International Journal of Engineering Research and Reviews ISSN 2348-697X (Online)
Vol. 10, Issue 2, pp: (19-34), Month: April - June 2022, Available at: www.researchpublish.com

Emissions and Emission Control Technologies of Diesel Combustion Engines

Ahmad Abdul Wahaab Obadah Al-Qenaeei[1], Hadyan Ali Al-Ajmi[2]

[1,2]The Public Authority for Applied Education and Training, Kuwait.

DOI: https://doi.org/10.5281/zenodo.6576811

Published Date: 24-May-2022

Abstract: **The diesel engines are the most preferred and selected power sources utilized in several industrial transmission applications, in addition to as an auxiliary/main power supply in the power stations. Emissions from this engine play an essential role in raising pollutants in the air, which greatly impact air quality. Also, it contributes to the destruction of the ozone coating, increasing the greenhouse impact and generating acid rain. This is because of the formation of the emission extracted by diesel gas, which contains dangerous and harmful components like NOx (Nitrogen Oxides), SD (smoke density), PM (Particulate Matter), and other hazardous gases.**

The research prime aims are to display the essential pollutants of diesel emissions, present their adverse impacts, illustrate global efforts to minimize their existence, introduce various mechanisms and techniques to control and lessen the emissions from a diesel engine, and eventually provide a comprehensive conclusion concerning the control and emissions technologies for this engine.

Keywords: **Emission, Diesel engine, control technologies, and pollutants.**

I. INTRODUCTION

Air pollution poses a rising threat to the environment and human health. ICE "Internal-Combustion-Engines" produce unwanted emissions throughout the combustion operation. Combustion operations participate greatly in the issue, and the utilization of petroleum goods has added a novel direction to the combustion pollution issue.

The enormous rise in the utilization of the Internal-Combustion-Engine in different modes of the transportation sector and markedly economic growth in developing countries led to a huge increase in the vehicle number that used this engine, which significantly contributed to the rise in air pollution problems. Control processes, including legislation and technology, have participated in lowering emissions, especially domestic and industrial emissions [1].

II. DIESEL ENGINES EMISSION

Pollutants that have been extracted from inner combustion engines impact the climate and environment. In the next section, the major pollutants that are emitted from this engine and the mechanisms or variables that lead to the formation of the pollutants will be taken into account [2].

CO (Carbon Monoxide): It is the output of incomplete/inadequate combustion; this happens when the amount of O2 (oxygen) is not enough to oxidize hydrocarbons fully. Carbon dioxide is an odourless, extremely toxic gas, and colourless, with an intensity close to air intensity. Carbon dioxide minimizes the oxygen flow into the bloodstream; also, CO is especially hazardous for people suffering from heart disease.

HC (Hydrocarbon): HC emission is related to the combustion operation because of partially burned or unburned fuel. Furthermore, the released HCs could also be produced from different reaction operations throughout combustion, like dehydrogenation, cracking, and hydrogenation.

The formation of carbon monoxide and hydrocarbons is related to a low-down combustion temperature, heterogeneity throughout the combustion process, or heterogeneity of physical factors that hinder the combustion operation. Another possible cause of hydrocarbon emissions is the wall-quenching/cooling phenomenon, where comparatively cold temperature (T) of chamber walls lead induce a flame to quench too early, and a few amounts of fuel stay unburned.

There are many health problems related to the existence of Hydrocarbon in the aerosphere. Hydrocarbons interact in the existence of sunlight and NO_x (nitrogen oxides) to make ground-level ozone, which is considered a main component of the smog phenomena. Ozone harms the lungs, eyes irritation, and exacerbates respiratory issues. It's considered the most intractable and widespread urban region air pollution issue. The exhaust hydrocarbons are as well toxic, which there is a possibility of causing cancer.

NOx (Nitrogen Oxides): The prime NOx emitted from the combustion process are NO_2 (nitrogen dioxide) and NO (nitric oxide). Nitrogen oxides, both NO_2 and NO, called together NOx, are created at a very high temperature throughout the combustion operation.

The nitrogen oxides formation rate is the oxygen availability function and is highly temperature-dependent with respect to its effects on the environment, and nitrogen oxides, such as HCs, are a precursor to ozone formation, which participate in the smog formation and acid rain formation [3].

PM (Particulate Matter): It's a collective idiom for an extremely complicated mixture of liquids and solids. The mixture could involve sulphites, oxides, chlorides, carbonates, metal compounds, soot carbon, and fuel. The PM composition is associated with the type of fuel and its purity.

For road transportation, the applications of diesel are the most horrible, whereas particulate matter emission from the gasoline engine is much lower. Worries surrounding particulate matter have increased notably in the last years, with the notice that particulate matter intensities in urban regions are unacceptably very high. PM harms the humans' lungs and respiratory.

SO_x (Sulphur Oxides): It is a mixture of SO_3 and SO_2. In the combustion operations, sulphur oxides created from the sulphur contained in fuel arise. SO_3 and SO_2 are colourless gases, toxic, water-soluble gases, and pungent. The high-water solubility has responsible for the major worries surrounding sulphur oxide's emissions its acidic nature, which could cause notable damage to the buildings and environment. If high concentrations of sulphur exist in the fuel, such as in marine fuels, acid mists formation could cause serious corrosion deterioration to post-processing abatement systems.

III. STANDARDS OF AUTOMOTIVE EMISSIONS

The rising utilization of ICE equipment and vehicles is a major challenge with respect to air pollution. To get rid of their impacts, many regulations of exhaust emission have lately come into force in large stationary diesel stations and vehicles. Developing the Internal-Combustion-Engine to keep up with the emissions regulations requirements is a critical need for the automotive industries around the world, which is a problematic research objective. Consequently, regulations on emissions restrictions are drivers that force the manufacturers of the vehicle to constantly develop and introduce novel technologies to control types of pollutants. Consequently, regulations on emissions restrictions are drivers that force the manufacturers of the vehicle to constantly develop and introduce novel technologies to control types of pollutants [4].

Manufacturers of emissions control equipment and ICE manufacturers have reacted to the defy of minimizing air pollution and have worked together in order to satisfy the requirements suggested by national and international emissions legislation and regulations. By their efforts, efficient technologies were developed to minimize harmful emissions.

IV. DIESEL EMISSION CONTROL STRATEGIES

For the purpose of complying with growingly stringent emissions standards around the world, engine manufacturers have been forced to minimize emissions from the ICE. The worries don't only aim to minimize emissions of PM significantly but as well reduce NOx emissions. This means observing a fundamental principle governing the combustion process:

- In the case the fuel has been burned inside the cylinder with a higher temp, a small amount of soot will produce, but a big amount of NOx will be produced.
- NOx emissions are very low at low temperatures of combustion, but soot particles production is high.

Therefore, all the main technologies that impact combustion should be exactly matched to get the proper balance. Generally, ICE's pollution control policies and strategies have two essential categories:

- Primary Approaches, which are described as procedures to prevent and stop pollution, involve engine modification also the utilization of alternate fuels like LPG (Liquefied-Petroleum-Gas) and NG (Natural-Gas) that are cleaner than gasoline or diesel.

- Secondary approaches are described as procedures to minimize pollutants emission once composed.

Control technology of exhaust emissions has offered significant pollution decreases and has shown perfect durability as a retrofit technology and as an original element.

V. DIESEL ENGINES CONTROL TECHNOLOGY

Manufacturers of the emissions control devices have reacted to the defy of minimizing air pollution produced from the diesel engine. Two essential methods aimed to minimize diesel emissions are taken, namely the exhaust controls and engine controls.

