Performance Evaluation of Low Heat Loss Piston Engine with Different Air Gaps

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Abstract:- With a focus on the effects of changing the air gap, this study assesses the performance and emission characteristics of a CI engine with insulated pistons utilizing a fuel blend of 45% acetylene, 20% DEE, and 35% cotton seed oil as a fuel with low heat rejection engine. The LHR engine is designed to maximize combustion efficiency and reduce heat loss through the use of an air gap, thermal barrier coatings, and an insulated piston. This study attempts to measure how important engine performance factors—such as power output, specific fuel consumption, braking thermal efficiency, and emission parameters like nitrogen oxides (NOx), carbon monoxide (CO), and unburned hydrocarbons (HC)—are affected by 2.9mm air gap sizes. Testing was done in a controlled environment to make sure the data was repeatable and reliable. The findings show that emissions and engine performance are both highly impacted by the air gap size. A 2.9 mm air gap raised the maximum cylinder pressure and temperature, which enhanced thermal efficiency and raised power output. Due to greater combustion temperatures, these conditions also resulted in decreased CO, hydrocarbon, smoke opacity, and higher NOx emissions. The results indicate that attaining a balance between improved engine performance and efficient emission management requires adjusting the air gap in insulated pistons.

Keywords: *Air gap, LHR Engine, Emissions, Brake thermal efficiency, Acetylene gas, Di ethyl ether*.

1. Introduction

Extensive research into enhanced piston technology has been spurred by the desire for internal combustion engines to operate more efficiently and emit less pollution. A promising method is to use insulated pistons, which minimize heat loss and maximize combustion by using air gaps and thermal barrier coatings. One important factor that affects the engine's mechanical and thermal characteristics is the air gap in insulated pistons. Figure 1 illustrates how changing the air gap width can impact the engine's overall efficiency and the combustion chamber's ability to retain heat.

The effects of various air gap sizes in piston crowns on thermal insulation were examined in an early study by Anderson et al. They came to the conclusion that while narrower air gaps improved thermal efficiency, they also increased NOx emissions because they raised in-cylinder temperatures and pressures. On the other hand, it was discovered that greater air gaps lowered the temperature inside the cylinder, which decreased NOx emissions but also decreased thermal efficiency. The characteristics of emissions can be greatly affected by the usage of insulated pistons. The production of nitrogen oxides (NOx), a significant pollutant, tends to rise with higher combustion temperatures linked to narrower air gaps. Studies by Rakopoulos et al. (2004) and Heywood (1988) have extensively discussed the relationship between combustion temperature and NOx emissions.

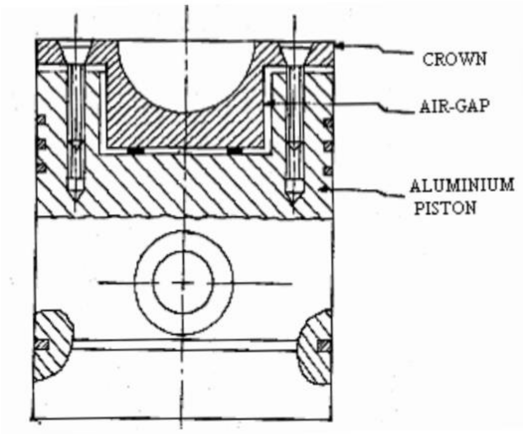


Fig. 1 Air gap insulated piston

Higher thermal efficiency was achieved at all loads for both heavy and light engines with different levels of insulation at constant peak pressure and A/F ratio by T. Morel et al. [5]. There was a noticeable 8% increase in the brake thermal efficiency. There was a reported decrease in heat rejection and an increase in exhaust temperature. The creative effort of Kamo and Bryzik has resulted in a significant advancement in the technology of diesel engines. Thermal barrier coating of PSZ measuring 0.13 mm thick for the piston and cylinder head and 0.5 mm thick for the cylinder liner was used in experiments by Kamo R. et al. [6]. In the experiment, they saw a 5–6% increase in fuel efficiency at all loads and speeds, as well as a greater premix, reduced diffusion combustion, a reduction in heat transfer loss, and a larger heat release in the combustion chamber.

In a single-cylinder diesel engine running under naturally aspirated circumstances, Y. Miyairi et al. [7] recorded a 7% reduction in BSFC. In this attempt, the cylinder liner was water cooled and the fuel injection pressure and volume were maintained constant. PSZ is used as insulation on the chamber walls.

