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A Theoretical Study of A Variable Compression Ratio Engine with Using Piston of Variable Height

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ABSTRACT

The engines with variable compression ratio have a significant effect on increasing the power of engine and decreasing the fuel consumption and pollutions. The modified engine was designed to produce the new technology for variable compression ratio engine using variable piston's height. Where the piston consists of two parts, (upper part and lower part), the height of piston varies by press hydraulic between these parts via pipe within cylinder head. The MATLAB program was used to determine the thermal characteristic for the studied engines (Otto Cycle Engine, Pre-Variable Compression Ratio Engine, Instantaneous Variable Compression Ratio Engine, Miller Cycle Engine with late valve close, Pre-Variable Compression Ratio Miller Cycle Engine with late valve close and Instantaneous Variable Compression Ratio Miller Cycle Engine with late valve close) with/without turbocharger. The results showed the Instantaneous Variable Compression Ratio Engine is the highest power when used without turbocharger. The Instantaneous Variable Compression Ratio Miller Cycle Engine with late valve close has the highest power when it used with turbocharger in maximum limit of compression ratio (1:12). Thus, the modified engine can be used in new technology of variable compression ratio engines.

KEYWORDS

Variable Compression Ratio, Spark Ignition Engine, Miller Engine.

INTRODUCTION

The higher economic fuel and thermodynamic efficiency parameters of engines are increasing with using variable compression ratio [1]. The first US patent of variable compression ratio engine in 1900. The VCR engine will be mainstream in some vehicle classes in near future [2]. Many researchers had studied the VCR engine, Asthana et al. [3] have investigated the different methods to VCR. The comparative efficiency, friction power, consumption of fuel, the rigidity of the engine and the piston kinematics have been studied. Hoeltgebaum et al. [4] have studied VCR's engine configurability, the VCR engines are showed high power output and emission/fuel consumption requirements. Aldhaidhawi et al. [5] have investigated the effect of compression ratio and fuel types on basic fuel consumption and heat efficiency of the brakes. Shelby et al. [6] have investigated improving of fuel consumption of the continuous variable compression ratio engine. The stroke/bore ratio of variable compression combustion of EIVC have been studied by Sens et al. [7].

The results has showed the turbulent kinematic energy was increased by 30 per cent. Nayyar et al. [8] have tested the small VCR engine with using the n-butanol-diesel blends at different concentrations. The results have been showed the low emission, with slight improvement in engine performance the alternative diesel engines when using fuels are 20% from an n-butanol-diesel blend. Mănescu et al. [9] have examined the VCR engine, which is consists of a crank, a shaft, control lever, and an intermediate triangular part. Soudagar et al. [10] have examined the effecting of compression ratio and blending ratio on engine performance characteristics such as fuel consumption, brake thermal efficiency. Mishra et al. [11] have tested an alternative fuel that satisfies oil or fossil fuels specifications. Dubey et al. [12] have studied the emission characteristics, combustion and engine's performance with using the dual biodiesel (Jatropha biodiesel) and turpentine oils. Rațiu et al. [13] have studied Compression ratio change technology an internal combustion engine during operation of the engine.

Mubarak [14] has investigated the most VCR technologies and has study the stress analysis on the VCR engine by Ansys software, in order to demonstrate the effect of the compression ratio of a piston. Maji et al. [15] have experimentally investigated the NOx pollution is substantially reduced with using of WED10. Wittek et al. [16] have researched the fuel consumption in low and high loads at higher variation in compression ratio. Guangfu et al. [17] have tested the effecting of compression ignition of the VCR and VVT strategies in heavy-duty diesel engines by using genetic algorithm. Mănescu et al.[18] have numerically studied the effect on the compression ratio of the geometric dimensions. García et al. [19] have experimentally studied the potential for VCR technology implementation in many electric vehicle hybrid platforms. The results are contrasted with a typical fixed compression engine. Nuthan Prasad et al. [20] have experimentally investigated thermal characteristics when using methanol fuel mixed gasoline fuel from single cylinder, 4-stroke, and VCR engine. The results have showed that improving in combustion because of improving in fuel atomizing quality.

