International Journal of Engineering and Advanced Technology (IJEAT)
ISSN: 2249-8958 (Online), Volume-9 Issue-6, August 2020

Sustainable Trend in Mitigating Fuel Emissions and Load Performance of Internal Combustion Engine (Empirical Research)

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Abstract**:** ***As technology strives with increase in energy demand, there is need of adopting reliable techniques towards maintaining green environment without affecting production. Knowing fossil and biomaterial feedstock with different percentages of NOx emissions generation. This research reviews the effective ways of reducing the various pollutants (NOx, CO, HC and smoke) emissions from different fuel types (petroleum and biodiesel). This centered on some factors on high generation of NOx emissions from biofuel and fossil which include flame adiabatic temperature, molecular structure of the bio-material (biofuel)and fossil, load conditions and ignition delay time. The paper further stated the adequate methods for reduction of NOx, HC, smoke and others for both in pre and post combustion approaches. However, the observed results from the adopted technologies indicates that EGR introduced, reduced the NOx emissions at about 5-25% EGR rate when used with bio-fueled engine. This is achievable via controlling the combustion peak temperature and oxygen content, also shows significant drop in CO and HC emissions. Finally, with this techniques and modifications, the fuel emissions will be greatly minimized for better environment for operational activities.***

Keywords: Combustion, Fuel emissions, NOx reduction methods and NOx reduction after treatment

I. INTRODUCTION

Internal combustion engine (ICE) is regarded as one of the famous mode of power generation and the prime mover in automotive application. The technology is associated with environmental pollution owning to the class of fuel applied during the mechanism. The operation of internal combustion engine varies depending on the application, technology, fuel used and others [1]. Conventionally, two and four stroke operating cycles are widely known for ICE, which has different advantages in processes and applications. Among these were scavenging process (two stroke) and intake/exhaust stroke (four stroke), which symotheniously work with compression and expansion stroke [2]. Although ICE has contributed greatly towards global development, but seriously, require advance modification and improvement so as to combat its emission effect in our environment, retain performance, minimize fuel consumption and optimize power output [3]. In line with these targets, it is obvious that change in fuel source, the mechanism in ICE required transformation for better utilization of the innovation [3]. Design modification of ICEs has continuously been the target of combustion experts to ensure upgrade of power output together with high efficiency in both unsteady and steady zone of operation [4][5] [6]. This is done in order to avert environmental issues been raised in resent time like greenhouse effect resulting from inadequate internal combustion engines operation [6]. According to global report on pollution. Most of air pollution are from combustion of fuels, which have their source from furnaces, mobile automotive, gas turbines and boilers. During the combustion of fuel, higher amount of energy is recorded with complete combustion, given out excess air closer to stoichiometric combustion which results in low formation of SO_x, CO, NO_2. Also, during incomplete combustion, unburned constituents discharges directly into the atmosphere, causes loss of heat energy, with corresponding decrease in thermal efficiency of the system producing great percentage of emissions. The scattered pollutants in the atmosphere during the combustion are term emissions and of two categories; gases and solid particles, while solid form returns to the ground to form hazardous substances [7]. Fossil based fuels pollutants widely obtained in the field of engineering, owing to trust on its combustion properties, availability and high calorific value. However, constant utilization of these fuel type adversely affects our eco-system. Considering the estimate record made by International Energy Agency, that 2030 worldwide energy consumption will rise by about 53%. The implication is that pollution in our environment by these fossil products will be outrageous, and needs strong measures to control the adverse emission of those pollutants in the atmosphere [8]. Numerous works has been done through energy saving approaches towards reduction of CO_2 and NO_x emissions during industrial activities [6], [9]. The idea of this formulations is to retain the original nature of our ecosystem, reduction of energy cost in production and increase productivity. Therefore, the objective of this research is to

Revised Manuscript Received on August 15, 2020.
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proffer effective and suitable approaches in mitigating various emissions from combustion of fuels, as well as improve output performance of an engine. According to the report on Green plan 2018, reduction on CO_2 during combustion where investigated in our production activities with vision of bringing down the CO_2 emission by 5% in due time. In view of mitigating pollutants of CO_2 and NO_x emissions, adoption and application of photovoltaic/solar power generation to enhance in visualizing the fiscal 2019 goal of achieving about 10,000 MWh of renewable energy. Furthermore, energy-saving formula in the factories to achieve the emission reduction were conducted in Japan as an approach in improving energy consumption per basic unit in the industry [10], thus illustrated in Fig. 1. below and also CO_2 emissions during factory operation in the region of the world is shown in Fig 2. below.