1. Engine Controls Method

Engine manufacturers in the late 1980s began developing cleaner and better diesel engines through employing several strategies targeting at controlling engine process to keep engine emissions as possible low. This is done by having a good understanding of the combustion operation as well modifying the engine parts design to improve the mixture of air and fuel at the combustion room/chamber and thus effectively controlling the combustion operation.

Modifying the injection port, combustion chamber, and fuel injector design are the most popular methods utilized to raise the mixing between air and fuel. Furthermore, the engine control method involves:

1.1 EGR (Exhaust-Gas-Recirculation): the method depends on directing some exhaust gas into an intake manifold. The EGR is a successful and effective strategy for controlling nitrogen oxide emissions produced from these engines. EGR minimizes nitrogen oxides by reducing the O2 concentricity in a combustion room and heat absorption [5].

EGR has two main types: high pressure and low pressure.

1.1.1 High-pressure EGR: The high-pressure type catches exhaust gas before the turbocharger then redirects it to intake air. Figure 1 shows this process.

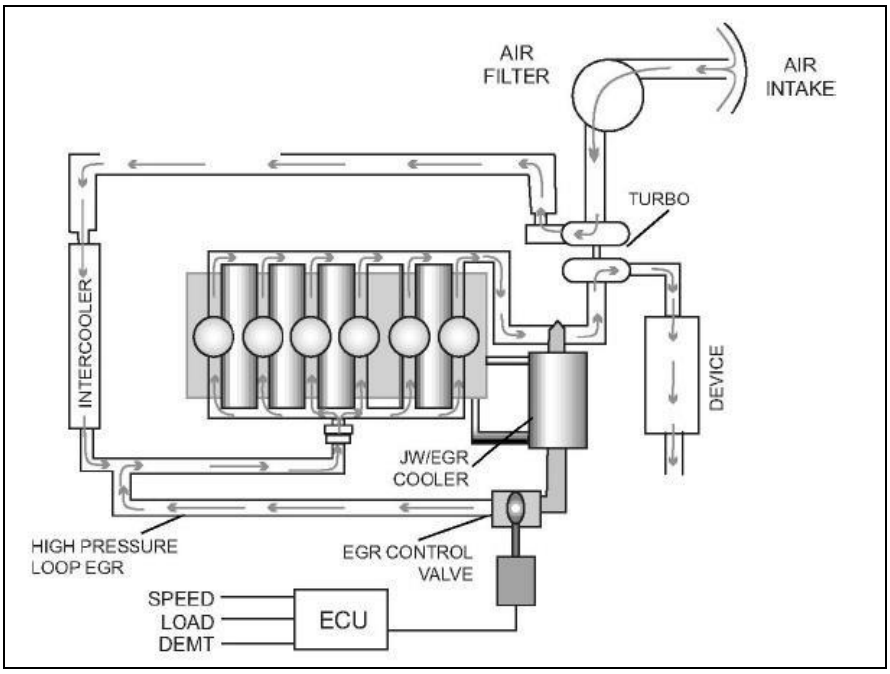

Figure 1: High-Pressure EGR [5].

1.1.2 Low-pressure EGR: After turbocharger and filter of diesel particulate, then the low-pressure EGR gathers clean exhaust and in the intake air. Figure 2 shows the low-pressure EGR structure.

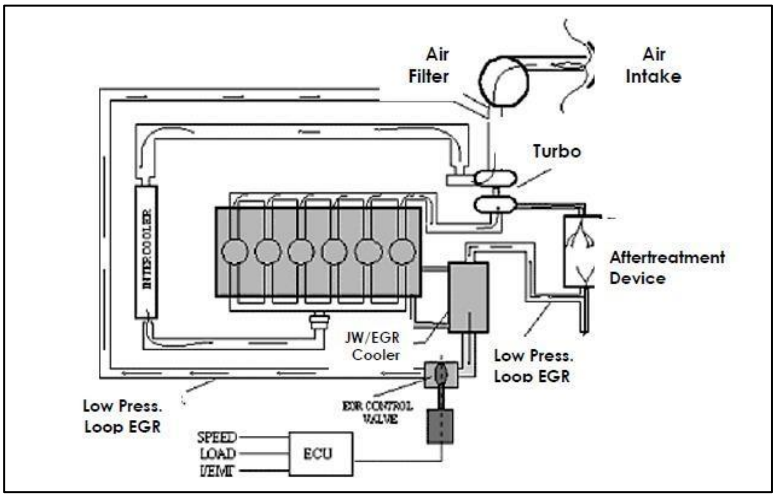

Figure 2: Low-Pressure EGR [6].

The intercooler has been utilized to cool down the recycled exhaust gases prior to mixing with intake air. EGR cooling could remarkably minimize the rise in inlet air temperature related to EGR. Although EGR cooling extremely expands the operational domain in which the EGR could be utilized, EGR electronic control is important to prevent the increase of large particles under heavy acceleration.

1.2 System of Hybrid EGR is merging the properties of low-pressure and high-pressure EGR, coming from the point above turbine (before the turbine), like in configuration of high-pressure EGR, also entering at the point of pre-compressor, like in configuration of low-pressure EGR, as in Figure 3.

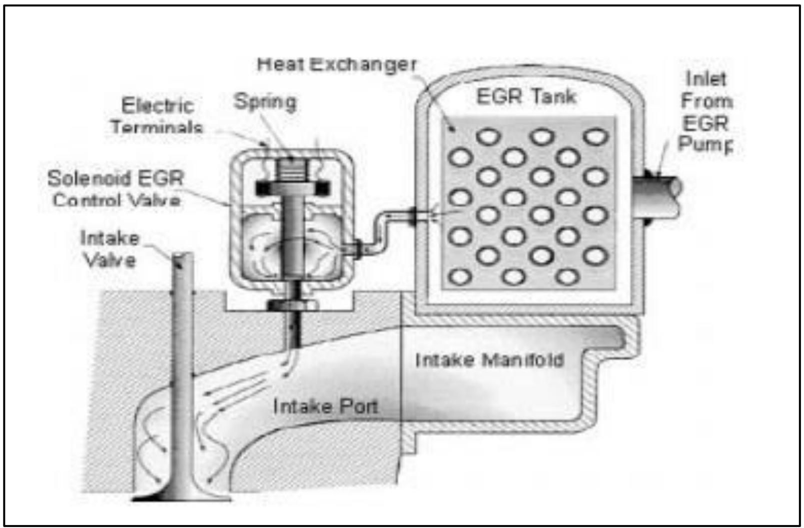

Figure 3: Hybrid EGR [7].

Nevertheless, this system offers a sufficient pressure variance between the intake and exhaust manifolds, permitting the rates of EGR to greatly minimize NOx without any require for pump or extreme exhaust pressure in order to push the EGR to the engine [7].

EGR demands control regrading to EGR electronically and EGR cooling to reduce the concomitant increase in the PM. Due to the EGR displacing a portion of intake air, the EGR could raise the total equivalence ratio of fuel-to-air to the point, leading to significant increases in particulate emissions. Hot EGR exacerbates this issue via increasing intake air temperature. Increasing the temperature reduces the density of air and minimizes the intake air volume pass into the engine. Filters of the diesel particulate are usually utilized with the system of low-pressure EGR to guarantee that big amounts of PM aren't recycled to the diesel engine, which can lead to accelerated wear of the turbocharger and engine.