López et al. [21] have enhanced the relative advantage of the VCR technology, considering the greater fuel consumption incentives of the instantaneous VCR device at road cycles, by an expanded amount of time spent on CR-high at all driving simulation cycles. Higher transitional periods at such applied load remained the higher. Likhanov et al. [22] have considered ways to decrease the grime content in the exhaust gases. Amaliyah et al. [23] have studied Change in the torque effect of compressive ratio, thermal efficiency of specific fuel consumption, power and braking. Gowtham et al. [24] have studied achieving potentially higher fuel consumption, more power and fewer emissions than other technologies available. The objective of this work is to study the thermal characteristics of variable compression ratio engine when using the modified varied height of piston within not exceed the limit of compression ratio to maintained the high engine performance and to reduce fuel consumption, reduce toxic and harmful emissions. The thermal characteristics and engine performance will study for variable compression ratio engine of traditional engine and Miller engine without/with turbocharger.

METHODOLOGY

To improve the thermal efficiency and brake power in internal combustion engines, in this study, a new design of a variable engine piston's height was designed to achieve a variable compression ratio engine as shown in figure 1. The piston consisted of two parts, the upper part and the lower part, where the height of the piston changes by control the hydraulic oil pressure between them, it is controlled by the electronic control module. For increasing the volumetric efficiency by increasing the displacement volume in intake stroke and increasing the allowable the compression ratio, by decreasing the clearance volume in compression stroke and exhaust stroke which can achieved by changing the piston's height in the four-stroke SI engine.

