INVESTIGATION OF THE IMPACT ON PERFORMANCE AND EMISSIONS ANALYSIS OF EXHAUST GAS RECIRCULATION & AIRPREHEATER FLOW RATE ON A CRDI ENGINE

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ABSTRACT
Different strategies have been developed to reduce the emissions of NOx from diesel engines. This study examines the application of two critical methods with a single-cylinder, four-stroke, water-cooled, direct-injection diesel engine: exhaust gas recirculation (EGR) and air preheater. An Eddy current Dynamometer with EGR was used in a number of studies to see how well these methods worked to lower NOx, CO2, hydrocarbon, and smoke density emissions.This research explores the performance characteristics of the diesel engine, such as brake power, brake thermal efficiency, and specific fuel consumption (SFC), in addition to providing insightful information on reducing hazardous emissions. The results enhance our comprehension of tactics to tackle the ecological issues related to diesel engines while maximizing their overall efficiency.
Keywords*: Diesel, Biodiesel, EGR, Air Preheater, Emission.*

INTRODUCTION
Diesel engines are extensively employed in numerous sectors because of their cheap fuel consumption and excellent thermal efficiency. However, the production of dangerous pollutants, especially nitrogen oxides (NOx), is one of the main disadvantages of diesel engines. Numerous techniques have been developed to reduce NOx emissions in order to address this problem. This study examines the application of two critical methods with a single-cylinder, four-stroke, water-cooled, direct-injection diesel engine: exhaust gas recirculation (EGR) and air preheater.
Diesel engines are widely used in various industries due to their high thermal efficiency and low fuel consumption. However, one of the major drawbacks of diesel engines is the emission of harmful pollutants, particularly Nitrogen Oxides (NOx). To address this issue, various methods have been developed to mitigate NOx emissions. This research focuses on the implementation of two crucial techniques, Exhaust Gas Recirculation (EGR) and Air Preheater, in conjunction with a single-cylinder, four-stroke, water-cooled, direct- injection diesel engine.
Diesel engines have high compression ratios and lean combustion, which naturally result in high thermal efficiency. The circumstances are perfect for auto-ignition because of this high compression ratio. The production of high flame temperatures in diesel engines is a significant difficulty, nevertheless, as it results from the uneven combustion of diesel due to localized stoichiometric air-to-fuel ratios [1]. Because of the higher combustion temperature, available oxygen and nitrogen from the intake air combine to generate nitrogen oxides, or NOx emissions, which are particularly nitrogen dioxide (NO2) and nitric oxide (NO) [2]. Furthermore, NOx generation is greatly aided by the copious amounts of oxygen that are available during diesel combustion [3].
EGR is a commonly utilized method for lowering diesel engine NOx emissions. In order to lower the amount of oxygen in the combustion chamber, some of the exhaust gas is circulated back into the engine intake. By lowering the temperature at which NOx is created, this technique lessens the likelihood that it will react and produce pollutants. Stricter emission control laws like EURO-V have motivated significant research efforts in the last few decades to reduce soot and NOx emissions from diesel engines. Utilizing exhaust gas recirculation (EGR) effectively is essential to meeting these strict emission regulations [4].
Another method for lowering NOx emissions from diesel engines is the use of an air preheater. Prior to being injected into the engine, the intake air is heated. By lowering the temperature differential between the combustion and intake charges, preheating the intake air also lowers the amount of NOx that is produced. Internal combustion engines are essential parts of power and transportation networks.

But during cold starts, particularly in cold weather, diesel engines frequently operate poorly. Longer cranking times, more fuel usage, and higher emissions are signs of this poor cold start performance [5]. Researchers have investigated many methodologies to augment engine performance. Among these is the application of pilot injection [6, 7].

TECHNIQUES FOR ENHANCE THE COMBUSTION PROCESS

Due to their efficiency and power, diesel engines have long been a mainstay of the industrial and transportation sectors. They are, meanwhile, also well-known for releasing a variety of pollutants, including particulate matter and nitrogen oxides (NOx), which present serious risks to the environment and human health. Researchers and engineers have been looking into cutting-edge technology to enhance the overall performance of diesel engines while lowering emissions in order to allay these worries and meet ever-tougher pollution rules [8]. Two key techniques that have emerged as effective strategies in this pursuit are Exhaust Gas Recirculation (EGR) and Air Preheater systems. These technologies aim to mitigate emissions and enhance the combustion process within diesel engines, ultimately contributing to a cleaner and more efficient operation [9].It provides an overview of EGR and Air Preheater techniques, their underlying principles, and their applications in diesel engines. We will explore how these methods work in tandem to address the challenges of emissions reduction and improved engine performance, setting the stage for a more detailed discussion in subsequent sections.

