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A Review Study on Diesel and Natural Gas and Its Impact on CI Engine Emissions

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ABSTRACT

Diesel engines produce high emissions of nitrogen oxide, smoke and particulate matter. The challenge is to reduce exhaust emissions but without making changing their mechanical configuration. This paper is an overview of the effect of natural gas on the diesel engine emissions. Literature review suggests that engine load, air-fuel ratio, and engine speed play a key role in reducing the pollutants in the diesel engine emissions with natural gas enrichment. It is found that increasing the percentage of natural gas (CNG) will affect emissions. Nitrogen oxide (NO_x) is decreased and increased at part loads and high loads respectively when adding CNG. The reduction in carbon dioxide (CO_2), particulate matter (PM) and smoke are observed when adding CNG. However, carbon monoxide (CO) and unburned hydrocarbon (HC) are increased when CNG is added.

Keywords: CO, CO_2, Diesel, Engine, Emissions, HC, Natural gas (CNG), NO_x

INTRODUCTION

One of the problems associated with petrol engine is its high emissions such as carbon dioxide, carbon monoxide, hydrocarbons, particulate matter and nitric oxides (Adnan, Masjuki & Mahlia, 2009; Alrazen, Talib, & Ahmad, 2016a; Sahoo, Sahoo, & Saha, 2009), which can contaminate the environment. In order to reduce emissions, Diesel Particulate Filter (DPF) and Selective Catalytic Reduction (SCR) have been used to reduce PM and NO_x emissions respectively. These As expensive

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metals are used as catalysts and to retrofit the engines alternative fuels are being developed and promoted to achieve the goals of reducing air pollution emissions (Alrazen, Talib, Adnan, & Ahmad, 2016b; Ibrahim & Bari, 2008; Karavalakis et al., 2013; Korakianitis, Namasivayam, & Crookes, 2011b).

The cleanest alternative fuel is the natural gas. Natural gas (NG) is an excellent fuel for heating and , power, due to its less harmful environmental side effects compared with conventional fuels. It is also an abundant source of clean energy.(Namasivayam, Korakianitis, Crookes, Bob-Manuel, & Olsen, 2010). Natural gas produces lower levels of emissions, such as CO_2 and NO_x, compared with traditional fuels like oil and coal (Alrazen et al., 2016a). Additionally, no particulate matter or sulphur dioxide are produced by NG and it is extensively used in the automobile and consumer goods sector, as a chemical feedstock in the manufacture of plastics and other commercially important organic chemicals (Papagiannakis & Hountalas, 2004; Ramamurthy, 2006).

The NG which contains between 85% and95% methane is gas extracted from the earth. It is a naturally occurring hydrocarbon gas mixture and includes varying amounts of other higher alkanes. It is formed when layers of decomposing plant and animal matter are exposed to intense heat and pressure under the surface of the Earth over millions of years. The energy that the plants originally obtained from the sun is stored in the form of chemical bonds in the gas.

It is usually found trapped among the rock in the earth's crust and located in close proximity with liquid petroleum. The NG has a broad flammability range between 5% and15% allowing for lean burn. Additionally, it has high octane rating (>120) with increased compression ratio (Korakianitis, Namasivayam, & Crookes, 2011a; Williams, 2004). The aim of this review paper is to investigate the impact of natural gas in diesel fuel engines.

EFFECTS OF CNG ON NO_X EMISSION

Nitrogen oxides (NO_x), released during coal burning, consists of nitric oxide (NO) and nitrogen dioxide (NO_2), known as NO_x; the latter is released through ignition and includes NO (90%-95%) and NO_2 (5%-10%) (Alrazen et al., 2016b).

Abhishek Paul et al. (2013) reported a reduction of NO_x emission with CNG-diesel combination. Figure 1 shows at 80% load condition, the emission of NO_x diminishes with increased CNG for all load conditions. When the CNG injection durations increase from 4000 sac to 7500 sac, 12,000 μSec, 15,000 μSec and 18,000 μSec, it results in a maximum reduction in NO_x emission by 33%, 47.43%, 61.3%, 68.57% and 66.49% respectively (Paul et al., 2013). This is primarily because of cool gas entering the cylinder, so that it reduces ignition temperature (Kalam et al., 2009). Further, nonappearance of overabundant oxygen because of CNG supplanting admission air produces lower NO_x emission.

