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HCNG Fueled Compression-Ignition (CI) Engine with its Effect on Performance and Emissions

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Abstract: Because of the high energy consumption rates as well as creating a clean environment, we need a fuel which can be substituted for fossil fuels. Natural Gas (CNG) and Hydrogen (H_2) are the best among the alternative fuels and possess specific characteristics such as sustainability, renewability and clean burning capacity. This review study is presented of contemporary research and given a comprehensive overview on the HCNG fueled diesel engine. Major subjects that have discussed here include introduction and fundamentals of dual fuel diesel engine with using natural gas and hydrogen and details on the different mixture formation strategies of HCNG fueled and their effects on engine performance and emissions characteristics.

Key words: Diesel, CNG, HCNG, hydrogen, performance, emissions

INTRODUCTION

Definitely, the requirement of improved energy generation and lessening of environmental worries such as the emissions of Green House Gas (GHG), damages of ozone layer, decay of aquatics and global warming are topically essential. To fulfill the worldwide mounting energy demand by maintaining earth as a safer place for living, at least 10-15 Tera Watt (TW) of carbon-free power is required for the future. Rapid increase of fossil fuel cost and its restricted reserve forced us to explore for alternative energy resources to satisfy the transportation demand on the globe. With the advent of modernization and industrialization, a considerable amount of total energy is being universally used for transportation systems. Consequently, the emission of polluting agents in the atmosphere is exponentially escalating. Presently, the fossil fuel production is steadily declining. Fossil fuel driven transportation machineries consumes major portion of the globally produced diesel and petroleum (Shahraeeni *et al*., 2015; Sharma and Ghoshal, 2015). Development in such rapid space demands more and more oil and gas which is doubtful to be fulfilled by the present availability. Accordingly, H_2 and CNG emerged as an important energy substitution to maintain the future sustainability in every sphere including transports, industries and residences.

In the past, NG is widely employed in spark-ignition engines and applied in diesel engines with diesel-NG dual-fuel operation. Papagiannakis and Hountalas (2004) and Papagiannakis *et al*. (2007) reported the operational features of diesel-NG dual-fuel single-cylinder diesel engine. It is demonstrated that the ignition delay of diesel-NG dual-fuel operation is extended than the normal diesel fuel function. The peak heat release rate and cylinder pressure are observed to be decreasing with the increasing of NG contents at low to medium loads. Conversely, they are improved at high load via. the fast burning rate of diesel NG co-operated ignition. The use of diesel-NG dual-fuel engine displayed remarkable increase of CO/HC and PM emissions. The CO emission is controlled through the intake of pre-heated air and enhanced quantity of pilot diesel fuel and a slight decrease of NO emission is noticed as well (Papagiannakis *et al*., 2010; Poompipatpong and Cheenkachorn, 2011). Poompipatpong and Cheenkachorn (2011) examined in influence of compression ratio and engine speed on the emission levels of a four-cylinder diesel NG dual-fuel engine. Higher thermal efficiency and lower CO emission is achieved at upper compression ratio and elevated engine speed. Nevertheless, thermal efficiency appeared poor at low engine load.

Hydrogen being a potential alternative fuel for internal combustion engines improves their efficiency with reduced gas emissions. Liew *et al*. (2010) investigated the combustion process of diesel-H_2 assisted dual-fuel engine and achieved a remarkable enhancement is the peak cylinder pressure at 70% of the complete load. It is also acknowledged that controlling such effects is pre-requisite for safer and durable engine

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performances. The combustion efficiency is determined to be relatively lower with the incorporation of extra amount of H_2. Further studied (Alrazen *et al*., 2016a, b; Arrieta *et al*., 2016; Gatts *et al*., 2010; Kakaee *et al*., 2015) the combustion efficiency of hydrogen by measuring the unburned hydrogen exhaust. They suggested that the hydrogen combustion efficiency was engine load dependent and the hydrogen recommends supplemented at high load to achieve higher hydrogen energy conversion efficiency and better diesel fuel efficiency (Alrazen *et al*., 2016a, b Gatts *et al*., 2010). Gatts *et al*. (2010) examined the hydrogen combustion efficiency and measured the unburned hydrogen fuel persent in exhaust gases. The researchers suggested that the combustion efficiency of H_2 was engine load dependent and they suggested that to obtain higher combustion efficiency of H_2 the hydrogen fuel must be inserted at higher load. Liew *et al*. (2010) and Lilik *et al*. (2010) showed that with the incorporation of extra H_2 the emissions of $HC/CO/CO_2$/PPM are almost linearly reduced. This clearly indicates the correlation between the added amount of H_2 and reduced emission of carbon-monoxide and PPM. In contrast, at low to medium loads the amount of NO_x emission is found to decrease and increase at high load due to fast burning rate of hydrogen. This in turn, caused high combustion temperature and enhanced NO_x formation.

