Effect on changing of intake temperature to hydrogen-methane-diesel mixture combustion characteristics

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Abstract. Ultra clean fuels generally used along with the conventional fuels such as Compressed Natural Gas (CNG) and hydrogen. The implementation of these alternatives can help take care to the high demand of environment friendly vehicles. These natural gas fuels when blended with diesel are expected to decrease emissions along-with reduction of the petroleum fuel consumption. Diesel mixed with hydrogen and methane in different concentrations enhances the performance and efficiency of vehicles. A numerical study were conducted to observe the impact of diesel mixed with hydrogen and methane (dual or tri-fuel) in the combustion process. Intake temperature was increased in between 303 K to 338 K. The simulation of the combustion process used ANSYS Fluent software based on a Yanmar L100AED single-cylinder engine parameter. The simulation conducted with engine speed of 1500 rpm, compression ratio (CR) = 19.3, and λ = 1.2 at different intake temperatures. The results compared the combustion process between a baseline fuel (100% diesel) and diesel-hydrogen-methane tri-fuel. The study found that the optimum intake temperature to enhance performance relies on a concentration of gaseous mixed with diesel. The highest performance and efficiency were obtained at 318 K intake temperature using tri-fuel of 60D-28H-12CH₄. From the in-cylinder pressure and temperature, results show increased in performance when the amount of hydrogen increased at the intake temperature. In conclusion, increasing the intake temperature and the use of tri-fuel in a direct ignition engine significantly improved the performance and efficiency of the engine.  

Keywords: Tri-fuel, Compression Ignition, High Efficiency, Emission
1. Introduction

Ultra-clean fuels generally used along with conventional fuels such as methane and hydrogen. The implementation of these alternatives can help take care of the high demand for environment-friendly vehicles. These natural gas fuels, when blended with gasoline/diesel, are expected to decrease emissions along with reduction of petroleum fuel consumption. Methane has low density and a high auto-ignition temperature of 537°C and also higher flammability limits compared with 246-280°C for petrol and 257°C for diesel fuel [1].

Hydrogen as a fuel has some unique and highly desirable properties. The combustion produces water with some nitrogen oxides at a high-temperature condition. These features make hydrogen an excellent source to potentially meet the increasing demand for stringent environmental controls of exhaust emissions. Also, hydrogen has the highest energy content per unit weight and high calorific value. It also has a high range of flammability and burns in air at a concentration of 4-75% by volume [2]. Therefore, the hydrogen engine can operate on very lean mixtures and combust over a wide range of fuel-air mixtures.

In this study, diesel fuel injected into the combustion chamber along with CH₄ and H₂ at the intake, and the combustion characteristics and exhaust gases were studied through a simulation using computational fluid dynamics (CFD). The emissions analyzed in this study were CO₂ and NO, which are the main pollutants produced by diesel combustion, were calculated using a mass balance of the species involved in the combustion process.

2. Methodology

Simulation using ANSYS FLUENT with the parameter of a single-cylinder Yanmar L100AED diesel engine diesel was previously studied [3,4], and the results from the simulation validated with past work as shown in Figure 1. The simulation of diesel fuel injection to the cylinder where the inlet valve is closed at 233°CA and carried till the compression and expansion stroke completed also exhaust valve is open to the compression, and engine speed was 1500 RPM. This similarity in simulation indicates that currently established simulation and previously done simulation is reliable and validate. For Figure 2 the peak pressure difference between current simulation and experiment is less than 5% [4].

![Figure 1. Simulation validation for 60D-20H-20CH4](image)

Table 1 explained the baseline condition of diesel engine. The main purpose of the baseline condition determination is to investigate the phenomena occurring in the mixture formation and fuel combustion process like as cylinder pressure, temperature distribution, CO and NO gases formation and emission composition. Table 2 indicates that engine speed is 1500 rpm, as was in the previous case, mass flow rate (kg/s) 0.0006, Lambda (λ) 1.2, initial temperature 303-338 K, initial pressure 1.05 bar and start of injection timing 13 CA˚ BTDC.
Table 1. Engine operating conditions parameters

| Properties                  | Specification |
|-----------------------------|---------------|
| Engine speed rpm            | 1500          |
| Mass flow rate (kg/s)       | 0.0006        |
| Lambda, $\lambda$          | 1.2           |
| Initial temperature (K)     | 303-318-338   |
| Initial pressure (bar)      | 1.05          |
| Start of injection timing (° BTDC) | 13     |
| Compression ratio           | 19.3:1        |

