energies

Article

Application of Miller Cycle and Net-Zero Fuel(s) to Diesel Engine: Effect on the Performance and NOx Emissions of a Single-Cylinder Engine

Motong Yang and Yaodong Wang *

Department of Engineering, Durham University, Durham DH1 3LE, UK
* Correspondence: yaodong.wang@durham.ac.uk

Abstract: Diesel engines play a very significant role in the automotive industry, but the total emissions of diesel engines are more than 1.8 times that of petrol engines. It is therefore important for diesel engines to control emissions. Theoretically, the Miller cycle can be used to achieve NOx reductions by changing the effective compression ratio, while it has become increasingly popular in recent years with the increasing maturity of current turbocharging technology. Based on Ricardo WAVE software, this paper analyses the NOx emissions and engine performance of diesel engines by modelling and simulating their operation under different loads with two types of Miller cycles (EIVC and LIVC) at different degrees. Simulation of engines operating under different loads allows a more comprehensive study of the effects of the Miller cycle on the engine, and a specific analysis in the context of the actual engine operating environment. The result is that both versions of the Miller cycle are most effective in reducing NOx emissions at 10% load, showing a maximum reduction of 21% for EIVC and 37% for LIVC. However, as the Miller cycle decreases engine power, the paper further investigates the application of turbocharger systems in the EIVC Miller cycle, with results showing a 32% increase in brake power at 10% load and −25% EIVC Miller cycle degree. Both ethanol-fueled diesel-cycle and Miller cycle engines were also analyzed, and a reduction in NOx emissions was observed, as well as hydrogen engine performance and NOx emissions.

Keywords: Miller cycle; NOx emission; hydrogen; ethanol; engine performance

check for updates

Citation: Yang, M.; Wang, Y. Application of Miller Cycle and Net-Zero Fuel(s) to Diesel Engine: Effect on the Performance and NOx Emissions of a Single-Cylinder Engine. *Energies* **2023**, *16*, 2488. https://doi.org/10.3390/en16052488

Academic Editor: Dimitrios C. Rakopoulos

Received: 28 January 2023
Revised: 20 February 2023
Accepted: 26 February 2023
Published: 6 March 2023

1. Introduction

Due to its large torque and good economic performance, diesel engines are widely used and have become a significant source of power. They facilitate people's lives and brings huge economic benefits, but at the same time diesel engines also cause certain damage to the environment. Nitrogen oxides (NOx), as one of the harmful emissions of diesel engines, are driven by the following factors: combustion temperature, high temperature duration, oxygen concentration during combustion, of which the maximum combustion temperature is the most critical factor, if the maximum combustion temperature is reduced, then NOx emissions will decline [1]. As environmental protection becomes one of the important themes around the world, many countries have enacted increasingly stringent fuel consumption regulations. In early December 2020, the UK government announced a new target to tackle climate change by reducing the UK's greenhouse gas emissions by 68% over ten years, from 1990 levels. Meanwhile, with the increasing depletion of oil resources in the world today, using replaceable renewable energy sources has become one of the main directions in the development of internal combustion engines. The world energy structure is gradually diversifying from a single type of energy due to the increasing scarcity of primary energy sources and the growing demand for them, as well as the growing awareness of energy and environmental conservation. It is therefore an urgent responsibility to overcome the current challenges facing diesel engines and to develop high efficiency, low emission, environmentally friendly engines to meet the growing demands of society [2].

Miller cycle can reduce the temperature and pressure at the end of the compression stroke, so that the combustion temperature and pressure in the cylinder are reduced, which is conducive to reducing NOx emissions on the one hand and can also reduce the thermal load and mechanical load on the diesel engine [3]. Traditional internal combustion (IC) engines generally use the Otto cycle and the Diesel cycle. In 1947, Ralph H Miller proposed a new engine cycle, the Miller cycle [4]. The purpose of the Miller cycle is to reduce the effective compression ratio of the engine by changing the closing time of the valve, which can affect the effective compression ratio of the cylinder during the entire combustion process and maximize the conversion of thermal energy into mechanical energy during the expansion stroke [4]. Achieving the effect that the expansion ratio is greater than the compression ratio can reduce the thermal load and mechanical load of the engine, obtain higher specific power output and lower fuel consumption, as well as achieve the purpose of reducing combustion temperature and exhaust gas temperature, thereby controlling NOx emissions [4].

There are two main operation methods to achieve the application of the Miller cycle on the engine: (1) The intake valve is closed before the end of the intake stroke (the piston reaches the bottom dead center), which is called early intake valve closing (EIVC, shown in Figure 1); (2) Close the intake valve after the start of the compression stroke, keep the intake valve open during the partial compression stroke, so that part of the mixed gas in the cylinder is discharged, and then close the intake valve, which is called late intake valve closing (LIVC, as shown in Figure 2) [5]. Figure 1 [5,6] is the P-V diagram of the standard Dual cycle (also called Diesel cycle) of the engine and the Miller cycle EIVC version, while Figure 2 [6] is a version of the Miller cycle LIVC. In these two figures, 0 is the starting point of work. The pressure in the cylinder is P_0, the volume is V0, and the standard Dual cycle cylinder displacement is V_c, and the Miller cycle cylinder displacement is V'_c. The Dual cycle work process is: 0-1 is the intake stroke, 1-2 is the compression stroke, the expansion stroke is 2-3-3′-4, and the exhaust stroke is 4-1-0. In this cycle, the compression and expansion ratios of the engine are equal. The Miller cycle EIVC version is the green line cycle, which is 0-1a-1′a-2a-3a- 3′a-4a-1-0 [6]. The working process of LIVC version is: 0-1a- 1-1a-2-3-3′-4-4a-1-1a-0 (process 1-1a is an additional mixed gas discharge process), as shown in Figure 2 [5]. Therefore, in the Miller cycle, due to the advance or delayed closing of the intake valve, there will be part of the gas that has entered the cylinder is expelled, leading to a shorter effective compression stroke, and a smaller effective compression ratio, the result is that the compression ratio is not equal to the expansion ratio. This is the main difference between the Miller cycle and the diesel cycle.

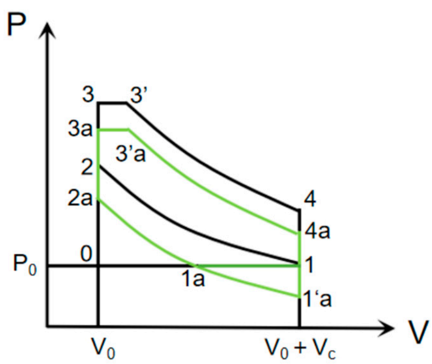

Figure 1. Dual cycle [5] and Miller cycle (EIVC) [6].

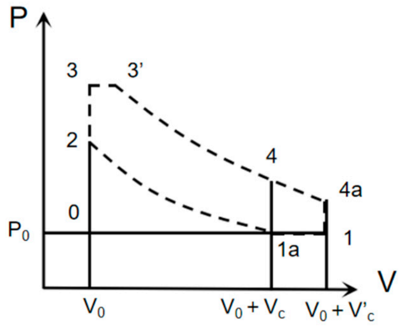

Figure 2. Miller cycle (LIVC) [5].

Although the Miller cycle has advantages in energy saving and emission reduction, it has not been widely used since it was proposed. Because the Miller cycle reduces the mixed gas entering the cylinder, the resulting decrease in the output torque will weaken the engine performance (especially in the case of medium and low speed operation). In recent years, as turbocharger and variable valve control (VVC) technology has become more sophisticated, the Miller cycle has regained the attention of scholars and researchers. Turbocharger systems can supplement the intake air volume of the engine and compensate for the shortcomings of the Miller cycle. Turbocharger technology utilizes exhaust gases to drive the turbine, which drives the compressor through the driveshaft, increasing the air intake to the engine, thereby improving the power and economy of the engine [7].

During the past years, more and more strict requirements for exhaust emissions have led to the gradual attention to the alternative fuel for diesel engines. Natural gas, biodiesel, liquefied petroleum gas, hydrogen and alcohol fuels are the dominant alternative energy sources at present [8]. As a self-oxygenating fuel, ethanol can increase the concentration of oxygen in the combustion reaction, resulting in more efficient combustion. Moreover, fuel ethanol can meet net zero emission requirements. The reason for this is that in the whole ecosystem, the process of ethanol production and consumption can become a pollution free closed-circuit cycle. Fuel ethanol can be obtained from a wide range of sources—grain and various plant fibres can be processed to generate fuel ethanol, and the CO_2 from the combustion of ethanol can be reabsorbed by plants, making ethanol an inexhaustible source of renewable energy that is very friendly to the environment [9]. Moreover, ethanol is a very popular biofuel with high octane number, high latent heat of evaporation and low calorific value. Concurrently, ethanol can reduce the intake temperature and maximum combustion temperature of the engine, thus reducing NOx emissions. There has been a long history of alcohol-based fuels powering internal combustion engines, with American Henry Ford designing and manufacturing the world's first vehicle powered by ethanol in 1909. However, ethanol burning forms compounds, such as acetic acid, that corrode metals and can cause wear and tear on engines. Currently, ethanol is used in engines mainly as a fuel blend, which means that fuel ethanol is added to petrol or diesel to make a blend that is then used in the engine. If pure ethanol is used as a fuel, the necessary changes need to be made to the conventional engine. For example, the compression ratio is increased to take full advantage of the high-octane rating of ethanol. When the compression ratio is increased, it is advisable to use cold spark plugs. In addition to this, the fuel supply capacity of the pump should be increased to avoid air resistance, an additional fuel supply system should be used to improve cold starting, the fuel tank should be increased to ensure the necessary range and the corrosion resistance of the parts concerned should be improved. Moreover, when burning pure ethanol fuel in a diesel engine, the problem of a stable ignition has to be solved. This can be solved by adding a fire improver to the diesel engine, which does not require major changes to the structure of the diesel engine and is a convenient way to switch to diesel fuel at any time. Commonly used additives are cyclohexyl nitrate, triethyl ammonium nitrate, isopropyl nitrate, etc. So far, many countries have started using ethanol. For example, the United States and Brazil were the first countries to add ethanol to gasoline and use it as fuel for car engines, and

India is stepping up research into adding ethanol to gasoline or diesel engines. It is clear that ethanol is already being emphasized as a clean fuel.