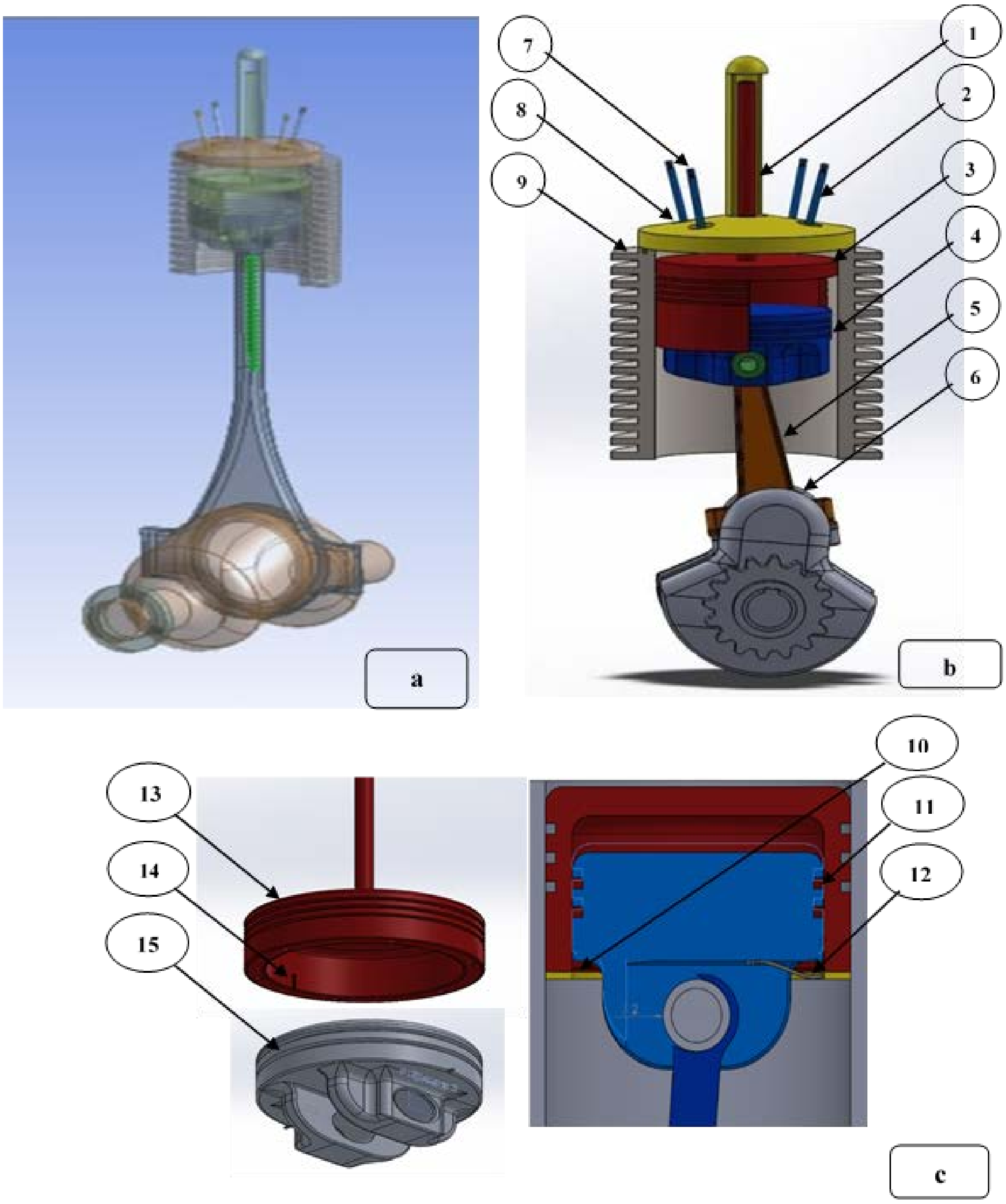

Figure 1. Variable Compression Ratio SI Engine with Using Variable Piston's Height (a) transparent view of the engine, (b) Engine section, (c) Variable-height piston section. (1) Hydraulic oil inlet pipe, (2) Exhaust valve, (3) upper part of piston, (4) lower part of piston, (5) Connected rod, (6) crank offset, (7) Inlet valve, (8) Head Cylinder, (9) cylinder, (10) piston lock, (11) piston rings, (12) return spring, (13) notches to restrict piston movement.

The thermal characteristics (thermal efficiency, net brake work, torque, power and average fuel consumption, etc.), are found with used the MATLAB 2020 program as shown in figure 2, where the piston's height is continuous varied linearly.

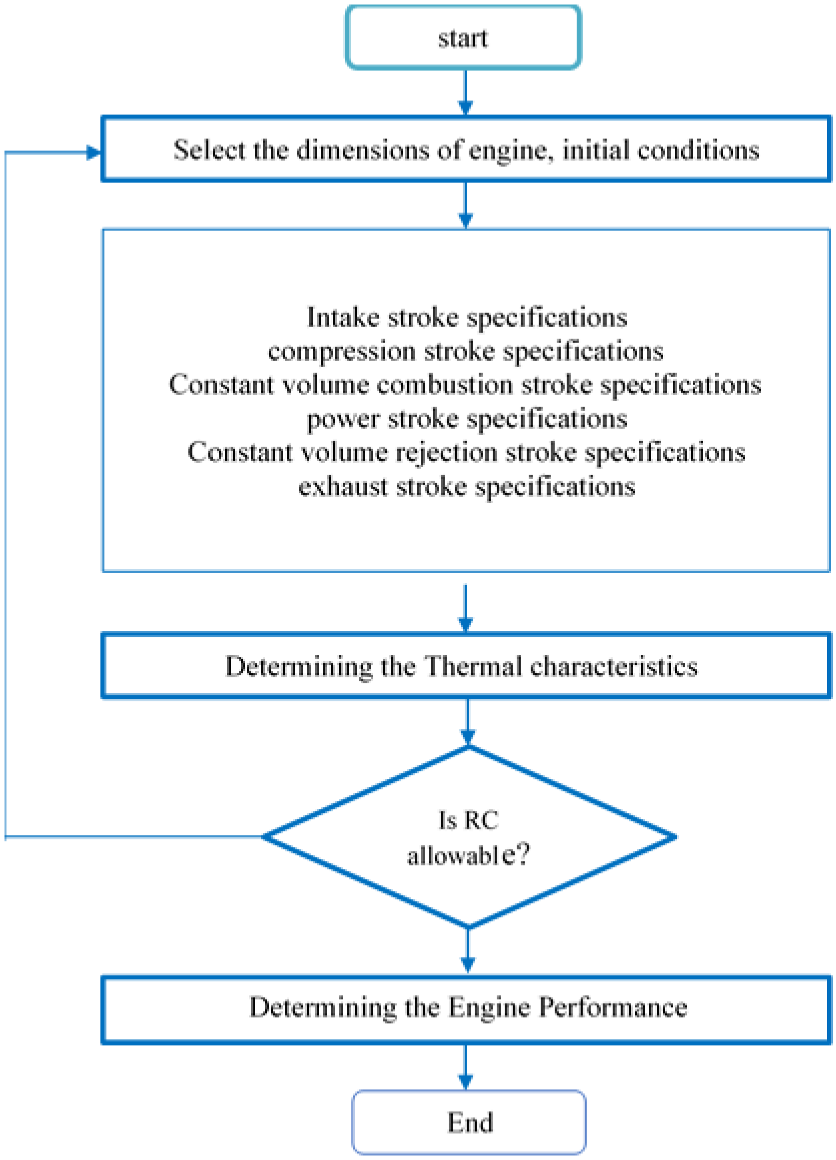

Figure 2. Flowchart for determining the engine performance and thermal characteristics for (Otto cycle engine, Pre-variable engine and Instantaneous variable engine).

