and maintenance while offering better volumetric efficiency. However, cavity pistons still provide superior turbulence generation and mixing characteristics.

The overall performance improvement depends on operating conditions, compression ratio, ignition timing, and air-fuel mixture quality. From the reviewed literature, flat-top pistons are particularly suitable for spark ignition CNG engines operating under lean-burn conditions and moderate compression ratios. Further optimization using CFD and experimental methods is required to achieve the best balance between efficiency and emissions.

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