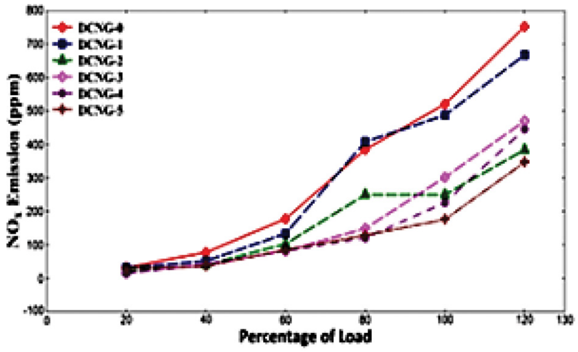

Figure 1. Variation of NO_x emission with load for D-CNG combination (Paul et al., 2013)

Lounici et al. (2014) found (see Figure 2) at low and medium loads, NO_x emission in dual mode is lower compared with traditional fuels. The development of thermal NO_x is for the most part supported by two parameters: high oxygen fraction and high charge temperature (Wang, Deng, He & Zhou, 2007). For these loads, the g temperatures for both modes are almost the same (see Figure 3(a)). Higher oxygen concentrations (see Figure 3(b)) results in higher level of NO_x emissions (Lounici et al., 2014). At high loads, the authors reported that the NO_x emission in dual fuel mode is higher than using diesel fuel alone. (Figure 3a). The higher temperature is due to release of heat in the premixed burning stage, which is the consequence of the fuel ignition at those loads (Lounici et al., 2014).

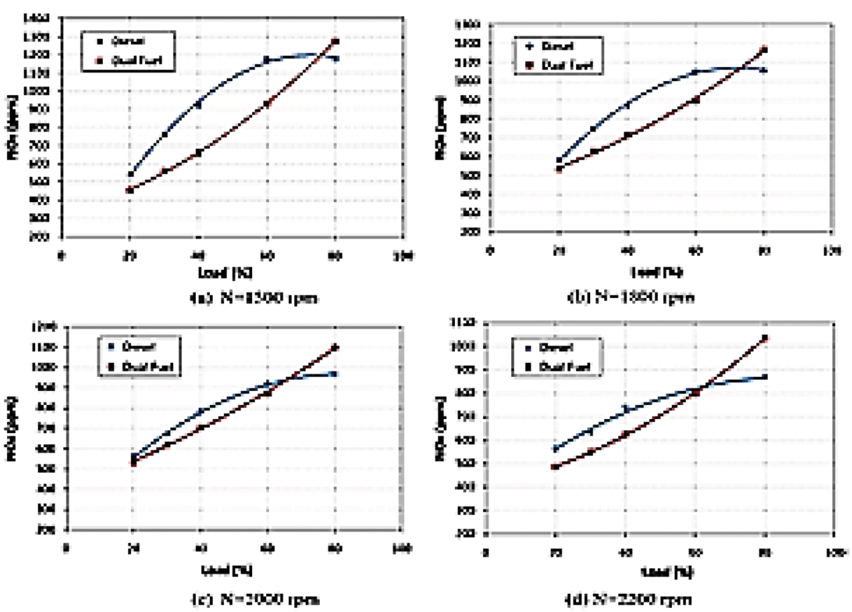

Figure 2. Variation of NO_x emission according to load at different engine speeds (Lounici et al., 2014)