Thermal efficiency of an engine is decided by its load, speed and the amount of incorporated H_2 (Miyamoto *et al*., 2011). The problem associated with limited engine efficiency and enhanced emissions of HC/CO from conventional gas-diesel dual-fuel engines remains unsolvable without post-treatment devices. New strategies are adopted to overcome such shortcomings. Hydrogen addition has the potential to enhance the combustion process and hence the energy efficiency of some gaseous fuels including NG and LPG can be enhanced by blending H_2. The ignition processes of spark-ignition engine containing NG-H_2 blend as fuel are extensively analyzed and certain limitations associated with the efficiency and emissions are removed (Korakianitis *et al*., 2011). This improvement is precisely due to exceptional features of H_2 such as its wide flammability and fast burning velocity.

Lately, the notion of tri-fuel engines is introduced to further improve the performance of conventional gas diesel dual-fuel engines. Lata *et al*. (2012) theoretically and experimentally investigated the diesel engine performance using LPG-H_2 mixture as the gaseous fuel in addition to pure diesel fuel. The low efficiency at lower load for diesel LPG dual-fuel engine exhibited remarkable improvement when H_2 is added. The engine showed much higher efficiency at 10% of full load. Properties of H_2 are opposite to that of methane. Methane possesses low flame propagation speed and narrow flammability than hydrogen. Accordingly, blending of H_2 to methane is thought as alternative route to improve the combustion process that makes the diesel engine operations more flexible. The fast burning rate, high diffusivity and low ignition energy of H_2 in diesel-H_2 dual-fuel engine enables the combustion unstable especially at higher engine loads. This results some knocking effect which is damaging for the endurance and safety feature of the engine. Addition of methane makes combustion of H_2 smoother and stable by avoiding unusual ignition. Nevertheless, methane reduces the combustion temperature of hydrogen and suppresses NO_x emission (Lata and Misra, 2011).

DUAL FUEL ENGINE

Much of the literature can be found to dwell into the conversion of existing engines to dual fuel operation. A typical investigation would also consider an easy conversion of a diesel engine to dual fuel operation assisted by the port injectors or a gas mixer. The engine is operated and the effect of a few, easily controlled parameters, typically pilot amount, pilot timing, intake temperature, load and speed with respect to emissions and efficiency are analyzed (Ahmad *et al*., 2005; Karavalakis *et al*., 2012; Selim, 2004; Shahraeeni *et al*., 2015; Stelmasiak, 2002). While these publications confirm the general trends for the DDF operation they do in common, lack depth and do not facilitate the understanding of the combustion process. The results in these studies are also very concentrated on the engine setup used and may for this reason seem to be contradictory if this fact fails to be considered. The results of more general investigations are presented by Karim (2003). However, the data presented is gained at λ between 2 and 10 which is not very relevant. More in-depth investigations on the effect of movement and gas supply strategy by means of the optical perception through an endoscope are performed by Hepp *et al*. (2014). A high speed camera was used and each frame was transformed into gray scale and the average luminosity across the entire frame was computed, resulting in a curve of luminosity versus crank angle. With regard to the very strong luminosity of soot particles compared to that of a propagating flame and the limited field of view provided by an endoscope, the results may be indicative of how much glowing soot is transported in front of the window by the air motion instead of an indication of the quality of the combustion. The researchers also do not provide information about λ

during the tests, making the results very difficult to be contextualized. Several try-outs to model dual fuel combustion have been made (Ahmad *et al*., 2005). These researchers agreed that the models are validated against small data sets and there is no conclusion regarding the validity over various conditions. Some of the models are validated for irrelevant operating conditions whereas others exhibit very poor congruence with measurements (Kusaka *et al*., 2002). There are two gaseous fuels that commonly used in dual fuel mode which are natural gas and hydrogen.

NATURAL GAS

CNG is already acknowledged as an option to vehicle fuels in the market that has its own economic advantages. There are also, the environmental advantages of natural gas which is later known as clean fuel, when alloyed with a compound called methane. Methane makes up the chief ingredient of CNG which is by far the best-suited fuel produced for spark-ignition engines. Despite all the plus points, the fuel does have its weakness in certain areas (Mansor *et al*., 2017; Sutkowski and Teodorczyk, 2004). CNG has a low lean-burn property and low burning velocity which keeps the engines from performing at an optimal level. Thus, the engines experience poor thermal efficiency, low lean-burn capacity, many cycle-by-cycle variations, etc. All these work together to produce the output and even increase the fuel consumption of the vehicle. Although, CNG is mostly made of CH_4 (methane), there are also, traces of propane, ethane, hydrogen sulfide, nitrogen, carbon dioxide as well as water vapor.

