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Energy and Exergy Analysis of Low Capacity Diesel Engine at Varying Compression Ratio

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ABSTRACT : *The current experimental study aims to investigate the impact of compression ratio (CR) on the energy-exergy performance of a small diesel engine. The experiment involved adjusting the CR from 15:1 to 18:1 in increments of one, maintaining an injection pressure (IP) of 400 bar, an injection timing (IT) of* 21^0 *bTDC, a constant engine speed of 1500 rpm, and operating at 75% load. The energy analysis results show that an increase in CR leads to higher energy levels in the cooling water, exhaust gas, and energy efficiency, while reducing the energy intake from fuel and unaccounted energy losses. The exergy study shows that the exergy rate of cooling water, exhaust gas, and exergy efficiency all increase as the CR increases. Conversely, the exergy rate of fuel energy, entropy generation, and sustainability index all decrease with an increase in CR. The maximum energy and exergy values were observed at a greater CR of 18:1, with percentages of 23.26% and 22.50% respectively. The entropy generation was minimized and the sustainability index was maximized at a greater compression ratio (18:1), with values of 0.019 kW/K and 1.29, respectively.*

KEY WORDS *-VCR-type diesel engine, Energy- exergy analysis, Entropy generation and Sustainability index.*

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I. INTRODUCTION

For more than a century, IC engines have played a fundamental role in the automotive and power generation industries. Although alternative energy technologies have made significant progress, IC engines continue to be extensively utilized because of their high energy density, efficiency, and well-established infrastructure. In order to enhance their efficiency and minimize their ecological footprint, scientists have been placing greater emphasis on energy and exergy evaluations [1]. These evaluations offer extensive understanding of the engine's thermodynamic processes, identifying inefficiencies and potential opportunities for enhancement.

Rakopoulos et al. [2] emphasize that a significant amount of fuel energy is wasted as heat through the discharge of exhaust gases and engine cooling systems. Efforts have been made to reduce these losses by exploring strategies like insulating coatings and sophisticated cooling technology. Moran and Shapiro [3] highlight that combustion irreversibilities play a crucial role in the degradation of exergy. Exergy analysis aids in comprehending the capacity for enhancing combustion efficiency by reducing these irreversible processes. Ghadikolaei et al. [4] examined the impact of homogeneous charge compression ignition (HCCI) and observed significant decreases in exergy destruction in comparison to traditional combustion techniques. HCCI results in a more consistent combustion process, resulting in decreased maximum temperatures and reduced inefficiencies. Lounici et al. [5] conducted a study on dual-fuel engines that use both natural gas and diesel. They showed that by using exergy analysis, it is possible to determine the best operating parameters that reduce exergy destruction and retain high energy efficiency.

Khoshbakhti Saray et al. [6] investigated how different compression ratios affect energy and exergy efficiency. Their research suggests that by optimizing the compression ratio, it is possible to greatly decrease exergy losses, hence improving the overall performance of the engine. Rakopoulos et al. [7] investigate the phenomenon of entropy formation in internal combustion engines. Through the correlation between entropy formation and exergy destruction, researchers can gain a deeper understanding of the processes by which energy is degraded and devise effective solutions to minimize these losses. The study conducted by Sayin et al. [8] demonstrates that by optimizing engine parameters to minimize exergy destruction, it is possible to concurrently decrease the levels of harmful emissions.

The literature review reveals that energy and exergy performance of an engine depends on the CR. It was also found that there is lack of literature showing the effect of CR on energy and exergy analysis of low capacity diesel engine at higher injection pressure of 400 bar. This experiment work has been conducted to study the effect of CR on energy and exergy analysis of a low capacity diesel engine at IP of 400 bar, IT of 21^0 bTDC, fixed engine speed of 1500 rpm, and 75% load condition.

II. EXPERIMENT METHODOLOGY

2.1 Experiment Setup

The experiment has been conducted on single cylinder diesel engine having power output of 3.5 kW at 1500 rpm. Diesel engine was VCR type, water cooled, and connected with the eddy current type dynamometer. The setup was provided with the stand alone control panel with fuel tank and air box. This control panel also equipped with the fuel flow and air flow transmitter to measure the flow rate of air and fuel supplied to the engine. Rota-meters are provided to measure the flow of cooling water supplied to the engine and calorimeter. Thermocouples RTD-PT-100 and K-type were fitted to measure the temperature of the cooling water and the exhaust gas. The actual schematic of setup shown in Fig.1.