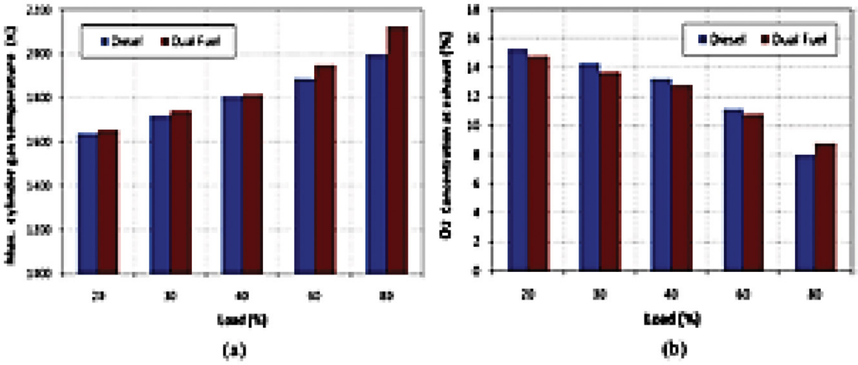

Figure 3. Maximum cylinder gas temperature (a) and oxygen concentration (b) at various loads (N = 2000 rpm) (Lounici et al., 2014)

EFFECTS OF CNG ON PARTICULATE MATTER (PM) & SMOKE

Particulate matter and smoke are an outcome of poor ignition (Saravanan & Nagarajan, 2008; Zhou, Cheung, & Leung, 2014). Exhaust smoke is considered as the contrast in the middle of development and oxidation of soot (Khan, Greeves, & Wang, 1973). Soot is formed amid ignition at high temperature. Fuel pyrolysis is portrayed as chain fracture of hydrocarbon when there is no oxygen. Such fractures along these lines transform into nucleation destinations which result in hydrocarbons and sulphates residue particles. In like manner, soot oxidation happens during high temperatures (Masood, Ishrat, & Reddy, 2007). Paul et al. (2013) noted different exhaust smoke related to distinctive fuel blends at diverse load conditions (see Figure 4). Figure 4 shows that use of CNG reduces emissions at all load conditions. At 40% load condition, CNG (15,000 µSec injection duration) demonstrates smoke haziness of 13%, which is half that of diesel. At full load condition, CNG (4,000 µSec injection duration) indicated smoke darkness of 17.4%, lower than that that of diesel (Paul et al., 2013).

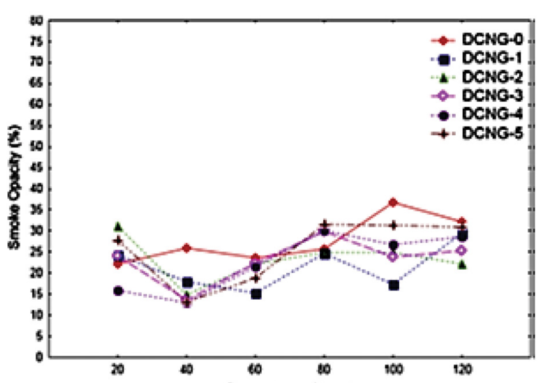

Figure 4. Variation of smoke opacity with load for D-CNG combination (Paul et al., 2013)

Lounici et al. (2014) measured soot emission for 1500, 1800, 2000 and 2200 rpm for the two engine modes. Figure 5 presents results for two engine speeds (1500 and 2000 rpm). It is clear that dual fuel mode is an effective strategy to lessen soot emission particularly at high loads. Soot emission in dual fuel mode is much lower compared with normal diesel especially for high loads. Use of Natural gas results in reduced soot emission as the former contains high methane levels which are responsible in producing small amounts of soot (Ibrahim & Bari, 2008; Lounici et al., 2014; Zhou et al., 2014).

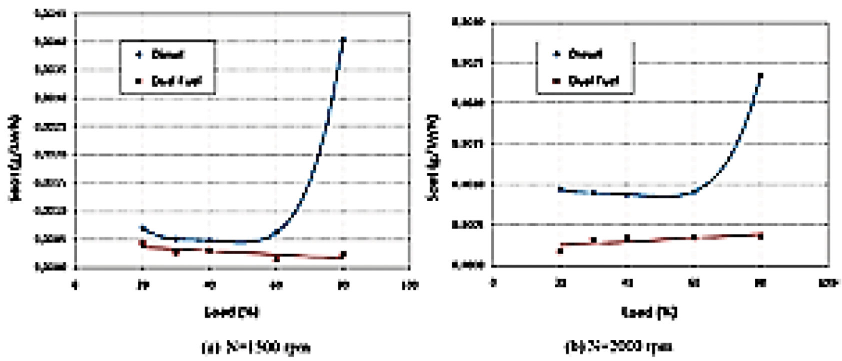

Figure 5. Soot emissions at various loads for both dual fuel and conventional diesel modes at different engine speeds (Lounici et al., 2014)