1.3 Minimize PM and HC emissions via reducing injection nozzle-sac size and the consumption of oil.

1.4 Reducing particulate matter emissions and enhancing the power output and fuel efficiency by turbocharging and by improving the fit between the engine and the turbocharger. VGT (Variable-Geometry-Turbocharging), which provides variable amounts of compressed air depending on the driving situations, efficiently minimized PM emissions via keeping lean combustion within the engine.

1.5 Minimizing NOx and PM emissions through cooling compressed-charge air using after-coolers.

1.6 Reducing emissions of NOx and HC by utilizing VVT (Variable-Valve-Timing) to enter a portion of the exhaust gas in the combustion operation. The EGR is utilized to dilute the intake air together with some portions of the exhaust gas, leading to lower emissions of nitrogen oxides from the engine exhaust. Nevertheless, this technique could cause a rise of particulate matter at the exhaust.

1.7 Further reduction nitrogen oxides emissions with systems of electronic injection and damped fuel-injection timing control across most of the range of speed-load with an elastic timing system.

1.8 Reducing emissions of PM and smoke by improving air movement within the cylinder by changing the geometry of the combustion chamber and a swirl of the intake air to offer proper mixing at very low speeds unaccompanied by mixing too fast at very high speeds increases consumption of nitrogen oxides, hydrocarbons, and the fuel consumption.

1.9 Decreasing cold-start emissions includes delaying the ignition timing to permit some of the hydrocarbons to move into the exhaust also the catalyst light sooner.

These approaches can significantly reduce the emissions of PM by 80% or more from the diesel engine and reduce the NOx emissions by (50-70) % compared with the ordinary conditions of un-controlling emissions levels. These improvements, which involves reducing the emissions and improving the fuel economy, required a redesign process of the engine parts, engine purchasers, combustion system, and re-estimation of the manufacturing cost. Further, in case of increasing the speed/load, or the transient operation which happens in the diesel engines due to the short time in the combustion process, all these factors increased the complexity of controlling the combustion process [8].

2. Exhaust Control Method

The primary aim of this strategy is to minimize the emissions pollutant without altering the parameters of the design process. The minimizing process is done by a distinct process that removes the exhaust pollutants after it moves away from the engine and before it releases into the air [9]. This strategy involves:

2.1 Vertical Exhausts Pipe.

Two forms of exhaust pipes exist on heavy-duty vehicles; they may be vertical above the vehicles or horizontal. Although total exhaust emissions are not affected by the exhaust location, the concentration of pollutants may be affected. The vertical exhaust pipe contributes to reducing the concentration of pollutants at the level of breathing, which reduces exposure to pollutants around% (65-87) [10].

2.2 PM trap-oxidizers.

what distinguish the trap oxidizer is the existence of a particulate filter inside the exhaust stream. This filter has the ability to collect the dust and various forms of particulate matters from the stream exhaust. Figure 4 represent the PM- trap oxidizers.

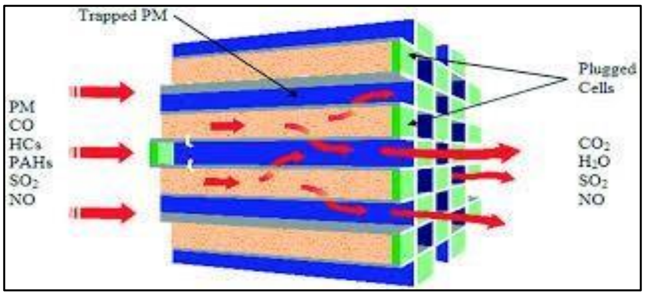

Figure 4: Schematic Diagram of Trap Oxidizer Operation [11].

The effective elimination of the dust and the regeneration process of the filter are the fundamental problems associated with the use of the trap-oxidizer. The diesel PM contains a solid carbon covered with heavy matters of hydrocarbons. These coats ignite at a range of temperature between (500 ºC – 600 ºC), which is considered higher than the temperature ranges that the diesel exhaust reaches (150 ºC - 400 ºC). For this reason, a distinct means is required to guarantee the completion of the ignition process without causing damage to the trap oxidizer. Several trap materials have been tested, including ceramic foam, catalyst-coated, cellular-ceramic-monoliths, stainless-steel mesh, woven-ceramic- fiber-coils. The most effective trap systems are ceramic- fiber-coils and the ceramic-monoliths. Depending on the trap, oxidizers increase the diesel engine costs, increasing the consumption of fuel and cost of maintenance. Whereas the cylinder PM reduces the emissions. Thus, this technology is facing tough resistance in the market [12].

2.3 Oxidation Catalysts Converters.

The most usually converter used in the diesel engines are the converters of type oxidation catalysts. It depends on using the oxygen gas in the exhaust in order to complete the oxidation process of the CO into CO_2, in addition to converting the hydrocarbons into CO_2 and water. as shown in the following equations.

$$2CO + O2 = 2CO2$$

$$\mathrm{CxH2x + 2\ + 2xO2\ = xCO2\ +\ 2xH2O}$$

when comparing between the trap oxidizer, and the oxidation catalysts it founds that the oxidation catalysts does not assemble the passing solid materials that passes through the exhaust.

There are several benefits of the oxidation catalysts, such as the removal of the odours problems and reducing the dust. On the other hand, the oxidation catalysts cannot minimize the NOx chemicals' because the chemical reactions are very simple. The main challenge in using oxidation catalysts is the application in heavy-duty related to diesel engines because it is connected with the formation of sulphates and sulphuric acid. In order to minimize the NOx inside the diesel engine, it should change firstly the chemical composition related to the exhaust. For this reason, there are two techniques; selective-catalytic-reduction (SCR) and NOx trap [13].

2.4 Lean NOx catalyst.

It is not easy to minimize the NOx into molecular nitrogen in an environment rich in oxygen. The decomposition of the NOx is a thermodynamically process. In this process, the required energy for activation is very high, and it is not significant for developing widespread use. The NOx catalyst is generally known as "lean NOx catalysts". This name is because there is an adequate amount of the reductant does not exist to enable the NOx reduction in diesel exhaust. The extra reductant permits the increase of conversion efficiency of NOx into N2. In some cases, this process is denoted as hydrocarbon catalytic reduction HC-SCR. Now, NOx conversion uses approximately (10-30)% of diesel fuel. The lean NOx catalysts consist of zeolite, which is considered a porous material, and these porous, which can be considered an open structure frame, provide a trapping site. These microscopic trapping sites enhance the reduction process of the reaction between the NOx and the molecules of trapped- hydrocarbon.

The system of lean NOx catalyst is established and proved for use within diesel applications. Further, it is applied commercially. The lean NOx catalysts are not considered in the united states because of the low NOx conversing as well as the consequences of fuel economy [14].

2.5 NOx Adsorber Catalysts.

NOx adsorber catalysts can be defined as lean NOx trap (LNT); it is the system that can provide an additional catalytic pathway to minimize the NOx in an environment rich in oxygen at the exhaust stream. The NOx adsorber catalytic can significantly eliminate the NOx in the lean exhaust for different engines, such as gasoline and diesel engines. The mechanism of the removal includes:

- Catalytically oxidizing the NO into NO2 above a valuable metallic catalyst.

- Storage the NO2 in a nearby alkaline-earth oxide-trapping site in the form of nitrate.

Nitrogen oxides stored through two phases are continuously removed by two phases. Phase I involves the temporary induction of the exhausted state and phase II, where nitrogen is reduced by a conventional trigonal catalytic reaction. Consideration must be given in designing control systems and controlling NOx emissions [15].