Fig.1.Experiment Setup

2.2 Uncertainty analysis

Uncertainty analysis involves assessing the potential variability in the output of a model or system due to uncertainties in its inputs. This process is crucial in many fields, including engineering and environmental science, to ensure that decisions are robust and well-informed. analysis is a powerful tool for enhancing the reliability and robustness of models and systems. By systematically identifying, quantifying, and analyzing uncertainties, decision-makers can better understand the risks and improve the quality of their decisions.

Uncertainty of experiment= Square root of ((Uncertainty of energy efficiency)^2+ (Uncertainty of exergy efficiency)^2 + (Uncertainty of heat loss)^2 +(Uncertainty of exhaust loss)2)$^{0.5}$
= ((1.4)2 + (1.4)2 + (0.01)2 + (2.383)2) 0.5
=±3.05 %

III. RESULT AND DISCUSSION

3.1 Energy Analysis

Conducting an energy analysis of IC engines is essential for understanding and optimizing their performance, efficiency, and environmental impact. This analysis helps engineers and researchers develop better engines and technologies that meet the evolving demands of the automotive industry and regulatory frameworks.

3.1.1 Input Energy

The energy supplied to the engine is a product of the mass flow rate of the fuel supplies and the lower calorific value of the fuel.

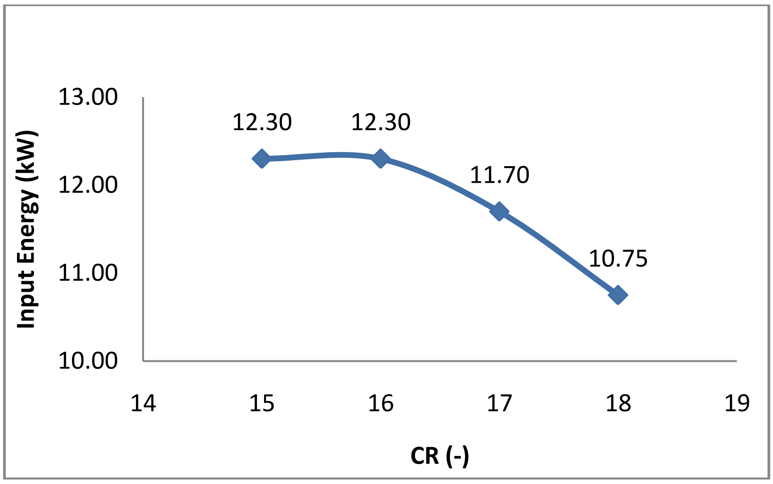

Fig.2. Change in input energy energy with CR

It was noted from the Fig.2. that an increase in CR results in a decrease in input energy. The minimum input energy recorded for the diesel was 10.75 kW at a higher CR of 18:1, which was 12.60% lower than the input energy recorded at a lower compression ratio of 15:1. The reason for this is that an increase in CR results in a decrease in the amount of fuel consumed to produce a given amount of power output. This is because an increase in CR reduces the time it takes for the fuel to ignite, hence improving the efficiency of combustion [9]. A greater compression ratio results in a more compacted air-fuel mixture prior to ignition. By compressing the mixture, the temperature and pressure are elevated, resulting in enhanced combustion efficiency upon ignition of the fuel. Greater efficiency in combustion leads to higher energy extraction from the fuel, resulting in an augmented power output.

3.1.2 Cooling Water Energy

Cooling water energy in the context of an IC engine pertains to the quantity of thermal energy that is assimilated and transported by the engine's cooling system to sustain ideal operating temperatures and avert overheating.

The heat transfer from the engine to the coolant is determined by considering the mass flow rate of the coolant and the temperature difference between the coolant entering and exiting the engine.

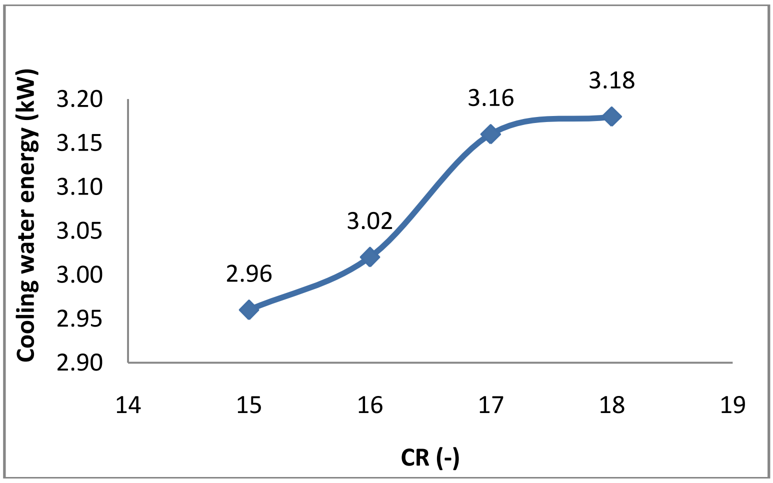

Fig.3. Change in cooling water energy with CR

Fig.3. illustrates the relationship between cooling water energy and CR for a CRDI diesel engine running on diesel fuel. The results show that the largest amount of cooling water energy was reported at a CR of 18:1, and it measured 3.18 kW. The discrepancy in cooling water energy between the stated values at

