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The Effect of Compression Ratio on the Performance and Emissions of Internal Combustion Engine Using Oxy Fuels: Review

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ABSTRACT
Energy sources are becoming a major issue, with the main concern being cost and continuous supply. The production of oxy fuels is cheap, simple and environmentally friendly, as well as being able to be produced locally, reducing the cost of transporting fuel. Oxy fuels are used as a pure fuel directly in an engine or can be mixed with fossil fuel. The fuels granted under oxy fuels are methanol, ethanol, butanol and biodiesel. Oxy fuel has a good impact on engine performance and emissions, due to higher vaporization, high octane value, high inflammability temperature and a single boiling point. The purpose of the paper was to examine the internal combustion engine performance and emission due to the effect of compression ratio powered by oxy fuels that could replace petrol fuel or improve its fuel properties. The higher-octane value of oxy fuels can result in higher compression ratios before engine knocking starts, thus more power can be developed economically in the engine. One of the facts found from this review study was the slight increases or decreases in power when oxy fuels were used at the original compression ratio in internal combustion engines. Also, carbon monoxide, hydrocarbon and nitrogen oxide emissions decreased while the fuel consumption increased. But higher compression ratio increased engine performance and fuel consumption both for spark ignition and compression ignition engines decreased. There were decreased emissions of carbon dioxide, carbon monoxide and nitrogen oxides from oxy fuels as the compression ratio of the spark ignition engine grew but the hydrocarbon emission increased. In the compression ignition engine, the hydrocarbon, carbon monoxide and nitrogen oxide emissions decreased as the compression ratio increased with biodiesel fuel.

Keywords: *biodiesel, oxy fuel, compression ignition engine, ethanol fuel, spark ignition engine*

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INTRODUCTION

The call for energy is increasing day by day, year by year because of the rise of economic activities and quality of lifestyles due to the depletion of non-renewable resources. Oxy fuels (also called as “oxygenated fuels”) made out of renewable sources, together with alcohols (those including more than two C atoms) and many other oxy compounds, had been proposed as mix parts in gas and diesel to lower fossil oil intake and emissions. Generally, oxygenates are referred as the compounds containing oxygen molecules.

The very common fuels that come under oxy fuels are alcohols such as ethanol, methanol and butanol. Also, biodiesel had been considered as one of the vital oxy fuels that attract the global attention of researchers and corporations [1–6]. Biodiesel and alcohols as fuels decrease the greenhouse gasses emissions, compared to gas and diesel fuels [7, 8]. Due to less pollutant content such as sulfur in these fuels, the emissions from these fuels are not up to that of fossil fuels [9, 10]. Increasing fear for environmental air pollution at the side of keeping up performance of diesel engines has led to in-depth analysis in area of fuels. Among many options investigated, biodiesels have confirmed to be the suitable fuels for diesel engines. It is observed that efficiency of biodiesel is very similar to diesel engines with less emission. One of the researchers [11] studied the oxygen content effect on emissions in a diesel engine, and found that the development of emissions depended on the amount of oxygen within the gasoline. Furthermore, the addition of oxy natural compounds to fossil fuel helps in improving diesel and gasoline combustion and emissions [12–15]. Decrease in engine air pollution is an important research aspect in engine building, with an expanding worry concerning the environmental coverage. The effects of gas–ethanol blends have been investigated by researchers [16], and they reported a buildup in engine torque and gasoline consumption. Also, it used to be noticed that carbon monoxide (CO) and hydrocarbon (HC) emissions decreased dramatically due to the use of ethanol additive, and carbon dioxide (CO_2) emission diminished because of the enhanced combustion. The thermal efficiency used to be stepped forward, and the premixed combustion was shorter due to the high oxygen content. The biodiesel enriched with oxygen produces cleaner and whole combustion. The diesel without oxygen content produces a black smoke and incomplete combustion all the way through burning [17]. There is a development of importance on the traditional techniques for reaching higher engine efficiency like raising the compression ratio (CR), in addition to a rising interest within the development of new approaches comparable to lean engine ideas [18]. The rise in CR led to bettering the specific gasoline consumption (SFC) and this has been examined in six vehicles [19]. Ethanol at different compression ratios (CR 9:1–11:1) has been studied [20]. As an end result, the efficiency used to be significantly enhanced. When raised, the CR diminished the gasoline consumption by way of roughly 8%–10% with natural gas, and 20%–21% with ethanol. Thermal efficiency used to be greater at higher CR. Fuel with a better octane number can undergo higher CRs earlier than an engine begins knocking, thus giving an engine the facility to ship more power successfully and economically. Oxy fuels with high octane value permit the increase of CR and may give higher density of fuel–air combination. The increase in CR improves the engine power output and efficiency. Improvements in engine performance by way of increasing the CR is limited via knocking in gasoline powered engines [21, 22]. Methanol and ethanol have a prime octane value that allows for a high CR and gives a decreased emission [23, 24]. The impacts of gasoline–ethanol blends through different CRs (5:1–22:1) on the engine efficiency had been studied [25]. Their experiment used to be completed beneath different mixing ratios of E10, E20, and E30 and E40. For E10, E20 and E30, the optimum CRs were found to be 8, 10 and 12, respectively. The effect of CRs (19:1, 18:1 and 17:1) on efficiency and emission parameters for a compression ignition (CI) engine working on biodiesel–diesel blend was investigated [26]. It was seen that gasoline intake and thermal efficiency had been enhanced via the increase of CR comprehensive to the original CR 18. Furthermore, brake thermal efficiency (BTE) was lowered by using biodiesel as fuel in a CI diesel engine [27]. The purpose of this paper is to study on the effect of CR at the performance and emissions of spark ignition (SI) and CI operated with oxy fuels.