2.6 Selective Catalytic Reduction (SCR).

Selective Catalytic Reduction refers to the chemical reaction that converts nitrogen oxides of nitrogen in exhaust gases into nitrogen and water. Using modern technologies, lower fuel consumption can be achieved with lower NOx emissions. An additional benefit of SSR is a 60% reduction in efficiency, indicating that there is no need to use a particle filter in diesel engines when using SCR.

Moreover, the SCR system provide another benefit in terms of particulate matter emissions reduction of about approximately 60%, which leads to dispense the extra diesel particulate, within the exhaust system. However, at the eclectic catalytic reduction, the catalytic converter transforms the involved NO_x into pure nitrogen and water within the exhaust gas. Due to that the reducing agents are persistently inserted at the exhaust gas, in terms of metering module. Within the gas flow at exhaust, fluid usually reacts through a period contains part into seconds in order to generate (NH3) ammonia. Thus, the formed chemical compound transformed the NOx, within the SCR, as illustrated below:

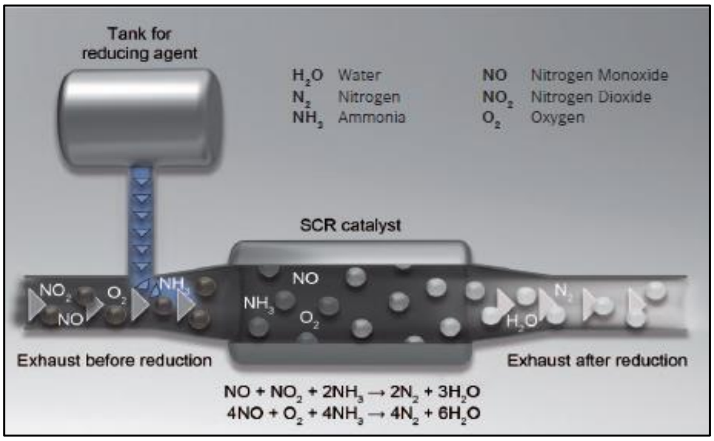

Figure 5: SCR operating principal system [16].

Lately, the SCR adopted for converting and controlling the NOx emission, were additionally adopted in diesel engine functions involving locomotives, and marine vessels. Special challenges were represented by the passengers' vehicles, and the smaller engines as a result of the require fuelling systems, of on-highway type.

However, it must develop and enhance the mechanism capability to include fuel injection of in-cylinder post type or the complementary in-exhaust fuel to match the requirements of the small engine. Additionally, for the purpose of using the SCR adopted for converting and controlling the NOx emission, such types of engines will require to be provided with suitable electronic control components and urea insertion systems. The use of particulate filters in such engines will as well need the use of technology to confirm that the regeneration of filter is attained.

3. Advancing Water to ICE

One of the highly active and cost-effective tools in order to lower (NOx) rates and particulates is the advancing of water vapours indirectly or directly within the diesel combustion chamber engine exhaust gases. However, the following introduce the impact of introducing water, the micro explosion, and the adopted system for the water vapour introduction process to ice.

3.1 The introducing water impacts within engine cylinder

The function of the water process in lowering nitrogen oxides emissions is represented by two phenomena. Vaporization represents the first phenomenon of the infiltrated water droplets that will reduce the inner energy to the water vaporization enthalpy proportionally. The specific heat represents the second phenomenon which increased as the content of water increased. However, both phenomena drive to decrease the temperatures. Due to the fact that the water and fuel is poured together the temperature will decrease within the censer flame gases; thus, fewer nitrogen oxides emissions will be formed.

3.2 Micro Explosion

Micro-explosion is described as a phenomenon that arises in the case of the water droplets vaporizing within the emulsion of water fuel instantly, due to the fact that the fuel is subjected to rising cylinder temperatures throughout injection process. This occurs when the fuel droplets' temperature rises beyond the boiling point temperature of the water. Thus, the water will quickly and violently vaporize; leading to splitting the droplets of the fuel into smaller droplets to maintain full fuel turbulent and vaporization mixing [17]. The following figure clarify the Micro Explosion effect within diesel emulsions.

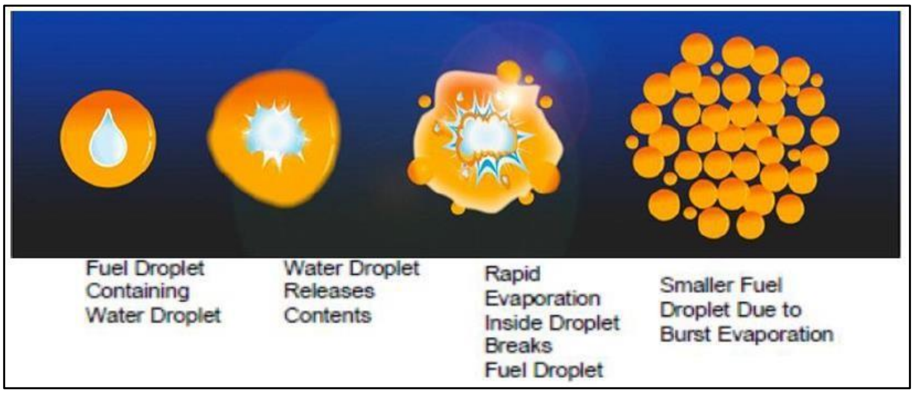

Figure 6: Phenomenon of Micro-explosion in diesel emulsions [18].

3.3 Introducing Water Systems into Combustion Chamber

Several researchers have established various systems in order to introduce water within the chamber of combustion. Usually, three useful main methods are adopted to introducing water into the chamber of combustion within the diesel engine. These systems represented by evaporation of water in the air flow into the engine, an emulsion of water-fuel in addition to water injection directly into the engine via individual injectors. The following figure shows schematic diagram of the introducing water system methods:

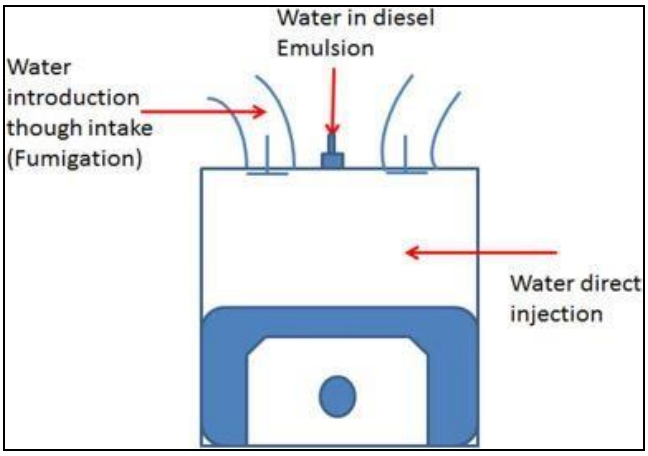

Figure 7: schematic diagram of the introducing water system methods [19].

3.3.1 Fumigation

Fumigation is represented by injecting the fluid water into the input upstream of the manifold intake valve. Currently, this method is commonly employed in enormous diesel engines. However, fumigation seems a more manageable method to provide water into the diesel engine combustion chamber without significant modifications. Moreover, the primary benefit of the fumigation system is provided by the transparency and ease with cases of integrating existing engines. Various techniques were experimented with and employed to inject water, such as multipoint water in the input pipes near the input valves in addition to the single-point injection to the compressor upstream or downstream. Positive results in reducing NOx emissions are shown by using the fumigation technique. However, the technique has a defect summarized in the water within the combustion chamber that will reduce the efficiency in reducing the emissions. As a result, fumigation needs about twice the volume of the liquid to reach the results obtained in water injection for reducing the NOx. Approximately a water mass of 60-65% of the fuel is required to reduce about 50% of NO. After combustion, the existence of liquid water might participate in oil contamination and engine wear [20].