compression ratios of 18:1 and 15:1 was 0.22 kW. A larger compression ratio results in more compression of the air-fuel combination, which in turn leads to elevated temperatures during combustion. The rise in temperature is a result of the greater energy release that occurs throughout the process of combustion. As the combustion temperature increases, the cooling system must also dissipate a greater amount of heat. The extra heat load causes the cooling water temperature to rise [10].

3.1.3 Exhaust Gas Energy

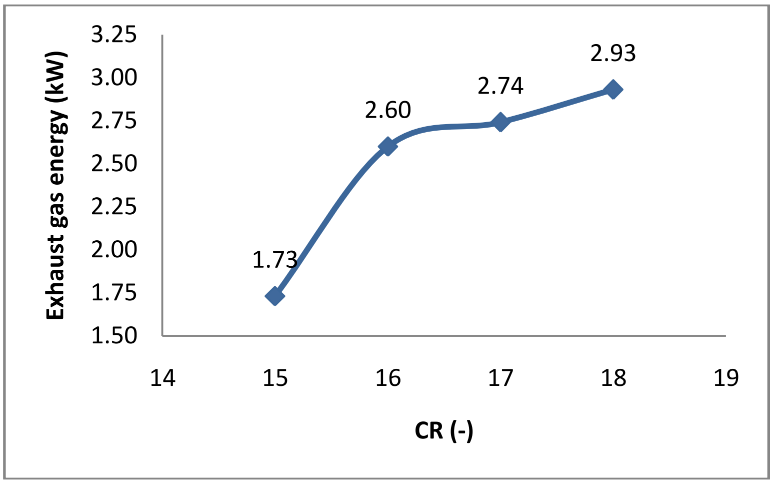

Fig.4. Change in exhaust gas energy with CR

Fig.4. shows the change in exhaust gas energy with CR for CRDI type diesel engine fueled with the diesel. The results indicate that exhaust gas energy incresases with increase in CR and minimum exhaust gas energy reported was 2.93 kW at higher CR of 18:1. The difference between the exhaust gas energy reported at CR of 15:1 and 18:1 was 1.20 kW. This is due to fact that at higher CR the mean temperature and pressure of the gases inside the cylinder increases which leading to higher temperatures of the exhaust gases [11].

3.1.4 Unaccounted Energy Losses

Unaccounted losses in an internal combustion engine mostly stem from combustion inefficiencies, frictional losses, auxiliary power usage, and fundamental thermodynamic limitations.

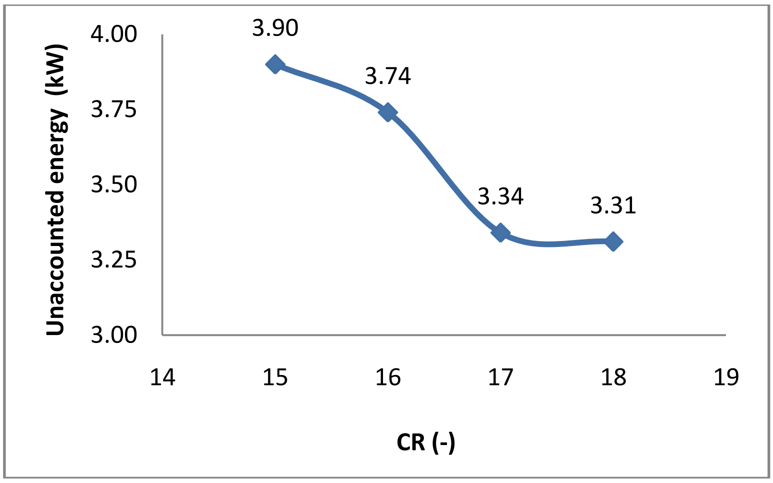

Fig.5. Change in cooling water energy with CR

Fig.5. illustrates the relationship between unaccounted energy and CR for a diesel engine of the CRDI type, which is fueled by diesel. The outcome suggests that the amount of unaccounted energy decreases as the CR increases. The least unaccounted energy recorded was 3.31 kW at a CR of 18:1, which was 0.59 kW lower than the unaccounted energy recorded at a lower CR of 15:1. This phenomenon is mostly attributed to the enhancement of combustion efficiency at greater compression ratios. An increase in the compression ratio (CR) reduces the ignition delay and enhances the available response time and efficiency [12].