EFFECTS OF CNG ON UNBURNED HYDROCARBON

Unburnt hydrocarbon emissions are the consequences of inadequate burnings (Alla, Soliman, Badr, & Rabbo, 2002). Numerous studies have shown that dual fuel mode emits higher HC in contrast to suing traditional diesel mode, especially at part load conditions (Abdelaal & Hegab, 2012; Zhou et al., 2014). This is a direct result of the blend of gaseous fuel and air at such conditions and poor fuel efficiency since much of the natural gas escapes from the ignition procedure increasing the HC emissions. At high loads, the blend and the change in the fuel use reduces HC, but it is higher than using traditional diesel mode (Abdelaal & Hegab, 2012). Paul et al. (2013) reported that (Figure 6), the unburned hydrocarbon was increased along with adding natural gas into diesel. They discovered the most noteworthy unburned hydrocarbon outflow of 352 ppm was seen with most astounding CNG infusion at 20% load, which is 311 ppm (just about 8.5 times) higher than that of diesel at the same load condition. This could be because methane is slower to respond than hydrocarbon and the burning velocity may be too moderate for burning at extremely lean blend. With expanding load, the mean viable weight rises, bringing about a higher exhaust temperature, which results in decrease of unburnt hydrocarbons (Bedoya, Arrieta, & Cadavid, 2009).

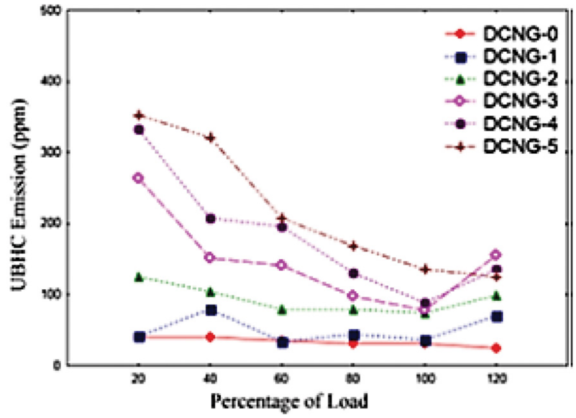

Figure 6. Variation of UBHC emission with load for D-CNG combination (Paul et al., 2013)

Lounici et al. (Lounici et al., 2014) analysed unburned hydrocarbon emissions, as a component of engine load, for the two modes at 1500, 1800, 2000 and 2200 rpm engine speeds (Figure 8). They found that the pattern of aggregate hydrocarbon (THC) outflow is comparable. At any engine load, THC emissions for dual mode are significantly higher compared with using diesel. At low load, the low temperature and the high air-fuel proportion of gaseous fuel blend result in weak ignition. Thus, the level of methane does not influence ignition. On the other hand, at lower loads, regardless of the fact that the ignition conditions are not positive, (see Figure 7), the THC outflows are lower. At the point when the load increases, the emissions increases as ignition quality is not adequate to bring down the THC outflows. For high loads, higher charge temperature and increased gaseous fuel result in a further change in the ignition process, and a reduction in the unburned hydrocarbon outflows (Alla et al., 2002).

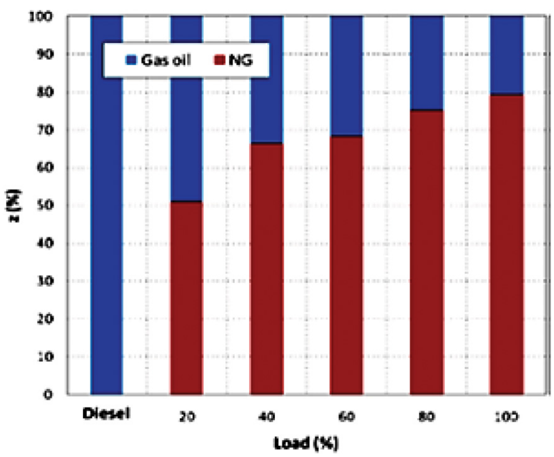

Figure 7. Variation of the participation rate (Z) as a function of load, N = 1500 rpm (Lounici et al., 2014)