EXHAUST GAS RE-CIRCULATION SYSTEM

EGR is a widely used technique used to reduce NOx emissions from diesel engines. It involves recirculating a portion of the exhaust gas back into the engine intake, thereby reducing the oxygen concentration in the combustion chamber [10]. This process reduces the temperature at which the NOx is formed, making it less likely to react and form pollutants.
EGR offers several benefits in reducing NOx emissions:

- Reduced NOx Formation: By reducing the oxygen concentration in the combustion chamber, EGR reduces the temperature at which NOx is formed. This reduces the formation of NOx, leading to lower emissions.
- Fuel Economy: EGR improves engine efficiency by recirculating a portion of exhaust gas, which can be reused to combust the fuel. This leads to lower fuel consumption and lower operational costs.
- Improved Engine Stability: By reducing the peak cylinder temperature, EGR helps prevent engine knocking and pinging, resulting in smoother combustion and improved engine stability.
- One method used to lower nitrogen oxide (NOx) emissions from diesel engines is exhaust gas recirculation, or EGR. When the temperature inside the combustion chamber rises above a particular point, NOx is produced. A part of the exhaust gas is circulated back into the intake manifold via EGR. As a result, there is less oxygen available for burning, which decreases the temperature during combustion and lessens the production of NOx [11].
- Although EGR is a highly efficient method of reducing NOx emissions, engine performance may be negatively impacted. EGR, for instance, can lower engine output and fuel economy. Additionally, it may make corrosion and engine deposits more likely.
- Operating circumstances and engine design determine how much EGR is used. Generally speaking, greater engine temperatures and lower engine loads result in the utilization of more EGR.

AIR PREHEATER

An air preheater is another technique used to reduce NOx emissions from diesel engines. It works by preheating the intake air before it is injected into the engine. Preheating the intake air reduces the temperature difference between the intake charge and combustion temperature, which also reduces the formation of NOx.

- Reduced NOx Formation: Preheating the intake air reduces the temperature difference between the intake charge and combustion temperature, which suppresses the formation of NOx.

- Fuel Economy: Preheating the intake air improves engine efficiency by allowing the engine to reach peak combustion temperatures more quickly. This leads to lower fuel consumption and reduced operational costs.
- Improved Cold-Start Performance: During the cold-start phase, the air preheater helps ignite the fuel more efficiently, reducing the warm-up time and improving cold-start performance.
- Preheating the intake air prior to it entering the engine's combustion chamber is the basic idea of the Air Preheater. Despite its apparent simplicity, this procedure has a significant impact on the engine's efficiency and operating range, particularly in the difficult field of HCCI combustion.

One of the primary benefits of air preheating is the elevation of air temperature, a key factor that reduces the risk of condensation of diesel vapor within the intake manifold. This temperature increase allows for a higher mass fraction of vapor to be inducted into the engine, thereby optimizing the combustion process [12]. In this introductory exploration of the Air Preheater, we delve into its mechanisms and the pivotal role it plays in facilitating HCCI combustion, ultimately leading to enhanced engine performance and reduced emissions.

EXPERIMENTAL SETUP

In order to assess the effectiveness of EGR and Air Preheater in reducing NOx emissions, a series of experiments were conducted on a single-cylinder, four-stroke, water-cooled, direct- injection diesel engine. The experimental setup consisted of an Eddy current Dynamometer, which was used for measuring the engine performance, emissions, and fuel consumption. A four-stroke, water-cooled, single-cylinder, direct-injection (DI), vertical diesel engine was employed for the investigation. Its rated speed is 1500 rpm, and its rated power is 5.2 kW. Table 1 displays the test engine's specifications. There were two stages to the experimental work. The diesel engine's emissions, combustion, and performance with exhaust gas recirculation (EGR) were examined in the first phase. The engine's operation, combustion, and emissions with the air preheater (APH) were examined in the second phase. Readings were obtained at different loads, including 20%, 40%, 60%, 80%, and 100% load, in both phases. An AVL gas analyzer was used to measure the emissions of hydrocarbons (HC), carbon monoxide (CO), and nitrogen oxides (NOx), and an AVL smoke meter was used to measure the density of smoke. A thermocouple was used to measure the exhaust gas temperature.

