# CHAPTER IV

# RESULTS

The results of this experimental study explain many characteristics in performance and emission of using pilot diesel injection and HCNG as a secondary source of fuel in dual fuel engine. It explains why there is better fuel saving when using HCNG in diesel HCNG dual fuel mode as comparing to the normal diesel operation. Three different sections are separated to explain this experimental study results.

**Performance Characteristics**

Performance characteristics of the engine are shown in figure 16, 17 and table 18, 19, 20, 21, and 41. Figure 16 shows the engine horsepower versus the speed (RPM) of diesel engine operating in pure diesel operation and diesel with HCNG diesel dual fuel operation. It can be seen that engine operating in diesel with HCNG DDF mode provided more horsepower of the average of 30% to the engine as comparing against the pure diesel operation. The reason for that is because the combustion speed is higher than that of diesel operation alone. Using HCNG together with pilot diesel injection in diesel engine also provides higher torques of 30% comparing to the pure diesel operation as shown in figure 17. This was due to the more complete combustion of fuels in the internal combustion engine.

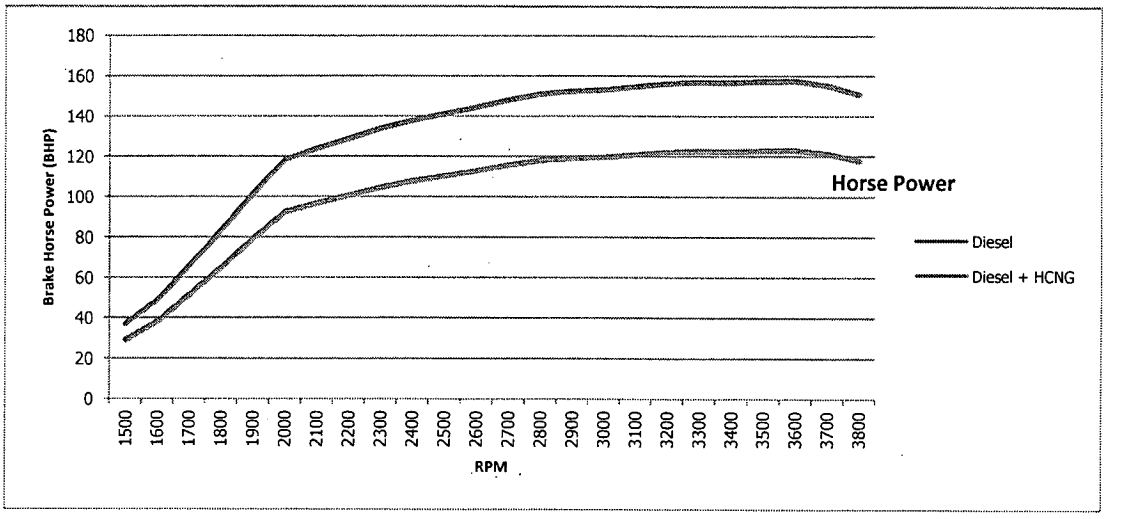


**Figure 16 BHP comparison of Diesel Operation and Diesel with HCNG Operation**

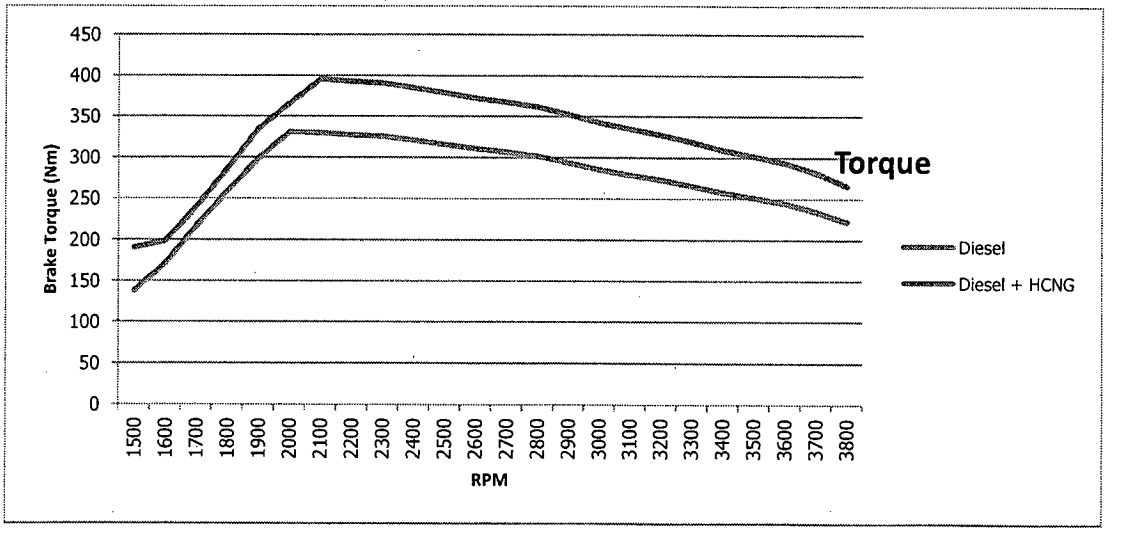


**Figure 17 RPM versus Torques**

Another important performance parameter is the thermal efficiency. Brake thermal efficiency has been calculated and averaged out of the three tests in table 41. The results in table 41 show BSTE of normal diesel operation and HCNG DDF operation. Thermal efficiency has increased with satisfactory results in HCNG DDF mode comparing to normal diesel mode because better combustion, perfect timing of injection each fuel into the cylinder and perfect controlled of the whole system.