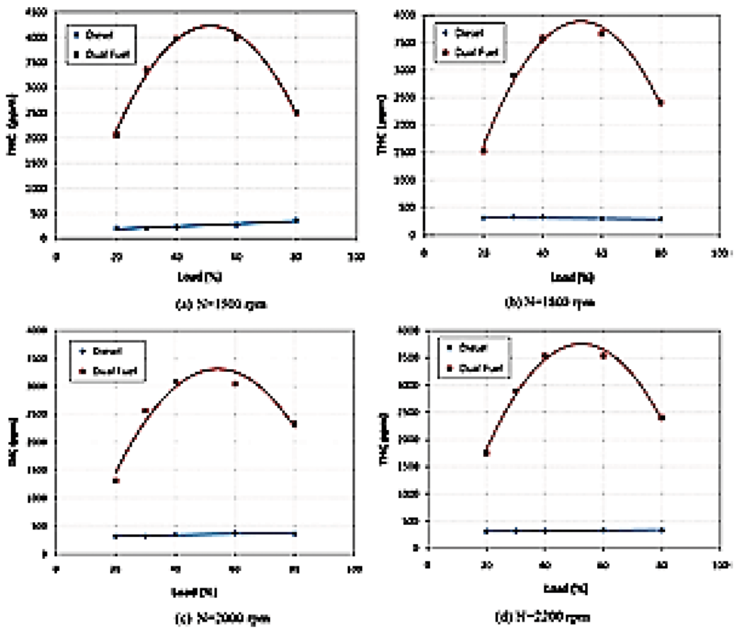

Figure 8. Unburned hydrocarbon emissions at various loads for both dual fuel and conventional diesel modes for different engine speeds (Lounici et al., 2014)

EFFECTS OF CNG ON CARBON MONOXIDE

Carbon monoxide (CO) is a component of the unburned gaseous fuel and blend temperature, both of which control the rate of fuel disintegration and oxidation (Heywood, 1988; Turns, 1996). CO is released through the ignition process with rich fuel-air blends and when there is lack of oxygen to completely burn all the carbon in the fuel to CO_2 (Alrazen et al., 2016a). Paul et al. (2013) studied different load conditions for all fuel combinations to see their effect on the CO emission(Figure 9). It is clear at 40% lead, CO emissions is increased by 41.37%,, 70% at 80% load, and 94.21% at 120% load (Paul et al., 2013). This increase in CO emissions when CNG is increased is a sign of deficient oxygen inside the cylinder through combustion. Kalam et al. (2009) had similar findings.

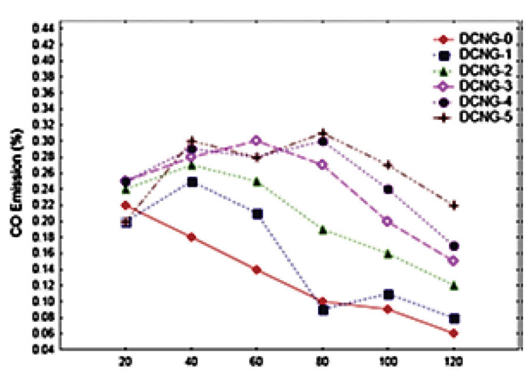

Figure 9. Variation of CO emission with load for D-CNG combination (Paul et al., 2013)

Lounici et al. (Lounici et al., 2014) reported the variation of carbon monoxide emissions under diesel mode and CNG-diesel dual mode and 1500 and 2000 rpm, as a function of engine load. As illustrated in Figure 10, CO outflows are higher for dual fuel mode at low and medium loads. On the other hand, CO for dual mode diminishes when engine load is increased as a consequence of gaseous fuel use. Then again, for high loads, in light of extremely rich blends in traditional diesel, which bring about bad burning, the CO outflows are fundamentally higher (Lounici et al., 2014). In brief, it can be seen that CO emissions with dual mode is consistently higher. This is due to the fact dual fuel mode experiences a poor fuel usage that prompts deficient ignition and high HC emission. That is, fuel disintegration and oxidation is not upgraded, and hence, CO emissions are increased. I Increasing the load diminishes CO emissions; as more fuel results in a complete ignition.