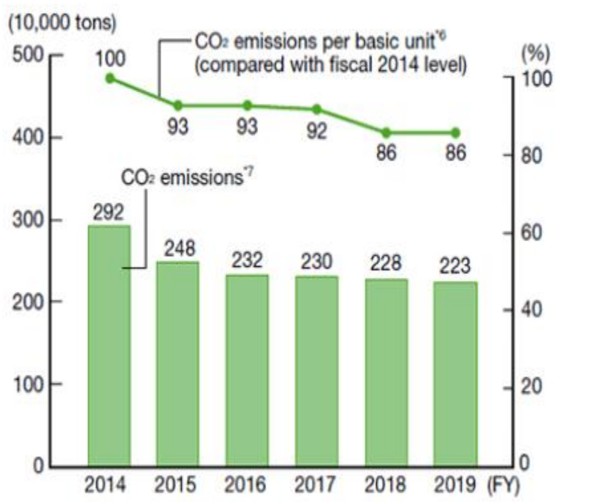

Fig 1: Amount of CO_2 emission in production time and CO_2 emission per basic unit [10]

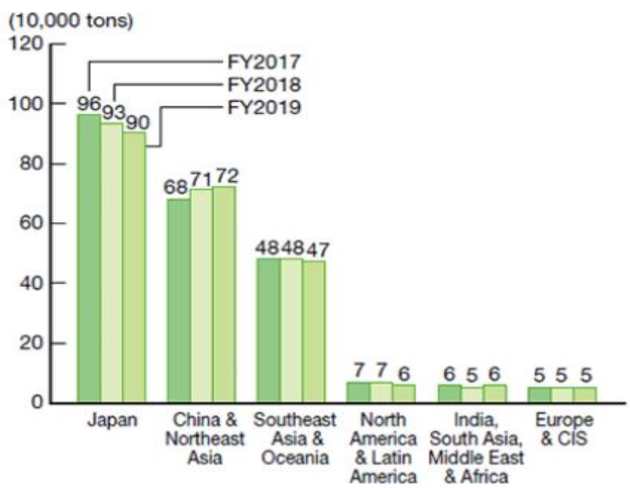

Fig 2: Level of CO_2 emission during factory activities in the world regions [10]

II. ADOPTIVE APPROACH IN REDUCING COMBUSTION EMISSIONS

Following the investigations on different fuel sources for internal combustion application through their properties toward reduction on by-products emissions of the products. Therefore, three sustainable way of combating global challenges on industrial pollutants emissions. They are;

A Biomass Utilization (Low Carbon Content)

Biofuel is widely considered suitable alternative fuel to fossil, owing to their eco-friendly potentials, thus possesses functional features similar to petroleum counterpart in generating energy [11]. Supporting technological innovation through sophisticated equipment's, utilization of biofuel (biodiesel) in the ICEs by industrialized countries significantly contribute in reducing the fossil fuel environmental hazard and minimizes its demand in the labour market [3],[11]. Biofuels are product of biomass thus renewable in nature and due obtained from edible and non-edible vegetable oils, animal fats via transesterification process, waste materials/sewage, plants and others [13]–[15]. Recommending biofuel for industrial application is based on the low content of emissions constituents [10],[15]. The available of biomass materials is so copious in our environment, thus detailed in Fig.3.