**Table 41 Brake thermal efficiency of original diesel operation and HCNG DDF operation**

| RPM | BSTE (Diesel Mode) % | BSTE (HCNG DDF mode) % |
|---|---|---|
| 1500 | 20 | 23.32 |
| 1600 | 21.25 | 23.39 |
| 1700 | 22.36 | 25.21 |
| 1800 | 24.23 | 26.95 |
| 1900 | 25.46 | 28.24 |
| 2000 | 25.98 | 29.32 |
| 2100 | 26.78 | 29.98 |
| 2200 | 27.25 | 31.12 |
| 2300 | 29.41 | 32.82 |
| 2400 | 30.15 | 33.84 |
| 2500 | 31.25 | 35.05 |
| 2600 | 33.25 | 37 |
| 2700 | 33.45 | 38.25 |
| 2800 | 35.25 | 39.12 |
| 2900 | 35.89 | 40.12 |
| 3000 | 36.45 | 41.23 |
| 3100 | 34.26 | 38.75 |
| 3200 | 34.55 | 38.59 |
| 3300 | 33.25 | 37.56 |
| 3400 | 33.2 | 38.01 |
| 3500 | 31 | 36.89 |
| 3600 | 30 | 37.56 |
| 3700 | 29.2 | 33.98 |
| 3800 | 28.45 | 33.86 |

## Emission Characteristics

Emissions of nitrogen oxides ($NO_x$), total hydrocarbon (HC), carbon monoxide (CO) and particulate matter (PM) are regulated for most vehicle types but the worldwide standards are under EURO standards. This section shows results of each different emission recorded between normal diesel operations against diesel with HCNG dual fuel operations from low RPM (800) to highest RPM of 4000. The expected emission results will be comparing against EURO IV standards as the vehicle was made under this standard.

### 1. Carbon Monoxide (CO)

Figure 18 shows comparison of carbon monoxide between pure diesel operation and diesel with HCNG operation. The results were clearly seen that average CO emission decreased by 12.97% within all speed of the engine (RPM) under diesel and HCNG dual fuel mode comparing against the pure original diesel operation, except at nearly no acceleration (800 rpm to 1200 rpm) on the engine; CO emission levels were nearly the same in both operations.