In the meantime, hydrogen is also a promising alternative energy source. Since the mid to late 20th century, research on hydrogen-fueled engines has gradually emerged in countries, such as the USA, Germany, Japan, and Russia, and continues to this day [10]. Hydrogen can be obtained by electrolysis of water from renewable sources such as solar, tidal and wind energy, which can be regenerated, and the substance formed by the complete combustion of hydrogen is water vapor, resulting in reuse and net zero carbon emissions, making it a highly promising fuel. It is also a green fuel and very environmentally friendly as it produces very little exhaust gas, no CO, HC or soot emissions. In addition to this, the hydrogen flame travels faster in the engine than diesel, resulting in higher efficiency [8]. Hydrogen also has a larger ignition limit and a higher diffusion coefficient, making it easier to achieve leaner combustion, which results in better fuel economy [8]. Hydrogen has a high calorific value and more heat can be released by burning the same mass of hydrogen compare to diesel, so hydrogen engines are more efficient. However, there are some abnormal combustion conditions in some current internal combustion engines, such as backfire and premature combustion, both of which are likely to occur in inlet injection hydrogen engines [11]. Backfire refers to a phenomenon where the gas mixture starts to burn before the inlet valve is closed and is mainly related to the concentration of the inlet mixture, the valve timing, and the ignition system. Premature ignition is mainly due to the low ignition energy and rapid flame spread of the hydrogen gas itself [11]. These problems have now been tentatively solved by optimizing the structure of the engine ignition and cooling systems, reducing the engine mixer temperature and other measures. In comparison, a direct injection hydrogen engine is more advantageous because the hydrogen is injected directly into the combustion chamber, so that no backfire occurs and the power of the engine is also increased [11]. As a result, various countries have become more committed to hydrogen engines. In 2003, the German company BMW put the 750hl hydrogen fuel engine car into the market in Berlin. Ford Motor Company in the USA is working on both hydrogen powered vehicles and fuel cell vehicles. Musashi Institute of Technology in Japan and Nissan Motor Company have been cooperating for a long time in the research of liquid hydrogen engine vehicles. Hence, the future of hydrogen engines is quite prospectively developed.

More and more scholars have paid attention to the Miller cycle in recent years, and many experimental and theoretical research has been carried out. Wang [1] took a List-Petter TS12 Diesel Engine as the experimental object and applied the Miller cycle to it. Experimental results and theoretical analysis showed that the Miller cycle could reduce NOx emissions by reducing the exhaust temperature of the engine. Wang et al. [5] conducted an experimental study on the NOx emissions of the Miller cycle applied to diesel engines, comparing three versions of Miller cycle (ERVC, EIVC, and LIVC) all had a positive effect on the reduction of NOx in diesel engines compared with the standard Dual cycle. This experiment provides the feasibility of the Miller cycle for reducing NOx emissions from diesel engines and is the cornerstone of future research in this field. Wartsila [12] conducted a study on the influence of Miller cycle on NOx emissions of a six-cylinder direct injection marine diesel engine and used GTSuite software to simulate two different early closing angles. The result showed that when the advance closing angle was 100 CA and the boost pressure was 1.2 MPa, the NOx emission was reduced by 50%. Gonca et al. [13] used a zero-dimensional two-zone combustion model to model an air-jet Miller cycle diesel engine, and compared the results with conventional diesel engines, Miller cycle diesel engines and steam injection diesel engines in terms of performance and CO emissions and found that it was more efficient at low and medium speeds. Moreover, NO emissions decreased under all the comparative conditions. Rinaldini et al. [14] applied the Miller cycle to high-speed direct injection diesel generator by establishing a computer model, which reduced the combustion temperature of the engine and thus reduced NOx emissions. Gonca et al. [15] used a single cylinder, four stroke, direct injection naturally aspirated diesel engine as the prototype for computer simulation, and determined the optimal camshaft crank angle by constant adjustment. Experimental results showed that in this case, NO emission was reduced by 30% compared with the traditional diesel engine with 0 CA, but the power was reduced by 2.5%. Wei et al. [16] established a one-dimensional simulation model of a Miller cycle diesel engine and found that under the condition of EIVC and low load, Nox emissions would be reduced, but there is a danger of fire when the intake valve closes prematurely.

As the Miller cycle reduces the volume of air going into the engine cylinders, it may lead to a reduction in engine performance. In order to compensate for the inadequacy of the Miller cycle air intake, many scholars have also made relevant studies on the turbocharger. Zhu [2] modelled a four-cylinder diesel engine with a two-stage turbocharger model and then applied the Miller cycle with early intake valve closed. The simulation results show that the two-stage turbocharger technology can reduce the diesel specific fuel consumption, in addition to improving the engine performance at low speeds. Rakopoulos and Giakoumis [17] carried out a second law analysis of a six-cylinder turbocharged diesel engine and applied the availability equations to various parts of the diesel engine and discussed the results. Gonca and Sahin [18] used a simulated model of a turbocharged Miller cycle diesel engine to Investigate the effect of engine operating parameters on effective power and efficiency and found that engine performance increased with higher cycle temperature ratios, inlet pressures and other parameters. Wu et al. [19] experimentally investigated the effect of the Miller cycle and variable geometry turbocharger (VGT) on the performance and emissions of a six-cylinder diesel engine and showed that by adjusting the VGT, it was still possible to achieve low soot and NOx emissions from a diesel engine under cold operating conditions while maintaining high brake thermal efficiency (BTE). Pan et al. [20] studied the influence of the Miller cycle on the fuel economy of a turbocharged direct injection gasoline engine under different load conditions and demonstrated that the BTE of the gasoline engine with the Miller cycle applied increased at all loads compared to the original gasoline engine, and then further simulations of the diesel engine resulted in a 2.9% increase in BTE.

Recently, scholars have devoted themselves to exploring renewable energy sources that can replace fossil fuels, and some clean energy sources (ethanol, hydrogen, etc.) have become the focus of research. Martins and Lanzanova [21] conducted one-dimensional simulation analysis of a fully loaded Miler cycle spark ignition engine using ethanol as fuel and analyzed its future prospects. Chen et al. [22] designed experiments to explore the combustion, performance, and emissions of ethanol engines. It is concluded that the diesel micro-ignited ethanol engine can achieve a low level of NOx emissions, but under high loads, the thermal efficiency and NOx emissions are higher. Pedrozo and Zhao [23] designed an experimental study on ethanol-diesel dual-fuel compression ignition engine, using Miller cycle and charge air cooling technology to reduce the intake temperature in the cylinder. It demonstrated that compared with traditional diesel engine combustion, this engine produces lower NOx emissions and higher net indicated efficiency. Wang et al. [24] simulated the combustion process of ethanol diesel in 475 diesel engines by establishing a simulation model and explored the combustion and emission characteristics of mixed fuels with different ethanol proportions. They found that with the increase of ethanol proportions, the temperature in the engine cylinder and the mass fraction of NOx emission gradually decreased. Jahanbakhshi et al. [25] established an engine model using bioethanol and diesel as fuel. By comparing Miller cycle and Otto cycle, they found that under the same volume efficiency of the engine, bioethanol engines have higher power output and thermal efficiency. Balki applied Taguchi's [26] experimental method to a spark ignition engine fueled by pure ethanol and analyzed it against a gasoline engine, finding that both brake engine power and brake thermal efficiency were higher in the pure ethanol engine than in the gasoline engine, with an increase in BSFC. Khoa [27] combines the results of experiments and simulations to investigate pure ethanol and methanol engines, where ethanol instead of methanol improves the BSFC at the optimum combustion time for both engines. Boretti [28] simulates an inline four-spark ignition engine with turbo-cooling, and the pure ethanol engine shows better performance compared to the gasoline engine, with an increase of

20% in maximum torque and 23% in power output. Martínez and Ganji [29] conducted experiments on an engine using pure gasoline and pure ethanol as fuel to compare engine performance and emissions. The results were 35% higher engine power, 38% higher engine efficiency, and 37% lower NOx emissions for the ethanol fuel than for gasoline fuel. Gomes et al. [30] made an experimental study of a direct injection compression ignition hydrogen engine and found that compared with diesel engines, its power was significantly higher, and its efficiency was much increased. Tang [31] experimentally explored the combustion and emission characteristics of hydrogen engines and found that hydrogen fueled engines cause higher NOx production and knocking at high loads. Chaichan [32] studied a spark-ignition single cylinder hydrogen engine experimentally, testing both hot and cold exhaust gas recirculation (EGR) systems separately and proving that EGR can reduce NOx emissions. White et al. [33] provide a theoretical analysis of the current state of hydrogen internal combustion engines nowadays, especially small and medium-sized engines, and makes recommendations for future development in the light of the current circumstances. Qin et al. [34] conducted experiments on a diesel engine in which different proportions of hydrogen fuel were mixed into the diesel fuel to observe the combustion characteristics of the engine. It was found that the addition of hydrogen fuel increased the thermal efficiency of the engine compared to a conventional diesel engine. Lee [35] tested a high-pressure direct injection hydrogen engine that was producing a large amount of NOx because of the high in-cylinder temperature due to the fast combustion of the hydrogen flame. Wright and Lewis [36] based on available literature experimental data inferred that the use of EGR at very high and very low loads can contribute to the reduction of NOx emissions and suggested that if the cost is reasonable, technology can be used to reduce NOx emissions from hydrogen engines depending on the actual engine operating load. Bao et al. [37] experimented on a direct injection hydrogen engine where the addition of a turbocharger increased maximum power at 2000 rpm and maximum torque lift at 4400 rpm by 123% and 195% respectively. Babayev et al. [38] present a conceptual model and simulation study of a pure hydrogen engine with compression ignition and using hydrogen for ignition. The results are that the pure hydrogen engine has a higher brake thermal efficiency compared to the diesel engine. In addition to this, the heat loss of the hydrogen engine is lower. Although there has been a lot of research into alternative engine fuels, there has been relatively little research into the Miller cycle as applied to renewable energy sources, so this paper will be a simulation study of an ethanol engine and a hydrogen engine with the simultaneous application of the Miller cycle.

Based on the above information, it is clear that the Miller cycle has been extensively researched both experimentally and theoretically, and that it has proven to be potentially beneficial in terms of reducing NOx emissions. Although these studies can provide a strong reference for designers when designing engines, there is little literature comparing in detail the performance and emissions of engines at different levels of Miller cycles at different loads. The purpose of this research is to demonstrate the influence of Miller cycle on the performance and NOx emissions of diesel engines under different load conditions, and to achieve the advantages of Miller cycle with the addition of a turbocharger system to enhance engine power. The performance and NOx emissions of pure ethanol and hydrogen engines have also been investigated, and the Miller cycle was also applied. The final aim is to improve NOx emissions while maintaining the best possible engine performance, including brake power (BP), brake specific fuel consumption (BSFC), and brake thermal engine efficiency (BTEE), and to provide a reference for the design of future energy-efficient, low-emission, and high-efficiency engines.