Methane, CH_4, although known as a hydrocarbon by definition is also inert and does not contribute to smog production or respiratory diseases. Despite this, methane is a very strong greenhouse gas and if not addressed carefully, methane seeped from engines can nullify any environmental benefits as it switches from gasoline or diesel.

Methane mono fuel engines: Methane is more commonly used in SI engines. In applications that are characteristically light-duty these engines are usually bi-fuel engines; they are expected to operate on gasoline fuel as well. This curbs the compression ratio and successfully limits the efficiency of the engine as well. For medium and heavy duty applications, SI gas engines are typically mono-fuel and this implies that they can be optimized for methane operation that provides better efficiency. These engines still suffer from something recognized as the achilles heel of the otto engines; pumping losses and poor part load efficiency. The pumping losses can be addressed to some extent by running the engine lean and with the addition of the EGR.

Methane dual fuel engines: The solution to using methane in a CI engine is to introduce a pilot-fuel with higher octane number which kick-starts the combustion and ignites the methane, thus, giving rise to the Diesel Dual Fuel (DDF) engine. Currently, researcher is performed both in the field of direct injected DDF as well as port injected DDF.

Direct injected DDF involves a special DI injector which handles both the diesel and the methane fuel. A small pilot amount of diesel fuel is injected ahead of the main injection to increase the temperature and to ignite the methane (Brown *et al*., 2011; Mansor *et al*., 2017). The methane is then injected and burns in a diffusion flame in a similar way to diesel combustion. This concept enables anunthrottled operation with little methane slip but particles and NO_x do bring about a problem. The system is also complex and expensive and it is not possible to run the vehicle on diesel alone thus fuel flexibility can be easily lost.

In port injected DDF, the methane is injected into the intake manifold and is premixed with the air in the induction and compression stages. A small diesel pilot is used to start the combustion. The researcher presented in this thesis sheds light on the port injected DDF and henceforth this is what is referred to when the acronym DDF is adopted. Port injected DDF is beneficial in the sense that it makes the conversion of existing vehicles relatively simple while maintaining full diesel capability in case methane happens to be not available. Both of these factors are essential when promoting the technology to the market.

CNG vs. diesel and petroleum: Natural gas is forming a suitable mixture and it has a good combustion property. The engines of vehicles researcher well without suffering from knocks because of the fuels' octane value 120. Low lean-burning ensures lower fuel cost while its flame speed ensures prolonged engine durability (Sharma and Ghoshal, 2015). The good news is that any kind of diesel or gasoline engines can be transformed into the natural gas versions and one will not require any serious mechanical changes. Understandably, such engines have very wide combustion range. Even the PM emissions are insignificant in this case. All these points are able to explain the constantly growing count of CNG vehicles in the market as well as those getting transformed into CNG engines (Gopal and Rajendra, 2013).

There are various reasons why CNG has proven to be a more accepted alternative than petrol. In this vein, CNG, when it comes to safety, needs the strongest mention. It is more secure than both the variants of diesel engine, due to the high-level auto-ignition temperature. Natural gas is most certainly a cheaper alternative than petrol and additionally, it is also cleaner where carbon emission is concerned. Regular automobile engines can run on both, under the condition that one has a dual-fuel system (Gopal and Rajendra, 2013).

Nonetheless, one realization is that the engine performance will be affected when running on CNG due to the comfort factor. Users have made some comments on the dropper pickup and power of the engines when they run on CNG. Also, the engines start to run smoother with the fuel that maintains a high level of heat which lets the engine up and running (Sharma and Ghoshal, 2015). However, one prominent disadvantage with using CNG lies in the relatively low availability of CNG filling stations on all routes.

CNG has become very popular among all other fuels in the market as the Green gas. Low carbon emission has brought about effective management of environmental pollution (Gopal and Rajendra, 2013). Increase in usage can become very timely in a pollutant-free environment in the long run. Assisted by the advocators, a large number of automobile variants are coming engineered with the retro fitted CNG. Hence, users can experience both speed and pickup of petrol engines, disregarding the cost and emission.

The injection timing, the SOI timing and ignition delay time are considered to be the main and very important factors that can determine the combustion process, engine performance and exhaust emission (Abdullah *et al*., 2008). New studies show that using combinations of hydrogen and diesel mixing together or natural gas and diesel mixing together and even HCNG blended together in the internal combustion engine will lower the levels of emission and lend to better overall performances. Paul *et al*. (2013) scrutinized the emission characteristics of diesel and CNG blended against based diesel operation. Their study had pointed to the increase in the CO level with diesel and CNG blended. Moreover, their results show that CNG enrichment also reduces both the NO_x and smoke.