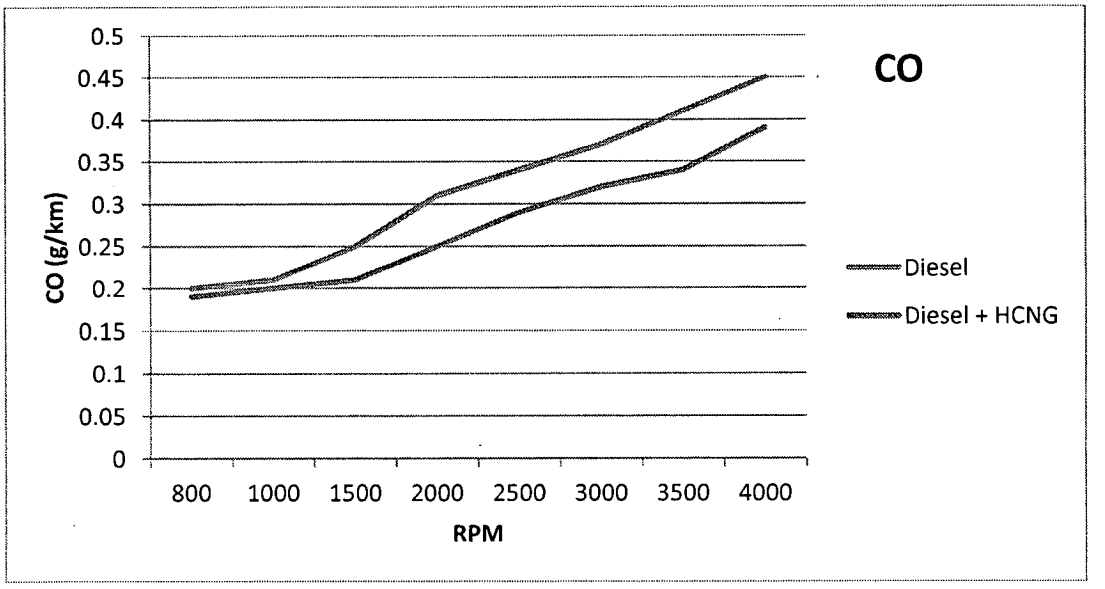


**Figure 18 CO emission in comparison between diesel and diesel with HCNG**

2. Hydro Carbon (HC)

Figure 19 shows comparison of hydro carbon between pure diesel operation and diesel with HCNG operation. The results demonstrated that the average HC emission decreased by 15.84% substantially with all speed of the engine (from 800 rpm to 4000 rpm) under diesel and HCNG dual fuel mode comparing against the pure original diesel operation.