3.1.5 Energy Efficiency

The ratio of the engine's brake power—or useful power output at the crankshaft—to the fuel-input energy is known as energy efficiency.

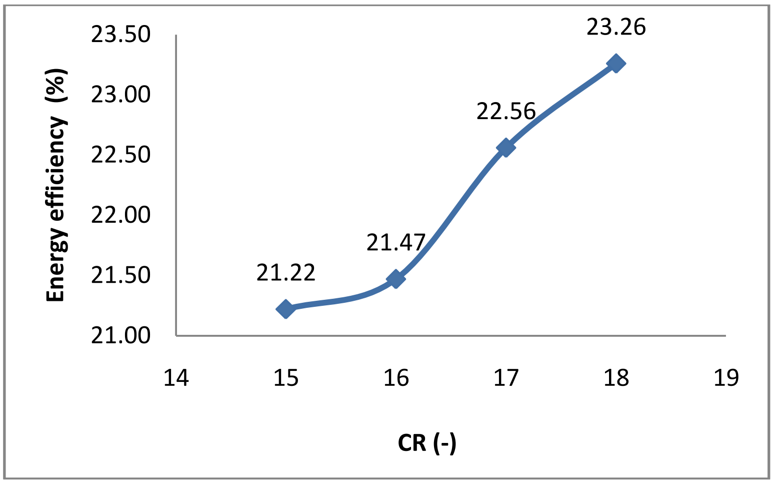

Fig.6. Change in cooling water energy with CR

Fig.6. illustrates the relationship between energy efficiency and CR for a diesel engine. The data shows that there is a positive correlation between energy efficiency and CR, with the best efficiency of 23.26% being achieved at a CR of 18:1.As previously mentioned in the section on inlet energy, an increase in CR results in a decrease in fuel consumption required to achieve a certain power output. Furthermore, it was noted that as the CR increases, there is a decrease in unaccounted losses and combustion irreversibility [13].

3.2 Exergy analysis

An exergy analysis of an internal combustion engine offers a thorough comprehension of its thermodynamic efficiency by considering both the quality of energy and the presence of irreversibilities. Through the assessment of the exergy of the fuel, exhaust gases, cooling water, and mechanical work, it becomes feasible to pinpoint specific locations where efficiency can be enhanced and energy losses can be minimized. This approach provides useful insights for optimizing engine design and operation to enhance performance and reduce environmental impact.

3.2.1 Available Input Energy

The fuel exergy rate is calculated by multiplying the fuel inflow energy with the chemical exergy factor. The fuel exergy is consistently greater than the fuel inflow energy due to the chemical exergy factor always being greater than one.The chemical exergy of a fuel refers to the greatest possible work that can be obtained when the fuel is brought into equilibrium with the surrounding environment. This encompasses both the heat energy emitted during the process of burning and the stored energy potential of the fuel.

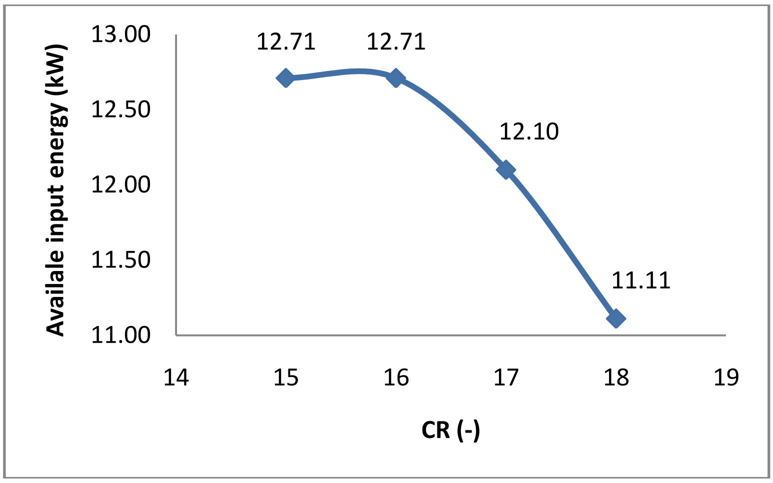

Fig.7. Change in available input energy with CR

The transformation of the fuel exergy for a diesel engine as a function of CR is depicted in Fig.7. It demonstrates that the fuel exergy declines as the CR increases, with a minimum fuel exergy of 11.11 kW being measured at a CR of 18:1. When the CR is higher, the amount of fuel that is required to produce one unit of power is decreased, and as a result, the fuel exergy rate is also decreased [14]. This was addressed in the section on fuel inlet energy.