2. Methodology

2.1. Research Methods

In this research, the computer simulation software Ricardo WAVE is used to simulate the working process of the engine. Ricardo WAVE is an advanced aerodynamic simulation software developed by Ricardo for computational fluid dynamics and thermodynamic calculations based on one-dimensional flow theory with limited volume. It can simulate and analyze the performance of any form of intake, combustion, and exhaust system. This software can control the mass flow, momentum, and energy transfer of compressed gases through one-dimensional forms of the Navier–Stokes equations, including sub-models of combustion and emission. This study uses the WAVE software to build a diesel engine simulation model, which can easily modify various parameters of the engine and quickly achieve testing and diagnosis [39].

2.2. Model Setup and Validation

The engine prototype used in this study is YANMAR TF120M. Table 1 [39] shows specifications of the engine, according to which related parameters are set in Ricardo WAVE, the fixed speed of the model is set as 2400 rpm [39]. Table 2 [39] shows the engine power, electrical power, fuel consumption, thermal efficiency, and NOx emission of the engine under different loads. The engine simulation output results are compared with the experimental data in reference [39], and the absolute and relative errors are calculated to verify the validity of the results.

Table 1. Specifications of YANMAR TF 120 M [39].

Specification	Values
Number of cylinders	1
Fuel consumption	2.8 L/hour
Revolution	2400 rpm
Rate continuous output	7.8 kW
Bore	92 mm
Stroke	96 mm
Displacement	0.638 L

Table 2. Engine Performance Under Different Loads [39].

Load	Engine Power (kW)	Electrical Power (kW)	Fuel Consumption (g/h)	Thermal Efficiency (%)	NOx Emission (ppm)
10%	0.99	0.65	705	11.85	222.57
25%	2.4	1.63	878	23.04	314.04
50%	4.58	3.27	1182	32.53	487.86
75%	6.5	4.85	1534	35.98	703.57
100%	8.83	6.51	1975	36.01	973.65
100%	8.83	6.51	1975	36.01	973.65

Based on the fuel consumption and engine power given in the reference [39], the BSFC of the engine can be calculated.

The comparison shows that the relative errors between the simulation results and the experimental results are within 5%, as shown in the Tables 3–6, indicating that the model has the physical characteristics of the engine. Although there are deviations in the output results, the generation of these deviations is unpredictable and avoidable, which proves that the output results have been successfully verified, indicating the accuracy of the results. Therefore, it is considered that the simulation model is effective and can be used in the following research.

Table 3. Results Validation.

Load		10%	25%	50%	75%	100%
Brake power	Experimental result (kW)	0.99	2.40	4.58	6.50	8.83
	Simulated result (kW)	0.940	2.438	4.801	6.849	8.939
	Relative errors	−5.02%	1.58%	4.83%	5.36%	1.23%
Thermal efficiency	Experimental result (%)	11.85	23.04	23.04	35.98	37.69
	Simulated result (%)	12.071	23.537	30.988	34.045	36.009
	Relative errors	1.84%	2.14%	−4.74%	−5.37%	−4.45%
BSFC	Experimental result (g/kWh)	710.6	364.6	258.3	235.6	223.6
	Simulated result (g/kWh)	696.798	357.367	271.437	247.063	233.588
	Relative errors	1.94%	1.98%	−5.09%	−4.87%	−4.47%
NOx emission	Experimental result (ppm)	222.57	314.04	497.86	703.57	973.65
	Simulated result (ppm)	241.057	302.21	467.78	732.979	931.685
	Relative errors	−8.31%	3.77%	6.04%	−4.18%	4.31%

Table 4. Miller cycle setup.

Miller Cycle Percentage	Change in Crank Angle (°)	New Open Duration (°)
−40%	−112	168
−35%	−98	182
−30%	−84	196
−25%	−70	210
0	0	280
5%	14	294
10%	28	308
15%	42	322
20%	56	336

Table 5. Mass per injection (mg) of diesel, ethanol and hydrogen engine models under different loads.

Load	Diesel Engine	Ethanol Engine	Hydrogen Engine
10%	9.8	15.6	3.5
25%	12.2	19.5	4.4
50%	16.4	26.2	5.9
75%	21.3	34	7.6
100%	27.4	43.8	9.8

Table 6. Results of ethanol engine with diesel cycle and the difference between the diesel engine.

Load	Brake Power (kW)	Difference	BSFC (kg/kWh)	Difference	BTEE (%)	Difference	NOx Emission (ppm)	Difference
10%	0.688	−26.82%	1.264	81.37%	10.617	−12.04%	228.659	−5.14%
25%	2.451	1%	51%	42.58%	2633%	11.88%	297.688	−1.50%
50%	5.31	10.60%	0.37	36.48%	3621.90%	16.88%	447.422	−4.35%
75%	6.516	−4.85%	0.355	43.55%	37.834	11.13%	565.968	−22.79%
100%	7.538	−15.67%	0.342	46.35%	39.25	9.00%	945.741	1.51%

2.3. Miller Cycle Model Setup

The Miller cycle was set up on the basis of a validated diesel engine and this was achieved by adjusting the timing of the intake valve closing and valve lift. The original intake valve closing time is 280 CA, from which the intake valve closing time is proportionally advanced and delayed respectively. LIVC is achieved by extending the duration of the original maximum lift of the crankshaft and EIVC is achieved by a reduction in the original lift percentage, both of which can vary the closing time of the intake valve. The Miller cycle setting data is shown in the Table 7. When the percentage is negative, it means that the intake valve closes early, which is the EIVC version. Conversely, a positive value is the LIVC version where the intake valve closes late. As an example, −25% EIVC indicates 25% of the original case of early intake valve closure; +5% LIVC indicates 5% of the original case of delayed intake valve closure. Engine performance (including BP, BSFC, BTE) and NOx emissions are studied at different degrees of Miller cycle under different loads at a rated engine speed of 2400 rpm.

Table 7. Comparison of BP (kW), BTEE (%), BSFC (kg/kWh) and NOx emissions (ppm) for diesel cycle diesel engines, diesel cycle hydrogen engines and miller cycle hydrogen engines.

	Load	**10%**	**25%**	**50%**	**75%**	**100%**
Brake Power (kW)	Diesel engine with diesel cycle	0.94	2.438	4.801	6.848	8.939
	Hydrogen engine with diesel cycle	0.96	3.162	5.911	8.052	10.151
	Hydrogen engine with Miller cycle	1.026	3.143	5.924	8.083	10.192
Brake Thermal Engine Efficiency (%)	Diesel engine with diesel cycle	12.071	23.537	30.988	34.045	36.009
	Hydrogen engine with diesel cycle	12.322	30.531	38.151	40.03	40.892
	Hydrogen engine with Miller cycle	13.173	30.344	38.235	40.179	41.055
BSFC (kg/kWh)	Diesel engine with diesel cycle	0.697	0.357	0.271	0.247	0.234
	Hydrogen engine with diesel cycle	0.244	0.098	0.079	0.075	0.073
	Hydrogen engine with Miller cycle	0.228	0.09	0.078	0.075	0.073
Nox emission (ppm)	Diesel engine with diesel cycle	241.057	302.21	467.78	732.979	931.685
	Hydrogen engine with diesel cycle	2328.07	2676.16	3503.81	3818.16	4022.71
	Hydrogen engine with Miller cycle	2049.08	2621.41	3324.05	3588.6	3803.55

2.4. Ethanol Engine and Hydrogen Engine Model Setup

The ethanol engine and the diesel engine have basically the same setting parameters. However, due to the different calorific values of the three fuels, the injection masses of the ethanol and hydrogen engines need to be changed accordingly compared to the diesel engines. Based on the fact that the three types of engines with different fuels produce the same amount of heat per fuel injection, the injection masses of the ethanol and hydrogen engines are calculated for five operating conditions (10%, 25%, 50%, 75%, 100%) and the parameters are modified in WAVE.

Using a 100% load condition as an example, a diesel engine will generate 1.174 kJ of heat in one injection at full load, so an ethanol engine and a hydrogen engine will need to get an equal amount of heat in one injection. The calorific value of ethanol is 26.83 MJ/kg, giving a mass of 43.758 mg for one injection, and the calorific value of hydrogen is 119.95 MJ/kg, giving a mass of 9.788 mg for one injection. This method of calculation can be used to obtain the masses of ethanol and hydrogen injected at 75%, 50%, 25%, and 10% load conditions. Table 5 shows the injection mass for the diesel, ethanol, and hydrogen engines at five loads.

3. Results and Discussion

3.1. Diesel Engine Performance and Emissions with Miller Cycle EIVC and LIVC

Because the model simulation results show that there is very little improvement for the Miller Cycle at degrees below the −25% EIVC Miller cycle are confusing with no regularity compared to the original diesel cycle, it is considered that the EIVC from −25%. Figures 3–5 show the brake power, BSFC, and brake thermal efficiency of the engine at different degrees of the EIVC version of the Miller cycle. From these data, it can be seen that the EIVC Miller cycle has different effects on engine performance. As the intake valve closing time is advanced, at low loads (10%) the engine brake power and brake thermal efficiency increase with increasing percentage of the Miller cycle and the BSFC decreases. At medium loads

(50%, 25%), engine brake power and brake thermal efficiency increase slightly and then decrease, and BSFC decreases and then increases. At high loads (100%, 75%), the engine brake power and brake thermal efficiency gradually decrease and the BSFC increases, resulting in a reduction in performance. This is caused by the loss of power output due to premature closure of the intake valve when a higher boost pressure is required to maintain a steady power output.

