Journal of Engineering for Gas Turbines and Power. Received May 03, 2022;
Accepted manuscript posted October 05, 2022. doi:10.1115/1.4055882

Effect of Intake Charge Temperature on Oxy-Fuel Combustion (OFC) in an HCCI Diesel Engine under Different CO_2 Dilutions

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Abstract

Carbon dioxide is one of the leading contributors to global warming. Oxy-fuel combustion (OFC) integrated with Carbon Capture and Storage (CCS) technology is an efficient way to reduce carbon dioxide emissions. In OFC, pure oxygen (O_2) is used instead of air to react with hydrocarbon fuel. Consequently, the products of combustion mainly include carbon dioxide (CO_2) and water vapor (H_2O) under lean conditions. Meanwhile, due to the absence of N_2 in the intake charge, nitrogen-related emissions such as NOx are greatly removed from the exhaust gases. In the present study, the effect of intake charge

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temperature on OFC has been investigated in a diesel engine under the Homogeneous Charge Compression Ignition (HCCI) mode. In order to control combustion temperature and avoid overheating problems caused by oxygen in OFC, a portion of the exhaust CO_2 was added to the O_2. For this purpose, different CO_2 dilutions ranging from 79-85% have been employed. It has been found that OFC can significantly reduce CO and PM emissions while eliminating NOx emissions. With a higher intake charge temperature, combustion occurs earlier with shorter main stages, reducing the Indicated Mean Effective Pressure (IMEP) and increasing the Indicated Specific Fuel Consumption (ISFC), whereas, with a lower intake charge temperature, combustion stability deteriorates leading to incomplete OFC. By raising the intake charge temperature from 140°C to 220°C and applying 21% O_2 and 79% CO_2 v/v, the Indicated Thermal Efficiency (ITE) is reduced from 34.6% to 29.2% while ISFC is increased from 0.24 to 0.285 Kg/kWh.

1. Introduction

Global warming due to greenhouse gases (GHG) is a growing concern worldwide [1]. All countries face global climate change, a major challenge affecting human survival and development [2-4]. GHGs have long-term effects on global climate change, which has a variety of environmental impacts. CO_2 is one of the leading causes of global warming [5-6]. The primary source of CO_2 is the burning of fossil fuels to generate energy. Further development of low-carbon technologies can improve energy efficiency, reduce reliance on fossil fuels, and prevent the rapid growth of CO_2 and other greenhouse gases [7]. Over the years, the interest in developing new techniques that result in reducing the emissions of primary long-lasting GHG carbon dioxide (CO_2) has considerably arisen among scientists and engineers. For conventional internal combustion engines (ICEs), oxy-fuel combustion (OFC) and carbon capture and storage (CCS) techniques are considered to offer great potential [8-10]. Currently, the OFC technology is mostly applied in the thermal power generation industry focused on the coal power plant [11-13], biomass-fired power plants

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[14], and high-velocity oxy-fuel coating processes [15]. In addition, its utilization is assessed as being employed for the refining sector [16].

The European Union (EU) has reported that the transportation sector is responsible for about 28% of the total CO_2 emissions, while road transport is subject for more than 70% of the total emissions of the transportation sector [17]. The majority of GHG emissions of the transportation sector come from burning fossil fuels for cars, trucks, trains, ships, and planes [18]. Approximately 90% of transportation fuel is petroleum, mostly gasoline and diesel [19]. The combustion of petroleum-based products leads to CO_2 emissions. EU regulations have imposed limits on carbon emissions and certification of internal combustion engines for non-road mobile machinery. As a result, the inland waterways (IW) vessels must meet the prescribed emission standards [20].

Many research has emerged to improve the overall performance and fuel economy of conventional engines to meet the demands of a clean and efficient diesel engine [21]. Innovative technologies, such as alternative solar power, hybrid electricity, plug-in hybrid power, and battery power, are reducing diesel engines' carbon emissions. Nevertheless, these technologies are too expensive and their output torque is low to be widely applied to heavy-duty engines used in waterway transportation. [22-23].

Besides the application of the OFC technology to other sectors, such as coal-fired power generation [24-25], it has been of interest to use it in ICEs. The application of OFC in ICEs was studied by Osman, in 2009 [26]. In this study, a water injection system was applied to control the in-cylinder temperature. The results showed that heated water absorbs combustion heat and becomes vapor once it is inside the combustion chamber. In the vapor state, it will enhance the gas expansion during the expansion stroke. Additionally, heated water and fuel oxidation complement one another and produce a high work output. Recently, a number of studies have been conducted on OFC, including Kang et al. [27], who demonstrated that OFC technology can be used in a homogeneous charge compression ignition engine (HCCI) in order to reduce complexity in engine emissions after-treatment techniques and reduction of pollutant emission. In their test

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bench, they simulated exhaust gas recirculation by using an oxygen and carbon dioxide mixture intake system with variable oxygen fraction adjustment capability. Their results showed that the high-temperature and high-pressure water injected into the combustion chamber with an appropriate injection strategy controls the abnormal combustion and helps to increase the thermal efficiency of the system. Li et al. [28] demonstrated numerically the use of OFC on a practical diesel engine at the economical oxygen-fuel ratios. In their study, a 1D simulation analysis of the influence of various operating parameters on engine power recovery was considered. They concluded that, within a certain range, a decrease in the intake temperature or the CO_2 ratio could lead to a recovery in engine power. In addition, the increase of lambda_{O_2} from 1.0 to 1.5, which is chosen as the final solution due to improvements in oxygen consumption, can significantly improve engine power from 33.5kW to 40kW, even though other operating parameters remain unchanged. Xiao Yu et al. [29] studied the combustion characteristics of a quasi ICRC on a single-cylinder SI engine fueled with propane. In their research, a gas mixture of O_2-CO_2 has been used to simulate EGR to control the temperature in the cylinder. They considered water injection into the cylinder near the top dead center in order to control the OFC process. Their results revealed that a quasi ICRC cycle was established on a reciprocating engine by injecting overheated water into the cylinder near the top dead center in an oxy-fuel combustion process and resulting in the enhancement of the cycle performance. In addition, they reported that the evaporation of injected water increases the working gas near the top dead center and extends the isobaric expansion process. Based on their results, they report an 8.4% increase in the indicated work. As the literature indicates, the use of OFC makes it possible to completely reduce the expensive NOx after-treatment systems. It is also fuel-efficient and has low levels of particulate emissions [30]. This paper discusses the effect of intake charge temperature (in a range of 140°C to 220°C) on OFC in an HCCI diesel engine under different diluent strategies. The HCCI mode has been used due to its high thermal efficiency and ultra-low NOx and particulate matter (PM) emissions [31].

2. Integrated concept of the RIVER project

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The current study has been done as a part of an EU-Funded project called RIVER (funded by Interreg North-West Europe) [20]. The purpose of the RIVER project is to apply OFC technology accompanied by CCS techniques to develop possible solutions to eliminate NOx emissions from inland boat engines as well as to capture and store carbon emissions from these engines.

Figure 1 shows a schematic view of OFC technology proposed by RIVER project. As shown in Figure 1, the boat utilizes a diesel-generator as its power system. According to RIVER's technology, O_2 is supplied via a high-pressure oxygen tank. The flue gas stream, which mainly contains CO_2-rich combustion gases, is condensed in a condenser with connected water separation. During the OFC working conditions, some part of the CO_2 is returned to the cylinder, pre-mixed with O_2 in a chamber for being fed into the engine. The remaining CO_2 is then compressed and stored in the storage tank. The implementation of this technology will be of great value to the removal of NOx emissions while storing all carbon dioxide.