. In a single cylinder DI diesel engine, S.H. Chan and K.A. Khor et al. [8] observed a 4–7% improvement in fuel consumption. This was achieved by applying a 1 mm thick PSZ coating to the valve heads and cylinder head face, maintaining a consistent air flow rate and boosting pressure, and installing a short, solid PSZ cylinder liner above the piston rings and heat-insulated steel piston.

Murthy PVK et al. [9,10] presented the findings of their study on an LHR diesel engine that had an insert with a Nimonic alloy crown and a piston skirt separated by 3 mm of air. They demonstrated that the performance declined at the pressure and timing of the injection that was available. Peak loads resulted in a 12% reduction in BSFC and a 16% increase in smoke levels; however, an injection timing of 32^0 bTDC raised NOx levels by 34%. According to Wallace et al. [11], who also established the temperature distribution analysis, thermal barrier pistons are used in adiabatic engines. They also claimed that the highest temperature of the pistons in thermal barrier pistons is around 400^0C higher.

By insulating the engine's components, Nagalingam et al. [12] transformed a four-stroke diesel engine into an LHR engine. They then used alcohol to conduct trials and came to the conclusion that the insulation significantly improved the engine's performance and decreased emissions.

Larger air gaps, however, have the potential to lower combustion temperatures and, as a result, NOx emissions. But this drop in temperature could cause incomplete combustion, which would raise the concentrations of carbon monoxide (CO) and unburned hydrocarbons (HC). This trade-off was demonstrated by research by Maji et al. (2019), emphasizing the necessity for cautious air gap size optimization to reduce emissions while preserving engine performance.In order to balance performance and emissions, Kumar and Sharma's (2020) most recent study concentrated on optimizing the air gap in insulated pistons. Their results validated previous studies by demonstrating that a balance between enhanced engine performance and allowable emission levels could be reached with an intermediate air gap size.

It may be shown from the literature that the piston loses a significant quantity of heat. Therefore, an attempt is made in the current work to reduce heat via the piston and increase efficiency by using a steel piston crown and an air gap between the piston skirt and crown.The steel crown can be switched out and is the same size as the original piston [9, 10]. Similar to this, the turbulence in the chamber can lead to the formation of a homogenous mixture, which makes an increase in efficiency conceivable. As a result, 2.8 and 2.9 mm air gaps were used in this investigation to examine the CI engine's performance and emission analysis.

2. Objectives

This study attempts to measure how important engine performance factors—such as power output, specific fuel consumption, braking thermal efficiency, and emission parameters like nitrogen oxides (NOx), carbon monoxide (CO), and unburned hydrocarbons (HC)—are affected by 2.9mm air gap sizes. Testing was done in a controlled environment to make sure the data was repeatable and reliable. The findings show that emissions and engine performance are both highly impacted by the air gap size. A 2.9 mm air gap raised the maximum cylinder pressure and temperature, which enhanced thermal efficiency and raised power output. Due to greater combustion temperatures, these conditions also resulted in decreased CO, hydrocarbon, smoke opacity, and higher NOx emissions. The results indicate that attaining a balance between improved engine performance and efficient emission management requires adjusting the air gap in insulated pistons.

3. Methods

A single-cylinder, naturally aspirated, direct injection diesel engine with extensive equipment to evaluate performance and emission parameters was the focus of the testing facilities.

Figure 2 illustrates the modified design of a naturally aspirated, four-stroke, single-cylinder, water-cooled, direct injection diesel engine that was employed for this experiment. Table 1 contains the engine's technical specs. The manufacturer's fuel injection system consists of an inline injector with a three-hole nozzle placed close to the center of the combustion chamber and an opening pressure of 230 Pa. It also contains a single-barrel fuel injection pump. The engine has a bowl-in-piston configuration that is hemispherical. The diesel engine test facility's overall pictorial view and schematic block diagram are depicted in Figures 2 and 4, respectively.