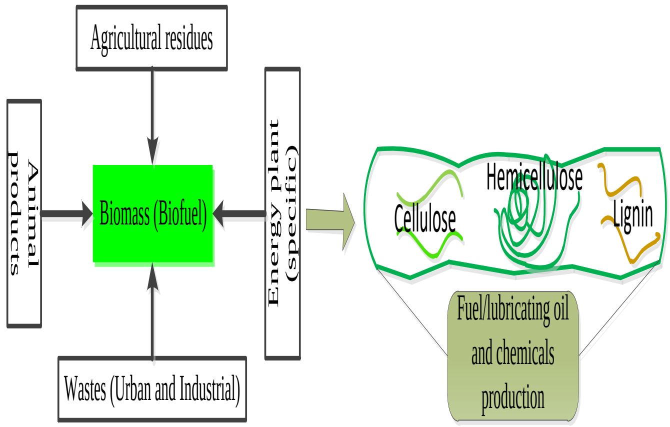

Fig 3::Biomass various source and key components [17]

As by-products of biomass fuel is free from the constituent of $NO_{x,}$ which is classified as the most dangerous parameters that destroy environment via acid rain and causes various human diseases. Furthermore, NO and CO are the greatest pollutant constituents of fossil, deposited in zone of troposphere, which generally leads to greenhouse gases [4]. Fossil fuels contain heavy metals (As, Cr, V Pb, Zn, Hg, Cu, Cd, Ni, Se) which normally undergoes emission during burning, though Hg and Se are found little in the vapor phase. Hydrochloric acid (HCL) emission during the utilization of petroleum/coal fuel is because of some percentages of chloride found in fossil source. This is mostly pronounced in operation of power plants that is not incorporated with flue-gas desulphurization (FGD). During the utilization of fossil fuel without use of FGD system, gases of fluoride is formed and discharged through flue gas. Further reaction of the fluoride with hydrogen turns into hydrogen fluoride, with ambient air of moisture result into hydrofluoric acid [18]. Conventionally, organic and inorganic fuels contain SOx contents in different percentage. In the combustion processes, various Sulphur oxides are generated.

Retrieval Number: C4741029320/2020©BEIESP
DOI: 10.35940/ijeat.C4741.089620
Journal Website: www.ijeat.org

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International Journal of Engineering and Advanced Technology (IJEAT)
ISSN: 2249-8958 (Online), Volume-9 Issue-6, August 2020

Using fossil substance as fuel, about 3% of Sulphur is oxidized into Sulphur trioxide (SO_3), while biomass counterpart is known with infinitesimal Sulphur content [sulfuret oxides SOx formation] [16].

B. High Oxygen Content

Assessment conducted on biofuel indicates present of about 11% of oxygen by weight [19]. Researchers have done many investigations on the exhaust emissions of biodiesel fuel, with optimum reduction on Sulphur, CO and smoke emissions. This is the attribute of high oxygen content in the biomaterial of biodiesel used, thus leading to complete combustion (proper F/a ratio)[20][4][21]. High release of heat during the premixed phase combustion of biofuel is due to the percentage of oxygen present in the biomass (biofuel). Applying biofuel on four stroke diesel engine, increase in on NOx emission to about 15% while operating on high load conditions. The high emissions seem as a result of higher (12%) content of oxygen (B100), yielding higher gas temperature in the burner [2]. According to [22] there is no significant variation in the NOx emissions between biodiesel and fossil diesel product. Also, conducted research on waste bio-oil of ethyl esters and methyl in a CRDI diesel engine, 2.2 L with result of slight variation in fossil fuel and biofuel NOx emissions. Contesting the results [20-22], stated that biofuel of oxygenated content, produced low NOx emissions if compared to fossil fuel. Supporting the result, [21] investigations further report that oxygenated fuel increase in oxygen content, linearly decrease the NOx emissions as shown in Fig 4. The report also indicated the influence of thermal efficiency on the oxygen content of the oxygenated biofuels, thus found constant when oxygen content is below 30% w/w, but gradually decreases with increase in oxygen value beyond 30% w/w. Also, increase in oxygen content led to decrease in density, viscosity and low heating or calorific value [20].