EFFECTS OF CR WITH OXY FUELS ON SI ENGINE

Oxy fuels have a significant effect on the performance and emission of SI engine by varying the CR due to the high latent vaporization heat (LHOV), high oxygen content and high-octane number. CR's effects on SI engine are reviewed in the following sections.

Effect on Engine Efficiency and Performance

Oxy fuels such as ethanol, methanol and butanol are suitable fuels for high-power engines with variable CR due to high octane value. Most researchers [24, 28–32] reported that, by increasing the CR with oxy fuels, the power (P), torque (T) and thermal efficiency (TE) improved. Meanwhile, 100% of researchers [24, 28–31] reported a decrease in SFC in the SI engine, as discussed in this section in detail. Increase in the CR gives an increase in flame speed, an increase in the air–fuel ratio, and a high CR (15:1) for an SI engine improved the peak engine efficiency by 6%–7% [18]. Study done on the effects of pure methanol and gasoline with a high CR in the SI engine, with different CRs (6:1, 8:1and 10:1), different engine speeds (1500–3500 rpm) and full engine load [34]. By using methanol at the same CR, the engine power and torque decreased insignificantly, and the thermal efficiency of the brake increased. By increasing the CR from 6:1 to 10:1 in addition to methanol as the fuel, the engine torque, power and thermal efficiency of the brake increased while the SFC decreased the CR. Finally, at the same CR as gasoline, using methanol as fuel SFC

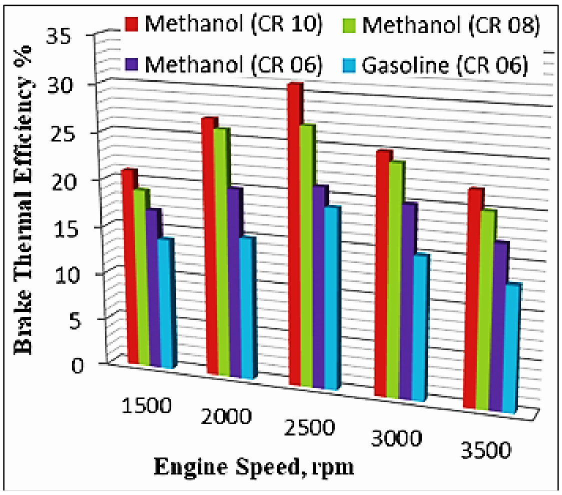

Fig. 1. *Variation of brake thermal efficiency of methanol at different compression ratio and variable engine speeds [25].*

increased and was 90% higher than gasoline. However, when the CR was raised to 10:1, it was only 40% higher. In addition, by increasing CR from 6:1 to 10:1, there was a 36% increase in BTE by using methanol as shown in Figure 1.