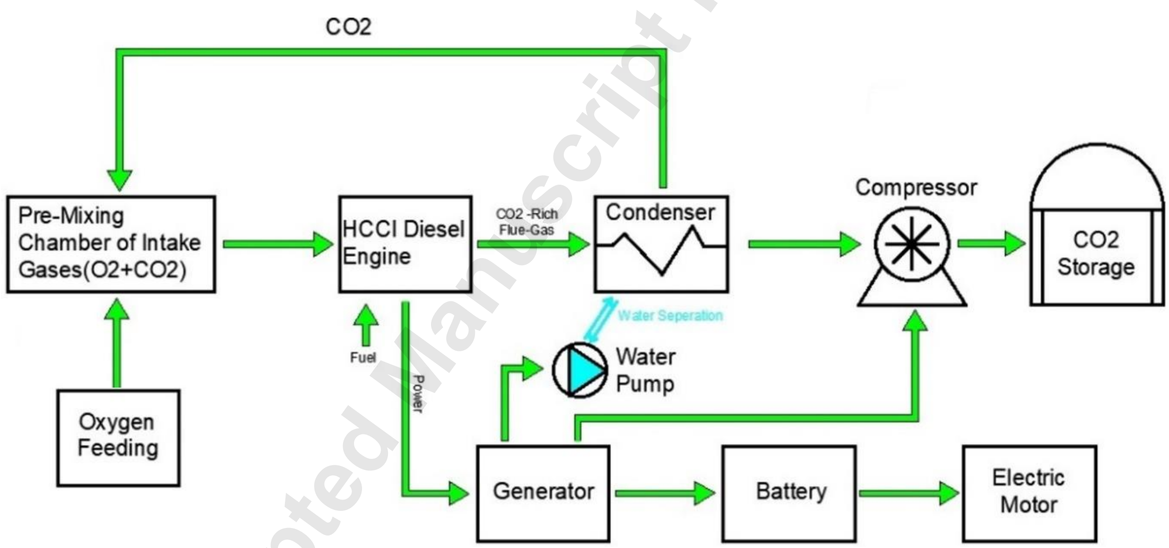

Figure 1. Schematic view of OFC technology proposed by RIVER project

The proposed idea of using OFC has a significant advantage over previous studies in that the diluent strategy is integrated with HCCI combustion to control the OFC process instead of direct in-cylinder water injection, meanwhile, it can eliminate problems associated with water injection such as lubrication and corrosion [26].

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3. Numerical study

A commercial CFD package AVL Fire code was used to perform the CFD simulation [32]. A reduced chemical mechanism with 349 reactions and 76 species [33] was applied to simulate the combustion process and emission under the HCCI combustion and OFC technology. The authors have already applied this mechanism for simulating various combustion regimes and have achieved good agreement when modeling combustion and emissions [33-36].

Table 1 summarizes all computational models used for CFD simulations. In addition, Table 2 shows the setting for the KHRT breakup model parameter applied to the simulation.

Table 1. Applied computational models

Combustion and emissions	Reduced chemical n-heptane-n-butanol-PAH mechanism (349 reactions and 76 species)
Turbulence	K-zeta-f model
Primary breakup	Blob Injection model
Breakup	KHRT model
Evaporation	Dukowicz model
Particle interaction	Schmidt model
Drag law	Schiller Naumann
Wall interaction	Walljet1

Table 2. The parameters set up for the KHRT breakup model

Model constants	Value
KH-WAVE to adjust the stable radius of droplets (C1)	0.61
KH-WAVE used to adjust the break-up time (C2)	12
Type constant to adjust break-up length (C3)	10
RT model constant used to adjust wavelength (C4)	5.33
RT model constant used to adjust break-up time (C5)	1
Constant for child droplet parcel number adjustment (C6)	0.3
Constant for child droplet parcel mass adjustment (C7)	0.05
Constant to adjust droplet normal velocity (C8)	0.188

The engine specifications are listed in Table 3. The experiment was carried out on a single cylinder of this engine at 1500 rev/min and 6.8 bar IMEP (Indicated Mean Effective Pressure) [21].

Table 3. Engine Specification

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Engine name	Ford Puma DuraTorq
Type	4 Cylinder, 4 stroke diesel engine
Combustion chamber	Bowl in piston
Valves per cylinder	4
Bore [mm] × stroke [mm]	86 × 86
Squish Height [mm]	0.86
Comperation ratio	18.2:1
Displacement [cm^3]	1998
IVC [BTDC]	143°
IVO [ATDC]	335°
EVC [BTDC]	355°
EVO [ATDC]	131°
Swirl ratio @ IVC	1.1
Connecting rod length [mm]	155
Peak cylinder pressure [MPa]	18
Injection system	Common rail DI [up to 180 MPa]
Injector	Solenoid with 6 holes
Injector hole diameter [mm]	0.159
Injection angle	154°
Diesel injection pressure[MPa]	150
Number of injection [/cycle]	4
Diesel SOI [°CA]	@ 306, 314, 326, 338
Injection Duration [μs/injection]	230

The CFD calculations was performed on a 60° sector mesh as the injector is symmetrically located in the middle of the combustion chamber. In this study, the computational grids were firstly created with different computational cell sizes including 0.6 mm (fine), 0.8 mm (medium), and 0.10 mm (coarse). Figure 2 shows the computational grid at TDC with three different cell sizes. When a computational grid with a medium cell size of 0.6 mm was used, the results obtained of the in-cylinder mean pressure and rate of heat release were independent of the number of grid cells. For this reason, the simulations were performed with a grid of 0.8 mm average cells. The exact number of cells in the mesh was 35240 and 90476 at Top Dead Center (TDC) and Bottom Dead Center (BDC), respectively.

In addition, as can be seen in Figure 2, the crevice above the top piston ring (between the piston and liner) is resolved and the region under the ring is represented as an additional volume attached to the top ring crevice. Furthermore, the volumes associated with the valve pockets and pressure transducer crevices are added to the volume attached to the top ring crevice in order to give the correct compression ratio.

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Moreover, the ground of the bowl meshed with three continuous layers for a proper calculation of the heat transfer through the piston wall.

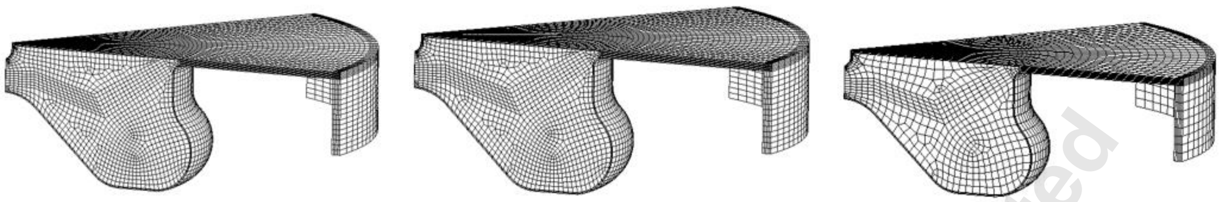

Figure 2. Computational grids at TDC with three different cell sizes

A comparison of the predicted and measured in-cylinder pressure and heat release rate is shown in Figure 3. The experimental study run at EGR rate equal to 69.6% is used for the validation of the current CFD model.

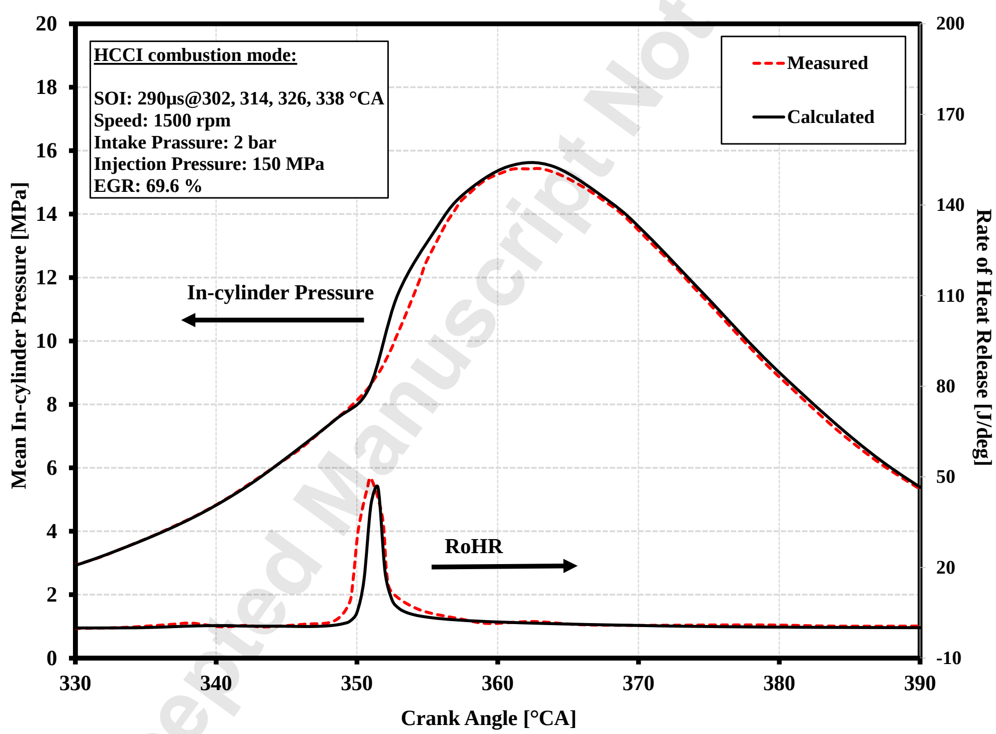

Figure 3. Validation of mean in-cylinder pressure and rate of heat release

As can be seen in Figure 3, the present model is seen to perform well, particularly to capture the phasing of the main combustion stage (MSC) under HCCI regime. This confirms that the chemistry scheme employed can be used to simulate the HCCI combustion process. It should be pointed out that in past studies of the authors [21], the current model was analyzed in more detail under other EGR rates and also to

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evaluate its capabilities to simulate pollutant emissions and a good agreement was obtained for all operating points.