3.2.2 Available Energy in Cooling Water

In order to protect the engine from overheating, the cooling water takes in heat from the engine. There exists a correlation between the temperature difference between the cooling water and the surroundings and the exergy that the cooling water possesses.

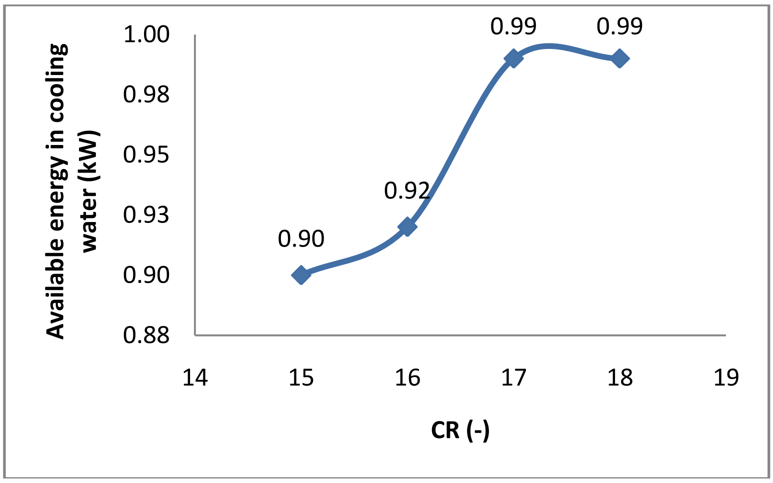

Fig.8. Change in available cooling water energy with CR

Fig.8. shows that the available energy in the cooling water increases with increase in CR and maximum available energy of cooling water reported at higher CR of 18:1.The minimum recorded cooling water energy was 0.90 kW with a compression ratio of 15:1. The discrepancy in cooling water energy between the highest and lowest values reported at compression ratios of 15:1 and 18:1 was 0.09 kW. The exergy of the cooling water is contingent upon the disparity in temperature between the cooling water and the surrounding environment. Elevated temperatures in the cooling water, resulting from enhanced heat transfer, amplify this temperature disparity, thereby augmenting the exergy content of the cooling water [15].

3.2.3 Available Energy in Exhaust

The exhaust gases possess both physical and chemical exergy. The physical exergy following combustion is a result of the elevated temperature and pressure of the exhaust gases, whereas the chemical exergy originates from incomplete combustion byproducts such as carbon monoxide (CO), unburnt hydrocarbons, and other reactive substances.

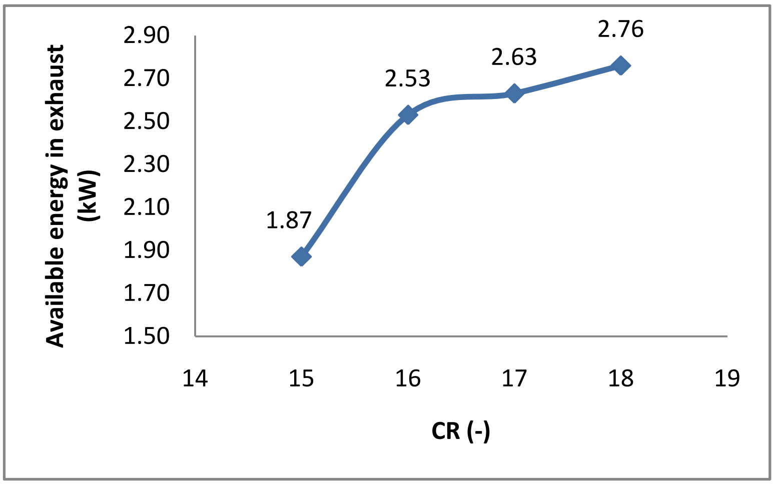

Fig.9. Change in available exhaust gas energy with CR

Fig.9. illustrates that an increase in CR results in an increase in the amount of energy available in the exhaust gas. The minimum reported exhaust gas exergy was 1.87 kW at a CR of 15:1, while the maximum reported exhaust gas exergy was 2.76 kW with a CR of 18:1. The exergy of the exhaust gases is influenced by their temperature and pressure in relation to the surrounding environment. This may be attributed to the fact that with greater compression ratios, the combustion temperatures rise as a result of improved combustion efficiency, leading to an increase in the thermal exergy of the exhaust gases [16]. Moreover, the increased pressure can enhance the mechanical exergy when effectively utilized, such as by employing turbo charging.