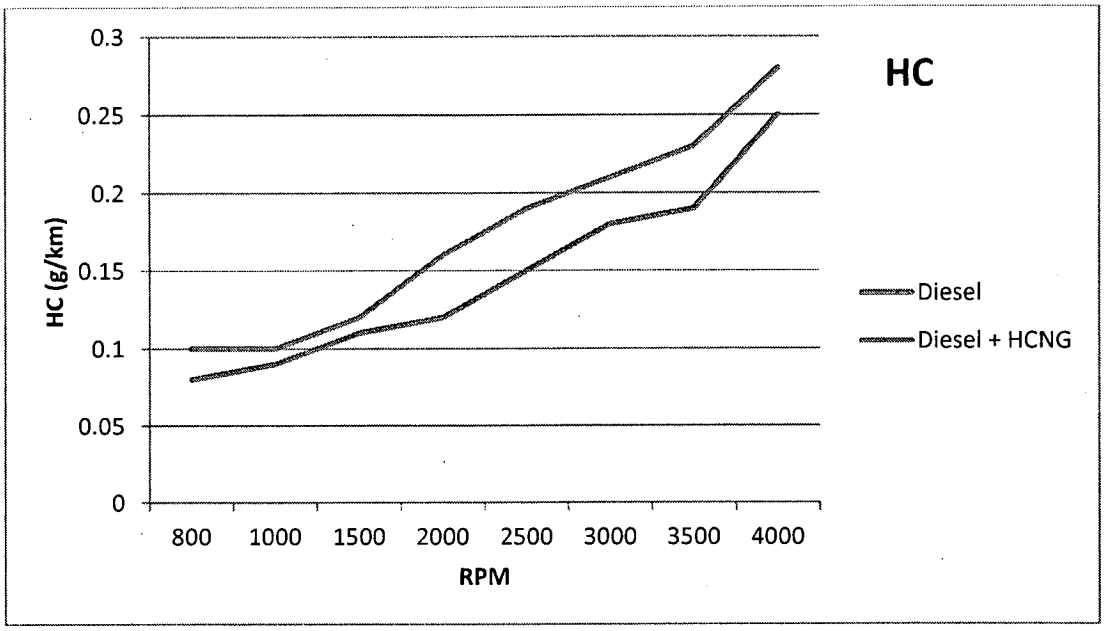


**Figure 19 HC emission in comparison between diesel and diesel with HCNG**

3. Nitrogen oxide ($NO_x$)

Figure 20 shows the comparison of nitrogen oxide between pure diesel operation and diesel with HCNG operation. The results demonstrated that the average $NO_x$ emission level decreased by 1.16%. However, $NO_x$ increased in low RPM (from 1000 rpm to 2500 rpm) under diesel and HCNG diesel dual fuel mode comparing against the pure original diesel operation. And $NO_x$ decreased in higher RPM from 2600 up to 4000 RPM. This is due to the fact that in higher RPM, there is a faster rate of combustion which would leave small amount of nitric oxide as exhaust gaseous.

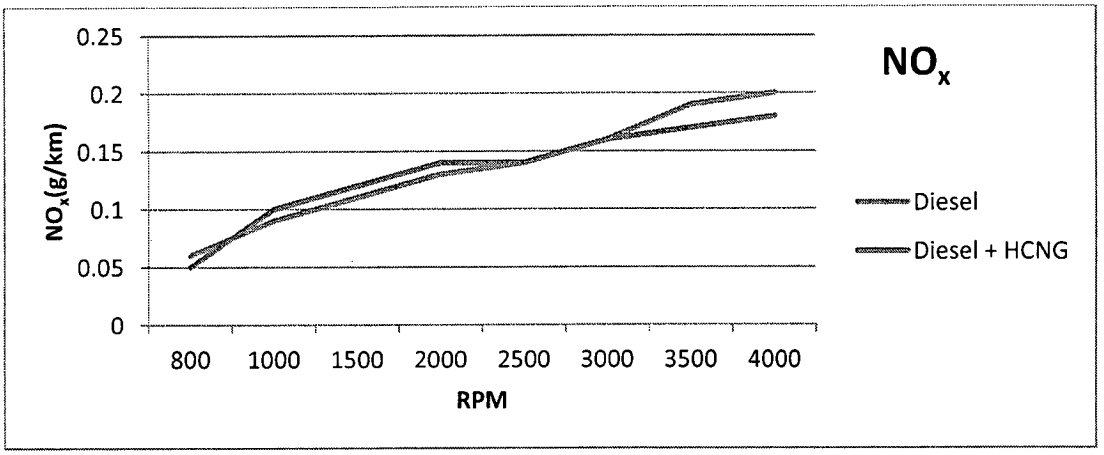


**Figure 20 $NO_x$ emission in comparison between diesel and diesel with HCNG**

4. Particulate Matter (PM)

Figure 21 shows comparison of particulate matter due to incomplete combustion burning between pure diesel operation and diesel with HCNG operation. The results demonstrated that the average PM emission level decreased by 9.14% from in all speed (800 rpm to 4000 rpm) under diesel and HCNG dual fuel mode comparing against the pure original diesel operation.