HYDROGEN FUEL

Hydrogen as an energy carrier is proven to offer great potential towards transportation. Internal combustion engines are the most established tools, several technologies can use hydrogen as an energy carrier

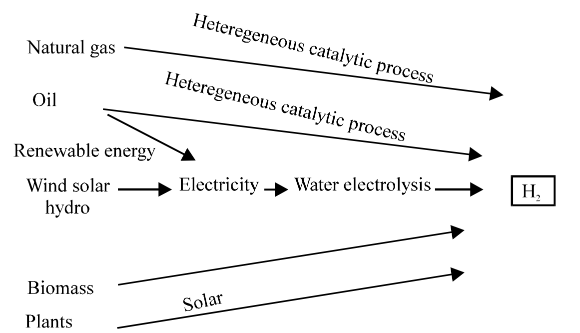

Fig. 1: Various processes for the production of hydrogen (Dunn-Rankin, 2007; Ceper, 2012)

(Verhelst and Wallner, 2009). Presently, 96% of hydrogen comes from the fossil fuels where 90% of hydrogen in USA is produced by using natural gas with 72% efficiency while 4% of hydrogen is produced by using water by means of electrolysis. Most of the power that originates from fossil energizes in plants that are 30% effective. Undoubtedly, use of renewable energy is much more effective to produce hydrogen than fossil fuel. The efficiency of present wind turbines is 30-40% that of hydrogen which is 25%. The best available solar cells have an efficiency of 10%, prompting to a general effectiveness rate of 7%. Algae as appeared in Fig. 1. Algae can be utilized to create hydrogen at a productivity rate of around 0.1% (Ceper, 2012; Mason, 2007).

The use of hydrogen as an automotive fuel is promising in terms of significant improvement in the spark-ignition engines performance (Alrazen *et al*., 2016a, b; Ceper, 2012; Javed *et al*., 2015; Veziroglu and Barbir, 1991). Furthermore, the self-ignition temperature of the hydrogen/air mixture is higher than that of other fuels. Therefore, hydrogen is regarded as an antiknock quality of fuel. The high ignition temperature and low fire glow of hydrogen makes it a more dependable fuel than others. On top, it is additionally non-poisonous. Hydrogen is portrayed by its most elevated energy-mass coefficient among other chemical fuels. The hydrogen mass energy consumption exceeds the traditional gasoline fuel by around 3 times and alcohol by 5 and 6 times (Veziroglu and Barbir, 1991). It is established that hydrogen can enhance the effective efficiency of an engine with reduced specific fuel consumption.

A small amount of H_2 mixed with air produces a combustible mixture. This can be burnt in a conventional spark-ignition engine at an equivalence ratio below the lean limit of gasoline/air mixture. The ultra-lean combustion produces a low flame temperature and leads to lower heat transfer to the walls, greater engine efficiency and lower NO_x emissions. It is worth noting that the burning velocity of hydrogen/air mixture is approximately 6 times greater than that of gasoline/air mixtures. With the increase of burning velocity, the actual indicator diagram becomes nearer to the ideal diagram to achieve higher thermodynamic efficiency.

Combustion characteristics of hydrogen in dual fuel model: Auto ignition temperature, minimum ignition energy, wider flammability range and shorter quenching distance are several properties that ascertain the suitability of a fuel for engine applications. Unless the properties are suitably exploited to an advantage for improved engine characteristics they might invite various unwanted combustion issues. Low ignition energy enables the conventional ignition system to be workable even with very low spark energy but it also results in surface ignition. Surface ignition brings about undesirable combustion phenomenon such as flash back, pre-ignition and rapid rate of pressure rise. The method thought to be the easiest to avoid backfire is to ensure that there is no combustible mixture in the intake manifold. Having the crank case ventilation would be required to avoid any abnormal combustion in the crankcase. By optimizing the pressure rise rate, the knocking problem in gaseous engine can be addressed and solved. The abnormal combustion in an engine is classified as:

- Knocking
- Pre-ignition and backfire

The literature survey done on the combustion characteristics of gas operated dual fuel engines shall be discussed below: Lee *et al*. (1995) constructed an intake port hydrogen injector using a solenoid driven gas valve and experiments were carried out with this system to study the combustion characteristics of hydrogen fuel including the flashback phenomenon. Conclusively, by using solenoid driven gas valve, the amount of hydrogen supplied could be controlled very easily by changing the solenoid driving signal's duration. The cylinder peak pressure of hydrogen operation was above 50 bars and was higher than that of gasoline operation by more than 10 bar. Because of the high cylinder pressure, the amount of NO_x emissions increases. NO_x emission concentration of hydrogen operation was 856 ppm/kW and that of gasoline operation was 371 ppm/kW. A stable engine operation was noted between the equivalence ratios of 0.32-0.8. Above 0.8 equivalence ratio, decrease in BMEP due to the incomplete combustion of hydrogen was noticed. To operate the engine at a higher speed without flashback, equivalence ratio and injection timing should be controlled precisely accounting for the delay of the solenoid.