Table 4 shows a comparison between experimental data with CFD results to demonstrate the model's capability to predict NOx, soot and CO emissions. As can be seen in the Table 4, a very good match was achieved between NOx and soot and CO magnitudes in the simulation.

Table 4. Measured and calculated engine-out emissions

Emission	69.6% EGR rate @ 1500 rev/min	
	Measured	Calculated
NOx [ppm]	13.0	14.0
Soot [g/kWh]	0.000800	0.000850
CO [ppm]	6350	6380

4. Oxy-fuel Combustion (OFC)

As it is well-known intake temperature is one of the most important engine parameters in controlling the HCCI combustion process. This section describes the CFD investigations performed to analyze the effects of the intake charge temperature on the HCCI OFC characteristics using different CO_2 dilutions. While studying the influence of intake temperature, intake pressure has set to 2.2 bar. Investigations have been conducted using four different CO_2 dilutions ranging from 79% to 85%. Table 5 shows percentages of O_2 and CO_2 vol.%, intake charge temperature and the relative O_2-fuel ratio ($Lambda_{O_2}$) for each strategy. In Table 2, relative O_2-fuel ratio ($Lambda_{O_2}$) is defined using Equation. 1. It must be noted that the oxy-fuel combustion with CO_2 dilution uses a mixture of O_2 and CO_2 rather than air, so instead of "lambda," which represents the actual air-fuel ratio to the stoichiometric air-fuel ratio, we have used the parameter "Lambda O_2" (Relative O_2-fuel ratio), which determines the actual O_2-fuel ratio over O_2-fuel ratio during stoichiometric combustion. Throughout this research, it has been attempted to minimize the cost of oxygen supply by using the lowest relative O2-fuel ratio (around 1) while maintaining a complete combustion process.

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$$\text{Lambda}_{O_2} = \frac{\text{Actual } O_2\text{−fuel ratio}}{O_2\text{−fuel ratio for stoichiemetric combustion}} \tag{3}$$

Table 5. Intake charge temperature and relative O_2-fuel ratio for different CO_2 dilutions

Case study (vol.%)	Intake Charge Temperature (°C)	Lambda_{O_2} (Relative O_2-fuel ratio)
21% O_2 + 79% CO_2	220	1.141
	200	1.189
	180	1.24
	160	1.29
	140	1.36
19% O_2 + 81% CO_2	220	1.03
	200	1.07
	180	1.12
	160	1.17
	140	1.23
17% O_2 + 83% CO_2	220	0.92
	200	0.96
	180	1.00
	160	1.05
	140	1.10
15% O_2 + 85% CO_2	220	0.81
	200	0.84
	180	0.88
	160	0.92
	140	0.96

The effect of different CO_2 dilutions on in-cylinder cylinder pressure, and in-cylinder temperature are shown in Figure 4 and Figure 5, respectively, under a constant intake temperature and intake pressure.

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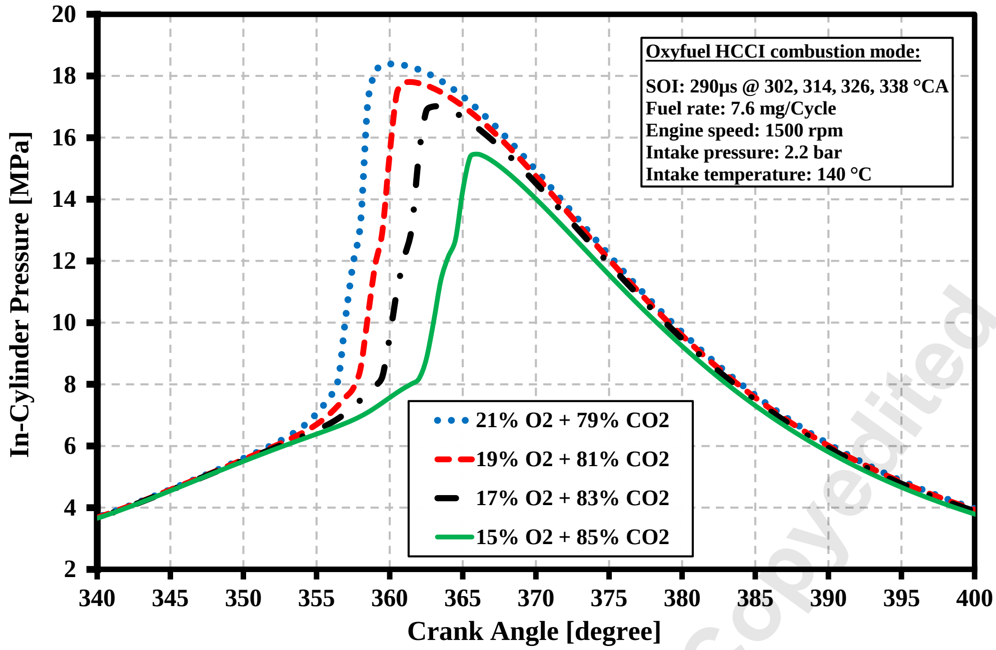

Figure 4. Effect of different CO_2 dilutions on in-cylinder pressure

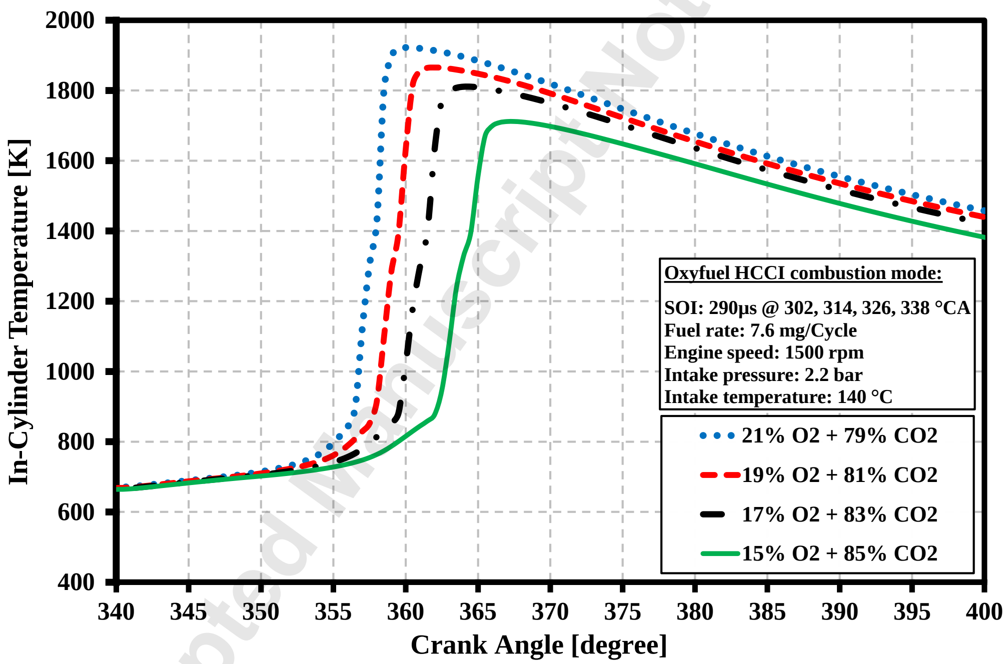

Figure 5. Effect of different CO_2 dilutions on in-cylinder temperature

As illustrated in Figure 4 and Figure 5, the increase of intake-air oxygen content from 15% to 21% results in a significant increase of peak in-cylinder pressure and peak in-cylinder temperature after TDC. In addition, it tends to advance peak pressure location and peak temperature location. Applying oxy-fuel combustion leads to acceleration of the combustion process which results in a shorter ignition delay period. In addition, premixed combustion is minimized while diffusion combustion is maximized. With the heat

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release rate dramatically increased, it takes a much shorter time to complete the entire heat release process. Subsequently, with such a high heat release rate, the in-cylinder temperature and in-cylinder pressure have increased.

The effect of CO_2 dilutions and intake temperature on IMEP is shown in Figure 6.