Table 2. Term and mass flow rate at exceeding air of 40% gaseous fuel (kg/hr)

| Fuel                     | Mass of gas H-M | $\varnothing$ | $\lambda$ |
|--------------------------|-----------------|---------------|------------|
| Baseline                 | 100% Diesel     | 0             | 0.833      | 1.2        |
| 60D-40CH4                 | 60% Diesel and 40% Methane | 2.03     | 0.88       | 1.361      |
| 60D-12H-28CH4             | 60% Diesel, 12% Hydrogen and 28% Methane | 0.254-1.421 | 0.928     | 1.161      |
| 60D-20H-20CH4             | 60% Diesel, 20% Hydrogen and 20% Methane | 0.433-1.014 | 0.941     | 1.062      |
| 60D-28H-12CH4             | 60% Diesel, 28% Hydrogen and 12% Methane | 0.594-0.609 | 0.935     | 1.07       |
| 60D-40H                   | 60% Diesel and 40% Hydrogen | 0.848     | 0.893      | 1.12       |

This study uses the dynamic mesh to simulate 2D combustion of direct injection diesel fuel blend with six different gaseous constellation mixture of hydrogen and methane, as illustrated in Table 2 with some further information from [5]. Firstly, independent case of simulation for diesel fuel injection was run using ANSYS Fluent software. The mesh of the independent test was carried out by knowing the number of cells in medium and fine mesh. The number of cells in medium mesh is 5837 cells as shown in Figure (2-A) and 11019 cells are in the fine mesh as shown in Figure (2-B). Figure 3 indicated that medium and fine mesh does not affect the numerical values of in-cylinder pressure for the compression and expansion stroke. Since the result of both meshes shows no difference, medium mesh were used throughout the study to reduce the time for simulation.

Figure (2-A). Combustion chamber (medium-mesh of 5837 cells)

Figure (2-B). Combustion chamber (fine mesh of 11019 cells)
Results and Discussion

Different intake temperatures influenced the combustion characteristics of diesel in methane and hydrogen combustion engine. The combustion characteristics are focused on the in-cylinder pressure and in-cylinder temperature at intake temperature of 303K, 318K and 338K.

3.1 In-cylinder Pressure at Different Intake Temperature

At intake temperature of 303 K, the simulation was run using ANSYS Fluent R14.5 based on the stated characteristics with changing of temperature. Figure 4 shows that the lowest in-cylinder pressure developed on baseline mixture 6.25 MPa and highest cylinder pressure developed 13 MPa on the maximum hydrogen percentage mixed with diesel as 60% diesel and 40% hydrogen. The addition of gaseous fuel increased cylinder pressure. However the highest in-cylinder pressure developed by increasing hydrogen fraction in gaseous fuel.

Figure 5 shows the result for intake temperature of 318 K. The peak in-cylinder pressure at 318K intake temperature shows that diesel hydrogen (60-40%) gives the highest in-cylinder pressure of 13.7 MPa. From the past studies and the past case of increasing cylinder temperature for diesel gaseous mixture fuel on various concentrations the diesel, hydrogen produces the highest cylinder pressure. The increasing cylinder pressure using diesel hydrogen (60-40%) justify the study from [6]. Moreover it is caused by high hydrogen flammability, and fast burning velocity.

The graph shown in Figure 6 indicated the obtained result by increasing intake temperature for 338 K. The concentration of diesel fuel mix D-H (60-40%) obtained the peak cylinder pressure of 14.42 MPa. The tabulated results below clearly show that the higher concentration of hydrogen in the fuel mixture has produced high cylinder pressure compare to lower hydrogen concentration. The higher in-cylinder pressure leads to the efficiency of an engine and enhances the performance.
3.2 In-cylinder Temperature at Different Intake Temperature

At the end of compression stroke the temperature is very high to help the ignition process in the engine cylinder. The addition of hydrogen shows higher temperature which leads to higher engine efficiency while resulted in the reduction of carbon monoxide CO. Moreover, the combustion efficiency also increased, which affects the diesel combustion process.

Figure 7 and 8 shows the temperature at intake temperature of 303 K and 318 K respectively. In the combustion process, diesel mixture fuel generates a huge amount of heat where high temperature helps ignition process in the engine cylinder. The illustrated results show that higher hydrogen mix with diesel has produced the higher temperature in the cylinder.

Diesel-hydrogen (60-40%) produced the peak temperature of 3450 K, the peak temperature in cylinder advanced the ignition process, where higher efficiency will be achieved, and reduce the formation of CO. The in-cylinder temperature will increase with increasing intake temperature and a higher concentration of hydrogen with diesel increase the cylinder temperature.

Figure 9 represents the obtained result with the increasing intake temperature of diesel ignition engine at the intake temperature of 338 K. The diesel gaseous mixture designed and used in the previous study by Mansor, 2017 [4] was re-used with higher intake temperature to study the impact. The effect of increasing temperature shows that the peak of in-cylinder temperature for 60D-40H is 3690 K.
4. Conclusion
The optimum intake temperature of the fuel in lean conditions is dependent on the assisting gasses hydrogen percentage. Increasing intake temperature will enhance the tri-fuel mixture performance (pressure and temperature). Meanwhile, increasing inlet temperature also improved the premixed gaseous temperature and led to better combustion with higher heat release. The best intake temperature of 318K result in good performance with reasonable mass friction emissions.

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