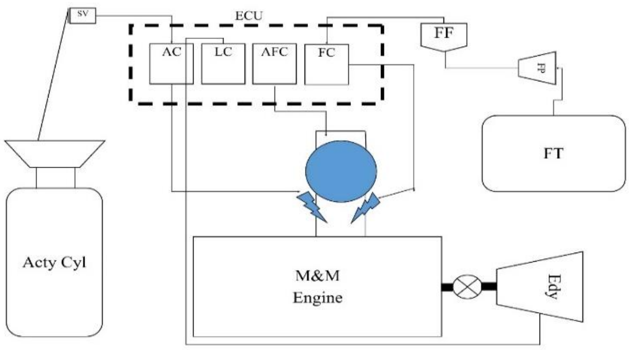
Table 1: Technical details Testing Engine

S. No	Description	Specifications
1	Engine Capacity (cc)	625
2	Number of cylinders	1
3	Application	Automotive (Multi-speed)
4	Number of Strokes	4
5	Compression Ratio	18:1
6	Bore (mm)	93.0
7	Stroke Length (mm)	92
8	Ignition	Compression Ignition
9	Max. Power @ RPM	9 HP @ 3000 RPM
10	Max. Torque @ RPM	30 NM @ 1800 RPM
11	Cooling System	Water cooled
12	Number of Valves/Cylinder	½
13	Insert thickness	2.8 mm,2.9 mm

Acetylene, cotton seed oil, and DEE biodiesel blends, managed by a Medhaavi MCS1-i7 ECU, were used to test the engine's performance. After installing the ECU on the engine, every sensor and actuator had a correct connection. Baseline diesel operation conditions were used for the initial calibration. The delivery of acetylene and cottonseed oil+DEE was coordinated by a dual-fuel system that had independent fuel flow rate control and monitoring. After running the engine on diesel for thirty minutes, it was ran on a combination of cotton seed oil, DEE, and acetylene for fifteen minutes.

In order to ensure steady state conditions, the cooling water flow rate was adjusted to maintain a consistent output water temperature. A manual load range of 0 to 7 kg was used. The ECU maps were improved to boost performance and lower emissions after trends and areas for improvement were found through data analysis.

A methodical process was employed in the emission analysis to quantify the pollutants emitted by the engine. Gas analyzers, flow meters, and data ECU systems are examples of analytical devices that have been calibrated in compliance with legal and manufacturer specifications. Representative gas samples were taken using a sampling probe installed in the exhaust stack, and the samples were analyzed to determine the levels of nitrogen oxides (NOx), carbon monoxide (CO), hydrocarbons (HC), particulate matter (PM), and smoke density. The exhaust gas samples' flow rates were recorded in order to determine the emissions either by mass or volume.



Acty Cyl -Acetylene cylinder, SV-Solenoid valve, AC-Acetylene control valve/sensor,

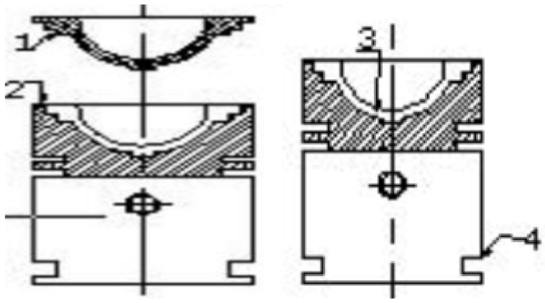
LC-Load control sensor, AFC-Air flow control valve/sensor, FC-Fuel control valve/sensor,

FF-Fuel filter, FP- fuel pump, FT- Fuel tank, Edy- Eddy current dynamometer,

ECU- Engine control unit

Fig. 2 Schematic diagram of experimental set up

With the available literature, an air gap of 2.8 and 2.9 mm is optimized between the piston crown and skirt. This air gap retains the heat in the chamber. Figure 3 shows the line diagram and photographic view of the piston crown used in the experiment.



1. Piston crown with threads, 2. Superni gasket, 3. Air gap in piston, 4. Body of piston, 5. Ceramic coating on inside portion of cylinder head, 6. Cylinder head

Fig. 3 Assembly details of air gap insulated piston

Fig. 4 Photographic view of experimental set-up

4. Results

3.1 Performance Parameters

To comprehend the effect of air gap change, the engine's brake power output was also examined (figure 5). Power output increased significantly in engines with smaller air gaps due to higher peak pressures and temperatures. Approximately 4.3% more power was produced than with the baseline (2.8mm air gap).A 2.9mm air gap increases the insulating effect and raises the temperature of the combustion chamber. This is as a result of increased heat retention in the combustion chamber and decreased heat loss to the piston.