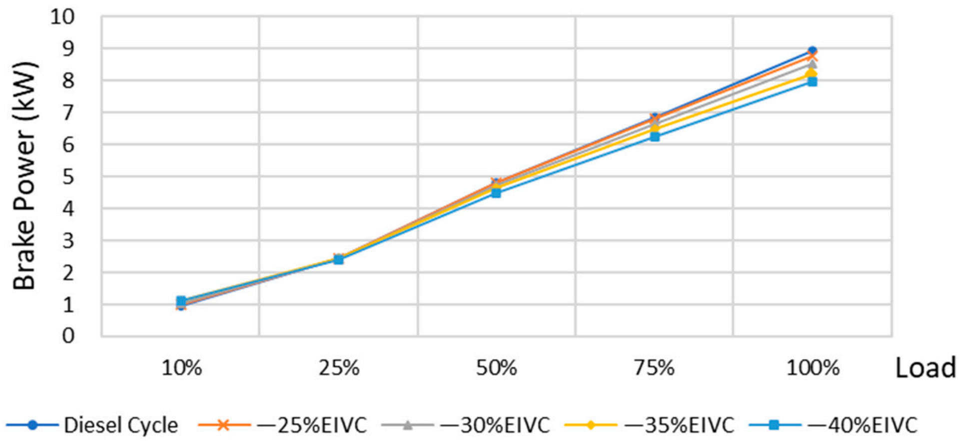

Figure 3. Comparison of BP under diesel engine EIVC Miller cycle.

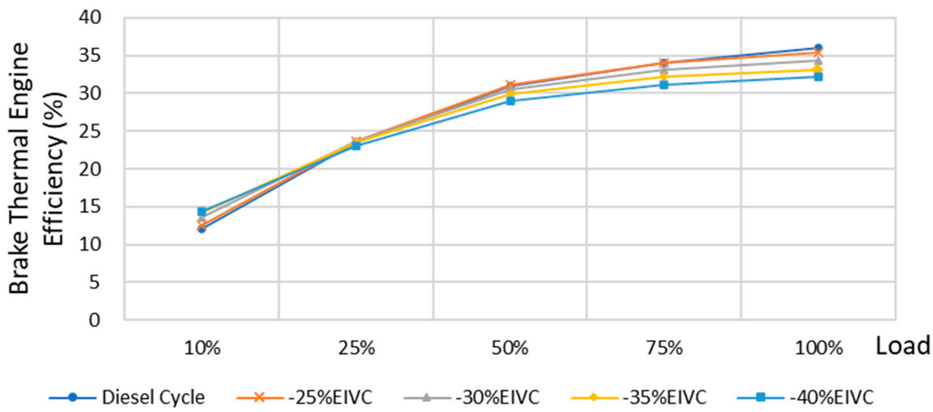

Figure 4. Comparison of BTEE under diesel engine EIVC Miller cycle.

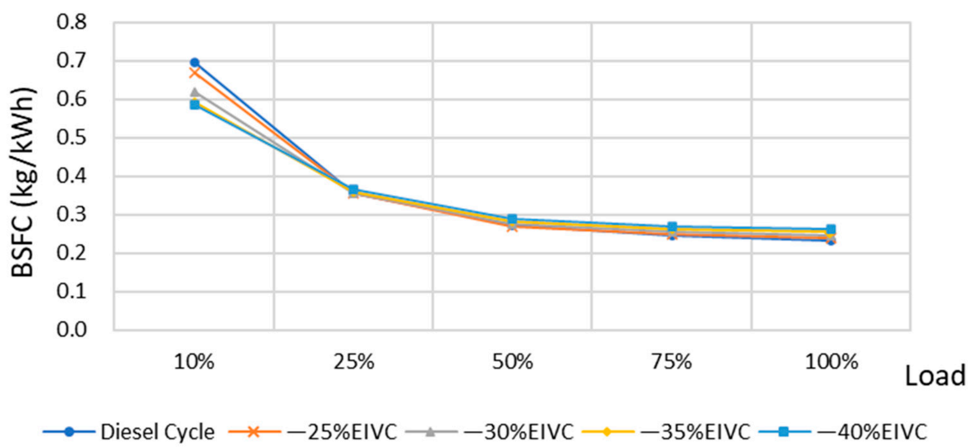

Figure 5. Comparison of BSFC under diesel engine EIVC Miller cycle.

Figure 6 shows diesel NOx emissions under the EIVC Miller cycle, which has a beneficial effect on the reduction of NOx emissions. As the Miller cycle degree becomes larger, the NOx emissions are reduced more. The positive effect of the Miller cycle on NOx emissions is most pronounced at 10% load, with a maximum reduction of 21%.

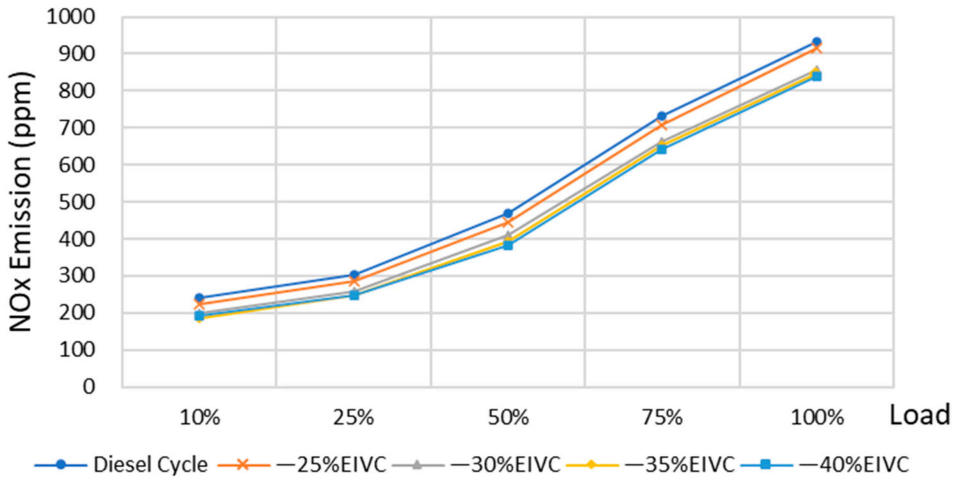

Figure 6. Comparison of NOx emission under diesel engine EIVC Miller cycle.

From the Figures 7–9 it is clear that, in the LIVC version of Miller Cycle, at 10% engine load, brake power and brake thermal efficiency get higher and BSFC gets lower as the intake valve closing time is delayed. At 25% load, the brake power and brake thermal efficiency tend to rise slightly and then drop as the Miller cycle degree gets larger, while the BSFC, in contrast, reduces and then grows, but the overall change is not very significant. In the remaining cases (100%, 75%, and 50% load), the greater the Miller cycle, the lower the brake power, the lower the brake thermal efficiency and the higher BSFC. The reason for this trend is that with the delay in closing the intake valve, some of the gas entering the cylinder and the fuel injected is pushed out of the cylinder, the effective compression stroke becomes shorter, and the effective compression ratio decreases, resulting in a reduction in both the pressure and temperature at the end of compression and the mean effective pressure, making the diesel engine less thermally efficient [40,41].

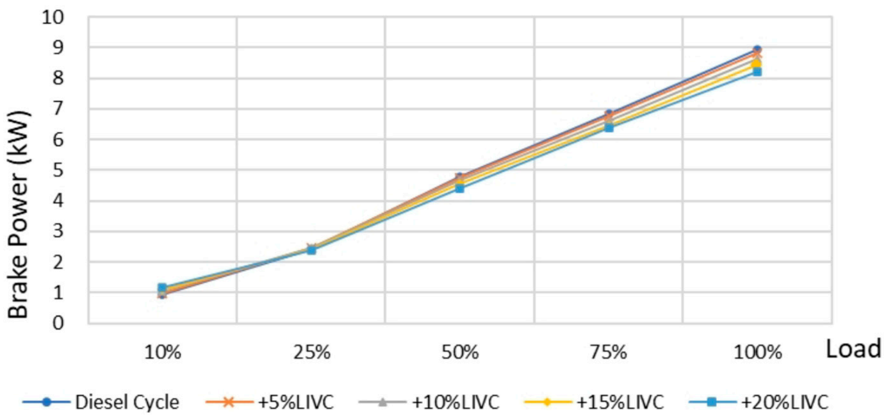

Figure 7. Comparison of BP under diesel engine LIVC Miller cycle.

Under the influence of the LIVC Miller cycle, NOx emissions from diesel engines are reduced and become less as the delay in closing the intake valve increases. Similar to the EIVC, the Miller cycle of the LIVC is most effective in improving NOx emissions at 10% load of the engine (Figure 10).

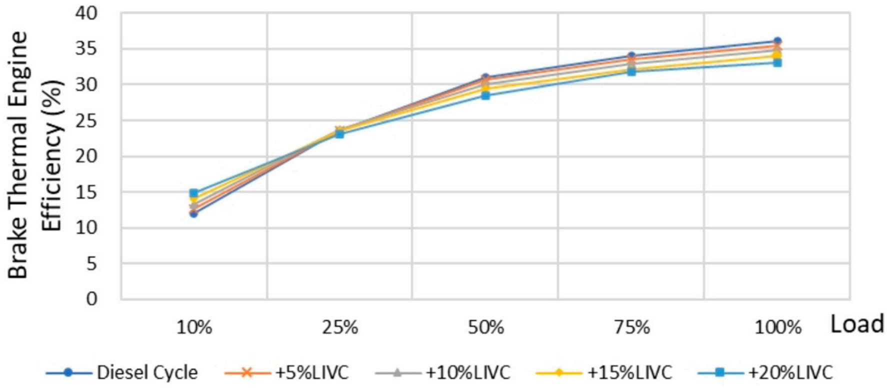

Figure 8. Comparison of BTEE under diesel engine LIVC Miller cycle.

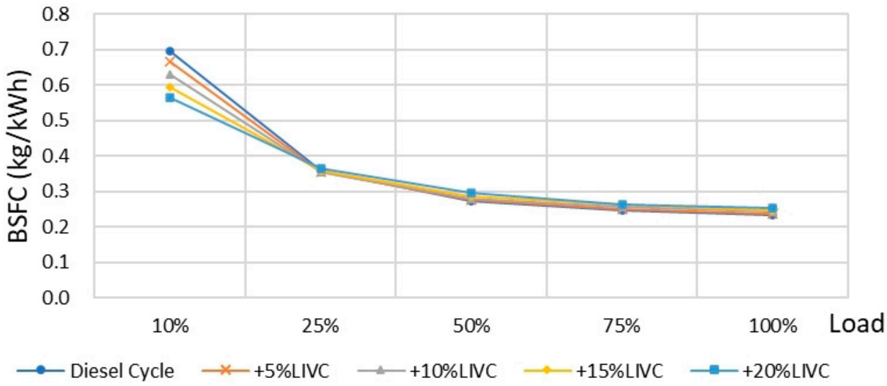

Figure 9. Comparison of BSFC under diesel engine LIVC Miller cycle.