Poonia *et al*. (2011) ran some experiments on a single cylinder DI water-cooled LPG diesel dual fuel engine at a number of intake temperatures and pilot quantities. Pilot fuel quantity and intake temperatures are two essential parameters which control the combustion process in a dual fuel engine. The ignition delay in the dual fuel mode was noted to have always been greater than that in the diesel mode. At a certain intake temperature and pilot quantity the ignition delay increases with an increase in the power output. Thus, gas to air fuel is a very essential factor in controlling ignition delay. At low outputs, the heat release in the first stage following the combustion of the pilot fuel and entrained gas is the dominant factor. The heat release that followed, mainly due to the combustion of the gas was affected favorably by the amount of pilot fuel injected. At high outputs, after the combustion of the pilot fuel and entrained gas, the remaining gas burns in two stages. The first of these was at a high rate which was remarkably affected by the pilot quantity or the intake temperature. The maximum rate of pressure rise increases in direct proportion with the pilot diesel quantity. The peak pressure in the dual fuel mode was significantly higher than diesel operation at high outputs, especially when the intake temperature is high caused by the rapid combustion of the gas air mixture. The combustion duration in the dual fuel mode was higher than diesel values at low outputs. However, it was lower than diesel values at high outputs. It was suggested that, high pilot diesel quantities have to be used at low outputs to ensure that the combustion of the gaseous fuel is proper. As the power output increases, the pilot quantity has to be mitigated to control both the rapid combustion and knock.

Nwafor (2000) studied the combustion knock characteristics of diesel engines running on natural gas using the pilot injection of diesel as a way of starting combustion. The cylinder pressure crank angle and heat release diagrams indicate that dual fuel operation demonstrates a longer ignition delay and slower burning rates. Maximum peak cylinder pressure was reduced and the initial rate of pressure rise was lower in comparison to the diesel fuel operation. The power output of the dual fuel operation was inferior to diesel fuel. In dual fuel engines three types of knock were recognized they are: diesel knock due to the combustion of the premixed pilot fuel, knock because of the auto ignition of end gas and erratic knock because of the secondary ignition of the alternative fuel. The main factors which ascertain the occurrence of these knock is the pilot quantity, delay period, load, speed, gas flow rate and time interval for secondary ignition. Increasing the pilot fuel and reducing secondary fuel slow down the knocking phenomena in dual fuel engines.

Rao *et al*. (2010) carried out a series of experimental investigations on a single cylinder vertical water cooled 5.2 kW CI engine run in dual fuel mode with diesel as injected primary fuel and LPG as the inducted secondary gaseous fuel. The combustion studies were done based on the heat release patterns which were calculated thermodynamically in the dual fuel mode. The results show that the brake thermal efficiency improves with an increase in LPG flow rate until the onset of knock at higher loads. It was found to increase from 30% in the diesel mode to 34% in the dual fuel mode at LPG flow rate of 0.6 kg/h at full load. Exhaust smoke level is reduced with the increasing LPG flow rate at all loads. It decreased in a full load from 29-14 HSU from diesel fuel to dual fuel mode. The peak cylinder pressure and maximum rate of pressure rise increased with the load increase. At full load, the peak pressure was 73 and 84 bar in single and dual fuel modes, respectively. The corresponding maximum pressure rise rates were 6.8 and 8 bar/°CA in diesel and dual fuel modes. The combustion temperature increased with load. At full load, the calculated peak temperatures were 1940 and 2020 K in single and dual fuel modes, respectively. The calculated maximum equilibrium concentration of NO_x increased in direct proportion with LPG flow rate at full load. The equilibrium CO concentration was negligibly small at all operating conditions following the overall lean mixture.

Heat losses in hydrogen fuel: It is revealed during testing that usage of hydrogen fuel results in heat loss when a hydrogen-fueled spark ignition engine is power-stroked. Following this other parameters of the engine performance such as engine speed and pickup, ignition timing, equivalence ratio, compression ratio, etc. were examined. Even the emission characteristics of the engine coupled with its engine performance are studied to corroborate the matter of heat loss. It was found out that the loss of heat reduces as the speed of the engine is accelerated. However, the mechanism of the engine takes the internal combustion engine to yield higher power output which releases emissions at a lower level (Sharma and Ghoshal, 2015). Recently, the engines are getting modeled addressing the concept of heat transfer but results are still crowded with inaccuracy. Heat loss within the cylinder walls has however been measured to be the same for all other lean mixtures. The key reason behind heat loss for hydrogen-methane fuel is its low density, added to which is low luminosity.