3.3.2 Direct Water injection (DWI)

DWI holds a double supply injection outlet with subsequent water resource system. In the DWI the water will be targeted to the regions that need freezing. Main benefit of the DWI system is represented by the separated water and fuel injecting systems, hence, the water added is being able to be monitored within much bigger fields compared to the emulsion-system. Fig. (8) and fig.9 demonstrates nitrogen oxides reduction within DWI.

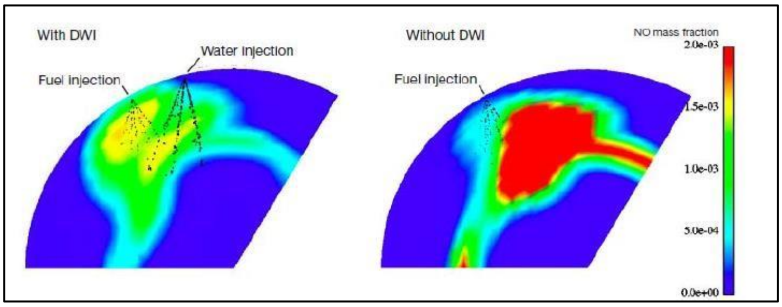

Figure 8: Direct Water injection (DWI) of nitrogen oxides reduction [21].

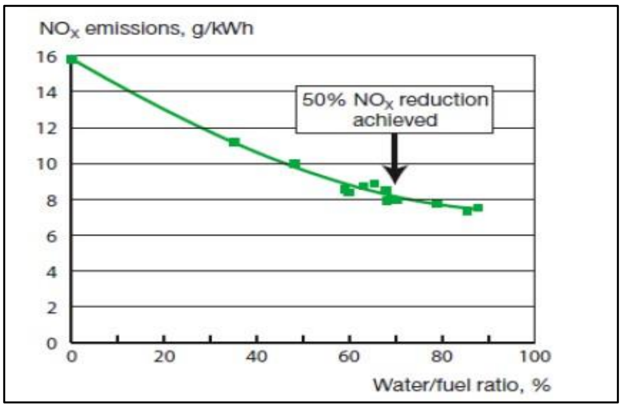

Fig. 9: Decreased the NOX emissions of Wärtsilä Sulzer motor utilizing DUI.

The advantages of DWI above fumigation from having liquid water near a fire and far from a wall and water could be injected in the limited end of pressure straight the fuel, then, the injection of DWI permits the percentage of fuel and water to be converted of cold to begin or various operating domains. However, the DWI system has more freedom degrees contrasted with fumigation systems.

The opener of the DWI system is a double-feed injection tap with identical supply of water system. Then, the system of injection wants to be changed at DW injection, individual injector for cylinder is utilized thus that the total cost will be minimal than equivalent injection system. The principle schematic of double-feed is shown in the figure 10.

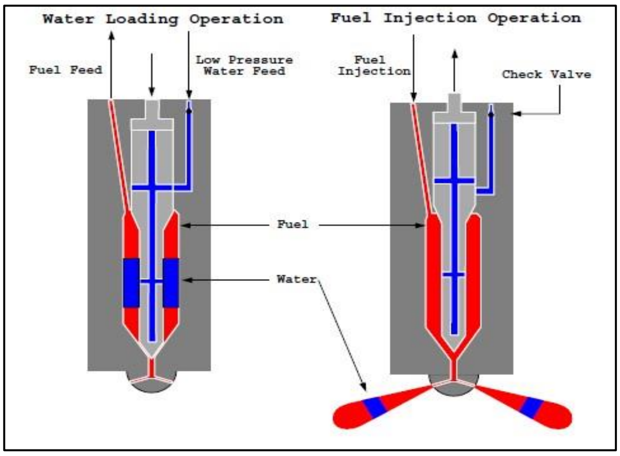

Fig. 10: The principle operating of Direct Water Injection System [22].

Addendum cost on adjustment in injector produces the system minimal popular contrasted to any systems. As well, the diesel and the water blended in the side of the injector that the elementary section of injected diesel included mostly diesel [22]. But the water a crosses the injection of the front might reason ignition delay.

Emulsified Fuel

Fuel water emulsion (FWE) is wherever water and fuel are mixed utilizing surfactants into composing an emulsion that could be utilized as a substitutional fuel. The FWE is as well-known as an accurate scattered blend from two liquids which could not generally be blended without visual separation. The fuels emulsified are emulsions formed of fuel and water. The water injection started via utilizing divide water injection into formula 1 and aircraft to develop performance, then, the WFE is now utilized to minimize emissions that mainly via improving the combustion operation [23].

The emulsion is a blend of more or two liquids, not a mixture in nature; the first liquid existing in droplets from ultramicroscopic or macroscopic size extends over the other. The emulsion is produced via mechanical incitation operation as shown in figure 11 active surface factors, including blend stability.

The active surface agents called surfactants or emulsifiers are utilized to weaken a tension surface of moderate in that it melts. When talking about fuel emulsion, the surfactant is fundamental to make stable emulsion also shall readily fire with free and no soot of nitrogen and sulfur [24].

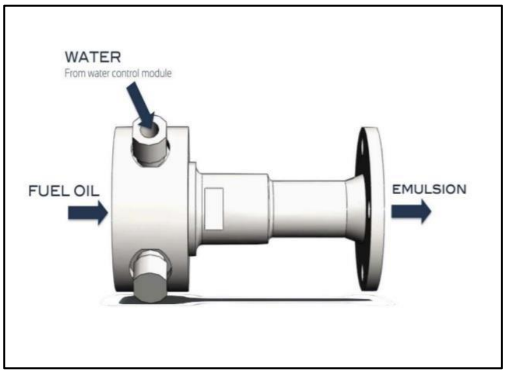

Fig. 11: The Emulsion fuel generation [24].

Emulsions Type

According to dispersing medium and dispersed phase-type, an emulsion is categorized in two major types [25] and [26].

1. **The Emulsion of Two-phase**

The emulsion of two-phase consists of one dispersed and one continuous phase liquid that is well called an essential emulsion. In Particular, there are basically two types of emulsion: emulsion of water-in-oil (w/o) and oil-in-water (o/w) are shown in figure 12.

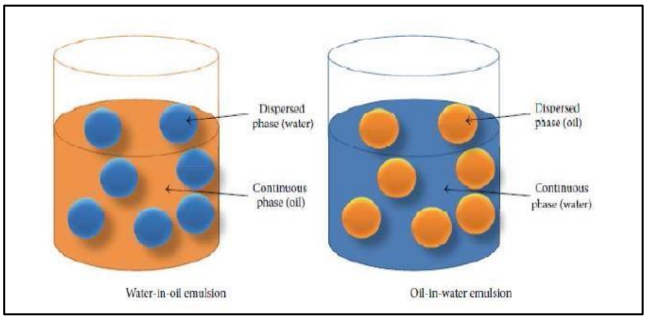

Fig. 12: The block diagram of two-phase water-in-oil and oil-in-water emulsion [27].