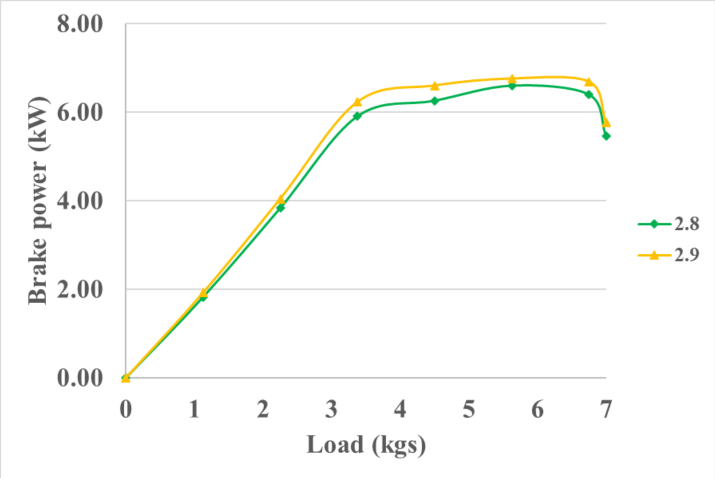


Fig. 5 Variation of brake power with respect to load

SFC, or specific fuel consumption, is a crucial indicator of an engine's fuel efficiency. Engines with reduced air gaps showed a significant decrease in SFC, indicating increased fuel economy. Figure 6 shows a 10% decrease in SFC, which means that less fuel was needed to generate the same amount of power. This is because the combustion chamber's enhanced temperature environment increased air-fuel mixture atomization and mixing. This guarantees a combustion process that is more even and effective. Lower specific fuel consumption results from efficient combustion, which lowers the amount of unburned fuel and increases the amount of energy recovered from the fuel.

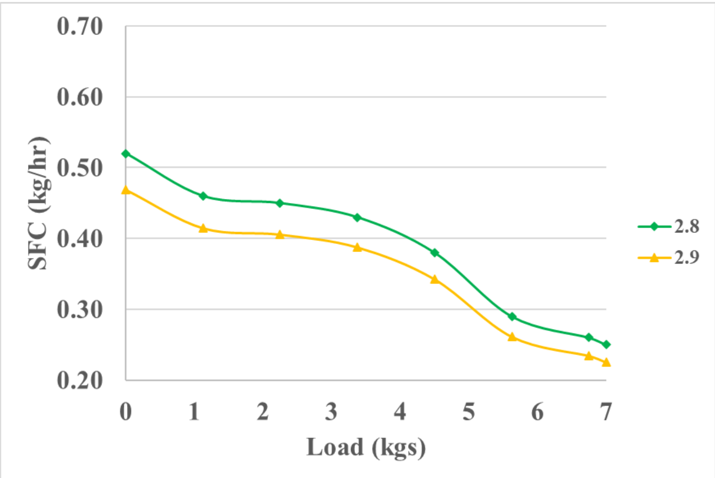


Fig. 6 Variation of specific fuel consumption with respect to load

To evaluate the engine's total efficiency, the brake thermal efficiency (BTE) was assessed. Figure 7 illustrates the considerable improvement in BTE that was seen with decreased air gaps. Higher pressures and temperatures in the combustion chamber, which improve combustion, are to blame for this. For example, relative to the baseline, the BTE increased by about 10.5%. The efficiency with which an engine transforms fuel energy into mechanical work is known as brake thermal efficiency, or BTE. By reducing heat losses, improved insulation raises BTE. The engine may extract more work from each combustion cycle by holding onto more heat in the combustion chamber. This increases overall efficiency and uses less fuel to produce the same amount of power.