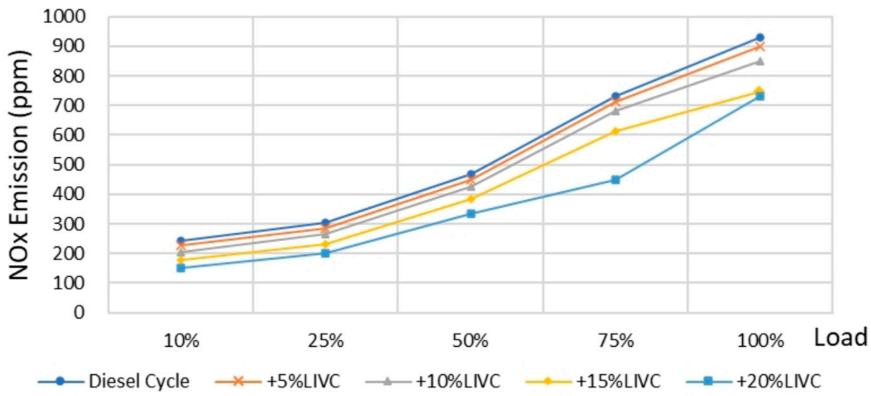

Figure 10. Comparison of NOx emission under diesel engine LIVC Miller cycle.

Combining the simulation results of both versions of the Miller cycle on a diesel engine, it can be concluded that the Miller cycle has a positive effect on NOx emission reduction and that LIVC is better than EIVC. For engine performance, the Miller cycle reduces engine brake power and brake thermal efficiency in most cases, causing poor engine performance.

3.2. *Performance of the Turbocharger Diesel Engine under the Miller Cycle*

The Miller cycle makes the effective compression stroke shorter by controlling the timing of the intake valve closure, but it also results in less intake air, especially at medium to high loads, resulting in less engine power, so the Miller cycle cannot be used to its advantage. To compensate for this, turbocharging is often applied to increase the volume of air into the cylinders and thus improve the power performance of the engine.

Figures 11–14 shows the engine performance and NOx emission results under the simultaneous application of turbocharger and the EIVC Miller cycle to the diesel engine.

As can be seen from results, the combined effect of turbocharger and the Miller cycle led to a general increase in diesel engine performance, as evidenced by an increase in brake power and brake thermal efficiency and a decrease in BSFC. However, there are also some situations where there is a slight decrease in brake thermal efficiency and a small increase in BSFC and NOx emission. One of the best impact effects is the −25%EIVC Miller cycle, where the maximum increase in power can reach 32%. These results show the −25%EIVC Miller cycle with turbocharger applied compared to the performance of the original diesel engine. As the diesel intake is substantially increased by the application of the turbocharger system, sufficient intake is maintained even if the intake valves are closed early.

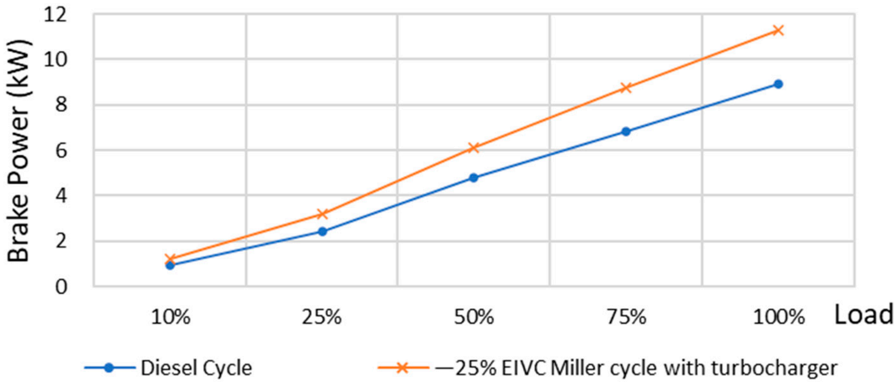

Figure 11. Comparison of BP between diesel engine and EIVC Miller cycle turbocharger diesel engine.

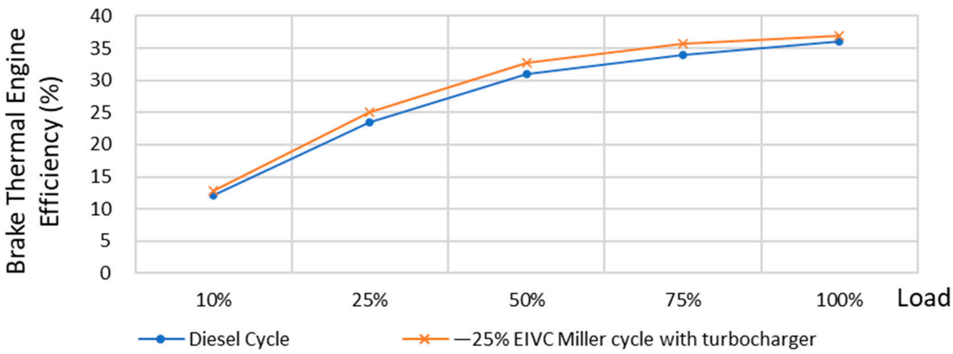

Figure 12. Comparison of BTEE between diesel engine and EIVC Miller cycle turbocharger diesel engine.

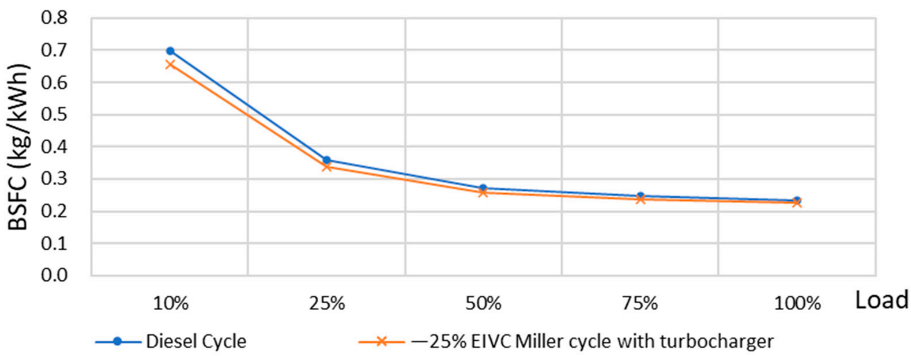

Figure 13. Comparison of BSFC between diesel engine and EIVC Miller cycle turbocharger diesel engine.

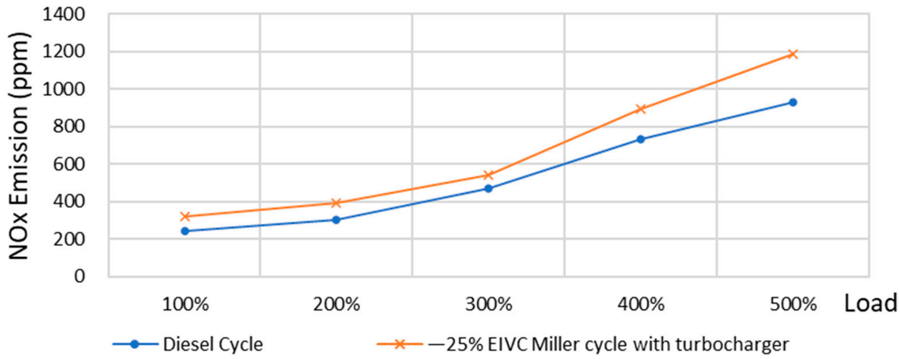

Figure 14. Comparison of NOx between diesel engine and EIVC Miller cycle turbocharger diesel engine.

3.3. Performance and Emission of Diesel Cycle Engines Using Ethanol

As can be seen from the Figure 11, brake power is decreased to different degrees in engines using ethanol as fuel compared to diesel, which is normal because the calorific value of ethanol is lower than that of diesel, approximately two thirds of diesel [42]. What is noteworthy, however, is the increase in brake power of approximately 11% for 50% load and 0.5% for 25% load, which can be explained by the fact that ethanol contains 34.8% oxygen, which allows for the full combustion of the incomplete part of the diesel fuel, thus increasing the power [43]. In addition, ethanol causes a significant growth in BSFC, with a maximum increment of 81%, occurring at 10% load. This is a result of the high latent heat of vaporization and low cetane number of ethanol. Another possible reason is that ethanol fuels cause a delay in ignition leading to inadequate combustion, especially at low loads [42].

Except at 10% load, the brake thermal efficiency is increased compared to diesel, with a maximum increase of 17%. It is possible that the increase in brake thermal efficiency at medium and high loads can be attributed to ethanol being an oxygenated fuel that supplies its own oxygen during combustion, especially at medium and high loads, where the volume fraction of ethanol in the fuel enrichment zone is relatively high, leading to fuller combustion. In addition, the low boiling point of ethanol makes it easier to vaporize, resulting in an enhancement in the atomization qualities of the fuel [42]. However, for low load braking, thermal efficiency is reduced, probably due to the high latent heat of vaporization of ethanol, which further reduces the in-cylinder temperature of the engine under low load conditions, and the high excess air coefficient at low load, which shortens the absolute combustion time during engine operation and slows down the combustion rate, making it difficult to concentrate the effective combustion at the upper stop point, resulting in a lower fuel working capacity, which detracts from the engine's thermal efficiency.

Compared to the diesel engine, NOx emissions are basically reduced (the largest reduction is 23% at a 75% load), but at full engine load, NOx emissions increase by 1.5%. The reason for this can be explained by the low combustion temperature of the engine at low and medium loads, the latent heat of vaporization of ethanol makes the combustion temperature lower, so NOx emissions are less; however, at high loads, the oxygen carried by the ethanol increases the oxygen concentration in the engine combustion gases, the combustion rate is faster, and the combustion temperature is higher, thus increasing NOx emissions.

3.4. Performance and Emissions of the Ethanol Engine with the Application of the Miller Cycle

The Miller cycle was applied on the ethanol engine, and the percentage of EIVC and LIVC versions was set to 5%, 10%, 15%, and 20% valve timing changes, respectively, and the output engine BP, BSFC, BTEE, and NOx emissions, are shown in Figures 15–22.