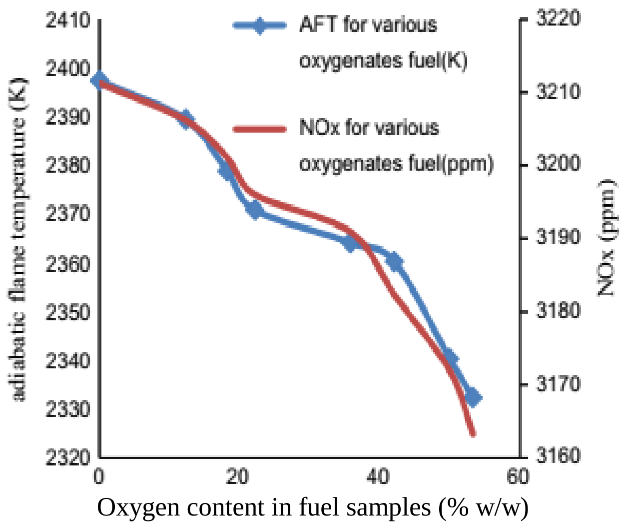

Fig 4: NOx emissions and adiabatic flame temperature (T_{ad}) using Pentadecane and unlike oxygenated fuel samples (Φ$\frac{1}{4}$ 1.0) [23].

Unsaturated molecules produced higher adiabatic temperature (T_{ad}) when compared with saturated counterparts in respect of their combustion compounds [24]. Literarily, biofuels yield greater temperature of flames than conventional fossil fuel, owning to the higher percentage of unsaturated compounds. As a result of this high flame temperature in biofuel, much NO_x emissions due observed. Even at this high emission of NO_X by biofuel, assessment by [23], proves in Figure 5, that even the amount of NO_X emissions by biofuel, used in gas turbine, found to be lesser than NO_X formation by fossil at lower adiabatic temperature (T_{ad}).

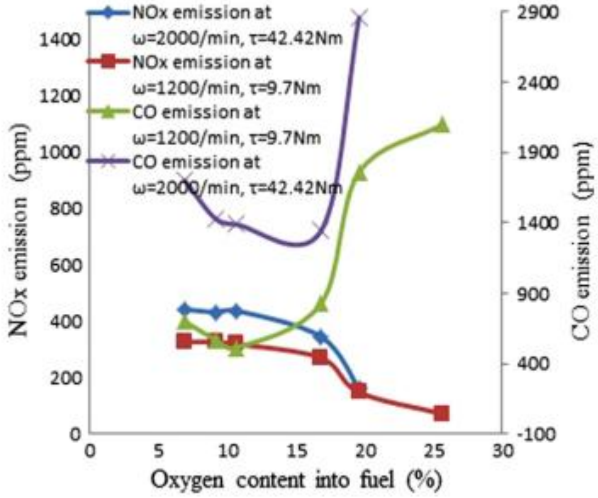

Fig 5: Influence of oxygen content in fuel samples on NOx and CO emissions [4], [23].

C. Molecular Structure of Biofuels

Combustion performance and pollutants emissions are prime factors of fuel molecular structure [20],[21]. These recorded factors include; cetane number, melting point, fatty compounds viscosity and combustion heat (calorific value). For instance, fatty compounds viscosity increases with increase in chain length, decreases with respect of unsaturated constituent's molecule increase. Also, melting point, cetane value and oxidation stability decrease when bulk modulus, fuel lubricity, density and iodine content increase, showing increase in the degree of unsaturation of the fuel material [26]–[28] Furthermore, [29] studied the effect of molecular structure of fuel materials (biofuel and fossil), on NO_X emissions. The chemistry structure on the bonds together the fatty acid chain length was seriously examined. The results show increase in NO_X formation in the areas of double bond associated fuel, which further categorized as iodine content effect. The higher emission results on biofuel were contested by [30], with strong investigation as illustrated in Fig. 6, stated that T_{ad} of biofuel is lower, if compared with fossil fuel counterpart.