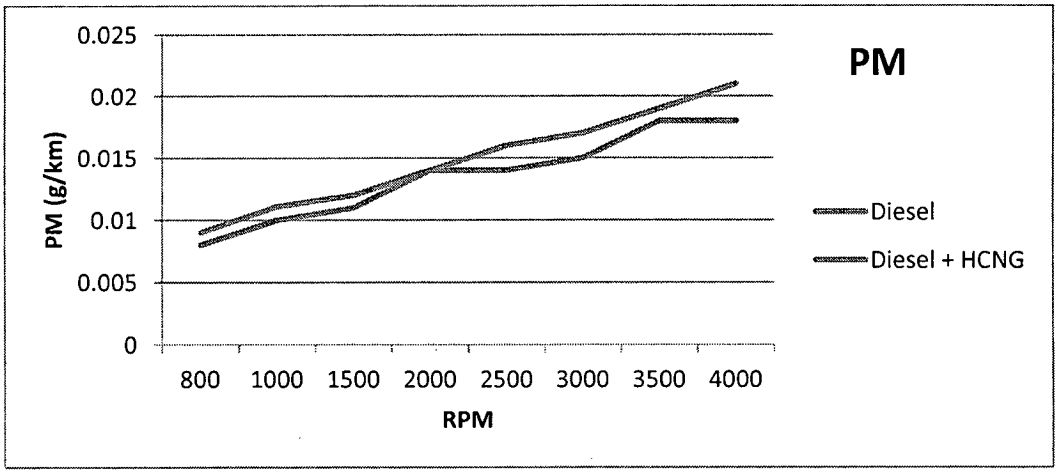


**Figure 21 PM emission in comparison between diesel and diesel with HCNG**

5. Smoke Density

Smoke opacity measurement has been measured and shown in figure 22 and figure 23. Figure 22 shows smoke density of both diesel mode and diesel with HCNG DDF mode. The results of three trials on each operation were clearly seen that using HCNG DDF with pilot diesel injection lower smoke density on average of 10% comparing to pure diesel operation. Figure 23 shows smoke opacity in both diesel mode and diesel with HCNG DDF mode. The reason for lower smoke is due to the fact that HCNG DDF increases higher performance and lower the engine temperature, thus resulting in more complete combustion stability of the engine. Therefore, the smoke emission is lesser than pure diesel operation.