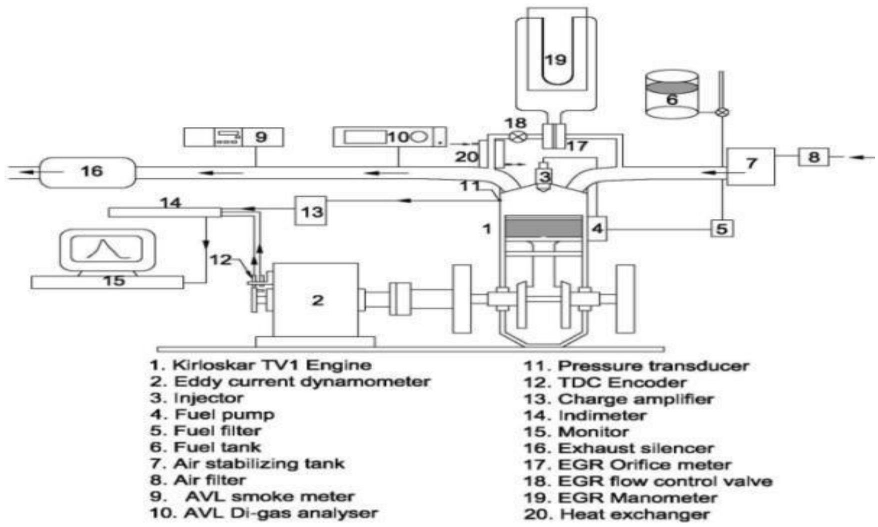


Fig – 1 Experimental Setup

Table -1 Specifications of the DI- Diesel Engine

S.No	Descriptions	Remarks
1.	Rated Horse power	7 hp (5.2 kW)
2.	Rated Speed	1500rpm
3.	No of Strokes	4
4.	No of Cylinders	1
5.	Stroke length	110 mm
6.	Bore	87.5 mm
7.	Compression ratio	16.5
8.	Orifice diameter	0.02 m
9.	Dynamometer arm length: 0.195 m	0.195 m
10.	Type of EGR	Hot EGR

EXPERIMENTAL PROCEDURE

Throughout the experimental stage, the engine runs continuously at 1500 rpm. Until the engine reaches the required warm-up time, it is left to run. Then different loads are applied, 20% to 100%, which correspond to the loads of 33.354 N, 67.689 N, 101.043 N, 135.378 N, and 169.713 N that were calculated. At each specific load condition, the engine maintains a constant speed of 1500 rpm while operating under specific EGR settings. To control the rate of EGR, a specialized system is implemented, comprising a control valve and a manometer setup that allows manual adjustment of EGR flow rates. Comprehensive data gathering begins as soon as a steady-state condition is reached, with an emphasis on important variables like fuel consumption, brake-specific fuel consumption, and exhaust gas temperature. Concurrently, an AVL gas analyzer is utilized to document exhaust emissions, encompassing CO, HC, CO2, and NOx, and an AVL smoke meter is worked to evaluate smoke density. The purpose of this experimentation is to evaluate the effects on engine performance and emissions of various fuel blends and EGR rates. The assessment is regularly carried out at 1500 rpm engine speed. In the first phase of the experiment, different loads with various EGR flow rates are applied to pure diesel fuel. To maximize combustion conditions, the Air Preheater's job is to warm up the intake air before it enters the engine's combustion chamber.