EFFECT OF HCNG ON DIESEL ENGINE EMISSIONS

Definitely, the most significant determining factor for the feasibility of alternative fuels relies on the exhaust emissions. The strictly controlled emissions regulations forced to identify a fuel with optimum performance obeying the respective emissions standards. As far as emissions are concerned, HCNG appeared to be prospective alternative fuel compared with gasoline and diesel. Compared to diesel, HCNG almost eliminates the alarming particulate matter. Methane chemical structure being relatively stable, it is difficult to reduce emissions via. post-treatment. Thus, the engine fueled with HCNG is highly advantageous than CNG fuel in terms of HC emissions (Alrazen *et al*., 2016a, b; Mansor *et al*., 2017; Thipse *et al*., 2009). The biggest benefit of running the engine on lean burn has to do with the remarkable reduction of NO_x emissions. The increased airflow causing the engine to run at a lower temperature is mainly responsible for the dramatic reduction of NO_x emissions. Furthermore, the incorporation of hydrogen in CNG lowers the emissions concentrations. The increased combustion stability of HCNG engine causes a reduction of HC emissions than pure natural gas fuelled engine However, the increase of the temperature and combustion duration due to the addition of hydrogen results an increase in NO_x emissions (Ashok *et al*., 2015).

Figure 2 and 3 illustrate the experimental results from earlier studies where a change in the excess air ratio from 1.2-2.0 is found to alter the NO_x emission to an extremely lower level. For the excess air ratio about 1.8, the maximum cylinder pressure and maximum heat release was significantly increased due to hydrogen addition compared to excess air ratio of 1.2. It was suggested that, the addition of more than 20% of hydrogen volume into CNG well optimized the lean mixture combustion

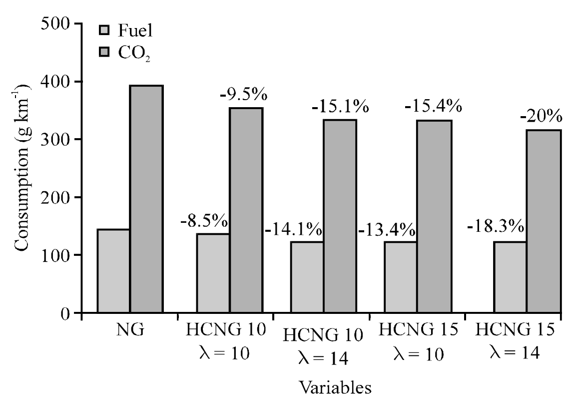

Fig. 2: Gas consumption and emissions of greenhouse gases for different hydrogen contents in HCNG

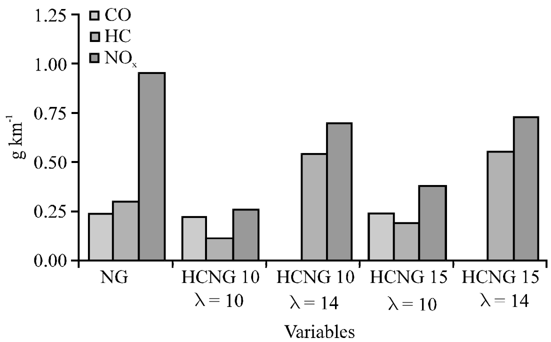

Fig. 3: Local emissions of different volumes of hydrogen in HCNG

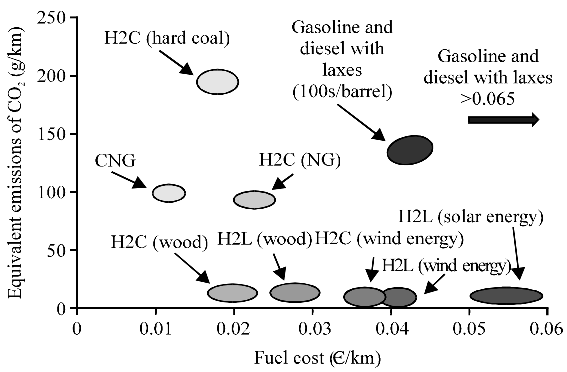

Fig. 4: Cost and CO_2 emissions for different fuels (Ceper, 2012)

and ignition timing. This caused a significant reduction of NO_x emission and maintained relatively higher thermal efficiency under certain fixed engine conditions. Figure 2 and 3 demonstrate the gas consumption and the emission of greenhouse gases for various hydrogen contents in HCNG. The local emissions of different volumes of hydrogen in HCNG are also shown. Figure 2 depicts the emission potential of HCNG engine.

Carbon monoxide: Much attention is paid to the emission of pollutants such as CO, HC and NO_x emissions during any experimental or simulation studies on reciprocating engines. Measurements and calculations of CO_2 emissions are omitted from many studies despite its importance as greenhouse gas (Navarro *et al*., 2013). Figure 4 presents the fuel costs and their relationship to equivalent CO_2 emissions for various types of fuel (Ceper, 2012). Clearly, the global CO_2 emissions associated with CNG and their costs are observed to be lower than those produced by gasoline or diesel. Hydrogen produced lower CO_2 emissions than CNG, gasoline or diesel. However, hydrogen is always produced from renewable sources Because of the high price of crude oil in some cases the cost of H_2 is lower than that of gasoline or diesel. These studies did not consider the possible effects increasing demand or mass production of fuel (Ceper, 2012).