3.2.4 Destructed Available Energy

The destructed available energy of an internal combustion engine refers to the exergy that is not transformed into productive work or recoverable energy as a result of inefficiencies and irreversibilities in the system. Engineers can optimize engine efficiency and reduce energy waste by using exergy analysis to detect and quantify losses, allowing them to focus on particular areas for improvement.

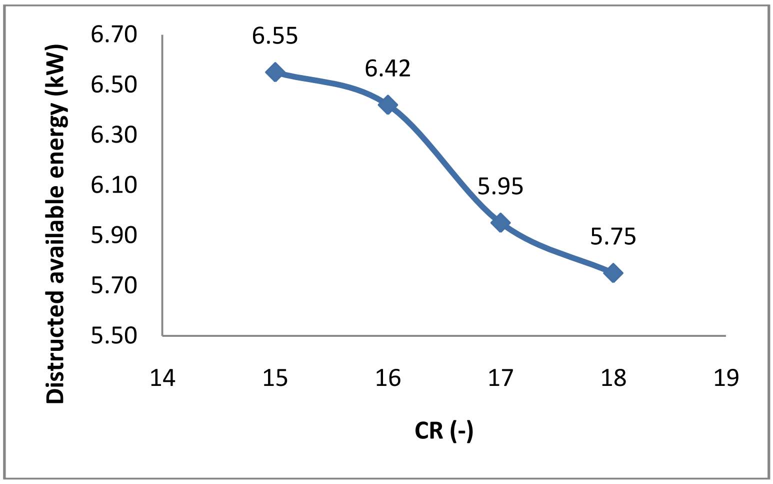

Fig.10. Change in destructed available energy with CR

Fig.10. demonstrates that the rate of exergy drop of the destroyed energy is inversely proportional to the rise in CR. The lowest dissipation of usable energy recorded at the higher CR of 18:1 was 5.75 kW. The discrepancy in the maximum and minimum dissipated energy, as reported at compression ratios of 15:1 and 18:1, was 0.80 kW. The improvement in thermal efficiency at higher CR leads to a reduction in exergy destruction by transforming a greater portion of the chemical exergy of the fuel into mechanical effort [17].

3.2.5 Exergy Efficiency

The exergy efficiency of an internal combustion engine quantifies the engine's ability to transform the available exergy, which represents the potential for useful work, from the fuel into actual useful work. Exergy efficiency is a measure that evaluates both the amount and the usefulness of energy, while also accounting for the principles of the second law of thermodynamics and the inefficiencies inside the system.

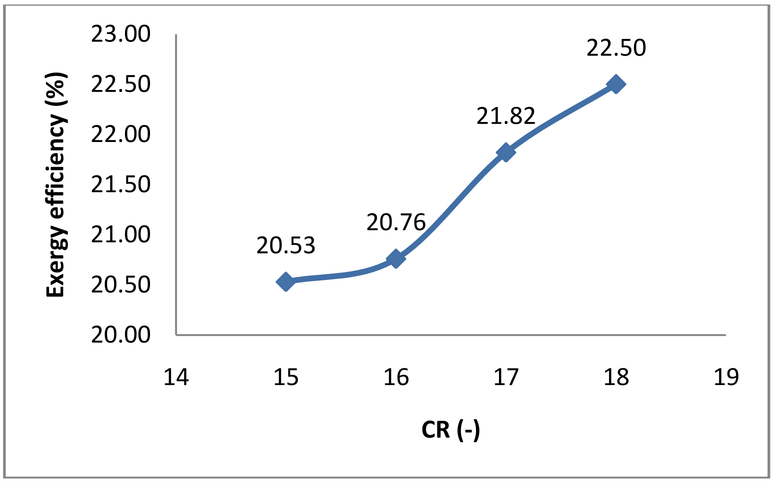

Fig.11. Change in exergy efficiency with CR

Fig.11. demonstrates that an increase in CR leads to an improvement in the exergy efficiency of an engine. The exergy efficiency reached its peak at 22.50 % when the CR was set at 18:1.The increase in CR leads to higher peak temperatures, which in turn can cause increased heat transfer losses and thermal irreversibilities. However, despite these losses, the overall improvement in combustion and thermal efficiency usually surpasses them, resulting in a net gain in exergy efficiency [18].

3.2.6 Entropy Generation

Entropy generation in an internal combustion engine is the phenomenon where the level of thermodynamic disorder or unpredictability, known as entropy, grows during the engine's operation. The primary cause of this increase in entropy is the presence of irreversibilities and inefficiencies in different processes occurring within the engine.