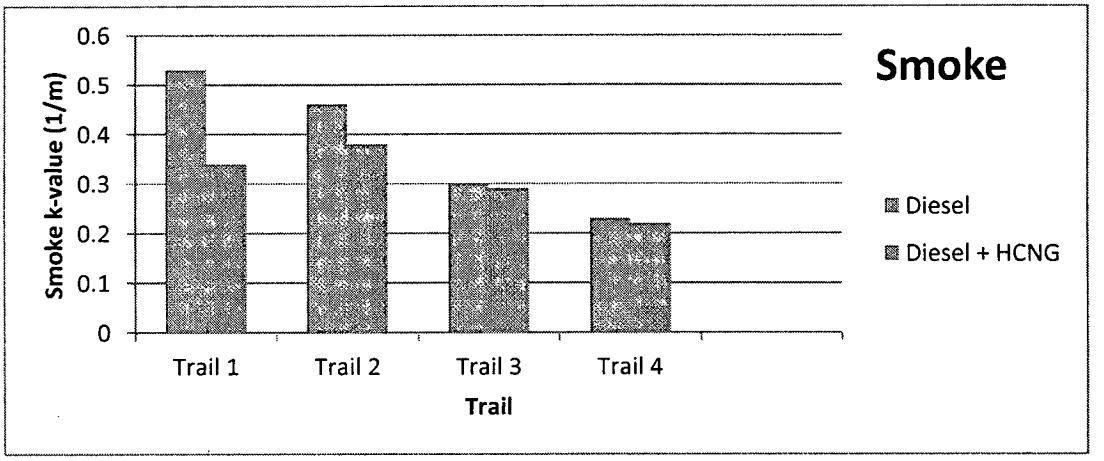


**Figure 22 Smoke density**

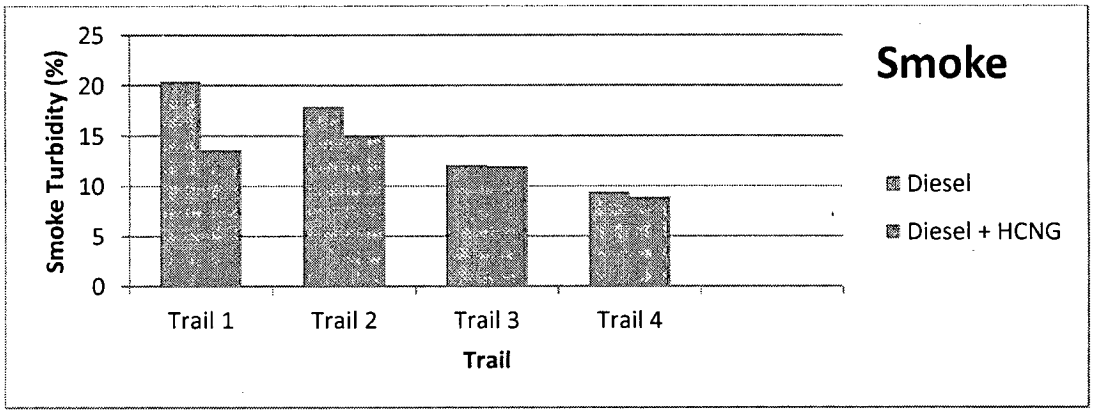


**Figure 23 Smoke turbidity**

**Fuel Economy**

Fuel Economy of an automobile is the relationship between distance travelled and the amount of fuel consumed by the vehicle. Fuel consumption of vehicles is a great factor of air pollution; therefore vehicles with the least fuel economy will greatly reduce air pollution. Figure 24 shows a comparison of fuel economy between driving with pure diesel operation and driving with diesel plus HCNG DDF on the road with a constant speed of 80 kilometer per hour. It certainly shows that HCNG DDF mode provides longer distance with the same amount of diesel per one liter. The average improvement of fuel economy is 177% in HCNG DDF mode comparing to the normal diesel mode.

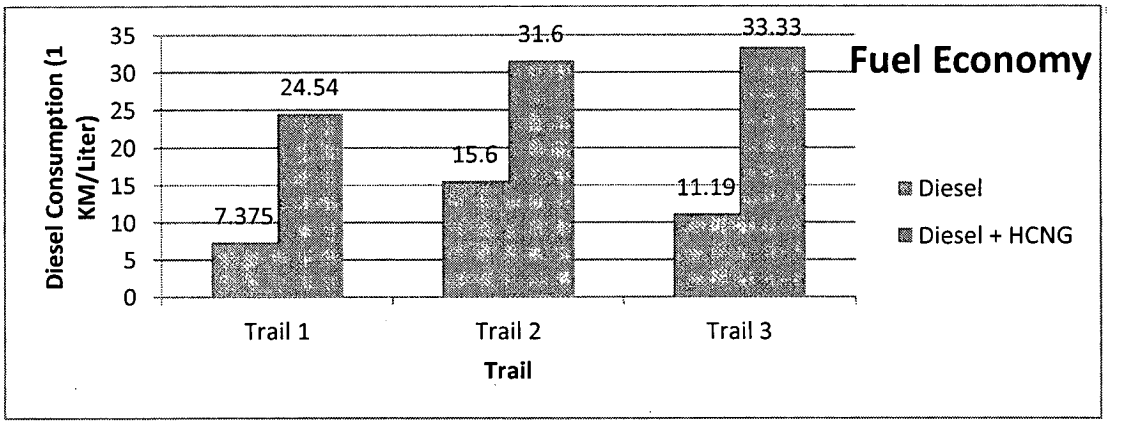


**Figure 24 Fuel economy of pilot diesel in 1 liter per a kilometer**

In summary, by creating initial optimum point between great performance and better emission levels; this experiment leads up to overall improved version of dual fuel engine. It advises that using HCNG diesel dual fuel system in the common rail diesel vehicle reduce emission lower than the EURO IV standard requirement from the automobile manufacturer and provide greater performance with eventually reduce the normal expenses when comparing to the original diesel operation alone.