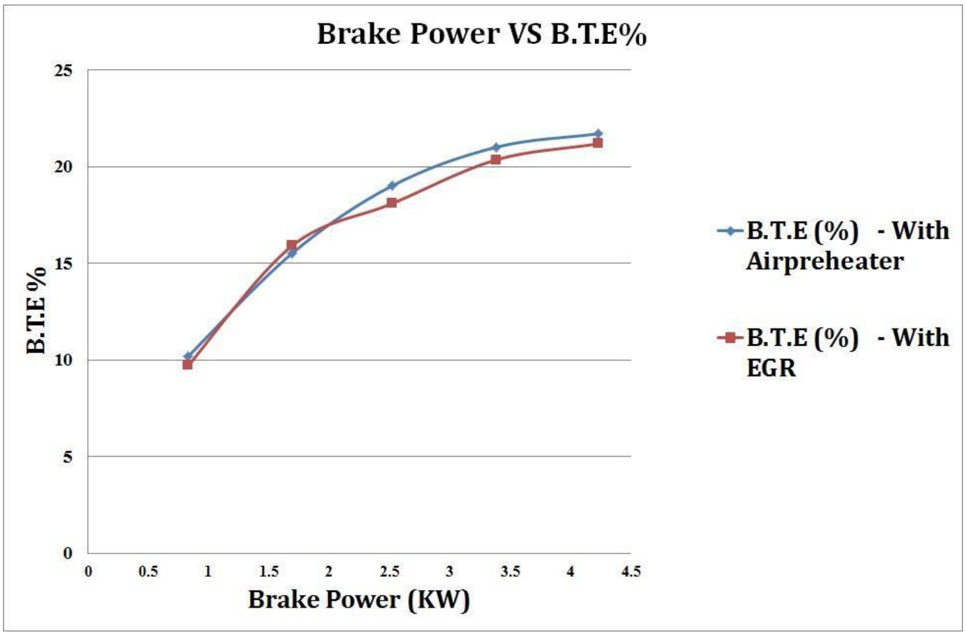
Now that the Air Preheater is installed, the engine is subjected to the same load conditions, which range from 20% to 100%, while maintaining a constant speed of 1500 rpm. This makes it possible to compare engine emissions and performance between EGR and air preheater installations. To evaluate the impact of this alteration on variables such exhaust gas temperature, fuel consumption, brake-specific fuel consumption, and exhaust emissions, extensive data collection is done, as it was in phase I. Overall, phase II of the experiment serves to uncover the distinct contributions of the Air Preheater to the engine's behavior and emissions, providing valuable insights into its potential as an emission-reduction and performance-enhancing technology for diesel engines.

RESULTS AND DISCUSSIONS

The experimental results demonstrated the effectiveness of EGR and Air Preheater in reducing NOx emissions. The combination of these techniques showed a significant reduction in NOx emissions, with EGR being the more effective method. Additionally, the combined use of EGR and Air Preheater also resulted in lower emissions of Carbon Dioxide (CO2) and Hydrocarbons (HC). In terms of smoke density, the combination of EGR and Air Preheater resulted in improved smoke emissions. This can be attributed to the lower combustion temperatures achieved through the use of EGR, resulting in cleaner and more efficient combustion. A four-stroke, single-cylinder diesel engine fitted with an air preheater and exhaust gas recirculation (EGR) was used for the experimental inquiry. The engine was run continuously at 1500 rpm under a range of load scenarios. The purpose of this extensive study was to evaluate how the Air Preheater and EGR affected engine performance metrics such as braking thermal efficiency and particular fuel consumption. The examination also examined the characteristics of the emissions, with a particular emphasis on the concentration of NOx, smoke density, and HC emissions in the tailpipe emissions. Notably, there was a noticeable rise in exhaust smoke emissions when the engine was run with EGR. There was a clear relationship between engine load and EGR rates and the amount of smoke emissions. This phenomenon can be explained by the EGR's reduction of the amount of oxygen accessible to the combustion process, which leads to a comparatively incomplete combustion and more particulate matter (PM) generation. Interestingly, EGR decreased NOx emissions from the diesel engine while simultaneously contributing to greater smoke emissions This investigation sheds light on the intricate balance between emission characteristics and engine performance parameters, offering valuable insights into the trade-offs associated with the use of EGR and the Air Preheater in diesel engines.