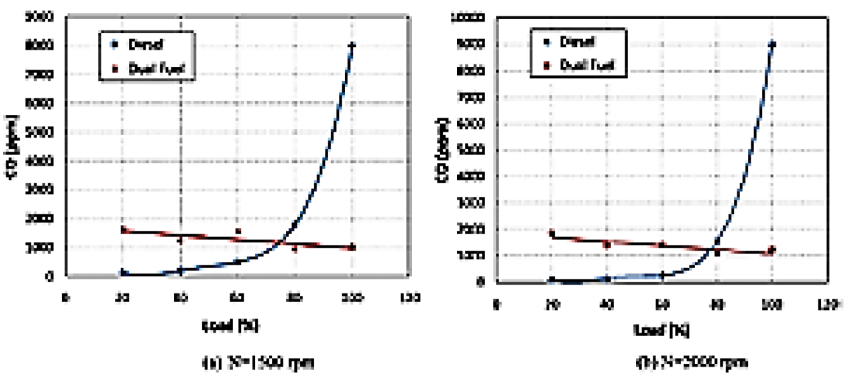

Figure 10. Variation of the CO emissions according to load, for various engine speeds (Lounici et al., 2014)

EFFECTS OF CNG ON CARBON DIOXIDE

Carbon dioxide (CO_2) is the most noticeable human made Greenhouse gas emission. (Alrazen et al., 2016a). Natural gas has one of the least carbon substance among hydrocarbons, bringing about a capability of lower CO_2 emission than that of clean diesel (Caillol, Berardi, Brecq, Ramspacher, & Meunier, 2004). Most studies affirmed that the utilisation of natural gas in a dual fuel engine at high loads as a good strategy to reduce climate change (Lounici et al., 2014). Lounici et al. (2014) compared conventional diesel mode and CNG-diesel dual mode under two engine speeds as shown in Figure 11. They showed that the CO_2 emission for diesel mode was higher compared with CNG-diesel mode. At low loads, the contrast between CO_2 emissions for traditional diesel and dual fuel mode is not significant. As for higher loads, because of the increase of engine load under dual fuel mode which is accomplished by expanding the measure of natural gas, the distinction is clearer. In this situation, the important role of natural gas to reduce the CO_2 emissions is clear (Martínez, Mahkamov, Andrade, & Lora, 2012; Lounici et al., 2014).

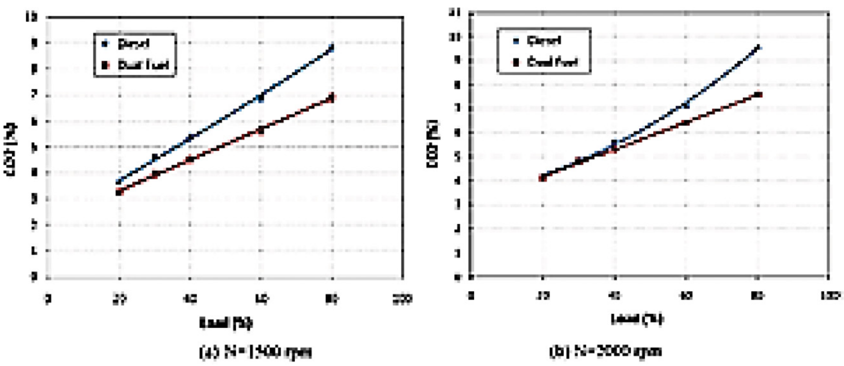

Figure 11. Variation of the CO_2 emissions according to load, for various engine speeds (Lounici et al., 2014)

Thus, it can be seen that dual fuel mode emits lower CO_2 in contrast with diesel mode. This is due to the perfect way of burning of the natural gas, lower carbon-to-hydrogen proportion (C/H); for one reason. The other reason may be the high HC outflow of dual fuel mode and the abnormal burning, as uncovered by the high CO emit; especially at part load (Alrazen et al., 2016a). At high load, on the other hand, the change in the burning procedure causes CO_2 emissions to increment, however its worth stays substandard compared to that of diesel ignition (Abdelaal & Hegab, 2012).