RESULTS AND DISCUSSION

In this present work, the four strokes, SI, L4, engine was numerically examined of for Otto cycle engine, Miller engine with/without turbocharger. The inlet pressure and temperature and the dimensional specifications of the engine such as crank offset, connected rod length, bore diameter, and clearance volume were taken as shown in table 1.

Table 1. The engine parameters and operating conditions.

Parameter	**Value**
Crank Offset	4.65575 e-2 m
Connected Rod	16.6e-2 m

Cylinder Bore	9.19e-2 m
Clearance Volume	82.2e-6 m^3
Inlet Pressure	100 kPa
Inlet Temperature	333 K

The results were implemented for two methods as:

Pre-Variable Compression Ratio Method:

It is assumed that there is the piston height was adjusted before operating the engine by (2mm).

Instantaneous Variable Compression Ratio Method:

The variation of piston's height is varying linearly during the strokes of cycle. During compression and exhaust strokes, the hydraulic oil pressed to the chamber between the piston's parts which leads to increases the piston's height (the height of piston increase about 3.6 mm), thus the clearance volume decreased. In the intake stroke, when the piston down from top dead center (TDC), the hydraulic oil is gradually withdrawn to minimum piston height until it reaches the bottom dead center (BDC), this leads to an increase in the length of the stroke and ultimately, an increase in the displacement volume, which leads to an increase in the compression ratio and volumetric efficiency. The results show thermal characteristics of the Instantaneous-variable compression ratio engine, pre-variable compression ratio engine, and Otto engines with and without the turbocharger such as: net brake work, thermal efficiency, volumetric efficiency, engine capacity, brake torque, fuel consumption rate, specific brake power as detailed below:

Comparing the Otto engine, pre-variable engine, and instantaneous variable engine without turbocharger:

Table 2. shows the thermal characteristics and compression ratios of these three engines, it was found that the highest values of the properties were achieved when using variable compression ratio with instantaneous variable engine as shown in figure 3.

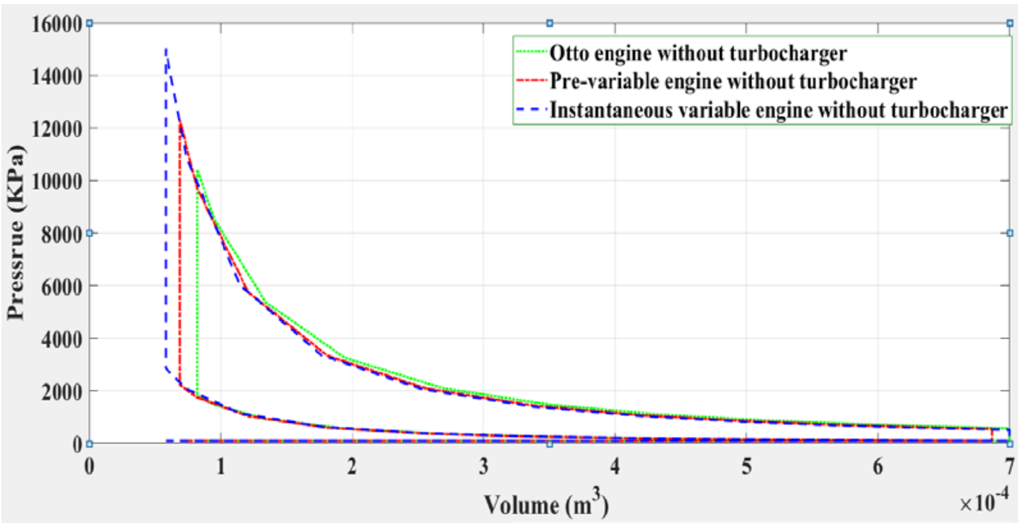

Figure 3. Comparison between pressure and volume for (Otto Engine, Pre-Variable Engine and Instantaneous Variable Engine) without turbocharger.