It is important to mention that the rate of conversion of CO to CO_2 at a given temperature is not instantaneous. Thus, in exceeding the rate of cooling over the conversion rate, CO becomes “frozen” and greater than the equilibrium concentrations. Moreover, CO also formed an oxygen deficient rich mixture of environments. Most recent reports revealed that the fuel cost of gasoline and diesel is marked higher than CNG and that too for the CO_2 gas release. Currently, it is established that hydrogen source is categorized as renewable with less CO_2 and CO emissions compared to their hydrogen-less counterparts (Arat *et al*., 2013). Interestingly, considering the costs of mining and advancement in processing and transportation of hydrogen a significant difference is expected in the future where the price of crude oil will be much higher than hydrogen.

For experiments under low compression ratio, the H_2 percent goes up at the expense of lower BSHC value. It means that for 100% H_2, the BSHC would be zero. Accordingly, if the maximum value is 64 g/KWH then a blend with 80% CH_4 and 20% H_2 would produce BSHC = 0.060. The HC emission for the same fuel would be lesser than all methane fuel used (Arat *et al*., 2013). Normally, the engine configuration reacted similarly in the regular operating ranges. However, with richer mixtures the changes were significant. The given CH_4/H_2 mixture exhibited a reduced BSCO output. This is because the CO output production is regulated by the combustion stoichiometry and not by the engine as presumed. The lower amount of carbon emission with the addition of hydrogen in the fuel is mainly due to the lowering of carbon content in the fuel. If the fuel is blended with hydrogen to a whole 60% then it shows a drop in BSCO to about 20 g/kW h. However, for 60/40 CH_4/H_2 blending, the BSCO displayed a hike in the ultra-lean area primarily due to the engine power decay aroused from insufficient combustion.

NO_x emission: The blend has so far worked great in curbing down the demand for pure hydrogen as fuel while tuning up the engine performance and lowering the carbon emission through the combustion properties of H_2O. This new fuel prepared can serve as a perfect alternative to hydrocarbon fuels when it comes to its application in internal combustion engines. In the past, a lot of experiments have been carried out with engines reacting to alternative fuels but the emission of pollutants as HC, CO and No_x was never the point of focus (Dunn-Rankin, 2007).

When analyzing the emission ratio, the engine performance parameters were also examined and they were found to be in direct relationship. Even though higher compression ratios are considered favorable in terms of tuning up the thermal efficiency, it also turns to be a contributory factor in yielding greater NO_x which is natural under the condition of upped temperature in the combustion chamber. The output is pretty much the same when stoichiometric fuel-air blends are used in general gasoline engines. In this light, it should also be stated that NO_x emission is in reverse with power output which justifies why lean fuel-air blends burn to produce low toxin as well as lower the power performance ($\varphi<1$) (Dunn-Rankin, 2007).

Alternately, if fuel-rich mixtures are used to meet the shortcomings, it will result in a lot of unburnt CO and HC emissions that are equally detrimental to the air around. There are certain factors that need to be taken into consideration when trying to optimize the engine performance with a fuel oil and knock limit comes first in terms of priority.

When the compression ratio of an engine is tuned up too high, the knock resistance automatically shoots downward. In that case, spark retardation would be necessary to tune up the combustion TDC that is directly influential to the power output and thermal efficiency of the engine not to mention the emission volume. Going a little deeper into the matter, the H_2 percentage in an engine determines the $BSNO_x$ value. Bauer and Forest (2001) observed and later stated that the $BSNO_x$ and H_2 percentage are directly proportional to each other (Sharma and Ghoshal, 2015). The former increases or diminishes with the later, precisely stating. Speaking in agreement is the theory proposed by Raman and his co-authors who suggested the same with supporting experiments. However, interestingly, at a lower ratio, the NO_x emission remains low as well.

Experiments were also made by against release of brake NO_x, CO, CO_2 and HC against hydrogen fraction at differently timed injections. Experiment results of Mohammed *et al*. (2011) show that brake NO_x emission goes parallel with the hydrogen fraction in the upward movements and this happens when the fraction value is lower than 10%. Other factors that contribute to this reaction are the cylinder temperature, length of combustion and air ratio (Mohammed *et al*., 2011).