The emulsions of oil-in-water (O/W) is emulsions in which the oil is a scattered phase also, the water is current as a scuttle medium called continuous phase. An example of emulsion of type (o/w) is milk. Therefore, the milk lipid globule is scattered within water. Whereas the emulsion of (W/O) is emulsion in that water composes a dispersed phase also, an oil is current as a scattering medium called continuous phase. Cold cream, cod liver oil, butter are examples of emulsion [28].

2. The Emulsion of Three-phase:

The emulsion of three-phase includes more scattered liquid and one phase continuous that is known as a secondary and multiphase emulsion. There are examples from three-phase emulsions called water-in-oil-water and oil-in-water-in-oil are shown in figure 13.

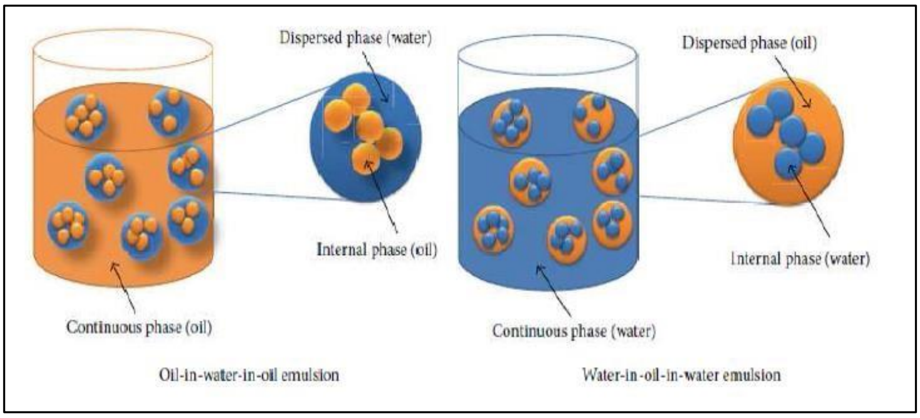

Fig. 13: The block diagram of three-phase oil-in-water-in-oil and water-in-oil-in-water [27]

The emulsions of Oil-in-water-in-oil apply to fuelling intention in an interior burning motor; however, the emulsion of water-in-oil-in-water is affected in food, pharmaceutical manufacturing, and cosmetics. Furthermore, based on a volume of emulsions and droplets categorized in two kinds:

1. The first type is Macro emulsions: The volume of particles domains for 0.2 to 50 mm.
2. The first type is Micro emulsions: The volume of particles domains for 0.01 to 0.02 mm.

The Impact of W/D Emulsion on Combustion

The combustion operation for W/D emulsions have many advantages. Beginning at injection from W/D emulsion in combustion room, then the heat is transformed to a superficies of droplets fuel via radiation and convection. Ago the temperature boiling of diesel and water are various, so the rate of evaporations of twain liquids would be distinct too [29].

The water molecules arrive at the stage of superheated quickly than a diesel that faces to originating steam extension breakup [30].

There are two phenomena, prevail, puffing and micro explosion. The phenomenon of micro explosion is the event when the total droplet divides to small droplets fast outcoming in quick secondary atomization breakdown of droplets of fuel. Therefore, cases quickly fuel evaporation also developed air fuel blending as shown in figure 14. However, the puffing events is while neglect the droplets into a fine mist [31]

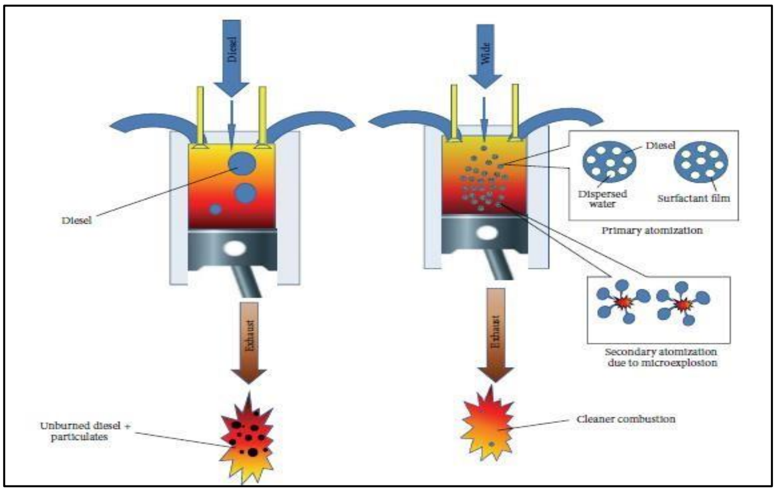

Fig. 14: The secondary and primary atomization in sprinkle flame of emulsified fuel [32].

The survey studies were executed to examine the impacting parameters of the W/D micro explosion emulsion that it is effective in developing a combustion characteristic. The author in [33] reported which micro explosions are fundamentally impacted via the volatility from the standard fuel, water content, and emulsion type. Depending on that, a raise in the content of the emulsifier raises waiting time and a micro explosion temperature.

Itemized studies to examine the technique for parameters impacting micro explosions and micro explosion were performed [34]. The results for the studies references that of two oil-in-water and water in-oil emulsions could micro burst within specific conditions. However, the author has connected a diameter from the scattered liquid for microburst strengths by physical typical.

The Microburst phenomena are performed a substantial function into secondary atomization operations from (W/D) emulsion fuels, that is mostly impacted via scattered liquid diameter, water content, emulsion type, ambient condition, and location of scattered as temperature and pressure.

The numerical and experimental study is conducted to recognize a phenomenon from microburst internal a combustion room and impact within process of combustion as evaporation, spray penetration, mixture ignition, and secondary atomization.

The combustion operation is mostly characterized through factors like evaporation, spray penetration, physical and chemical atomization, mixture ignition, injection characteristics, temperature, heat emission characteristics, and pressure. The studies of experimental within W/D emulsion drizzle behaviour contrasted to traditional diesel at high temperature and high pressure fixed size chamber [35], referencing the followings:

- The penetration of long droplets and the angle of the wide cone in fuel emulsified contrasted to clear diesel fuel, that was connected to water lower volatility [36].
- delay of a Slightly longer ignition [37].
- Combustion longer period the outcome of flame lower temperature.
- ignition period delay reaches 29%. Therefore, the impact on water content, the ambient temperature of ignition period delay, and injection pressure were over investigated and studied. The temperature of ambient has a considerable impact on period delay of ignition and no important impact was looked for injection pressure [38].
- Raise in flare lift-off for a raise into water content and injection pressure however it reduced with a raise in temperature.

Impact of W/D Emulsion at Performance of Engine.

The study was examined the impact water proportion into an emulsion on the engine performance. The following could be understood as the impact of W/D emulsion at an engine parameter performance:

- The water content reaches 5-40 percent via size into emulsion could be used to fixed diesel engines and transport fuelling.
- The numerical paths and systematic experimental are substantial to research the water content optimization into the emulsion to better performance of engine and emission.

Impact of W/D Emulsion

The air contamination caused via engines of diesel has shown a lot of attention in an eco-friendly domain diesel fuels ago developed human health and environment are of worry. Low motor contamination has been supported via adopting the forming pre or/and forming post-emission control mechanisms like particulate filters, catalytic converters, W/D emulsion fuel, and biodiesel introduction. The W/D emulsion is an economically viable solution, as it can be presented into the diesel engine without any modification to the engine. The better economy and the best effective combustion during the fuel consumption process are also advantages of the (W/D) emulsion fuel.