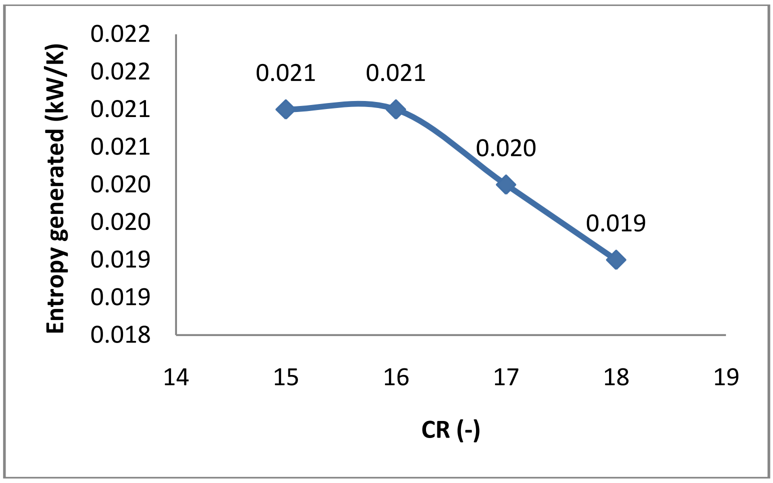

Fig.12. Change in entropy generation with CR

Fig.12. illustrates the relationship between the entropy generation and the CR for a diesel engine. According to the report, a decrease in entropy creation occurs when the CR is increased and minimum entropy generation reported was 0.019 kW/K at higher CR of 18:1. This may be attributed to the fact that larger compression ratios typically result in enhanced combustion and thermal efficiency [19].

3.2.6 Sustainability Index

The sustainability index of an IC engine offers a comprehensive evaluation of its performance, encompassing energy efficiency, environmental effect, resource use, economic viability, and social impact.

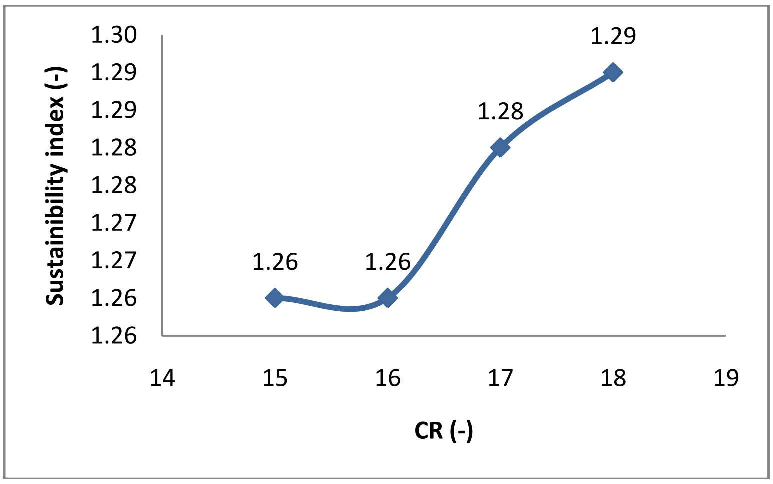

Fig.13. Change in SI with CR

Figure 13 illustrates the changes in the sustainability index at various compression ratios for a diesel engine with low capacity. The observation revealed that the Spark Ignition (SI) increases proportionally with the increase in Compression Ratio (CR). The highest SI value recorded for the diesel was 1.29, which occurred at the highest operational CR of 18:1. The reason for this is that the specific output (SI) is directly proportional to the exergy efficiency, which in turn increases as the compression ratio (CR) and spark ignition (SI) increase.

IV. CONCLUSION

The energy study revealed that the energy of the cooling water and exhaust gas increases as the compression ratio (CR) increases. The highest recorded energy values for the cooling water and exhaust gas were 3.18 and 2.93 kW, respectively, at a compression ratio of 18:1. The fuel inlet energy and unaccounted losses drop as the compression ratio (CR) increases. The minimal values for fuel inlet energy and unaccounted losses are recorded at a compression ratio of 18:1, with values of 10.75 kW and 3.31 kW, respectively. The best energy efficiency is observed at a greater compression ratio (CR) of 18:1, with a value of 23.26%.

The exergy analysis reveals that the exergy rate of the cooling water and exhaust gas rises as the compression ratio (CR) increases. The maximum recorded values for cooling water and exhaust gas exergy were 0.99 and 2.76 kW, respectively, at a CR of 18:1. The fuel inlet energy and available destructed energy drop as the compression ratio (CR) increases. The minimum values for fuel inlet energy and available destructed energy are provided for a compression ratio of 18:1, with values of 11.11 kW and 5.75 kW, respectively. The exergy efficiency reaches its peak with a compression ratio (CR) of 18:1, with a value of 22.50%. The minimal entropy generation and highest SI were reported with a compression ratio (CR) of 18:1, with values of 0.019 kW/K and 1.29,respectively.