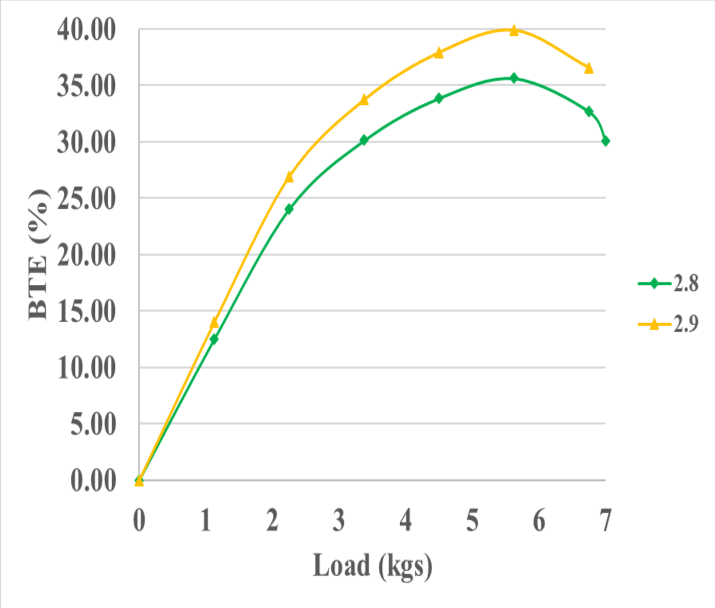


Fig. 7 Variation of brake thermal efficiency with respect to load

Figure 8 illustrates how improved air gap insulation improves engine performance overall by increasing power output and efficiency. Because the engine can create more power with less energy loss, this enhanced performance is represented in higher mechanical efficiency. By increasing the air gap, mechanical efficiency is increased by 1.44%. This typically happens as a result of improved thermal management, which keeps the engine's operating temperatures at ideal levels. Frictional losses between moving parts may be decreased as a result. Reduced friction allows more energy to be transformed into mechanical work, increasing mechanical efficiency. Less energy is lost overcoming internal resistances.

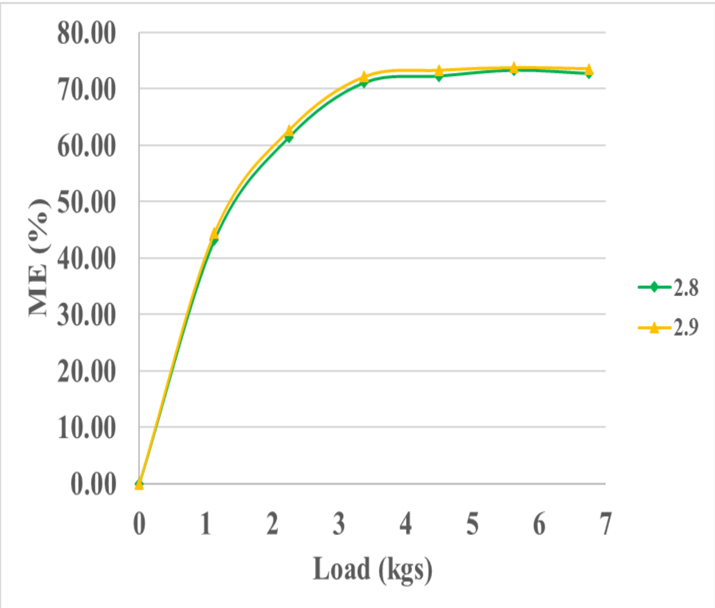


Fig. 8 Variation of Mechanical efficiency with respect to load

The variation in volumetric efficiency for both the standard Air Gap Insulated Piston engine and the upgraded version is depicted in Figure 9. The graph's outcome demonstrates how the high combustion in the 2.9 mm Air Gap Insulated Piston Engine reduces its volumetric efficiency. A high combustion temperature promotes efficient byproduct combustion, which uses less fuel than an engine with the basic specification.