1. Nitrogen oxides (NOx)

The NOx forming into engines of diesel is extremely attached to raise the temperature of a combustion chamber and oxygen accessibility [39]. Then, a lowering in temperature of the combustion chamber leads to a fall in NOx forming into diesel engines. Water existence in W/D emulsion decreases the combustion chamber of temperature in rising water vaporization of potential heat that reduces the NOx creation. The emulsified fuel impact in decreasing NOx from engine of diesel is shown in figure 15.

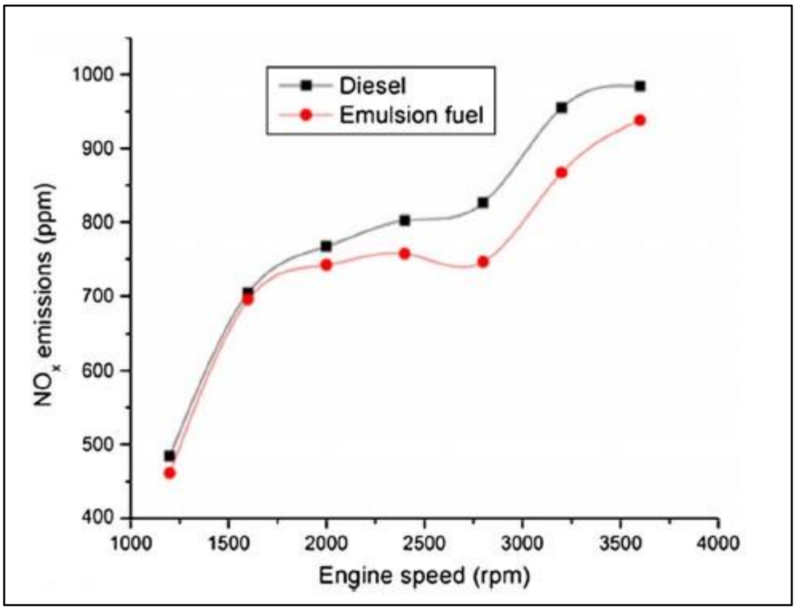

Figure 15: The emissions of NOx of engine worked via pure diesel and emulsion fuel in a full load [40].

The experiment was conducted to examine the emulsified fuel impact in decreasing emissions of NOx of dense vehicles. The outcomes of dense vehicles of road trails, engine dynamometer experiences of bus, and chassis dynamometer experiences were conducted through an Australian shell company reported 15.2 percentage lowering of NOx while utilizing 13 percentage water via emulsion fuels size.

2. Particulate matter (PM)

The primary components of the particulates inside the diesel engines are ash and soot. Ash and soot are mainly composed of condensed unburned HC. When lubricating oil is burned, the ash is formed. In contrast, the soot results in fuel-rich areas within the combustion chamber. The soot is formed at the fuel-injection completion after the early diffusion stage. Emulsified fuel research showed a decrease in PM because of the water in the diesel emulsified fuel, which will minimize the polycyclic-aromatic-hydrocarbons (PAHs) amount in the flame the emissions of exhaust gas. PAHs work as precursors to the soot particles, in which the micro-explosions enhance the hydrocarbons oxidation during the emulsified diesel fuel combustion. Accordingly, the formation of both PAHs and soot amounts will be reduced. This PM reduction is due to the micro-explosion phenomena as shown in figure 16.

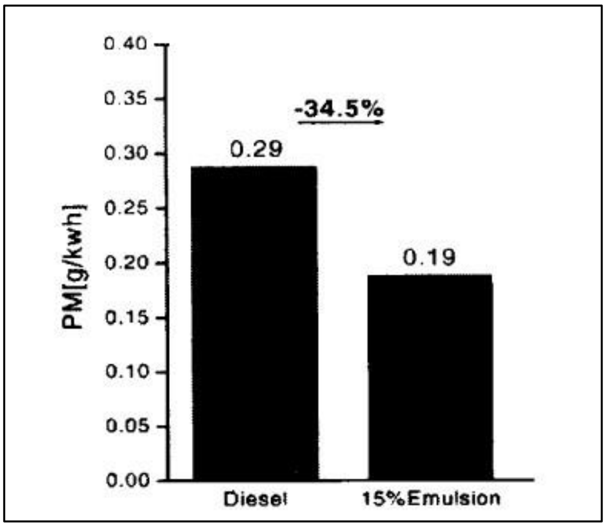

Figure 16: Micro particle reading at 2000 rpm and at 100% load [40]

Remarks

It was proved that water drops that is micrometre-sized affects the fuel combustion in a positive way. Accordingly, the water-in-diesel emulsions concept was drawn. Different water-in-oil emulsions formulations were evaluated within different fuel types such as hydrocarbons and triglycerides. Furthermore, the conditions that exist within the diesel engine are favourable for water-in-diesel emulsions concept such as the high pressure and the high temperature of combustion. Researcher concentrated on researching the concept related to the water in diesel fuel rather than water in gasoline emulsion. Consequently, the emulsified diesel fuel is considered a good alternative that replace diesel fuel since it minimizes the PM and NOx.

The research has been permitted both numerically and experimentally to research the impacts of diesel fuel emulsified on air pollution and the performance of engines. The fuels of Emulsion significantly decreased the PM and NOx levels at the same time from diesel engines. The decrease in NOx reach from 20 to 90 percent and the decrease in PM reach from 16 to 60 percent could be realized via emulsifying from 20 to 40 percent.

REFERENCES

[1] V. Ganesan, Internal combustion engines, India: McGraw Hill Education, 2012.

[2] R. Patel and C. Sankhavara, "Biodiesel production from Karanja oil and its use in diesel engine: A review.," Renewable and Sustainable Energy Reviews, vol. 71, pp. 464-474, 2017.

[3] A. Koc and M. Abdullah, "Performance and NOx emissions of a diesel engine fueled with biodiesel-diesel-water nanoemulsions," Fuel Processing Technology, vol. 109, pp. 70-77, 2013.

[4] M. Maricq, "Chemical characterization of particulate emissions from diesel engines: A review.," Journal of Aerosol Science, vol. 38, no. 11, pp. 1079-1118, 2007.

[5] H. Wei, T. Zhu, G. Shu, L. Tan and Y. Wang, "Gasoline engine exhaust gas recirculation–A review.," Applied energy, vol. 99, pp. 534-544, 2012.

[6] Y. Park and C. Bae, "Experimental study on the effects of high/low pressure EGR proportion in a passenger car diesel engine.," Applied Energy, vol. 133, pp. 308-316., 2014.

[7] Y. Qureshi, U. Ali and F. Sher, "Part load operation of natural gas fired power plant with CO2 capture system for selective exhaust gas recirculation," Applied Thermal Engineering, vol. 190, p. 116808, 2021.

[8] A.. C. Alkidas, "89N3PDyZzakoH7W6n8ZrjGDDktjh8iWFG6eKRvi3kvpQ," Energy Conversion and Management, vol. 48, no. 11, pp. 2751-2761, 2007.

[9] R. S. Wijetunge , J. G. Hawley and N. D. Vaughan, "An exhaust pressure control strategy for a diesel engine," Journal of Automobile Engineering, vol. 218, no. 4, 2004.

[10] M. Kang, J. Wei, J. Yuan, J. Guo, Y. Zhang, . J. Hang, Y. Qu, . H. Qian, Y. Zhuang, X. Chen, . X. Peng, T. Shi, J. Wang, . J. Wu, . T. Song, J. He, . Y. Li and N. Zhong, "Probable Evidence of Fecal Aerosol Transmission of SARS-CoV-2 in a High-Rise Building," ACP journal, 2020.