CONCLUSIONS

There are five significant findings in this review paper:

- moderate and low loads, NO_x emissions of CNG-diesel dual fuel mode are lower compared with using diesel fuel alone. At high loads, however, the emissions of NO_x of CNG-diesel dual fuel mode is higher compared with that of diesel one. This is due to heat released in the early premixed burning stage, which is the consequence of the fuel ignition change at those loads.
- The utilisation of natural gas results in dramatically reduced soot emission. This reduction is due to methane which is the main component of natural gas.
- Dual fuel mode leads to greater HC emissions compared with traditional diesel mode, especially at part load conditions. This is a direct result of the blend of gaseous fuel and air at such conditions as well as poor fuel efficiency; much of the natural gas escapes from the ignition procedure leading to greater HC emissions.
- Majority of studies have reported that CO emission with dual mode is always higher than conventional diesel mode. The reason for this is due poor fuel utilisation leading to abnormal combustion and high level of CO emission.
- Dual fuel mode produces significantly reduced CO_2 emissions in contrast with using diesel mode alone. This is due to perfect burning of the natural gas and the lower carbon-to-hydrogen proportion (C/H). Additionally, dual fuel mode and the abnormal burning produces high levels CO emit, especially at part load. At high load, on the other hand, the change in the burning procedure leads to higher CO_2 emissions; however, it is lower compared with that of diesel ignition.

Further experiments are need to study the actual emission styles for example, the NOx-HC trade-off, engine parameter choices, different engine configurations, and combustion regimes.

REFERENCES

Abdelaal, M., & Hegab, A. (2012). Combustion and emission characteristics of a natural gas-fueled diesel engine with EGR. *Energy Conversion and Management, 64*, 301-312.

Adnan, R., Masjuki, H., & Mahlia, T. (2009). An experimental investigation of unmodified DI diesel engine with hydrogen addition. In *3rd International Conference on Energy and Environment, 2009, ICEE 2009* (pp. 45-49). UPM, Malaysia.

Alla, G. A., Soliman, H., Badr, O., & Rabbo, M. A. (2002). Effect of injection timing on the performance of a dual fuel engine. *Energy Conversion and Management, 43*(2), 269-277.

Alrazen H. A., Talib, A. A., & Ahmad, K. A. (2016a). A two-component CFD studies of the effects of H_2, CNG, and diesel blend on combustion characteristics and emissions of a diesel engine. *International Journal of Hydrogen Energy, 41*(24), 10483-10495.

Alrazen, H. A., Talib, A. A., Adnan, R., & Ahmad, K. (2016b). A review of the effect of hydrogen addition on the performance and emissions of the compression–Ignition engine. *Renewable and Sustainable Energy Reviews, 54*, 785-796.

Bedoya, I. D., Arrieta, A. A., & Cadavid, F. J. (2009). Effects of mixing system and pilot fuel quality on diesel–biogas dual fuel engine performance. *Bioresource Technology, 100*(24), 6624-6629.

Caillol, C., Berardi, G., Brecq, G., Ramspacher, M., & Meunier, P. (2004). A simulation tool for evaluating gas composition effects on engine performance. *International Gas Research Conference,* (pp. 1-19).

Heywood, J. B. (1988). *Internal combustion engine fundamentals.* New York, NY: Mcgraw-hill.

Ibrahim, A., & Bari, S. (2008). Optimization of a natural gas SI engine employing EGR strategy using a two-zone combustion model. *Fuel, 87*(10), 1824-1834.