To increase the CR of SI engines, it is necessary to avoid the event of engine knock. The brake-specific fuel consumption (BSFC) under the high-load and low-speed engine was increased at the high CR, while the BSFC was improved according to the higher thermal efficiency with the part load and average engine speed. Finally, it was found that high CR and high-octane value fuel had some effects on the improvement of the fuel economy. At different engine speeds (2000, 3500, and 5000 rpm), the effect of different CRs (7:1–13:1) and different gasoline–ethanol blends (E0, E10, E20, E40 and E60) on the performance and emissions of an SI engine was investigated [31]. The increase in fuel consumption was approximately 14% between the CR of E40 and E60 (CR 13:1 and CR 8:1). BSFC's brake-specific fuel consumption of E40 at 2000 rpm engine speed was nearly 15%. BSFC's highest improvements were achieved with E60 fuel below 3500 and

5000 rpm, respectively (14.5% and 17%). In addition, with gasoline fuel, the torque increased at 2000 rpm engine speed by raising the CR to 11:1. The increased ratio was about 8% compared to CR 8:1. At the higher CR, the engine torque change was not clearly observed, while at CR 13:1, the large increase was at nearly 14 % for E40 and E60 fuels compared to 8:1. In addition, the effects of CR and air–fuel ratio on the performance of a single SI engine cylinder were investigated [33]. Tests were conducted at three different ranges (7:1, 9:1 and 11:1) for E10, E30, E85 and different engine speeds. The output power increased as a result of this study with the increased CR. High engine power was achieved at high CR (11:1) at full load with a speed of 3500 rpm for E30 use. It was also decided that by raising the CR [34], both the fuel cost and the engine power could be improved.

Effects on Engine Emissions

According to previous researchers [10, 25, 32, 34, 35], using oxy fuel, NO_x, CO_2 and CO decreased when CR increased, while HC increased with increased CR. It was reported that reduction in CO, CO_2, and NO_x emissions of approximately 37%, 30%, and 22%, respectively, while HC increased in addition to methanol as fuel with increase in CR [5]. A study by the use of ethanol ratio (E0, E25, E50, E75 and E100) in single-cylinder SI engine was also carried out, with an original 6:1 CR modified by changing the cylinder head to different CRs (6:1–10:1) [35]. This study focused in particular on the effect on emissions and engine performance of E50 fuel and pure gasoline under full load and different engine speeds (1500–4000 rpm). As reported in this, with the rise in the concentration of ethanol, the oxygen content increased; thus the combustion of the engine increased due to oxygen, increasing the CO emission. The CO emission reduction with E50 was 45% lower than pure gasoline at same CR 6:1. The maximum CO emission reduction was 53%, with E50 at CR 10:1 compared to pure CR 6:1 gasoline. Meanwhile, CR 10:1 was the highest CO_2 emission reduction with E50 compared to CR 6:1 pure gasoline, which was 10%. The reduction in emissions of HC with E50 was 26% lower than pure gasoline at CR 6:1. The decrease in HC emissions was also 12%, with E50 at CR10:1 compared to pure CR 6:1 gasoline. With respect to NO_x, 33% reduction of NO_x at CR 6:1 and 19% at CR 10:1 compared to pure gasoline. From this study, we can conclude that emissions of CO_2, CO, and NO_x decreased by about 3%, 10%, 12%, and 19%, respectively, when fueled by E50 at high CR compared to gasoline. CO_2 is non-toxic but has a major impact on the greenhouse effect. Because ethanol includes lower carbon atom compared to gasoline, it provides less CO_2 [35]. The HC and CO emissions were evaluated [31], where the HC increased as the CR increased, but reduction occurred with the increased engine speeds as shown in Figure 2. Meanwhile, CO emissions decreased as the CR increased and the lowest CO emissions were with a higher engine speed. Furthermore, researcher [30] examined the emissions of CO and HC using a hydra single-cylinder, four-stroke, SI engine under different CR and other related parameters. As a result, more than 31.8% of CO was reduced under CR 9:1 with E40 compared to around 19.8% and 22.3% under CR 8:1 and CR 9:1, respectively, with E60. In addition, the HC with E60 decreased by 31.45% compared to the CR 10:1 gasoline.

EFFECTS OF CR WITH OXY FUELS ON CI ENGINE

Engines for CI were significantly more efficient than engines for SI [44]. Usually, the diesel engines have 14:1–18:1 engine CR, but some engines have a high CR which may reach 22:1. Oxy fuel properties like cetane number, viscosity, LHOV, contents of oxygen, carbon and hydrogen have a significant effect on the CI engine [10, 45, 46]. Variable compression diesel engines could make an important contribution to improve engine performance and emissions [47, 48]. In the following sections, the effects of CR on CI engines are fully reviewed.