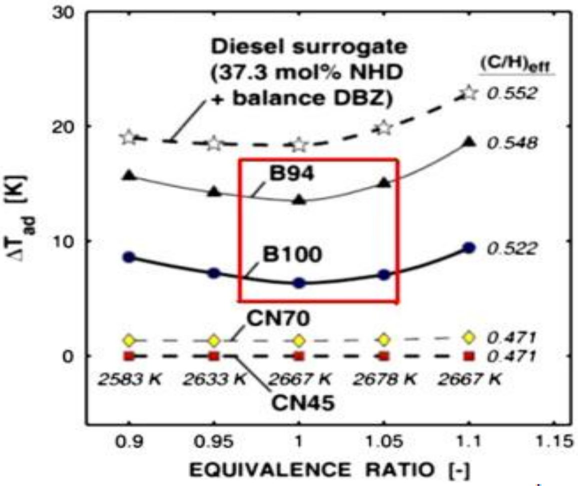

Fig. 6: Difference in T_{ad} relative to CN45 ($\Delta T_{ad} \frac{1}{4} T_{ad,}$ fuel-T_{ad}, CN45), for prefer stoichiometric mixtures of B100, B94, CN70, CN45 and a diesel surrogate fuel with air [30].

Further explained that the differences in T_{ad} were the NOx influencing factor as in Fig. 6, sample B94 always show greater NOx than B100, biofuel, due give lesser NOx than fossil fuel, and CN70 constantly produces higher NOx than CN45, thus found reverse by other reporters.

III. COMBUSTION MODIFICATION TECHNIQUES

Several advance approaches can be introduced into the combustion reaction as to reduce the excessive pollutant (NOx emissions) formation. This is based on the tested combustion investigations, which mostly performed by the utilization of self-generated energy as a medium of NOx emission reduction [18]. Where self-generated enthalpy could not function, water Injection (WI) Technique or strong additives are introduced, all for pollution control purposes and performance improvement.

A Self-generated enthalpy (SGE) or Exhaust gas recirculation (EGR) Approach

Self-generated enthalpy (SGE) or Exhaust gas recirculation (EGR) technique is treatment method applied in combustion process widely as to minimize the formation of pollutant (NOx and CO) during operation. This is achieved through regulating combustion peak and oxygen density [26],[27]. Combustion gas temperature decrease is obtained, suitable for emissions control without any dilution effect with flameless burning formation [33]. During the operation of this technique, the percentage of oxygen in the fresh intake mixture is reduce by the enthalpy of the recirculating exhaust gas [34]. This effect also lowers the effective air/fuel ratio of the mixture, thus affects the exhaust NOx emissions. As there is exchange of energy between the hot exhaust gas and cold fresh intake air, apparently, specific heat (energy) of fresh intake mixture conventionally increases after air/fuel mixture, resulting in decrease in flame temperature [31], obeying the law of heat transfer (energy transfers from hot region to cold region). The EGR technique for reduction of NOx emissions as illustrated in Table 1, shows optimum control of pollutant emission from various fuels of biodiesel and petroleum [35]–[39]. Consequently, drop in the emission percentage of smoke, HC, and CO_2 were recorded as well, while there is increase in BSFC to compared with pure fossil combustion without exhaust gas recirculation EGR [28]. Furthermore, from biodiesel fuel investigation using EGR at range of 5-25%, also gives supportive adoption of the technique over emission reduction. Also the investigation using JME biodiesel for EGR rate of 10%, shows drastic reduction on smoke and NOx emissions for about 31% and 36% respectively [31].

B Water Injection (WI) Technique

Injecting water to the hot chamber of combustor, plays an important role in controlling NOx emissions during combustion processes. Two method are used for the water injection; inlet water injection and direct water injection into combustion chamber. The inlet injection experiment was conducted by [40], for both single point of downstream and upstream of compressor and multipoint, shows good reduction in NOx emissions for two modes. Some other studies are shown in Table 2.5 below. In the course of this study, it was proven that water-fuel emulsion approach of NOx reduction gives optimum and effective result [36][41], if compared with water injection technique. However, approach with direct water injection, provide comfort over water-emulsion method [41].