[11] V. Šimonka, " Thermal Oxidation and Dopant Activation of Silicon Carbide," tuwien, 2020. [Online]. Available: https://www.iue.tuwien.ac.at/phd/simonka/Thermal-Oxidation.html.

[12] M. Neelakshi, Essays on environmental technological change Adoption of environmental regulations and diffusion of environmentally sound technologies in developing countries, 2009.

[13] S. Dey and G. C. Dhal, "Controlling carbon monoxide emissions from automobile vehicle exhaust using copper oxide catalysts in a catalytic converter," Materialstoday CHEMISTRY, vol. 17, 2020.

[14] C.-. W. Park, C.-. G. Kim and Y. Choi, "Effect of Hydrogen-Enriched Gas as a Reductant on the Performance of a Lean NOx Trap Catalyst for a Light-Duty Diesel Engine," SAGE Journals, vol. 224, no. 11, 2010.

[15] V. V., S. D. and Z. O., "THE NEW EXHAUST AFTERTREATMENT SYSTEM FOR REDUCING NOX EMISSIONS OF DIESEL ENGINES: LEAN NOX TRAP (LNT). A STUDY," International Scientific Journals, vol. 1, no. 4, pp. 35-38, 2016.

[16] F. T. US, "SCR,DEF, DPF, EGR," fcarusa, 2021. [Online]. Available: https://www.fcarusa.com/TechSupport/KB/scr-def-dpf-egr.

[17] S. Fostiropoulos, G. Strotos, N. Nikolopoulos and M. Gavaises, "Numerical investigation of heavy fuel oil droplet breakup enhancement with water emulsions ," Fuel, 2020.

[18] F. Y. Hagos, A. R. Aziz and I. M. Tan, "Water-in-diesel emulsion and its micro-explosion phenomenon-review," In 2011 IEEE 3rd international conference on communication software and networks, pp. 314-318, 2011.

[19] F. Y. Hagos, M. Obed and A. Mamatl, "Effect of emulsification and blending on the oxygenation and substitution of diesel fuel for compression ignition engine," Renewable and Sustainable Energy Reviews, 2016.

[20] D. Kumar, "Experimental investigation on performance and emission characteristics of direct injection diesel engine operating on dual fuel mode with polanga based biodiesel and ethanol," Doctoral dissertation, UPES, 2016.

[21] S. Shahpouri and E. Houshfar, "Nitrogen oxides reduction and performance enhancement of combustor with direct water injection and humidification of inlet air," Clean Technologies and Environmental Policy, vol. 21, no. 3, pp. 667-683, 2019.

[22] B. Tesfa, R. Mishra, F. Gu and A. D. Ball, "Water injection effects on the performance and emission characteristics of a CI engine operating with biodiesel," Renewable Energy, vol. 37, no. 1, pp. 333-344, 2012.

[23] O. Armas, R. Ballesteros, F. J. Martos and J. R. Agudelo, "Characterization of light duty diesel engine pollutant emissions using water-emulsified fuel ," Fuel, vol. 84, no. 7-8, pp. 1011-1018., 2005.

[24] M. Chmielewski, P. Niszczota and M. Gieras, "Combustion efficiency of fuel-water emulsion in a small gas turbine," Energy, vol. 211, p. 118961, 2020.

[25] C. X. Zhao and . A. P. Middelberg, "Two-phase microfluidic flows. ," Chemical Engineering Science, vol. 66, no. 7, pp. 1394-1411, 2011.

[26] C. Y. Lin and H. A. Lin, "Engine performance and emission characteristics of a three-phase emulsion of biodiesel produced by peroxidation," Fuel Processing Technology, vol. 88, no. 1, pp. 35-41, 2007.

[27] M. Yahaya Khan, Z. A. Abdul Karim, F. Y. Hagos and A. R. A. Aziz, "Current trends in water-in-diesel emulsion as a fuel," The Scientific world journal, 2014.

[28] Y. P. Filippov and K. S. Panferov, "Diagnostics of salty water-in-oil two-phase flow.," International journal of multiphase flow, vol. 41, pp. 36-43, 2012.

[29] S. Vellaiyan, K. S. Amirthagadeswaran. and S. Vijayakumar, "Combustion of stable water-in-diesel emulsion fuel and performance assessment," Energy Sources, Part A: Recovery, Utilization, and Environmental Effects, vol. 39, no. 5, pp. 505-513, 2017.

[30] A. M. Ithnin, M. A. Ahmad, M. A. A. Bakar, S. Rajoo and Yah, "Combustion performance and emission analysis of diesel engine fuelled with water-in-diesel emulsion fuel made from low-grade diesel fuel," Energy Conversion and Management, vol. 90, 2015.

[31] K. C. Adiga, H. D. Willauer, R. Ananth and F. Williams, "Implications of droplet breakup and formation of ultra fine mist in blast mitigation.," Fire Safety Journal, vol. 44, no. 3, pp. 363-369, 2009.

[32] H. Watanabe, Y. Shoji, T. Yamagaki, J. Hayashi, F. Akamatsu and K. Okazaki, "Secondary atomization and spray flame characteristics of carbonated W/O emulsified fuel," Fuel, vol. 182, pp. 259-265, 2016.

[33] M. Y. Selim and M. Ghannam, "Combustion study of stabilized water-in-diesel fuel emulsion.," Energy Sources, Part A: Recovery, Utilization, and Environmental Effects, , vol. 32, no. 2, pp. 256-274, 2009.

[34] F. Y. Hagos, . A. R. A. Aziz and I. M. Tan, "Water-in-diesel emulsion and its micro-explosion phenomenon-review," IEEE 3rd international conference on communication software and networks . Ieee., pp. 314-318, 2011.

[35] C. D. Rakopoulos and E. G. Giakoumis, "Second-law analyses applied to internal combustion engines operation ," Progress in energy and combustion science, vol. 32, no. 1, pp. 2-47, 2006.

[36] M. Denesuk, G. L. Smith, B. J. J. Zelinski and N. J. Kreidl, "Capillary penetration of liquid droplets into porous materials," Journal of colloid and interface science, vol. 158, no. 1, pp. 114-120, 1993.

[37] F. Contino, P. Dagaut, . G. Dayma, F. Halter and F. Foucher, "Combustion and emissions characteristics of valeric biofuels in a compression ignition engine.," Journal of Energy Engineering, vol. 140, no. 3, p. A4014013, 2014.

[38] V. A. Likhanov and O. P. Lopatin, "Investigation of the ignition delay period in the diesel combustion chamber when working on an alcohol-fuel emulsion," In IOP Conference Series: Materials Science and Engineering, vol. 862, no. 6, p. 062027, 2020.

[39] Y. Cheng, L. He, W. He, P. Zhao, P. Wang, J. Zhao and S. Zhang, "Evaluating on-board sensing-based nitrogen oxides (NOX) emissions from a heavy-duty diesel truck in China ," Atmospheric Environment, vol. 216, p. 116908, 2019.

[40] A. K. Hasannuddin, . J. Y. Wira, R. Srithar, S. Sarah, M. I. Ahmad, S. A. Aizam, M. A. Aiman, M. Zahari, . S. Watanabe, M. A. Azrin and S. S. Mohd, "Sarah, S.; Ahmad, M. I.; Aizam, S. A.; Aiman, M. A. B.; Zahari, M.; Watanabe, S.; Azrin, M. A.; Mohd, S. S. (2016).," Clean Technologies and Environmental Policy, vol. 18, no. 1, p. 17–32, 2016.