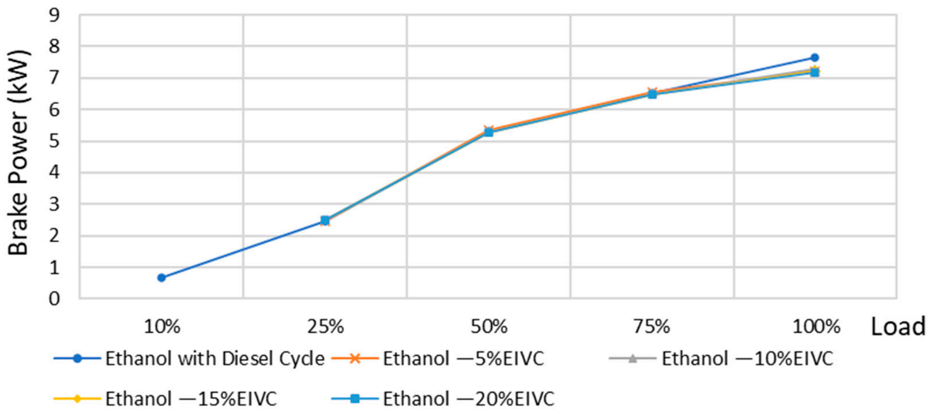

Figure 15. BP(kW) of ethanol engine with EIVC Miller Cycle.

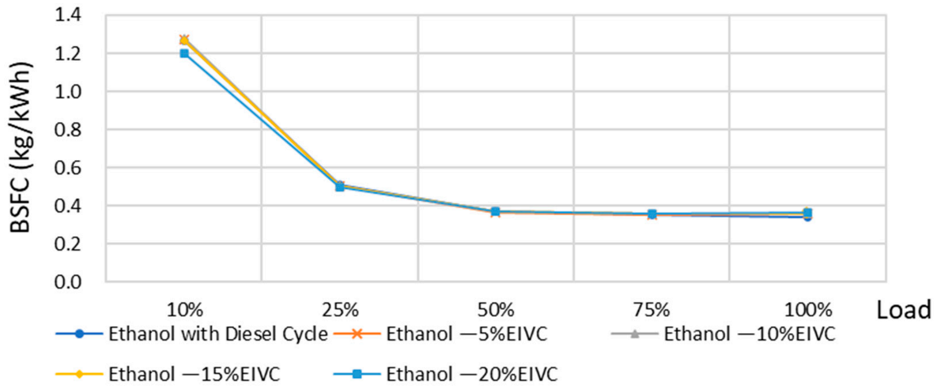

Figure 16. BSFC(g/kWh) of ethanol engine with EIVC Miller Cycle.

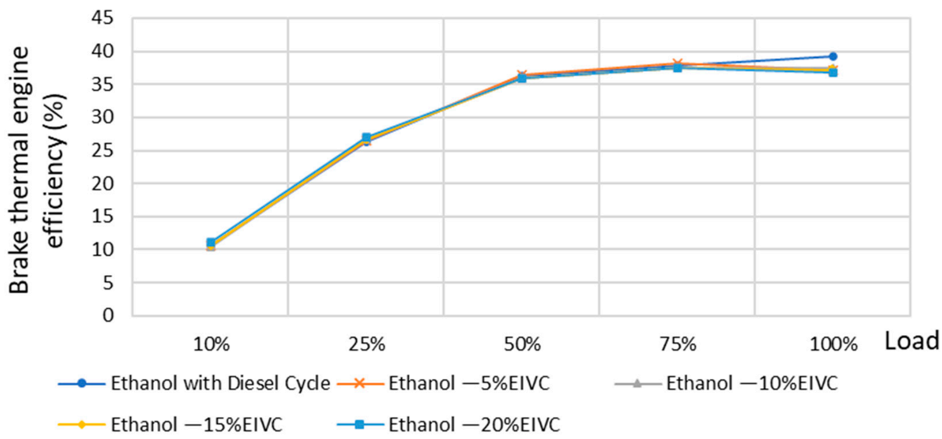

Figure 17. BTEE(%) of ethanol engine with EIVC Miller Cycle.

The variability in brake power, BSFC and brake thermal efficiency for the EIVC version of the Miller cycle compared to the original diesel cycle ethanol-fueled engine at 10%, 25%, 50% and 75% load is quite small, remaining at around ±5% (except for the 10% load −20%EIVC condition). Ethanol has a low ignition point and burns easily in reaction with air. In addition, as ethanol is an oxygenated fuel, it provides oxygen by itself, which facilitates combustion, so the volume of oxygen in the air entering the cylinder, which is involved in the combustion reaction, does not have a significant impact on the overall combustion reaction. When the EIVC Miller cycle is applied, there is less intake air into the cylinder, but it does not have a greater impact on the ethanol combustion. At full load, however, the effect of the EIVC Miller cycle on the engine is more pronounced, with variations ranging from 5% to 6%, and the BSFC increases with the degree of Miller cycle as the engine brake power and brake thermal efficiency decrease. The reason for this is that the combustion reaction in the cylinder requires a much larger volume of oxygen, and apart from the oxygen carried by the ethanol itself, there is also outside air carried into the cylinder, and the Miller cycle reduces the intake air, so the power performance of the ethanol engine is significantly weakened.

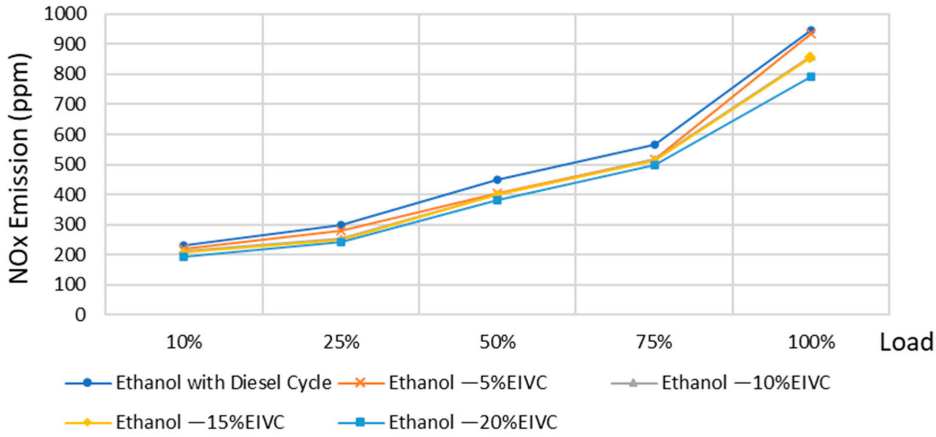

Figure 18. NOx emission(ppm) of ethanol engine with EIVC Miller Cycle.

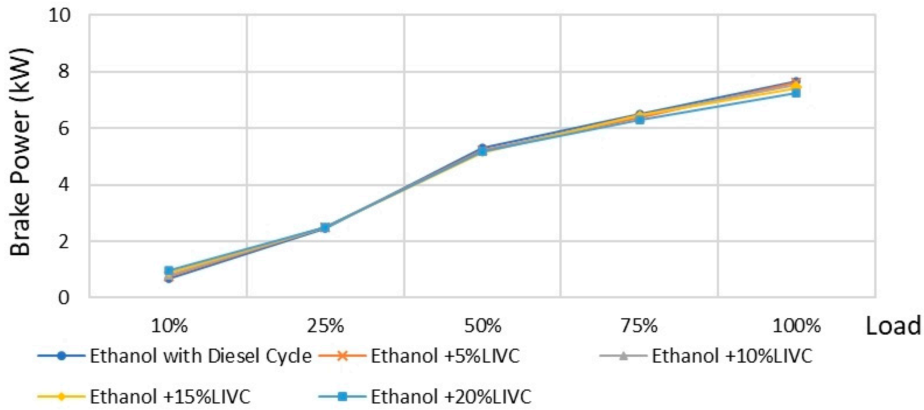

Figure 19. BP(kW) of ethanol engine with LIVC Miller Cycle.

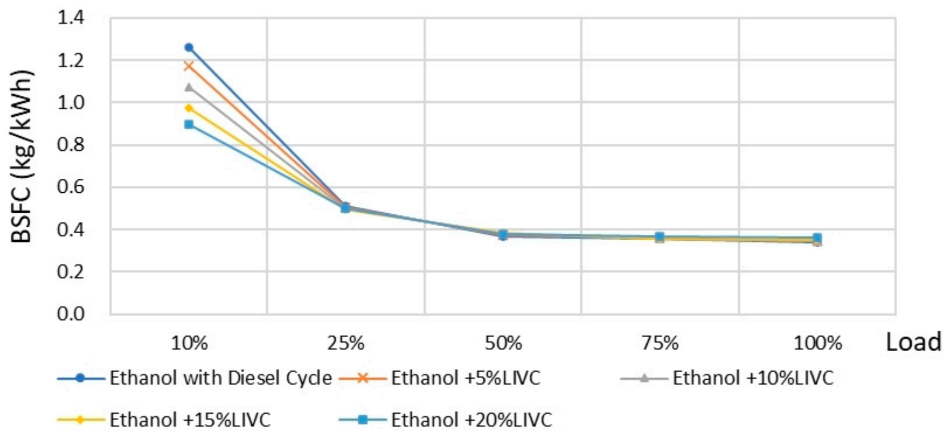

Figure 20. BSFC(g/kWh) of ethanol engine with LIVC Miller Cycle.

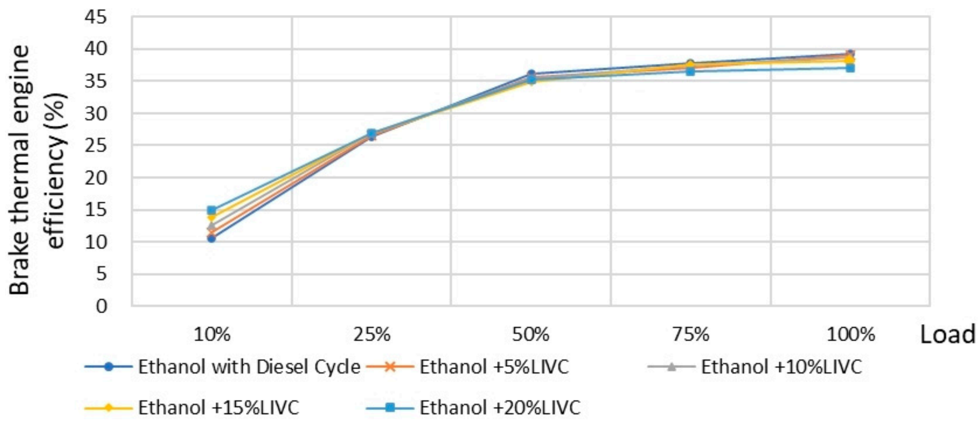

Figure 21. BTEE(%) of ethanol engine with LIVC Miller Cycle.