C Application of Strong Additives

Many additives have been investigated towards combustion emissions control [42], include; oxygenated fuel (ethanol, dimethyl ether and methanol), metal based, antioxidant, diesel vegetable oil blends and octane number enhancer. Introduction of ethanol additive into biodiesel during combustion, reduces the NOx formation, due to low percentage of heating value [43]. Again, lowering premixed combustion phase and ignition delay are done by octane number enhancer with result of burning less fuel at premixed burning phase, thus leads to great reduction of NOx emissions [42]. Materials of strong antioxidant potentials, also applied as additives for pollutants control during combustion. These additives are capable of forming free radical, usually by four ways; chelating formation (transition metal catalysts), reaction chain breaker, reactive radical’s inhibitor and scavenger operator [44]. Reports from combustion researchers [45], strongly support the use of additives and catalysts as emissions regulation and performance biodiesel combustion processes, thus considered additives as a method of developing better combustion characteristics.

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DOI: 10.35940/ijeat.C4741.089620
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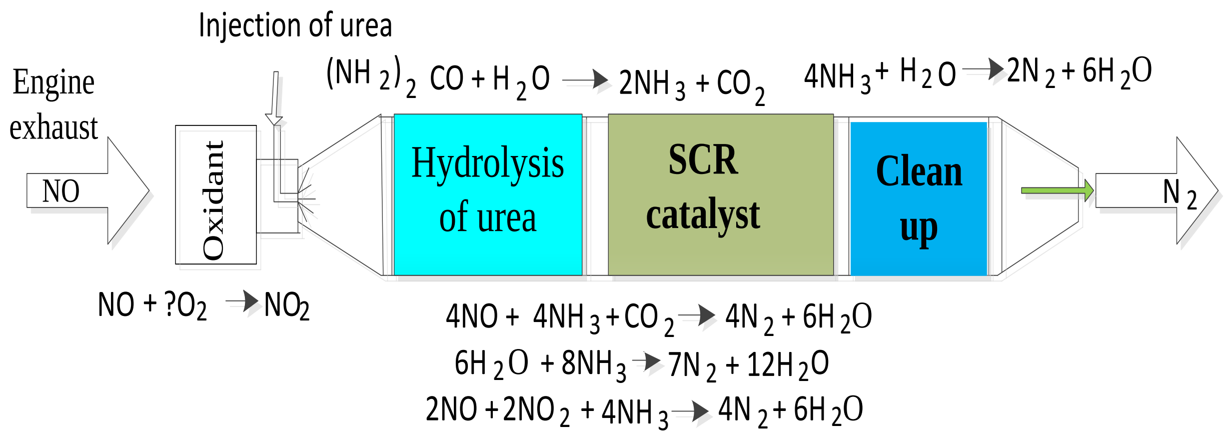

Fig. 6: Schematic illustration of Catalyst application towards Pollutants control [54][24]

However, in the application of this SCR, NH_3 with NOx could lead to generation of another dangerous compound of ammonium sulphates [12]. This is deposited on the downstream devices like the air preheater and the catalyst, thus increase the percentage of NH_3 in the air heater cleaning water, exhaust gas desulphurization waste waters and finally high the amount of NH_3 in the ash. In addition, the high concentration of NH_3 in the ash content can be solved through application of larger catalyst volume, which also could be by mixing of NH_3 and NOx at the flue or exhaust gas. Note; the catalyst lifetime for oil combustion is 7-10 years, 4-5 years for coal combustion and above 10 years for gas combustion [12].

Also, use of DeNOx otherwise known as lean NOx catalyst is another impressive approach of reducing NOx after treatment system. Application of this is the same as SCR but utilises hydrocarbons as the reductant agent to NOx instead of ammonia solutions [4].

IV. RESULTS

According to the findings on the above aforementioned techniques of mitigating combustion emissions, the results shows the effective and adequate mode towards combating the effect. The table 2.4 below interpret the variations on NOx, CO, HC and soot emissions reduction by using EGR method for petroleum and biodiesel blends fuel.