Brake thermal efficiency

The exhaust gas recirculation (EGR), braking power, and brake thermal efficiency (BTE) of an automobile at various engine speeds are displayed on the graph. The BTE is the proportion of engine power that is converted to brake power, whereas brake power is the power that is available at the brake disc. The BTE can be increased by using the EGR system, which recycles a portion of the exhaust gases back into the engine. The graph shows that the brake power increases with the engine speed, while the BTE decreases. This is because the engine is working harder at higher speeds, which produces moreheat and reduces the BTE. By lowering the quantity of heat wasted from the engine, the EGR can assist in raising the BTE. The graph also mentions that the BTE with air preheater is higher than the BTE without air preheater. This is because the air preheater helps to heat the air intake, which makes it easier forthe fuel to burn and increases the BTE. Overall, the graph shows that the brake power, BTE, and EGR are all interrelated. Thebrake power increases with the engine speed, while the BTE decreases. The EGR can help to improve the BTE, and the air preheater can further improve the BTE.

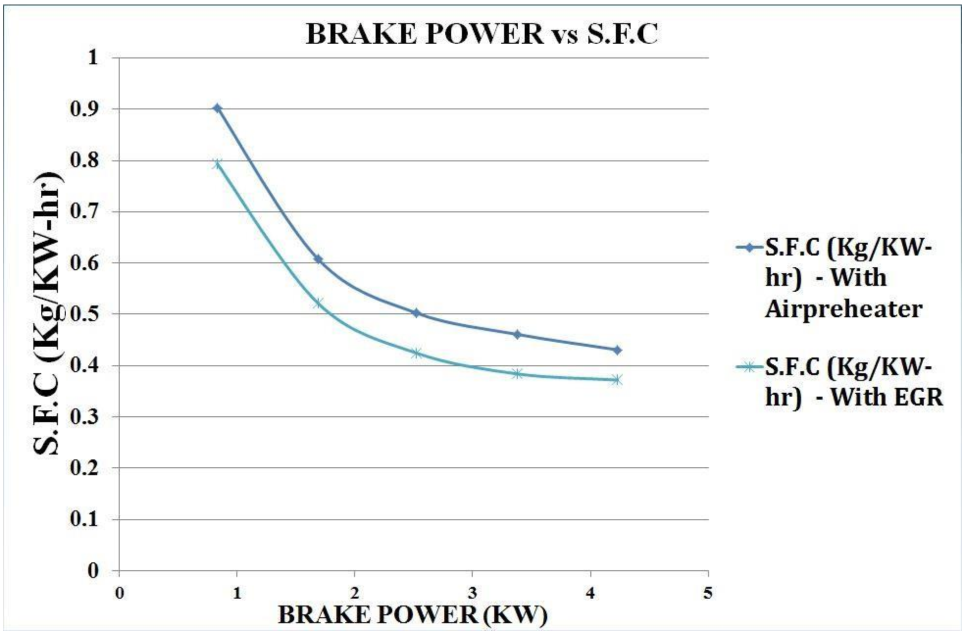


Specific fuel consumption (SFC)

The graph displays an automobile's specific fuel consumption (SFC) at various brake powers both with and without an exhaust gas recirculation system (EGR) and air preheater. The fuel consumption per unit of power output is known as the SFC.As expected given that the engine operates more efficiently at lower power outputs, the graph indicates that the SFC declines with braking power. By lowering the quantity of fuel required to generate a specific amount of power, the air preheater and EGR can both contribute to an improvement in the SFC. By heating the air intake, the air preheater facilitates easier fuel burning and lowers the required fuel quantity. Recirculating a portion of the exhaust gases back into the engine lowers the temperature at which fuel is needed for combustion and is made possible by the EGR. Overall, the graph shows that the air preheater and EGR can both be used to improve the SFC of a car. The air preheater is more effective at low brake powers, while the EGR is more effective