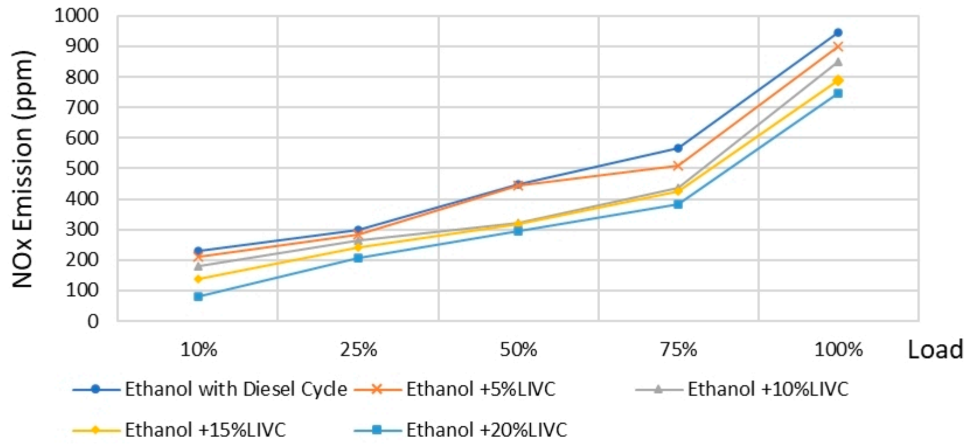

Figure 22. NOx emission(ppm) of ethanol engine with LIVC Miller Cycle.

In terms of NOx emissions, the Miller cycle of the EIVC is associated with a reduction in NOx emissions at all loads, with −20% EIVC presenting the best improvement.

There is a more significant effect of LIVC on ethanol engine performance and NOx emissions than that of EIVC. At 10% and 25% load, brake power and brake thermal efficiency become higher and BSFC becomes smaller as the degree of LIVC becomes greater; at 50%, 75% and 100% load, as the degree of LIVC becomes larger, brake power and brake thermal efficiency become lower and BSFC becomes higher. NOx emissions are reduced at all operating conditions, with the largest reduction of 66% occurring at 10% load with 20% LIVC.

In terms of NOx emissions, both versions of the Miller cycle have a positive impact on ethanol engines. This is because the Miller cycle reduces the effective compression ratio and lowers the in-cylinder combustion temperature at the same time as the high latent heat of vaporization of ethanol leads to a lower in-cylinder combustion temperature, resulting in lower engine NOx emissions. Nevertheless, the LIVC is more effective than the EIVC in decreasing NOx emissions from ethanol engines. The reason for this can be explained as the intake time of the LIVC continues until the valve is closed. After reaching the bottom dead center, the upward movement of the piston pushes some of the air out of the cylinder, thus taking part of the heat out of the cylinder, resulting in a lower temperature in the cylinder than the EIVC, and therefore controlling NOx emissions more effectively than the EIVC.

3.5. Performance and Emissions of the Hydrogen-Fuelled Engine

Table 7 shows the performance and NOx emission output results for the original diesel engine, the hydrogen engine with diesel cycle and the hydrogen engine with −5% EIVC Miller cycle (only one degree of Miller cycle is applied here for the hydrogen engine because the Miller cycle has a slight effect on it). Hydrogen has many advantages as a fuel; it burns quickly, ten times faster than diesel, and its low density and high diffusion coefficient facilitate rapid mixing of hydrogen and air, so a hydrogen fueled engine will have higher power and thermal efficiency, as can be seen in the Table 7 Compared to diesel engines, hydrogen engines using the Miller cycle and the diesel cycle have a significant increase in power and efficiency and a reduction in BSFC. Combining the results for brake power, brake thermal efficiency, and BSFC, the hydrogen engine is found to outperform the diesel engine. The most notable performance was found at 25% load, where brake power increased by 30%, efficiency increased by 30%, and BSFC decreased by 72% compared to a diesel engine at the same load.

Nevertheless, when it comes to NOx emissions, hydrogen engines do not have an advantage over diesel engines. At every load, there is a sharp increase in NOx emissions from hydrogen engines. For this result, two reasons can be analyzed in relation to the factors contributing to NOx emissions. The first is that although hydrogen is a typically clean and nonpolluting fuel, the main product of combustion is water and no CO or HC is generated, but NOx is still emitted due to the mixture of hydrogen and air, where a large amount of nitrogen is involved in the reaction, as well as the fast combustion rate and high combustion temperature of hydrogen, with high temperatures being the main factor contributing to higher NOx emissions. The second reason is probably caused by the rapid increase in pressure in the cylinder of the hydrogen engine (Figure 23 shows the pressure in the cylinder of the hydrogen engine with crank angle, with data obtained from the model simulation in WAVE). The rapid increase in cylinder pressure after hydrogen ignition is greater than that of a diesel engine, and the excessive rate of increase in cylinder pressure can cause deterioration in combustion, resulting in higher NOx emissions.

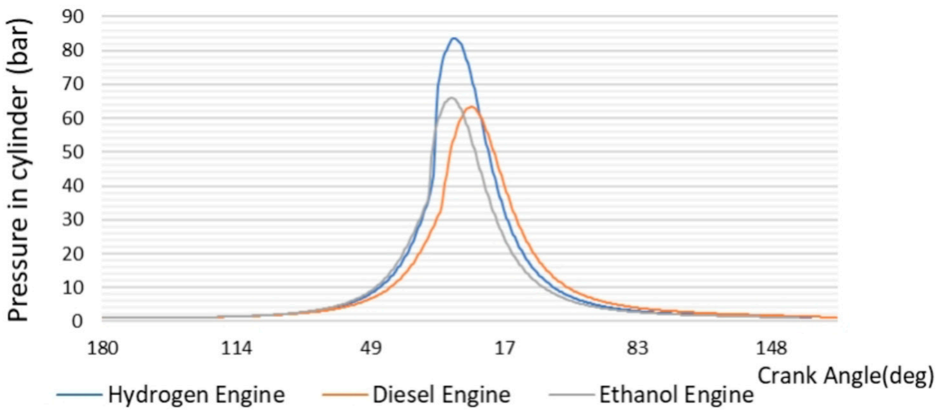

Figure 23. Diesel, ethanol and hydrogen engine in-cylinder pressure.

After applying the Miller cycle, the results showed an improvement in engine performance, but there were still high NOx emissions. So, to solve the problem of high NOx emissions from hydrogen engines, other technologies need to be utilized. The main control measure in current studies in the internal combustion engine field is using exhaust gas recirculation (EGR) technology. EGR technology means that part of the exhaust gas from the engine is returned to the intake pipe and mixed with fresh air to enter the cylinder again, which not only dilutes the oxygen concentration of the gas entering the cylinder and adds an inert gas, thus reducing NOx emissions. EGR systems are often used to improve NOx emissions and improve fuel economy in engines of any fuel type. The current research results show that EGR technology is effective, and future research on hydrogen engines to reduce NOx emissions will still focus on EGR technology, such as EGR systems at different temperatures and pressures [11]. Due to the limited time available for the whole study in this paper, no simulations related to EGR technology were carried out, and the literature can be consulted for reference regarding its specific effects.

4. Conclusions

The main aim of this research is to investigate the effect of the Miller cycle and renewable energy sources on engine performance and NOx emissions by modelling the engine using Ricardo WAVE and applying two versions of the Miller cycle (EIVC and LIVC) and renewable energy sources, namely ethanol and hydrogen, to simulate their operation and analyze and discuss their outputs. The performance output of turbocharged diesel engines under EIVC Miller cycle is also explored.

From this study, the following conclusions were obtained:

1. The application of two versions of the Miller cycle (EIVC and LIVC) to diesel engines both lead to a lower NOx emission, and the reduction in NOx emissions becomes greater as the degree of Miller cycle increases. Moreover, comparing the two versions of the Miller cycle, LIVC is more effective in NOx reduction than EIVC. Diesel engines with the Miller cycle applied show a decrease in brake power and brake thermal efficiency and an increase in BSFC at medium to high loads.
2. In general, the power performance of the Miller cycle diesel engine improved after the application of turbocharger, with the most significant improvement being the −25%EIVC Miller cycle turbocharger diesel engine, as demonstrated by a maximum increase in brake power of 32%, accompanied by an increase in brake thermal efficiency and a decrease in BSFC, compared to the original diesel engine.
3. The ethanol engine with the original diesel cycle has lower brake power (but higher power at 50% and 25% load), higher BSFC, and higher brake thermal efficiency (lower thermal efficiency at 10% load) compared to the diesel engine. NOx increases slightly at 100% load and decreases at all other loads.
4. NOx emissions are reduced for the ethanol engine with the addition of both versions of the Miller cycle. The EIVC Miller cycle has a small effect on engine performance within ±6.6%. The LIVC version of the Miller cycle has a large effect on the performance of the ethanol engine at 10% load, with an increase in brake power and brake thermal efficiency, a decrease in BSFC, and a slight influence on the other four loads.
5. Hydrogen engines have noticeable improvement in brake power and brake thermal efficiency compared to diesel engines, but this is accompanied by much more NOx emissions. However, this phenomenon can be solved by using a three-way catalytic method. Thus, the NOx emitted from the vehicle exhaust gas is converted into a harmless gas by oxidation and reduction. This technology is currently relatively mature, and the three-way catalytic converter is installed in the exhaust pipe to reduce NOx emissions.
6. Through this research, it can be concluded that the influences of the Miller cycle on the engine under different operating conditions are extremely complex, and in order to design the engine to achieve energy saving and emission reduction with good performance, different factors need to be considered, such as the load of the real working conditions of the engine and the fuel type of the engine.

Author Contributions: Conceptualization, Y.W. and M.Y.; methodology, M.Y.; software, M.Y.; validation, M.Y. and Y.W.; formal analysis, M.Y.; investigation, M.Y.; resources, Y.W.; data curation, M.Y.; writing—original draft preparation, M.Y.; writing—review and editing, M.Y.; visualization, M.Y.; supervision, Y.W.; project administration, Y.W.; funding acquisition, Y.W. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by EPSRC grant number (EP/R041970/2 and EP/S032134/1).

Data Availability Statement: All the data for the research are included in the paper.