Table 2. The results of the thermal characteristic of the three-mentioned engines.

parameters	Unit	Otto engine	Pre-variable engine	Instantaneous variable engine
Net Brake output Work	kJ	1.0680	1.0980	1.1764
Thermal Efficiency	--	0.5268	0.5520	0.5802
Indicated Mean Effective Pressure	kPa	1.7293e+03	1.7777e+03	1.8338e+03
indicate power for all cylinder	kJ	1.0680e+02	1.0980e+02	1.1764e+02
Brake Work	kJ	0.9186	0.9443	1.0117
brake power for all cylinder	kJ	91.8557	94.4278	101.1705
Torque	N*m	2.9238e+02	3.0057e+02	3.2203e+02
friction power	kW	14.9532	15.3719	16.4696
Brake Mean Effective Pressure	kPa	1.4872e+03	1.5288e+03	1.5770e+03
Brake Specific Power	kW/m3	0.3462	0.3559	0.3813
Output Per Displacement	kW/L	37.1796	38.2208	40.9499
brake specific fuel consumption	kg/s/kW	4.9825e-05	4.7549e-05	4.5237e-05
Volumetric Efficiency	--	0.9411	0.9233	0.9411
Compression Ratio	--	8.5140	9.9600	12.0000

Comparison of Otto engine, pre-variable engine and instantaneous variable engine with the turbocharger:

Where the air intake pressure and temperature of (250 kPa) and (400 K) respectively, table 3. shows the thermal characteristics of these three engines, it was found that the highest values of the thermal characteristics were achieved when using instantaneous variable engine as shown in figure 4.

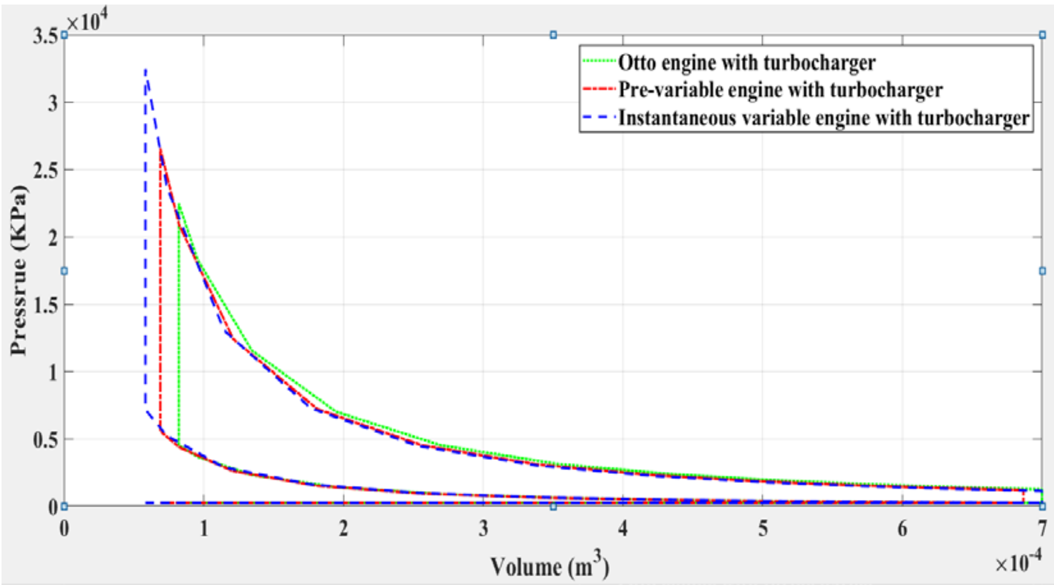

Figure 4. Comparison between Pressure and Volume for (Otto Engine, Pre-Variable Engine and Instantaneous Variable Engine) with Turbocharger.