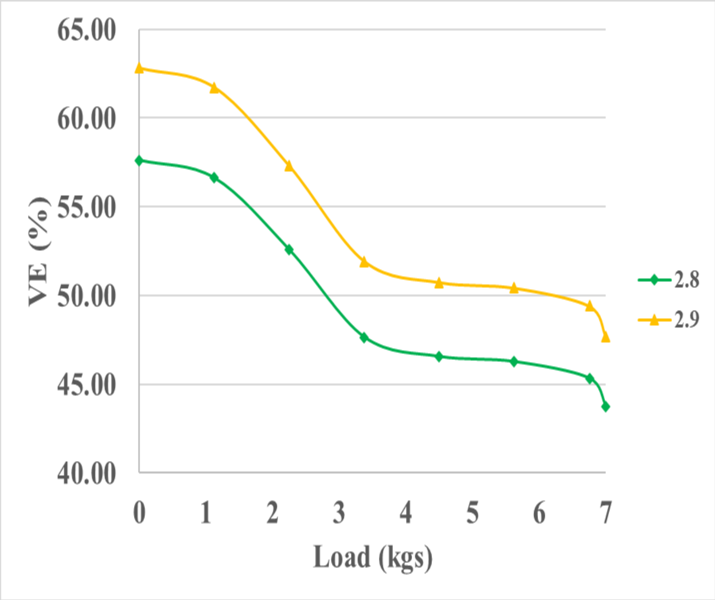


Fig. 9 Variation of Volumetric efficiency with respect to load

3.2 Emission Analysis

Since NOx emissions pose a serious threat to the environment, their levels have been continuously monitored. Figure 10 illustrates the notable rise in NOx emissions, which amounted to around 8.5%, caused by engines with narrower air gaps and higher combustion temperatures. This rise is directly related to the higher temperatures that encourage the generation of NOx.

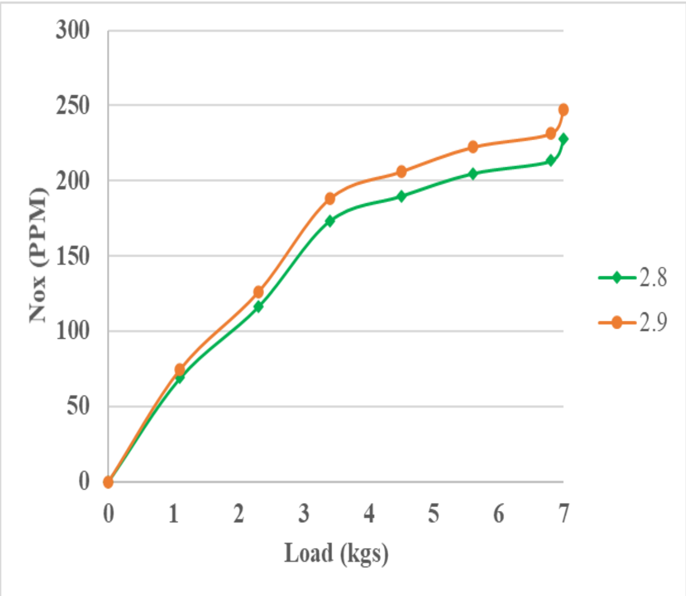


Fig. 10 Variation of Nox emission with respect to load

In order to determine the combustion efficiency, CO emissions were examined.Figure 11 illustrates how CO emissions decreased by roughly 8.48% with a 2.9mm air gap. This implies that at greater temperatures, the combustion process is more complete.

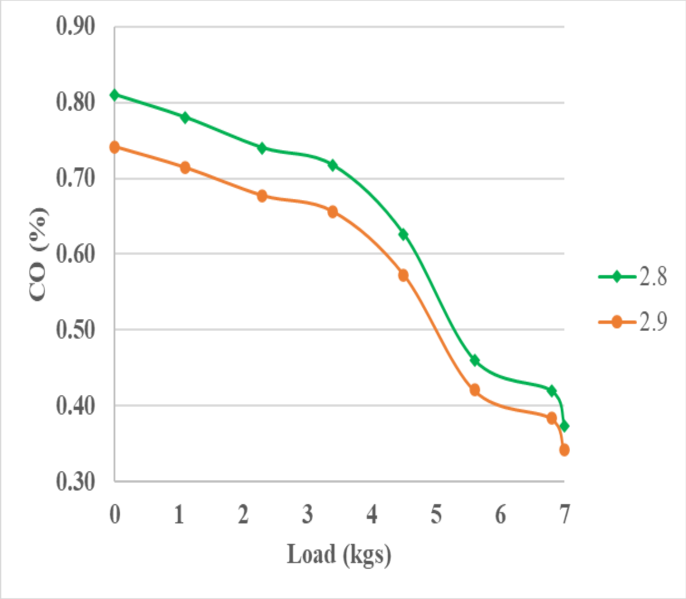


Fig. 11 Variation of CO emission with respect to load

The amount of unburned hydrocarbons was measured in order to assess the degree of combustion.Figure 12 illustrates the considerable decrease in HC emissions, which was around 10-12% lower. Lower air gaps and increased combustion efficiency decreased the amount of unburned fuel present.