Acknowledgments: This work was supported funded by the projects of EPSRC (EP/R041970/2 and EP/S032134/1). The authors would like to thank EPSRC.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Wang, Y. Study of reducing nitride oxide emission from diesel engines. *Guangxi Mach.* **2013**, 24–26. [CrossRef]
2. Zhu, C. Miller Cycle Performance Simulation of a Diesel Engine Based on Two-Stage Supercharging. Ph.D. Dissertation, Southwest Jiaotong University, Chengdu, China, 2016.
3. Yang, F. Research on the Influence of Miller Cycle on the High Strength Diesel Engine Performance. Master's Thesis, Taiyuan University of Technology, Taiyuan, China, 2020.
4. Hu, Y.; Ni, J.; Shi, X.; Guan, Z. CFD simulation analysis of diesel engine combustion based on miller cycle. *Veh. Engine* **2020**, 31–37. [CrossRef]
5. Wang, Y.; Zeng, S.; Huang, J.; He, Y.; Huang, X.; Lin, L.; Li, S. Experimental investigation of applying miller cycle to reduce NOx emission from diesel engine. *Proc. Inst. Mech. Eng. Part A J. Power Energy* **2005**, *219*, 631–638. [CrossRef]
6. Li, C.; Wang, Y.; Jia, B.; Roskilly, A.P. Application of miller cycle with turbocharger and ethanol to reduce NOx and particulates emissions from diesel engine—A numerical approach with model validations. *Appl. Therm. Eng.* **2019**, *150*, 904–911. Available online: https://www.sciencedirect.com/science/article/pii/S1359431118375628 (accessed on 16 January 2022). [CrossRef]
7. Zhang, X. Research of Miller Cycle and Sequential Turbocharging System on Diesel Engine. Ph.D. Dissertation, North Central University, Minneapolis, MN, USA, 2022.
8. Wei, W.; He, X.; Zhu, H.; Duan, J.; Qin, G. Effect of different combustion modes on the performance of hydrogen internal combustion engines under low load. *Sustainability* **2022**, *14*, 6095. [CrossRef]
9. Li, N. Optimized Matching of an Ethanol-Diesel Engine, Its Properties and Emission Characteristics. Ph.D. Dissertation, Tianjin University, Tianjin, China, 2007.
10. Zhang, Y.; Luo, Q.; Liu, F. Research status and development prospect of hydrogen engine. *Small Intern. Combust. Motorcycle* **2007**, *36*, 7.
11. Fan, Y. Review of research progress on hydrogen engines for vehicles. *Intern. Combust. Engines Accessories* **2021**, *3*, 3.
12. Millo, F.; Bernardi, M.G.; Delneri, D. Computational Analysis of Internal and External EGR Strategies Combined with Miller Cycle Concept for a Two Stage Turbocharged Medium Speed Marine Diesel Engine. *SAE Int. J. Engines* **2011**, *4*, 1319–1330. [CrossRef]
13. Gonca, G.; Sahin, B.; Ust, Y.; Parlak, A.; Safa, A. Comparison of steam injected diesel engine and Miller cycled diesel engine by using two zone combustion model. *J. Energy Inst.* **2015**, *88*, 43–52. [CrossRef]
14. Rinaldini, C.A.; Mattarelli, E.; Golovitchev, V.I. Potential of the Miller cycle on a HSDI diesel automotive engine. *Appl. Energy* **2013**, *112*, 102–119. Available online: https://www.sciencedirect.com/science/article/pii/S0306261913004698 (accessed on 16 January 2022). [CrossRef]
15. Wu, C.; Puzinauskas, P.V.; Tsai, J.S. Performance analysis and optimization of a supercharged Miller cycle Otto engine. *Appl. Therm. Eng.* **2003**, *23*, 511–521. [CrossRef]
16. Wei, S.; Zhao, X.; Liu, X.; Qu, X.; He, C.; Leng, X. Research on effects of early intake valve closure (EIVC) miller cycle on combustion and emissions of marine diesel engines at medium and low loads. *Energy* **2019**, *173*, 48–58. [CrossRef]
17. Rakopoulos, C.; Giakoumis, E. Speed and load effects on the availability balances and irreversibilities production in a multi-cylinder turbocharged diesel engine. *Appl. Therm. Eng.* **1997**, *17*, 299–313. Available online: https://www.sciencedirect.com/science/article/pii/S1359431196000142 (accessed on 17 January 2022). [CrossRef]
18. Gonca, G.; Sahin, B. The influences of the engine design and operating parameters on the performance of a turbocharged and steam injected diesel engine running with the Miller cycle. *Appl. Math. Model.* **2016**, *40*, 3764–3782. Available online: https://www.sciencedirect.com/science/article/pii/S0307904X15007076 (accessed on 17 January 2022). [CrossRef]
19. Wu, B.; Zhan, Q.; Yu, X.; Lv, G.; Nie, X.; Liu, S. Effects of Miller cycle and variable geometry turbocharger on combustion and emissions in steady and transient cold process. *Appl. Therm. Eng.* **2017**, *118*, 621–629. [CrossRef]
20. Pan, X.; Zhao, Y.; Lou, D.; Fang, L. Study of the Miller Cycle on a Turbocharged DI Gasoline Engine Regarding Fuel Economy Improvement at Part Load. *Energies* **2020**, *13*, 1500. [CrossRef]
21. Martins, M.E.; Lanzanova, T.D. Full-load Miller cycle with ethanol and EGR: Potential benefits and challenges. *Appl. Therm. Eng.* **2015**, *90*, 274–285. [CrossRef]
22. Chen, Z.; Li, T.; Wang, B.; Gao, T.; Zheng, M. Combustion, performance and emission characteristics of ethanol–fueled engine with diesel micro-pilot injection ignition. *Veh. Engine* **2017**, 7–12. [CrossRef]
23. Pedrozo, V.B.; Zhao, H. Improvement in high load ethanol-diesel dual-fuel combustion by Miller cycle and charge air cooling. *Appl. Energy* **2018**, *210*, 138–151. [CrossRef]
24. Wang, W.; Hou, Q.; Bai, S.; Cai, Y. Numerical simulation on 475 diesel engine use ethanol-diesel mixed fuel. *Intern. Combust. Engine Parts* **2018**.
25. Jahanbakhshi, A.; Karami-Boozhani, S.; Yousefi, M.; Ooi, J.B. Performance of bioethanol and diesel fuel by thermodynamic simulation of the miller cycle in the diesel engine. *Results Eng.* **2021**, *12*, 100279. [CrossRef]
26. Balki, M.K.; Sayin, C.; Sarıkaya, M. Optimization of the operating parameters based on Taguchi method in an SI engine used pure gasoline, ethanol and methanol. *Fuel* **2016**, *180*, 630–637. [CrossRef]
27. Khoa, N.X.; Lim, O. Influence of combustion duration on theperformance and emission characteristics of a spark-ignition enginefueled with pure methanol and ethanol. *ACS Omega* **2022**, *7*, 14505–14515. [CrossRef] [PubMed]
28. Boretti, A. *Analysis of Design of Pure Ethanol Engines*; SAE Technical Paper, Tech. Rep.; SAE: Warrendale, PA, USA, 2010.

29. Martínez, F.A.; Ganji, A.R. *Performance and Exhaust Emissions of a Single-Cylinder Utility Engine Using Ethanol Fuel*; SAE Technical Paper; SAE: Warrendale, PA, USA, 2006.
30. Antunes, J.G.; Mikalsen, R.; Roskilly, A. An experimental study of a direct injection compression ignition hydrogen engine. *Int. J. Hydrogen Energy* **2009**, *34*, 6516–6522. [CrossRef]
31. Qi, T. Combustion and Emission Characteristics of Hydrogen and Hydrogen-Containing Fuel Engines. Ph.D. Dissertation, Shanghai Jiao Tong University, Shanghai, China, 2009.
32. Chaichan, M.T. Egr effects on hydrogen engines performance and emissions. *Int. J. Sci. Eng. Res.* **2016**, *7*, 80–90.
33. White, C.; Steeper, R.; Lutz, A. The hydrogen-fueled internal combustion engine: A technical review. *Int. J. Hydrogen Energy* **2006**, *31*, 1292–1305. [CrossRef]
34. Qin, Z.; Yang, Z.; Jia, C.; Duan, J.; Wang, L. Experimental study on combustion characteristics of diesel–hydrogen dual-fuel engine. *J. Therm. Anal. Calorim.* **2020**, *142*, 1483–1491. [CrossRef]
35. Lee, S.; Kim, G.; Bae, C. Effect of injection and ignition timing on a hydrogen-lean stratified charge combustion engine. *Int. J. Engine Res.* **2022**, *23*, 816–829. [CrossRef]
36. Wright, M.L.; Lewis, A.C. Decarbonisation of heavy-duty diesel engines using hydrogen fuel: A review of the potential impact on no x emissions. *Environ. Sci. Atmos.* **2022**, *2*, 852–866. [CrossRef]
37. Bao, L.Z.; Sun, B.G.; Luo, Q.H.; Li, J.C.; Qian, D.C.; Ma, H.Y.; Guo, Y.J. Development of a turbocharged direct-injection hydrogen engine to achieve clean, efficient, and high-power performance. *Fuel* **2022**, *324*, 124713. [CrossRef]
38. Babayev, R.; Andersson, A.; Dalmau, A.S.; Im, H.G.; Johansson, B. Computational comparison of the conventional diesel and hydrogen direct-injection compression-ignition combustion engines. *Fuel* **2022**, *307*, 12190. [CrossRef]
39. Luo, L. Design and Simulation of an Organic Rankine Cycle System Driven by Waste Heat from a Diesel Engine. Master's Thesis, Newcastle University, Newcastle upon Tyne, UK, 2017.
40. Liu, Q.; Xing, H.; Wu, Z.; Duan, S.; Song, Y. Miller cycle to reduce Nox emission for marine low-speed diesel engine. *Navig. China* **2016**, *39*, 5.
41. Roper, E.; Wang, Y.; Zhang, Z. Numerical investigation of the application of miller cycle and low-carbon fuels to increase diesel engine efficiency and reduce emissions. *Energies* **2022**, *15*, 1783. [CrossRef]
42. Li, D.-G.; Zhen, H.; Xingcai, L.; Wu-Gao, Z.; Jian-Guang, Y. Physico-chemical properties of ethanol–diesel blend fuel and its effect on performance and emissions of diesel engines. *Renew. Energy* **2005**, *30*, 967–976. Available online: https://www.sciencedirect.com/science/article/pii/S0960148104003039 (accessed on 24 January 2022). [CrossRef]
43. Sun, J.; Tang, Z. Ethanol-diesel oil fuel and its affect on the engine performance. *Small Intern. Combust. Engine Motorcycle* **2008**, *37*, 4.