Table 3. Shows thermal characteristics for the three-mentioned engines.

parameters	Unit	Otto engine	Pre-variable engine	Instantaneous variable engine
Net Brake output Work	kJ	2.2230	2.2852	2.4484
Thermal Efficiency	--	0.5268	0.5520	0.5802
Indicated Mean Effective Pressure	kPa	3.5991e+03	3.6999e+03	3.8165e+03
indicate power for all cylinder	kJ	2.2229e+02	2.2852e+02	2.4484e+02
Brake Work	kJ	1.9117	1.9653	2.1056
brake power for all cylinder	kJ	1.9117e+02	1.9653e+02	2.1056e+02
Torque	N*m	6.0853e+02	6.2557e+02	6.7024e+02
friction power	kW	31.1214	31.9929	34.2774
Brake Mean Effective Pressure	kPa	3.0952e+03	3.1819e+03	3.2822e+03
Brake Specific Power	kW/m3	0.7205	0.7407	0.7936
Output Per Displacement	kW/L	77.3801	79.5470	85.2270
brake specific fuel consumption	kg/s/kW	4.9825e-05	4.7549e-05	4.5238e-05
Volumetric Efficiency	--	1.9588	1.9216	1.9588
Compression Ratio	--	8.5140	9.9600	12.0000

Comparison of the Miller engine, Miller's pre-variable engine and Miller's instantaneous variable engine naturally inspirited:

Table 4. shows the thermal characteristics and expansion ratio of these three engines, it was found that the highest values of thermal characteristics were achieved when using the instantaneous variable Miller engine as shown in figure 5, where the engine dimensions and operating conditions as mentioned in table 1.

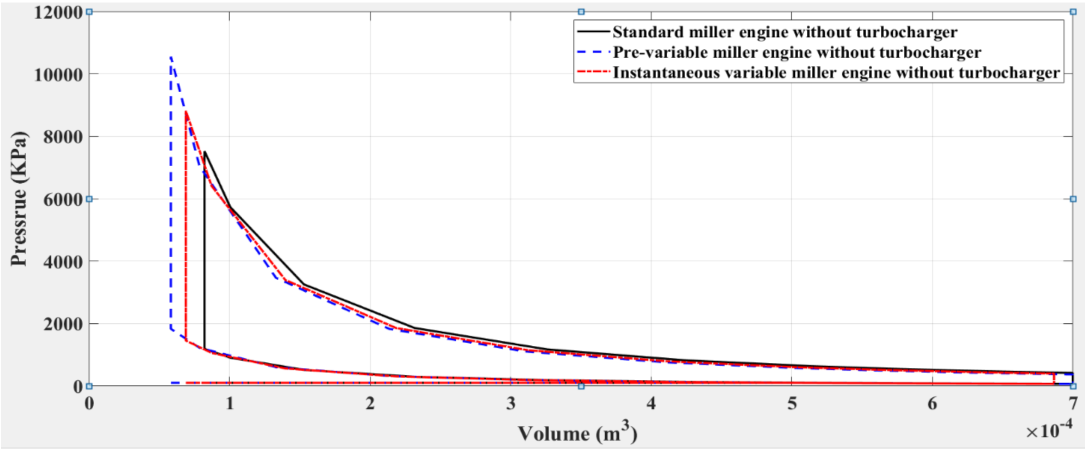

Figure 5. Comparison between Pressure and Volume for (Standard Miller Engine, Pre Variable Miller Engine and Instantaneous Variable Miller Engine) without Turbocharger.

Table 4. shows thermal characteristic for the three-mentioned engines.

Parameters	Unit	Miller engine	Miller Pre-variable engine	Miller Instantaneous variable engine
Net Brake output Work	kJ	0.7811	0.7974	0.8401
heat added for one cylinder during one cycle	kJ	1.4895	1.4511	1.4549
Thermal Efficiency	--	0.5244	0.5495	0.5775
Indicated Mean Effective Pressure	kPa	1.2647e+03	1.2910e+03	1.3096e+03
indicate power for all cylinder	kJ	78.1130	79.7399	84.0143
Brake Work	kJ	0.6718	0.6858	0.7225
brake power for all cylinder	kJ	67.1771	68.5763	72.2523
Torque	N*m	2.1383e+02	2.1829e+02	2.2999e+02
friction power	kW	10.9358	11.1636	11.7620
Brake Mean Effective Pressure	kPa	1.0876e+03	1.1103e+03	1.1263e+03
Brake Specific Power	kW/m3	0.2531	0.2585	0.2723
Output Per Displacement	kW/L	27.1907	27.7570	29.2450
brake specific fuel consumption	kg/S/kW	5.0051e-05	4.7765e-05	4.5455e-05