The findings from the energy and exergy analysis demonstrate that operating the engine at a greater compression ratio (CR) of 18:1 is beneficial. This choice yields the maximum levels of energy efficiency, exergy efficiency, sustainability index, and minimizes entropy generation.

References

[1]. Heywood, J. B. (1988). Internal Combustion Engine Fundamentals. McGraw-Hill.

[2]. Rakopoulos, C. D., Giakoumis, E. G. (2004). Second-law analyses applied to internal combustion engines operation. Progress in Energy and Combustion Science, 30(5), 353-381.

[3]. Moran, M. J., Shapiro, H. N. (2000). Fundamentals of Engineering Thermodynamics. John Wiley & Sons.

[4]. Ghadikolaei, M. A., Hosseini, S. H., Ghobadian, B. (2019). Exergy analysis of HCCI engines: A comprehensive review. Energy, 166, 445-462.

[5]. Lounici, M. S., Loubar, K., Niculescu, D. C., Tazerout, M. (2014). Towards the improvement of natural gas-diesel dual-fuel mode: An experimental investigation on performance and exhaust emissions. Energy, 64, 200-211.

[6]. Khoshbakhti, Saray, R., Tazerout, M., Loubar, K. (2016). Exergy analysis of a variable compression ratio engine operating on hydrogen and natural gas blends. International Journal of Hydrogen Energy, 41(4), 3081-3092.

[7]. Rakopoulos, C. D., Giakoumis, E. G. (2006). Diesel Engine Transient Operation: Principles of Operation and Simulation Analysis. Springer.

[8]. Saylin.C., Kilicaslan, I., Canakci, M. (2007). The influence of operating parameters on the performance and emissions of a DI diesel engine fueled with diesel–methanol blends. Fuel, 86(7-8) 1007-1013.

[9]. V. Hariram and R. Vagesh Shangar, “Influence of compression ratio on combustion and performance characteristics of direct injection compression ignition engine,” Alexandria Eng. J., vol. 54, no. 4, pp. 807–814, 2015.

[10]. Gnanamoorthi, V., & Devaradjane, G. (2015). Effect of compression ratio on the performance, combustion and emission of DI diesel engine fueled with ethanol–Diesel blend. Journal of the Energy Institute, 88(1), 19-26.

[11]. Verma, S., Das, L. M., & Kaushik, S. C. (2017). Effects of varying composition of biogas on performance and emission characteristics of compression ignition engine using exergy analysis. Energy conversion and management, 138, 346-359.

[12]. Bridjesh, P., & Arunkumar, G. (2015). Energy and exergy analysis of diesel engine by varying compression ratio. Int J Chem Sci, 13(2), 997-1013.

[13]. Bhatti, S. S., Verma, S., & Tyagi, S. K. (2019). Energy and exergy based performance evaluation of variable compression ratio spark ignition engine based on experimental work. Thermal Science and Engineering Progress, 9, 332-339.

[14]. Wang, B., Pamminger, M., & Wallner, T. (2019). Impact of fuel and engine operating conditions on efficiency of a heavy duty truck engine running compression ignition mode using energy and exergy analysis. Applied energy, 254, 113645.

[15]. Yaman, H. (2022). Investigation of the effect of compression ratio on the energetic and exergetic performance of a CI engine operating with safflower oil methyl ester. Process Safety and Environmental Protection, 158, 607-624.

[16]. Chaudhari, S. G., Modi, M. A., Patel, T. M., & Rathod, G. P. (2016). Exergy Analysis of Compression Ignition Engine Using Biodiesel Blend: Effect of Compression Ratio and Injection Pressure. Exergy, 6(04).

[17]. Yesilyurt, M. K. (2020). The examination of a compression-ignition engine powered by peanut oil biodiesel and diesel fuel in terms of energetic and exergetic performance parameters. Fuel, 278, 118319.

[18]. Yao, Z. M., Qian, Z. Q., Li, R., & Hu, E. (2019). Energy efficiency analysis of marine high-powered medium-speed diesel engine base on energy balance and exergy. Energy, 176, 991-1006.

[19]. Ebrahimi, R., & Dehkordi, N. S. (2018). Effects of design and operating parameters on entropy generation of a dual cycle. Journal of Thermal Analysis and Calorimetry, 133, 1609-1616.

[20]. Leone, T. G., Anderson, J. E., Davis, R. S., Iqbal, A., Reese, R. A., Shelby, M. H., & Studzinski, W. M. (2015). The effect of compression ratio, fuel octane rating, and ethanol content on spark-ignition engine efficiency. Environmental science & technology, 49(18), 10778-10789.