Table 1: NOx and others emissions effect by using EGR method for fossil and biodiesel fuels

Fuel used	Engine used	EGR condition	Investigation	Results
Diesel (petroleum)	IC,DI diesel engine	Cold start OEV (0,5,100) OCV (100,50,10)	Less common rail pressure fluctuation and stable combustion	NOx deceases by 60% at 100% opening of chocking valve (OCV) and 100% opening of EGR valve (OEV)
Diesel	6C, TC Volvo(D-12)	12%EGR at full load condition	Lower the peak elevated tempt	NOx decreases by 65.2%, and brake specific fuel consumption (BSFC) increase by 8.6%
LPG +Diethyl ether (DEE)	4S, 1C,(DI) diesel engine at HCC	20%EGR at full load condition	Lower the peak elevated tempt	NOx reduces by 68% at full load & brake thermal efficiency (BTE) increases by 2.5% at partial load
B20 (20% SOME +80% diesel)	2C, vertical DI, WC, diesel engine	15% EGR rate	Less flame tempts due to few O_2 available in the REG	NOx reduction by 25%, decrease in hydrocarbon (HC) by 5%, carbon monoxide decrease (CO),10% smoke little increase
Diesel $+H_2$ (.15kg /h)	IC, vertical, 4S, HCCL diesel engine	20% EGR at 80% engine load	Reduction in combustion peak tempt causes inert gas of EGR	NOx decrease by 41.4%, smoke reduction by 8.3%, carbon monoxide decrease (CO) by 29.1%, hydrocarbon decrease by (HC) by 12.3%, brake thermal efficiency (BTE) decrease by 2% compared to neat diesel
20% JME diesel	4C,WC, TC,IDI diesel engine	10% EGR rate	Limited EGR rate of 5-15%, with small effect on engine performance	NOx reduction by 36% as well as smoke decrease by 31%

Also investigating the emission conditions on NOx and CO emissions reduction by using a water injection method. The Table 2.5 describe it more clearly.

Table 2: Result investigation on NOx emissions reduction by using a water injection method

Engine used/specifications Fuel used	Injection condition	Results on NOx	Results on CO
2.0 LWC, HSDI diesel engine Diesel	Mw=60-65% of fuel	NOx reduction by 50%	Slightly increase
6C, TC Volvo-(D-12) Diesel	30% H_2O used	Decrease in NOx by 42%	No visible change

Note: HSDI = high speed direct injection

Furthermore, in the case of additives application, there is NOx conversion efficiency of SCR system. This gives optimum reduction by 6% if used in fossil fuel and found sustainable. Also with SNCR mechanism, the NOx emission can be significantly reduced up to 70%. More so, relatively high concentration of amine compounds found effective both in biodiesel and fossil fuels.

V. CONCLUSION

Conventionally, mechanism of thermal NOx and prompt NOx are the most pronounced combustion process and contributes significantly both in petroleum and biodiesel combustions. However, research on various feedstock and their emission conditions together with the engine overall performances has been investigated. On this, many considerable factors recorded towards formation of CO, SOx and NOx emissions on both fossil and biodiesel fuelled engine with corresponding mitigating approaches for the emissions reduction, thus has been examined in this research. Optimum reduction on the NOx emissions for the used oxygenated fuels due observed by some researchers, while oxygen content in most of biodiesel fuel results in significant increase in NOx emissions mostly at the premixed phase of the burning process. High percentage of cetane number in biodiesel, contributes in NOx emissions reduction through ignition delay mechanisms. The introduction of EGR, proffer the highest contribution towards NOx emissions reduction. The percentage of reduction of EGR on biodiesel is around 75-25% on 5-25% EGR rate. At this low formation of NOx, reduction on CO and HC were recorded. In the technique of water injection mode, significant decrease in NOx emissions by about 50% on the test of biodiesel were observed, with little increase in the content of CO product. Finally, effective method of additives inclusion, reduces NOx emissions in the utilization of biodiesel fuel, increase output efficiency and enhancement on fuel properties with better reliability in the operation of the engine.

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