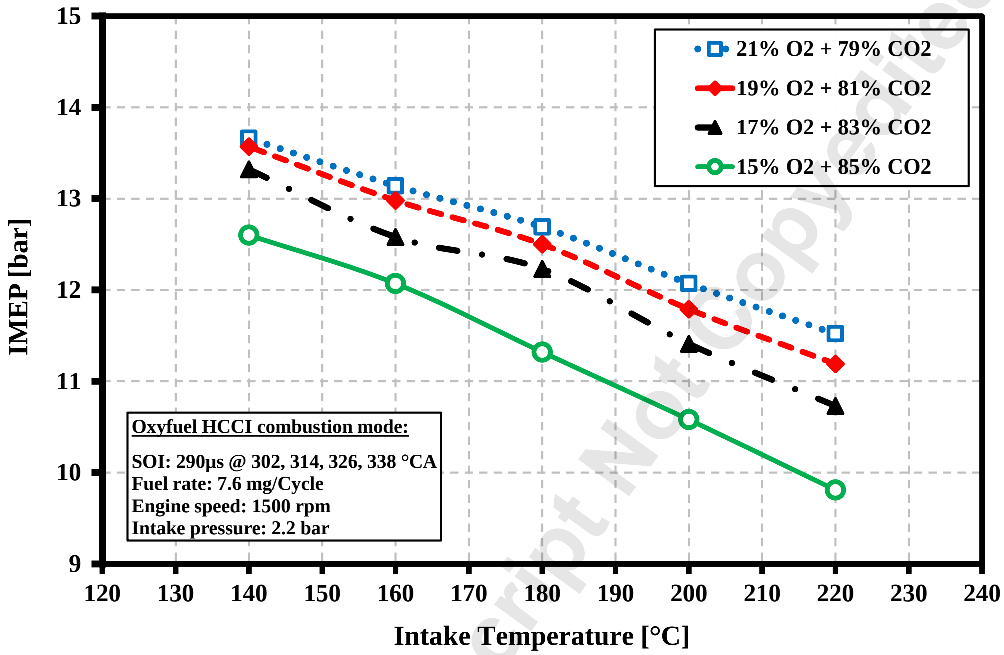

Figure 6. Effect of different CO_2 dilutions and intake temperature on IMEP

According to Figure 6, maintaining a constant intake pressure while increasing intake temperature from 140°C to 220°C decreases IMEP for all diluent cases considered. It can be concluded that increasing intake temperature results in advancing the start of combustion which mainly occurred in the compression stroke. Therefore, some portion of work from the combustion is produced during the compression stroke and it pushes on the piston top as negative work while the piston is still compressing the charge. Then it implies this portion of work has been wasted. Consequently, the IMEP has been negatively affected by increasing the intake temperature. Based on the CFD results, further reduction of intake temperature charge, lower than 140°C, leads to deteriorating the combustion stability and incomplete combustion. Therefore, the implementation of OFC mode using diluent cases must be accompanied by an appropriate intake temperature adjustment.

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Figure 7 shows the relative O_2-fuel ratio versus IMEP for different CO_2 dilutions. As shown in Figure 7, the IMEP is found to increase when a higher inlet oxygen percentage has applied as represented by increased the relative O_2-fuel ratio while the mass of injected fuel was kept constant.

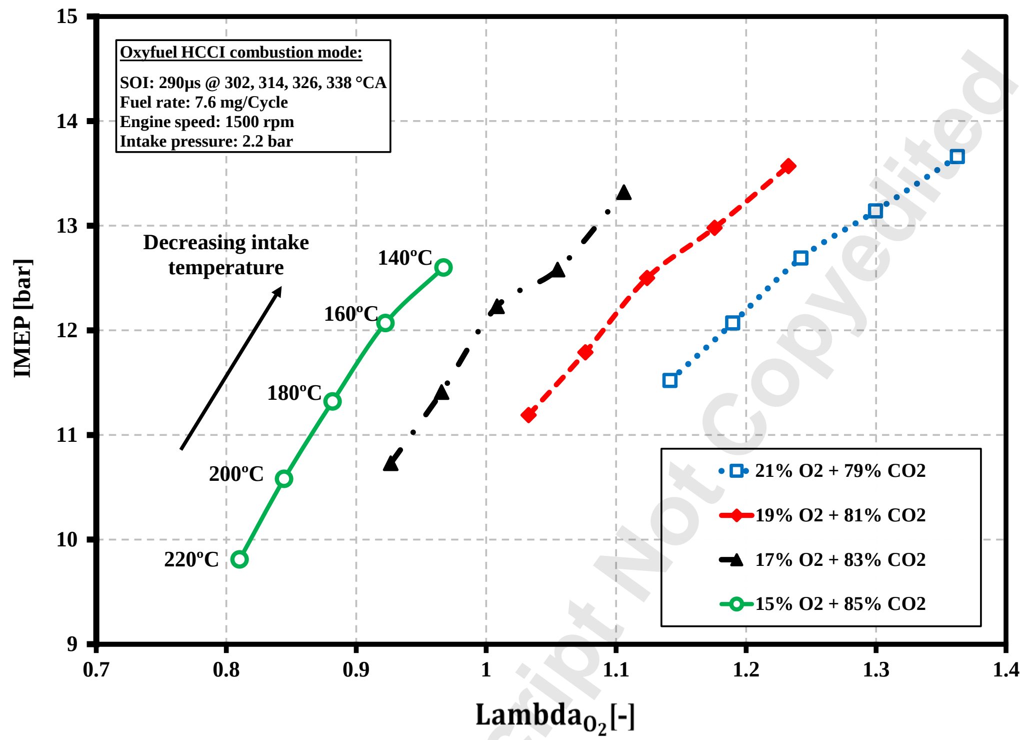

Figure 7. Relative O_2-fuel ratio versus IMEP under different CO_2 dilutions

The effect of different diluent strategies and intake temperature on ISFC is shown in Figure 8.

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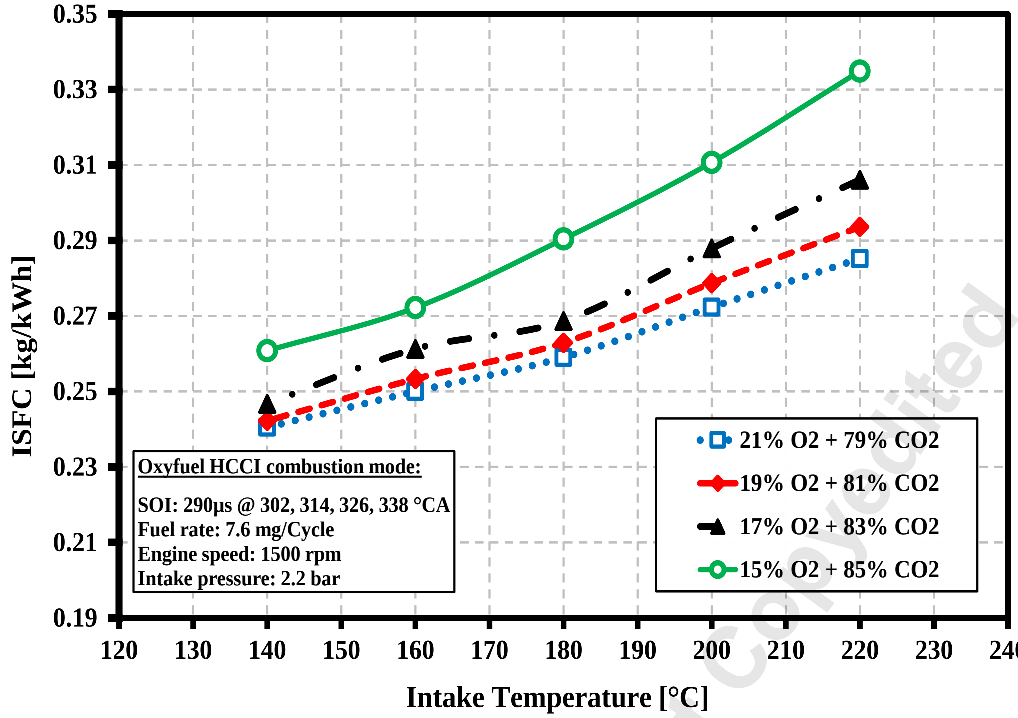

Figure 8. Effect of different CO_2 dilutions and intake temperature on ISFC

As can be seen in Figure 8, the increase of intake temperature under four dilutions results in an increase in ISFC. The ISFC has been increased by 18% when 21% v/v oxygen was applied. It is more pronounced when the intake oxygen fraction is 15%v/v, where the highest ISFC deterioration is around 26%.

Figure 9 shows the relative O_2-fuel ratio versus ISFC under different CO_2 dilutions.