Kalam, M., Masjuki, H., Mahlia, T., Fuad, M., Halim, K., Ishak, A., … & Shahrir, A. (2009). Experimental test of a new compressed natural gas engine with direct injection. In *SAE 2009 International Powertrains, Fuels and Lubricants Meeting, 2009* (pp. 1-7). Florence, Italy. doi:10.4271/2009-01-1967

Karavalakis, G., Hajbabaei, M., Durbin, T. D., Johnson, K. C., Zheng, Z., & Miller, W. J. (2013). The effect of natural gas composition on the regulated emissions, gaseous toxic pollutants, and ultrafine particle number emissions from a refuse hauler vehicle. *Energy, 50*, 280-291.

Khan, I. M., Greeves, G., & Wang, C. H. T. (1973). *Factors affecting smoke and gaseous emissions from direct injection engines and a method of calculation* (No. 730169). SAE Technical Paper.

Korakianitis, T., Namasivayam, A., & Crookes, R. (2011a). Diesel and rapeseed methyl ester (RME) pilot fuels for hydrogen and natural gas dual-fuel combustion in compression–ignition engines. *Fuel, 90*(7), 2384-2395.

Korakianitis, T., Namasivayam, A., & Crookes, R. (2011b). Natural-gas fueled spark-ignition (SI) and compression-ignition (CI) engine performance and emissions. *Progress in Energy and Combustion Science, 37*(1), 89-112.

Lounici, M. S., Loubar, K., Tarabet, L., Balistrou, M., Niculescu, D., & Tazerout, M. (2014). Towards improvement of natural gas-diesel dual fuel mode: An experimental investigation on performance and exhaust emissions. *Energy, 64*, 200-211.

Martínez, J. D., Mahkamov, K., Andrade, R. V., & Lora, E. E. S. (2012). Syngas production in downdraft biomass gasifiers and its application using internal combustion engines. *Renewable Energy, 38*(1), 1-9.

Masood, M., Ishrat, M., & Reddy, A. (2007). Computational combustion and emission analysis of hydrogen–diesel blends with experimental verification. *International Journal of Hydrogen Energy, 32*(13), 2539-2547.

Namasivayam, A., Korakianitis, T., Crookes, R., Bob-Manuel, K., & Olsen, J. (2010). Biodiesel, emulsified biodiesel and dimethyl ether as pilot fuels for natural gas fuelled engines. *Applied Energy, 87*(3), 769-778.

Papagiannakis, R., & Hountalas, D. (2004). Combustion and exhaust emission characteristics of a dual fuel compression ignition engine operated with pilot diesel fuel and natural gas. *Energy Conversion and Management, 45*(18), 2971-2987.

Paul, A., Bose, P. K., Panua, R. S., & Banerjee, R. (2013). An experimental investigation of performance-emission trade off of a CI engine fueled by diesel–compressed natural gas (CNG) combination and diesel–ethanol blends with CNG enrichment. *Energy, 55*, 787-802.

Ramamurthy, B. (2006). *Design of a catalyst system with periodic flow reversal for lean burn natural gas engines*. (Master's thesis). University of Tennessee, Knoxville.

Sahoo, B., Sahoo, N., & Saha, U. (2009). Effect of engine parameters and type of gaseous fuel on the performance of dual-fuel gas diesel engines—A critical review. *Renewable and Sustainable Energy Reviews, 13*(6), 1151-1184.

Saravanan, N., & Nagarajan, G. (2008). An experimental investigation of hydrogen-enriched air induction in a diesel engine system. *International Journal of Hydrogen Energy, 33*(6), 1769-1775.

Turns, S. R. (1996). *An introduction to combustion* (3rd Ed.). New York, NY: McGraw Hill.

Wang, X., Deng, K., He, F., & Zhou, Z. (2007). A thermodynamics model for the compression and expansion process during the engine's motoring and a new method for the determination of TDC with simulation technique. *Applied Thermal Engineering, 27*(11), 2003-2010.

Williams, A. M. (2004). *Lean NOx trap catalysis for lean burn natural gas engines*. (Master's Thesis). University of Tennessee, USA. Retrieved from http://trace.tennessee.edu/utk_gradthes/2224

Zhou, J., Cheung, C., & Leung, C. (2014). Combustion, performance and emissions of a diesel engine with H_2, CH_4 and H_2–CH_4 addition. *International Journal of Hydrogen Energy, 39*(9), 4611-4621.