Effects on Engine Efficiency and Performance

Most researchers [37–41, 49] have reported that power (P), torque (T), thermal efficiency (TE) and SFC have improved, and descriptions are provided in this section. In addition, the effect of various engine parameters with biodiesel took one or more parameters at a time and was studied by many researchers. Methyl esters of palm stearin (PSME) oil and diesel engine with different CR were investigated [41] and conducted with 40% palm stearin methyl esters and 60% diesel (PSME40) at constant speed of engine, full load, variable fuel injection pressures (FIPs) and different CRs (16.5:1 and 19:1). According to this study, the BTE engine was increased at PSME40 as the fuel with an injection pressure (IP) below 210 bar and CR 16.5:1 compared to other 190 and 230 bar FIPs. However, at the rated IP of 190 bar, the engine performance was better with CR 19. CR 19:1 has seen higher peak pressures. The engine's volumetric efficiency was about small with PSME40 comparing with diesel; therefore, the BSFC values were reduced. In addition, the impact of the various parameters including different CRs (CR16, CR17 and CR18) and FIPs on the performance and emissions of the diesel engine using Karanj methyl ester (KME) and diesel was investigated in this study [38]. The highest performance was achieved at 250 bar IP and 18 CR, with the BSFC dropping to nearly 2.94% and the BTE rising to nearly 8.2%. At a CR of 18, the BTE improved by 5.45%. Due to high oxygen content, this could result in improved engine combustion. In addition, with a longer heat release time, the delay period was reduced, leading to higher mean pressure. The rate of heat release was seen to increase during the low CR and decrease slightly at high CR. Reason may be the intake of air and lower mixing rate of air/fuel and the influence of blend viscosity. The fuel's heating value is considered as one of the very important parameters to choose the fuel. In particular, alcohol fuels have a low heating value compared to fossil oil, affecting the fuel consumption of the engine. Meanwhile, the CR is considered as a solution to the problem of fuel consumption. The effects of different ethanol blending ratio (E5, E10 and E15) on engine performance and emission on a single ASTM-CFR engine under different CRs (14.85:1, 16:1, 17.48:1, 19:1 and 21:1) were studied [39]. The engine power of ethanol–diesel blends decreased due to the lower heating value and lesser cetane number of ethanol compared to diesel. But as the CR increased, both for blends and pure diesel power and torque increased. As the CR and velocities increased, the torque of the engine rose with the ethanol ratio. However, rise in the CR resulted in the rise in the thermal efficiency of the engine, resulting in a decrement in the fuel consumption specific to the brake [39].

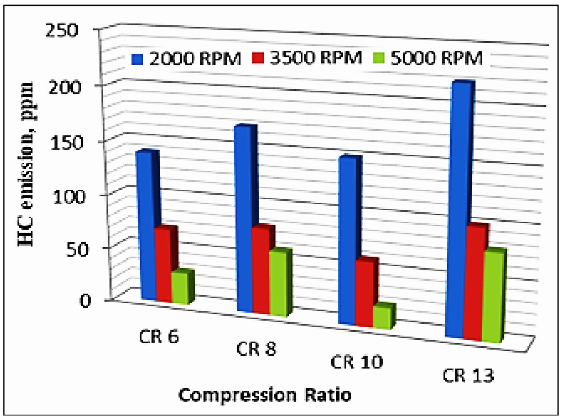

Fig. 2. *Variation of HC emissions with E60 at various compression ratios and speeds [33].*