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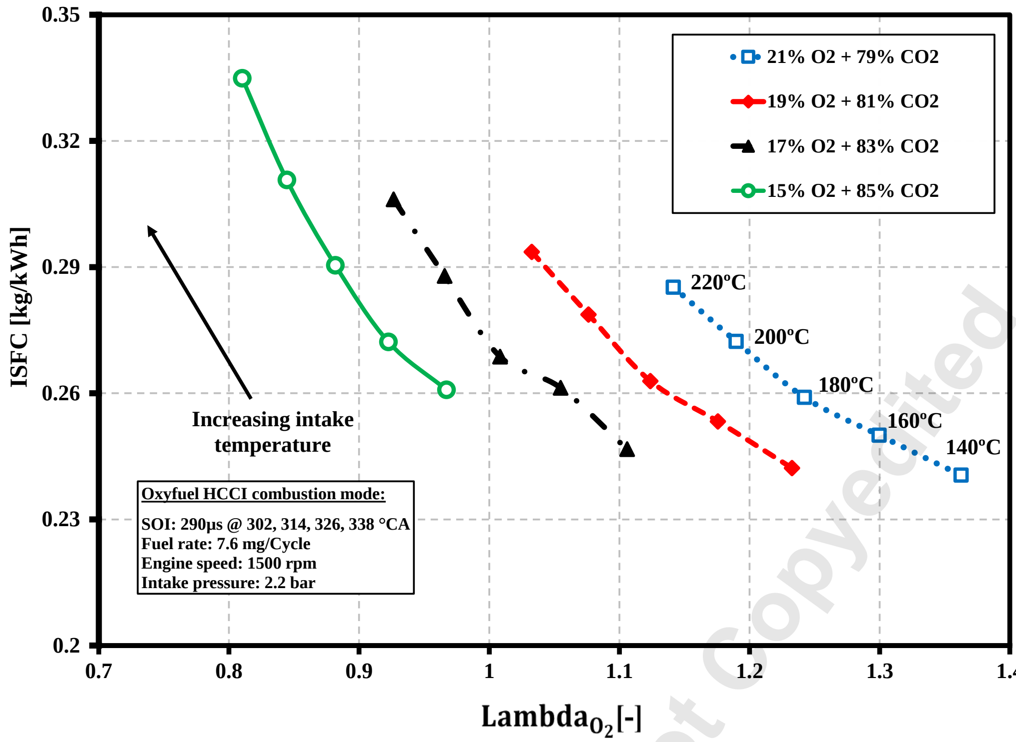

Figure 9. Relative O_2-fuel ratio versus ISFC for different diluent cases

As illustrated in Figure 9, by raising the intake charge temperature from 140°C to 220°C and applying 21% O2 and 79% CO2 v/v, ISFC is increased from 0.24 to 0.285 Kg/kWh. In addition, the ISFC has decreased when a higher inlet O_2 percentage has applied as represented by increased the relative O_2-fuel ratio. By increasing O_2 percentage from 15%v/v to 21%v/v, the ignition period is shortened and fuel is burned more rapidly which results in a more complete combustion process and less ISFC while the mass of injected fuel was kept constant.

Figure 10 shows the effect of oxy-fuel HCCI combustion at different intake temperature charges on CA50.

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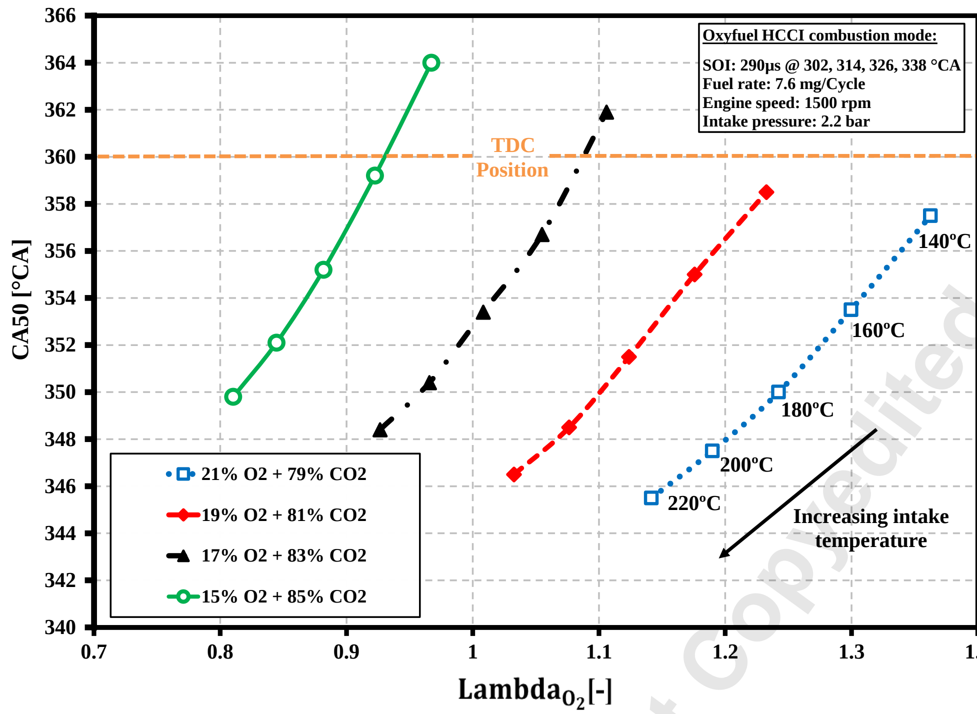

Figure 10. Relative O_2-fuel ratio versus CA50 under different intake temperature charges and CO_2 dilutions

According to Figure 10, CA50 timing advances for each dilution strategy as the intake temperature charge increases between 140ºC and 220ºC. The earliest CA50 is obtained at 345.5ºCA when 21% O_2 concentration is applied at 220ºC. In addition, at each intake temperature, CA50 retards by decreasing O_2 concentrations from 21 to 15%. The latest CA50 occurred at 4ºCA after TDC when 15% of intake O_2 is utilized at 140ºC. It can be concluded that decreasing O_2 concentration decreases reaction kinetics, resulting in more delays in the auto-ignition process.

Figure 11 illustrates the in-cylinder pressure at different intake charge temperatures when 21% O_2 and 79% CO_2 v/v is applied.

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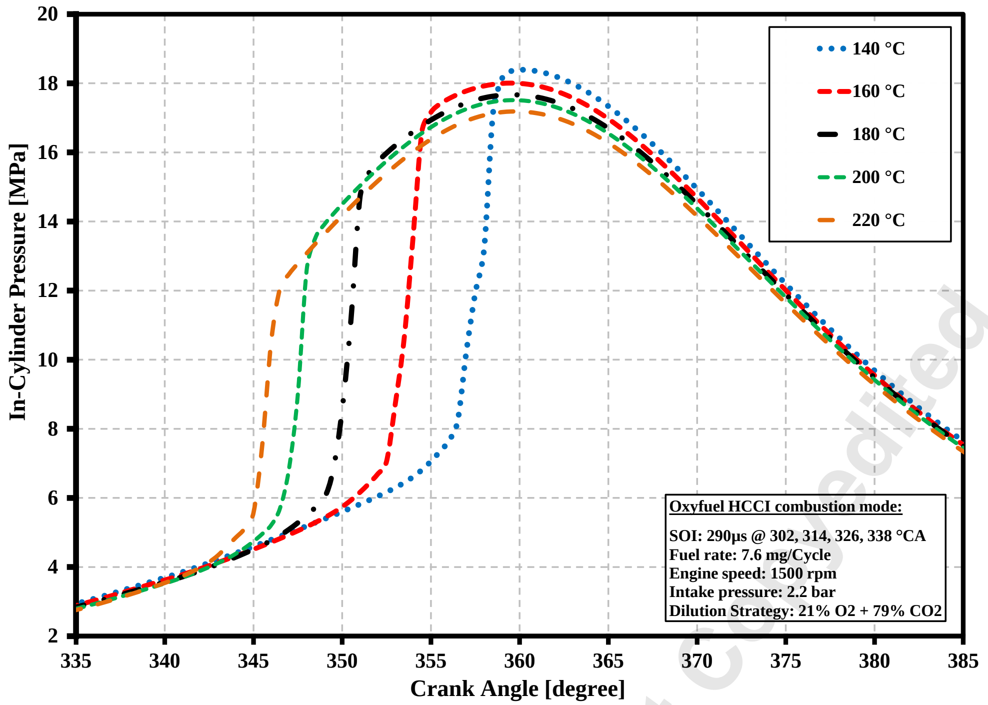

Figure 11. Variations of mean in-cylinder pressure under different intake temperatures for the case of $21\%O_2 + 79\%CO_2$

Based on Figure 11, the combustion process is advanced with an increase in intake temperature from 140°C to 220°C, but the maximum in-cylinder pressure gradually decreases: maximum in-cylinder pressure dropped from 18.34 MPa (under 140°C intake temperature) to 17.18 MPa (under 220°C intake temperature). The comparison of Figure 11 with Figure 6 illustrates how the advancement of the combustion process has decreased the IMEP and produced much negative work during the compression stroke as a result of the increasing intake charge temperature.