EFFECT OF HCNG ON DIESEL ENGINE PERFORMANCE

The natural gas-hydrogen blends maintained high thermal efficiency at high engine load and the effective thermal efficiency is almost constant or slightly increases with the increase of hydrogen fraction at the small and medium engine loads two factors due to hydrogen addition influence the variation of thermal efficiency on one hand, the increase of combustion velocity by hydrogen addition shortens the combustion duration and increases the thermal efficiency and on the other hand, the heat loss to the chamber wall will be increased by hydrogen addition due to the decreased quench distance and increased combustion temperature and this will decrease the thermal efficiency. Brake effective thermal efficiency increased with the increase of hydrogen fraction at low and medium engine loads and high thermal efficiency is maintained at high engine load which makes it an ideal fuel for high load applications and heavy duty vehicles (Ma *et al*., 2010). One important detail about CNG vs. HCNG is reported by Nanthagopal *et al*. (2011) that the brake thermal efficiency for HCNG is greater than CNG for the same excess air ratio (λ) and the difference in brake thermal efficiency between HCNG and CNG increases with increasing excess air ratio. Also, experimental results indicated that under certain conditions, the maximum cylinder gas pressure, maximum heat release rate increased with the increase of hydrogen fraction. The beginning of heat release advanced with the increase of hydrogen fraction (Nanthagopal *et al*., 2011). Another advantage to lean burn is that as the excess air ratio is increased, the brake specific fuel consumption decreases. This is because of the air-fuel ratio which increased it usually leaves less unburned fuel. That is true until the excess air ratio reaches a certain limit when the cycle-by-cycle variations begin to increase because of the lack of fuel. Lean operation also reduces the likelihood of knocking which allows the use of a higher compression ratio. The addition of hydrogen can greatly improve the performance and emissions of the fuel. There have been many studies completed in efforts to obtain the ideal hydrogen ratio and the general consensus is that hydrogen/natural gas blends around 20%, results in the best overall combination of emissions and engine performance (Ma *et al*., 2010). Fundamentally, the addition of hydrogen provides a large pool of H and OH radicals whose increases make the combustion reaction much easier and faster, thus, leading to shorter burn duration. With these important engine performance criterions, the pilot injection phenomena and combustion chamber issue should not be forgotten. The optimized design of the combustion chamber is an important way of improving the mechanism of HCNG combustion (Morrone and Unich, 2009). The engine operating and design parameters include load, speed, compression ratio, pilot fuel injection timing, pilot fuel mass inducted, intake manifold conditions and type of gaseous fuel. The amount of pilot fuel needed for this ignition is between 10 and 20% of the operation on diesel alone at normal working loads and the amount differs with the point of engine operation and its design parameters. For a dual-fuel engine or gas diesel engines, diesel combustion phases occurs 5 parts, the pilot ignition delay, pilot premixed combustion, primary fuel ignition delay, rapid combustion of primary fuel and the diffusion combustion stage. Summarily, increasing the load at constant speed results in an increase in the mass of gaseous fuel admitted to the engine, since, the pilot mass injected remains constant at all loads. This increase in the mass of methane then causes an increase in the ignition delay period of pilot diesel which then auto-ignites and starts burning the gaseous fuel at a higher rate of pressure rise (Sahoo *et al*., 2009).

CONCLUSION

There are many disadvantageous when using gaseous fuel in dual fuel diesel engines. The ignition delay of diesel-NG dual-fuel operation is extended than the normal diesel fuel function. The peak heat release rate and cylinder pressure are observed to decrease with the increase of NG contents at low to medium loads. Conversely they are enhanced at high load via. the fast burning rate of diesel NG co-operated ignition. The use of diesel-NG dual-fuel engine displayed remarkable increase of CO/HC emissions. For H_2-diesel mode, NO_x emission is found to increase at high load due to fast burning rate of hydrogen. This in turn, caused high combustion temperature and enhanced NO_x formation.

Therefore, researchers and investigators have tried to use tri-fuel technique in order to mitigate the negative aspects in dual fuel diesel engines. Blending of H_2 to CNG is thought as alternative route to improve the combustion process that makes the diesel engine operations more flexible. The fast burning rate, high diffusivity and low ignition energy of H_2 in diesel-H_2 dual-fuel engine enables the combustion unstable, especially at higher engine loads. This results some knocking effect which is damaging for the endurance and safety feature of the engine. Addition of CNG makes combustion of H_2 smoother and stable by avoiding unusual ignition. Nevertheless, CNG reduces the combustion temperature of hydrogen and suppresses NO_x emission.

The Nitrogen Oxide (NO_x) was increased as hydrogen fuel was enriched into CNG and diesel but HC and CO emissions were decreased when hydrogen was added. Brake specific fuel consumption is decreased with increasing hydrogen fraction that due to increase air-fuel ratio. The natural gas-hydrogen blends maintained high thermal efficiency at high engine load and the effective thermal efficiency is almost constant or slightly increases with the increase of hydrogen fraction at the small and medium engine loads, the factors due to hydrogen addition influence the variation of thermal efficiency, the increase of combustion velocity by hydrogen addition shortens the combustion duration and increases the thermal efficiency.

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