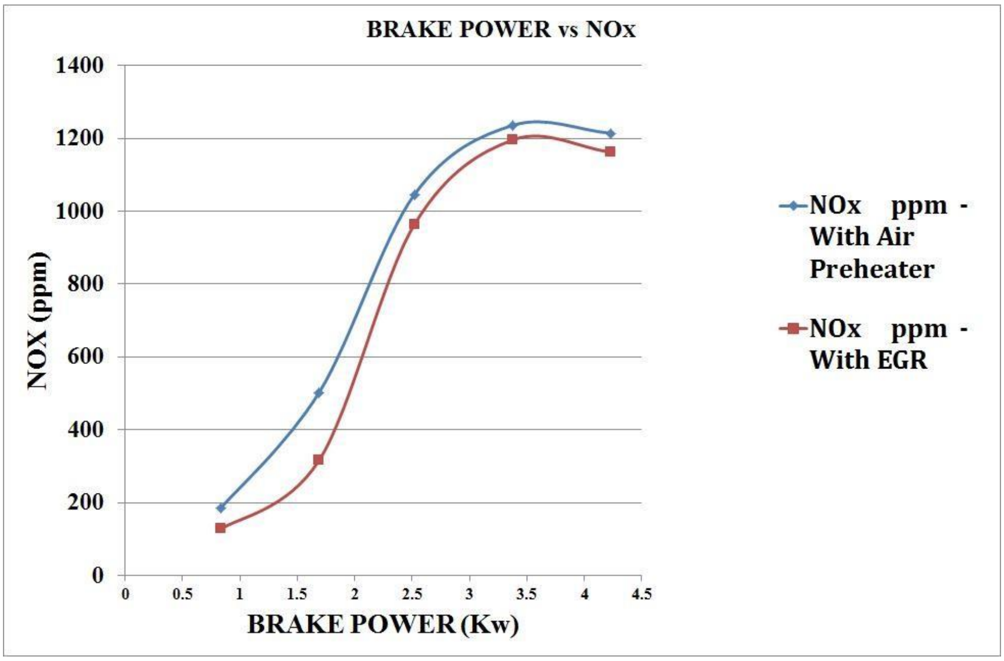
 ISSN: 2278-4632
Vol-14, Issue-2, No.02, February: 2024

at high brake powers.



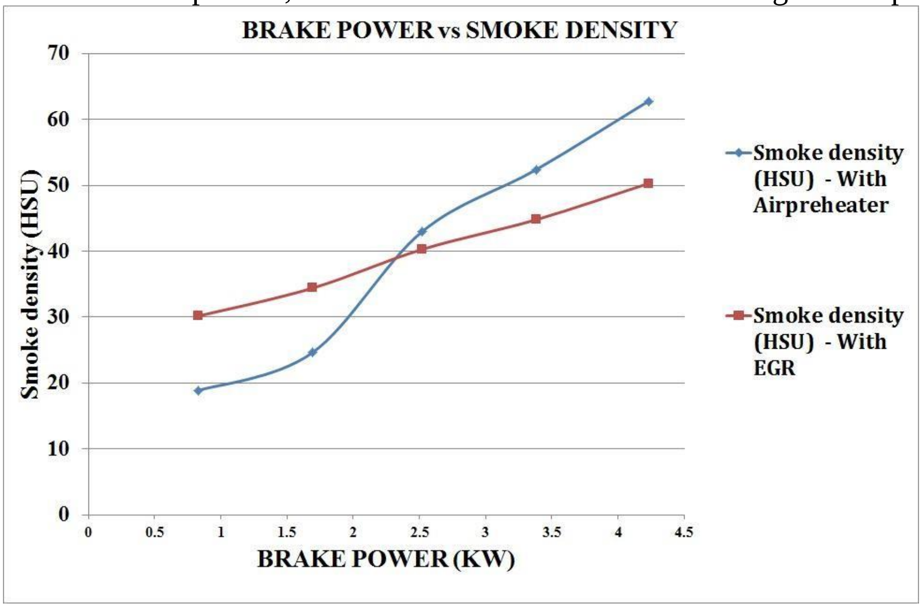
Nitrogen Oxides emission (NOx)

The brake power and NOx emissions of an automobile with and without an air preheater are displayed in the table. The brake power is the power available at the brake disc, while NOx is a harmful pollutant emitted by diesel engines. The brake power rises as NOx emissions do, as the table illustrates. This is becausethe engine is working harder to produce more power, which produces more NOx emissions. The air preheater can help to reduce the NOx emissions by preheating the air intake, which makes it easier for the fuel to burn and reduces the combustion temperature. The table additionally demonstrates that EGR reduces NOx emissions. By returning a portion of the exhaust gases into the engine, the EGR system lowers the combustion temperature and NOx emissions. The table indicates a general relationship between the air preheater, NOx emissions, and brake power. Brake power rises in proportion to NOx emissions, but the air preheater can help to reduce the NOx emissions. EGR can also help to reduce the NOx emissions.