An important parameter in the performance of an engine is rate of pressure rise (ROPR), which is a measure of combustion roughness. A comparison of the maximum rate of pressure rise for different diluent cases and intake temperature is shown in Figure 12.

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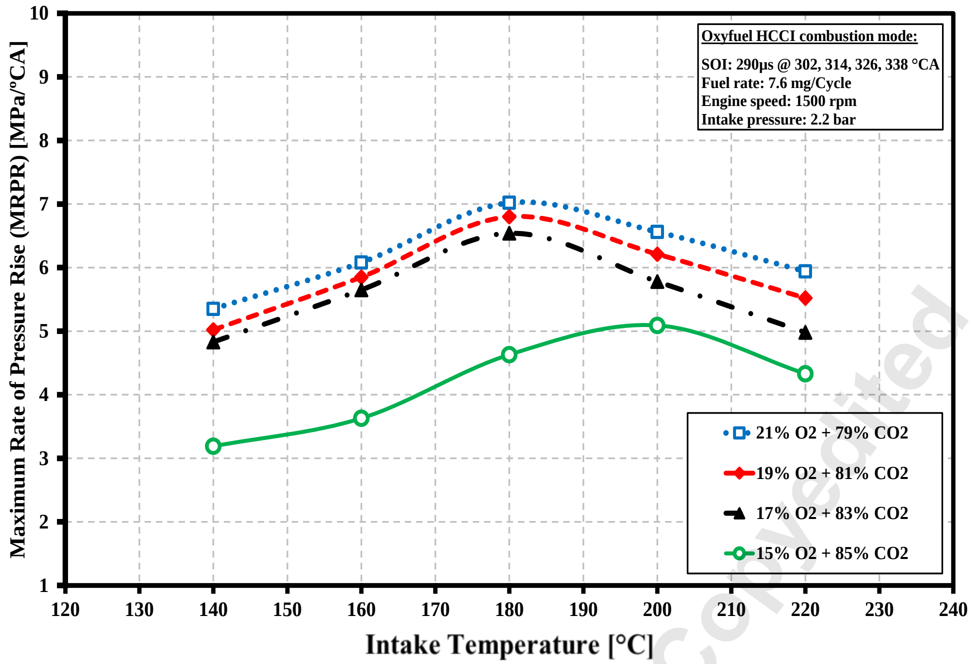

Figure 12. Intake temperature versus maximum rate of pressure rise (MRPR) under different CO_2 dilutions

It has been observed that the MRPR has increased by increasing the concentration of O_2 in the inlet. A higher ROPR indicates a higher proportion of fuel is burned in the premixed combustion phase. When the intake temperature increases from 180°C to 220°C, the MRPR declines with every diluent strategy, possibly due to the decreasing density at higher temperature. Based on these results, the rate of pressure rise in oxy-fuel HCCI combustion increases with intake temperature, then starts to decrease once the intake temperature exceeds 180°C. It may be possible to increase the upper load limit with a lower diluent gas percentage. According to the Figure 12, the maximum MRPR value is 7.02 MPA/°CA which is obtained when 21% of intake O_2 is applied.

Figure 13 illustrates the maximum rate of pressure rise (MRPR) versus the Relative O_2-fuel ratio for various diluent cases.

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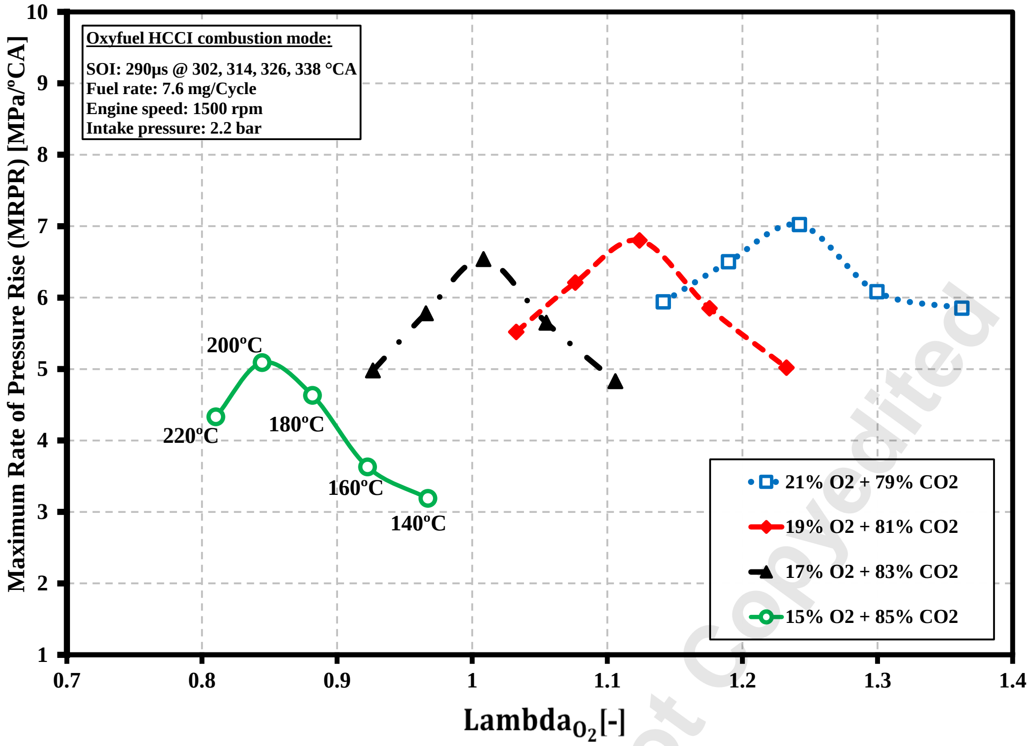

Figure 13. Relative O_2-fuel ratio versus maximum rate of pressure rise (MRPR)

As shown in Figure 13, the MRPR at each intake temperature point has increased as the O_2 concentration increases between 15 and 21 vol.%. It can be concluded that increasing O_2 concentration results in increasing the speed of reaction kinetics which leads to an earlier auto-ignition process that results in higher MRPR. When fuel rate is increased (lower lambda), diluent strategies become more apparent as the minimum MRPR has achieved by using 15 vol% O2 in the intake charge. It can be concluded that the maximum pressure rise rate correlates very strongly with the diluent gas percentage for different intake charge temperatures. This could result in an increase in HCCI load by increasing the diluent gas concentration.

Effects of intake temperature on exhaust CO_2 for different diluent strategies is shown in Figure 14. As can be seen in Figure 14, with increasing the intake temperature from 140°C to 220°C under all diluent strategies, the amount of exhaust CO_2 have decreased uniformly. This effect can be also attributed to the increase of burning rate of the injected fuel mass due to higher oxygen availability during the premixed and diffusion combustion which results in lower exhaust CO_2.

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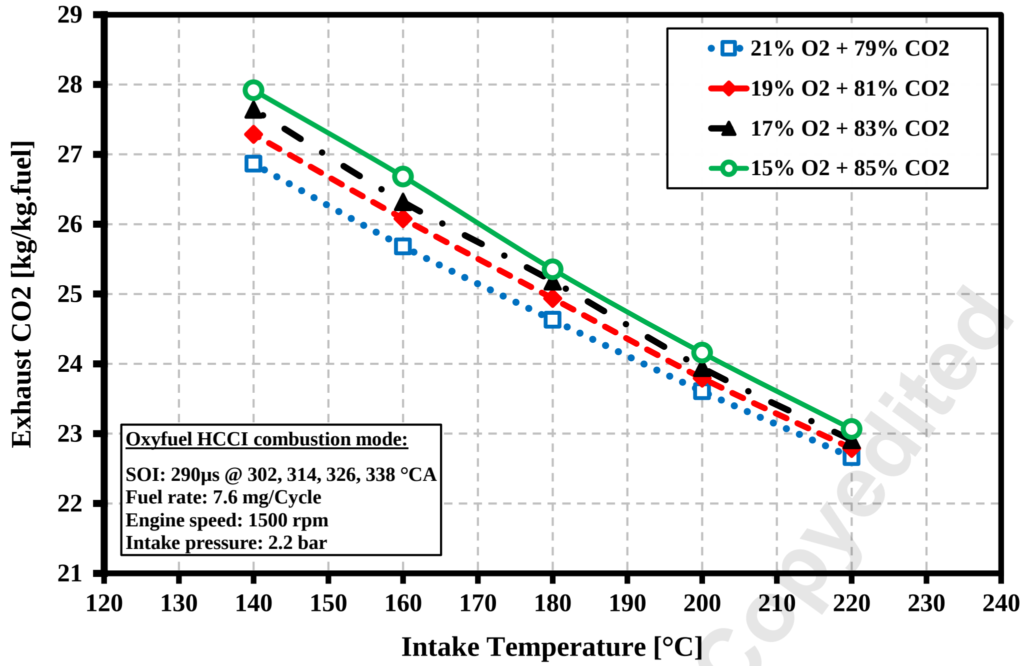

Figure 14. Effects of intake temperature on exhaust CO_2 for different CO_2 dilutions

Figure 15 illustrates the effects of different diluent strategies on exhaust CO emission.