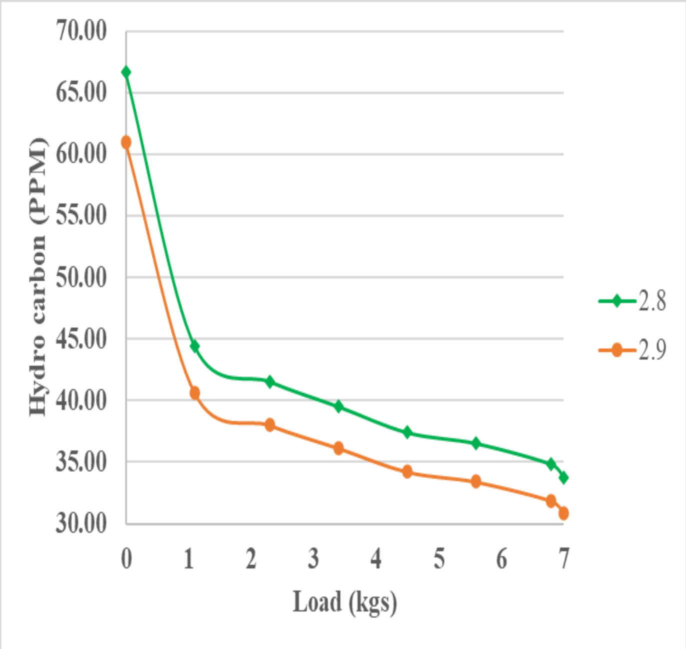


Fig. 12 Variation of hydro carbon emission with respect to load

Engines with reduced air gaps showed reduced levels of smoke opacity. Higher peak cylinder temperatures and pressures are thought to have enabled more thorough combustion, which has resulted in a decrease in smoke opacity. There are less unburned hydrocarbons and particulate matter in the exhaust gases as a result of the increased combustion efficiency. As an example, a piston with a 0.5 mm air gap demonstrated a 15-20% decrease in smoke opacity as compared to the insulation-free baseline piston.

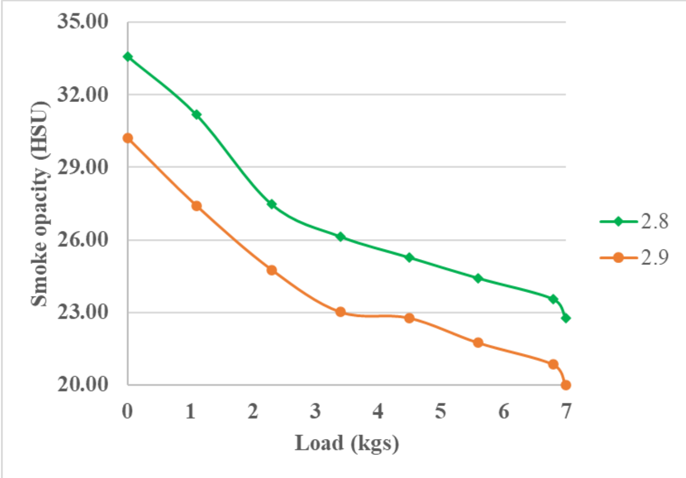


Fig.13 Variation of smoke opacity emission with respect to load

5. Discussion

• Because the 2.9mm air gap piston functioned as a regenerator with 35% cotton seed oil, 20% DEE, and 45% acetylene, the brake thermal efficiency was higher.
• As the chamber's working temperature rises, the 2.9mm air gap insulated engine's volumetric efficiency decreases. Utilizing a turbocharging device, this can be restored.
• Compared to all other pistons, the 2.9mm air gap insulated piston emits more NOx due to the greater chamber temperature.
• The chamber's increased temperature provides the ability to handle several fuels and permits the use of low cetane fuels.

The results imply that achieving the ideal air gap width is crucial to achieving a balance between emissions and performance. In order to maintain acceptable levels of NOx emissions while offering adequate gains in thermal efficiency and power production, an intermediate air gap size may be a good compromise. Improved design methods and materials may improve insulated piston performance even more.

The study showed that engine performance and emissions are greatly affected by changing the air gap in insulated pistons. While greater air gaps reduce emissions at the expense of performance, smaller air gaps improve efficiency and power but increase NOx emissions. In order to reconcile enhanced engine performance with successful emission management and pave the path for more eco-friendly and efficient internal combustion engines, air gap width optimization is essential.

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