Smoke density (HSU)

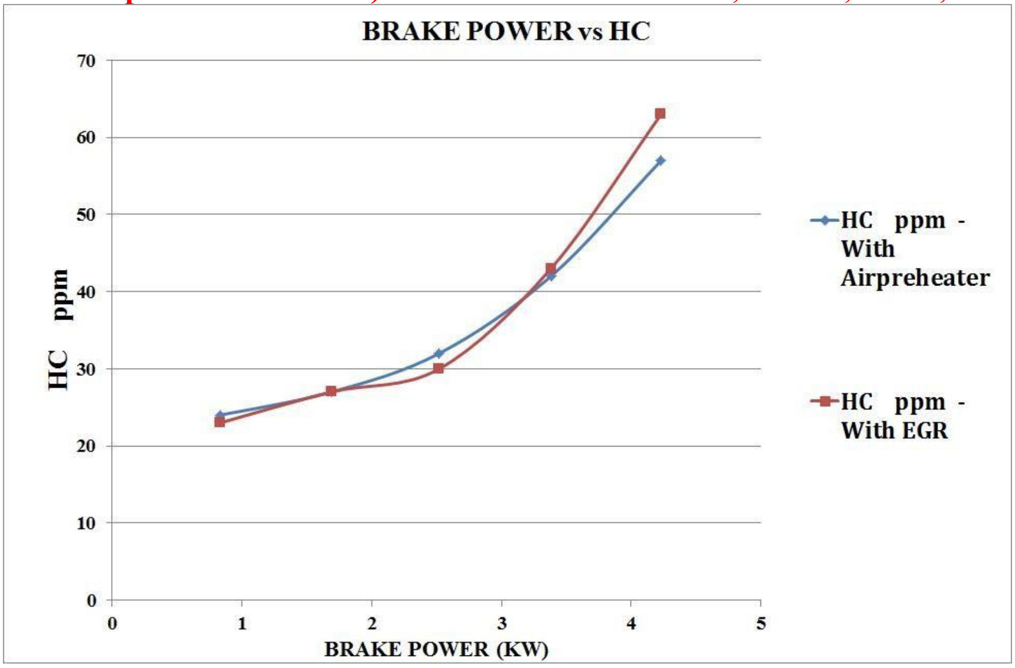
The graph shows the smoke density of a diesel engine at different brake powers with and without an air preheater and EGR. Smoke density is a measure of the opacity of exhaust fumes, and it is an indicator of the amount of pollutants emitted by the engine. The graph shows that the smoke density decreases with the brake power, which is expected as the engine is more efficient at lower power outputs. Because they lessen the quantity of pollutants the engine emits, the air preheater and EGR can both aid in lowering the smoke density. The air preheater works by heating the air intake, which makes it easier for the fuel to burn and reduces the amount of pollutants that are emitted. Recirculating a portion of the exhaust gases back into the engine lowers the temperature at which pollutants burn and lessens their emission. This is how the EGR operates. Overall, the graph demonstrates that a diesel engine's smoke density may be decreased using both the air preheater and the EGR. The air preheater is more efficient at low brake powers, whilethe EGR is more effective at high brake powers.



Hydrocarbon emission (HC)