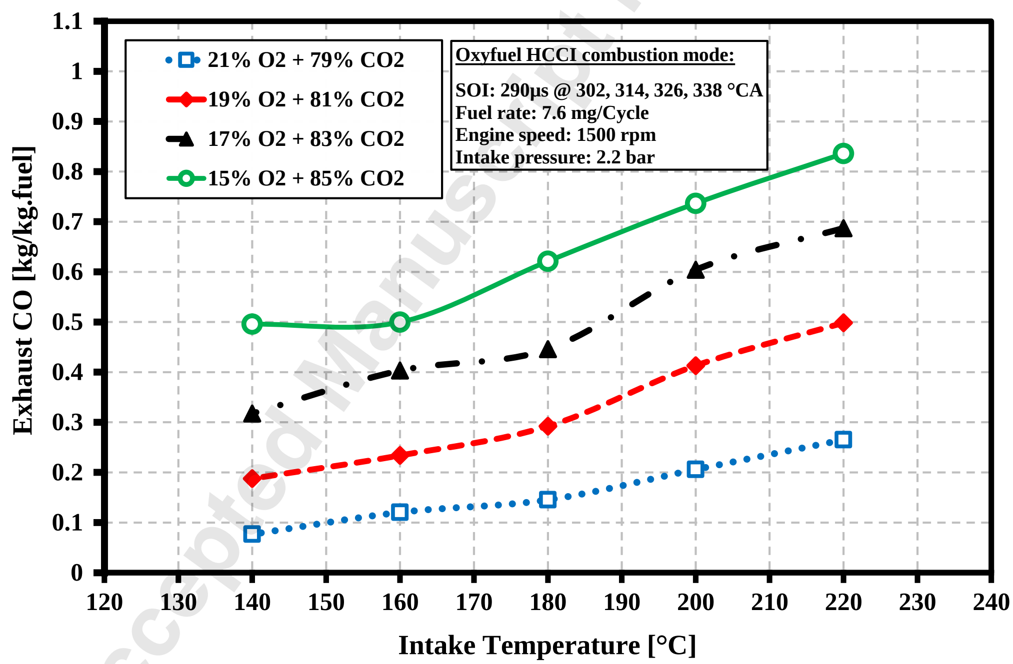

Figure 15. Effects of intake temperature on exhaust CO for different CO_2 dilutions

As shown in Figure 15, the amount of CO emission for all diluent cases was at a low level. The lowest value of exhaust CO was 0.08 kg/kg-fuel which has obtained at 140℃ intake temperature when 15% of intake CO_2 has been used as a diluent gas. But, when the intake temperature increases up to 220℃ the

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exhaust CO has increased. Moreover, by increasing the intake CO_2 concentration from 79% to 85%, as it has already been discussed, the in-cylinder pressure has reduced further which leads to more delays in combustion phasing and a higher amount of CO emissions. In addition, PM emissions from all dilution cases were extremely low (less than 0.0004 g/kg-fuel) while NOx emissions were eliminated completely using HCCI OFC mode.

Figure 16 shows the Relative O_2-fuel ratio versus ITE for different diluent cases. As can be seen in Figure 16, by raising the intake charge temperature from 140°C to 220°C and applying 21% O_2 and 79% CO_2 v/v, ITE is reduced from 34.6% to 29.2% . Moreover, increasing the intake O_2 mass fraction from 15% to 21% results in an increase in ITE. It can be concluded that, since CO_2 has higher specific heat capacity compared to O_2, applying the higher percentage of CO_2 dilution will increase the overall specific heat capacity of the intake charge results in an decrease in in-cylinder pressure during the combustion process which leads to less ITE.