Effects on Engine Emissions

Biodiesel as oxy fuels increased nitrogen oxide (NO_x) when the CR increased in CI engine, according to researchers [38–43]. The NO_x, CO, and HC emissions lowered with the rise in CR when ethanol was used as oxy fuel. The brake-specific emissions of methanol and diesel as fuel were studied [40]. As a result, methanol brake-specific emissions of NO_x and HC were higher with CR increases, whereas emission of CO slightly decreased with an increased CR. Methanol NO_x emission were about 50% lower than diesel, whereas HC emissions were higher and CO emissions were slightly lower. These results may be because of the higher methanol LHOV which resulted in a drop in the methanol combustion temperature. In addition, researchers [37] used dimethyl ether (DME) as a fuel in a low compression DICI engine to determine the combustion products HC, CO emissions, and engine noise for DME remained nearly constant with different CR (18:1–12:1). To achieve a cleaner and complete combustion, biodiesel with the reality of oxygen could be advanced. Also, the conventional, oxygen-free diesel produces a black smoke and incomplete burning. Under full load and CR 16.5, CO, HC, smoke emission rates of PSME 40 (palm stearin methyl ester) dropped by approximately 8.66%, 27.36% and 1.66%, respectively, comparing with pure diesel, also NO_x emissions rose by 8.42% [41]. As the CR rose to CR 19, NO_x emissions rose by 13.13% compared to diesel emissions. FIP has also played a key role in reducing emissions. In addition, the rise in CR influenced an increase in HC emissions and exhaust temperatures, while reducing smoke and CO emissions. At higher IP, NO_x emissions were determined to remain unchanged [38]. Emissions from biodiesel were lower compared to diesel fuel for all possible CR and IP. The investigation showed that the CR was the very much affecting factor on emissions of CO and HC, followed by the blend of IP and biodiesel. As shown in Figure 3, the increased CR as well as biodiesel reduced the HC emission compared with pure diesel. It was observed that with a rise in CR and IPs, the CO emissions decreased, but with the rise in CR and IP, the NO_x emissions rose. Researcher [37] reported that engine emissions like CO, HC, and NO_x were lower compared to diesel with DME, and when the CR increased, the NO_x rose, still it was lower than diesel emissions. There have been no significant changes in CO and HC with high CR in the meantime. For DME, significantly low CO and HC concentrations implied a very high DME combustion efficiency, close to 99% of all CRs tested. In a study [45] to determine engine emissions using Jatropha biodiesel under different CRs, it was found that HC and CO emissions reduced by an increase in engine load and CR, and a reduction in the emissions of HC and CO was approximately 43% and 50%, respectively, compared to diesel emissions. In the meantime, NO_x increased as the CR increased, with the highest increase being 20%. The behavior of the emissions may be because of the amount of oxygen in biodiesel (11.68%) that influenced complete combustion.

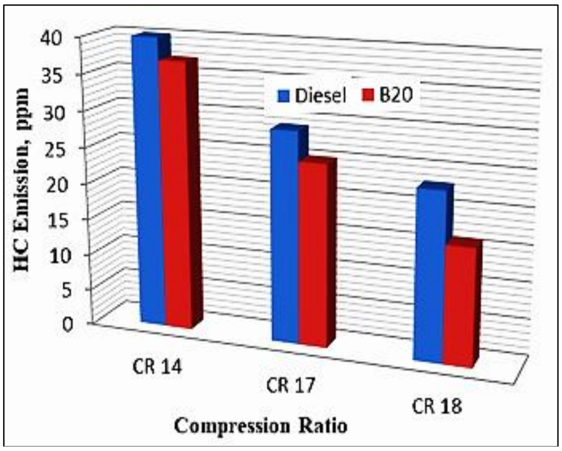

Fig. 3. *Variations of HC emission with various compression ratios for biodiesel and diesel [43].*

CONCLUSIONS

Many types of research works conducted on engines using oxy fuels have shown that they offer an excellent potential for operating ICEs in automobile field. However, this paper investigated the effects of CR on the performance and emission of ICE fuelled by oxy fuels. As reported in this review, the following conclusions are drawn:

1. From the above review, it was found that the engines were run by oxy fuels with original CR of the SI engine had a slight rise or drop in power. In addition, decreases in CO, HC and NO_x emissions have been achieved, while fuel consumption (FC) has increased. Alcohol-based oxy fuels had a higher LHOV, resulting in lower NO_x emissions and increased engine power.
2. The rise in the CR resulted in a rise in flame speed, rise in the air–fuel ratio, and a higher CR improved the engine efficiency.
3. It was seen that NO_x, CO and CO_2 emissions decreased due to more oxygen content due to the rising CR in the SI engine, but with an increase in CR. HC emissions were increased. Also, the HC and CO emissions lowered in the CI engine as the CR increased and the NO_x emission also increased with biodiesel in particular.
4. High CR was used in a low load operating condition for better stability, while the low CR at full load would be better.

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