Volumetric Efficiency	--	0.6914	0.6736	0.6754
Compression Ratio	--	6.2548	7.2661	8.6111
Expansion Ratio	--	8.5140	9.9600	12.0000

Comparison of Miller engine, Miller's pre-variable engine and Miller's instantaneous variable engine with the turbocharger:

Where the air intake pressure and temperature of (250 kPa) and (400 K) respectively, table 5. shows the thermal characteristics and expansion ratio of these three engines, it was found that the highest values of the thermal characteristics were achieved when using the instantaneous variable Miller engine, followed by the pre-variable Miller engine and then the conventional Miller engine, as shown in figure 6.

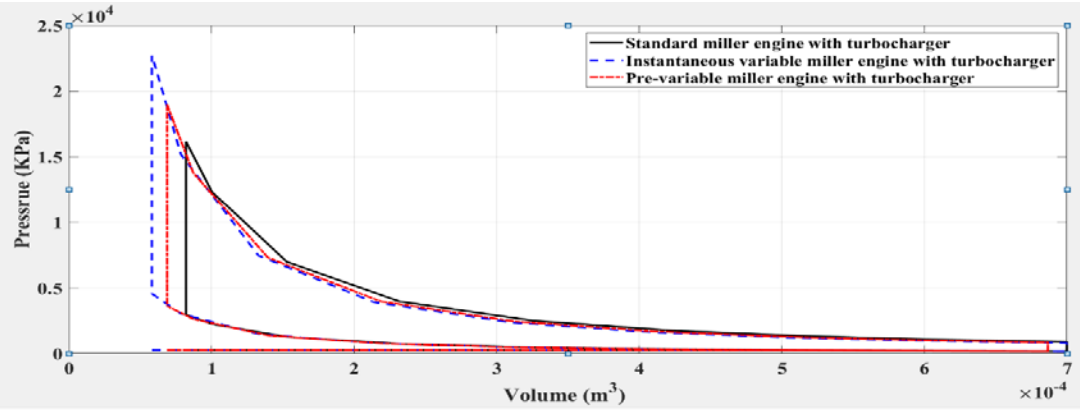

Figure 6. Comparison between Pressure and Volume for (Standard Miller Engine, Pre-Variable Miller Engine and Instantaneous Variable Miller Engine) with Turbocharger.

Table 5. Shows thermal characteristic.

Parameters	Unit	Miller engine	Miller Pre-variable engine	Miller Instantaneous variable engine
Net Brake output Work	kJ	1.7169	1.7507	1.8431
heat added for one cylinder during one cycle	kJ	3.1000	3.0200	3.0280
Thermal Efficiency	--	0.5538	0.5797	0.6087
Indicated Mean Effective Pressure	kPa	2.7797e+03	2.8345e+03	2.8730e+03
indicate power for all cylinder	kJ	1.7168e+02	1.7507e+02	1.8430e+02
Brake Work	kJ	1.4765	1.5056	1.5851
brake power for all cylinder	kJ	1.4765e+02	1.5056e+02	1.5850e+02
Torque	N*m	4.6999e+02	4.7925e+02	5.0453e+02
friction power	kW	24.0365	24.5101	25.8033
Brake Mean	kPa	2.3906e+03	2.4377e+03	2.4708e+03

Effective Pressure				
Brake Specific Power	kW/m3	0.5565	0.5675	0.5974
Output Per Displacement	kW/L	59.7641	60.9417	64.1571
brake specific fuel consumption	kg/s/kW	4.7394e-05	4.5279e-05	4.3123e-05
Volumetric Efficiency	--	1.4390	1.4019	1.4056
Compression Ratio	--	6.2548	7.2661	8.6111
Expansion Ratio	--	8.5140	9.9600	12.0000

CONCLUSIONS

The modified variable compression ratio engine with variable height of piston produced the high thermal efficiency, high brake power, low fuel consumption and less harmful emissions when used with traditional engine or Miller engine. This modified design is characterized by ease of manufacture, where, it was noted that the best thermal characteristic and engine performance was with the instantaneous variable engine with turbocharger. The variable compression ratio engine with linear variable piston' height gives efficient thermal characteristics comparing with Otto engine and pre-variable Piston's height engine.

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