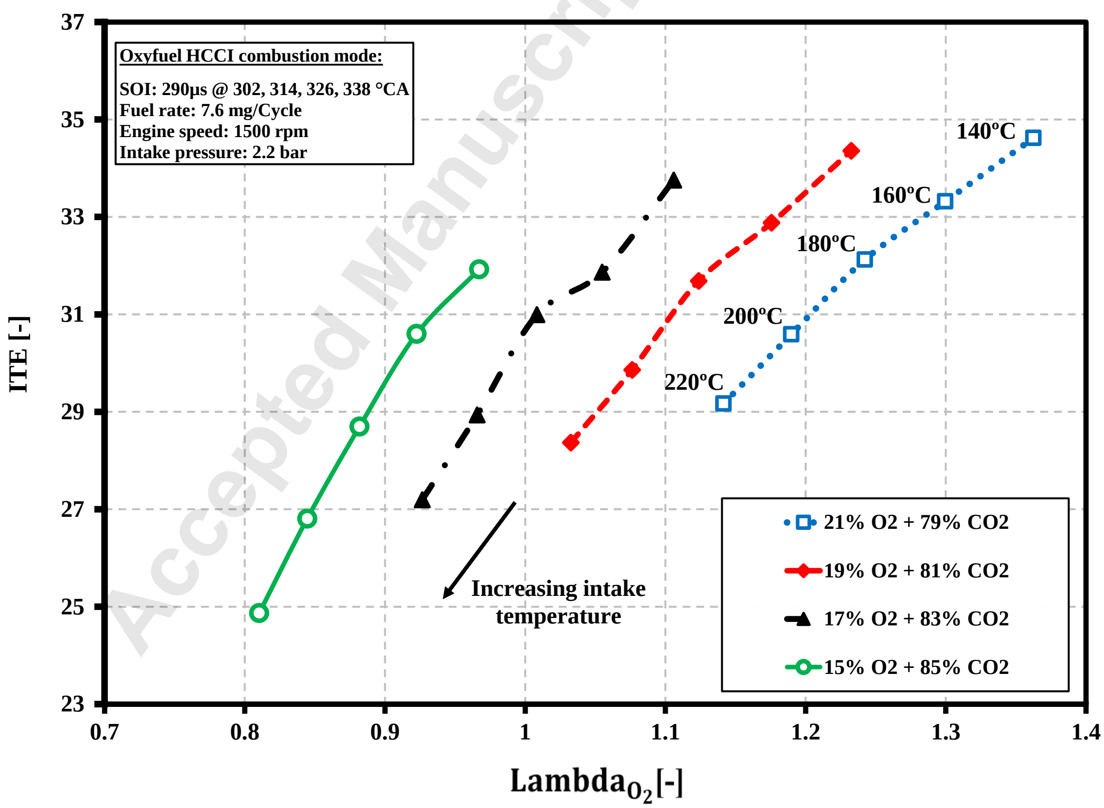

Figure 16. Relative O_2-fuel ratio versus ITE

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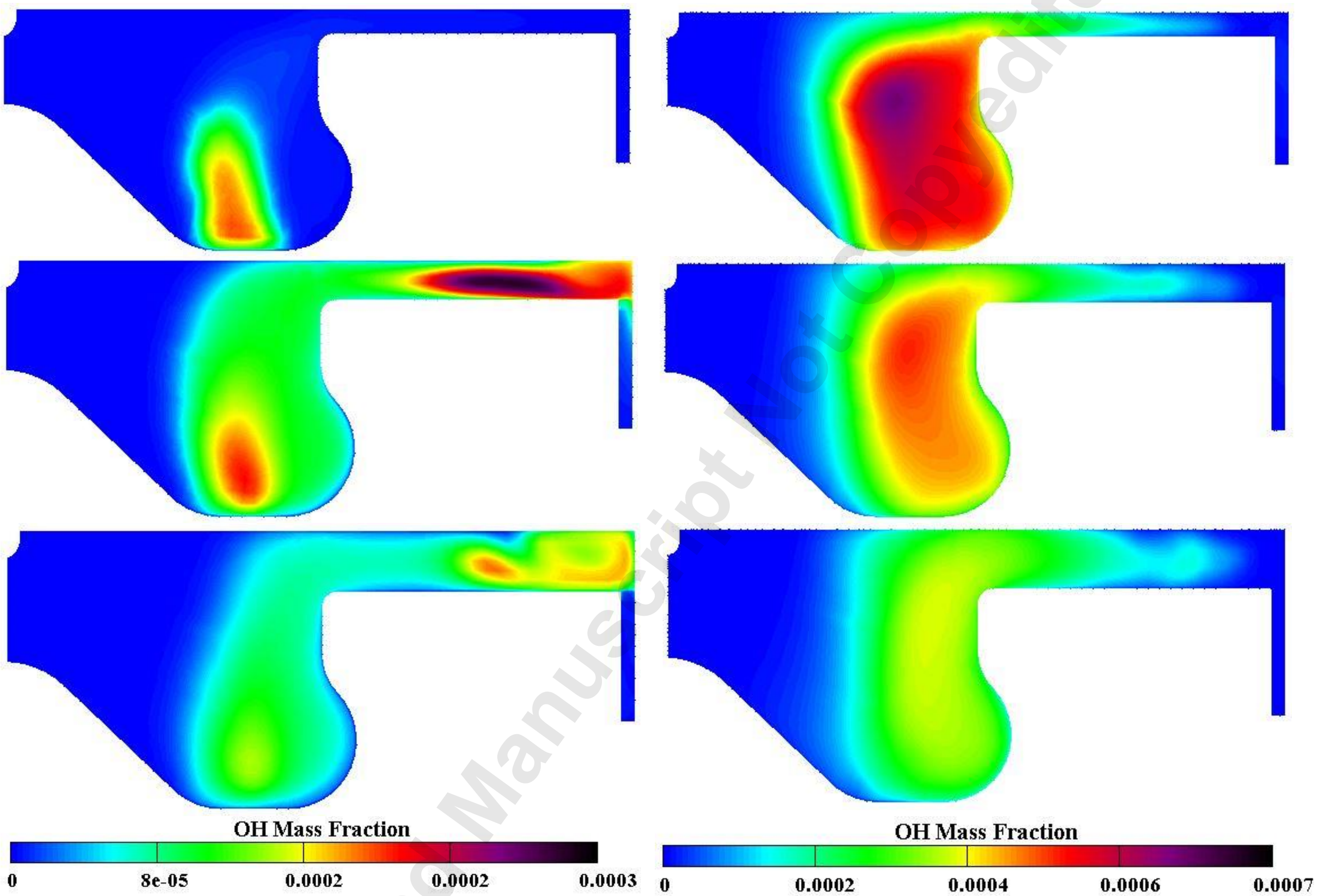
A comparison of OH radical distributions at 370, 375 and 380 CA degree at two different intake temperatures under the same diluent strategy is shown in Figure 17. Oxidation and soot formation are directly affected by the OH radical, which is one of the most important intermediate species during combustion. Increasing the intake temperature has increased OH formation within the cylinder, as can be observed in Figure 17. Although the amount of OH in both cases is relatively small.



140°C

21%O_2+79%CO_2

220°C

21%O_2+79%CO_2

Figure 17. OH distribution at two different intake temperatures under the same diluent strategy

Figure 18 shows a comparison of O_2 distributions at 370, 375, and 380 CA degree under the same diluent strategy at two different intake temperatures. As can be seen in Figure 18, the oxygen fraction inside the combustion chamber has decreased with increasing the intake temperature from 140°C to 220°C. At a

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higher intake temperature, the increase in oxygen consumption results in a shortened ignition time and faster burning of fuel during the combustion process, which leaves less oxygen inside the chamber.

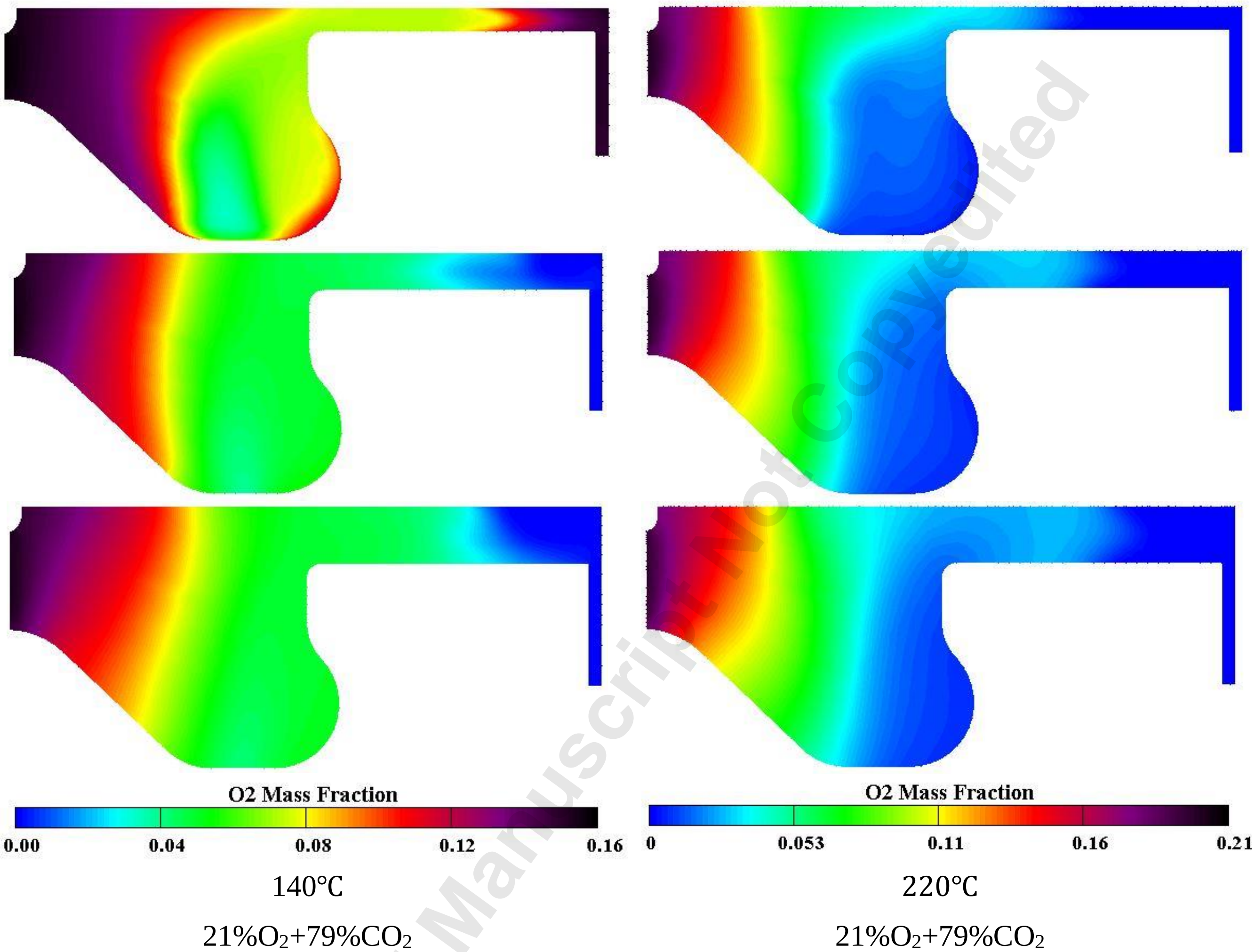

Figure 18. O_2 distribution at two different intake temperatures under the same diluent strategy

5. Summary and conclusion

In this study, a CFD simulation accompanied with the detailed chemistry has been applied to analyze the effects of intake oxygen temperature accompanied with different diluent strategies on the performance characteristics in an HSDI diesel engine under HCCI OFC mode. The following conclusions may be drawn:

- With OFC technology, PM and CO emissions can be reduced dramatically, while NOx emissions can be eliminated completely.

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- A proper intake temperature adjustment must accompany the implementation of OFC using CO_2 dilution. This study shows that reducing the intake charge temperature to below 140°C over a range of dilution rates adversely affects the combustion stability and results in incomplete combustion.

- By increasing the concentration of O_2 in the intake charge in a range of 15% to 21% v/v, the reaction kinetics will speed up, leading to an earlier autoignition process with a higher MRPR. For different intake charge temperatures, the maximum pressure rise rate correlates very strongly with the dilution rate. This could potentially allow the HCCI load to be increased by increasing the diluent percentage rate.

- Under constant diluent rate, by increasing the intake charge temperature from 140°C to 220°C the combustion is advanced which has a negative effect on IMEP as it produced much negative work during the compression stroke. As a result of applying 21% O_2 v/v to the intake charge, the maximum in-cylinder pressure dropped from 18.34 MPa (under 140°C intake temperature) to 17.18 MPa (under 220°C intake temperature).

- A higher proportion of CO_2 dilution will increase the overall specific heat capacity of the intake charge, resulting in a decrease in in-cylinder pressure during the combustion process, which also leads to less ITE.

Acknowledgment

This work is financially supported by the European Regional Development Fund (ERDF) via Interreg North-West Europe (Project No. NWE553). The authors would like to thank the AVL Company for their collaboration in this work to provide the AVL simulation software at JUNIA Graduate School of Engineering, France.

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