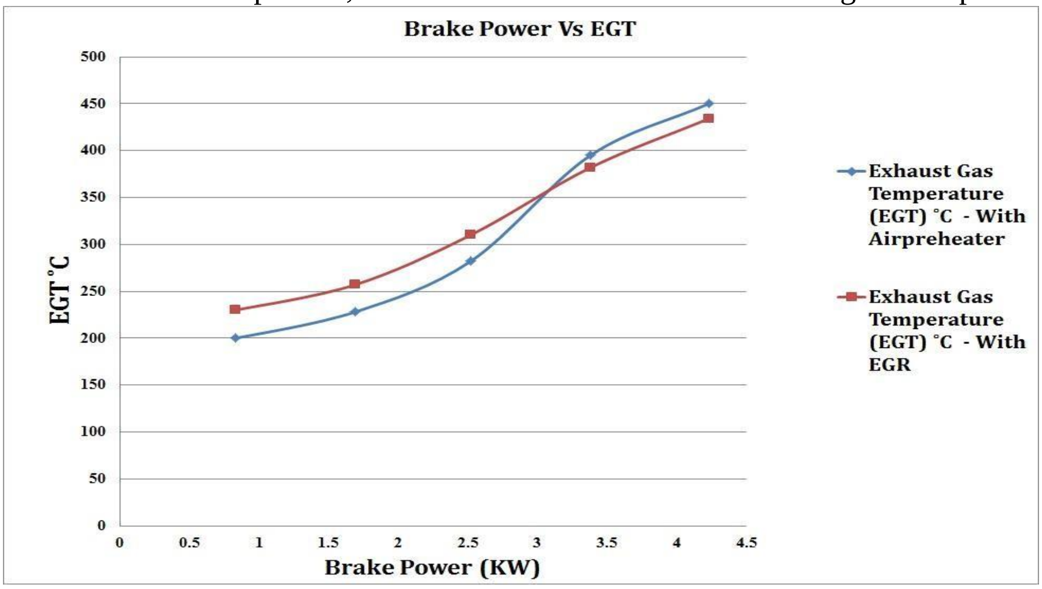
The graph displays a diesel engine's brake power, exhaust gas recirculation (EGR), and hydrocarbon (HC) emissions at various engine speeds. The brake power is the power available at the brake disc, while HC emissions are a type of air pollutant emitted by diesel engines. The graph shows that the brake power increases with the engine speed, while the HC emissions decrease. This is because the engine is working harder at higher speeds, which produces more heat and reduces the HC emissions. By lowering the oxygen content of the combustion chamber, the EGR can help reduce hydrocarbon emissions by making it harder for the fuel to burn and resulting in lower hydrocarbon emissions. The graph also shows that the HC emissions are lower with air preheater. Air preheater is a device that heats the air intake before it enters the engine, which makes it easier for the fuel to burnand reduces the HC emissions. Overall, the graph shows that the brake power, HC emissions, and EGR are all interrelated. The brake power increases with the engine speed, while the HC emissions decrease. The EGR can help to improve the HC emissions, and the air preheater can further improve the HC emissions.

 ISSN: 2278-4632
Vol-14, Issue-2, No.02, February: 2024



Temperature of Exhaust Gas

The graph displays a diesel engine's brake power, exhaust gas temperature (EGT), air preheater, and exhaust gas temperature at various brake powers both with and without exhaust gas recirculation (EGR). The brake disc's available power is known as brake power, while the exhaust gasses' temperature is known as EGT. The graph shows that the brake power increases with the EGT, which is expected as the engine is working harder to produce more power. By lowering the quantity of heat the engine produces, the air preheater and EGR can both aid in lowering the EGT. The air preheater works by heating the air intake, which makes it easier for the fuel to burn and reduces the amount of heat that is produced. Recirculating a portion of the exhaust gases back into the engine lowers the temperature at which combustion occurs and consequently the quantity of heat generated. This is how the EGR operates. In order to lower the combustion temperature and the amount of heat produced, the EGR functions by returning a portion of the exhaust gases back into the engine. The air preheater is more efficient at low brake powers, while the EGR is more effective at high brake powers.



CONCLUSION

In conclusion, this research has shown that the implementation of EGR and Air Preheater in conjunction with a single-cylinder, four-stroke, water-cooled, direct- injection diesel engine can effectively mitigate NOx emissions. The combination of these techniques resulted in a significant reduction in NOx emissions, along with improvements in emissions of CO2 and HC. Additionally, the use of EGR and Air Preheater improved the smoke density of the engine. Further research and optimization of these approaches can lead to further improvements in diesel engine emissions, contributing to cleaner and more sustainable transportation. The findings demonstrate the interdependence of the brake thermal efficiency (BTE), specific fuel consumption (SFC), smoke density (HSU), hydrocarbon emission (HC), exhaust gas temperature (EGT), and oxides of nitrogen emission (NOx). The BTE and SFC decrease with increasing brake power, while the NOx, HSU, and HC emissions decrease with increasing brake power. The EGT increases with increasing brake power. Enhancing the BTE, SFC, NOx, HSU, and HC emissions while lowering the EGT is possible with the help of the air preheater and exhaust gas recirculation (EGR).The air preheater is more effectiveat low brake powers, while the EGR is more effective at high brake powers. In conclusion, the findings demonstrate that the EGR and air preheater are useful technologies for raising the efficiency and emissions of diesel engines. The specific benefits of each technology will depend on the operating conditions of the engine.

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